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北京航空航天大学“空间技术应用”系列丛书

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导弹制导原理

Jiang Jiahe

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Abstract

The intent of this book is to present guidance and control principle of tactical missiles. It includes basic concepts of guided missile, fundamental concepts of vehicle dynamics, dynamical equations and kinematic equations of vehicle, longitudinal state equation and transfer functions, lateral state equation and transfer functions, fundamental principle of missile guidance and control system, guidance laws, autopilot design, command guidance systems, homing guidance systems, and guidance and control system hardware-in-the-loop simulation.

This book is suitable for international postgraduate and advanced undergraduates majoring in navigation, guidance and control, and also suitable for engineering and technical personnel engaged in the design and development of guided missiles.

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Preface

The intent of this book is to present guidance and control principle of tactical missiles. The book describes onboard control and guidance devices and off-board guidance devices, and moreover, discusses the analysis and design about the system. This book consists of eleven chapters. Chapter 1 introduces basic concepts of guided missile. Chapter 2 presents the fundamental concepts of vehicle dynamics. The forces and moments acting on the vehicle are also presented. Chapter 3 discusses vehicle dynamical equations and kinematic equations. Based on small-disturbance theory, Chapter 4 discusses vehicle longitudinal state equations and transfer functions. Chapter 5 deals with lateral state equations and transfer functions. Chapter 6 presents fundamental principle of missile guidance and control system. Chapter 7 focuses on guidance laws. Autopilot design is discussed in Chapter 8. Chapter 9 is devoted to command guidance systems. Chapter 10 focuses on homing guidance system. Chapter 11 summarizes guidance and control system hardware-in-the-loop simulation.

To help readers understand the concepts presented in the text, a number of worked-out examples are given throughout the book. MATLAB source code listings about these examples are also presented in the text. The examples demonstrate ideas in analysis, computer-aided design, simulation, and numerical algorithms. The examples, which are easily reproducible, offer reference for students to study or for engineers to perform engineering design. This book differs from similar books on the subject in that it presents a detailed account of vehicle aerodynamics, vehicle mathematical models, flight control, and guidance devices (mainly including radar guidance devices and infrared devices). The book maintains certain essential contents about guidance theory. Further more, it discusses guidance techniques from engineering application view. Guidance devices and guidance methods directly or indirectly come from actual missile types. Hardware-in-the-loop simulation is a vital phase in development process for guided missiles. This technique is described in the book as well.

This book is intended as a textbook for the guidance principle course for international postgraduates, and will be of benefit to advanced undergraduates majoring in navigation, guidance and control as well. The book offers very useful help to engineers engaged in the design and development of guided missiles.

I would like to take the opportunity to thank many people who contributed in some way to the contents and publication of this book. First of all, I would like to express my appreciation to Dr. Zhao Haiyuan for her support. Next, I would like to thank Professor Li Chunjin who reviewed the manuscript and made many helpful, constructive suggestions. In addition, I would like to thank my student, Miss Guo Yanlin, who checked the manuscript. Finally, I would like to express my gratitude to the editorial and production staff of Beihang University Press for their hard work in the publication of this book.

To this end, all criticism and suggestions for future improvement of the book are welcomed.

Jiang Jiahe
November, 2011

Contents

CHAPTER 1
Introduction to Missile Guidance

1.1 Development History of Rockets and Missiles

The primitive rocket was a great creation of Chinese ancient laboring people. As early as the beginning years (about A. D. 682) of Tang dynasty of China, the writings of alchemists recorded recipes about the powder and at the time the powder was invented. Until Song dynasty (about A. D. 1000) the rockets made of the powder appeared, and were used to resist invaders. This rocket consisted of an arrowhead, an arrow body, an arrow tail, and its powered device, which was a section of bamboo full of the powder and tied on the arrow body. See Figure 1.1 - 1. Although the primitive rocket is not as complicated as modern rocket, it is an embryo of modern rocket with a warhead (corresponding to an arrowhead), a propulsive system (corresponding to a bamboo full of powder), a rocket airframe (corresponding to an arrow body), and a stabilizing system (corresponding to feather). After the black powder was ignited, the arrow is shot from a bow. Obviously, the rocket could increase the range and speed of the arrow. The weapon had been used in wars until Ming dynasty about 360 years ago. In the thirteenth century, the powder, rockets, and flames invented by Chinese people were introduced into Arabia. Later, they were transferred from Arabia to Europe.

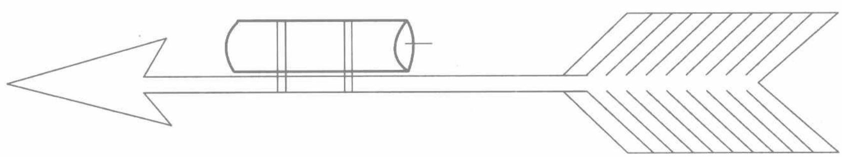

Figure 1.1 - 1 Chinese ancient rocket

After the rockets were introduced to Europe, they were developed to the rocket projectiles in the end of the eighteenth century. After the rocket techniques underwent tortuous road in the nineteenth century due to the invention of the artillery, the rocket weapon went into rapidly developing period during World War Ⅱ. On October 3, 1942, Germany successfully launched V—2 missile. The V—2 was powered by a liquid-propellant rocket.

The V—2 was the first long-range, rocket-propelled missile to be put into combat. The V—2 was a supersonic missile, launched vertically and automatically tilted over a 41° to 47° angle a short time after launch. Furthermore V—2 had a liftoff weight of 12 873 kg (28 380 lb), developing a thrust of 27 125 kg (59 800 lb), a maximum acceleration 6. 4*g*, reaching a maximum speed of about 5 705 km/h (3 545 mph), an effective range of about 354 km (220 miles), carrying a warhead of 998 kg (2 201 lb). In addition, the powered flight lasted 70 s, reaching a speed of about 1 828. 8 m/s(6 000 ft/s) at burnout, with a burnout angle 45° measured from horizontal. No control was exerted after the propelling motor was shut off. Subsequently, the V—2 continued on a free-fall (ballistic) trajectory.

At that time, Germany developed aerodynamic missile V—1. The V—1, the forerunner of modern cruise missiles, was a small, midwing, pilotless monoplane, lacking ailerons but using conventional airframe and tail construction, having an overall length of 7. 9 m (25. 9 ft) and a wingspan of 5. 3 m (17. 3 ft). It weighed 2 180 kg (4 806 lb), including gasoline fuel and 850 kg (1 874 lb) warhead. Powered by a pulsejet engine and launched from inclined ramp 45. 72 m (150 ft) long and 4. 88 m above the ground at the highest end, the V—1 flew a preset distance, and then switched on a release system, which deflected the elevators, diving the missile straight into the ground. The engine was capable of propelling the V—1 up to 724 km/h(450 mph). A speed of 322 km/h had to be reached before the V—1 propulsion unit could maintain the missile in flight. The range of the V—1 was 370 km (230 miles). Guidance was accomplished by an autopilot along a preset path. Specifically, the plane's (or missile's) course stabilization was maintained by a magnetically controlled gyroscope that directed a tail rudder. When the predetermined distance was reached, as mentioned above, a servomechanism depressed the elevators, sending the plane into a steep dive. The V—1 was not accurate, and it was susceptible to destruction by antiaircraft fire and aircraft.

At the end of the war, the United States and the USSR captured a number of V—2s, parts and staff. On the basis of V—2 and V—1, their guided weapons got rapid development, various missile weapons came out one after another, and a complete missile system was formed.

1.2 Categories of Guided Missiles

A guided missile is defined as an unmanned vehicle which contains the warhead, is driven by its own propulsion, depends on the guidance system to guide its flight path, and ultimately hit a target. Missile-borne engines are all jet engines which include rocket engines (solid rocket engines and liquid rocket engines), aerojet engines (turbojet engines and ramjet engines), and composite engines (solid-liquid composite engines, rocket-ramjet composite engines). Generally, a missile includes the following parts: ① a propulsion system, ② a warhead section, ③ a guidance system, and ④ an airframe. According to incomplete statistics, up to now, the types of missiles have reached more than 600 types. 200 types of them have released from military service. 400 types of them are on active service. Missiles are important weapons in modern wars. Almost all of military forces are equipped with missiles. For convenience of analysis and research, it is necessary to classify missiles. Customarily, according to the physical area of launching missile and the physical area of the target, missiles are divided into four categories: ① surface-to-surface missiles——SSM, ②surface-to-air missiles——SAM, ③ air-to-surface missiles——ASM, and ④ air-to-air missiles——AAM. We further make division as shown in Figure 1.2-1.

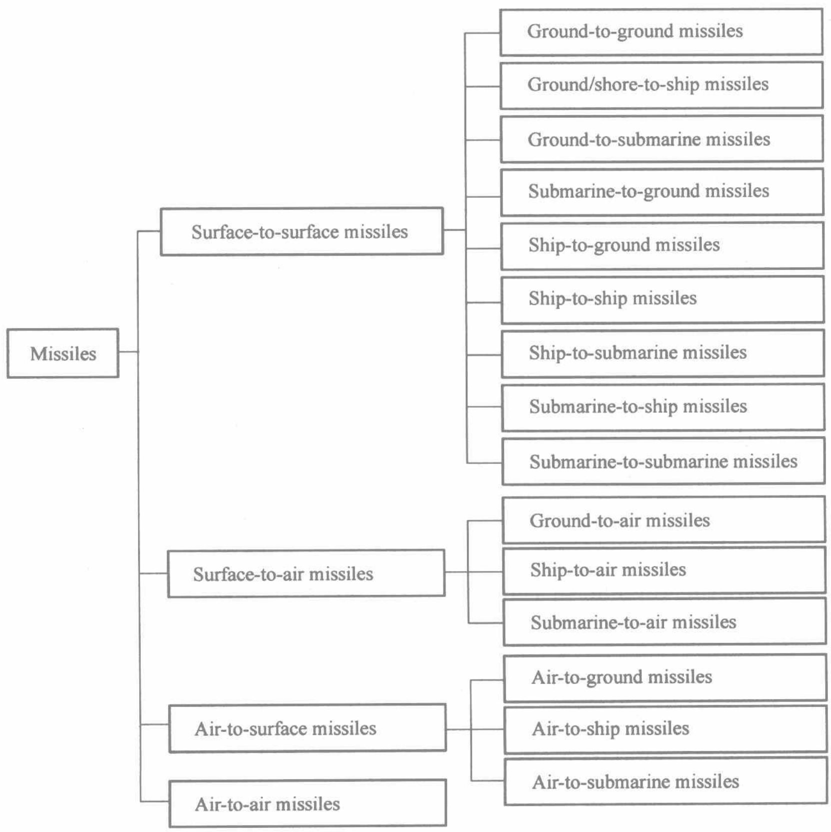

Figure 1.2-1 Categories of missiles

In addition, there are other classifications. For example, in view of fighting missions, missiles include strategic, operational, and tactical missiles. As to ranges, there are short-range missiles, medium-range missiles, intermediate-long range missiles, long-range missiles, and intercontinental missiles. In respect of warhead, missiles are divided into three categories: ①nuclear missiles, ②conventional missiles, and ③special missiles.

1.3 Missile Guidance Systems

A missile guidance system is defined as a group of components by which the missile is directed and controlled to fly toward a target. That is, a guidance system is composed of a directing subsystem and a controlling subsystem. The function of the directing subsystem is to measure the missile-target relative position, make manipulation, and then form control (i. e. guidance) commands. The function of the controlling subsystem is to execute the control commands from the directing subsystem, and hold stable flight as required. Normally the missile guidance system includes sensing, computing, stabilizing and servo-control components.

In general, a guidance process is divided into three phases: ① boost or launch, ②midcourse, and ③terminal. For example, a surface-to-air missile is launched by a booster, which is an auxiliary propulsion system. The boost phase lasts from the time the missile leaves the launcher until the booster separates from the missile. Generally, during this phase a missile may employ self-contained guidance, such as programmed guidance and INS (inertial navigation system). The characteristics of a missile vary radically before and after booster separation. The midcourse phase, when it has a distinct existence, is usually the longest in terms of both distance and time. During this phase, a missile is guided to desired course until it enters a required area (in parametric space) from which terminal guidance can successfully take over. During the midcourse phase, a missile may employ command guidance, GPS (global positioning system), or INS (inertial navigation system). The terminal phase lasts from the end of the midcourse phase to impact with a target. During this phase, command guidance or homing guidance may be employed.

According to the source of intelligence, guidance systems include self-contained guidance, non-self-contained guidance, and combined guidance systems.

In the self-contained guidance system, the generation of guidance commands does not depend on information of target and interference of external system, but rely on missile-borne instruments to measure flight data of missile and then determine flight path. For example, inertial navigation system is a typical self-contained guidance system. In inertial navigation system (INS), navigational data come from self-contained sensors (i. e., gyroscopes and accelerometers), which include a vertical accelerometer, two horizontal accelerometers, and three single-degree-of-freedom gyroscopes (or 2 two-degree-of-freedom gyroscopes). The inertial navigation system depends on integration of acceleration to obtain velocity and position. The accelerometers are mounted in gyro-stabilized inertial platform, which is used as reference. After being supplied with initial position information, the INS is capable of continuously update accurate parameters about position, ground speed, attitude, and heading. A strapdown INS employs mathematical platform instead of mechanic platform. In this way the gimbal structure is eliminated. Sensors are directly mounted on the vehicle. In strapdown INS, the transformation from the sensor to inertial reference is "computed" rather than mechanized.

In INS (including strapdown INS), since the navigation data comes from itself, the INS is insusceptible to external environment, and provides reliable all-weather navigation data. The INS is applied to ballistic and cruise missile. Other types of missiles use it for launching phase and midcourse phase.

Remote control guidance and homing guidance belong to non-self-contained guidance. The remote control guidance includes beam-riding guidance and command guidance.

Figure 1.3-1 shows an example of a beam-riding guidance system. Referring to Figure 1.3-1, there are four components: ① a tracking and guiding radar, ② a launcher, ③ a missile, and ④ a target.

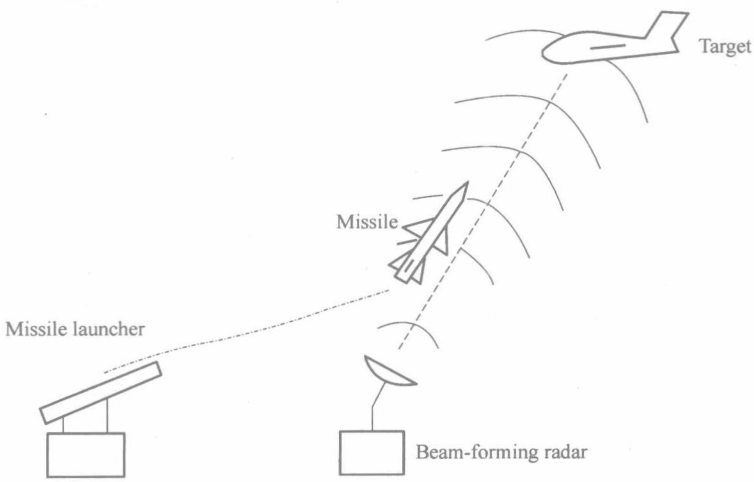

Figure 1.3-1 Beam-riding system