INTRODUCTION TO FLIGHT VEHICLE SYSTEMS

飞行器系统概论

唐胜景 郭杰 李响 等编著

国防工业出版社
National Defense Industry Press

Introduction to Flight Vehicle Systems

飞行器系统概论

唐胜景　郭杰　李响　徐瑞　王晓芳　编著

国防工业出版社
·北京·

内 容 简 介

本书系统地介绍了飞行器系统的基本概念和基本原理，主要包括空间环境、力学环境、飞行原理、系统组成、推进系统、外形与结构、制导与控制系统、地面设备与发射方式、有效载荷等。对飞行器设计与研究的基本概念、研究方法和典型实验等也有介绍。

本书可作为高等学校有关专业教材，也可供从事飞行器设计、研究、生产的相关人员参考。

The fundamental concepts and principles of flight vehicle systems are systematically introduced in this book, which includes atmospheric environment, mechanics circumstances, flight principles, system compositions, propulsion system, aerodynamic configuration and structures, guidance and control system, ground equipment and launch modes, payloads, etc. As well, the basic concepts of flight vehicle design, research and development, research methods and typical experiments and so on are given.

The book can be used as the textbook or reference book for the related specialties in higher universities. And it can be also utilized by those who are engaged in flight vehicle design, research, manufacture and application, and so on.

图书在版编目(CIP)数据

飞行器系统概论 = Introduction to Flight Vehicle Systems：英文／唐胜景等编著. —北京：国防工业出版社，2012.1

ISBN 978-7-118-07809-1

Ⅰ.①飞… Ⅱ.①唐… Ⅲ.①飞行器－概论－英文 Ⅳ.①V47

中国版本图书馆 CIP 数据核字(2012)第 020520 号

※

国防工业出版社出版发行

（北京市海淀区紫竹院南路 23 号　邮政编码 100048）

涿中印刷厂印刷

新华书店经售

*

开本 787×1092　1/16　**印张** 20½　**字数** 470 千字

2012 年 1 月第 1 版第 1 次印刷　**印数** 1—4000 册　**定价** 45.00 元

（本书如有印装错误，我社负责调换）

国防书店：(010)88540777　　发行邮购：(010)88540776

发行传真：(010)88540755　　发行业务：(010)88540717

前言/Preface

自1903年莱特兄弟的“飞行者”首次实现人类有动力连续飞行以来，航空宇航科学与技术成为20世纪以来人类发展的卓越成效的领域之一。航空器、航天器、火箭与导弹及其它飞行器得以迅速发展。从微小型无人机到大型运输机，从火箭、导弹到运载火箭和远程洲际弹道导弹，从人造卫星到载人空间站和深空探测器等。从大气层内到大气层外飞行以及星际航行，人类远古时代的诸多飞天梦想变成了今天的现实。这让我们联想起航空宇航领域的著名科学家罗伯特·H·戈达特1904年高中毕业时的一句话：“很难说有什么是不可能的！昨天的梦想就是今天的希望和明天的现实。”如今，我们更应牢记他的名言，展开想象的翅膀，不断开拓创新，朝着更高、更快、更远的目标迈进。

Since the Wright Brothers' Flyer realized the human continuous powered flight for the first time in 1903, aeronautical and astronautical science and technology have become one of the outstanding achievements of the humankind development field since the 20th century. Aircraft, spacecraft, rockets, missiles and other flying vehicles have been developed rapidly. Research fields range from micro UAVs to large transports, from rockets and missiles to carrier rockets and long-range intercontinental ballistic missiles, from artificial satellites to manned space stations and deep space probes, from in atmosphere to extraatmospheric flight and interstellar travel. Many humankind dreams of flight in ancient time have become a reality today. This reminds us of one word from Robert H. Goddard, a famous scientist in aerospace, said when he graduated from the high school in 1904, "It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow." Today, We, engaged in the aerospace industry, should remember his famous word, begin to unfurl our imagination wings, keep on exploring and innovating, and march towards the higher, faster and farther goals.

基于多年来在飞行器系统与设计及其相关领域研究与教学实践的总结，综合了航空宇航科学与技术领域的最新研究成果和发展动态，我们编写了本书，在内容安排上力求既注意反映本学科的基础理论、新技术和新发展，又注重理论与实践的结合。

Based on the summary of research and teaching in the flight vehicle systems and design, as well related fields for years, integrated the latest research results and developments of aerospace science and technology at home and abroad, authors have made the English version of *Introduction to Flight Vehicle Systems*. And the authors strive not only to reflect the fundamental theory, new technologies and development, but also focus on the combination theory with practice in the organization of this book.

本书内容以导弹为主，兼顾飞机与航天器，强化飞行器系统概念，从飞行器系统的角度组织教材的内容结构，并贯穿于本书的各个章节。其次，系统地介绍了飞行器的基本原理，突出基本概念、原理和方法。第三，关注国内外前沿发展动态，内容涵盖有关航空宇航科学与技术发展的新概念和新技术，如高超声速飞行器研究进展、多学科优化设计理念等。

The main characteristics of the book are as follows. Firstly, the main content of this book is about missiles, in addition to airplanes and space vehicles. As well the system of flight vehicles is emphasized. It is or-

ganized from the perspective of flight vehicle system and the system concept is throughout all the chapters. Secondly, the fundamental principles of flight vehicle motion are introduced systematically in this book, the essential concepts, principles and methods are highly emphasized. Finally, the trends and developing state of the discipline at home and aboard are also focused on, including the new concepts and technologies with regard to the development of aerospace technology, such as the research progress of hypersonic vehicles, concept of multidisciplinary design optimization.

本书可为航空航天类专业的本科生、研究生及相关人员学习飞行器系统基本概念、基本原理、理解飞行奠定基础;并有助于航空航天类专业双语教学的开展;同时可供航空航天技术爱好者、专业领域的科技人员作为参考。

This book is suitable for aeronautical and astronautical undergraduates, graduates and relevant personnel to study fundamental concepts and principles of flight vehicle systems, and understand the flight. This book is also beneficial to bilingual teaching of the aeronautical and astronautical science and technology. It can be used as the reference book for enthusiasts, professional scientists and technicians in such field.

全书由唐胜景主编,唐胜景、郭杰、李响、徐瑞、王晓芳共同完成。由于专业知识所限,书中一定存在不足之处,恳请读者批评指正。本书完成过程中,部分研究生做出了贡献。对此,我们表示诚挚的谢意。本书编写时参阅了大量国内外相关文献,对于作者们的辛勤劳动,我们深表感谢。

Tang Shengjing acts as the editor-in-chief of the book which is compiled by Tang Shengjing, Guo Jie, Li Xiang, Xu Rui, Wang Xiaofang together. Due to our limited professional knowledge, there must exist some shortcomings in the book. It is very pleased for us to receive readers' comments and corrections. During the whole process to finish this book, some graduate students have contributed their efforts for it. The authors would express sincere thanks for their work. Meanwhile, we have referred to a large number of relevant literatures and monographs in the process of completing this book. The authors would like to express the thanks to the authors whose name are listed and not listed in the references for their hard work.

本书出版得到了北京理工大学教务处和国防工业出版社的大力支持,在此我们表示衷心感谢!

The publication of this book has been supported by the Office of Undergraduate Education, Beijing Institute of Technology and the National Defense Industry Press. We would express our sincere thanks to them!

编著者

The authors

Contents

Chapter 1 Brief introduction to flight vehicles

1.1 Basic concepts

Generally speaking, two terms are often mentioned in aerospace field, which are aeronautics and astronautics. The brief expressions are as follows.

Aeronautics, usually called aviation, means the research, design, development and production of flight vehicles flying in the aerosphere. While this term originally referred solely to the science of operating the aircraft, it has since been expanded to include technology, business and other aspects related to aircraft.

Astronautics implies the research, development, design and construction of space vehicles which fly into the space. Astronautics is the branch of engineering that deals with machines designed to work outside of earth's atmosphere, whether manned or unmanned or not. In other words, it is the science and technology of space flight.

However, a spacecraft has to fly across the aerosphere when it is launched or returned. Particularly, for a space shuttle, though its main activities occur out of the aerospace, the courses of takeoff and landing are similar to a plane's. So it is accompanied with the characteristics of aviation and spaceflight. It is difficult to clearly distinguish the aeronautics and astronautics on technology, and the aerospace not only means how to develop the aerospace vehicles, but also contains the technology which is involved during the activities.

Just as we know, aerospace science is the high technology. As well it is the development symbol of science and technology in a country. That is to say, it is the synthesized technology, including many fields such as mechanical engineering, material science, electronic science, control system and so on. The development of flight vehicles will bring about the development and applications in different fields, such as military, civil, scientific research etc. In 21st century, man will have more activities to explore space and utilize space resources.

1.2 Overview of flight vehicles

Generally, some machines that fly near the earth or among the planets are called flight vehicles. It is a usual term. In the 20th century, the development of flight vehicles was one of the most effective activities and the great achievements of the humankind.

Generally speaking, flight vehicles can be divided into three categories, as shown in Figure 1.1. The first is air vehicles or aircrafts which fly in the air. The second is called

spacecrafts or space vehicles which fly in the space. And rockets and missiles belong to the third type, they can fly both in the air and space. The following begins with rockets and missiles.

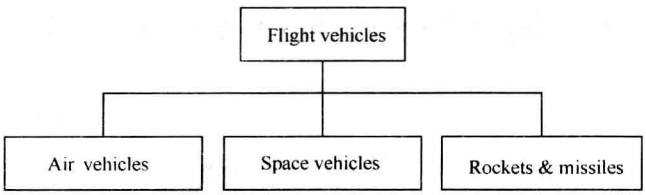

Figure 1.1 Classification of flight vehicles

1.2.1 Rockets

Rocket is the flight vehicle whose propulsion is supplied by the rocket engine. The rocket engine with propellant does not depend on the air or other actuating mediums to produce thrust. The rocket engine works by action and reaction and it pushes rocket forward simply by throwing their exhaust backward extremely fast.

The basic compositions of a rocket include propulsion system, payloads and body of the rocket. Propulsion system is the power supply of the rocket. The body loads all the components of the rocket together. Payloads are the main objects carried by the rocket. Payloads of the armament rocket are the warheads, while those of the carrier rocket are a variety of space vehicles. Different kinds of instruments are the payloads of rocket for scientific research.

Some main parts of compositions are same for rockets and missiles. Actually, there are relatively large differences between them. Rockets always have no guidance system, especially in early times, no controlled rockets existed. By means of guidance and control system, the missile can hit the targets with high precision. They have been developed since the World War Ⅱ on the basis of rockets.

Sometimes, the terms of rockets and missiles are confused. For example, in Russia, the concepts are same for rockets and missiles. Russian strategically rocket army is in fact strategic missile army. While in the United States, they are different concepts for missiles and rockets. At the same time, with the development of aerospace technologies, the difference between rockets and missiles are getting smaller. For example, some rockets have simplified guidance and control system.

1.2.1.1 Classification

Rocket can be divided into chemical rocket, nuclear rocket and electrical rocket according to the different supplied power for engines. Considering the applications, which involve fireworks, weaponry, ejection seats, launch vehicles for artificial satellites, human spaceflight and space exploration etc, rocket also can be divided into weaponry rocket, space sounding rocket and carrier rocket.

1) Weaponry rocket

The weaponry rockets are used as weapons, the aim of which is to cause damage or harm

(either physical or mental) to living beings, artificial structures or systems. Additionally, weaponry rocket can also be called armament rocket. Rockets for military and recreational uses date back to at least 13th century in China.

As mentioned above, a weaponry rocket is a self propelled, unguided weapon system powered by a rocket engine. However, the distinction can become somewhat blurred, especially where a weapon begins as an unguided rocket and is then fitted with a guidance system. For example, some types of rocket are developed with terminal guidance and are still called rockets instead of missiles. Moreover, the GMLRS (Guided Multiple Launch Rocket System) is still referred to as rocket artillery, despite employing guided munitions. Rocket artillery is a type of artillery equipped with rocket launchers instead of conventional guns or mortars.

The weaponry rockets' payloads, which are multifarious warheads such as blast warhead, fragmenting warhead, shaped-charge warhead, chemical warhead etc, are the symbolic dissimilarity comparing with other rocket classifications. Figure 1.2 and Figure 1.3 respectively show the uncontrolled rocket and the MLRS (Multiple Launch Rocket System).

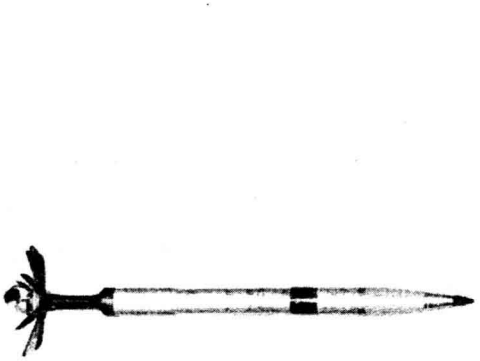

Figure 1.2 Uncontrolled rocket

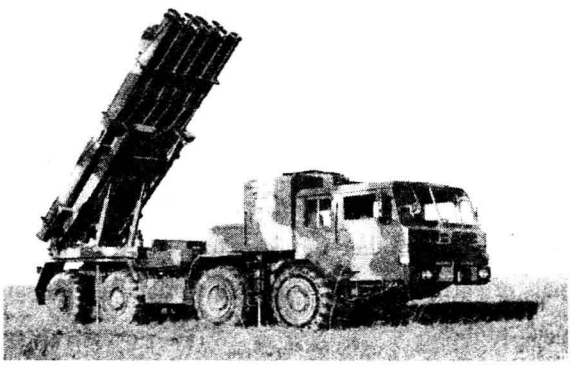

Figure 1.3 Rocket bomb launcher

2) Space sounding rocket

A sounding rocket, sometimes called a research rocket, is an instrument-carrying rocket designed to take measurements and perform scientific experiments during its sub-orbital flight. Sounding rockets take their name from the nautical term "to sound" which means to take measurements of the water's depth by a weight line. Sounding in the rocket context is equivalent to taking a measurement.

A common sounding rocket is basically divided into two parts: a solid fueled rocket motor and the payload. The payload is the section which carries the instruments to conduct the experiment and send the data back to Earth.

The sounding rockets are used to carry instruments from 50km to 1,500km above the surface of the Earth, the altitude generally between weather balloons and satellites. The average flight time is less than 30min, usually between 5min to 20min. Sounding rockets are commonly used to research the aeronomy, ultraviolet and X-ray astronomy, and the microgravity. Sounding rockets are low cost and the payload can be developed as quickly as six months. These

rockets allow scientists to conduct investigations at specified times and altitudes. The experiments provide a variety of information on the upper atmosphere, the Sun, stars, galaxies and other planets. Figure 1.4 shows a typical mission profile of the sounding rocket.

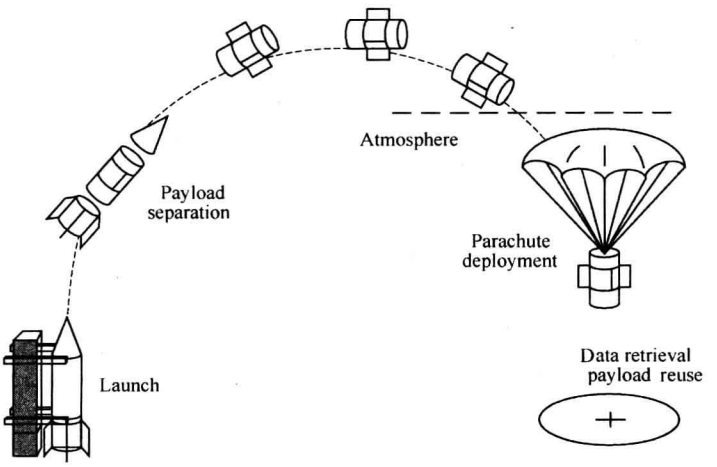

Figure 1.4 Typical mission profile of a sounding rocket

3) Carrier rocket

A carrier rocket (or called launch vehicle) is a rocket used to carry a payload from the Earth's surface into outer space. A carrier rocket system includes the launch vehicle, the launch pad and other infrastructure. Carrier rocket has evolved from the missile and the payloads of carrier rockets usually include artificial satellite, manned spaceship, space station and space probe.

As expendable launch vehicles, carrier rockets are designed for one-time use. They usually separate from their payload, and may break up during atmospheric reentry. Reusable launch vehicles, on the other hand, are designed to be recovered intact and used again for subsequent launches. For orbital spaceflights, the space shuttle is currently the only launch vehicle with components which have been used for multiple flights. Non-rocket spacelaunch alternatives are at the planning stage.

Carrier rockets are often characterized by the amount of mass they can lift into orbit. For example, a Proton rocket has a launch capacity of 22000kg into low earth orbit. Carrier rockets are also characterized by the number of stages they employ. Rockets with as many as five stages have been successfully launched, and there have been designs for several single-stage-to-orbit vehicles. Additionally, launch vehicles are very often supplied with boosters, which supply high thrust early on in the flight, and normally in parallel with other engines on the vehicle. Boosters allow the remaining engines to be smaller, which reduces the burnout mass of later stages, and thus allows for larger payloads.

The primary carrier rocket families in the world include Titan series, Delta series, Vostok series, Proton series, Ariane series and Long March series.

1.2.1.2 Typical rockets

1) CZ series

Long March rocket (or called Chang Zheng rocket in Chinese pinyin) is the rocket family of expendable launch systems operated by the People's Republic of China. Development and design falls under the auspices of the China Academy of Launch Vehicle Technology. In English, the rockets are abbreviated as LM- for export and CZ-within China, as "Long March" means "Chang Zheng" in Chinese pinyin. The rockets are named after the Long March of Chinese communist history.

The Long March is China's primary expendable launch system family. The Shenzhou spacecrafts and Chang'e 1 lunar orbiter are also launched by the Long March rocket. The maximum payload for LEO(Low Earth Orbit) is 12000kg (CZ-3B), the maximum payload for GTO (Geostationary transfer orbit) is 5500kg (CZ-3B/E). The next generation rocket—Long March 5 variants will offer much payload in the future.

The development of Long March 2F began in 1992, which is a man-rated version of Long March 2E. Its first launch was in November 19, 1999, and accomplished a successful mission that carrying the first spacecraft of China—Shenzhou 1 into the space. This version is the safest model in the Long March 2 family, with 7 launches and no failure record.

2) Delta series

Delta is a versatile family of expendable launch systems that has provided space launch capability in the United States since 1960. There have been more than 300 Delta rockets launched, with a 95 percent success rate. Two Delta launch systems—Delta Ⅱ and Delta Ⅳ— are in active use. Delta rockets are currently manufactured and launched by the United Launch Alliance. Currently development of the Delta rocket series is focused on the Delta Ⅳ Heavy, which uses three common booster cores to lift higher masses to orbit and escape velocity.

Delta Ⅳ is an active expendable launch system in the Delta rocket family. Delta Ⅳ uses rockets designed by Boeing's Integrated Defense Systems division and built in the United Launch Alliance (ULA) facility in Decatur, Alabama. Final assembly is completed at the launch site by ULA. The rockets were designed to launch payloads into orbit for the United States Air Force Evolved Expendable Launch Vehicle (EELV) program and commercial satellite business. Delta Ⅳ rockets are available in five versions which are tailored to suit specific payload size and weight ranges. Delta Ⅳ was primarily designed to satisfy the needs of the U. S. military.

3) Vostok series

Vostok (Russian word, translated as "East"), of which the total number of launched rockets are the most in the world, was a family of rockets designed for the human spaceflight programme. This famous family of rockets launched the first artificial satellite ("Sputnik"), the first Venus probe, the first Mars probe, the first unmanned expendable freighter spacecraft, and the first manned spacecraft in human history. It was a subset of the R-7 family of rockets. The Soyuz rocket family is the subset of the Vostok rocket family, mainly charged in launching the Soyuz manned spacecraft and the progress resupply spacecraft.

The Vostok rockets have two basic launching configurations, lunar exploration and manned spaceflight, varying in length, take-off weight and payload weight etc. The Vostok rocket's most important achievement may be that on April 12, 1961, Vostok 1 spacecraft was successfully launched by Vostok rocket, which made Yuri Alekseyevich Gagarin the first human being to flight into outer space.

4) Ariane series

Ariane is a series of a European civilian expendable launch vehicles developed by European Space Agency (ESA) for space launching. The name comes from the French spelling of the mythological character Ariadne; the word is also used in French to describe some types of hummingbird. The several versions of the launcher include Ariane 1-Ariane 5. Ariane 4 and Ariane 5 are in active service. The maximum payloads of them for LEO are from 9.4t to 25t, while for GTO are from 4.2t to 7.5t. The maximum payload of the recent version of Ariane 5 for GTO has supposedly increased to 13t-15t.

Ariane 5 has been refined since the first launch in successive versions, "G", "G +", "GS", "ECA", and most recently, "ES". By mid 2007, Arianespace (a commercial subsidiary handling the Ariane's production, operations and marketing) has ordered a total of 99 Ariane 5 launchers from Astrium. The first batch ordered in 1995 consisted of 14 launchers, while the second batch ordered in 1999 consisted of 20 launchers. A third batch consisting of 25 ECA and 5 ES launchers was ordered in 2004. The latest batch ordered in mid 2007, consist of another 35 ECA launchers. Through these orders, the Ariane 5 will serve at least through 2015.

1.2.2 Missiles

Usually, a missile contains a warhead, pushed by its own propulsion system and guided by the guidance and control system, which is used to attack the target.

1.2.2.1 Classifications

To define the missile categories, there are different methods as follows.

1) Surface & air combination missiles

The Category of missile is defined according to the launching and attacking instances. In fact, the positions of the missiles and targets are determined on the surface or in the air. Then, the combinations of the surface and air are made. Surface means on the ground, ship, seashore and submarine. And the air is simple.

According to Figure 1.5, four types of missiles can be divided into, surface to surface, air to air, surface to air and air to surface.

2) Strategic & tactical missiles

Furthermore, it can be divided into strategic and tactical missiles.

The strategic missiles mean that the missiles would attack strategic targets including important bases, such as nuclear weapon bases, key communications equipment, headquarters, military airports and so on.

The tactical missiles indicate that the missiles would attack some objective targets, such