什么是制导

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目录

1 什么是制导

官方定义：

Guidance is about the determination of the maneuvering commands to steer the vehicle to fly a trajectory that satisfies the specified terminal/targeting condition as well as other pertinent constraints, and, if required, optimizes a defined performance.

制导是指，确定**机动命令**以引导飞行器在飞行时满足**指定终端/目标条件以及其他相关约束**的轨迹，并在需要时优化定义的性能。

Journal of Guidance, Control, and Dynamics

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What Is Guidance?

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THE first word in the title of JGCD defining the scope of this journal is "Guidance", as well as the first word of the aerospace field of Guidance, Navigation, and Control (GN&C). Still, what is guidance? From my 26-year experience as an editor of the JGCD in evaluating numerous manuscripts, I can say with certainty that this is a question which many cannot answer in a succinct and precise manner. Worse, there is considerable confusion and misconception when the term "guidance" is used. Too often "guidance" and "control" are used interchangeably and incorrectly. While such problems are more common in papers written by graduate students (but with senior co-author(s)), even experienced aerospace professionals and university faculty in the GN&C field can stumble in using the correct terminology to describe their work in guidance and control.

Guidance as a technical area in aerospace engineering is a relatively young entry. Even though guided rockets existed since the late phase of World War II and missile guidance received a good deal of attention in the 1950s, guidance really became a recognized stand-alone technical specialty because of the Apollo program (see Battin, R. H., "Space Guidance Evolution — A Personal Narrative," *Journal of Guidance and Control*, Vol. 5, No. 2, 1982). Some of the terms used in the early days may have contributed to the confusion on guidance, navigation, and control. For example, "proportional navigation" is really a form of guidance, and "control guidance" in the earlier literature on missiles refers to a class of guidance approaches. Similarly, the frequently used term "trajectory control" actually means a guidance function. I can recall my own struggle as a graduate student in trying to understand clearly what guidance was about. The confusing terms in the literature certainly did not help make it any easier.

So, what is guidance? Over the past 3 years I conducted a personal survey of 10 experts who have worked extensively on aerospace guidance — their combined years of experience are close to 300. They are from NASA, industry, and academia. I asked each to give me their definition of aerospace guidance in 2–3 sentences or less. I have also looked up in technical papers, books, and reports. Not surprisingly, just like a colleague commented matter-of-factly on my little project "you may get 10 answers when you ask 5 engineers", the answers are quite divergent. With their permissions, I list in the following some of the answers I have received (in no particular order) and some of the definitions I have found from other sources:

> "Guidance in the aerospace context is the means by which a flight vehicle determines its needed changes in flight path to achieve vehicle mission objectives."

> "The role of guidance is the determination of the vehicle-generated acceleration (magnitude and/or direction) history, and the instantaneous command in particular (for output to controls), to achieve a set of translation-maneuver targets subject to a set of (translation-maneuver) constraints."

> "(Guidance is) The process of determining a desired trajectory of an object and the change in object force vectors required to achieve it."

> "A guidance system determines an aerospace vehicle's trajectory-control commands so that it follows a path from its current state to a target state, where "state" is defined by position and velocity coordinates."

> "Guidance is responsible for determining the desired vehicle attitude and propulsion system commands such that mission objectives are accomplished, while maintaining flight path and mission constraints."

> "Guidance starts with the current position and velocity and determines the desired attitude (and sometimes throttle) for best getting to the target condition".

> "Guidance selects the maneuvering sequence to get from the instantaneous state to a required state" (Haeussermann, W., "Development in the Field of Automatic Guidance and Control of Rockets," *Journal of Guidance and Control*, Vol. 4, No. 3, 1981.)

> "Guidance is the process of calculating the changes in position, velocity, attitude, and/or rotation rates of a moving object required to follow a certain trajectory and/or attitude profile based on information about the object's state of motion." (Wikipedia, https://en.wikipedia.org/wiki/Guidance_system).

Each of the above definitions leaves something to be desired. The definition from Wikipedia is, not surprisingly, the least accurate one. It is clear that individual engineer's personal experience influences, and in some cases limits the scope of, the definition they offered. A good definition should capture the generic essence of guidance but not be tied to a particular class of problems and the specific form of guidance used in these problems, and encompass the key elements in guidance. Here is my attempt to define modern aerospace guidance:

Guidance is about the determination of the maneuvering commands to steer the vehicle to fly a trajectory that satisfies the specified terminal/targeting condition as well as other pertinent constraints, and, if required, optimizes a defined performance.

A major distinction in this definition from the preceding ones is to accentuate the presence of optimal guidance which is becoming an increasingly prominent feature of aerospace guidance. Some additional elaboration is in order.

1) The generation of guidance commands is necessarily carried out onboard and in real time. Hence compound terms such as "onboard guidance", "online guidance", and "real-time guidance" are unnecessary and redundant.

2) In the vast majority of aerospace applications, guidance commands are determined on the basis of the actual current trajectory state, thus guidance is *closed loop* in nature. There are some notable exceptions though. For instance, the current technology in endo-atmospheric ascent guidance for launch vehicles still uses pre-programmed command sequences (albeit updated right before launch), essentially rendering it open-loop guidance.

3) Commonly seen guidance commands include orientation and directional angles, aerodynamic angles, vectors defining the direction of the applied force or acceleration vector, the magnitude of the applied force (e. g., thrust) when it can be modulated, engine cut-off and/or ignition times, turning rates, and other flight parameters.

4) A key word in the proposed definition of guidance is "trajectory". The translational (3DOF) dynamics are commonly employed in the guidance solution process (here I purposely omit works where only kinematics are used in path planning, which generally is not advisable for aerospace applications, a topic for another time perhaps). This practice is implicitly rooted in the assumption of natural time-scale separation between the translational and rotational dynamics of aerospace vehicles where the latter are considered faster than the former. Even though the realization of the desired trajectory invariably must be through appropriate body attitude of the vehicle for pointing the applied force in the correct direction, the faster rotational dynamics are ignored in the guidance solution to reduce the complexity of the problem.

There are however exceptions to the above stated rule. There exists the literature on "6DOF guidance". Here the applied force vector

(e. g., engine thrust) not only affects the translational motion, but also generate an applied moment vector with respect to the center of gravity (CG) of the vehicle (through gimbal angles or reaction control thrusters placed at different locations of the vehicle, for instance). The direction of the applied force vector is determined (or affected) by the vehicle's body attitude which in turn depends on the applied moment vector. Through the coupled 6DOF dynamics, the desired applied force vector achieves a feasible trajectory of the CG and, when required, optimize the performance (e.g., propellant consumption). In such a case the time-scale separation assumption is no longer used, and the full 6DOF dynamics are employed. In this sense, this approach provides a higher-fidelity guidance solution at the expense of higher complexity and computational requirements.

5) Stability is usually not a requirement in guidance designs because in most cases the notion of stability is inapplicable for the guidance problem (stability, on the other hand, is the foremost design requirement for the control system)

Common guidance approaches include but are not limited to:

1) Reference based guidance. The guidance commands are generated by tracking a reference trajectory or profile of a function of the state, or nulling an estimated targeting condition error calculated by using sensitivity coefficients and current trajectory dispersions from the reference. The former is a prevalent technique used in many legacy aerospace systems (e.g., Space Shuttle entry guidance). Two representative examples of the latter are the Apollo direct entry guidance and ballistic missile guidance that determines the correct engine cut-off time.

2) Targeting condition driven guidance. This class of guidance approaches works to drive continuously the trajectory toward the specified targeting condition (but they do not rely on a reference trajectory). Among the notable applications are missile homing guidance, velocity-to-be-gained guidance for spacecraft, and Apollo lunar powered descent guidance (or the more general recently discovered family of fractional-polynomial powered descent guidance).

3) Computational guidance. Two defining characteristics of these techniques are that they are physics and model based and they leverage the dramatically increased onboard computational capability in modern aerospace vehicles. They can offer significantly enhanced adaptability and performance when compared to traditional approaches (Lu, P., "Introducing Computational Guidance and Control," *Journal of Guidance, Control, and Dynamics*, Vol. 40, No. 2, 2017). The examples are predictor-corrector entry guidance and optimal aerocapture guidance, fuel-optimal exo-atmospheric powered guidance, and fuel-optimal powered descent guidance.

In contrast, control is the process of determining the applied forces and torques or the actions of the control effectors required to maintain *stability* and achieve the specified body attitude or flight condition of the vehicle. When the applied forces and torques are the outputs of the controller, a procedure called control allocation is usually used to distribute the actions by the control effectors to produce the required forces and torques, especially when redundancy exists in the control effectors.

The output of the guidance system leads to the commanded input to the control system when executing a maneuver. The control system then actuates the control effectors to generate the required forces and torques to realize the maneuver. It is worth mentioning that there are "integrated guidance and control" designs that do not follow this classical cascade structure which still represents the prevailing G&C architecture.

It is my hope that this piece provides a clarity to the question asked in the title and clears some of the long-running confusion. Equally importantly, if this editorial can help authors describe their work more accurately in their submissions in the time to come, it would be a mission well accomplished.

Ping Lu
Editor-in-Chief

1 什么是制导

（1）**导引**飞行器从当前位置**到达目标位置**

（2）按照**既定轨迹导引**飞行器从当前位置**到达目标位置**

（3）按照**期望**的加速度（姿态/方向）**指令导引**飞行器从当前位置**到达目标位置**

（4）确定**期望**的姿态或推力，使飞行器能够按照**既定**轨迹从当前位置**到达目标位置**

1 什么是制导

制导的目的：通过给定**加速度指令**，使其满足期望的**约束条件**

加速度指令 $\xrightarrow{\text{积分}}$ 速度 $\xrightarrow{\text{积分}}$ 位置

与自身、目标运动状态相关

约束

（1）打中目标
（2）能量最省
（3）打中时间最短

传统制导律设计的基本准则——位置约束：相对位置/相对距离为零

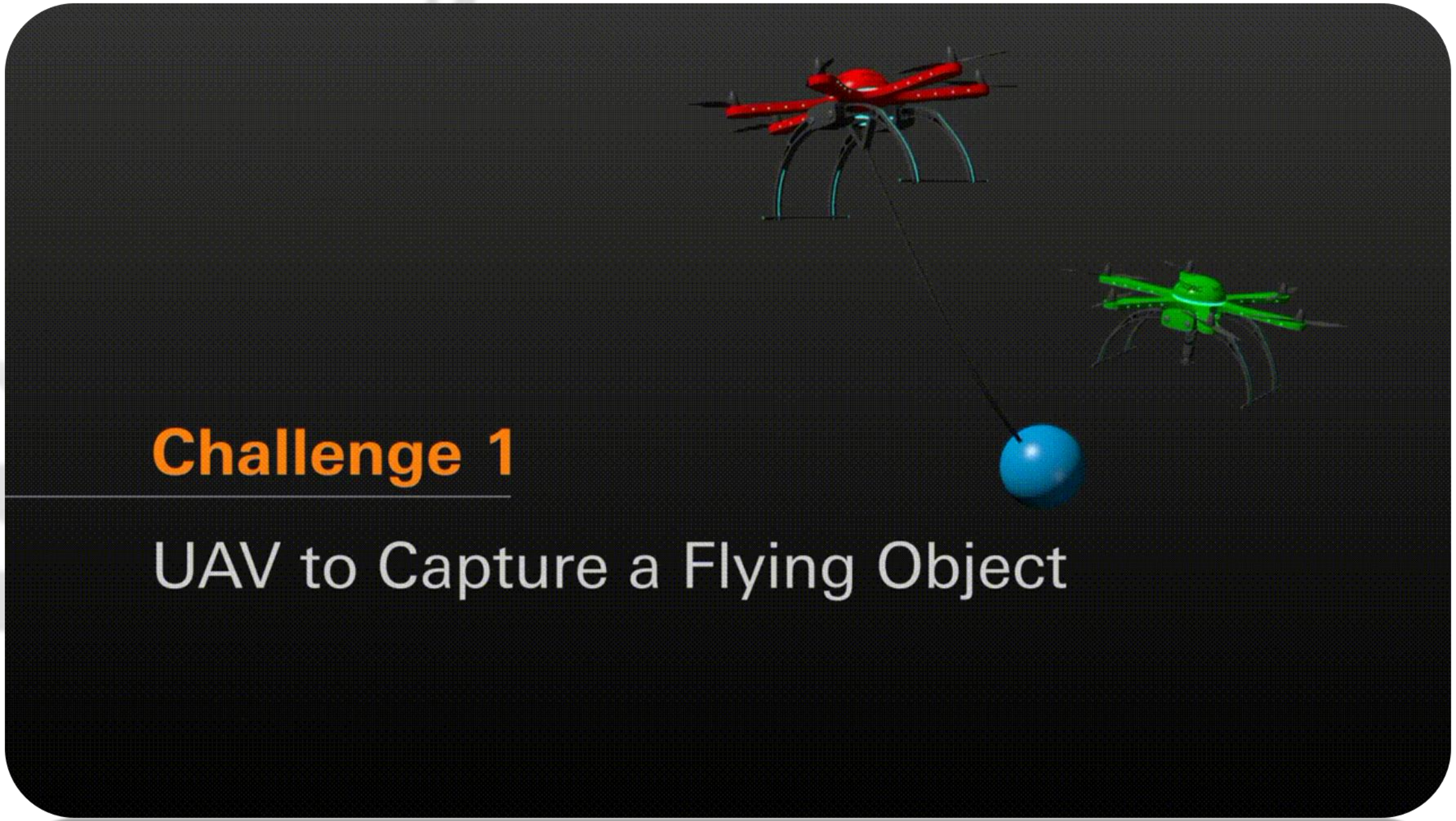
2 控制和制导的区别

制导： “我要去哪儿”

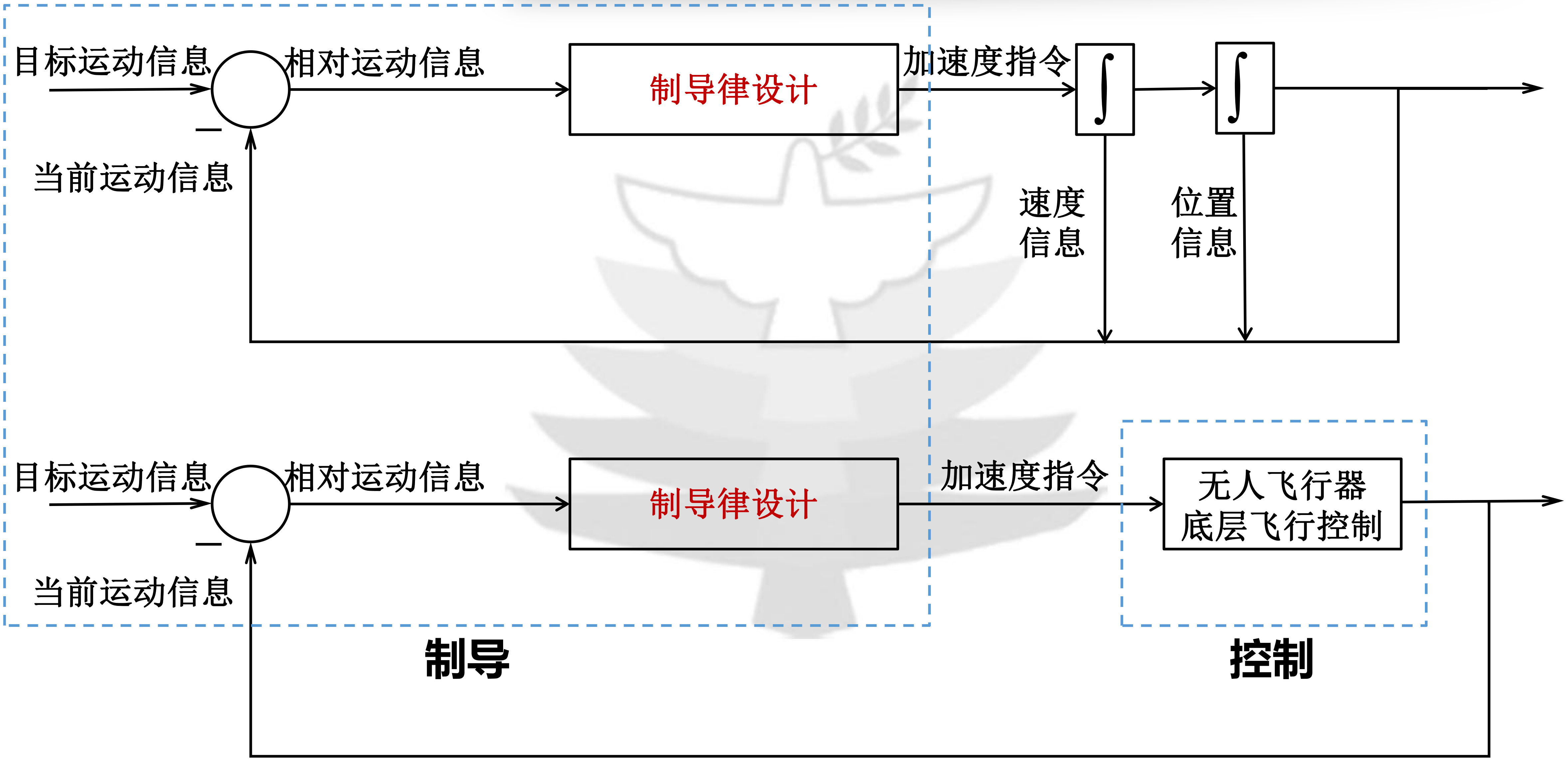
确定飞行器的机动指令，并用于生成满足指定条件或约束的飞行轨迹。

控制： “怎么去”

根据飞行指令控制飞行器按照期望的姿态飞行，解决飞行器的稳定和操纵问题。



2 控制和制导的区别


目标运动信息
相对运动信息
制导律设计
加速度指令
—
当前运动信息
速度
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位置
信息
目标运动信息
相对运动信息
制导律设计
加速度指令
无人飞行器
底层飞行控制
—
当前运动信息
制导
控制

3 制导的分类

不同阶段的制导

起飞阶段

空中飞行阶段
拦截目标

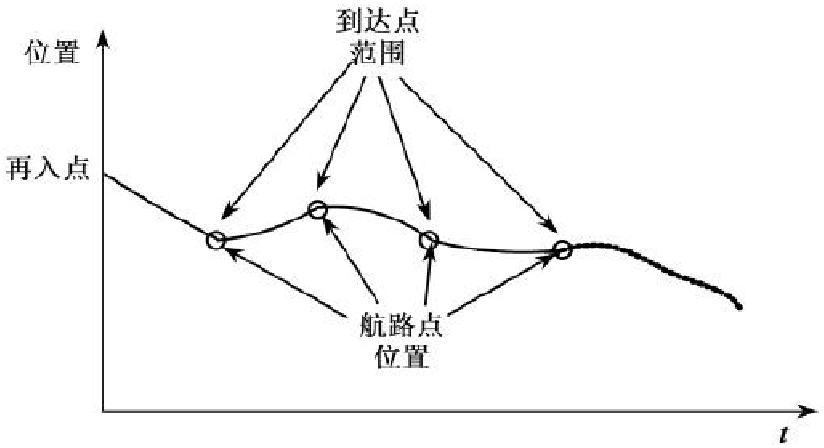
末端降落阶段

3 制导的分类

不同方式的制导

基于参考轨迹或
状态函数的制导

基于与目标相对运动的制导

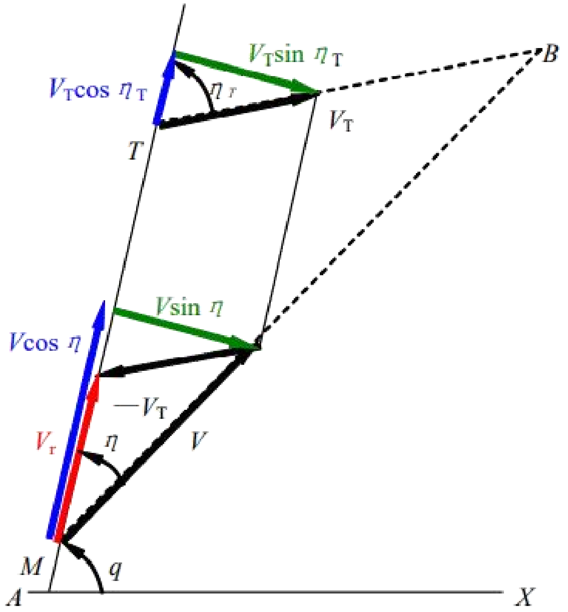


基于物理和模型的
计算制导

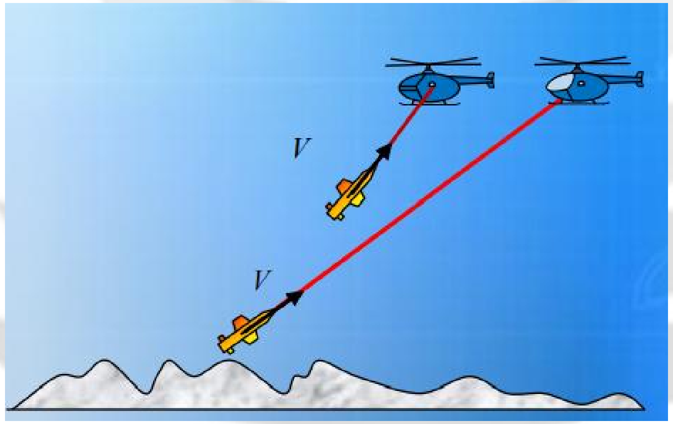
3 制导的分类

我们要学习的制导：

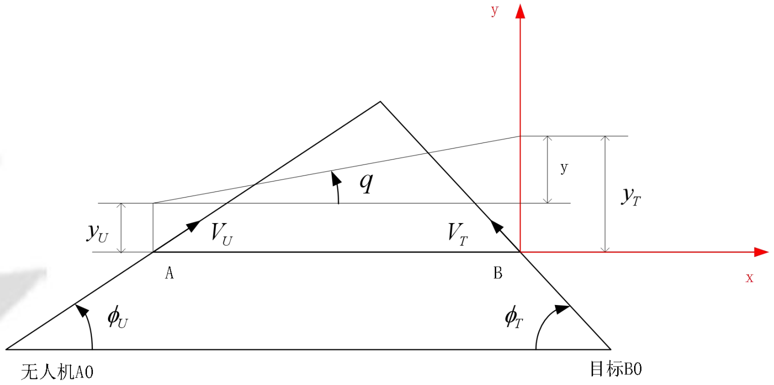
基于与目标**相对运动**的 **实时**测算的 **制导律**



平行接近法：在整个导引过程中，导弹与目标视线在空间保持平行移相对速度指向目标。



追踪法：导弹的速度矢量始终指向目标的一种导引方法。即导弹的速度矢量前置角恒为零



比例导引法：在导引过程中，导弹速度矢量的旋转角速度 与视线旋转角速度成正比

4 课程安排

- 软件：matlab（Simulink）
- 频率：一/两周一次
- 考核：课程作业（制导律仿真）

1. 认识制导控制
2. 坐标系定义与转换
3. 飞行器运动的数学模型（相关基本方程）
4. 传统制导律介绍，过载、曲率等指标介绍
5. 其他制导律介绍（角度约束、时间约束等）
6. 其他拓展内容（集群、生物围猎）

4 课程安排

飞行力学

北京理工大学　林海、唐胜景、王晓芳

建立合适的数学模型描述飞行器的运动规律，设计合适的方案弹道和导引弹道确保导弹命中目标，定性定量分析和评价飞行器的稳定性、操纵性和机动性——《飞行力学》带你完成一次从理论到方法、从原理到应用、...

612人参加　已结束

第一章　作用在飞行器上的力和力矩（上）

初等旋转矩阵与坐标系变换规则

常用坐标系之间的直接变换

逆变换与间接变换

常用坐标系的定义（上）

常用坐标系的定义（下）

常用坐标系之间的关系

坐标系转换的常用方法

第二章　飞行器运动的数学模型

导弹作为变质量系的动力学基本方程

导弹动力学方程

导弹运动学方程

质量变化和几何关系方程

控制关系方程

导弹的纵向运动与侧向运动

导弹的平面运动

导弹的质心运动

飞行器的机动性和过载

第四章 导引弹道的运动学分析（上）

导引弹道概述

相对运动方程组

追踪法（上）

追踪法（下）

第四章 导引弹道的运动学分析（下）

平行接近法

比例导引法（上）

比例导引法（下）

谢谢观看

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