Preface

Pedagogically, the fundamental principles are the foundation for lifelong learning. Thus, this book through a simple treatment can provide students of aerospace/aeronautical and mechanical engineering with a deep understanding of both aircraft and spacecraft propulsions. The development of aircrafts in only one century is far beyond expectations.

December 1903 was the dawn of human-engineered flight when the Wright Brothers flew their first flights that lasted for a few seconds in Ohio, USA. This first aircraft was powered by a single piston engine and had no passengers, neither did it have a fuselage nor landing gears. It is extremely amazing that in 2011 over 2.8 billion passengers were carried by the world's commercial airlines via more than 222,500 aircrafts powered by more than 260,000 different types of aero engines. Some of these aircrafts can carry as many as 800 passengers for more than 15 h of flying time, while others can fly at supersonic speeds. In 2015, the number of passengers exceeded 3.3 billion. Now, piston engines are no longer the single actor in propulsion theater, though they are still dominant! Turbojet engines were the first jet engines invented in the late 1930s and took a reasonable share in military and civil-powered flights for nearly two decades. In the late 1950s and early 1960s, turbofan engines (or bypass turbojet engines) were invented. These are the present prevailing engines which power faster, quieter, cleaner, and heavier aircrafts. In the 1950s also two other engine types, namely, turboprop and turboshaft, were invented to power commercial airliners and military transport aircrafts and rotorcrafts.

Due to the rapid advance in air transportation as well as military and intelligence missions, aircraft and rocket propulsion has become an essential part of engineering education. Propulsion is the combined aero-thermal science for aircrafts and rockets. Propulsion has both macro- and microscales. Macroscale handles the performance and operation of aircrafts and rockets during different missions, while microscale is concerned with component design including both rotary modules (i.e., compressor, fan, pump, and turbine) and stationary modules (i.e., intake, combustor, afterburner, and nozzle).

The primary aim of this text is to give students a thorough grounding in both the theory and practice of propulsion. It discusses the design, operation, installation and several inspections, repair, and maintenance aspects of aircraft and rocket engines.

This book serves as a text for undergraduate and first year graduate students in mechanical, aeronautical, aerospace, avionics, and aviation engineering departments. Moreover, it can be used by practicing engineers in aviation and gas turbine industries. Background in fluid mechanics and thermodynamics at fundamental levels is assumed. The book also provides educators with comprehensive solved examples, practical engine case studies, intelligent unsolved problems, and design projects. The material of this book is the outcome of industrial, research, and educational experience for more than 40 years in numerous civil, military institutions, and companies of 9 countries including the USA, Russia, Austria, UK, Belgium, China, and Japan as well as Egypt.

The book is composed of 11 chapters and 4 appendices. The first ten chapters handle air-breathing engines, while non-air-breathing (or rocket) engines are analyzed in Chap. 11.

Chapter 1 is rather a unique one! It provides a rigorous classification of all types of aircrafts and its sources of power. The first part classifies aircrafts as aerostats/aerodynes, fixed wing/rotary wing (or rotorcrafts), and hybrid fixed/rotary wings as well as all other lift aircrafts (flapping wing or ornithopter, lifting body, and fan wing). The second part handles power plant types. Power plants belong to two main groups, namely, external and internal combustion engines. External combustion engines are steam, Stirling, and nuclear engines. Internal combustion engines are further classified as shaft and reaction engines. Shaft engine group is either of the intermittent combustion types (Wankel and piston) or continuous combustion types (turboprop, turboshaft, and propfan). Reaction engines are either of the athodyd or turbine engines. Athodyd engines include ramjet, scramjet, and pulsejet (valved, valveless, and pulse detonation types). Finally, turbine-based engines include turbojet, turbofan, and turbo-ramjet engines.

Chapters 2 and 3 emphasize that a few fundamental physical principles, rightly applied, can provide a deep understanding of operation and performance of aircrafts and space vehicles.

Chapter 2 provides a review of basic laws of compressible flow with heat and friction. Conservation of mass, momentum, moment of momentum, and energy equations applied to open control volume are reviewed. A review for aspects of normal and oblique shock waves and Fanno and Rayleigh flows follows. Flow in diffusers in aircrafts as well as flow in nozzles in both aircrafts and rockets are discussed. Standard atmosphere is highlighted to emphasize variations of air properties at different altitudes.

Chapter 3 relies upon governing formulae reviewed in Chap. 2 in driving the different performance parameters of jet propulsion, namely, thrust force, operation efficiencies (propulsive, thermal, and overall), specific impulse, and fuel consumption. Other parameters that couple aircraft and engine performance like aircraft range and endurance are presented. Analysis of aircraft mission, route planning, and non-return point are next highlighted.

Chapter 4 provides the necessary analyses of piston engines and propellers. Though piston engine was the first in-flight air-breathing engine employed by the Wright brothers in 1903, it maintains its strong existence until now. It represents more than 70 % of present-day air-breathing engines. They are extensively used in small fixed wing, sport aircrafts, UAVs, and lighter than air flying vehicles, as well as many rotorcrafts. Unfortunately, it is overlooked in most available propulsion books. A concise analysis of power cycles for two- and four-stroke engines, compression or spark ignition (CI and SI), and Wankel engines as well as turbo- and superchargers is reviewed for power and thermal efficiency optimization. Piston engines cannot generate the necessary propulsive force for a flying vehicle on its own. Thus, it should be coupled to propellers. Classifications of propellers based on various aspects are defined. Propeller's power and thrust force coefficients are defined using simple aerodynamic theories (momentum, modified momentum, and blade-element).

Chapter 5 is devoted to athodyd (nonrotating modules) engines, namely, pulsejet, ramjet, and scramjet engines. All cannot produce thrust force at zero flight speed, so other propulsive methods are used for takeoff operation. Each engine is composed of intake, combustion chamber, and nozzle. An analysis of ideal and real cycles as well as performance parameters of all engines is identified. Pulsejet engine is an internal combustion engine that produces thrust intermittently and is either of the valved or valveless type. Pulse detonation engine (PDE) is evolved in the last decade. PDE promises higher fuel efficiency (even compared with turbofan jet engines). Ramjet engine represents the first invented continuous combustion engine. It is used in both aircrafts and rockets. The third engine analyzed in this chapter is *scramjet* (*supersonic combustion ramjet*). Combustion takes place in supersonic airflow. Thus it can fly at extremely high speeds (NASA X-43A reached Mach 9.6). Finally, dual-mode (Ram-Scram) combustion engine is analyzed.

Chapters 6 and 7 treat air-breathing engines incorporating rotating modules. Chapter 6 handles turbine-based engines (turbojet, turbofan, and turbo-ramjet), while Chap. 7 treats shaft-based engines (turboprop, turboshaft, and propfan). One of the objectives of both chapters is to exercise students to practice realistic engines, build confidence, and a sense of professionalism. Both chapters start with a historical prospective and a classification of each engine. Next, thermodynamic and performance analyses for ideal and real cycles are introduced and further explained via solved examples. Chapter 6 starts by the first flown jet engine, namely, turbojet engine, which was coinvented in the 1930s by British and German activities. Analyses of single and double spools in the presence and absence of afterburner are described. Though rarely used in airliners or military planes in present days, it is still used in micro turbojets and turbojets powering rockets during sustained flight.

Turbofan engines are continuing its superiority for most present commercial airliners and military planes as well as some rockets for sustained flight. A unique classification of the numerous types of this engine based on fan location (forward/aft), bypass ratio (low/high), number of spools (single/double/triple), number of nozzles (single/double), fan/turbine coupling (geared/ungeared), and finally afterburner (present/absent) is given. After detailed analyses for some (not all) types of turbofan, the third engine, namely, turbo-ramjet, is presented. It is found in two configurations: wraparound or above/under types. An analysis of its single mode or combined mode is precisely defined.

Chapter 7 is confined to shaft-based engines in which performance is controlled by shaft power rather than thrust force. Also, its economy is governed by brake-specific fuel consumption rather than thrust-specific fuel consumption. Turboprop engines power manned and unmanned aircrafts. It may be of the puller (tractor) or pusher types. It may be also either a single or double spool. This section is ended by an analogy between turboprop and turbofan engines. Next, turboshaft engines which mainly power helicopters are classified and analyzed. Exhaust speeds are no longer important in this type of engines as all available energy is converted into shaft power. Finally, propfan or unducted fan (UDF) engines, normally described as ultrahigh bypass (UHP) ratio engine, are classified based on fan location (forward/aft) and numbers of fan stages (single/double). A thermodynamic analysis of this engine is presented for the first time in this book. It combines features from both turbofan and turboprop engines.

Chapter 8 presents aero-/thermodynamic analyses of stationary modules of jet engines, namely, intakes, combustion chamber, afterburner, and nozzle. At first, different methods for power plant installation (wing/fuselage/tail, or combinations) are discussed as it has a direct influence on air flow rates into intakes and ingestion of foreign objects into the engines. Also, intakes for fixed and rotary wing aircrafts as well as rockets are described. Moreover, subsonic and supersonic intakes are reviewed for optimum jet engine performance. Intake geometry and its performance are also presented. A review of combustion chambers including types, chemistry of combustion, aerodynamics, and thermodynamics of flow in its different elements is presented. Afterburners in turbojets/turbofans in supersonic aircrafts are analyzed. Different types of aviation fuels and biofuels as a future jet fuel for green aviation are examined. The exhaust system is treated here in a general scope. Convergent and convergent divergent (de Laval) nozzles are analyzed. Moreover, thrust reverse and thrust vectoring are reviewed. Noise control for nozzles is given.

Turbomachinery (i.e., fans, compressors, and turbines) are treated in Chaps. 9 and 10. The objective of both chapters is to provide a simplified understanding of its aerodynamics, thermal, and stresses in both compressors and turbines. In Chap. 9, different types of compressors are first identified, but only centrifugal and axial flow types are analyzed. The three main components of centrifugal compressor, namely, impeller, stator, and volute/scroll, are first analyzed taking into consideration their different types. Positive/negative prewhirl is also presented. Concerning axial compressor, the aerodynamics of single and multistages is reviewed. A performance map for both compressors is employed in identifying design and off-design operation. Lastly, different mechanisms for avoiding surge and rotating stall are discussed.

Chapter 10 treats radial and axial flow turbines. Radial turbine is to a great extent similar to centrifugal compressor. The aerodynamics and thermodynamics of its components (i.e., inlet, nozzle, rotor, and outlet duct) are presented. Next, single and multistage axial flow turbines are treated with either impulse or reaction blading. Mechanical design and cooling techniques are reviewed. Finally, turbine map and off-design performance of both turbines are discussed. Matching between compressors and turbines in both gas generators and jet engines ends this chapter.

Rocket propulsion is discussed in Chap. 11. It starts with a brief history of rocketry followed by classifications of rockets based on type, launching mode, range, engine, warhead, and guidance systems. Rocket performance parameters (i.e., thrust force, effective exhaust velocity, specific impulse, thrust coefficient, and combustion chamber pressure drop) are derived in closed forms similar to those in Chap. 3 for air-breathing engines. A comprehensive section for multistaging is presented. Finally, an analysis of exhaust system (i.e., nozzle geometry, exhaust velocity, and structural coefficient) is given. Both chemical and nonchemical rocket engines are reviewed. Chemical rockets are further divided into liquid, solid, and hybrid rockets. Solid propellant types, combustion chamber, and nozzles are defined. In liquid propellant rockets, a turbopump is added. A hybrid rocket combines liquid and solid propellant systems. Nonchemical rockets including nuclear heating and electrically powered and electrothermal, electromagnetic, and electrostatic thrusters are reviewed.

The book ends with 4 appendices. These lists chronicle details of piston, turbojet, and turbofan engines, as well as milestones for rockets.

Finally, I would like to express my sincere appreciation and gratitude to Airbus Industries and Rolls-Royce plc for their permission to use illustrations and photographs within this text.

I would like to express my sincere thanks to my editor, Charlotte Cross, who was a great help since day one and continued her support during the tough time of manuscript writing.

I'm deeply honored by the support of the dean and staff of Moscow Institute for Physics and Technology (MIPT), Moscow University, and for granting me their medal of 50th anniversary

Particular thanks for the continuous help and technical support of:

- Professor Darrell Pepper, Director, NCACM, University of Nevada Las Vegas, USA
- Mr. Joseph Veres, Compressor Section, NASA Glenn Research Center, Cleveland, USA
- Professor Louis Chow, University of Central Florida, Orlando, USA
- Dr. Dennis Barbeau, AIAA Phoenix Section, USA

I would like to express my sincere thanks and utmost gratitude to my students: Ahmed Z. Almeldein, Aerospace Department, Korea Advanced Institute of Science and Technology, South Korea; Mohamed Aziz and Eslam Said Ahmed, Institute of Aviation Engineering and Technology (IAET); Amr Kamel, Egyptian Air Force; Mohamed Emera and Ibrahim Roufael, Mechanical Power Engineering

Department, Zagazig University; and Ahmed Hamed, Senior Production Engineer, Engine Overhaul Directorate, EgyptAir Maintenance and Engineering Company.

At last, I extend my heartfelt gratitude to my wife, Amany, and sons Mohamed, Abdallah, and Khalid who were the real inspiration and motivation behind this work.

Zagazig, Egypt Ahmed F. El-Sayed

http://www.springer.com/978-1-4471-6794-5

Fundamentals of Aircraft and Rocket Propulsion
El-Sayed, A.F.
2016, XXI, 1010 p. 571 illus., 242 illus. in color. With
online files/update., Hardcover
ISBN: 978-1-4471-6794-5