Elements of Propulsion: Gas Turbines and Rockets

Jack D. Mattingly

Professor Emeritus Department of Mechanical Engineering Seattle University, Seattle, Washington

j^{*j*} Foreword by Hans von Ohain German Inventor of the Jet Engine



EDUCATION SERIES Joseph A. Schetz Series Editor-in-Chief Virginia Polytechnic Institute and State University Blacksburg, Virginia

Published by the American Institute of Aeronautics and Astronautics, Inc. 1801 Alexander Bell Drive, Reston, Virginia 20191-4344

Table of Contents

,

Foreword to the Second Edition ix						
Foreword to the First Edition						
Preface	li					
Acknowledg	gments					
Nomenclatu	re					
Chapter 1.	Introduction 1					
1.1	Propulsion					
1.2	Units and Dimensions					
1.3	Operational Envelopes and Standard Atmosphere					
1.4	Airbreathing Engines					
1.5	Aircraft Performance					
1.6	Rocket Engines					
	Problems					
Chapter 2.	Review of Fundamentals					
2.1	Introduction					
2.2	Equations of State and Conservation of Mass					
2.3	Steady Flow Energy Equation					
2.4	Steady Flow Entropy Equation					
2.5	Steady Flow Momentum Equation					
2.6	Perfect Gas					
2.7	Compressible Flow Properties					
2.8	One-Dimensional Gas Dynamics—Finite Control Volume					
	Analysis and the <i>H</i> - <i>K</i> Diagram 107					
2.9	Nozzle Design and Nozzle Operating Characteristics					
2.10	One-Dimensional Gas Dynamics—Differential Control					
	Volume Analysis					
2.11	Chemical Reactions					
	Problems					

Chapter 3.	Rocket Propulsion	161
3.1	Introduction.	161
3.2	Rocket Propulsion Requirements and Capabilities.	166
3.3	Rocket Propulsion Engines	176
3.4	Types of Rocket Nozzles	189
3.5	Parameters for Chemical Rockets	194
	Problems.	228
Chapter 4.	Aircraft Gas Turbine Engine	233
4.1	Introduction.	233
4.2	Thrust Equation	233
4.3	Note on Propulsive Efficiency	243
4.4	Gas Turbine Engine Components	244
4.5	Brayton Cycle	252
4.6	Aircraft Engine Design.	257
	Problems	258
Chapter 5.	Parametric Cvcle Analysis of Ideal Engines	261
5.1	Introduction.	261
52	Notation	262
53	Design Innuts	264
5.5	Steps of Engine Parametric Cycle Analysis	264
5.5	Assumptions of Ideal Cycle Analysis	266
5.5	Ideal Pamiet	200
5.0	Ideal Turboiat	200
5.7	Ideal Turbojet	2/0
5.0		291
5.9	Ideal Turbolan	302
5.10	Ideal Turboian with Optimum Bypass Ratio	325
5.11	Ideal Iurboran with Optimum Fan Pressure Ratio	332
5.12	Ideal Pulse Detonation Engine	341
	Problems	344
Chanter 6.	Component Performance	355
61	Introduction	355
6.7	Variation in Gas Properties	355
63	Component Performance	357
6.4	Inlat and Diffuser Pressure Recovery	358
0.4	Compressor and Typhing Efficiencies	260
0.5	Dumon Efficiency and Process Lago	270
0.0	Burner Elliciency and Pressure Loss	270
6.7		3/1
6.8	Mechanical Efficiency of Power Shaft	5/1
6.9	Summary of Component Figures of Merit	271
< • • •	(Constant c_p Values)	3/1
6.10	Component Performance with Variable c_p	373
	Problems	378

Chapter 7.	Parametric Cycle Analysis of Real Engines	381
7.1	Introduction.	381
7.2	Turbojet	381
7.3	Turbojet with Afterburner	399
7.4	Turbofan—Separate Exhaust Streams.	404
	Problems.	427
Chapter 8.	Engine Performance Analysis	437
8.1	Introduction	437
8.2	Gas Generator	447
8.3	Turboiet Engine	464
8.4	Turbojet Engine with Afterburning	486
8.5	Turbofan Engine—Separate Exhausts and	
0.0	Convergent Nozzles	499
	Problems	524
	110000005	524
Chanter 0	Turbomachinary	537
	Introduction	537
9.1	Euler's Techonican Equations	507
9.2	Euler's Turbomachinery Equations	537
9.3	Axial-Flow Compressor Analysis	539
9.4	Centrifugal-Flow Compressor Analysis	600
9.5	Axial-Flow Iurbine Analysis	607
9.6	Centrifugal-Flow Turbine Analysis	668
	Problems	674
Chapton 10	Inlate Norales and Combustion Systems	205
10.1	Interst, NOZZIES, and Combustion Systems	205
10.1		085
10.2	Imets	083
10.3		080
10.4	Supersonic Inlets	695
10.5	Exhaust Nozzles	726
10.6	Introduction to Combustion Systems	744
10.7	Main Burners.	757
10.8	Afterburners	769
	Problems	779
Annendiy A	Altitude Tables	785
Appendix A.	Annual Tables	/05
Appendix B.	Gas Turbine Engine Data	793
Appendix C.	Data for Some Liquid-Propellant Rocket Engines	801
Appendix D.	Air and $(CH_2)_n$ Properties at Low Pressure	803
Appendix E.	Turbomachinery Stresses and Materials	821

xiii

v	11.7	
х	IV.	

•		
Appendix F.	About the Software	
Appendix G.	Answers to Selected Problems	
References .		
Index		
Supporting Materials		
Supporting M	laterial for Chapter 5: Parametric Cycle Analysis of	
Ideal Engines		
SM5.1	Ideal Mixed-Flow Turbofan with Afterburning	
SM5.2	Ideal Turboprop Engines	
SM5.3	Ideal Turboshaft Engine with Regeneration	
Supporting M	laterial for Chapter 7: Parametric Cycle Analysis for	
Real Engines	ť	
SM7.1	Turbofan with Afterburning—Separate Exhaust Systems	
an 15 a		

- SM7.2 Turbofan with Afterburning—Mixed Exhaust Stream
- SM7.3 Turboprop Engine
- SM7.4 Variable Gas Properties

Supporting Material for Chapter 8: Engine Performance Analysis

- SM8.1 Turbofan with Afterburning—Mixed Exhaust Stream
- SM8.2 Turboprop Engine
- SM8.3 Variable Gas Properties
- SM8.4 Performance Analysis----Dual-Spool Afterburning Turbojet Engine