NOMENCLATURE

a	speed of sound
A	area
A	$\partial F/\partial u$
$\mathbf{A}$	area vector
c	wave speed
c	specific heat
c_f	skin-friction coefficient
c_i	species mass fraction
c_p	specific heat at constant pressure
c_v	specific heat at constant volume
C_p	pressure coefficient
dA	differential area
dl	differential length
$\mathbf{dr}$	differential length vector along a line
dR	differential volume
dS	differential surface area
dt	differential time
dx, dy, dz	differential lengths in Cartesian system
dv	differential volume
dV	differential volume
$d\mathscr{V}$	differential volume
D	diameter
$\mathscr{D}_{\text{im}}$	multi-component diffusion coefficient
e	error

e	internal energy per unit mass
E	shift operator
Ec	Eckert number
E_t	total energy per unit volume, [$= \rho(e + V^2/2)$ if only internal energy and kinetic energy are included]
f	function
f	numerical flux
$\mathbf{f}$	body force per unit mass
f_x, f_y, f_z	components of body force per unit mass in a Cartesian system
F	denotes function, nondimensional velocity variable
$\mathbf{F}$	flux
$\mathbf{g}$	gravity vector
G	amplification factor
G	nondimensional velocity variable
h	height
h	enthalpy per unit mass ($= e + p/\rho$)
h	Δx
h	heat transfer coefficient
h_i°	enthalpy of formation for species i
h_1, h_2, h_3	scale factors in an orthogonal curvilinear coordinate system
H	total enthalpy ($= h + V^2/2$)
i	$\sqrt{-1}$
$\mathbf{i}_1, \mathbf{i}_2, \mathbf{i}_3$	unit vectors in a generalized curvilinear coordinate system
$\mathbf{i}, \mathbf{j}, \mathbf{k}$	unit vectors in a Cartesian coordinate system
I	nondimensional enthalpy variable
I	inverse Jacobian
I	transfer operator
J	Jacobian
k	Δy
k	coefficient of thermal conductivity
$\overline{k}$	kinetic energy of turbulence
k_m	wave number
k_T	turbulent thermal conductivity
K	local body curvature
K	$\Delta y_+/\Delta y_-$
l	length
l	mixing length
l_ϵ	dissipation length
$l_{1,2}$	scalar components of $\mathbf{L}$
L	difference operator
L	reference length
$\mathbf{L}$	eigenvector
$\dot{m}$	mass flow rate
M	Mach number
M_x	local streamwise Mach number

$\mathscr{M}$	molecular weight of mixture
$\mathscr{M}_i$	molecular weight of species i
n	time level
n	normal distance
$\mathbf{n}$	unit normal
N	total number of time steps
p	pressure
Pr	Prandtl number
Pr_T	turbulent Prandtl number
q	intensity of line source or sink
q	magnitude of heat flux vector
$\mathbf{q}$	heat flux vector
Q	external heat addition per unit volume
r	$\alpha \Delta t/(\Delta x)^2$
r	radius, radial distance
$\mathbf{r}$	position vector
r_x	$\alpha \Delta t/(\Delta x)^2$
r_y	$\alpha \Delta t/(\Delta y)^2$
r_z	$\alpha \Delta t/(\Delta z)^2$
R	explicit operator
R	residual
R	radius of curvature
R	volume
R	gas constant
Re	Reynolds number
Re_L	freestream Reynolds number based on length $L, (= \rho_\infty V_\infty L/\mu_\infty)$
$\mathrm{Re}_{\Delta x}$	mesh Reynolds number ($= c\,\Delta x/\mu$ for Burgers' equation)
$\mathscr{R}$	universal gas constant
s	entropy per unit mass
s	arc length
S	source term
$\mathbf{S}$	surface area vector
S_{ij}	mean strain tensor
t	time
T	temperature
TV	total variation
u	unknown
u^+	nondimensional velocity used in turbulent flow
u, v, w	velocity components in a Cartesian system
u_1, u_2, u_3	velocity components in a generalized coordinate system
u_r, u_θ, u_z	velocity components in a cylindrical coordinate system
u_r, u_θ, u_ϕ	velocity components in a spherical coordinate system
U, V, W	contravariant velocity components
U	freestream velocity in x direction
$\mathbf{U}_i$	species diffusion velocity

v	unknown
v_T	characteristic velocity of the turbulence
$\mathbf{V}$	velocity vector
V	magnitude of velocity vector
w	weight function
w	unknown
$\mathbf{w}$	primitive variable vector
x, y, z	Cartesian coordinates
x_1, x_2, x_3	generalized curvilinear coordinates
y^+	nondimensional distance used in turbulent flow
α	thermal diffusivity
α, β, γ	conical coordinates
β	volumetric expansion coefficient
β	grid aspect ratio ($= \Delta x/\Delta y$)
β	artificial compressibility factor
β	stretching parameter
β	$k_m \Delta x$
β	$\sqrt{M_\infty^2 - 1}$
β	pressure gradient parameter, $[= (x/u_e)\, du_e/dx]$
β_x	$k_m \Delta x$
β_y	$k_m \Delta y$
γ	ratio of specific heats
Γ	finite-difference operator, circulation
δ	characteristic length in y direction
δ	boundary-layer thickness
δ	central-difference operator defined by Eq. (3.14)
δ_u	represents change in u between two iterations
$\bar{\delta}$	central-difference operator defined by Eq. (3.13)
$\hat{\delta}$	central-difference operator defined by Eqs. (4.100)
δ^*	displacement thickness
δ_{ij}	Kronecker delta
Δ	forward-difference operator defined by Eq. (3.9)
Δx_+	$x_{j+1} - x_j$
Δx_-	$x_j - x_{j-1}$
Δy_+	$y_{j+1} - y_j$
Δy_-	$y_j - y_{j-1}$
$\Delta^n( )$	$( )^{n+1} - ( )^n$
η	nondimensional distance variable
ϵ	turbulence dissipation rate
ϵ	round-off error
ϵ_i	coefficient of implicit smoothing term
ϵ_e	coefficient of explicit smoothing term
$\boldsymbol{\zeta}$	vorticity ($= \nabla \times \mathbf{V}$)
ζ	magnitude of vorticity vector

θ	nondimensional thermal variable defined by Eq. (5.95)
θ	angle measured in circumferential direction
θ	parameter controlling type of difference scheme
θ	momentum thickness
θ_1, θ_2	parameters controlling type of difference scheme
κ	coefficient of bulk viscosity
κ	von Kármán constant
λ	eigenvalue
λ	generalized diffusion coefficient
$\overline{\lambda}$	$\lambda_T + \lambda$
μ	viscous coefficient in Burgers' equation
μ	coefficient of viscosity
μ	averaging operator defined by Eq. (3.16)
$\overline{\mu}$	$\mu + \mu_T$
μ'	second coefficient of viscosity
μ_T	eddy viscosity
ξ, η, ζ	transformed coordinates
π	3.14159...
$\mathbf{\Pi}_{ij}$	stress tensor
ρ	density
ρ	artificial density
ρ_i	species density
σ	eigenvalue
σ	shock angle
τ	parameter
τ	computational time or pseudo time
τ	shear stress
$\boldsymbol{\tau}_{ij}$	viscous stress tensor
ν	kinematic viscosity ($= \mu/\rho$)
ν	$c\,\Delta t/\Delta x$
ϕ	velocity potential
ϕ	angle in spherical coordinate system
ϕ	phase angle
ϕ	generalized variable
ϕ	limiter function
ϕ	grid control function
ϕ, ψ	boundary point clustering function
Φ	dissipation function
χ	strong-interaction parameter
χ	pressure gradient parameter, $[= (-1/\rho)\,dp/dx]$
ψ	stream function
$\boldsymbol{\psi}$	vector potential
ψ	limiter function
ψ	grid control function
ω	fraction of streamwise pressure gradient term

ω	damping function or damping parameter
ω_i	rate of production of species i
$\omega, \overline{\omega}$	overrelaxation parameters
∇	backward-difference operator defined by Eq. (3.11)
$\boldsymbol{\nabla}$	vector differential operator
∇^2	Laplacian operator ($= \boldsymbol{\nabla} \cdot \boldsymbol{\nabla}$)

SUBSCRIPTS

b	body value
bdy	boundary value
B	boundary value
CFL	Courant-Friedrichs-Lewy condition
e	exact value
e	edge of boundary layer
f	frozen
i	inlet
i	inner
i	inviscid term
i, j, k	grid locations in x, y, z directions
inv	denotes inviscid value
lam	laminar-like in form
l	lower
l	left value
L	left value
min	minimum
max	maximum
n	normal or normal component
nose	nose value
o	intermediate (or estimated) value
o	initial value
o	outer
opt	optimum value
r	right value
ref	reference conditions
R	right value
s	shock value
stag	stagnation value
t	tangential or tangential component
t	thermal
t	partial differentiation with respect to time
T	tangential
T	turbulent
turb	turbulent quantity

u	upper
v	viscous term
wall	wall value
x	partial differentiation with respect to x
y	partial differentiation with respect to y
z	partial differentiation with respect to z
x, y, z	differences in x, y, z directions
x, y, z	components in x, y, z directions
1	conditions in front of shock
2	conditions behind shock
∞	freestream value

SUPERSCRIPTS

i	index in marching direction
k	iteration level
m	iteration level
n	index in marching direction
n	time level
*	dummy time index
**	dummy time index
*	denotes a nondimensional quantity
*	sonic conditions
+	positive state
−	negative state
′	denotes fluctuation in turbulent flow, conventionally-averaged variables
′	perturbation quantity
′	correction term
″	denotes fluctuation in turbulent flow, mass-averaged variables

OVERBARS

¯	denotes averaged quantity or time-averaged quantity
~	dimensional variables
~	denotes mass-averaged variables [see Eq. (5.64)]
^	Roe-averaged quantity
^	denotes value of variable from previous iteration

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