

Use of the “Radiosity Importance Concept” in the Error Estimation in Radiative Heat Transfer Design of Spacecraft

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Abstract—The use of importance functions started in neutron transport simulations soon after World War II. It was used to accelerate ray tracing and later for global illumination, to optimize finite element methods (radiosity) and various Monte Carlo methods (path tracing, random walk radiosity, stochastic relaxation radiosity, ray bundles, and photon particle tracing for photon maps).

In this paper, the “Radiosity Importance Concept”, an adjoint of the radiosity equation in the case of isothermal, diffuse surfaces is used to estimate the errors in radiative heat transfer in Spacecraft. The formulation of the radiosity equation is recalled as a function of the nature of the boundary conditions (either known temperature or fixed radiative heat flux). The importance is then defined as the dual quantity to radiosity. We explain how these equations can be used after the resolution of a radiative heat transfer situation, as a post processing step, to establish the accuracy of each individual radiative link between the active faces of a tri-dimensional surface geometrical model. Examples are provided.

I. INTRODUCTION

In order to design the thermal control subsystem of a spacecraft, the thermal engineer often uses dedicated software. As the radiative component can be predominant, software is often based on stochastic ray tracing to compute the energy exchanges between the surfaces which compose the tri-dimensional model of the spacecraft, as well as the heat fluxes from the heat sources to the spacecraft and the evacuation of heat to the deep space. A drawback of current software for space thermal engineering is the fact that the accuracy of the thermal results (temperatures and radiative heat fluxes) cannot be insured.

The purpose of this paper is to present an innovative method in order to bridge the gap.

II. RADIOSITY EQUATION

Following Modest [1], the radiative balance of a tri-dimensional geometrical model can be expressed by the following set of equations, based on the radiosities J_i of the

surfaces:

$$\frac{q_i}{\epsilon_i} = E_{0,i} - \sum_{j=1}^N F_{i-j} J_j - H_{0,i} \quad (1)$$

The radiative heat flux q_i , the self-emitted power $E_{0,i}$ and the radiosity J_i of a patch P_i are linked by the following relation:

$$\frac{q_i}{\epsilon_i} = \frac{1}{1 - \epsilon_i} (E_{0,i} - J_i) \quad (2)$$

A. Boundary condition

For each patch P_i , two expressions of the radiosity equation can be obtained, in function of the nature of the boundary condition. Let us assume that the temperatures of the n first patches are known while the corresponding heat fluxes are unknown. On the other hand, the radiative heat fluxes of the $N - n$ other patches are fixed and their temperatures have been computed.¹ For each patch, the radiosity equation is given by the following relation, in function of the boundary condition:

$$\begin{cases} J_i = \epsilon_i E_{0,i} + \rho_i H_{0,i} + \rho_i \sum_{j=1}^N F_{i-j} J_j & \forall i \in [1, n] \\ J_i = q_i + H_{0,i} + \sum_{j=1}^N F_{i-j} J_j & \forall i \in [n + 1, N] \end{cases} \quad (3)$$

B. Radiosity equation

The set of radiosity equations can be rewritten as follows:

$$TJ = S \quad (4)$$

The thermal source vector S is based on the boundary conditions and the external irradiation; this vector is assumed to be exact.

$$S = \begin{pmatrix} \epsilon_1 E_{0,1} + \rho_1 H_{0,1} \\ \vdots \\ \epsilon_n E_{0,n} + \rho_n H_{0,n} \\ q_{n+1} + H_{0,n+1} \\ \vdots \\ q_N + H_{0,N} \end{pmatrix} \quad (5)$$

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