

Aircraft Design Projects

for engineering students

Lloyd R. Jenkinson
James F. Marchman III

BUTTERWORTH
HEINEMANN

OXFORD AMSTERDAM BOSTON LONDON NEW YORK PARIS
SAN DIEGO SAN FRANCISCO SINGAPORE SYDNEY TOKYO

Contents

Preface	xiii
Acknowledgements	xvi
Introduction	xvii
1 Design methodology	1
2 Preliminary design	6
2.1 Problem definition	6
2.1.1 The customers	7
2.1.2 Aircraft viability	8
2.1.3 Understanding the problem	8
2.1.4 Innovation	9
2.1.5 Organising the design process	10
2.1.6 Summary	11
2.2 Information retrieval	11
2.2.1 Existing and competitive aircraft	11
2.2.2 Technical reports	12
2.2.3 Operational experience	12
2.3 Aircraft requirements	12
2.3.1 Market and mission issues	13
2.3.2 Airworthiness and other standards	13
2.3.3 Environmental and social issues	13
2.3.4 Commercial and manufacturing considerations	14
2.3.5 Systems and equipment requirements	14
2.4 Configuration options	14
2.5 Initial baseline sizing	15
2.5.1 Initial mass (weight) estimation	16
2.5.2 Initial layout drawing	19
2.6 Baseline evaluation	19
2.6.1 Mass statement	19
2.6.2 Aircraft balance	21
2.6.3 Aerodynamic analysis	22
2.6.4 Engine data	24
2.6.5 Aircraft performance	25
2.6.6 Initial technical report	25
2.7 Refining the initial layout	25
2.7.1 Constraint analysis	26
2.7.2 Trade-off studies	29

vi Contents

2.8	Refined baseline design	31
2.9	Parametric and trade studies	32
2.9.1	Example aircraft used to illustrate trade-off and parametric studies	33
2.10	Final baseline configuration	39
2.10.1	Additional technical considerations	39
2.10.2	Broader-based considerations	39
2.11	Type specification	40
2.11.1	Report format	40
2.11.2	Illustrations, drawings and diagrams	41
	References	41
3	Introduction to the project studies	43
4	Project study: scheduled long-range business jet	46
4.1	Introduction	47
4.2	Project brief	49
4.2.1	Project requirements	50
4.3	Project analysis	50
4.3.1	Payload/range	50
4.3.2	Passenger comfort	51
4.3.3	Field requirements	51
4.3.4	Technology assessments	52
4.3.5	Marketing	53
4.3.6	Alternative roles	54
4.3.7	Aircraft developments	54
4.3.8	Commercial analysis	55
4.4	Information retrieval	56
4.5	Design concepts	57
4.5.1	Conventional layout(s)	57
4.5.2	Braced wing/canard layout	58
4.5.3	Three-surface layout	59
4.5.4	Blended body layout	60
4.5.5	Configuration selection	61
4.6	Initial sizing and layout	62
4.6.1	Mass estimation	62
4.6.2	Engine size and selection	63
4.6.3	Wing geometry	63
4.6.4	Fuselage geometry	67
4.6.5	Initial 'baseline aircraft' general arrangement drawing	68
4.7	Initial estimates	70
4.7.1	Mass and balance analysis	70
4.7.2	Aerodynamic estimations	75
4.7.3	Initial performance estimates	76
4.7.4	Constraint analysis	78
4.7.5	Revised performance estimates	79
4.7.6	Cost estimations	80
4.8	Trade-off studies	82
4.8.1	Alternative roles and layout	82
4.8.2	Payload/range studies	85

4.8.3	Field performance studies	86
4.8.4	Wing geometry studies	87
4.8.5	Economic analysis	91
4.9	Initial 'type specification'	96
4.9.1	General aircraft description	96
4.9.2	Aircraft geometry	97
4.9.3	Mass (weight) and performance statements	97
4.9.4	Economic and operational issues	98
4.10	Study review	99
	References	100
5	Project study: military training system	101
5.1	Introduction	102
5.2	Project brief	102
5.2.1	Aircraft requirements	103
5.2.2	Mission profiles	104
5.3	Problem definition	105
5.4	Information retrieval	106
5.4.1	Technical analysis	108
5.4.2	Aircraft configurations	110
5.4.3	Engine data	110
5.5	Design concepts	110
5.6	Initial sizing	112
5.6.1	Initial baseline layout	113
5.7	Initial estimates	115
5.7.1	Mass estimates	115
5.7.2	Aerodynamic estimates	117
5.7.3	Performance estimates	119
5.8	Constraint analysis	129
5.8.1	Take-off distance	129
5.8.2	Approach speed	129
5.8.3	Landing distance	130
5.8.4	Fundamental flight analysis	130
5.8.5	Combat turns at SL	130
5.8.6	Combat turn at 25 000 ft	131
5.8.7	Climb rate	131
5.8.8	Constraint diagram	131
5.9	Revised baseline layout	132
5.9.1	Wing fuel volume	133
5.10	Further work	134
5.11	Study review	137
5.11.1	Strengths	137
5.11.2	Weaknesses	137
5.11.3	Opportunities	139
5.11.4	Threats	139
5.11.5	Revised aircraft layout	140
5.12	Postscript	141
	References	141

6	Project study: electric-powered racing aircraft	143
6.1	Introduction	144
6.2	Project brief	144
	6.2.1 The racecourse and procedures	144
	6.2.2 History of Formula 1 racing	145
	6.2.3 Comments from a racing pilot	146
	6.2.4 Official Formula 1 rules	147
6.3	Problem definition	149
6.4	Information retrieval	150
	6.4.1 Existing aircraft	150
	6.4.2 Configurational analysis	152
	6.4.3 Electrical propulsion system	154
6.5	Design concepts	157
6.6	Initial sizing	158
	6.6.1 Initial mass estimations	159
	6.6.2 Initial aerodynamic considerations	162
	6.6.3 Propeller analysis	165
6.7	Initial performance estimation	166
	6.7.1 Maximum level speed	166
	6.7.2 Climb performance	169
	6.7.3 Turn performance	171
	6.7.4 Field performance	173
6.8	Study review	173
	References	174
7	Project study: a dual-mode (road/air) vehicle	175
7.1	Introduction	176
7.2	Project brief (flying car or roadable aircraft?)	176
7.3	Initial design considerations	177
7.4	Design concepts and options	179
7.5	Initial layout	181
7.6	Initial estimates	186
	7.6.1 Aerodynamic estimates	186
	7.6.2 Powerplant selection	189
	7.6.3 Weight and balance predictions	190
	7.6.4 Flight performance estimates	190
	7.6.5 Structural details	193
	7.6.6 Stability, control and 'roadability' assessment	196
	7.6.7 Systems	197
	7.6.8 Vehicle cost assessment	198
7.7	Wind tunnel testing	199
7.8	Study review	200
	References	201
8	Project study: advanced deep interdiction aircraft	202
8.1	Introduction	203
8.2	Project brief	203
	8.2.1 Threat analysis	203
	8.2.2 Stealth considerations	204
	8.2.3 Aerodynamic efficiency	206

8.3	Problem definition	208
8.4	Design concepts and selection	210
8.5	Initial sizing and layout	213
8.6	Initial estimates	215
	8.6.1 Initial mass estimations	216
	8.6.2 Initial aerodynamic estimations	217
8.7	Constraint analysis	221
	8.7.1 Conclusion	227
8.8	Revised baseline layout	228
	8.8.1 General arrangement	228
	8.8.2 Mass evaluation	233
	8.8.3 Aircraft balance	233
	8.8.4 Aerodynamic analysis	234
	8.8.5 Propulsion	241
8.9	Performance estimations	242
	8.9.1 Manoeuvre performance	242
	8.9.2 Mission analysis	250
	8.9.3 Field performance	254
8.10	Cost estimations	259
8.11	Trade-off studies	261
8.12	Design review	263
	8.12.1 Final baseline aircraft description	263
	8.12.2 Future considerations	267
8.13	Study review	268
	References	268
9	Project study: high-altitude, long-endurance (HALE) uninhabited aerial surveillance vehicle (UASV)	270
9.1	Introduction	271
9.2	Project brief	271
	9.2.1 Aircraft requirements	272
9.3	Problem definition	272
9.4	Initial design considerations	275
9.5	Information retrieval	275
	9.5.1 Lockheed Martin U-2S	276
	9.5.2 Grob Strato 2C	276
	9.5.3 Northrop Grumman RQ-4A Global Hawk	277
	9.5.4 Grob G520 Strato 1	277
	9.5.5 Stemme S10VC	277
9.6	Design concepts	278
	9.6.1 Conventional layout	279
	9.6.2 Joined wing layout	280
	9.6.3 Flying wing layout	280
	9.6.4 Braced wing layout	281
	9.6.5 Configuration selection	282
9.7	Initial sizing and layout	283
	9.7.1 Aircraft mass estimation	283
	9.7.2 Fuel volume assessment	285
	9.7.3 Wing loading analysis	285
	9.7.4 Aircraft speed considerations	286

x Contents

9.7.5	Wing planform geometry	288
9.7.6	Engine sizing	290
9.7.7	Initial aircraft layout	292
9.7.8	Aircraft data summary	293
9.8	Initial estimates	294
9.8.1	Component mass estimations	294
9.8.2	Aircraft mass statement and balance	297
9.8.3	Aircraft drag estimations	298
9.8.4	Aircraft lift estimations	299
9.8.5	Aircraft propulsion	300
9.8.6	Aircraft performance estimations	300
9.9	Trade-off studies	305
9.10	Revised baseline layout	305
9.11	Aircraft specification	307
9.11.1	Aircraft description	307
9.11.2	Aircraft data	307
9.12	Study review	308
	References	309
10	Project study: a general aviation amphibian aircraft	310
10.1	Introduction	311
10.2	Project brief	311
10.2.1	Aircraft requirements	312
10.3	Initial design considerations	312
10.4	Design concepts	312
10.5	Initial layout and sizing	313
10.5.1	Wing selection	313
10.5.2	Engine selection	314
10.5.3	Hull design	314
10.5.4	Sponson design	316
10.5.5	Other water operation considerations	317
10.5.6	Other design factors	318
10.6	Initial estimates	318
10.6.1	Aerodynamic estimates	318
10.6.2	Mass and balance	318
10.6.3	Performance estimations	321
10.6.4	Stability and control	323
10.6.5	Structural details	323
10.7	Baseline layout	324
10.8	Revised baseline layout	325
10.9	Further work	325
10.10	Study review	328
	References	329
11	Design organisation and presentation	331
11.1	Student's checklist	332
11.1.1	Initial questions	332
11.1.2	Technical tasks	332
11.2	Teamworking	333
11.2.1	Team development	335

11.2.2	Team member responsibilities	336
11.2.3	Team leadership requirements	336
11.2.4	Team operating principles	337
11.2.5	Brainstorming	337
11.3	Managing design meetings	338
11.3.1	Prior to the meeting	339
11.3.2	Minutes of the meeting	339
11.3.3	Dispersed meetings	341
11.4	Writing technical reports	341
11.4.1	Planning the report	342
11.4.2	Organising the report	342
11.4.3	Writing the report	343
11.4.4	Referencing	344
11.4.5	Use of figures, tables and appendices	345
11.4.6	Group reports	346
11.4.7	Review of the report	347
11.5	Making a technical presentation	348
11.5.1	Planning the presentation	349
11.5.2	Organising the presentation	349
11.5.3	Use of equipment	350
11.5.4	Management of the presentation	351
11.5.5	Review of the presentation	352
11.6	Design course structure and student assessment	353
11.6.1	Course aims	353
11.6.2	Course objectives	354
11.6.3	Course structure	354
11.6.4	Assessment criteria	355
11.6.5	Peer review	356
11.7	Naming your aircraft	356
	Footnote	357
Appendix A: Units and conversion factors		359
	Derived units	360
	Funny units	360
	Conversions (exact conversions can be found in British Standards BS350/2856)	361
	Some useful constants (standard values)	362
Appendix B: Design data sources		363
	Technical books (in alphabetical order)	363
	Reference books	365
	Research papers	365
	Journals and articles	366
	The Internet	366
Index		367