MODELLING OF TRANSPORT PHENOMENA FOR THE HYPERSONIC STAGNATION POINT HEAT TRANSFER PROBLEM

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Abstract

Several approximations to the transport phenomena in rarefied gas mixtures are reviewed and evaluated for 5 component air. The investigation includes the exact formulations according to the kinetic theory, mixing rules, Eucken relations and constant Schmidt and Prandtl numbers. Suitable values for the latter are determined. The approximate models are used within the same Navier Stokes code for the chemical non-equilibrium flow with Mach 26 about the RAM-C II vehicle. With the present calculations, the effect of the approximations on the prediction of stagnation point heat flux is examined. It is shown, that the use of the suggested Schmidt and Prandtl numbers leads to proper results. The effect of pressure diffusion is also taken into consideration.

List of Symbols

ρ mass density [kg/m^3]
T temperature [K]
p hydrostatic pressure [N/m^2]
h specific enthalpy [J/kg]
e specific energy [J/kg]
x mass fraction [-]
y mole fraction [-]
c_v specific heat at constant volume [J/kg/K]
c_p specific heat at constant pressure [J/kg/K]
$\underset{\sim}{c}$ diffusion velocity [m/s]
$\underset{\sim}{q}$ heat flux vector [W/m^2]
$\underset{\sim}{V}$ velocity vector [m/s]
M molar mass [kg/mol]
R gas constant [J/kg/K]
D multi-component diffusion coefficient [m^2/s]
$\mathcal{D}$ binary diffusion coefficient [m^2/s]
D^T thermal diffusion coefficient [m^2/s]
η viscosity coefficient coefficient [kg/m/s]
η_b bulk viscosity coefficient [kg/m/s]
K conductivity coefficient [W/m/K]
$\underset{\approx}{P}$ stress tensor [N/m^2]
$\underset{\approx}{\tau}$ shear stress tensor [N/m^2]
$\underset{\approx}{\tau}_b$ bulk viscosity tensor [N/m^2]
$\Omega^{(1,1)}_{\alpha\beta}$, $\Omega^{(2,2)}_{\alpha\beta}$ collision cross sections [Å]
L geometrical scale [m]
Ma Mach number [-]
St Stanton number [-]
Sc Schmidt number [-]
Pr Prandtl number [-]
Re Reynolds number [-]
α, β indices referring to components
w/o subscript refers to mixture quantities
m refers to modes (tr,rot,vib,el)
tr refers to translational mode
rot refers to rotational mode
vib refers to vibrational mode
el refers to electronic mode

Introduction

One of the major problems encountered in hypersonic flight is the aerodynamic heating. In stagnation points the gas is heated by compression, while in boundary layers viscous dissipation causes the heating. In either case a heat flux from the hot gas to the colder body results.

Most severe heating rates are usually found in the stagnation point areas of the vehicle nose or leading edges. As the stagnation point heat flux is inversely proportional to the square root of the local surface radius ([4], p. 299), these areas are blunt shaped to reduce the heat loads.

The hypersonic flow about such surfaces is characterized by a strong bow shock, which converts the major part of the kinetic energy of the flow into internal energy. However, the molecular collision rate in the flow field is small due to the low density persisting along the

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