普通高等院校航空航天双语教学用书

INTRODUCTION TO HELICOPTER AND TILTROTOR FLIGHT SIMULATION

直升机和倾转旋翼飞行器飞行仿真引论

（双语教学精选版）

(美)马克 · E. 德雷尔(Mark E. Dreier) 著
孙传伟 孙文胜 刘 勇 傅见平 译
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内 容 提 要

本书为普通高等院校航空航天双语教学用书，其原版教材供美国工科院校高年级大学本科生和研究生使用。目的是让学生了解直升机和旋翼飞行器的基本知识，并提供飞行仿真建模方法。本双语版教材主要阐述的内容包括：翼型、机翼和垂尾空气动力学，螺旋桨空气动力学，旋翼空气动力学和动力学建模，气动干扰，发动机，传动系统，操纵，起落架和配平，适合相关专业院校师生使用，以及作为专业技术人员的参考用书。

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出版说明

适合教学和专业发展的双语教材的编写、引进和出版，是我国高等院校双语教学示范课程建设的重要内容之一。针对目前我国高等院校推广的双语教学课程建设项目，中航出版传媒有限责任公司（航空工业出版社）作为国内航空航天领域领先的专业出版机构，与国内各航空航天院校积极探索，根据各院校的实际教学需求，对国外成熟的、优秀的航空航天教材进行了甄选，形成了独具特色的航空航天类双语版专业教材。其中部分优选出的权威的、经典的教材已经在国内部分院校的教学实践中进行了使用，不但获得了教师和学生的肯定，而且取得了业内专家和学者的一致认同。

本套丛书所包含的双语教材均是由从事相关专业教学工作多年的一线教师根据教学实践内容编写、翻译或译注而成的。从出版形式上，既有中英文对照版，又有译注版。在中英文对照版中，教材作者又根据不同的教学安排对原版教材进行了取舍，集中精选了适合教学计划的内容编撰成双语教学精选版。译注版对原版教材中的要点进行了注释，这样可以使得学生在学习过程中更容易理清知识脉络，抓住重点，增加了注释的双语版教材基本保持了英文原版教材的结构和篇幅，不同的是，每章前面都增加了一部分提炼出来的知识要点。本套丛书所引进的原版教材，多是国外专业教材中的经典作品，被国外多所院校广泛采用，并经多次再版修订。此外，本套丛书基本保留了原版书的量和单位符号，公式中的矢量和标量等也大多沿用了原书的符号系统。

本套丛书的出版是我国航空航天专业教材出版领域的创新之举，得到了国内各航空相关院校的大力支持，由既熟悉原版教材，又具备丰富的双语教学经验和系统专业知识的任课教师担任丛书的作（译）者，他们在繁重的教学工作之余完成了各自书稿的编写和翻译工作，在此对他们的辛勤付出表示感谢！

由于出版工作繁杂，本套丛书难免会有疏漏、差错及不妥之处，敬请读者指正。

目　　录[1]

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① 本书为双语教学精选版，按从原版书中所选章节编排，保留了原版书中的章节序号。——译者注

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9 Aerodynamics of Airfoils, Wings, and Fins

9.1 Introduction

Save for spasmodic jumping, humankind's motion in space was limited to forward, backward, side to side, and down when falling. Sustained upward motion was not possible until enterprising observers and experimenters devised means for flight. Interestingly, some of the first attempts at flight did not try to emulate birds. In China, in the late third century B. C. E. , imperfectly sealed ceremonial bamboo tubes filled with saltpeter, sulphur, and charcoal formed the first rockets. Nineteen centuries later, Wan-Hu, a clever inventor of the Ming Dynasty, estimated the journey to the moon to be no more than 47 tubes worth. Strapping himself and said arsenal to a wicker chair and setting the rockets alight, he was determined to predate the Armstrong and Aldrin landing by 400 years. The ensuing explosion was spectacular; the results were less than stellar.

In ancient Greek mythology, and more to the point of atmospheric flight, King Minos commanded an Athenian artisan named Daedalus to construct a labyrinth to imprison the king's wife Pasiphae and their hideous child, the minotaur. Daedalus did the work, but then sought to leave Crete because he did not trust Minos. He fashioned wings made of wax to which he stuck feathers. One set he wore, and one set he gave to his son Icarus. Despite his father's advice, Icarus flew too close to the sun. The wax melted, feathers started flying, and Icarus stopped flying; his wings disassembled, sending him plunging into the sea to drown.

Other attempts to achieve flight have often focused on wings, especially moving wings. After all, this is how birds fly, is it not? Yes and no. Atmospheric flight is achieved with wings, sometimes moving wings. [Yes, the Darwin Awards speak of the anti-Einstein that strapped a couple of jet-assisted takeoff (JATO) bottles to his automobile and unintentionally achieved a low Earth orbit, culminating in a collision with a cumulo-granite cloud. However, this text is limited to the scientific method, not the "hold my beer and watch this" method. By the way, the story of the rocket car has been debunked as urban myth.] This chapter presents the mathematics and physics behind wings and several methods for modeling them. This chapter also looks at fins, which this chapter defines as partial-span wings. Fins are most often used as stabilizer surfaces or endplates. The mathematics used to model fins is essentially the same as the mathematics used on wings. The location of the reference axes is usually the difference, but this is not a confusing factor.

第9章 翼型、机翼和垂尾空气动力学

9.1 引言

除了间歇性的跳跃，人类在空间中的运动总是局限于向前、向后、向左、向右和从空中落下时向下的运动。在一些观察家和研究人员发明飞行方法前，人类还没有可能进行持续的向上的运动。有趣的是，初期的一些飞行尝试并不是去模仿鸟类飞行。在公元前3世纪末的中国，有人在一端开口的竹管中填充硝石、硫磺和木炭，制成了人类历史上第一支火箭。19世纪后期，中国明朝有一个聪明的发明家万户，他估测到月球的航程最多需要47支这样的火箭，于是他把自己和火箭绑到一把柳条椅上，并设置了火箭的点燃顺序，他决定把阿姆斯特朗和奥尔德林的月球着陆提前400年。随之发生的爆炸非常壮观，这种结果显然非常悲壮。

古希腊有很多关于大气飞行的神话。迈诺斯国王命令一名叫做代达罗斯的雅典工匠给他建造一座迷宫，用于囚禁王后帕西法厄和他们丑陋的孩子。代达罗斯完成了这项工作，但随后他试图离开克利特岛，因为他不相信迈诺斯。他用蜡将羽毛粘在一起，制造了两对翅膀，他和他的儿子伊卡洛斯各戴了一对。在他们飞离小岛的途中，伊卡洛斯不听从父亲的建议，飞得离太阳太近，导致翅膀上的蜡开始融化，羽毛随之飞散。就这样，伊卡洛斯再也无法继续飞行，他的翅膀在空中解体，最终摔在海里淹死了。

其他飞行尝试通常将注意力集中在翅膀上，特别是会动的翅膀。毕竟鸟就是这样飞的，不是吗？但是答案是：是，又不是。空气中的飞行是用翅膀进行的，但只是有些时候才使用会动的翅膀。（当然读者可能会想到，达尔文奖曾讨论过一种违反爱因斯坦相对论的说法：在汽车上绑上几个喷气辅助起飞（JATO）的瓶子，不出意外就可以使汽车进入到一个较低的轨道绕地球飞行，最后汽车可以与积雨云相撞。这种说法显然是不科学的，最后这种火箭车的传说被证明只是一个地方神话。本文的讨论仅限于科学的方法，不包括那些心血来潮的做法。）本章介绍有关机翼的数学和物理原理，以及进行机翼建模的几种方法。还要介绍垂尾，本章将其定义为部分展长的机翼。垂尾最常用作稳定面或端板，垂尾建模使用的基本数学方法与机翼建模使用的数学方法相同，参考坐标系的位置通常不同，但这不是难题。

9.2 Basic Geometry—Airfoils

Awing or fin is a three-dimensional device that generates lift. An airfoil (section) is an infinitesimally thin two-dimensional slice through the wing or fin created by two parallel vertical planes as shown in Fig. 9.1.

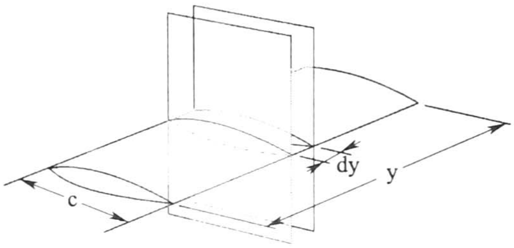

Fig. 9.1 Airfoil section of a wing or fin.

The study of wings and fins begins here at the airfoil section. Viewed from the side, an airfoil section resembles the top view of a trout. A straight line, which joins the leading edge to the trailing edge, is called the chord line and is given the symbol c. It is the reference line for several other important measurements.

For the purposes of analysis, an airfoil is decomposed into three pieces (Fig. 9.2a) The thickness distribution (Fig. 9.2b) describes how thick the airfoil is at any point measured along the chord. The thickness distribution is always symmetric. The camber line (Fig. 9.2c) is the locus of points midway between the upper and lower surfaces of the airfoil, measured from the chord. For symmetric airfoils, this line is straight. Finally, the flat plate (Fig. 9.2d) is the straight line that is used as a reference line to measure the aerodynamic angle of attack. It is usually the chord line.

For symmetric airfoils, the chord line and the zero lift line are coincident. Relative wind blowing parallel to the chord line will produce no lift. If the airfoil has camber as shown in Fig. 9.2, then relative wind blowing parallel to the chord line will produce lift toward the top of the page. Let this direction be called "away from the crown." In the discussions that follow, assume airfoil sections are symmetric, unless otherwise noted.

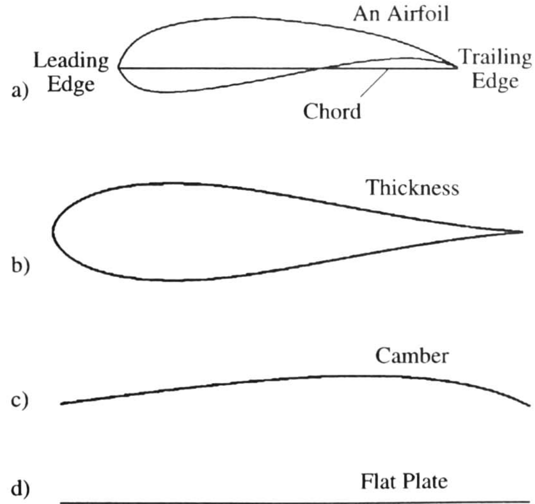

Fig. 9.2 Decomposition of a wing.

9.2　基本几何形状——翼型

机翼或垂尾是产生升力的三维部件。翼型（翼剖面）是一个无限薄的二维剖面，用两个互相平行的垂直面去切割机翼或垂尾，就可得到翼型，如图 9－1 所示。

对机翼和垂尾的研究从翼剖面开始，从侧面看，翼剖面很像鲑鱼的俯视图。连接前缘和后缘的直线称为弦线，用符号 c 表示，它是其他一些重要参数测量的基准线。

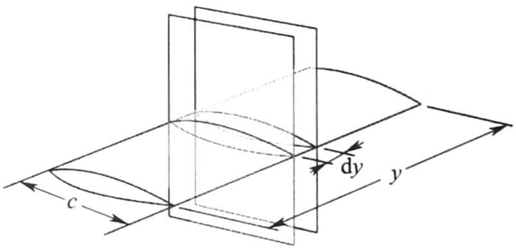

图 9－1　机翼或垂尾的翼型

为便于分析，翼型被分解为三段（图 9－2（a））。厚度分布（图 9－2（b））描绘了沿弦长任一点测量的翼型的厚度，厚度分布总是对称的。中弧线（图 9－2（c））是翼型上下表面平行于 y 轴的连线的中点所连成的曲线，对于对称翼型，这条线是直线。最后，平板直线（图 9－2（d））用来作为测量气动迎角的基准线，通常用弦线代表。

对于对称翼型，弦线和零升力线是一致的，平行吹过弦线的相对来流不产生升力。如果翼型的中弧线如图 9－2 所示，则平行于弦线的相对来流将产生指向页面顶部的升力，该方向称为“远离顶点”。在下面的讨论中，假设翼型剖面是对称的，除非另有说明。

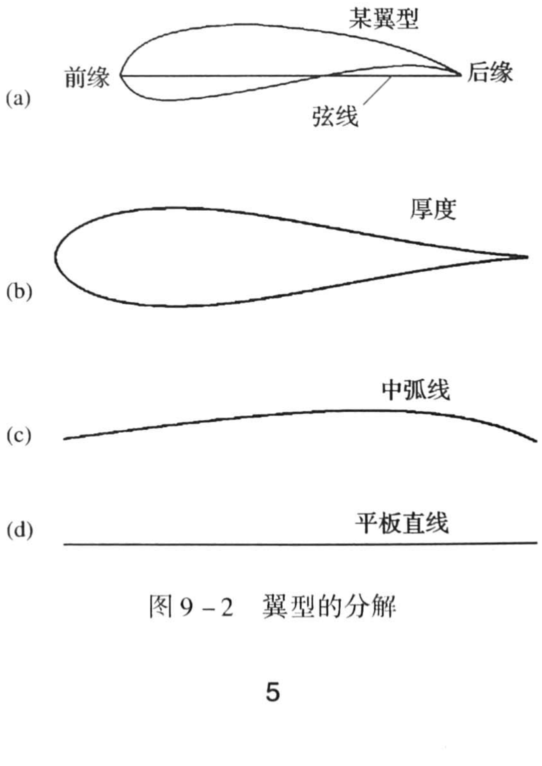

图 9－2　翼型的分解

The airfoil must have an axis system attached to it in order to make sense of the aerodynamic data and to properly report the forces and moment that it generates. A convention stemming from analysis and experimentation places the airfoil reference axes at the quarter-chord point, which is the point on the chord line one-fourth of the way back from the leading edge. All airfoil tables with which the author is aware use the quarter-chord point as the reference point. This text will position the airfoil reference axes at the quarter-chord point and the x axis coincident with the chord line and pointing toward the leading edge. The direction of the z axis is difficult to define without resorting to a "conventional" sense of orientation. Without belaboring the point, if the conventional orientation of an airfoil is such that lift is directed toward the top of the page when the wind attacks from beneath, then the positive z axis points toward the bottom of the page, which is the high-pressure side of the airfoil. This is illustrated in Fig. 9. 3. What is most important is this. Once a reference axis has been attached to the airfoil, it must remain attached no matter what the orientation of the airfoil. If the airfoil is rotated about the y axis through some angle, then the reference axes are rotated through that angle.

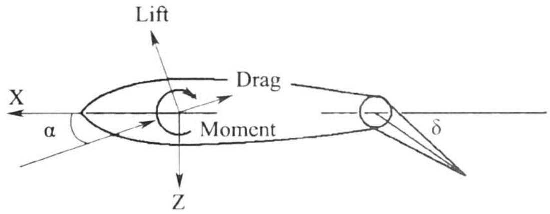

Fig. 9. 3 Airfoil section with a simple flap.

Airfoils can be of constant shape, or they can have various devices that extend from their surface to augment their lift. Figure 9. 3 also shows an airfoil with a simple flap. A positive flap deflection lowers the flap and increases the lift. A penalty in drag and pitching moment is the price. Flaps come in many flavors. Slats that extend from the leading edge also have several variations. A third device called a spoiler deploys from the center of the upper surface and, as its name implies, causes the lift to decrease and the drag to increase dramatically.

9.3 Individual Element Reference Axes, Individual Element Local Axes Orientation—Airfoils

Figure 9. 4 shows an airfoil with individual element reference axes (IERA) and individual element local axes (IELA). The x axis of the IERA is coincident with the chord line, the origin lies at the quarter-chord point, and the positive direction points toward the leading edge. The y axis points into the page, and the z axis is arranged according to the right-hand rule. If the airfoil has an angle of incidence, that angle is introduced by rotating the IERA relative to the IELA. See the chapter on axis systems for a reminder of the definitions of the IERA and IELA.

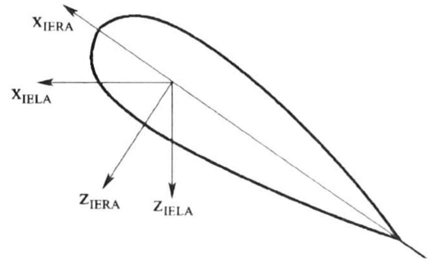

Fig. 9. 4 Airfoil with IELA, IERA attached.