

NOTATION

The symbols most commonly used throughout the book are defined below. When appearing in the text matrices, tensors, and vectors are identified by boldface type.

Mathematical Symbols

$(\hat{.})$	Based on element gradient
$(.^{*})$	Based on nodally continuous gradient
$\{.\}$	Column vector, n by 1
$\lvert . \rvert$	Determinant of a matrix
$\boldsymbol{\Delta}^T$	Divergence operator
$\varnothing$	Empty set
$\boldsymbol{\nabla}$	Gradient operator
$\in$	In
$\bigcap$	Intersection
$[.]^{-1}$	Inverse of a square matrix
$\square$	Non-dimensional parametric space
$\lVert . \rVert$	Norm of a matrix or vector
$]. , . [$	Open one-dimenswional domain
$\lfloor \ \rfloor^T \lfloor \ \rfloor$	Outer product square matrix, m by m
$,_{(.)}$	Partial differentiation with respect to $(.)$
$\boldsymbol{\partial}_G, \boldsymbol{\partial}_\Omega$	Partial derivatives in global Cartesian space
$\boldsymbol{\partial}_L, \boldsymbol{\partial}_\square$	Partial derivatives in local parametric space
$\propto$	Proportional to
$[.]$	Rectangular, m by n, or square matrix
$\lfloor . \rfloor$	Row vector, 1 by m
$\subset$	Subset
$[.]^T$	Transpose of a matrix
$\bigcup$	Union

Latin Symbols

A	Area
$\mathbf{a}$	Acceleration vector
a, b, c	Natural coordinates on −1 to +1
$(.)^b$	Relating to a boundary domain
$\mathbf{B}$	Differential operator acting on interpolation matrix **H** or **N**

$\mathbf{b}$	Differential operator acting on global interpolation matrix $\mathbf{h}$
C^n	Field continuity of degree n
$\mathbf{C}$	System source vector
$\mathbf{C}^b$	Source vector from a boundary segment
$\mathbf{C}^e$	Source vector from an element
$\mathbf{D}$	System degrees of freedom vector
D	Differential operator.
$\mathbf{D}^b$	Boundary segment degrees of freedom vector
$\mathbf{D}^e$	Element degrees of freedom vector
$\mathbf{d}$	Cartesian gradient of $\mathbf{H}$
$\mathbf{d}_x$	First row of $\mathbf{d}$, etc. for y, z
$d.o.f.$	Degree(s) of freedom
E	Modulus of elasticity of a material
$\mathbf{E}$	Constitutive law (stress-strain) matrix
e	Error
$(.)^e$	Relating to an element domain
$\mathbf{F}$	Resultant force vector
G	Shear modulus of a material
$\mathbf{G}$	Geometry interpolation row matrix (usually $\mathbf{G} = \mathbf{H}$)
$\mathbf{H}^b$	Boundary interpolation row matrix for a scalar
$\mathbf{H}^e$	Element interpolation row matrix for a scalar
h	Characteristic length. Convection coefficient
$\mathbf{h}$	Global interpolation matrix
$I^e, \mathbf{I}^e$	Integral of a scalar or matrix, respectively, on an element
$\mathbf{I}$	Identity matrix
$\mathbf{J}$	Jacobian matrix of a geometric transformation
$\mathbf{K}$	Stiffness matrix
k	Thermal conductivity of a material, or spring stiffness
$\mathbf{L}$	Differential operator
L	Length
L_k	Baracentric coordinates, $\sum L_k = 1$
$\mathbf{M}$	Mass matrix of the system
$\mathbf{m}^e$	Mass matrix, or thermal capacity matrix of an element
m	Mass
$\mathbf{N}$	Interpolation matrix for generalized degrees of freedom (often $\mathbf{N} = \mathbf{H}$)
$\mathbf{n}$	Unit normal vector
n_a	Number of adjacent elements, *NEIGH_L*
n_b	Number of boundary segments, *N_MIXED + N_SEG*
n_c	Number of constraint equations, *N_CEQ*
n_d	Number of system degrees of freedom ($n_m \times n_g$), *N_D_FRE*
n_e	Number of elements in the system, *N_ELEMS*
n_f	Maximum number of flux components, *N_G_FLUX*
n_g	Number of generalized dof per node, *N_G_DOF*
n_i	Number of element equation index terms ($n_n \times n_g$), *LT_FREE*
n_m	Maximum node number in the system, *MAX_NP*

n_n	Maximum number of nodes per element, *NOD_PER_EL*
n_p	Dimension of the parametric space, *N_PARM*
n_{pe}	Number of elements in a patch, *L_IN_PATCH*
n_q	Number of quadrature points, *N_QP*
n_r	Number of rows in the **B** matrix, *N_R_B*
n_s	Dimension of the physical space, *N_SPACE*
n_t	Number of different element types, *N_L_TYPE*
n_x	Number of element geometry definition nodes, *N_GEOM*
$\mathbf{P}$	Polynomial row matrix. Reaction vector
p	Pressure
$\mathbf{Q}$	Source per unit volume
$\mathbf{Q}^e$	Source per unit volume at element node points
q	Source per unit length
q_n	Heat flux normal to boundary ($\mathbf{q}_n = q_n\,\mathbf{n}$)
$\mathbf{q}$	Heat flux vector at a point
$\mathbf{R}$	Matrix of position vectors, $\mathbf{R} = [\mathbf{x}\,\mathbf{y}\,\mathbf{z}]$
R	Residual error in Ω^e
r, s, t	Unit coordinates on 0 to 1
$\mathbf{S}$	Square matrix of the system
$\mathbf{S}^b$	Square matrix from a boundary segment
$\mathbf{S}^e$	Square matrix from an element
t	Thickness, time
$\mathbf{T}$	Transformation matrix, or boundary traction matrix
U	Strain energy
$\mathbf{u}$	Displacement vector. Velocity vector
u, v, w	Components of displacement vector
V	Volume
$\mathbf{v}$	Velocity vector
W	Mechanical work
x, y, z	Cartesian coordinates
$\mathbf{X}$	Body force vector
$\mathbf{x}$	Vector of x-coordinates
$\mathbf{x}^e$	Vector of x-coordinates of the element nodes
$\mathbf{y}$	Vector of y-coordinates
$\mathbf{z}$	Vector of z-coordinates

Greek Symbols

α	Coefficient of thermal expansion
$\boldsymbol{\beta}$	Boolean gather matrix
$\boldsymbol{\beta}^T$	Boolean scatter matrix
$\sum_e \boldsymbol{\beta}^{eT}\,\mathbf{C}^e$	Column vector assembly process
$\sum_e \boldsymbol{\beta}^{eT}\,\mathbf{S}^e\,\boldsymbol{\beta}^e$	Square matrix assembly process
$\boldsymbol{\Gamma}$	Boundary of a domain, Ω
$\boldsymbol{\Gamma}^b$	Segment of the boundary $\boldsymbol{\Gamma}$

$\boldsymbol{\Gamma}^e$	Boundary of an element domain, Ω^e
γ	Weight per unit volume
$\boldsymbol{\Delta}$	Local derivatives of the interpolation matrix **H** or **N**
$\boldsymbol{\delta}$	Element or boundary segment d.o.f.
$\boldsymbol{\varepsilon}$	Strain or gradient
ζ	Refinement parameter
η	Allowed percentage error
θ	Temperature, or angle
Θ	Effectivity index
λ	Direction cosine. Lame' constant.
μ	Direction cosine. Lame' constant.
ν	Poisson's ratio for a material
$\boldsymbol{\Pi}$	Total potential energy, $\boldsymbol{\Pi} = U - W$
π	Mathematical constant 3.14159...
ρ	Mass density of a material
$\boldsymbol{\rho}$	Position vector to a point, $\boldsymbol{\rho} = [x, y, z]$
$\boldsymbol{\sigma}$	Flux or stress
$\boldsymbol{\sigma}^*$	Smoothed flux or stress approximation
$\hat{\boldsymbol{\sigma}}$	Finite element flux or stress approximation
τ	Stabilization parameter
$\boldsymbol{\tau}$	Shear stress
Φ	System degrees of freedom vector
Φ_k	k-th unknown
ϕ	Scalar unknown. Velocity potential
ψ	Stream function
ω	Angular velocity
$\boldsymbol{\Omega}$	Domain
$\boldsymbol{\Omega}^e$	Element domain

Selected Program Notation (Array sizes follow in parentheses.)

AJ	JACOBIAN MATRIX: (N_SPACE, N_SPACE)
B	GRADIENT VERSUS DOF MATRIX: (N_R_B, LT_FREE)
C	ELEMENT COLUMN MATRIX: (LT_FREE)
CC	COLUMN MATRIX OF SYSTEM EQUATIONS: (N_D_FRE)
COORD	COORDINATES OF ALL NODES ON ELEMENT: (LT_N, N_SPACE)
C_B	BOUNDARY SEGMENT COLUMN MATRIX
D	NODAL PARAMETERS ASSOCIATED WITH AN ELEMENT: (LT_FREE)
DD	SYSTEM LIST OF NODAL PARAMETERS: (N_D_FRE)
DGH	GLOBAL DERIVS OF SCALAR FUNCTIONS H: (N_SPACE, LT_N)
DGV	GLOBAL DERIVS OF VECTOR FUNCTIONS V: (N_SPACE, LT_FREE)
DLG	LOCAL DERIVS OF GEOMETRY FUNCTIONS G: (LT_PARM, LT_GEOM)
DLH	LOCAL DERIVATIVES OF SCALAR FUNCTIONS H: (LT_PARM, LT_N)
E	CONSTITUTIVE MATRIX: (N_R_B, N_R_B)
EL_M	ELEMENT MASS MATRIX: (LT_FREE, LT_FREE)
G	INTERPOLATION FUNCTIONS FOR GEOMETRY: (LT_GEOM)

GLOBAL	GLOBAL DERIV'S OF SCALAR INTERPOLATION FUNCTIONS H
H	INTERPOLATION FUNCTIONS FOR AN ELEMENT SCALAR: (LT_N)
H_INTG	INTEGRAL OF SCALAR INTERPOLATION FUNCTIONS: (LT_N)
H_QP	INTERPOLATION FOR H AT QUADRATURE POINT: (LT_N, LT_QP)
INDEX	SYSTEM DEGREE OF FREEDOM NUMBERS ARRAY: (LT_FREE)
LT	ELEMENT TYPE NUMBER
LT_FREE	NUMBER OF DEGREES OF FREEDOM PER ELEMENT
LT_GEOM	NUMBER OF GEOMETRIC NODES PER ELEMENT
LT_N	MAXIMUM NUMBER OF NODES FOR ELEMENT TYPE
LT_PARM	DIMENSION OF PARAMETRIC SPACE FOR ELEMENT TYPE
LT_QP	NUMBER OF QUADRATURE POINTS FOR ELEMENT TYPE
LT_SHAP	ELEMENT TYPE SHAPE FLAG NUMBER
L_B_N	NUMBER OF NODES ON AN ELEMENT BOUNDARY SEGMENT
L_SHAPE	ELEM SHAPE, 1=LINE 2=TRI 3=QUAD 4=HEX 5=TET 6=WEDGE
L_TYPE	ELEMENT TYPE NUMBER: (L_S_TOT)
MAT_FLO	NUMBER OF REAL MATERIAL PROPERTIES
MAX_NP	NUMBER OF SYSTEM NODES
MISC_FL	NUMBER OF MISC. FLOATING POINT SYSTEM PROPERTIES
MISC_FX	NUMBER OF MISC. FIXED POINT SYSTEM PROPERTIES
M_B_N	NUMBER OF NODES ON A MIXED BC SEGMENT
NODES	NODE INCIDENCES OF ALL ELEMENTS: (L_S_TOT, NOD_PER_EL)
NOD_PER_EL	MAXIMUM NUMBER OF NODES PER ELEMENT
N_BS_FIX	NUMBER OF BOUNDARY SEGMENT INTEGER PROPERTIES
N_BS_FLO	NUMBER OF BOUNDARY SEGMENT REAL PROPERTIES
N_D_FLUX	MAXIMUM NUMBER OF FLUX SEGMENT DOF, = L_B_N * N_G_DOF
N_D_FRE	TOTAL NUMBER OF SYSTEM DEGREES OF FREEDOM
N_ELEMS	NUMBER OF ELEMENTS IN SYSTEM
N_EL_FRE	NUMBER OF DEGREES OF FREEDOM PER ELEMENT
N_GEOM	NUMBER OF GEOMETRY NODES
N_G_DOF	NUMBER OF GENERALIZED PARAMETERS (DOF) PER NODE
N_G_FLUX	NUMBER OF FLUX COMPONENTS PER SEGMENT NODE
N_LP_FIX	NUMBER OF INTEGER ELEMENT PROPERTIES
N_LP_FLO	NUMBER OF FLOATING POINT ELEMENT PROPERTIES
N_MX_FIX	NUMBER OF FIXED POINT MIXED_SEGMENT PROPERTIES
N_MX_FLO	NUMBER OF FLOATING POINT MIXED_SEGMENT PROPERTIES
N_NP_FIX	NUMBER OF FIXED POINT NODAL PROPERTIES
N_NP_FLO	NUMBER OF FLOATING POINT NODAL PROPERTIES
N_PARM	DIMENSION OF PARAMETRIC SPACE
N_QP	MAXIMUM NUMBER OF QUADRATURE POINTS
N_R_B	NUMBER OF ROWS IN B AND E MATRICES
N_SEG	NUMBER OF ELEM BOUNDARY SEGMENTS WITH GIVEN FLUX
N_SPACE	DIMENSION OF SPACE
PT	QUADRATURE COORDINATES: (LT_PARM, LT_QP)
S	ELEMENT SQUARE MATRIX: (LT_FREE, LT_FREE)
SCP_FIT	NUMBER IF TERMS BEING FIT, N_R_B USUALLY

SCP_GEOM	NUMBER OF PATCH GEOMERTY NODES
SCP_H	INTERPOLATION FUNCTIONS FOR PATCH, USUALLY IS H (SCP_N)
SCP_LT	PATCH TYPE NUMBER
SCP_N	NUMBER OF NODES PER PATCH
SCP_PARM	NUMBER OF PARAMETRIC SPACES FOR PATCH
SCP_QP	NUMBER OF QUADRATURE POINTS NEEDED IN A SCP
SCP_SHAP	PATCH SHAPE FLAG NUMBER
SIGMA_HAT	FLUX COMPONENTS AT PT FROM ORIGINAL ELEMENT: (SCP_FIT)
SIGMA_SCP	FLUX COMPONENTS AT PT FROM SMOOTHED SCP: (SCP_FIT)
SS	SQUARE MATRIX OF SYSTEM EQUATIONS: (N_D_FREE, N_D_FREE)
STRAIN	STRAIN OR GRADIENT VECTOR: (N_R_B + 2)
STRAIN_0	INITIAL STRAIN OR GRADIENT VECTOR, IF ANY: (N_R_B)
STRESS	STRESS VECTOR: (N_R_B + 2)
S_B	BOUNDARY SEGMENT SQUARE MATRIX, IF ANY: (LT_FREE, LT_FREE)
V	INTERPOLATION FUNCTIONS FOR VECTORS: (LT_FREE)
WT	QUADRATURE WEIGHTS: (LT_QP)
X	COORDINATES OF ALL SYSTEM NODES: (MAX_NP, N_SPACE)
XYZ	SPACE COORDINATES AT A POINT: (N_SPACE)