<table>
<thead>
<tr>
<th>Aircraft materials, 2, 12–16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airy stress function, 56, 57</td>
</tr>
<tr>
<td>Aluminum alloys, 14, 15, 212</td>
</tr>
<tr>
<td>Angle of twist, in torsion, 69, 86–89, 246</td>
</tr>
<tr>
<td>multicell sections, 93</td>
</tr>
<tr>
<td>narrow rectangular section, 79</td>
</tr>
<tr>
<td>single-cell section, 81</td>
</tr>
<tr>
<td>Apparent engineering moduli, 275</td>
</tr>
<tr>
<td>Average stress, 189</td>
</tr>
<tr>
<td>Axial force, 117</td>
</tr>
<tr>
<td>Axial member, 2, 20, 25</td>
</tr>
<tr>
<td>Axial stiffness, 2</td>
</tr>
<tr>
<td>Axial stress, 26</td>
</tr>
<tr>
<td>Beam, 5, 115</td>
</tr>
<tr>
<td>Beam-column, 225</td>
</tr>
<tr>
<td>Bending, bidirectional, 120–128</td>
</tr>
<tr>
<td>Bending equations</td>
</tr>
<tr>
<td>for symmetrical section, 119</td>
</tr>
<tr>
<td>for unsymmetrical section, 122–124</td>
</tr>
<tr>
<td>Bending member, 5</td>
</tr>
<tr>
<td>Bending moments, 117, 121</td>
</tr>
<tr>
<td>Bending rigidity of plate, 257</td>
</tr>
<tr>
<td>Bending stiffness of beam, 5</td>
</tr>
<tr>
<td>Bending stress, 6, 122</td>
</tr>
<tr>
<td>Bernoulli–Euler beam, 115, 119</td>
</tr>
<tr>
<td>Bifurcation points, 230</td>
</tr>
<tr>
<td>Boundary conditions, 54</td>
</tr>
<tr>
<td>for plates, 257</td>
</tr>
<tr>
<td>Buckling</td>
</tr>
<tr>
<td>of bars of unsymmetric section, 244</td>
</tr>
<tr>
<td>effective length of, 235</td>
</tr>
<tr>
<td>of flat plate, 256</td>
</tr>
<tr>
<td>load, see Critical load</td>
</tr>
<tr>
<td>local, 264</td>
</tr>
<tr>
<td>mode shape, 230</td>
</tr>
<tr>
<td>of open section, 264</td>
</tr>
<tr>
<td>of rectangular plate, 259–263</td>
</tr>
<tr>
<td>of straight bar, 235</td>
</tr>
<tr>
<td>torsional, 248–250</td>
</tr>
<tr>
<td>torsional-flexural, 251</td>
</tr>
<tr>
<td>Center of twist, 68, 74, 77, 105</td>
</tr>
<tr>
<td>Centroidal axis, 115</td>
</tr>
<tr>
<td>Compatibility equation, 54, 71, 93, 176</td>
</tr>
<tr>
<td>Composites, 2, 12, 15–16, 45–46</td>
</tr>
<tr>
<td>ceramic matrix, 16</td>
</tr>
<tr>
<td>metal matrix, 16</td>
</tr>
<tr>
<td>polymer matrix, 16, 46</td>
</tr>
<tr>
<td>Coulomb–Mohr criterion, 184</td>
</tr>
<tr>
<td>Coupling, shear-extension, 274, 276</td>
</tr>
<tr>
<td>Crack closure method, 206</td>
</tr>
<tr>
<td>Crack, Griffith, 194</td>
</tr>
<tr>
<td>Crack growth rate, 217</td>
</tr>
<tr>
<td>Crack surface displacement, 204, 205</td>
</tr>
<tr>
<td>Crack tip plasticity, 211</td>
</tr>
<tr>
<td>Crippling stress, 264</td>
</tr>
</tbody>
</table>
Critical load
   for clamped-clamped bar, 234–235
   for clamped-free bar, 231–232
   for clamped-pinned bar, 232–233
   for flat plate, 260–263
   for pinned-pinned bar, 230
   for torsional buckling, 248, 250, 253

Critical strain energy release rate, 196

Critical stress intensity factor, 208

Cylindrical bending, 258

Dilatation, 188

Dislocation, 187

Displacement, concept of, 19–21

Distortional energy, 190

Doubly symmetric section, 248

Dowling, N. E., 212

Eccentrically loaded bars, buckling
   of, 225

Effective length of buckling, 235

Effective slenderness ratio, 235

Elastic compliances, 43, 44, 272

Elastic constants, 44, 45

Elastic symmetry, 45

End constraint, 103–110

Endurance limit, 216

Equilibrium equations, 28, 54
   for buckling of flat plates, 257
   for torsional buckling, 248
   for torsional-flexural buckling, 252

Euler’s formula, 230

Fatigue, 214–219
   crack growth rate, 217
   failure, 214–217
   life, 214
   limit, 216

Fiber-reinforced composites, 15–16, 46, 271

Fibers, mechanical properties of, 16

Flat plates
   elastic shear buckling of, 263
   equilibrium equations of, 257

Flexural shear flow, 151
   in closed sections, 165
   in multicell sections, 173–177
   in open sections, 149–157

Fracture criterion, 196
   for mixed mode fracture, 210

Fracture mechanics, 193–201

Fracture toughness, 196, 208
   effect of thickness, 212
   plane strain, 212

Fuselage, basic structure, 11

Gere, J. M., 246, 249

Griffith, A. A., 194

Hooke’s law, 44

Hydrostatic stress, 60

Inglis, N. P., 193

Initial imperfection of bar, 236

Isotropic materials, 43, 46–47, 183–223

\( J_2 \), 190

Lamina, 280

Laminar stress, 288

Laminate, composite, 16, 280
   angle-ply, 282
   balanced, 282
   cross-ply, 282
   quasi-isotropic, 286
   symmetric, 282, 285

Longitudinal modulus, 53

Maximum principal stress criterion, 184

Maximum shear stress, 35

Mean stress, 215

Metallic materials, 12–15

Modes of loading for fracture, 201, 204
Modulus
  bulk, 60, 189
effective, 285–286
  engineering, 43–45
  longitudinal Young’s, 53
  shear, 42
  transverse Young’s, 53
  Young’s, 39
Moment equation, 175
Moments of inertia, 121
Neutral axis, 118, 122
Neutral plane, 118, 122
Normal strains, 22
Normal stresses, 27, 32, 39
Off-axis loading, 277
Orthotropic solids, 45–46
  Palmgren–Miner rule, 216
  Paris fatigue model, 217
  Plane strain, definition of, 49
  Plane stress, definition of, 49
  Plastic strain, 187
  Ply, composite, 281
  Poisson’s ratios, definition of, 39
  Polar moment of inertia, 75, 248
  Postbuckling of bar, 238–243
  Prandtl stress function, 68, 70
  Primary warping, 97
  Principal axes (directions), 32
  Principal stresses, 31–34
  Product of inertia, 121
  Quasi-isotropic laminates, 286
  Radius of gyration, 235
    polar, 250
  Resultant force, 117, 118, 283
  Resultant moment, 117
  Rigid body motion, 24
  S–N curve, 215
  Saint-Venant’s principle, 63–67, 77
  Saint-Venant torsion, 106
  Secondary warping, 97
  Shear center, 177
    in closed sections, 167
    definition of, 159
    in open sections, 159–164
  Shear deformation, 133
  Shear-extension coupling, 274
  Shear flow, 84, 149–181; see also
    Flexural shear flow and
    Torsional shear flow
    junction, 157–158
    statically determinate, 171–173
    transverse, 130–132
  Shear force, 118, 128
  Shear lag, 140–144
  Shear panels, 4
  Shear strains, 23
  Shear stress, 27, 34–36, 128–132
  Singular stress field at crack tip, 202, 205
  Stacking sequence, 280–281
  Steel alloys, 14, 212
  Stiffnesses
    extensional, 284
    reduced, 272
  Strain component, 55
  Strain, definition of, 20–24
  Strain-displacement relations, 21–24
  Strain energy, 47–49
    in axial member, 197
    in beam, 197
    in torsion member, 198
  Strain energy density, 49
  Strain energy release rate, 194–196
  Strength criteria, 183–186
    Coulomb–Mohr, 184
    maximum principal stress, 184
  Stress concentration factor, 193
  Stress, definition of, 25
  Stress intensity factor, 201–210
    mode I, 202
    mode II, 205
  Stress range, 215
  Stress ratio, 215
Stress-strain relations, 38–47
   for orthotropic solids, 45, 53, 272–274
   for plane strain, 51–53
   for plane stress, 51–53
   for 3-D, 43
Stress vector, 26, 31

Timoshenko beam theory, 136–140, 208
   boundary conditions, 137
   equilibrium equations, 137
Timoshenko, S. P., 246, 249
Titanium alloys, 14, 15
Torque, 67
Torsion of bars of circular section, 74–77
Torsion constant, 74, 79, 89, 93
Torsion member, 7, 198
Torsion, nonuniform, 246
Torsion of thin-wall bars, 81–96
   multicell sections, 86–96
   narrow rectangular section, 77–80
   single-cell section, 81–91
Torsional rigidity, 74
Torsional shear flow, 84
Torsional stiffness (rigidity), 8
Transformation, coordinate
   of lamina stiffnesses and compliances, 274
   of strain, 273
   of stress, 36–38, 273
   of stress-strain relations, 283

Unidirectional lamina, 280

Variable amplitude loading, 216

Warping
   in closed thin-walled section, 101–103
   primary, 97
   secondary, 97
   in thin-walled bar, 246
   in thin-walled section, 96–101
Warping constant, 247
Warping function, 70, 77, 79
Wing, 8–11
   rib, 9
   spar, 10

Yield criterion
   maximum distortion energy, 190
   maximum shear stress, 192
   Tresca, 187
   von Mises, 190
Yield stress, 38, 186
Young’s modulus, 39