Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 57 (2016) 1087–1097

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Accurate calculation of conductive conductances in complex geometries for spacecrafts thermal models

Iñaki Garmendia [a,*], Eva Anglada [b], Haritz Vallejo [b], Miguel Seco [b]

[a] Mechanical Engineering Department, University of the Basque Country UPV/EHU, Polytechnic School of Engineering, Plaza de Europa, 1, E-20018 Donostia – San Sebastián, Spain

[b] TECNALIA, Industry and Transport Division, Mikeletegi Pasealekua, 2, E-20009 Donostia – San Sebastián, Spain

Received 15 May 2015; received in revised form 24 November 2015; accepted 17 December 2015
Available online 25 December 2015

Abstract

The thermal subsystem of spacecrafts and payloads is always designed with the help of Thermal Mathematical Models. In the case of the Thermal Lumped Parameter (TLP) method, the non-linear system of equations that is created is solved to calculate the temperature distribution and the heat power that goes between nodes. The accuracy of the results depends largely on the appropriate calculation of the conductive and radiative conductances.

Several established methods for the determination of conductive conductances exist but they present some limitations for complex geometries. Two new methods are proposed in this paper to calculate accurately these conductive conductances: The Extended Far Field method and the Mid-Section method. Both are based on a finite element calculation but while the Extended Far Field method uses the calculation of node mean temperatures, the Mid-Section method is based on assuming specific temperature values. They are compared with traditionally used methods showing the advantages of these two new methods.

Keywords: Space thermal control; Thermal lumped parameter method; FEM; Computational simulation; Conductances

1. Introduction

The thermal subsystem of a spacecraft is an important component of the design process of a space mission. Thermal environment in space is extremely harsh and a very careful design of the thermal subsystem is essential to complete successfully any kind of space mission. Many decisions that are made about the physical design of the spacecraft or the thermal subsystem are based on computational models that simulate the real thermal behaviour of the spacecraft once in space.

These computational models (usually called TMM, Thermal Mathematical Model) take into account the different components of the thermal subsystem that are present in the spacecraft or payload, as heaters, heat pipes, radiators, MLI (Multi Layer Insulation), etc. The TMM takes also into account the parts of the spacecraft that act as heat conductors: metallic walls, frames, components. Usually, heat is produced in some specific points of the spacecrafts, such as motors, scientific experiments, electronic boards,... and needs to be conducted towards the radiator, where is radiated to deep space.

For the computational thermal study of a mission, the spacecraft is divided into nodes, which are assumed to be each one isothermal. Heat is transferred among nodes at different temperatures through conduction, convection and radiation. Convection is only present if the spacecraft

* Corresponding author. Tel.: +34 943 018 627.
E-mail addresses: inaki.garmendia@ehu.es (I. Garmendia), eva.anglada@tecnalia.com (E. Anglada), haritz.vallejo@tecnalia.com (H. Vallejo), miguel.seco@tecnalia.com (M. Seco).

http://dx.doi.org/10.1016/j.asr.2015.12.027
0273-1177/

Nomenclature

A	auxiliary node	MC	thermal inertia
EFF	Extended Far Field	N	an integer number
FEM	Finite Element Method	Q	heat load
FF	Far Field	T	temperature
MLI	Multi Layer Insulation	a, b, w	real numbers
TLP	Thermal Lumped Parameter	i, j, k_t, n	integer numbers
TMM	Thermal Mathematical Model	k	thermal conductivity
A	cross-sectional area	q	heat flux
GL	conductive conductance	t	time
GR	radiative conductance	x	length
L	length		

has a pressurized volume, usually for manned expeditions, as the International Space Station and others. Heat transferred through conduction follows inside the spacecraft what are known as heat paths. To model adequately through the TMM these conductive paths it is necessary to calculate the conductive conductances (GLs) between the nodes. Heat is also conducted through radiation between the nodes, and the calculation of the radiative conductances (GRs) is also needed. This approach for the thermal subsystem computational study is known as the Thermal Lumped Parameter method (TLP) and has a long and successful history in the space industry. It is in itself an approximate method by the assumptions that have already been mentioned (i.e.: isothermal nodes) and also because of the discretization needed to solve the heat transfer differential equation.

The TLP method is described in detail elsewhere (Gilmore, 2002; Karam, 1998; Redor, 1995). The set of N non-linear algebraic transient equations that are obtained and that have to be solved is expressed by Eq. (1).

$$\sum_{j=1}^{n} GL(i,j)(T_i - T_j) + \sum_{j=1}^{n} GR(i,j)(T_i^4 - T_j^4) + M_i C_i \frac{dT_i}{dt} = Q_i \tag{1}$$

The term where GL appears is related to the conduction heat transfer between node i and the rest of the nodes of the model. The GR term describes the heat interchanged by radiation, while the M_iC_i term accounts for the temperature time change of the i node. Finally, Q_i represents the heat that comes directly from external sources (sun, albedo, infrared,...) and the heat that it is directly produced in the i node itself. After solving the set of N non-linear algebraic equations, the temperature in each node will be known and also their evolution with time, if the case is a transient one.

From this outlook of the heat equations, it is clear that an accurate calculation of the conductive conductances (GLs), the radiative conductances (GRs) and the thermal inertias (MCs) is of outmost importance to obtain precise temperature values for the nodes.

Apart from the Reduced Conductive Network Method (Soriano, 2010), which is a second order method, mathematically consistent with the thermal analysis of the commercial code THERMICA, several established methods have traditionally been used to calculate the GL values. Between them, it is worth to mention the simple hand calculations (Gilmore, 2002), finite element based calculations (Jacques, 2009), the Far Field method (Appel et al., 2004; Kirtley et al., 2005; Strutt et al., 2014) or the auxiliary node method (Gilmore, 2002). However, all the traditionally used methods present some limitations, especially to handle complex geometries. The objective of the present paper is to revise these known methods and to present two new methods that can deal adequately with the GL calculations, especially when considering not elemental geometries.

2. Established methods for conductive conductances calculation

2.1. Hand calculations

When the concept of conductive conductance is to be defined, it is very usual to start with a simplified expression of the Fourier law for one dimensional heat transfer, Eq. (2).

$$q = k \cdot A \frac{dT}{dx} \approx k \cdot A \cdot \frac{\Delta T}{\Delta x} \tag{2}$$

where q is the rate of heat transferred due to conduction (W), k is the thermal conductivity of the material (W/m° C), A is the cross sectional area normal to the heat flow (m^2) and ΔT the temperature increment (°C) in the space length Δx (m).

Then, the conductive conductance is calculated by Eq. (3).

$$GL = k \frac{A}{\Delta x} \rightarrow q = GL \cdot \Delta T \tag{3}$$

As an example, in Fig. 1, a rectangular geometry, with an area A as a cross section, is divided into seven equal nodes. The centre of each node is signalled with a cross. The GL corresponding to two nodes is calculated between the centres of these nodes with Eq. (3).