

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

$(\hat{\cdot})$	Based on element gradient
(\cdot^*)	Based on nodally continuous gradient
$\{.\}$	Column vector, n by 1
$ \cdot $	Determinant of a matrix
Δ^T	Divergence operator
\emptyset	Empty set
∇	Gradient operator
\in	In
\cap	Intersection
$[\cdot]^{-1}$	Inverse of a square matrix
\square	Non-dimensional parametric space
$\ \cdot\ $	Norm of a matrix or vector
$],.,.[$	Open one-dimensional domain
$[\cdot]^T[\cdot]$	Outer product square matrix, m by m
$\cdot,(\cdot)$	Partial differentiation with respect to (\cdot)
$\partial_G, \partial_\Omega$	Partial derivatives in global Cartesian space
$\partial_L, \partial_\square$	Partial derivatives in local parametric space
\propto	Proportional to
$[\cdot]$	Rectangular, m by n, or square matrix
$[\cdot]$	Row vector, 1 by m
\subset	Subset
$[\cdot]^T$	Transpose of a matrix
\cup	Union

Latin Symbols

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

b	Differential operator acting on global interpolation matrix h
C^n	Field continuity of degree n
C	System source vector
C^b	Source vector from a boundary segment
C^e	Source vector from an element
D	System degrees of freedom vector
D	Differential operator.
D^b	Boundary segment degrees of freedom vector
D^e	Element degrees of freedom vector
d	Cartesian gradient of H
d_x	First row of d , etc. for y, z
<i>d. o. f.</i>	Degree(s) of freedom
E	Modulus of elasticity of a material
E	Constitutive law (stress-strain) matrix
e	Error
$(.)^e$	Relating to an element domain
F	Resultant force vector
G	Shear modulus of a material
G	Geometry interpolation row matrix (usually G = H)
H^b	Boundary interpolation row matrix for a scalar
H^e	Element interpolation row matrix for a scalar
h	Characteristic length. Convection coefficient
h	Global interpolation matrix
I^e, \mathbf{I}^e	Integral of a scalar or matrix, respectively, on an element
I	Identity matrix
J	Jacobian matrix of a geometric transformation
K	Stiffness matrix
k	Thermal conductivity of a material, or spring stiffness
L	Differential operator
L	Length
L_k	Baracentric coordinates, $\sum L_k = 1$
M	Mass matrix of the system
m^e	Mass matrix, or thermal capacity matrix of an element
m	Mass
N	Interpolation matrix for generalized degrees of freedom (often N = H)
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 \mathbf{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
β	Boolean gather matrix
β^T	Boolean scatter matrix
$\sum \beta^{eT} \mathbf{C}^e$	Column vector assembly process
$\sum \beta^{eT} \mathbf{S}^e \beta^e$	Square matrix assembly process
Γ	Boundary of a domain, Ω
Γ^b	Segment of the boundary Γ

Γ^e	Boundary of an element domain, Ω^e
γ	Weight per unit volume
Δ	Local derivatives of the interpolation matrix \mathbf{H} or \mathbf{N}
δ	Element or boundary segment d.o.f.
ε	Strain or gradient
ζ	Refinement parameter
η	Allowed percentage error
θ	Temperature, or angle
Θ	Effectivity index
λ	Direction cosine. Lamé' constant.
μ	Direction cosine. Lamé' constant.
ν	Poisson's ratio for a material
Π	Total potential energy, $\Pi = U - W$
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
τ	Shear stress
Φ	System degrees of freedom vector
Φ_k	k-th unknown
ϕ	Scalar unknown. Velocity potential
ψ	Stream function
ω	Angular velocity
Ω	Domain
Ω^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 GEOMETRY 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)