UNCERTAINTY AND CONFIDENCE INTERVALS OF THE MONTE CARLO RAY-TRACE METHOD IN RADIATION HEAT TRANSFER

María Cristina Sánchez

Dissertation submitted to the Faculty of the
Virginia Polytechnic Institute and State University
In partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Mechanical Engineering

Dr. J. R. Mahan
Dr. Elaine Scott
Dr. Karen Thole
Dr. Marty Day
Dr. Kory Priestley

November 2002

Blacksburg, Virginia

Keywords: Monte Carlo Ray Trace, Radiation Heat Transfer, Uncertainty Analysis

UNCERTAINTY AND CONFIDENCE INTERVALS OF THE MONTE CARLO RAY-TRACE METHOD IN RADIATION HEAT TRANSFER

María Cristina Sánchez

Virginia Polytechnic Institute and State University

Abstract

The primary objective of the work reported here is to develop a methodology to predict the uncertainty associated with radiation heat transfer problems solved using the Monte Carlo ray-trace method (MCRT). Four equations are developed to predict the uncertainty of the distribution factor from one surface to another, the global uncertainty of all the distribution factors in an enclosure, the uncertainty of the net heat flux from a surface, and the global uncertainty of the net heat flux from all the surfaces in an enclosure, respectively. Numerical experiments are performed to successfully validate these equations and to study the impact of various parameters such as the number of surfaces in an enclosure, the number of energy bundles traced in the MCRT model, the fractional uncertainty of emissivity and temperature, and the temperature distribution in the enclosure. Finally, the methodology is successfully applied to a detailed MCRT model of a CERES-like radiometer.

Acknowledgements

I would first like to thank my advisor, Dr J. R. Mahan for giving me the opportunity to come to the United States to pursue my graduate studies and for his guidance, friendship, and support during my time at Virginia Tech. I would like to thank Dr. Elaine Scott, Dr. Karen Thole, Dr. Martin Day, and Dr. Kory Priestley for their willingness to serve as members of my doctoral committee. I would also like to thank the NASA Langley Research Center, which supported this work under grant NAG–1–01125.

También me gustaría agradecer a mis compañeros del TRG, Stéphanie Weckmann, Catherine Coffey, Amie Smith, María Santamaría, Jose Dobarco, Mamadou Barry, Joel Barreto, Edwin Ayala, Dwight Smith y, especialmente, Bernardo Carnicero y Félix Nevárez, con quienes compartimos sueños y sinsabores pero que además se convirtieron en amigos inolvidables.

Finalmente quisiera agradecer a mis dos familias. Mis padres, Mario y Margarita, y hermana, Luz Angela, quienes con su apoyo y cariño además de soportes en mi vida, representan las raíces de donde se desarrollan sueños como este. Y Ira, mi mejor complemento, quien con su amor estuvo siempre presente para ayudar a levantarme una vez más. Sin ellos, esto no hubiera sido posible.

Contents

List of Figures

List of Tables

Nomenclature

Symbols:

A	Area (m^2)
D'_{ij}	Distribution factor from surface i to surface j
E	Estimated value
Err	Error
$\vec{n}$	Normal vector
n	Number of surfaces
N	Number of energy bundles
P	Power (W)
q"	Net heat flux (W/m^2)
Q	Radiative energy (W)
r_s	Specularity ratio
R	Random number between zero and unity
s	Standard deviation
$\vec{t}$	Tangential vector
T	Temperature (K)
W	W-statistic

Greek:

α	Absorptivity (–)

ε	Emissivity (–)
ϕ	Circumferential angle (rad)
ρ	Reflectivity (–)
σ	Stefan-Boltzann constant (W/m^4)
θ	Azimuth angle (rad)
ω	Uncertainty
$\omega_{K\&M}$	Uncertainty obtained using the Kline and McClintock formalism
ω_{exp}	Experimental uncertainty