Types of Guidance

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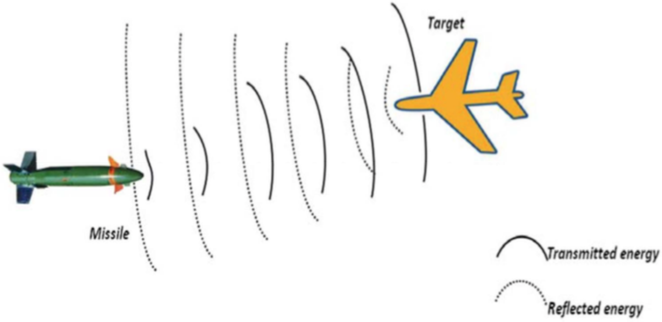
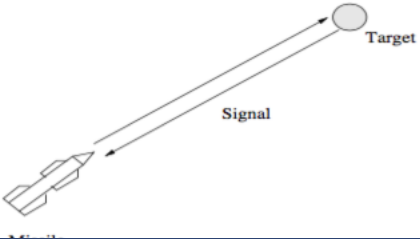
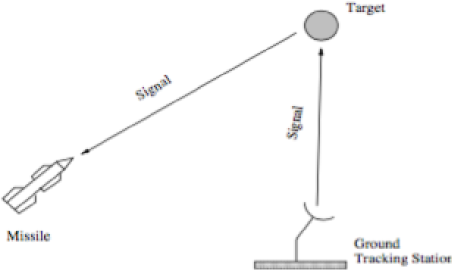
- Homing guidance
  - ⇒ More or less autonomous
  - ⇒ Fire-and-forget missiles
- Types of homing
  - ⇒ **Active homing**
  - ⇒ **Semi-active homing**
  - ⇒ **Passive homing**
- Active homing guidance system
  - ⇒ Both the source of energy to illuminate the target and the receiver of the energy reflected from the target are carried within the missile.
  - ⇒ 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.

Types of Guidance

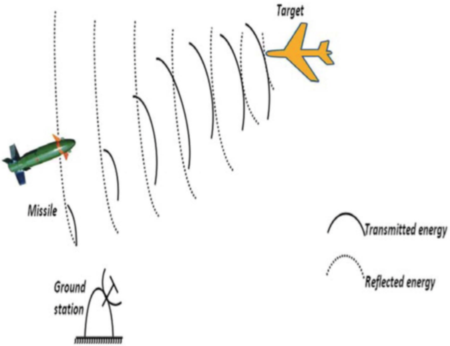
Active Homing Guidance



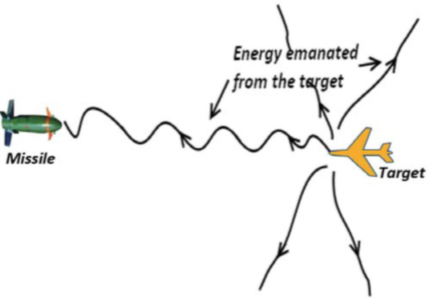




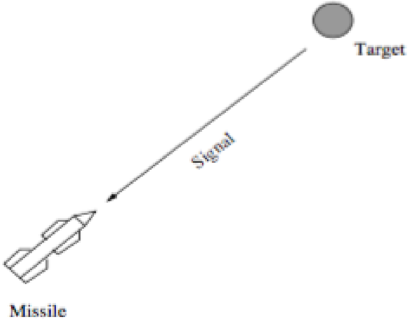
Target
Signal
Signal
Missile
Ground
Tracking Station



Target
Missile
Ground
station
Transmitted energy
Reflected energy



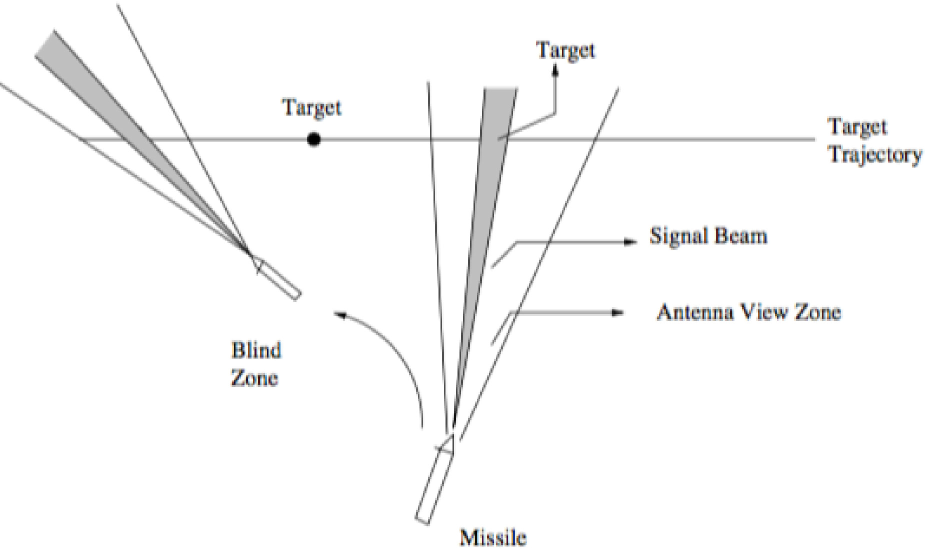
Energy emanated
from the target
Missile
Target



Target
Signal
Missile

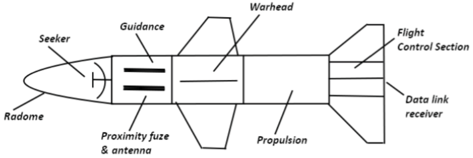
- Homing guidance system: Seeker has to keep pointing towards the target in order to track it.
- During terminal phase, missile could be pointing in such a direction that seeker has to turn by a very large angle to keep target within its field-of-view (FOV).
- Seeker turn angle is subject to mechanical limitations.
- 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 part of the missile trajectory is called blind zone for the missile.
- No information input from seeker during this phase and guidance system has to depend on previous information.

Types of Guidance
Blind Zone

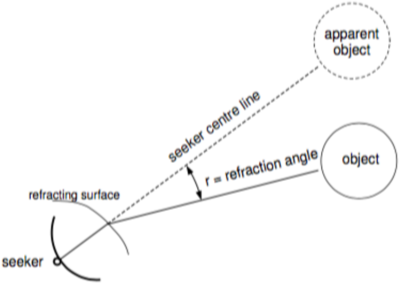


- **Lock-On Before Launch (LOBL)**: Launch platform radar performs the search and acquisition functions, and sends target's position information to the missile's seeker.
- It also directs missile's seeker to lock-on to the target before launch of missile.
- Difficulties:
  - ⇒ Missile's seeker may suffer interference due to the signals emanating from the launch platform radar.
  - ⇒ It is difficult for missile guidance system to track target when missile is experiencing a high acceleration during the boost phase that occurs immediately after the launch.
  - ⇒ Target may not be in the field-of-view (FoV) of the missile's seeker before launch.

- **Lock On After Launch (LOAL)**: Missile has to be provided with the target information to enable the missile seeker to acquire the target.
- Missile must go through process of search and acquisition.
- **Fire-and-Forget or Launch-and-Leave**: Missiles having capability to reach their targets after launch in the absence of any support from the launch platform or the operator.
- A target such as an aircraft has many radar reflector surfaces.
- **Glint noise**: Net return from these surfaces can be modelled as a movement of the apparent radar position, called glint noise.
- It is typically modelled as a Gaussian random variable with zero mean and some non-zero variance.



- Missile seeker is used to track target by processing reflected signal from it.
- Radome that covers the missile seeker causes deterioration to the angle of the incoming signal due to refraction.
- Need to be designed not only from aerodynamic point of view but also with electromagnetic considerations.
- Seeker actually tracks a virtual target, at shifted position from actual one.



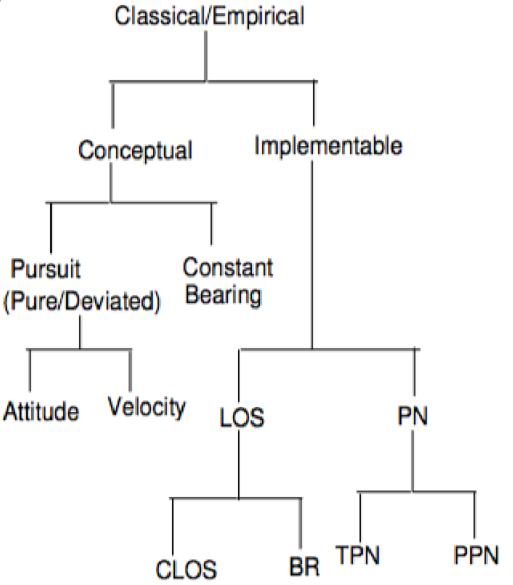
Causes of miss distance

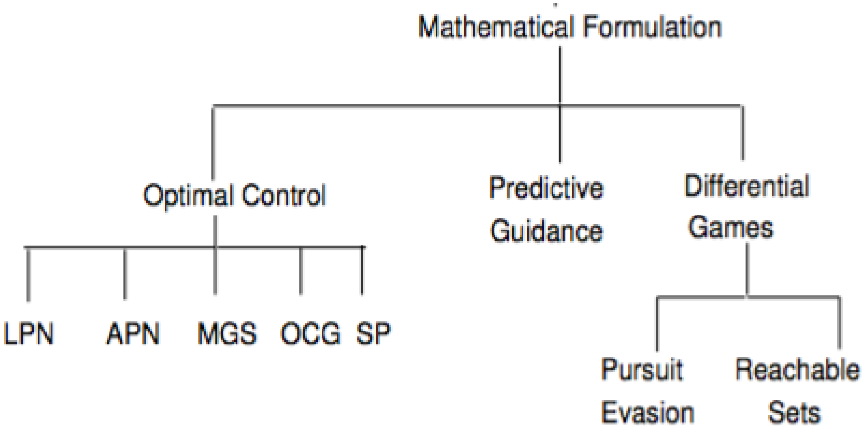
- $\Rightarrow$ Target's maneuver
- $\Rightarrow$ Glint noise
- $\Rightarrow$ Heading error at transition
- $\Rightarrow$ Missile response
- $\Rightarrow$ Receiver's noise
- $\Rightarrow$ Radome error

- **Classical/Empirical Guidance Laws**: based on very simple ideas
  - $\Rightarrow$ Easy to understand
  - $\Rightarrow$ Easy to implement
  - $\Rightarrow$ Requirement of simple information inputs
  - $\Rightarrow$ By their very simplicity, they provide a sense of confidence in their designers
- **Modern/Theoretically-rigorous Guidance Laws**:
  - $\Rightarrow$ Based on modern control techniques
  - $\Rightarrow$ Difficult to implement
  - $\Rightarrow$ Requirement of more information inputs
  - $\Rightarrow$ Provides elegant simulation results but in practice challenging

Types of Guidance

Types of Guidance: Classical Guidance

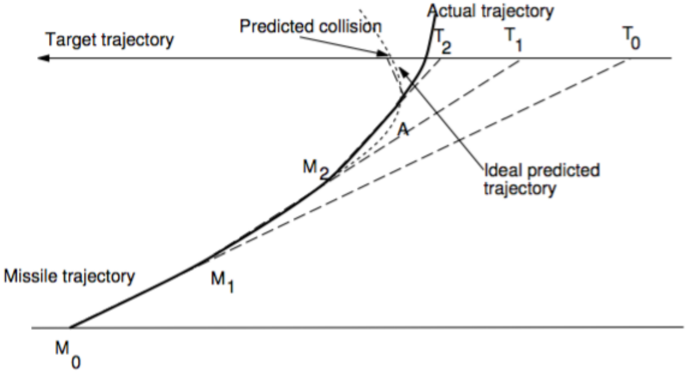



Mathematical Formulation
Optimal Control
Predictive Guidance
Differential Games
LPN
APN
MGS
OCG
SP
Pursuit Evasion
Reachable Sets

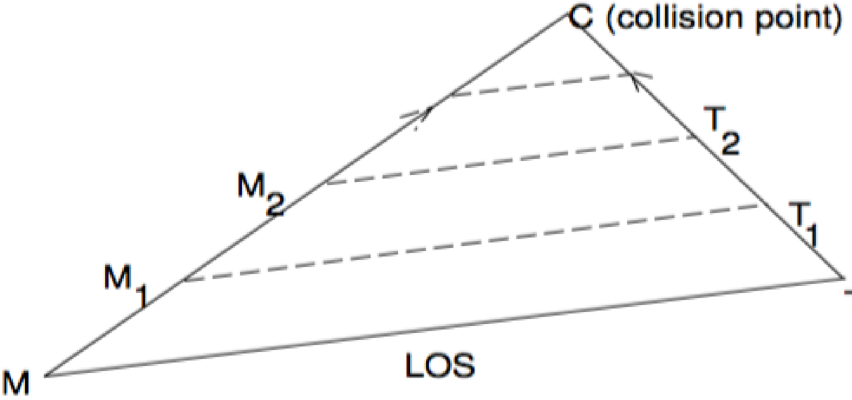
Types of Guidance

Conceptual Classical Guidance: Guidance Laws

- **Pursuit Guidance Laws**: dog-and-rabbit guidance law
  - ⇒ At every instant in time the missile is pointing towards the target.
  - ⇒ Requirement of a very sharp turn to continue pointing towards target.
  - ⇒ Limitation on minimum turn radius.
  - ⇒ No longer keep pointing towards the target and ultimately misses it.
  - ⇒ Called as pure pursuit guidance law.



- Variants of pursuit guidance laws
  - $\Rightarrow$ Attitude pursuit
  - $\Rightarrow$ Velocity pursuit
- **Attitude pursuit**
  - $\Rightarrow$ Missile's centerline or the longitudinal axis is made to point towards the target
- **Velocity pursuit**
  - $\Rightarrow$ Velocity vector of the missile is made to point towards the target
- Why are these two guidance different?
- These two are different since the velocity vector of a missile lags its longitudinal axis by the angle-of-attack.
- Inefficient guidance law for high speed aircraft targets, but good for slow moving targets.



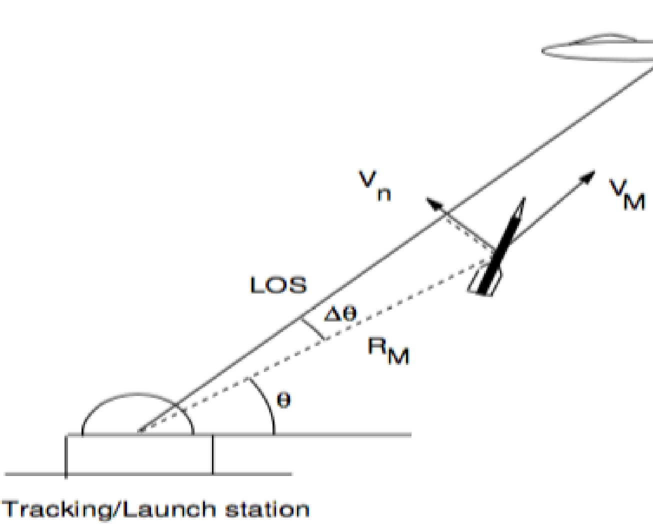
C (collision point)
T
2
M
2
T
1
M
1
T
LOS
M

Types of Guidance

Conceptual Classical Guidance: Constant Bearing Guidance Laws

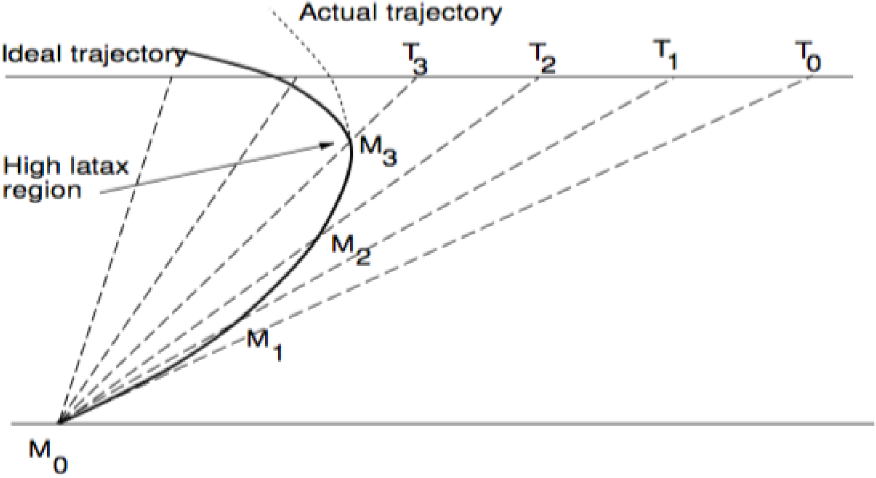
- Constant bearing guidance: No rotation of LOS
  - $\Rightarrow$ Negative rate of change of the LOS separation guarantees interception.
  - $\Rightarrow$ Necessary and sufficient conditions for collision to occur when the missile and the target are both flying in straight line paths.
- Appear to be the best guidance strategy for target interception
- What is the problem with this guidance law?
  - $\Rightarrow$ Missile and target never travel with constant speed and also perform maneuvers.
- LOS will tend to rotate in space.
- To implement the constant bearing guidance law, the guidance system must be able to take corrective actions for every such change instantaneously.
- An exact implementation of the constant bearing course is next to impossible.
- What is the possible alternative?
  - $\Rightarrow$ Proportional Navigation (PN) guidance law.

Implementable Classical Guidance: LOS Guidance



$$V_n = R_M \dot{\theta}$$

- **LOS guidance**:
  - ⇒ If missile remains on the LOS joining launch station and target, and it is fired in the direction of target then interception is guaranteed.
  - ⇒ LOS from launch station to target defines desired position of missile at any given instant in time.
  - ⇒ Missile guidance system acts in such a way that the missile attempts to remain on LOS.
- Missile has to turn in such a way that it has to match the LOS rate.
- How to achieve this constraint?
  - ⇒ Missile's velocity $\perp$ the LOS should equal the LOS velocity at that point
- Issue: Requirement of a very sharp turn like pursuit case.
- Mechanizations:
  - ⇒ Command-to-LOS (CLOS) guidance
  - ⇒ Beam Rider (BR) guidance

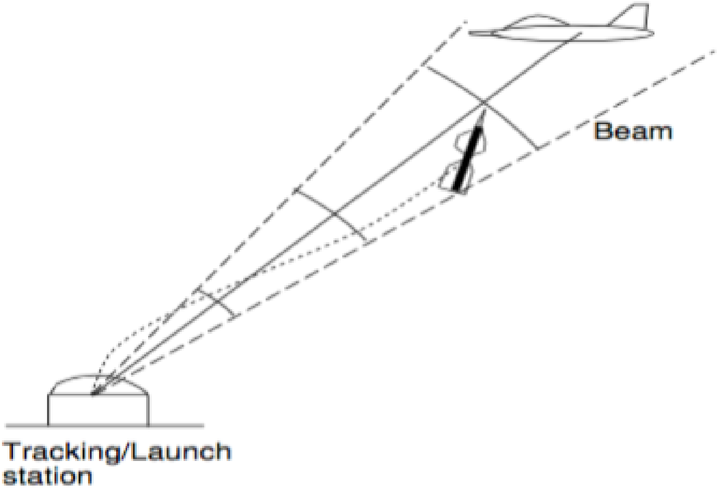

Actual trajectory
Ideal trajectory
T3
T2
T1
T0
High latax region
M3
M2
M1
M0

CLOS guidance

- $\Rightarrow$ An uplink is used to transmit guidance commands from a guidance computer to the missile.
- $\Rightarrow$ Ground station tracks the missile and the target, computes the guidance command which would enable the missile to remain on the LOS.
- $\Rightarrow$ Uplink could be a radio link or wire link.
- $\Rightarrow$ As ground station tracks missile, missile's position is known to it, and guidance command compensates for missile position before transmission of command to missile.
- $\Rightarrow$ Guidance command is proportional to angular error between LOS and line joining ground station and missile, and distance of missile from the ground station.
- $\Rightarrow$ This quantity is linear displacement of missile from LOS and normal to it.
- $\Rightarrow$ A compensation term is added to guidance command.

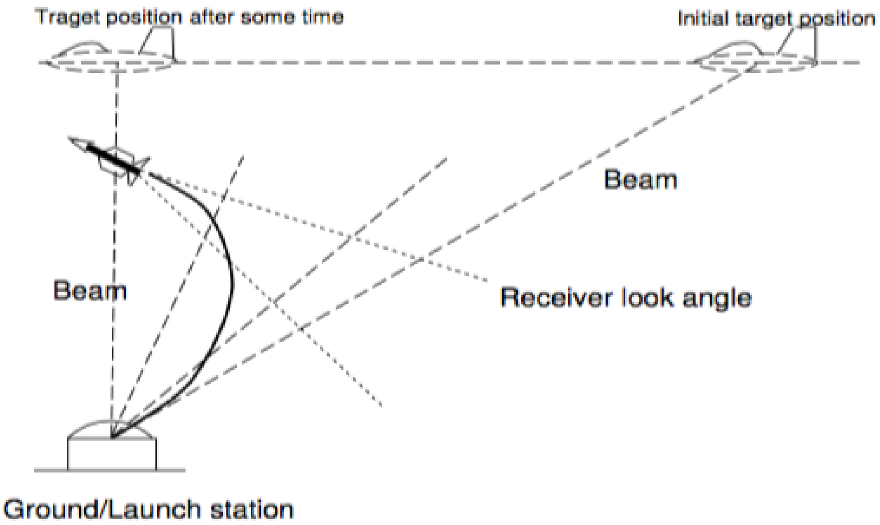
Types of Guidance

Implementable Guidance: Beam Rider Guidance



BR guidance

- $\Rightarrow$ There is an electro-optical beam that joins the ground station with the target.
- $\Rightarrow$ Missile guidance system, located inside missile, senses deviation of missile position from the beam and generates guidance commands to enable missile to stay inside the beam.
- $\Rightarrow$ Beam may be a radar beam or a laser one and the source of the beam is attached to the launcher itself.
- $\Rightarrow$ Missile carries a receiver at its rear end which receives the beam signal and helps the missile to determine how far away from the beam axis the missile is.
- $\Rightarrow$ Beam signal is reflected by the target and is in turn received by the ground radar. This signal is used to track the target.
- $\Rightarrow$ Issue with BR: Loss of beam signal and requirement of on-board autopilot compensation.



Traget position after some time
Initial target position
Beam
Beam
Receiver look angle
Ground/Launch station

PN guidance

- $\Rightarrow$ Principle of constant bearing guidance law
- $\Rightarrow$ When a neighbouring ship appears to be stationary and also seems to be grow in size a collision is imminent.
- $\Rightarrow$ To ensure positive closing speed, missile should be launched towards target
- $\Rightarrow$ To ensure zero LOS rate, missile must make its own turn rate $\propto$ LOS rate
- $\Rightarrow$ Necessary and sufficient conditions for interception
- $\Rightarrow$ To implement PN guidance, the measurement of LOS rate is required.
- $\Rightarrow$ Navigation word is misnomer here.

Modern guidance law

⇒ Optimal control theory
- Minimization of integral square control effort
- Minimization of maneuver induced drag on missile.
- Fixed final time and the constraint of zero miss-distance
- No constraint on the lateral acceleration capability of the missile.
- Fixed time of flight and constraints on the lateral acceleration that can be pulled by the missile was imposed.
- A weighted sum of the miss distance, integral square control effort, and the time for interception

⇒ No closed form solutions due to nonlinear equations

⇒ Linearization of the state equations and try to obtain simpler and quicker solutions.

Modern guidance scheme

- ⇒ Total integral square control effort as performance index
- ⇒ Known final time of interception
- ⇒ First order autopilot
- ⇒ Guidance command has a form

$$
\begin{aligned}
a_M = &\text{ PN Component} + \text{Target Maneuver Component}\\
&+ \text{Autopilot Lag Component}
\end{aligned}
$$

- ⇒ Issues with optimal control based guidance
- ⇒ How to avoid difficulty with optimal control based guidance?
- ⇒ Differential game based guidance

Reference

1. D. Ghose, *Lecture notes on Navigation, Guidance and Control*, Indian Institute of Science, Bangalore.