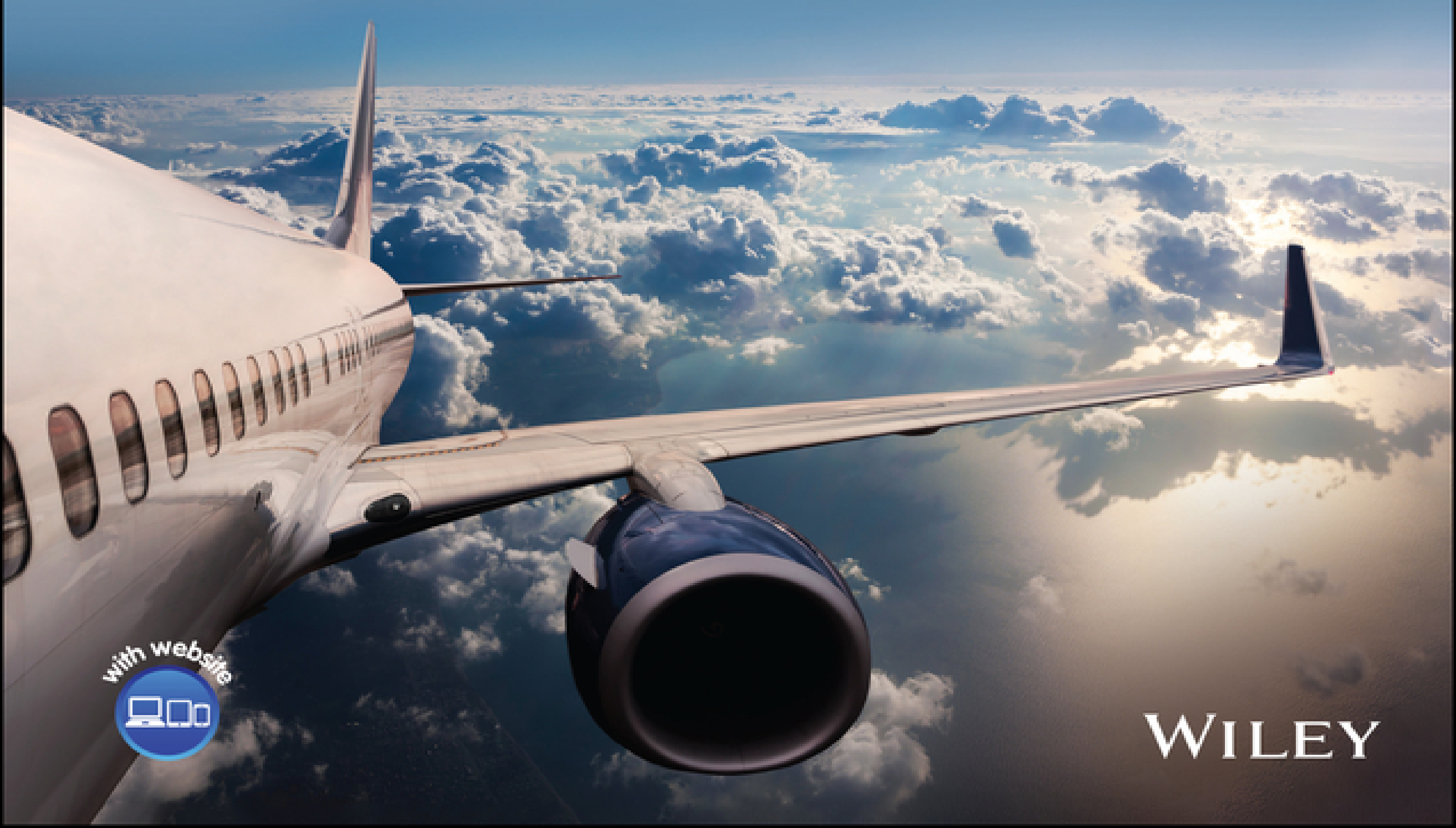
INTRODUCTION TO AEROSPACE ENGINEERING

BASIC PRINCIPLES OF FLIGHT

Ethirajan Rathakrishnan



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Introduction to Aerospace Engineering

Basic Principles of Flight

Ethirajan Rathakrishnan
Indian Institute of Technology, Kanpur

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This book is dedicated to my parents,

Mr. Thammanur Shunmugam Ethirajan

and

Mrs. Aandaal Ethirajan

Ethirajan Rathakrishnan

Preface

This book has been developed to introduce the subject of Aerospace Engineering to the beginners. Introduction to aerospace engineering is a compulsory course for Aerospace Engineering students. This book, being the manuscript developed using the course material used in teaching this course for a long period, precisely presents the basics of theoretical and application aspects of the subject.

This book is developed based on the class tested material for the course Introduction to Aerospace Engineering, at BS and MS levels, taught by the author at Indian Institute of Technology Kanpur. The topics covered are; Basics, International Standard Atmosphere, Aircraft Configurations, Low-Speed Aerofoils, High-Lift Devices, Thrust, Level Flight, Gliding, Performance, Stability and Control, Manoeuvres, Rockets. All these topics are introduced in such a manner that the students studying these for the first time could comfortably follow and assimilate the material covered.

The material covered in this book is so designed that any beginner can follow it comfortably. The book is organised in a logical manner and the topics are discussed in a systematic manner.

My sincere thanks to my undergraduate and graduate students at Indian Institute of Technology Kanpur, who are directly and indirectly responsible for the development of this book.

My special thanks to Dr. S.M. Aravindh Kumar, Department of Aerospace Engineering, S.R.M. Institute of Science and

Technology, Chennai, for critically checking the manuscript and giving some useful suggestions.

For instructors only, a companion Solutions Manual is available from John Wiley that contains typed solutions to the end-of-chapter problems.

Chennai, India
March 23, 2021

Ethirajan Rathakrishnan

About the Author

Ethirajan Rathakrishnan is professor of Aerospace Engineering at the Indian Institute of Technology Kanpur, India. He is well known internationally for his research in the area of high-speed jets. The limit for the passive control of jets, called the *Rathakrishnan Limit*, is his contribution to the field of jet research, and the concept of *breathing blunt nose (*BBN*)*, which simultaneously reduces the positive pressure at the nose and increases the low pressure at the base is his contribution to drag reduction at hypersonic speeds. Positioning the twin-vortex Reynolds number at around 5000, by changing the geometry from cylinder, for which the maximum limit for the Reynolds number for positioning the twin-vortex was found to be around 160, by von Karman, to flat plate, is his addition to vortex flow theory. He has published a large number of research articles in many reputed international journals. He is a Fellow of many professional societies including the Royal Aeronautical Society. Rathakrishnan serves as the Editor-in-Chief of the *International Review of Aerospace Engineering* (IREASE) and *International Review of Mechanical Engineering* (IREME) journals. He has authored 13 other books: *Gas Dynamics*, 7th ed. (PHI Learning, New Delhi, 2020); *Fundamentals of Engineering Thermodynamics*, 2nd ed. (PHI Learning, New Delhi, 2005); *Fluid Mechanics: An Introduction*, 4th ed. (PHI Learning, New Delhi, 2021); *Gas Tables*, 3rd ed. (Universities Press, Hyderabad, India, 2012); *Theory of Compressible Flows* (Maruzen Co., Ltd. Tokyo, Japan, 2008); *Gas Dynamics Work Book*, 2nd ed. (Praise Worthy Prize, Naples, Italy, 2013); *Elements of Heat Transfer* (CRC Press, Taylor & Francis Group, Boca Raton, FL, USA, 2012); *Theoretical Aerodynamics* (John Wiley, NJ, USA, 2013); *High Enthalpy Gas Dynamics* (John Wiley & Sons Inc., 2015); *Dynamique Des Gaz* (Praise Worthy Prize, Naples, Italy, 2015); and *Instrumentation, Measurements and Experiments in Fluids*, 2nd ed. (CRC Press, Taylor & Francis Group, Boca Raton, FL, USA, 2017), *Helicopter Aerodynamics* (PHI Learning, New Delhi, 2019); *Applied Gas Dynamics* 2nd ed. (John Wiley & Sons Inc., 2019).

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/Rathakrishnan/IntroductiontoAerospaceEngineering

The website has solutions manual and lecture slides.

1
Basics

1.1 Introduction

Aerodynamics is the study of forces and the resulting motion of objects through the air. This word is coined with the two Greek words: *aerios*, concerning the air, and *dynamis*, meaning force. Judging from the story of Daedalus and Icarus,[1] humans have been interested in aerodynamics and flying for thousands of years, although flying in a heavier-than-air machine has been possible only in the last century. Aerodynamics affects the motion of high-speed flying machines, such as aircraft and rockets, and low-speed machines, such as cars, trains, and so on. Therefore, *aerodynamics* may be described as a branch of dynamics concerned with studying the motion of air, particularly when it interacts with a solid object. Aerodynamics is a subfield of fluid dynamics and gas dynamics. It is often used synonymously with gas dynamics, with the difference being that gas dynamics applies to all gases.

Understanding the flow field around an object is essential for calculating the forces and moments acting on the object. Typical properties calculated for a flow field include velocity, pressure, density, and temperature as a function of spatial position and time. Aerodynamics allows the definition and solution of equations for the conservation of mass, momentum, and energy in air. The use of aerodynamics through mathematical analysis, empirical approximations, wind tunnel experimentation, and computer simulations forms the scientific basis for heavier-than-air flight and a number of other technologies.

Aerodynamic problems can be classified according to the flow environment. *External aerodynamics* is the study of flow around solid objects of various shapes. Evaluating the lift and drag on an airplane or the shock waves that form in front of the nose of a rocket are examples of external aerodynamics. *Internal aerodynamics* is the study of flow through passages in solid objects. For instance, internal aerodynamics encompasses the study of the airflow through a jet engine.

Aerodynamic problems can also be classified according to whether the flow speed is below, near or above the speed of sound. A problem is called *subsonic* if all the speeds in the problem are less than the speed of sound, *transonic* if speeds both below and above the speed of sound are present, *supersonic* if the flow speed is greater than the speed of sound, and *hypersonic* if the flow speed is more than five times the speed of sound.

The influence of viscosity in the flow dictates a third classification. Some problems may encounter only very small viscous effects on the solution; therefore the viscosity can be considered to be negligible. The approximations made in solving these problems is the viscous effect that can be regarded as negligible. These are called *inviscid flows*. Flows for which viscosity cannot be neglected are called *viscous flows*.

1.2 Overview

Humans have been harnessing aerodynamic forces for thousands of years with sailboats and windmills [1]. Images and stories of flight have appeared throughout recorded history [2], such as the legendary story of Icarus and Daedalus [3]. Although observations of some aerodynamic effects such as wind resistance (for example, drag) were recorded by Aristotle, Leonardo da Vinci, and Galileo

Galilei, very little effort was made to develop a rigorous quantitative theory of airflow prior to the seventeenth century.

In 1505, Leonardo da Vinci wrote the Codex (an ancient manuscript text in book form) on the *Flight of Birds*, one of the earliest treatises on aerodynamics. He was the first to note that the centre of gravity of a flying bird does not coincide with its centre of pressure, and he describes the construction of an ornithopter with flapping wings similar to birds.

Sir Isaac Newton was the first to develop a theory of air resistance [4], making him one of the first aerodynamicists. As a part of that theory, Newton considered that drag was due to the dimensions of the body, the density of the fluid, and the velocity raised to the second power. These all turned out to be correct for low-speed flow. Newton also developed a law for the drag force on a flat plate inclined towards the direction of the fluid flow. Using F for the drag force, ρ for the density, S for the area of the flat plate, V for the flow velocity, and θ for the inclination angle, his law was expressed as

$$F = \rho\, S\, V^2 \sin^2 \theta$$

This equation is incorrect for the calculation of drag in most cases. Drag on a flat plate is closer to being linear with the angle of inclination as opposed to acting quadratically at low angles. The Newton formula can lead one to believe that flight is more difficult than it actually is, due to this overprediction of drag, and thus required thrust, which might have contributed to a delay in human flight. However, it is more correct for a very slender plate when the angle becomes large and flow separation occurs or if the flow speed is supersonic [5].