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Effect of temperature dependent properties on thermal radiative loading of planar surfaces with distinct heaters

M.Y. Abdollahzadeh Jamalabadi*

Department of Mechanical, Robotics and Energy Engineering, Dongguk University, 30 Pildong-ro 1gil, Jung-gu, Seoul 100-715, Republic of Korea

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Abstract

The purpose of the current study is to investigate the effect of temperature dependent thermophysical properties on thermal radiative loading characteristics of an enclosure. The results are studied the effect of heating number ($\zeta = 0.05$–500), aspect ratio ($A = 0.1$–1), the number of heaters ($N = 1$–19), on the maximum and mean temperature of system, Nusselt number, and the maximum stream function rate have been quantitatively analyzed. The results reveal that the average heat transfer rate considering temperature-dependent viscosity are higher than considering temperature-dependent thermal conductivity and both temperature-dependent viscosity and thermal conductivity and the stream function are lower.

Keywords: Vented enclosure flows; Surface radiation; Natural convection; Numerical computation

1. Introduction

When a hypersonic vehicle, such as a planetary-entry capsule or a high-lift reentry vehicle Space Shuttle or a scramjet-powered aircraft, is designed to fly outside the region of the earth's atmosphere for distances of 5000 miles or near the outer edge of the atmosphere; it reenter the atmosphere with a large amount of kinetic energy due to its high velocity at suborbital speediness of from 20,000 to 22,000 ft/s and a large amount of potential energy due to its high altitude. At such high velocities, the aerodynamic heating of the reentry vehicle becomes severe because it needed that at the earth's surface it contains no kinetic or potential energy ($Q_{total} \approx 0.5C_f/C_D\ KE$). Since the shuttle must slow down early during reentry into the earth's atmosphere to avoid massive aerodynamic heating. Therefore, with the purpose of obtain this deceleration; a high drag is desirable for the space shuttle. In addition, the pointed-nose reentry body is doomed to failure because it would burn up in the atmosphere before reaching the earth's surface. To minimize aerodynamic heating ($C_f \ll C_D$), one actually wants a blunt (Drag mainly should be due to pressure drag rather than friction drag) rather than a slender body (the maximum L/D ratio, $6 + 12/M_\infty$, of the space shuttle during reentry is about 2) [1].

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* Tel.: +8210 91701983.
E-mail address: muhammad_yaghoob@yahoo.com.

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Nomenclature

Symbol	Description	Unit
A	Aspect ratio, $= H/L$	
C_p	Heat capacity	J/kg K
D	Heater characteristic size	m
F_{ij}	Configuration factor	
g	Acceleration due to gravity	m/s^2
H	Enclosure height	m
k	Thermal conductivity	W/m K
$\bar{k}$	Dimensionless thermal conductivity, k/k_∞	
L	Enclosure width	m
N	Number of heat source	
Nu	Nusselt Number, $= Lq''/k(T_{\max} - T_\infty)$	
p	Pressure	Pa
P	Dimensionless pressure, $= (p - p_\infty)L^2/\rho\alpha^2$	
Pr	Prandtl number, $= \upsilon/\alpha$	
q''	Heater heat flux	W/m^2
Ra	Rayleigh number, $= g\beta q'' L^4/k_f\alpha\upsilon$	
T	Temperature	K
U, V	Dimensionless fluid velocities, $= uL/\alpha;\ vL/\alpha$	
x, y	Cartesian coordinates	m
X, Y	Dimensionless Cartesian coordinates, $= x/H;\ y/H$	
Greek symbols		
A	Thermal diffusivity	m^2/s
B	Volumetric coefficient of thermal expansion	1/K
δ_{ij}	Kronecker delta	
E	Surface emissivity	
ζ	Heating number, dimensionless heat flux, $= q''/\sigma T_\infty^4$	
M	Dynamic viscosity	kg/m s
$\bar{\mu}$	Dimensionless dynamic viscosity, μ/μ_∞	
Υ	Kinematic viscosity, $= \mu/\rho$	m^2/s
P	Fluid density	kg/m^3
Ψ	Stream function	m^2/s
Ψ	Dimensionless stream function, $= \psi/\alpha$	
Ω	Dimensionless vorticity function	
θ	Dimensionless temperature, $= k_f\ (T - T_\infty)/(q''L)$	
Θ	Dimensionless temperature, $= T/T_\infty$	
Superscript		
M	Average	
max	Maximum	
min	Minimum	
∞	Ambient value	

Other than shuttles, the hypersonic vehicles for sustained hypersonic flight in the atmosphere are a major challenge to the next generation of aerospace engineers (the X-43 Hyper-X test vehicle powered by a supersonic combustion ramjet engine, achieved sustained flight for 11 s at Mach 6.9 in 2004). The aerodynamic heating rate varies as the cube of the velocity ($Q_w/A \approx 0.5\rho_\infty C_H V^3 \approx 0.25\rho_\infty C_f V^3$) is in contrast to aerodynamic drag, which varies only as the square of the velocity. Even ambient density at a height of about 74 km is not much more than one millionth of sea-level density, the Shuttle Orbiter experienced peak heating. Since the nose region of high-speed blunt bodies is of practical interest in the calculation of drag and aerodynamic heating ($q_w \approx R^{-1/2}$), the properties of the flow