

Chapter 6

MISSILE GUIDANCE LAWS

Keywords. LOS guidance, Beam rider guidance, pursuit guidance, Proportional Navigation guidance, Pure pursuit guidance, Deviated pursuit guidance

6.1 CLASSIFICATION OF MISSILE GUIDANCE LAWS

It is the guidance law which in principle, distinguishes an unguided projectile from a guided missile. In a way, the guidance law can be considered to be the "brain" of the missile. The more sophisticated the guidance law, the more effective is the missile. The primary function of the missile guidance law is to generate steering guidance commands based on some strategy which uses the missile and target information as inputs. The guidance command is usually in the form of the magnitude and direction of the lateral acceleration that the missile needs to apply. The guidance command is usually generated at very short intervals of time and, for most practical purposes, can be assumed to be continuously generated. The design and analysis of guidance laws has been an

active area of research for the past five decades. These guidance laws were first designed during the second world war and were subsequently refined. We may classify these guidance laws as classical and modern guidance laws. In the classical guidance laws we have line-of-sight (LOS) guidance, pursuit guidance and its variants, proportional navigation and its variants. The modern guidance laws are derived from optimal control theory, differential games, singular perturbation theory, and reachable set theory. Of these, the proportional navigation (PN) guidance laws form the boundary between the classical and the modern approach.

The basic PN law is a classical guidance law whereas many of its variants are recent extensions and should rightfully be treated as modern guidance laws. In these lecture notes we shall discuss the LOS, pursuit, PN and optimal control guidance laws only.

6.2 CLASSICAL GUIDANCE LAWS

The classical guidance laws are those which have been employed in missiles for decades and are designed using rather simple ideas. A majority of available guided missiles use these guidance laws or their refinements. They have the advantage of easy mechanization, standard equipments and minimal information requirement. Their disadvantage lies in the fact that their accuracy suffers against maneuvering and intelligent targets. This is especially of importance for SAMs and AAMs.

Line-of-sight (LOS) Guidance

The basic principle here is to guide the missile on a LOS course in an attempt to keep it on a line joining the target and the point of control (ground station). The LOS guidance geometry is shown in Fig.6.1. The guidance law should be such that the velocity of the missile perpendicular to

the LOS should be equal to the LOS velocity at that point, that is,

$$V_p = R\dot{\theta} \quad (6.1)$$

The LOS guidance scheme can be mechanized in two ways: command-line-of-sight (CLOS), and beam rider (BR) guidance scheme.

In CLOS guidance scheme there is an uplink to transmit guidance signals from a ground controller (point of control) to the missile. Here it is required by the ground station to track the missile as well as the target. Before transmitting the guidance signal the necessary compensation for the missile position is done.

In BR guidance scheme an electro-optical beam is directed at the target from the ground station. There are sensors inside the missile which sense the deviation of the missile from the centerline of the beam and the missile generates appropriate guidance commands to annul this deviation. Here, it is only required to track the target, and not the missile. Hence, the BR missile requires onboard autopilot compensation for the missile position. A BR missile system is shown in Fig.6.2.

Performance of missiles using LOS guidance has been found to be quite good against moderate speed, low maneuver targets at short ranges. However, these missiles suffer from certain disadvantages:

(1) Their performance degrades against high speed and maneuvering targets.

(2) A major disadvantage is that the commanded latax required for approaching targets (even for a non-maneuvering one) becomes very high towards the end. Since the missile achieved latax has an upper limit, the saturation effect causes miss-distance. This is shown in Fig 6.3 below.

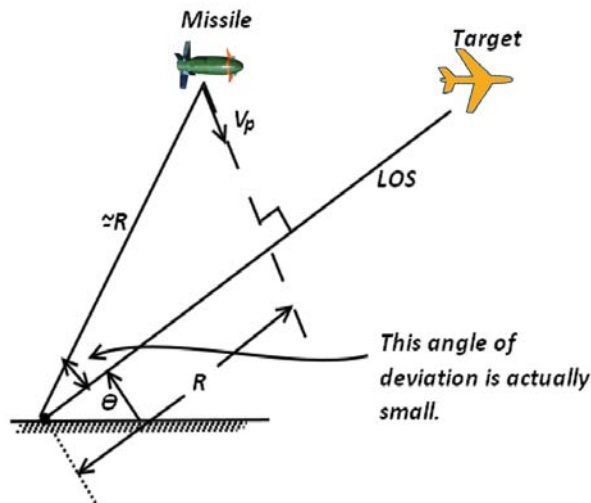


Figure 6.1: LOS guidance engagement geometry

(3) Since these guidance laws, by the very nature of their mechanization, depend completely, on information received from ground station, they do not have the "fire-and forget" capability of active homing guidance.

Pursuit Guidance Laws

The basic idea here is to keep the missile pointed towards the target. Whenever, there is a deviation a latex command is applied to annul the deviation. There are two kinds of pursuit guidance: (1) Attitude Pursuit, in which the missile longitudinal axis is kept pointed at the target; and (2) Velocity pursuit in which the missile's velocity vector is kept pointing at the target. These two are different since there is usually a non-zero angle-of-attack, which is the angle between the missile velocity vector and the missile

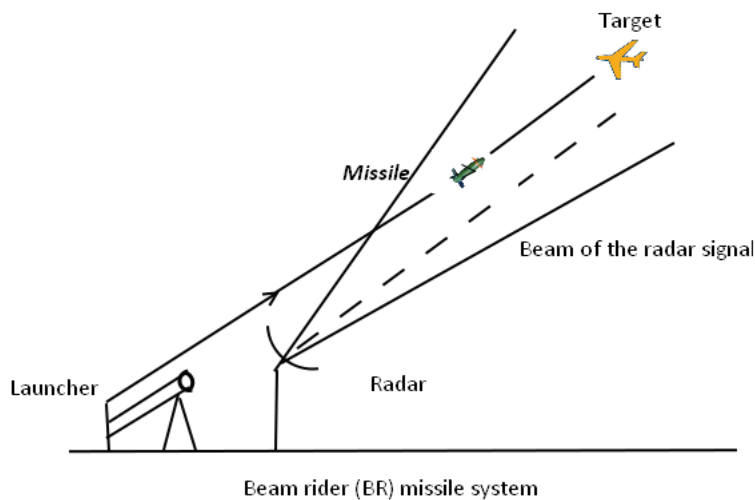


Figure 6.2: Beam rider guidance

longitudinal axis. Attitude pursuit is mechanized easily since the missile body axis is a fixed line with respect to the missile airframe in which the guidance system is housed. But velocity pursuit has to have an estimate of the angle of the velocity vector. This can be obtained by using an airvane which indicates the relative wind direction. There is a further classification of these guidance laws as pure pursuit and deviated pursuit. Pure pursuit makes them point at the target while Deviated pursuit makes them point at a spot ahead of the target by a fixed angle. The idea behind deviated pursuit is to take advantage of the information of the target's flight direction and thus reduce the latency demanded.

It has been found that the miss-distance performance of velocity pursuit

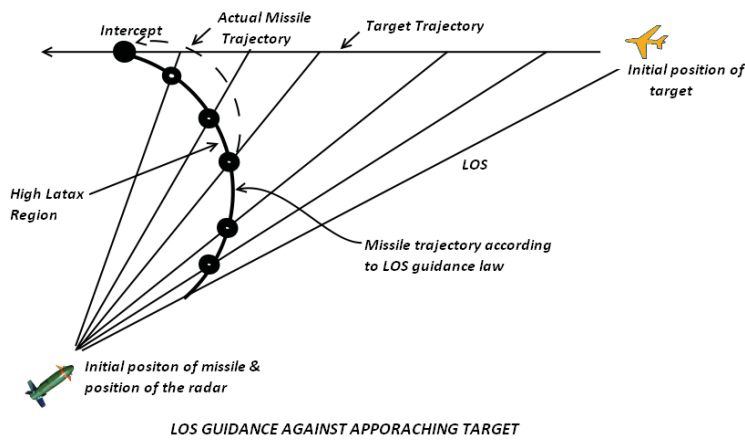


Figure 6.3: LOS guidance against approaching target

guidance is superior to attitude pursuit guidance. Fig.6.4 below shows the trajectory of a missile employing pure velocity pursuit guidance. Pursuit guidance also has the disadvantage of requiring high latax towards the end of the engagement, thus causing miss-distance. This is shown in Fig 6.4. Moreover, its miss-distance performance against high speed and maneuvering targets is also not satisfactory.

Proportional Navigation Guidance Law

Proportional navigation (PN) is perhaps the most widely used guidance law in sophisticated missiles. Before we describe the PN law let us clarify one point. Proportional navigation has nothing to do with navigation. It is purely a guidance law used to guide missiles. The reason for this misnomer is that in

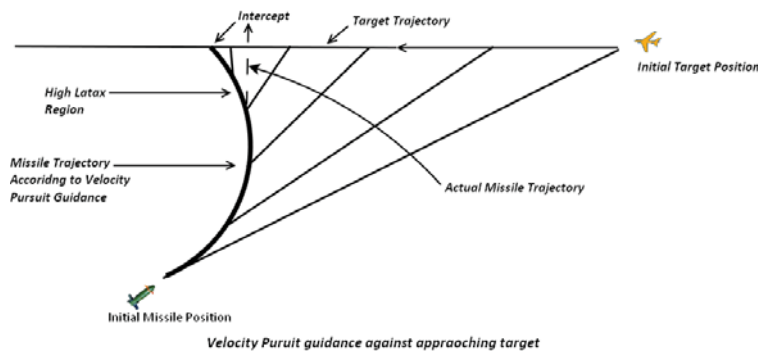


Figure 6.4: Velocity pursuit guidance against an approaching target

the early days of development of guided missiles the vocabulary of guidance literature was somewhat limited. But navigation of ships was a well-known science and was a popular scientific topic. It was only a matter of time before people decided that the idea of guiding missiles to follow a certain trajectory and of "navigating" a ship had certain similarities, and the name proportional navigation was invented. The idea behind proportional navigation guidance initially originated from a certain observation made by sailors. They observed that from a moving ship if another ship appears to be stationary and its size appears to be growing, then there is a certainty of imminent collision between the two ships. Essentially these two conditions imply that the two ships are on a collision course, i.e., there is no relative velocity between the two ships perpendicular to the LOS and the ships are approaching each

other. Translated to the language of LOS rate and closing velocity, it implies that the LOS rate is zero and the closing velocity is positive. PN law uses the idea that if the LOS rate at any time is non-zero then the guidance command applied should be such that it annuls the LOS rate. In fact the latax generated is made proportional to the LOS rate and the closing velocity. Thus the commanded latax according to PN law is,

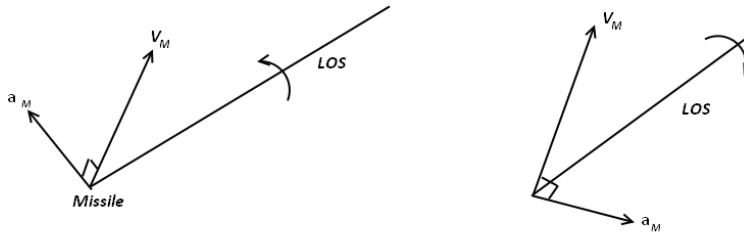
$$\begin{aligned} a_m &\propto \dot{\theta} \\ a_m &= NV_c \dot{\theta} \end{aligned}$$

where, N is called the navigation constant and usually lies between 3 and 5. $V_c = \dot{R}$ is the LOS rate. Usually the commanded latax is applied normal to the missile velocity vector. But there are many variations of the PN law in which the latax could be applied in directions different from the normal to the missile velocity vector.

Note that for most engagements between missile and target the initial and subsequent closing velocity remains positive till the distance of closest approach occurs. Hence, the direction in which the latax is applied is given by the direction of rotation of the LOS. This is shown in Fig. 6.5 below. In fact, when the LOS rate rotates in the clockwise or anti-clockwise direction the latax applied is such that the missile velocity vector also rotates in the same direction.

This is logical for the following reason: Consider that the LOS is rotating in the anti-clockwise direction. It implies that the target velocity component normal to the LOS. By turning the missile velocity vector in the anti-clockwise direction we are effectively increasing the component of the missile velocity normal to the LOS, thus reducing the LOS rate, which is desirable since it brings the missile close to the collision course.

The implementation of the PN law is done as follows: If the missile uses



Latax direction in PN Law

Figure 6.5: Direction of latax in PN guidance law

homing guidance then the closing velocity is obtained from the doppler radar used as the missile seeker or sensor and the LOS rate is obtained by measuring the rate of rotation of the missile seeker tracking the target. If the missile is command guided then these are computed on-ground from the tracking radar data.

The advantage of PN guidance law lies in the fact that it is easy to mechanize, requires easily obtainable information, and because of this, is less prone to external disturbances and noise. Unlike pursuit and LOS guidance, which have short term goals (of pointing a vector towards the target or of keeping the missile on the LOS), the PN law has some far-sightedness built into it in the sense that it tries to take corrective actions right from the

beginning. As a result, even an approaching but non-maneuvering target,

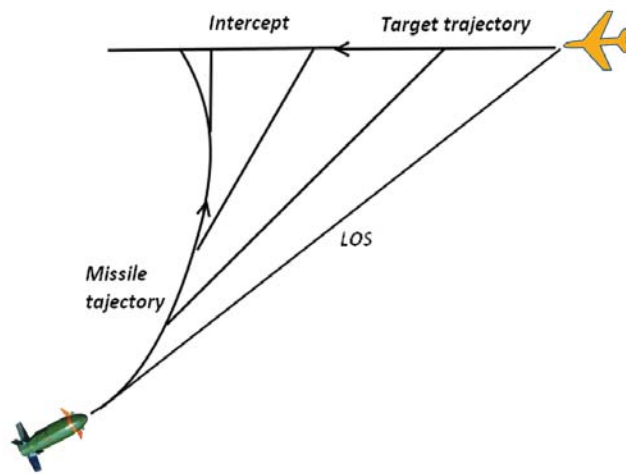


Figure 6.6: Proportional navigation against approaching target

the latex demanded in the terminal phase is within moderate limits. The trajectories for LOS and pursuit guidance given in Figs. 6.3 and 6.4, show that these laws demand a high latex in the terminal phase of interception. However, the PN guidance law does not perform well against maneuvering targets. The reason is that though the PN law accounts for the target velocity implicitly, it does not account for the target acceleration.

We shall discuss some modern extensions of PN guidance law in the subsequent section, in which this aspect is taken care of in some fashion.