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-dimensional 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 $\mathbf{H}$ or $\mathbf{N}$
$\mathbf{b}$	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
dof	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	Barycentric 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_h	Number of scalar interpolations in **H**, *LT_FREE*
n_i	Number of element equation index terms ($n_n \times n_g$), *LT_FREE*
n_l	Number of elements in a patch, *L_IN_PATCH*
n_m	Maximum node number in the system, *MAX_NP*
n_n	Maximum number of nodes per element, *NOD_PER_EL*
n_o	Number of mixed or Robin BC segments, *N_MIXED*
n_p	Dimension of the parametric space, *N_PARM*
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_v	Number of vector interpolations in **V**, *LT_FREE*
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 element assembly process
$\sum_e \boldsymbol{\beta}^{eT}\, \mathbf{S}^e\, \boldsymbol{\beta}^e$	Square matrix element 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 dof.
$\boldsymbol{\varepsilon}$	Strain or gradient
ζ	Refinement parameter
η	Allowed percentage error
θ	Temperature, or angle
Θ	Effectivity index
λ	Direction cosine wrt x. Lame' constant.
μ	Direction cosine wrt y. Lame' constant.
ν	Poisson's ratio of a material. Direction cosine wrt z.
$\boldsymbol{\Pi}$	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)
AVE	Average quantities at a system node: (N_R_B + 2, MAX_NP)
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 an element: (LT_N, N_SPACE)
C_B	Boundary segment column matrix: (LT_FREE)
D	Nodal parameters associated with an element: (LT_FREE)
DD	System list of nodal parameters: (N_D_FRE)
DGH	Global derivatives of scalar functions $\mathbf{H}$: (N_SPACE, LT_N)
DGV	Global derivatives of vector functions $\mathbf{V}$: (N_SPACE, LT_FREE)
DLG	Local derivatives of geometry functions $\mathbf{G}$: (LT_PARM, LT_GEOM)
DLH	Local derivatives of scalar functions $\mathbf{H}$: (LT_PARM, LT_N)
E	Constitutive matrix: (N_R_B, N_R_B)
EL_M	Element mass matrix: (LT_FREE, LT_FREE)
FLUX_LT	Flux at element nodes from a SCP: (SCP_FIT, LT_N
G	Interpolation functions for geometry: (LT_GEOM)
GLOBAL	Global derivatives of scalar interpolation functions $\mathbf{H}$
H	Interpolation functions for an element scalar: (LT_N)
H_INTG	Integral of scalar interpolation functions $\mathbf{H}$: (LT_N)
H_QP	Interpolation for $\mathbf{H}$ at quadrature point: (LT_N, LT_QP)
INDEX	System degree of freedom numbers array: (LT_FREE)
L_B_N	Maximum number of nodes on an element boundary segment
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	Current element type shape flag number
L_B_N	Number of nodes on an element boundary segment
L_SHAPE	Shape: 0=Point 1=Line 2=Triangle 3=Quadrilateral 4=Hexahedron 5=Tetrahedron etc.
L_TYPE	Type number array of all elements: (L_S_TOT)
MAT_FLO	Number of real material properties
MAX_NP	Number of system nodes
MISC_FL	Number of miscellaneous floating point (real) system properties
MISC_FX	Number of miscellaneous fixed point (integer) system properties
M_B_N	Number of nodes on a mixed boundagy condition 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_CEQ	Number of system constraint equations
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 the system
N_EL_FRE	Maximum number of degrees of freedom per element
N_GEOM	Maximum number of element 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 (real) element properties
N_MAT	Number of materail types
N_MX_FIX	Number of fixed point (integer) mixed segment properties
N_MX_FLO	Number of floating point (real) mixed segment properties
N_NP_FIX	Number of fixed point (integer) nodal properties
N_NP_FLO	Number of floating point (real) nodal properties
N_PARM	Dimension of parametric space
N_PATCH	Number of SCP patches = MAX_NP or N_ELEMS
N_QP	Maximum number of element quadrature points
N_R_B	Number of rows in $\mathbf{B}$ and $\mathbf{E}$ matrices
N_SEG	Number of element boundary segments with given flux
N_SPACE	Dimension of space
PATCH_FIT	Local patch flux values at its nodes: (SCP_N, SCP_FIT)
PT	Quadrature coordinates: (LT_PARM, LT_QP)
S	Element square matrix: (LT_FREE, LT_FREE)
SCP_COUNTS	Number of patches used for each nodal averages: (MAX_NP)
SCP_FIT	Number of terms being fit in a patch, N_R_B usually
SCP_GEOM	Number of patch geometry nodes
SCP_H	Interpolation functions for patch, usually is $\mathbf{H}$ (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 patch
SIGMA_HAT	Flux components at a point in original element: (SCP_FIT)
SIGMA_SCP	Flux components at a point in 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 at a point: (N_R_B + 2)
S_B	Boundary segment square matrix, if any: (LT_FREE, LT_FREE)
THIS_EL	Current element number
THIS_LT	Current element type number
THIS_STEP	Current time step number
TIME	Current time in dynamic or transient solution
V	Interpolation functions for vectors: (LT_FREE)
WT	Quadrature weights: (LT_QP)
X	Coordinates of all system nodes: (MAX_NP, N_SPACE)
XYZ	Spatial coordinates at a point: (N_SPACE)