

Keywords. Command guidance, Homing guidance, LOS angle, Closing velocity, Miss-distance, Time-to-go, Blind zone

5.4 GUIDANCE PHASES DURING MISSILE FLIGHT

The basic difference between an unguided projectile and a guided missile is the generation of guidance commands which attempts to change the missile's flight direction. This guidance command is in the form of a lateral acceleration command which the autopilot translates into the amount of lift necessary to produce the desired turn rate (or maneuver). Parts of the missile trajectory for SAMs and AAMs can be classified into several "guidance phases" based either on their function or on the mode of guidance employed. For example, in an air-to-air missile the first part of the trajectory is called a programmed maneuver phase, which is independent of the target information and is executed solely to ensure that the missile is clear of the launch aircraft. At the completion of this maneuver, midcourse guidance phase is initiated. The function of the midcourse guidance is to place the missile within the terminal acquisition range of the target with the missile seeker pointed at the target. The last few seconds of the engagement constitutes the terminal guidance phase, which is the most crucial phase since its success or failure determines the success or failure of the entire mission. In the terminal phase the missile locks on to the target and attempts to close the distance to the target as quickly as possible under the constraints of fuel and maneuver limitations. The intercept seldom takes place by the missile directly hitting the target. Usually the missile passes close to the target and the proximity fuze explodes the warhead. Hence, the effectiveness of the terminal guidance phase is solely judged on how close the missile can get to the target (that is, the miss-distance). These phases are shown in Fig.5.6 below.

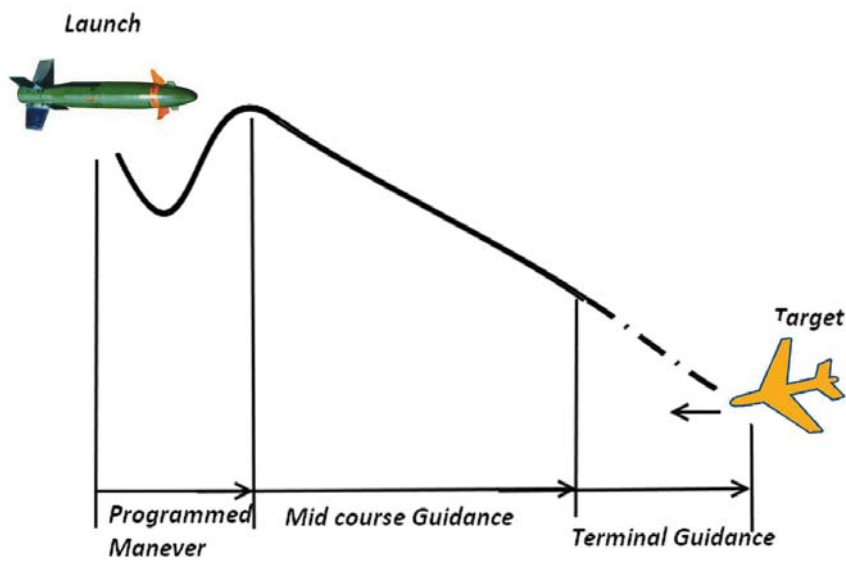


Figure 5.6: Guidance phases for an air-to-air missile

The missile trajectory for SAMs is almost the same except the initial phase which is called the boost phase. In this phase the missile's booster provides the required velocity to the missile. Since this phase occurs for a very short time during which the missile is marginally stable and has high longitudinal acceleration, no guidance commands are given to the missile. However, some modern missiles under development consider the incorporation of a boost phase guidance scheme to improve overall performance. Fig. 5.7 shows these phases for a SAM.

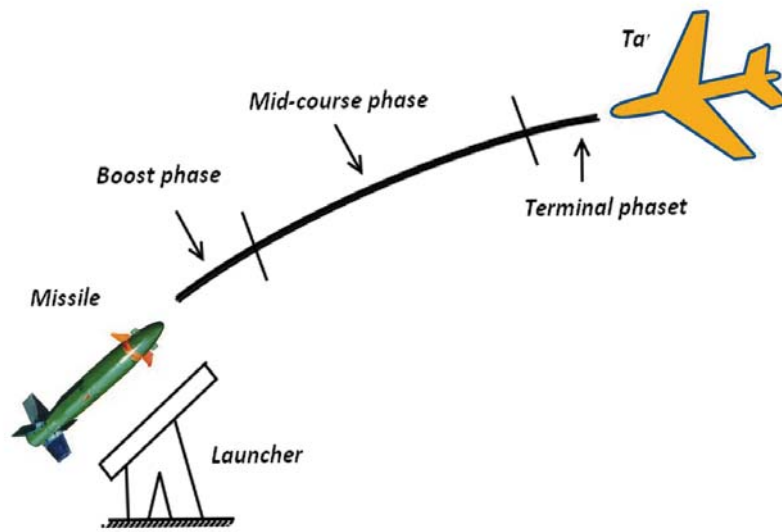


Figure 5.7: Guidance phases for a surface-to-air missile

The missile trajectory can also be classified according to the nature of the guidance scheme. This will be discussed in the context of surface-to-air missiles. In the command guidance scheme the target and missile positions and velocities are measured by a tracking radar situated at the ground station. This information is processed and fed into the guidance computer which generates the steering or guidance commands using some guidance law. The guidance computer is also situated at the ground station. The guidance commands are then communicated to the missile via a data uplink.

Based on these inputs the missile flight control system takes action. Thus, the computers and other equipment at the ground station "command" the missile to behave in a certain fashion. This kind of guidance is also known as three-point guidance there are three major points of reference : the missile, the target, and the ground station. The part of the trajectory in which the missile is command guided is called the command phase. Usually in purely command guided missiles there are three phases: boost phase, command guided phase, and the terminal phase. The last phase is for a short duration in which the missile is very close to the target and hence usually does not maneuver or uses some constant maneuver level obtained from previous guidance commands. The reason for this is that the missile during this phase is so close to the target that there is little time to generate new guidance commands and consequently update the maneuver level. This kind of trajectory is shown in Fig. 5.8 (a). Homing guidance scheme does not depend on any ground station for the generation of guidance commands. This is also called two-point guidance.

Though some homing guidance schemes need assistance from a ground station, the guidance commands themselves are generated inside the missile itself. Here also we have the boost phase, the homing guidance phase, and the terminal phase. This is shown in Fig.5.8(b). One can also have a mixed guidance scheme in which after the boost phase the missile is command guided from a ground station till the target comes within the acquisition range of the missile seeker antenna. Then the missile uses homing guidance till the terminal phase. This is shown in Fig.5.8(c).

5.5 DIFFERENT CATEGORIES OF HOMING GUIDANCE

Homing guidance schemes are desirable from the point of view that they require less control from a ground station and once launched could be more or less autonomous in guiding themselves. These are also called "Fire-and-Forget" missiles. However, there are many categories of homing guidance which invest varying degrees of autonomy to the missile. Some of these categories are discussed below.

Active Homing

An active homing guidance system is one in which both the source of energy to illuminate the target and the receiver of the energy reflected from the target are carried in the missile. Hence, the missile contains a transmitting antenna, a receiving antenna, and a receiver. It also carries within it the signal processor and the guidance computer. Missiles employing active homing are fully autonomous. Such a system is shown in Fig.5.9.

Semi-Active Homing

A system wherein the transmitter of the energy is at a point external to the missile, but the receiver is inside the missile. The missile contains a receiving antenna, a signal processor, and a guidance computer. Since the transmitting antenna is located externally (either land-based or ship-based), it has less autonomy than active homing guidance. This system is shown in Fig.5.10.

Passive Homing

In this system, in which the receiver, placed inside the missile, utilizes the energy emanating from the target. It does not require a transmitter. A heat seeking missile uses such a system. The missile contains the receiver for the

kind of energy that the target emanates, a signal processor, and a guidance computer. These missiles may appear to be as autonomous as active missiles but actually have less autonomy since they have to depend on the target to emanate the necessary energy. If the target stops emanating this energy, the missile stops functioning. This is shown in Fig.5.11 below.

5.6 SOME USEFUL CONCEPTS IN MISSILE GUIDANCE

One often comes across a number of standard terms in the literature on missile guidance. In this section we will try to define some of these terms precisely.

Lateral Acceleration

This is also called as latax. This is the acceleration that needs to be applied by the missile to achieve a desired turn rate. It is called lateral acceleration since it is usually applied in a direction close to the normal to the missile longitudinal axis or the missile velocity vector. In fact the guidance command generated by the guidance law is usually expressed as a lateral acceleration term. This is called the commanded latax and is fed into the lateral autopilots. Since the autopilots are essentially dynamical systems with time delay, the actual achieved latax is a time-varying quantity and is different from the instantaneous commanded latax at any moment in time. This difference may also occur due to saturation effect since the missile may not be able to pull very high commanded latax.

Line-of-Sight (LOS) Rate

During a missile-target engagement the imaginary line in space joining the missile and the target at any given moment in time is called the

instantaneous line-of-sight or LOS. This line changes in length and orientation as the engagement proceeds. The change in angular orientation is given by its angular velocity or rate of turn and is usually expressed in units of radians /sec. This is called the LOS rate.

Closing Velocity

This is the velocity with which the missile closes on to the target. Obviously this is given by the rate at which the length of the LOS shrinks. Hence, it is the negative of the rate of change of the LOS length. It is also the doppler relative velocity of the target with respect to the missile along the line-of-sight. Remember that the doppler relative velocity is positive when the target is approaching and negative when it is receding.

Miss Distance

This is the distance of closest approach of the missile to the target. When the missile directly hits the target the miss distance is zero. But when the missile passes close to the target the miss distance is non-zero. In this case the proximity fuze detonates the warhead and the engagement comes to an end. Obviously, the primary objective of a guidance system is to minimize the miss-distance. Also note that the miss-distance as a non-negative quantity. Consider fig.5.12 which shows the trajectories of a missile and a target, and also the miss-distance. It also shows the LOS at different instants in time.

Including the LOS at the instant of closest approach. The length of this LOS gives the miss-distance. Now, what distinguishes this LOS from all the other LOSs? It can be easily deduced that the closing velocity at this LOS is zero. The closing velocity of the LOS before this is positive and of the LOS after this is negative.

Time-to-go

The time-to-go is an important trajectory parameter which is used for

the implementation of many advanced guidance laws. Suppose we record the trajectory data of a missile-target engagement and find that the engagement ends with an interception at time t_f (final time). Note that interception is assumed to have taken place when either the missile directly hits the target or at the time of closest approach. Now, at any given instant in time t during the engagement the time-to-go is defined as the time remaining till interception and is given by $t_f - t$. It is usually denoted as t_{go} . This value is the actual time-to-go which is known only after the engagement is over. But, to implement the guidance law, we need to estimate the t_{go} during the engagement. There are many ways by which this can be done. One of the ways, based on the available instantaneous information, is to use the formula,

$$\hat{t}_{go} = \frac{R}{(-\dot{R})}$$

where, $\hat{t}_{go}$ is the estimated time-to-go and R is the LOS length or the distance between the target and the missile at that instant in time. This is not a very accurate method of estimating the t_{go} , but for some limited cases it is satisfactory. There are other, more accurate but complicated, ways of finding the t_{go} .

Blind Zone

In a homing guidance system the seeker has to keep pointing towards the target to track it. However, during the last part of the terminal phase the missile could be pointing in such a direction that the seeker has to turn by a very large angle to keep the target within its field of view. However, seeker turn angle is subject to mechanical limitations. Hence, it may not be possible for the seeker to turn by such a large angle. In this case the seeker loses track of the target and cannot "see" it any more. This is called the blind zone of the missile. This is shown in Fig. 5.13 below. There is no information input from the seeker during this phase and the guidance system has to depend on previous inputs.

5.7 THE KINEMATIC EQUATIONS

The kinematic equations for the missile-target engagement, assuming point mass models for the missile and the target are given below with reference to Fig. 5.14.

$$\dot{R} = V_T \cos(\beta - \theta) - V_M \cos(\alpha - \theta)$$

$$\dot{\theta} = (1/R)(V_T \sin(\beta - \theta) - V_M \sin(\alpha - \theta))$$

Here, V_T and V_M are the target and missile velocities, and R is the distance from the missile to the target (LOS length or LOS separation). The missile employs a lateral acceleration a_M to turn the missile in an appropriate direction. Note that $\dot{\theta}$ is the LOS rate and $\dot{R}$ is the rate of change of the LOS separation. Also, the closing velocity V_C is given by,

$$V_c = -\dot{R}$$

The above equations do not form the complete set of kinematic equations. The complete set will also consist of equations modelling the variations in α , β , θ , V_M and V_T . Integrating these equations with respect to time from some given initial conditions will give the complete trajectory of this system of equations.

PROBLEMS AND EXERCISES

1. Collect the following data for one missile each from the SSM, SAM, ASM and AAM categories: Name of the missile, type of missile(a short description), country of origin, height or length, diameter, weight, range ,

airframe configuration, warhead, guidance system, propulsion system, speed. Include any other data about the missile which you may find of interest.

You may consult JANE'S WEAPON SYSTEMS. Give reference to the specific volume you have consulted.

2. Consider the missile-target engagement geometry shown below. Find the following (a) closing velocity (b) $\dot{R}$ (c) LOS rate (d) estimated time-to-go (e) turn rate and the radius of turn of the missile if a latax of 25 m/sec^2 is applied by the missile in a direction normal to the missile velocity factor (f) the angle α so that the missile is on a collision course with the target (Note: The missile is on a collision course with the target if the LOS rate is zero) (g) the heading error (Note: The heading error is the difference between the actual missile-angle (with respect to the reference) and the missile angle required for collision course).

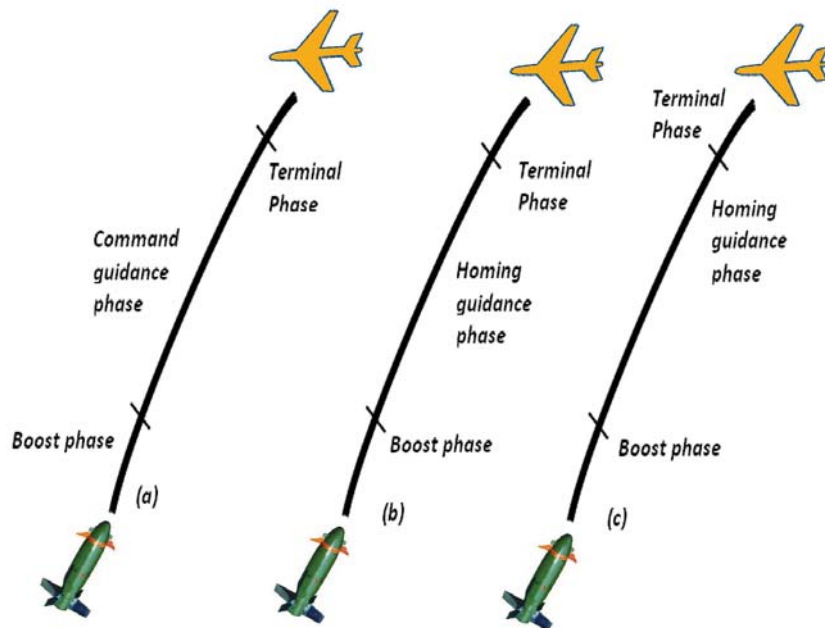


Figure 5.8: Trajectories for (a) command guidance (b) Homing guidance (c) Mixed guidance

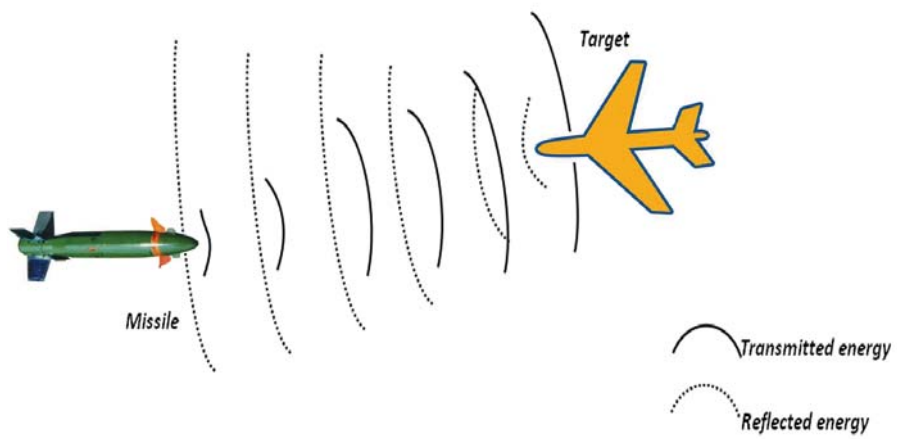


Figure 5.9: Active homing guidance

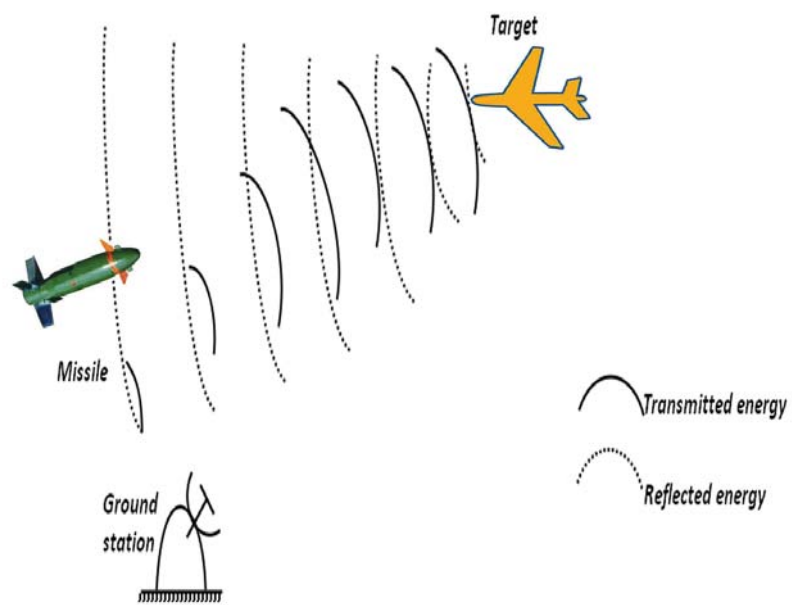


Figure 5.10: Semi-active homing guidance

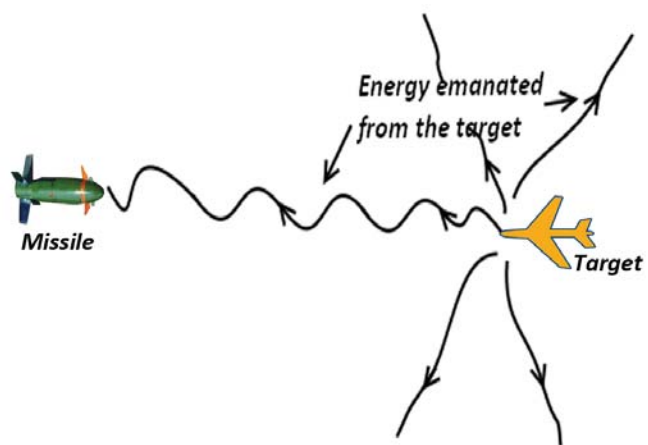


Figure 5.11: Passive homing guidance

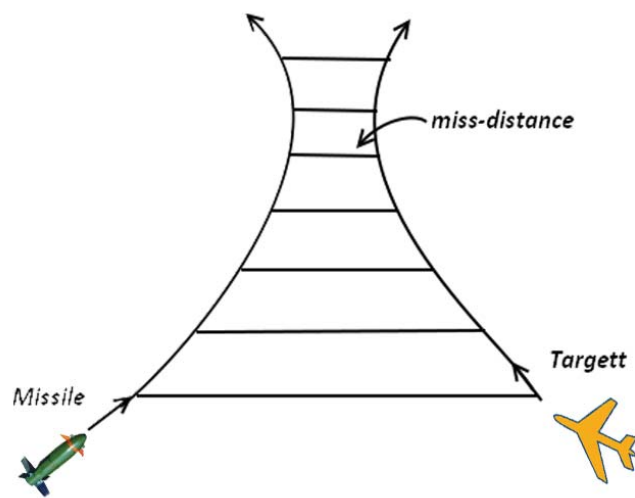


Figure 5.12: Miss-distance

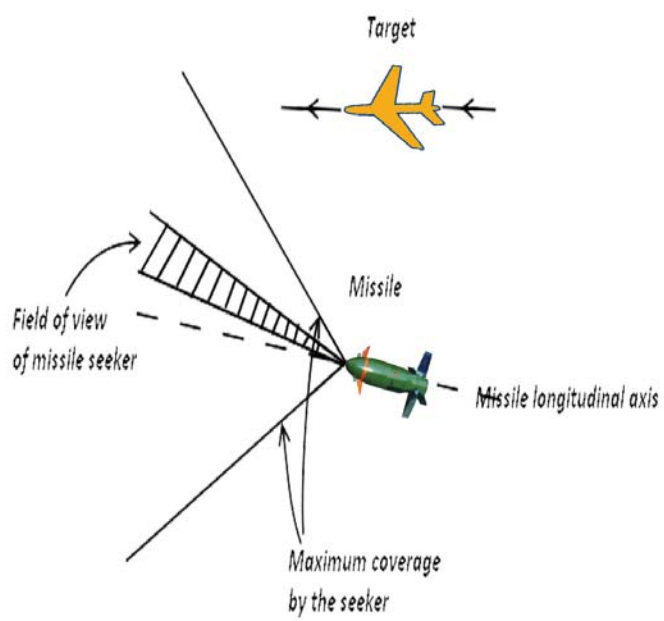


Figure 5.13: Blind zone in the terminal homing phase

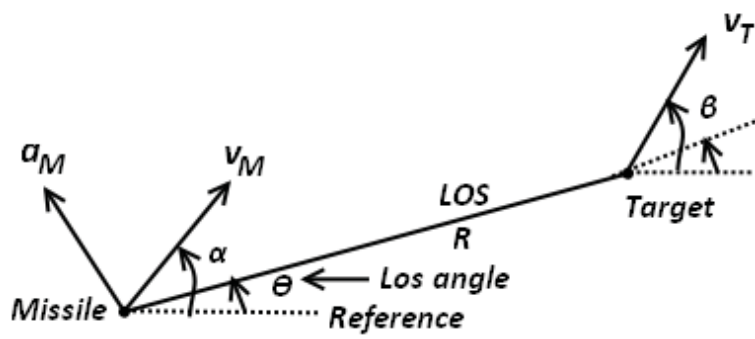


Figure 5.14: Missile-target engagement geometry

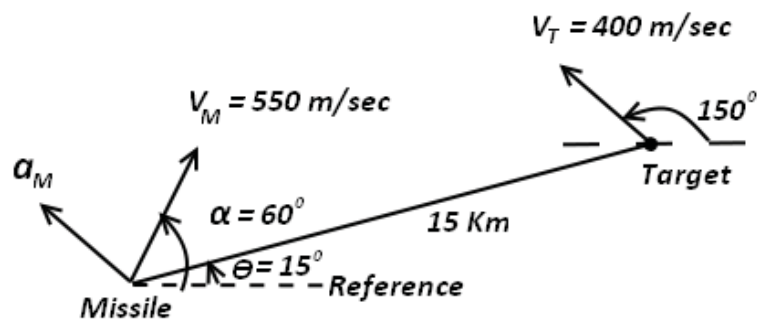


Figure 5.15: A missile-target engagement geometry