

# Contents

Preface ..... xv

## **PART A FUNDAMENTALS OF STRUCTURAL ANALYSIS**

---

<b>Section A1</b>	<b>Elasticity</b> .....	<b>3</b>
<b>CHAPTER 1</b>	<b>Basic elasticity</b> .....	<b>5</b>
1.1	Stress .....	5
1.2	Notation for forces and stresses.....	7
1.3	Equations of equilibrium.....	9
1.4	Plane stress .....	11
1.5	Boundary conditions.....	11
1.6	Determination of stresses on inclined planes.....	12
1.7	Principal stresses .....	15
1.8	Mohr's circle of stress .....	17
1.9	Strain.....	22
1.10	Compatibility equations .....	25
1.11	Plane strain .....	26
1.12	Determination of strains on inclined planes.....	27
1.13	Principal strains .....	29
1.14	Mohr's circle of strain .....	30
1.15	Stress–strain relationships .....	30
1.16	Experimental measurement of surface strains.....	37
	References.....	43
	Problems .....	43
<b>CHAPTER 2</b>	<b>Two-dimensional problems in elasticity</b> .....	<b>47</b>
2.1	Two-dimensional problems.....	47
2.2	Stress functions.....	49
2.3	Inverse and semi-inverse methods.....	50
2.4	St. Venant's principle.....	56
2.5	Displacements.....	57
2.6	Bending of an end-loaded cantilever.....	58
	Reference .....	63
	Problems .....	63
<b>CHAPTER 3</b>	<b>Torsion of solid sections</b> .....	<b>69</b>
3.1	Prandtl stress function solution.....	69
3.2	St. Venant warping function solution.....	81

3.3	The membrane analogy.....	82
3.4	Torsion of a narrow rectangular strip.....	84
	References.....	86
	Problems .....	87
<b>Section A2</b>	<b>Virtual work, energy, and matrix methods .....</b>	<b>89</b>
<b>CHAPTER 4</b>	<b>Virtual work and energy methods .....</b>	<b>91</b>
4.1	Work .....	91
4.2	Principle of virtual work.....	92
4.3	Applications of the principle of virtual work .....	106
	Reference .....	117
	Problems .....	118
<b>CHAPTER 5</b>	<b>Energy methods .....</b>	<b>123</b>
5.1	Strain energy and complementary energy .....	123
5.2	Principle of the stationary value of the total complementary energy .....	125
5.3	Application to deflection problems .....	126
5.4	Application to the solution of statically indeterminate systems.....	135
5.5	Unit load method.....	152
5.6	Flexibility method .....	155
5.7	Total potential energy .....	160
5.8	Principle of the stationary value of the total potential energy.....	161
5.9	Principle of superposition .....	164
5.10	Reciprocal theorem .....	164
5.11	Temperature effects.....	168
	References.....	171
	Problems .....	171
<b>CHAPTER 6</b>	<b>Matrix methods.....</b>	<b>183</b>
6.1	Notation .....	184
6.2	Stiffness matrix for an elastic spring.....	185
6.3	Stiffness matrix for two elastic springs in line .....	186
6.4	Matrix analysis of pin-jointed frameworks .....	189
6.5	Application to statically indeterminate frameworks .....	196
6.6	Matrix analysis of space frames .....	196
6.7	Stiffness matrix for a uniform beam .....	198
6.8	Finite element method for continuum structures .....	205
	References.....	223
	Further reading .....	223
	Problems .....	223

<b>Section A3</b>	<b>Thin plate theory.....</b>	<b>231</b>
<b>CHAPTER 7</b>	<b>Bending of thin plates.....</b>	<b>233</b>
7.1	Pure bending of thin plates.....	233
7.2	Plates subjected to bending and twisting.....	236
7.3	Plates subjected to a distributed transverse load.....	240
7.4	Combined bending and in-plane loading of a thin rectangular plate.....	250
7.5	Bending of thin plates having a small initial curvature.....	254
7.6	Energy method for the bending of thin plates.....	255
	Further reading.....	263
	Problems.....	263
<b>Section A4</b>	<b>Structural instability.....</b>	<b>267</b>
<b>CHAPTER 8</b>	<b>Columns.....</b>	<b>269</b>
8.1	Euler buckling of columns.....	269
8.2	Inelastic buckling.....	275
8.3	Effect of initial imperfections.....	279
8.4	Stability of beams under transverse and axial loads.....	282
8.5	Energy method for the calculation of buckling loads in columns.....	286
8.6	Flexural–torsional buckling of thin-walled columns.....	289
	References.....	301
	Problems.....	302
<b>CHAPTER 9</b>	<b>Thin plates.....</b>	<b>311</b>
9.1	Buckling of thin plates.....	311
9.2	Inelastic buckling of plates.....	314
9.3	Experimental determination of the critical load for a flat plate.....	316
9.4	Local instability.....	316
9.5	Instability of stiffened panels.....	317
9.6	Failure stress in plates and stiffened panels.....	319
9.7	Tension field beams.....	322
	References.....	338
	Problems.....	338
<b>Section A5</b>	<b>Vibration of structures.....</b>	<b>343</b>
<b>CHAPTER 10</b>	<b>Structural vibration.....</b>	<b>345</b>
10.1	Oscillation of mass–spring systems.....	345
10.2	Oscillation of beams.....	354
10.3	Approximate methods for determining natural frequencies.....	359
	Problems.....	362

## **PART B ANALYSIS OF AIRCRAFT STRUCTURES**

---

<b>Section B1 Principles of stressed skin construction .....</b>	<b>369</b>
<b>CHAPTER 11 Materials .....</b>	<b>371</b>
11.1 Aluminum alloys .....	371
11.2 Steel .....	373
11.3 Titanium.....	374
11.4 Plastics .....	375
11.5 Glass .....	375
11.6 Composite materials.....	375
11.7 Properties of materials .....	377
Problems .....	392
<b>CHAPTER 12 Structural components of aircraft .....</b>	<b>395</b>
12.1 Loads on structural components .....	395
12.2 Function of structural components .....	397
12.3 Fabrication of structural components .....	402
12.4 Connections .....	407
Reference .....	413
Problems .....	413
<b>Section B2 Airworthiness and airframe loads.....</b>	<b>417</b>
<b>CHAPTER 13 Airworthiness .....</b>	<b>419</b>
13.1 Factors of the safety-flight envelope .....	419
13.2 Load factor determination.....	421
Reference .....	424
<b>CHAPTER 14 Airframe loads.....</b>	<b>425</b>
14.1 Aircraft inertia loads .....	425
14.2 Symmetric maneuver loads.....	431
14.3 Normal accelerations associated with various types of maneuver.....	436
14.4 Gust loads .....	440
References.....	448
Problems .....	448
<b>CHAPTER 15 Fatigue.....</b>	<b>455</b>
15.1 Safe life and fail-safe structures .....	455
15.2 Designing against fatigue.....	456
15.3 Fatigue strength of components.....	457
15.4 Prediction of aircraft fatigue life .....	463

15.5	Crack propagation .....	469
	References.....	476
	Further reading .....	476
	Problems .....	476
<b>Section B3</b>	<b>Bending, shear and torsion of thin-walled beams .....</b>	<b>479</b>
<b>CHAPTER 16</b>	<b>Bending of open and closed, thin-walled beams.....</b>	<b>481</b>
16.1	Symmetrical bending.....	482
16.2	Unsymmetrical bending .....	490
16.3	Deflections due to bending.....	497
16.4	Calculation of section properties .....	512
16.5	Applicability of bending theory.....	521
16.6	Temperature effects.....	521
	Reference .....	525
	Problems .....	525
<b>CHAPTER 17</b>	<b>Shear of beams .....</b>	<b>535</b>
17.1	General stress, strain, and displacement relationships for open and single-cell closed section thin-walled beams .....	535
17.2	Shear of open section beams .....	539
17.3	Shear of closed section beams.....	548
	Reference .....	557
	Problems .....	557
<b>CHAPTER 18</b>	<b>Torsion of beams .....</b>	<b>567</b>
18.1	Torsion of closed section beams .....	567
18.2	Torsion of open section beams .....	577
	Problems .....	583
<b>CHAPTER 19</b>	<b>Combined open and closed section beams.....</b>	<b>591</b>
19.1	Bending.....	591
19.2	Shear .....	593
19.3	Torsion.....	596
	Problems .....	601
<b>CHAPTER 20</b>	<b>Structural idealization .....</b>	<b>603</b>
20.1	Principle.....	603
20.2	Idealization of a panel.....	604
20.3	Effect of idealization on the analysis of open and closed section beams .....	606
20.4	Deflection of open and closed section beams.....	618
	Problems .....	621

<b>Section B4</b>	<b>Stress analysis of aircraft components.....</b>	<b>627</b>
<b>CHAPTER 21</b>	<b>Wing spars and box beams .....</b>	<b>629</b>
21.1	Tapered wing spar.....	629
21.2	Open and closed section beams.....	633
21.3	Beams having variable stringer areas.....	638
	Problems .....	641
<b>CHAPTER 22</b>	<b>Fuselages.....</b>	<b>643</b>
22.1	Bending.....	643
22.2	Shear .....	645
22.3	Torsion.....	647
22.4	Cut-outs in fuselages.....	649
	Problems .....	650
<b>CHAPTER 23</b>	<b>Wings .....</b>	<b>653</b>
23.1	Three-boom shell.....	653
23.2	Bending.....	654
23.3	Torsion.....	655
23.4	Shear .....	660
23.5	Shear center .....	667
23.6	Tapered wings .....	667
23.7	Deflections.....	670
23.8	Cut-outs in wings .....	671
	Problems .....	679
<b>CHAPTER 24</b>	<b>Fuselage frames and wing ribs.....</b>	<b>687</b>
24.1	Principles of stiffener/web construction.....	687
24.2	Fuselage frames.....	692
24.3	Wing ribs .....	693
	Problems .....	697
<b>CHAPTER 25</b>	<b>Laminated composite structures .....</b>	<b>699</b>
25.1	Elastic constants of a simple lamina.....	699
25.2	Stress–strain relationships for an orthotropic ply (macro approach) .....	705
25.3	Thin-walled composite beams .....	714
	References.....	726
	Problems .....	726
<b>Section B5</b>	<b>Structural and loading discontinuities.....</b>	<b>731</b>
<b>CHAPTER 26</b>	<b>Closed section beams .....</b>	<b>733</b>
26.1	General aspects.....	733

26.2	Shear stress distribution at a built-in end of a closed section beam.....	734
26.3	Thin-walled rectangular section beam subjected to torsion .....	740
26.4	Shear lag .....	748
	Reference .....	765
	Problems .....	765
<b>CHAPTER 27</b>	<b>Open section beams.....</b>	<b>773</b>
27.1	I-section beam subjected to torsion .....	773
27.2	Torsion of an arbitrary section beam .....	775
27.3	Distributed torque loading .....	785
27.4	Extension of the theory to allow for general systems of loading .....	787
27.5	Moment couple (bimoment) .....	790
	References.....	793
	Problems .....	793
<b>Section B6</b>	<b>Introduction to aeroelasticity .....</b>	<b>799</b>
<b>CHAPTER 28</b>	<b>Wing problems .....</b>	<b>801</b>
28.1	Types of problem .....	801
28.2	Load distribution and divergence .....	802
28.3	Control effectiveness and reversal.....	808
28.4	Introduction to “flutter” .....	814
	References.....	821
	Problems .....	821
<b>Appendix:</b>	<b>Design of a rear fuselage .....</b>	<b>825</b>
<b>Index.....</b>		<b>853</b>