

# Table of Contents

<b>Foreword</b> .....	<b>xv</b>
<b>Preface</b> .....	<b>xvii</b>
<b>Acknowledgements</b> .....	<b>xxi</b>
<b>Chapter 1 Overview</b> .....	<b>1</b>
1.1 Introduction .....	1
1.2 The Product Development Process .....	2
1.3 Content and Organization .....	4
1.4 Best Practices .....	5
1.4.1 Survey Existing Products .....	5
1.4.2 Survey Related Products and Technologies .....	5
1.4.3 Make Decisions Based on Data .....	6
1.4.4 Manage Risk .....	6
1.4.5 Make and Evaluate Prototypes .....	7
1.5 How to Use this Book .....	7
1.6 Worksheets on Mini-CDROM .....	8
<b>Chapter 2 Goals</b> .....	<b>9</b>
2.1 Why Define Your Goals? .....	9
2.2 Scope Statement .....	9
2.2.1 Grab and Go Telescope .....	10
2.2.2 Light Bucket .....	10
2.2.3 Planet Killer .....	10
2.2.4 Airline Transportable Telescope .....	10
2.3 Identifying Needs .....	10
2.3.1 Telescope Use .....	11
2.3.2 Personal Satisfaction .....	12
2.3.2.1 Pride of ownership .....	12
2.3.2.2 Ergonomics .....	12
2.3.3 Storage .....	13
2.3.4 Transport .....	13
2.3.5 Construction .....	14
2.4 Defining Goals .....	14
2.4.1 Telescope Use .....	15
2.4.1.1 Focusers and Finders .....	15
2.4.1.2 Optical Performance .....	17
2.4.1.3 Field Illumination .....	19
2.4.1.4 Exit Pupil .....	19
2.4.1.5 Telescope Motions .....	20
2.4.1.6 Vibration .....	20
2.4.1.7 Environmental Exposure .....	21
2.4.1.8 Convenience .....	22

**iv Table of Contents**

2.4.2 Personal Satisfaction . . . . .	22
2.4.2.1 Pride of Ownership. . . . .	22
2.4.2.2 Ergonomics. . . . .	22
2.4.3 Storage. . . . .	22
2.4.4 Transport . . . . .	23
2.4.5 Construction. . . . .	24
2.5 Summarizing and Prioritizing Goals. . . . .	24
2.6 Avoid Common Pitfalls . . . . .	25
2.7 Reality Check . . . . .	26
<b>Chapter 3 Mechanics of Materials . . . . .</b>	<b>27</b>
3.1 Basic Engineering Terms . . . . .	28
3.1.1 Load. . . . .	28
3.1.2 Stress . . . . .	28
3.1.3 Deformation. . . . .	29
3.1.4 Strain . . . . .	30
3.2 Fundamental Materials Properties . . . . .	30
3.2.1 The Stress-Strain Curve. . . . .	30
3.2.2 Annealing. . . . .	33
3.3 Basic Structural Elements — Columns . . . . .	33
3.3.1 Elastic Buckling. . . . .	34
3.3.2 Eccentric Loading . . . . .	35
3.4 Basic Structural Elements — Beams . . . . .	37
3.4.1 Deflection of a Cantilevered Beam . . . . .	38
3.4.2 Deflection of Beams with Other End Supports . . . . .	41
3.4.3 The Moment of Inertia. . . . .	43
3.4.4 Stiffness of Laminate Structures . . . . .	44
3.4.5 Strength of Laminate Structures . . . . .	47
3.5 Measuring the Modulus (Inherent Stiffness) of Isotropic Materials. . . . .	47
3.5.1 Measuring Deflections of Selected Aluminum Beams . . . . .	49
3.5.1.1 Deflections of Solid Aluminum Bar. . . . .	49
3.5.1.2 Deflections of Aluminum Tubing . . . . .	51
3.6 Measuring Deflections of Beams Made from Other Materials. . . . .	53
3.6.1 Deflections of Rectangular Wood Beams . . . . .	54
3.6.2 Deflections of Laminated Composite Beams . . . . .	57
3.6.3 Deflections of Carbon Fiber/Epoxy Tubing . . . . .	58
3.7 Friction . . . . .	60
3.7.1 Bearing Materials . . . . .	61
3.7.2 Common Laminate Materials . . . . .	61
3.7.2.1 Ebony Star #50. . . . .	61
3.7.2.2 Alternatives to Ebony Star #50. . . . .	62
3.7.2.3 Fiber Reinforced Plastic . . . . .	63
3.7.2.4 Surface Treatment . . . . .	63
3.7.3 Measuring Static and Kinetic Friction. . . . .	63
3.7.4 Static and Kinetic Friction Results . . . . .	66

3.7.5 Kinetic Friction as a Function of Velocity . . . . .	69
3.7.6 Key Variables . . . . .	70
3.7.7 Alternative Test Systems . . . . .	73
3.8 Vibration . . . . .	75
3.8.1 Free versus Driven Vibration . . . . .	75
3.8.2 Mass-Spring Model . . . . .	75
3.8.3 Beam Vibration . . . . .	78
3.8.4 Simple Mass-Beam System . . . . .	81
3.9 Viscoelastic Materials . . . . .	82
3.9.1 Shear and Bulk Modulus . . . . .	82
3.9.2 Temperature Dependence . . . . .	83
3.9.3 Frequency Dependence . . . . .	84
3.10 Managing Vibration . . . . .	85
3.11 Vibration Isolation . . . . .	86
3.12 Vibration Damping . . . . .	90
3.12.1 Passive Dampers . . . . .	90
3.12.1.1 Free Viscoelastic Layer . . . . .	90
3.12.1.2 Constrained Viscoelastic Layer . . . . .	92
3.12.1.3 Measuring Effectiveness of Constrained-Layer Damping . . . . .	96
3.12.2 Dynamic Absorbers . . . . .	97
3.12.3 Active Dampers . . . . .	99
3.13 Measuring Vibration . . . . .	100
3.13.1 In Search of a Measurement System . . . . .	100
3.13.2 Identifying Sources of Vibration . . . . .	102
<b>Chapter 4 Reflector Basics — Optics . . . . .</b>	<b>105</b>
4.1 Nature of Light . . . . .	105
4.2 Newtonian Reflector — Geometric Optics . . . . .	106
4.2.1 The Focal Surface (Focal Plane) . . . . .	107
4.3 The Influence of Eyepieces on Telescope Design . . . . .	108
4.3.1 The Basic Eyepiece . . . . .	109
4.3.2 Basic Eyepiece Specifications . . . . .	110
4.3.3 Magnification . . . . .	111
4.3.4 Exit Pupil . . . . .	112
4.3.5 Selecting Longest Focal Length Eyepiece . . . . .	112
4.3.6 Diameter of the Field Stop . . . . .	113
4.3.7 Location of Focal Plane Relative to Focuser . . . . .	114
4.3.8 Location of Eyepiece Field Stop . . . . .	115
4.4 Illumination Profile of the Focal Surface (Focal Plane) . . . . .	115
4.4.1 Size of the Fully-illuminated Zone . . . . .	117
4.4.1.1 Constraints — Secondary Mirror . . . . .	117
4.4.1.2 Constraints — Focuser Drawtube . . . . .	119
4.4.1.3 Constraints — Telescope Tube Opening . . . . .	122
4.4.1.4 Constraints — Other . . . . .	123

**vi Table of Contents**

4.4.1.5 Example — 10-inch $f/5$ . . . . .	124
4.4.2 Illumination Profile Outside of the Fully-illuminated Zone . .	125
4.4.2.1 Quantitative Description. . . . .	127
4.4.2.2 Example 18-inch $f/4.5$ Telescope . . . . .	128
4.4.2.3 Illumination versus Field Diameter . . . . .	129
4.4.2.4 Contour Plot . . . . .	131
4.4.3 Selecting the Constraint. . . . .	132
4.4.4 Optimizing the Secondary Mirror . . . . .	132
4.4.4.1 Effect of Secondary Mirror Size. . . . .	133
4.4.4.2 Effect of Distance, $G$ , Between Secondary Mirror and Focal Plane . . . . .	134
4.4.4.3 Effect of Primary Mirror Focal Ratio. . . . .	135
4.4.5 Optimizing the Focuser Baffle . . . . .	137
4.5 Aligning the Optical Paths . . . . .	139
4.5.1 Secondary Mirror Offset . . . . .	141
4.5.2 The Sight Tube . . . . .	144
4.5.3 Centered Optics . . . . .	145
4.6 Deviations From Ideality . . . . .	147
4.6.1 Diffraction . . . . .	148
4.6.1.1 The Airy Disk. . . . .	148
4.6.1.2 Resolution of High-Contrast Point Objects . . . . .	150
4.6.1.3 Resolution and Contrast . . . . .	152
4.6.1.4 Other Diffraction Sources. . . . .	158
4.6.2 Optical Aberrations . . . . .	161
4.6.2.1 Coma. . . . .	161
4.6.2.2 Eyepiece Aberrations . . . . .	168
4.6.2.3 Coma Corrector . . . . .	171
4.6.2.4 Focus Tolerance . . . . .	171
4.6.2.5 Selecting the Focuser . . . . .	174
4.6.3 Seeing . . . . .	175
4.7 Performance of the Human Eye . . . . .	178
<b>Chapter 5 Reflector Basics — Structures . . . . .</b>	<b>181</b>
5.1 Historical Optical Assembly And Mount . . . . .	181
5.2 Portable Newtonian Innovations. . . . .	182
5.3 Improving Portability . . . . .	186
5.3.1 Identifying and Prioritizing Design Opportunities . . . . .	188
5.3.1.1 The Pareto Chart. . . . .	188
5.3.1.2 Weight Distribution in the TOA. . . . .	190
5.3.2 Weight Reduction Feasibility . . . . .	191
5.3.2.1 Primary Mirror . . . . .	191
5.3.2.2 LOA Structure . . . . .	192
5.3.2.3 Mirror Cell . . . . .	193
5.3.2.4 Interim Results 1. . . . .	194
5.4 Integrated Design — Balance of TOA . . . . .	194

5.4.1	Calculating Horizontal Balance Point . . . . .	194
5.4.2	Pareto Analysis of Moments . . . . .	197
5.4.3	Interim Results 2 . . . . .	198
5.4.4	Other Opportunities for Moving COM . . . . .	199
5.4.4.1	Re-examine Modified Structure . . . . .	199
5.4.4.2	Adding Weight . . . . .	201
5.4.4.3	Smaller Focal Ratio . . . . .	201
5.5	Integrated Design — Impact on Performance . . . . .	202
5.5.1	Evaluating TOA Alternatives . . . . .	203
5.5.1.1	Minimalist TOA Example 1 . . . . .	204
5.5.1.2	Minimalist TOA Example 2 . . . . .	206
5.5.1.3	Minimalist TOA Example 3 . . . . .	207
5.5.1.4	Other Alternatives . . . . .	208
5.5.2	Additional Evaluation of UOA Alternatives . . . . .	209
5.6	Designing a Single UOA Ring . . . . .	211
5.6.1	In-plane Deformation . . . . .	211
5.6.2	Measuring Ring Stiffness . . . . .	213
5.6.3	Calculating In-plane Ring Deformation . . . . .	214
5.6.4	Out-of-plane Deformation . . . . .	214
5.6.5	Design Scaling . . . . .	215
5.6.6	Scaling Examples . . . . .	219
5.6.7	Design Cautions . . . . .	220
5.7	Designing an UOA Tube . . . . .	221
5.7.1	Tube Deformation . . . . .	221
5.7.2	Measuring Tube Stiffness . . . . .	222
5.7.3	Designing a Lightweight Stiff Tube . . . . .	224
5.7.3.1	UOA Deflection versus Spider Tension . . . . .	226
5.7.3.2	Stiffness of UOA Lower Ring . . . . .	229
5.7.3.3	UOA With Internal Hoops . . . . .	230
5.8	Designing the LOA . . . . .	233
5.9	Alternate Methods for Connecting Lower and Upper Optical Assemblies . . . . .	236
5.9.1	Single External Strut . . . . .	236
5.9.2	Two Parallel Struts . . . . .	237
5.9.3	Three Parallel Struts . . . . .	241
5.9.4	Modified Parallel Strut Systems . . . . .	244
5.10	Altitude Bearing Design . . . . .	247
5.11	Calculating Vertical Balance Point . . . . .	254
5.12	The Altazimuth Assembly . . . . .	257
5.12.1	Basic Structures . . . . .	257
5.12.2	Friction-Controlled Motions . . . . .	259
5.12.2.1	Altitude Control . . . . .	260
5.12.2.2	Azimuth Control . . . . .	263
5.12.2.3	Altitude and Azimuth Control . . . . .	266

**viii Table of Contents**

5.12.2.4 Teflon Pad Size . . . . .	268
5.12.2.5 Structure Stiffness . . . . .	269
5.12.3 The “Flex Rocker”. . . . .	271
5.12.4 Weight Reduction . . . . .	272
5.13 Articulating Altitude Bearings . . . . .	274
<b>Chapter 6 The Truss — Theory . . . . .</b>	<b>277</b>
6.1 The Basic Truss. . . . .	277
6.1.1 Definition. . . . .	277
6.1.2 Force Analysis. . . . .	278
6.2 The Four-Truss Telescope . . . . .	280
6.2.1 Vertical Truss Subjected to Vertical Load . . . . .	281
6.2.2 Horizontal Truss Subjected to Vertical Load . . . . .	284
6.2.3 Truss Deflections versus Elevation Angle. . . . .	288
6.2.4 Truss Deflection versus Collimation Orientation . . . . .	290
6.2.5 Lateral Deflections . . . . .	291
6.2.6 Rotational Deflection with Horizontal TOA. . . . .	293
6.2.7 Rotational Deflection with Vertical TOA . . . . .	295
6.2.8 Relative Magnitude of Truss Deflections . . . . .	299
6.3 The Three-Truss Telescope. . . . .	299
6.3.1 Vertical Truss Subjected to Vertical Load . . . . .	300
6.3.2 Horizontal Truss Subjected to Vertical Load . . . . .	301
6.3.3 Truss Deflections versus Elevation Angle. . . . .	302
6.3.4 Lateral Deflections . . . . .	303
6.3.5 Other Deflections. . . . .	304
6.4 Comparison Between Three- and Four-Truss Structures . . . . .	304
6.5 The Pseudo-truss Telescope . . . . .	306
6.5.1 Horizontal Pseudo Truss Subjected to Vertical Load . . . . .	307
6.5.2 Lateral Deflections . . . . .	308
6.5.3 Forces in Six-Strut Structures . . . . .	309
6.5.4 Variations of Symmetrical Six-Strut Structures . . . . .	311
6.6 Structures Consisting of Unequal Trusses and Struts. . . . .	313
6.6.1 Truss Bases Perpendicular to Optical Axis . . . . .	313
6.6.2 Truss Bases Not Perpendicular to Optical Axis . . . . .	316
6.6.3 Unequal Truss Structures Oriented Vertically and Subjected to Vertical Load. . . . .	320
6.7 Truss Vibrations . . . . .	321
6.7.1 Truss Structure. . . . .	321
6.7.2 Individual Struts . . . . .	325
6.8 The Serrurier Truss . . . . .	326
<b>Chapter 7 The Truss — Practice. . . . .</b>	<b>331</b>
7.1 Test Fixture and Method. . . . .	331
7.2 Agreement Between Experiment and Theory. . . . .	335
7.2.1 Example 1: Four-Truss Structure with Long 1.000-inch Diameter Struts. . . . .	336

7.2.2 Example 2: Four-Truss Structure with Short 1.000-inch Diameter Struts . . . . .	338
7.2.3 Example 3: Three-Truss Structure with Long 1.000-inch Diameter Struts . . . . .	338
7.2.4 Example 4: Pseudo-Truss Structures with Short 1.000-inch Diameter Struts . . . . .	341
7.2.5 Observations and Recommendations . . . . .	344
7.3 Non-ideal Performance of Idealized Truss Structures . . . . .	345
7.3.1 Bent Struts . . . . .	346
7.3.2 Strut Sag . . . . .	346
7.3.3 Example 5: Four-Truss Structure with Long 0.625-inch Diameter Struts . . . . .	346
7.3.4 Elastic (Euler) Buckling . . . . .	347
7.3.5 Example 6: Structure with Long, Curved 0.625-inch Diameter Struts . . . . .	348
7.3.6 Example 7: Structure with Short, Curved 0.625-inch Diameter Struts . . . . .	350
7.3.7 Observations and Recommendations . . . . .	351
7.4 Strut Connection Practices Influencing Structure Stiffness . . . . .	351
7.4.1 Example 8: Flattened Strut Ends Connected to Common Mounting Plate . . . . .	353
7.4.2 Example 9: Minimizing Eccentricity on Common Mounting Plate . . . . .	356
7.4.3 Example 10: Deflection versus In-plane Eccentricity . . . . .	357
7.4.4 Example 11: Deflection of Structure with Out-of-Plane Eccentricity . . . . .	359
7.4.5 Example 12: Deflection of Three-Pseudo-Truss Structure with Eccentricity . . . . .	362
7.4.6 Observations and Recommendations . . . . .	364
7.4.6.1 Calculating Deflection due to Eccentricity . . . . .	364
7.4.6.2 Selecting Struts to Minimize Effect of Eccentric Loads . . . . .	365
7.4.6.3 Minimizing Eccentricity with Flattened, Overlapping Strut Ends . . . . .	367
7.4.6.4 Minimizing Eccentricity by Controlling Location of Applied Force . . . . .	369
7.4.6.5 Eccentricity at Lower Strut Connections . . . . .	372
7.4.6.6 Structure Deflection Due to Strut Connection Play . . . . .	373
7.5 Criteria for Structure Deflection . . . . .	373
7.5.1 Static Stiffness . . . . .	374
7.5.1.1 Allowed Coma Aberration Equal to Telescope Resolution . . . . .	375
7.5.1.2 Allowed Coma Aberration Equal to Seeing Resolution . . . . .	376

**x Table of Contents**

7.5.1.3 Allowed Coma Aberration Less Than Typical Coma . . . . .	376
7.5.1.4 Selecting the Static Deflection Specification . . . . .	377
7.5.2 Dynamic Stiffness . . . . .	378
7.5.2.1 Transient Forces . . . . .	378
7.5.2.2 Modified Static Deflection Specification . . . . .	380
7.5.2.3 Persistent Forces . . . . .	381
<b>Chapter 8 16-inch <math>f/4.5</math> Truss Telescope . . . . .</b>	<b>383</b>
8.1 Introduction and Goals . . . . .	383
8.1.1 Design Scope Statement . . . . .	383
8.1.2 Goals and Specifications . . . . .	384
8.2 Design . . . . .	386
8.2.1 Overview of the Completed Telescope . . . . .	386
8.2.2 Optical Design . . . . .	388
8.2.2.1 Primary Mirror . . . . .	388
8.2.2.2 Primary Mirror Support . . . . .	388
8.2.2.3 Telescope Optical Assembly . . . . .	392
8.2.3 Eyepiece Height and Location . . . . .	393
8.2.4 The Truss System . . . . .	396
8.2.4.1 Calculating Truss Deflections . . . . .	396
8.2.4.2 LOA Strut Connections . . . . .	398
8.2.4.3 Truss Selection . . . . .	399
8.2.4.4 UOA Strut Connections . . . . .	400
8.2.4.5 Modified UOA Strut Connections to UOA . . . . .	400
8.2.5 Balancing the TOA — Horizontal . . . . .	402
8.2.6 Altitude Bearings . . . . .	405
8.2.7 Balancing the TOA — Vertical . . . . .	408
8.2.8 Altazimuth Assembly (Rocker Box) . . . . .	409
8.3 Telescope Construction . . . . .	412
8.3.1 Upper Optical Assembly . . . . .	413
8.3.1.1 Drum Shell . . . . .	413
8.3.1.2 Reinforcing Ring . . . . .	414
8.3.1.3 Bottom End Ring . . . . .	418
8.3.1.4 Focuser and Finder Reinforcements . . . . .	422
8.3.1.5 Hole for Focuser Drawtube . . . . .	423
8.3.1.6 Strut Connection Brackets . . . . .	423
8.3.1.7 Attaching the Secondary Mirror . . . . .	427
8.3.1.8 Baffles . . . . .	429
8.3.2 Primary Mirror Cell . . . . .	429
8.3.2.1 Rocker Bars . . . . .	429
8.3.2.2 Triangular Frame . . . . .	432
8.3.2.3 Mirror Cell Assembly . . . . .	439
8.3.2.4 Gluing the Cell to the Primary Mirror . . . . .	441
8.3.3 Lower Optical Assembly — Mirror Box . . . . .	444



8.3.3.1 Mirror Box Top and Bottom Panels . . . . .	444
8.3.3.2 Bottom Panel . . . . .	445
8.3.3.3 Top Panel . . . . .	447
8.3.3.4 Mirror Box Sides . . . . .	448
8.3.3.5 Internal Drum Shell . . . . .	450
8.3.3.6 Assembling the Mirror Box . . . . .	451
8.3.3.7 Beveling the Lower Front Edge of the Mirror Box . .	453
8.3.3.8 Clamp Block Support Bracket . . . . .	456
8.3.3.9 Mirror Box Cover . . . . .	456
8.3.3.10 Installing the Primary Mirror . . . . .	457
8.3.4 Aluminum Struts . . . . .	459
8.3.5 Altitude Bearings . . . . .	462
8.3.6 Altitude Bearing Brace . . . . .	469
8.3.7 Rocker Box . . . . .	471
8.3.7.1 Left and Right Side Panels . . . . .	471
8.3.7.2 Front and Rear Panels . . . . .	473
8.3.7.3 Bottom Panel . . . . .	475
8.3.7.4 Assembling the Rocker Box . . . . .	477
8.3.7.5 Teflon Pads . . . . .	479
8.3.8 The Ground Board . . . . .	479
8.3.9 Finishing . . . . .	480
8.3.10 Wheelbarrow Wheel Brackets . . . . .	482
8.3.11 Wheelbarrow Handles . . . . .	484
8.3.12 Transport Brackets . . . . .	484
8.4 Comments and Suggestions . . . . .	486
8.4.1 Use . . . . .	486
8.4.2 Personal Satisfaction, Ergonomics, Convenience . . . . .	487
8.4.3 Transport and Storage . . . . .	488
8.4.4 Construction . . . . .	488
<b>Chapter 9 20-inch <i>f</i>/4 Truss Telescope . . . . .</b>	<b>489</b>
9.1 Introduction and Goals . . . . .	489
9.1.1 Design Scope . . . . .	489
9.1.2 Goals and Specifications . . . . .	490
9.2 Design . . . . .	492
9.2.1 Overview of the Completed Telescope . . . . .	492
9.2.2 Optical Design . . . . .	494
9.2.2.1 Primary Mirror . . . . .	494
9.2.2.2 Primary Mirror Support . . . . .	496
9.2.2.3 Telescope Optical Assembly . . . . .	499
9.2.3 Eyepiece Height, Location, and Tilt . . . . .	499
9.2.4 The Truss System . . . . .	503
9.2.4.1 Calculating Truss Deflections . . . . .	504
9.2.4.2 Truss Selection . . . . .	505
9.2.4.3 UOA Strut Connections . . . . .	505

## **xii Table of Contents**

9.2.4.4 LOA Strut Connections . . . . .	505
9.2.5 Upper Optical Assembly . . . . .	508
9.2.5.1 Structure . . . . .	508
9.2.5.2 Spider and Secondary holder . . . . .	508
9.2.5.3 Baffles. . . . .	509
9.2.6 Lower Optical Assembly . . . . .	509
9.2.6.1 Structure . . . . .	509
9.2.6.2 Mirror Cell Support and Adjustment . . . . .	511
9.2.6.3 Mirror Cell . . . . .	512
9.2.7 Balancing the TOA — Horizontal. . . . .	514
9.2.8 Altitude Bearings. . . . .	514
9.2.9 Balancing the TOA — Vertical. . . . .	517
9.2.10 Altazimuth Assembly (Rocker Box). . . . .	518
9.2.11 Telescope Transport . . . . .	520
9.3 Telescope Construction. . . . .	520
9.3.1 Upper Optical Assembly . . . . .	523
9.3.1.1 Spider and Secondary Holder. . . . .	523
9.3.1.1.1 Mounting Plate. . . . .	524
9.3.1.1.2 Spider Hub . . . . .	527
9.3.1.1.3 Spider Vanes . . . . .	530
9.3.1.1.4 Finishing . . . . .	533
9.3.1.1.5 Collimation Thumb Screws . . . . .	534
9.3.1.1.6 Attaching the Secondary Mirror . . . . .	534
9.3.1.1.7 Assembly . . . . .	536
9.3.1.2 Drum Shell . . . . .	536
9.3.1.3 Upper Reinforcing Ring . . . . .	539
9.3.1.4 Bottom End Ring . . . . .	543
9.3.1.5 Spider Mounting Holes. . . . .	545
9.3.1.6 Mounting Tilted Focuser . . . . .	545
9.3.1.7 Hole for Focuser Drawtube . . . . .	550
9.3.1.8 Finder Reinforcements . . . . .	552
9.3.1.9 Strut Connection Brackets . . . . .	553
9.3.1.10 Baffles. . . . .	553
9.3.2 Primary Mirror Cell. . . . .	553
9.3.2.1 Support Triangles . . . . .	553
9.3.2.2 Rocker Bars . . . . .	557
9.3.2.3 Triangular Frame . . . . .	557
9.3.2.4 Mirror Clips . . . . .	562
9.3.2.5 Mirror Cell Assembly. . . . .	563
9.3.3 Lower Optical Assembly . . . . .	565
9.3.3.1 Top and Bottom Panels . . . . .	565
9.3.3.1.1 Bottom Panel . . . . .	566
9.3.3.1.2 Top Panel . . . . .	569
9.3.3.2 LOA Strut Connection System . . . . .	572

9.3.3.2.1 Aluminum Clamping Plates . . . . .	573
9.3.3.2.2 Wood Clamp Blocks . . . . .	573
9.3.3.3 Drum Shell . . . . .	577
9.3.3.4 Braces . . . . .	577
9.3.3.5 Assembling the LOA . . . . .	580
9.3.3.6 LOA Cover . . . . .	584
9.3.3.7 Collimation Knobs with Extension Shafts . . . . .	584
9.3.3.8 Installing the Primary Mirror and Cell . . . . .	585
9.3.4 Aluminum Struts . . . . .	585
9.3.5 Altitude Bearings . . . . .	587
9.3.6 The Rocker Box . . . . .	598
9.3.6.1 Left and Right Side Panels . . . . .	598
9.3.6.2 Front and Rear Panels . . . . .	599
9.3.6.3 Reinforcing Shelf . . . . .	601
9.3.6.4 Bottom Panel . . . . .	602
9.3.6.5 Assembling the Rocker Box . . . . .	606
9.3.6.6 Teflon Pads . . . . .	608
9.3.7 Ground Support . . . . .	608
9.3.8 Retaining Clips . . . . .	610
9.3.9 Finishing . . . . .	612
9.3.10 Wheelbarrow Wheel Brackets . . . . .	612
9.3.11 Wheelbarrow Handles . . . . .	613
9.3.12 Transport Brackets . . . . .	613
9.4 Comments and Suggestions . . . . .	613
9.4.1 Tilting the Focuser . . . . .	613
9.4.2 Spider and Secondary Mirror Holder . . . . .	615
9.4.3 LOA and Mirror Cell . . . . .	615
9.4.4 Strut Connection System . . . . .	618
9.4.4.1 UOA . . . . .	618
9.4.4.2 LOA . . . . .	618
9.4.5 Weight Reduction Techniques . . . . .	620
9.4.6 Finishing . . . . .	621
<b>Appendix A — Design Basis Example . . . . .</b>	<b>623</b>
A.1 Scope Statement — Loaner Telescope for Intermediate-level Observers . . . . .	623
A.2 Needs . . . . .	623
A.2.1 Telescope Use . . . . .	623
A.2.2 Personal Satisfaction . . . . .	624
A.2.2.1 Pride of ownership . . . . .	624
A.2.2.2 Ergonomics . . . . .	624
A.2.3 Storage . . . . .	624
A.2.4 Transport . . . . .	624
A.2.5 Construction . . . . .	625
A.3 Goals . . . . .	625

**xiv Table of Contents**

<b>Appendix B — Units of Measure</b> .....	<b>629</b>
B.1 Fundamental Quantities of Mechanics .....	629
B.2 Other Important Quantities .....	630
B.2.1 Density .....	630
B.2.2 Angle .....	630
B.2.3 Frequency .....	631
B.2.4 Wavelength .....	632
B.2.5 Temperature .....	633
B.3 Significant Figures .....	634
B.4 Converting between Units .....	636
B.5 Sources of Potential Confusion .....	636
<b>Appendix C — Capable Measurement Systems</b> .....	<b>639</b>
C.1 Measurement Variation .....	639
C.2 Weight .....	640
C.3 Size .....	642
C.4 Beam Deflection .....	643
C.5 Coefficient of Friction .....	644
C.6 Truss Deflection .....	645
C.7 Number of Samples .....	647
C.8 Complications and Restrictions .....	649
<b>Appendix D — Eyepiece Height</b> .....	<b>651</b>
D.1 Eyepiece Height versus Telescope Elevation Angle .....	651
D.2 Defining Limits .....	654
D.3 Strategies for Reducing Maximum Eyepiece Height .....	655
D.3.1 Move Secondary Mirror Closer to Primary Mirror .....	655
D.3.2 Move Pivot Axis Closer to the Ground .....	655
D.3.3 Use Shorter Focal Length Mirror .....	657
D.3.4 Tilt Secondary Mirror Less Than 45° .....	658
<b>Index</b> .....	<b>663</b>