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Boundary Layers and Convective Heat Transfer-Laminar; Radiation and Radiation Heat Transfer

Theme

Describes and analyzes a thermal protection system applicable to high-altitude sustained flight of hypersonic aircraft involving injection of cooled air in regions of the body wherein the maximum radiative cooling from the surface is less than the convective heating and the suction of air in regions of the body wherein the maximum radiation is normally less than the convective heating. By appropriate distribution of injection and suction an active cooling system involving a porous surface but without net energy and mass exchange is shown to be possible. Aside from the practical applicability of this system for thermal protection, the calculation of the laminar boundary layer with a distribution of mass transfer only implicitly specified by a local energy balance is of interest.

Content

The concept of a local energy balance among convective heating to the porous surface, radiation from the porous surface and energy exchange to the air in its passage through the porous surface is described first. Then there is given the exact formulation of the equations describing the laminar boundary layer for two dimensional or axisymmetric flows wherein the mass transfer distribution corresponding to that local energy balance is computed as part of the solution. An approximate method of analysis based on an eigenfunction expansion is carried out in detail. It is shown that according to this method the mass transfer distribution is given by an integro-differential equation which may be solved numerically. Several examples illustrating the effect of the several parameters entering this calculation are presented.

Analysis of an Active Thermal Protection System for High-Altitude Flight

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A thermal protection system which may be of interest for sustained, high-altitude hypersonic flight is analyzed. It involves no net mass and energy transfer, air being injected into the boundary layer in the nose region where convective heating cannot be handled by radiation and withdrawn from the boundary layer in downstream region where possible radiative cooling normally exceeds convective heating. A zero net mass transfer can be achieved. Radiation cooling plays a dominant role in the system. Quite aside from the practical applicability of the system there would appear to be interest in the analysis of the laminar boundary layer with a mass transfer distribution, which is initially unknown but which is determined by a local energy balance involving radiative transfer.

Nomenclature

f = modified stream function
g = stagnation enthalpy ratio, $h_s/h_{s,e}$
h = static enthalpy
h_s = stagnation enthalpy
j = index, 0 for two-dimensional cases; 1 for axisymmetric cases
$\tilde{m}$ = Mach number parameter, $u_e^2/2h_{s,e}$
q_r = radiative transfer from the body surface
Q_r = radiative transfer function [cf. Eq. (13)]
r = cylindrical radius
s = transformed streamwise coordinate [cf. Eq. (4)]
s_1 = value of s where $(\rho v)_w = 0$
s_2 = value of s where mass balance is achieved
S = function in radiative transfer [cf. Eq. (33)]
u = streamwise velocity component
v = normal velocity component
x = streamwise coordinate
y = normal coordinate
α = acceleration parameter $(du_e/dx)_{x=0}$
β = pressure gradient parameter
γ = ratio of specific heats
η = transformed normal coordinate [cf. Eq. (4)]
μ = viscosity coefficient
ρ = mass density

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