

Contents

Acknowledgements	11
List of abbreviations	13
Preface	16
1. Introduction to aircraft structures	19
1.1. Aircraft structural components	19
1.1.1. Construction of structural components	20
1.1.2. Loads of airframe	33
1.2. Materials used for aircraft structures	37
1.2.1. Steel alloys	38
1.2.2. Magnesium alloys	39
1.2.3. Aluminum alloys	40
1.2.4. Titanium alloys	42
1.2.5. Polymer matrix composites	43
1.2.6. Metal matrix composites	47
1.2.7. Fiber-metal laminates	47
1.2.8. Sandwich composites	48
1.3. Trends in applicability of structural materials	50
2. Mechanics and failure of aircraft structures	59
2.1. Fundamentals on elasticity	59
2.1.1. Generalized Hooke's law	60
2.1.2. Anisotropic engineering elastic constants	63
2.2. Mechanics of laminated structures	67
2.2.1. Micromechanics of laminated structures	68
2.2.2. Constitutive relations of an orthotropic lamina	70
2.2.3. Classical lamination theory	71

2.3.	Fundamentals on plasticity	75
2.3.1.	Constitutive relations for generalized plasticity	76
2.3.2.	Idealized models of plasticity	77
2.4.	Fundamentals on viscoelasticity	81
2.4.1.	Fundamental models of viscoelasticity	82
2.4.2.	Boltzmann superposition principle	88
2.5.	Yield and failure criteria for aircraft structures	89
2.5.1.	Yield criteria for ductile aircraft materials	90
2.5.2.	Failure criteria for advanced aircraft materials	93
3.	Fundamentals on fracture mechanics	98
3.1.	Introduction to fracture mechanics	101
3.2.	Linear elastic fracture mechanics	102
3.2.1.	Strain energy release rate concept	103
3.2.2.	Basic crack extension modes	104
3.2.3.	Linear elastic fracture of anisotropic materials	107
3.3.	Elastic-plastic fracture mechanics	108
3.3.1.	Simplified elastic-plastic fracture models	109
3.3.2.	J -integral and related fracture criterion	112
3.3.3.	Experimental determination of critical SERR values	116
3.4.	Dynamic fracture	122
3.4.1.	Mott's model	123
3.4.2.	Stress field and SERR during dynamic fracture	124
3.4.3.	Dynamic fracture criterion	125
4.	Fatigue of aircraft structures	129
4.1.	Fundamentals on fatigue	130
4.1.1.	Fatigue process of materials	130
4.1.2.	Models of fatigue fracture	136
4.1.3.	Crack closure	140
4.2.	Fatigue of composites	142
4.2.1.	Fatigue fracture of polymers and polymeric composites	142
4.2.2.	Fatigue fracture of fiber-metal laminates	150
4.3.	Fatigue of joints	152
4.3.1.	Threaded fasteners	153
4.3.2.	Riveted joints	156

4.3.3.	Welding joints	158
4.3.4.	Adhesive joints	162
4.4.	Environment-assisted fatigue	167
4.4.1.	Environment-assisted fatigue and fracture of metals	167
4.4.2.	Environment-assisted fracture of polymers and PMCs	176
4.5.	Prediction of fatigue failure of aircraft structures	179
5.	Defects and damage in aircraft structures	183
5.1.	Design errors	185
5.2.	Material and manufacturing defects	188
5.2.1.	Microstructural inhomogeneity	189
5.2.2.	Casting and forging defects	193
5.2.3.	Sheet forming defects	197
5.2.4.	Welding defects	198
5.2.5.	Surface defects	203
5.2.6.	Defects related to storage and manufacturing of PMCs	204
5.3.	In-service damage	209
5.3.1.	Damage of metallic structures	210
5.3.2.	Damage of composite structures	213
6.	Design philosophies of aircraft structures	225
6.1.	Safe-life	225
6.2.	Fail-safe	232
6.3.	Damage tolerance	237
6.3.1.	Design methodology	238
6.3.2.	Fracture control	244
6.3.3.	Damage tolerance aircraft requirements	250
6.4.	Condition-based maintenance	255
7.	Non-destructive testing and monitoring of aircraft structures	258
7.1.	Non-destructive testing methods	259
7.1.1.	Introduction to non-destructive testing	260
7.1.2.	Visual testing	263
7.1.3.	Penetrant testing	266
7.1.4.	Magnetic testing	272
7.1.5.	Eddy current testing	278
7.1.6.	Acoustic testing	284

7.1.7.	Ultrasonic testing	288
7.1.8.	Vibration testing	296
7.1.9.	Double pass retroreflection	305
7.1.10.	Interferometric testing	306
7.1.11.	Infrared thermography	313
7.1.12.	Radiographic testing	321
7.1.13.	Terahertz spectroscopy	331
7.1.14.	Training and certification of NDT operators	333
7.2.	Structural health monitoring methods	334
7.2.1.	Introduction to structural health monitoring	335
7.2.2.	SHM systems based on elastic wave propagation	340
7.2.3.	Vibration-based SHM systems	345
7.2.4.	SHM systems based on acoustic emission	347
7.2.5.	SHM systems based on electromechanical impedance	348
7.2.6.	SHM systems based on embedded optical fibers	349
7.2.7.	SHM systems based on electrical resistance	353
7.2.8.	Other sensing technologies used in SHM	356
8.	Aircraft structural repair	359
8.1.	Introduction to aircraft structural repair	360
8.2.	Structural repair of metallic aircraft structures	363
8.2.1.	Welding and cold working repair	363
8.2.2.	Sheet metal repair	365
8.3.	Structural repair of polymeric and composite aircraft structures	367
8.3.1.	Repair of cracks and holes in polymeric structures	367
8.3.2.	Repair of damage in laminated composite structures	367
8.3.3.	Repair of damage in sandwich structures	369
8.4.	Materials used for repair of metal and composite structures	370
8.5.	Testing and quality control of repaired structures	373
	References	376
	Index	409
	Abstract	421