Flight Performance of Fixed and Rotary Wing Aircraft

Antonio Filippone



AMSTERDAM • BOSTON • HEIDELBERG • LONDON • NEW YORK • OXFORD PARIS • SAN DIEGO • SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO Butterworth-Heinemann is an imprint of Elsevier

67



Contents

Preface	xi
Acknowledgments	xv
List of Tables	xvii
Nomenclature: organizations	xix
Nomenclature: acronyms	xx
Nomenclature: main symbols	xxii
Nomenclature: Greek symbols	XXV
Nomenclature: subscripts/superscripts	xxvi
Supplements to the text	xxvii

Part I Fixed-Wing Aircraft Performance

Intr	oduction	3
1.1	Physical units used	4
1.2	Performance parameters	5
1.3	Performance optimization	7
1.4	Certificate of Airworthiness	7
1.5	Upgrading of aircraft performance	8
1.6	Mission profiles	9
Prot	blems	13
The	aircraft and its environment	15
2.1	General aircraft model	15
2.2	Reference systems	17
2.3		20
2.4	Moments of inertia	21
2.5	Flight dynamics equations	22
2.6	The International Standard Atmosphere	23
2.7	Non-standard conditions	28
Prot	blems	30
Wei	ght performance	33
3.1	The aircraft's weight	33
3.2	Definition of weights	40
3.3	Weight estimation	42
	1.1 1.2 1.3 1.4 1.5 1.6 Prol The 2.1 2.2 2.3 2.4 2.5 2.6 2.7 Prol Wei 3.1 3.2	 1.2 Performance parameters 1.3 Performance optimization 1.4 Certificate of Airworthiness 1.5 Upgrading of aircraft performance 1.6 Mission profiles Problems The aircraft and its environment 2.1 General aircraft model 2.2 Reference systems 2.3 Forces on the aircraft 2.4 Moments of inertia 2.5 Flight dynamics equations 2.6 The International Standard Atmosphere 2.7 Non-standard conditions Problems Weight performance 3.1 The aircraft's weight 3.2 Definition of weights

.

	3.4	Weight management	42
	3.5	Range/payload diagram	44
	3.6	Direct Operating Costs	46
	Probl	ems	47
4	Aero	dynamic performance	49
	4.1	Aerodynamic forces	49
	4.2	Lift equation	51
	4,3	Vortex lift	52
	4.4	High-lift systems	55
	4.5	Drag equation	57
	4.6	Glide ratio	61
	4.7	Glide ratio at transonic and supersonic speed	63
	4.8	Practical estimation of the drag coefficient	65
	4.9	Compressibility effects	66
	4.10	Transonic drag rise	67
	4.11	Lift and transonic buffet	68
	4.12		69
	4.13		71
	4.14		72
	4.15	· ·	74
	Probl	ems	75
5	-	ne performance	77
	5.1	Gas turbine engines	77
	5.2	Internal combustion engines	81
	5.3	Engine flight envelopes	83
	5.4	Power and thrust definitions	84
	5.5	Generalized engine performance	86
	5.6	Fuel flow	88
	5.7	Propulsive efficiency	93
	5.8	Thrust characteristics	94
	5.9	Propeller characteristics	95
	Probl	lems	108
6	0	nt envelopes	111
	6.1	General definitions	111
	6.2	Aircraft speed range	112
	6.3	Definition of speeds	113
	6.4	Steady state level flight	117
	6.5	Speed in level flight	117
	6.6	Absolute ceiling of jet aircraft	119
	6.7	Absolute ceiling of propeller aircraft	119
	6.8	Optimal speeds for level flight	121
	6.9	e 1	124
	6.10	Limiting factors on flight envelopes	126
	6.11	Dash speed of supersonic aircraft	128

•

	6.12	Absolute ceiling of supersonic aircraft	131
	6.13	Supersonic acceleration	131
	Probl	ems	135
7	Take	137	
	7.1	Definition of terminal phases	137
	7.2	Conventional take-off	139
	7.3	Ground run of jet aircraft	141
	7.4	Solutions of the take-off equation	143
	7.5	Rotation and initial climb	148
	7.6	Take-off with one engine inoperative	150
	7.7	Calculation of the balanced field length	151
	7.8	Ground run of propeller aircraft	153
	7.9	WAT charts	154
	7.10	Missed take-off	155
	7.11	Final approach and landing	156
	7.12	Landing run	157
	7.13	Effects of the wind	161
	7.14	Ground maneuvering	161
	Probl	ems	161
8	Clim	b and gliding	165
	8.1	Governing equations	165
	8.2	Rate of climb	166
	8.3	Steady climb of propeller airplane	167
	8.4	Climb of jet airplane	175
	8.5	Polar diagram for rate of climb	179
	8.6	Energy methods	181
	8.7	Specific excess power diagrams	183
	8.8	Differential excess power plots	184
	8.9	Minimum problems with energy method	186
	8.10	Steady state gliding	190
	8.11	General gliding flight	194
	8.12	Maximum glide range with energy method	196
	8.13	Minimum flight paths	198
	8.14	Additional research on aircraft climb	201
	Probl	ems	202
9		se performance	205
	9.1	Importance of the cruise flight	205
	9.2	General definitions	206
	9.3	Point performance	206
	9.4	The Breguet range equation	216
	9.5	Subsonic cruise of jet aircraft	218
	9.6	Mission fuel	224
	9.7	Cruise with intermediate stop	230
	9.8	Aircraft selection	232

•

	9.9	Supersonic cruise	233
	9.10	Cruise range of propeller aircraft	237
	9.11	Endurance	238
	9.12	Effect of weight on cruise range	239
	9.13	Effect of the wind on cruise range	239
	9.14	Additional research on aircraft cruise	241
	9.15	Formation flight	241
	Proble		248
10	Maneu	uver performance	251
	10.1	Banked level turns	251
	10.2	Banked turn at constant thrust	253
	10.3	Power requirements	255
	10.4	Effect of weight on turn radius	256
	10.5	Maneuver envelope: n-V diagram	257
	10.6	Turn rates	259
	10.7	Sustainable g-loads	262
	10.8	Unpowered turn	264
	10.9	Soaring flight	265
	10.10	Roll performance	271
	10.11	Aircraft control under thrust asymmetry	283
	10.12	Pull-up maneuver and the loop	287
	10.13	Zero-gravity atmospheric flight	289
	10.14	Flight path to a moving target	295
	Proble	ms	297
Par	tII Ro	tary-Wing Aircraft Performance	
11	Rotore	craft performance	301
	11.1	Fundamentals	301

•

	11.1	Fundamentals	301
	11.2	Helicopter configurations	302
	11.3	Mission profiles	305
	11.4	Flight envelopes	306
	11.5	Definitions and reference systems	307
	11.6	Non-dimensional parameters	311
	11.7	Methods for performance calculations	312
	Proble	ems	313
		ø	
12	Rotor	craft in vertical flight	315
	12.1	Hover performance	315
	12.2	Effect of blade twist	323
	12.3	Non-dimensional hover performance	324
	12.4	Vertical climb	326
	12.5	Ceiling performance	328
	12.6-	Ground effect	331
	12.7	Vertical descent	332
	12.8	Hover endurance	334
	Proble	ems	335

	Power requirements	33
13.3		3
		3.
	Rotor disk angle	3:
13.4	Calculation of forward flight power	3:
13.5	L/D of the helicopter	30
13.6	Forward flight analysis	30
13.7	Propulsive efficiency	30
13.8	Climb performance	3
13.9	Performance of tandem helicopters	3
13.1	0 Single or tandem helicopter?	3
Prob	lems	3
14 Rota	prcraft maneuver	3
14.1	Limits on flight envelopes	3
14.2	Kinetic energy of the rotor	3
14.3	Autorotative index	3
14.4	Autorotative performance	3
14.5		3
14.6	The vortex ring state	4
14.7	-	4
14.8		4
14.9	8	4
14.1	0 More on tail rotor performance	4
Prob	lems	4
15 Rota	orcraft mission analysis	4
15.1	F · · · · · · · · · · · · · · · · · · ·	4
15.2		4
15.3	*	4
15.4	1 1	4
15.5	Speed for maximum range	4
15.6		4
15.7	, , ,	4
15.8	1 17	4
15.9		4
Prob	lems	4
Dowt III '	V/STOL and Noise Performance	
	roL performance	4

.

.

•

6	V/STC	DL performance	435	
	16.1	Hover characteristics	435	
	16.2.	Jet-induced lift	437	
	16.3	Lift augmentation	440	
	16.4	Calculation of short take-off	441	
	16.5	Ski jump	445	

•

	16.6	Convertiplanes or tilt rotors	448
	16.7	V/STOL flight envelopes	449
	Proble	ems	449
17	Noise performance		451
	17.1	Definitions of sound and noise	452
	17.2	Trends in noise reduction	454
	17.3	Airframe noise of fixed-wing aircraft	456
	17.4	Engine noise	460
	17.5	Noise certification procedure	461
	17.6	Noise reduction from operations	464
	17.7	Minimum noise to climb	467
	17.8	Helicopter noise	469
	17.9	Helicopter noise reduction	472
	17.10	Noise certification of civil helicopters	472
	17.11	Sonic boom	473
	Proble	ems	478
Арр		A Aircraft models	479
A.1		aft A: subsonic commercial jet	479
A.2		aft B: turboprop transport aircraft	484
A.3		aft C: supersonic jet fighter	487
A.4		aft D: General utility helicopter	494
A.5	Aircr	aft E: tandem helicopter	502
Арр	endix l	B Noise data	507
Арр	endix (509
C.1		mbling aircraft forces	509
C.2		lation of numerical derivatives	510
C.3	-	nal climb of fighter jet aircraft	510
C.4	- r	nal climb rate of turboprop	513
C.5		ulation of mission fuel	515
C.6		rsonic acceleration	518
C.7		ametric thrust control	521
C.8		r power with blade element theory	524
C.9	Forwa	ard flight power of helicopter	526
Bibl	liograph	'ny	531
Index			553

•.C

۰.

5