In the Name of GOD

Guidance and Navigation

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Flight Mission

Every Flying Vehicle is designed to perform a mission:






Guidance, Navigation and Control

To perform a mission leg, the following questions should be answered:

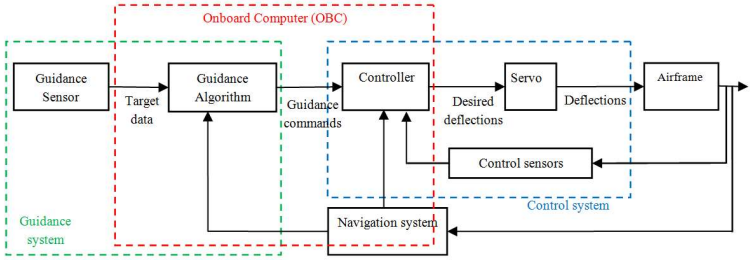
- Where is the Flying Vehicle (FV) now? What are the attitudes?
  X=?, Y=?, Z=?, Ψ=?, θ=?, Φ=? — Navigation
- Where is the FV going to go?
- What should the FV do to go from the current situation to the target situation or to track the desired trajectory?
- How much roll angle, lateral acceleration, heading, altitude, … is required at the moment? — Guidance
- What inputs must be applied to airframe to perform the guidance requirements?
- Who must apply these inputs? — Control

Basic Navigation, Guidance and Control systems

- **Navigation Systems**
  - Inertial Navigation
  - Radio Navigation
  - Visual Navigation
  - Celestial Navigation
  - Magnetic Navigation
  - Sonic Navigation
- **Guidance Systems**
  - Command Guidance
  - Homing Guidance
  - Inertial Guidance
- **Control Systems**
  - Aerodynamic Control
  - Thrust Vector Control (TVC)
  - Reaction Jet Control
  - Partial Thrust Control

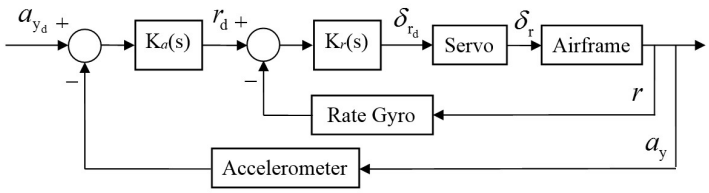
Guidance, Navigation and Control

- Sample Schematic

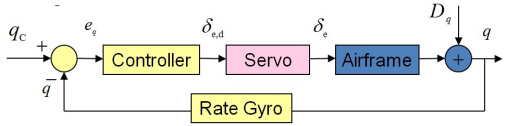


Schematic of Control Systems

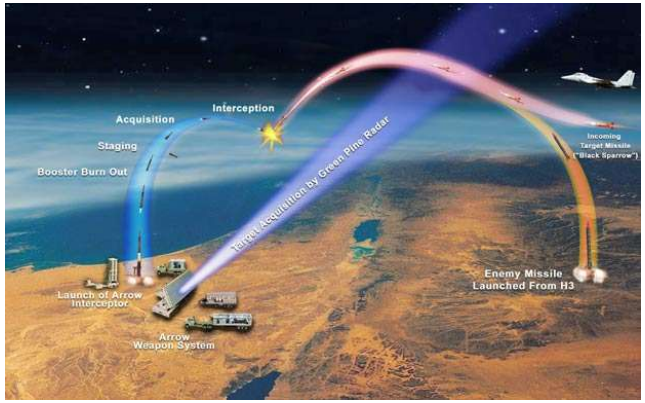
- Sample Lateral Acceleration Control



- Sample Angular Rate Control



Guidance, Navigation and Control: Examples



Course Syllabus

Part I: Guidance

- Introduction, Definitions and Concepts
- Classification of Guidance and Navigation Systems
- Three-point Tactical Guidance Laws
- Two-point Tactical Guidance Laws
- Ballistic Guidance Laws
- UAV Guidance

Course Syllabus

Part II: Navigation

- Principles of Inertial Navigation
- Inertial Sensors
- Tests and Calibration of Inertial Navigation Systems
- Initial Alignment of INS

Guidance System vs Guidance Algorithm/Law

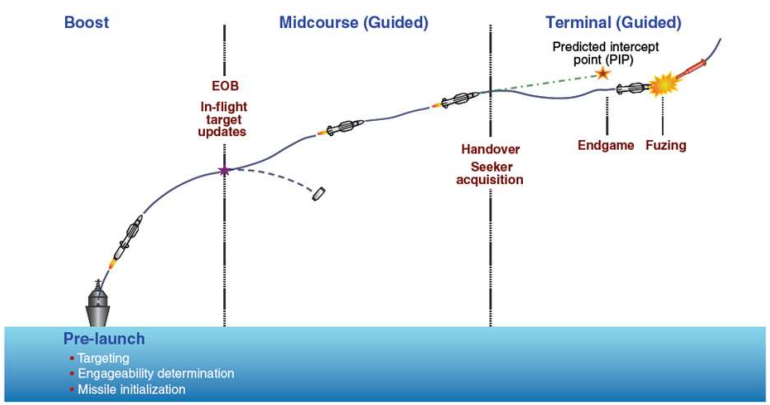
- Guidance System: all hardware and software, used together to generate the guidance commands
  - Guidance Algorithm
  - Guidance Sensor(s)
    - External (Offboard)
    - Onboard
  - Guidance Computer(s)
    - External (Offboard)
    - Onboard
  - Transponder(s) and receiver(s)
- Guidance Algorithm/Law: the software logic, used to provide the guidance commands (a part of guidance system)

External versus Onboard Guidance Sensor

Open-loop vs Closed-loop Guidance

- Open-loop guidance: predetermined guidance commands are issued as a function of time, e.g.
  - Pitch Program
- Closed-loop Guidance: commands are generated based on a compensated comparison between the desired and the instantaneous position or velocity, e.g.
  - Trajectory Tracking
  - Approach

Guidance Phases (Example)



The Goals of each Guidance Phase

- Boost
  - To increase the velocity and make the FV controllable
  - To put the FV within the tracker field of view
  - To guide the vehicle away from the launcher
- Midcourse
  - To bring the interceptor to a neighborhood of the target
  - To save the FV energy
  - To save the FV from the enemy
- Terminal
  - To perform the task with the maximum accuracy

Guidance Phases (More Examples)

- Boost
  - Launch
  - Take-off
- Midcourse
  - Climb, Cruise, Loiter, Descend
  - Terrain Following
  - Trajectory Shaping
  - Orbit Transfer
- Terminal
  - Intercept
  - Landing
  - Rendezvous and Docking

Guidance Trajectories

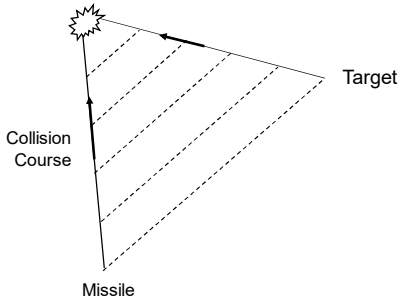
Each guidance law works based on a geometrical rule or a guidance trajectory.

The most important guidance trajectories are:

- Direct/Collision Course
- Ballistic
- LOS
- Optimal
- Cruise
- Terrain Following

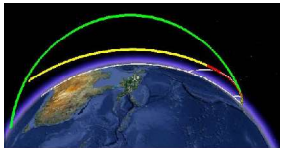
Guidance Trajectories

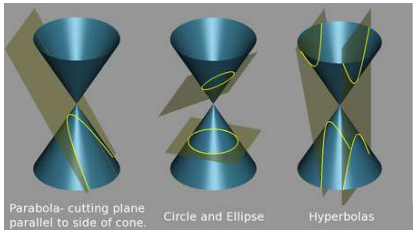
- Direct/Collision Course
  - Missile
  - VOR holding in airplanes



Guidance Trajectories

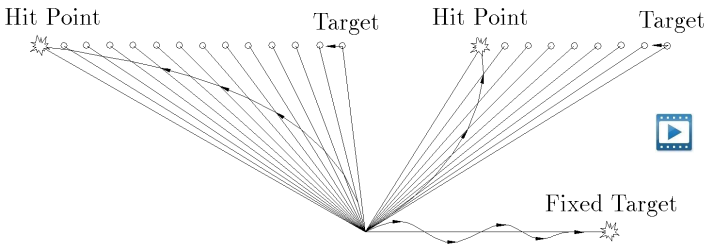
- Ballistic Trajectory: curved trajectory produced in the absence of non-gravitational forces such as aerodynamic, thrust, etc. It is a part of a conical section
  - Ballistic Missiles
  - Launch Vehicles
  - Satellites





Guidance Trajectories

- LOS Trajectory
  - Tactical Missiles

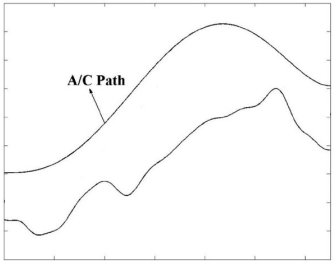


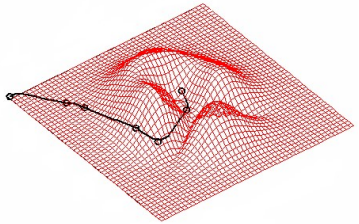
Guidance Trajectories

- Optimal
  - Midcourse Guidance
    - To maximize range or minimize fuel consumption
    - To maximize terminal velocity => maneuverability
  - Terminal Guidance
    - To maximize accuracy
- Cruise
  - Airplanes
    - To minimize fuel consumption
  - Sea skimming missiles
    - To be invisible

Guidance Trajectories

- Terrain Following/Terrain Avoidance
  - Ground-based Cruise Missiles and UAVs
    - To be invisible



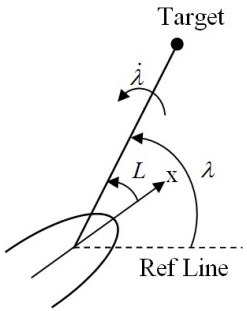


Guidance Sensors

- Absolute Sensors: provide position and attitudes WRT an inertial reference frame
  - INS
    - Position
    - Velocity
    - Attitude
    - Angular rates
  - GPS
    - Position
    - Velocity
  - AHRS
    - Attitude
    - Angular rates

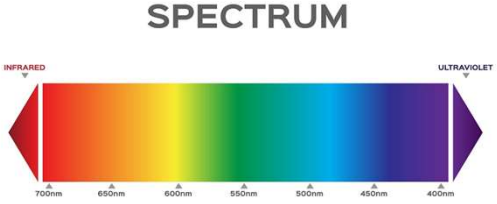
Guidance Sensors

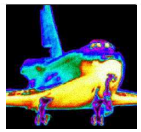
- Relative Sensors: provide relative position and velocity WRT the sensor
  - Homing Seekers
    - LOS angles and rates (bearing)
    - Distance (sometimes)
    - Closing Velocity (sometimes)
  - External Tracker
    - LOS angles and rates (bearing)
    - Distance (sometimes)
    - Closing Velocity (sometimes)

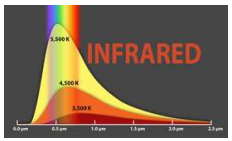


Guidance Sensors

- Detection Tech
  - Radar
  - Laser
  - TV
  - IR
  - UV
  - Sonar
  - Dual/Multiple

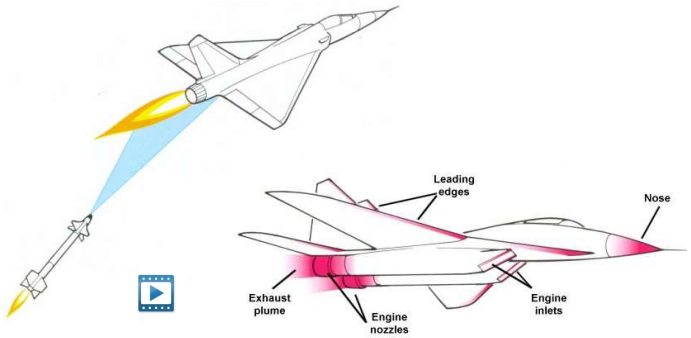






Guidance Sensors

- IR Detection



Guidance Sensors

- Laser Detection

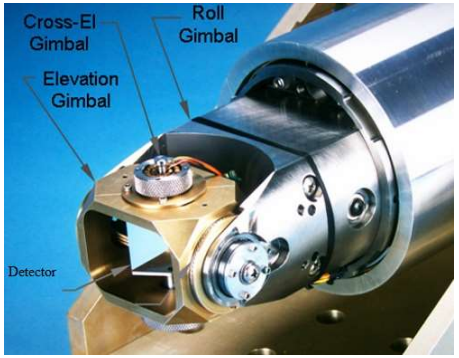
Methods of Target Tracking

Seekers and Trackers detect and track the target using energy emitted by the target

- Active Tracking
  - Target reflects the energy beamed at it by seeker or tracker
- Semi-active Tracking
  - Target is illuminated by an external source
- Passive Tracking
  - Target is itself the source of energy

Seeker

- An onboard tracker to detect and track a target.



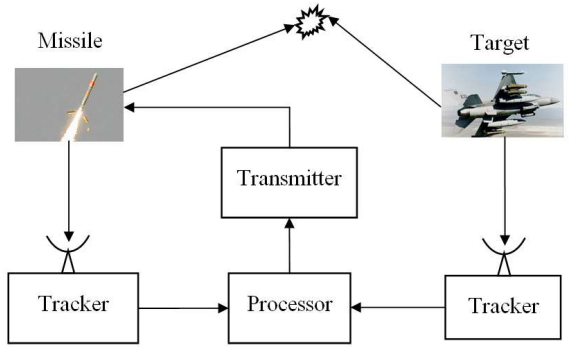
Seeker

- Strapdown
- Gimbaled
  - Servo Stabilized
  - Gyro Stabilized

Video link

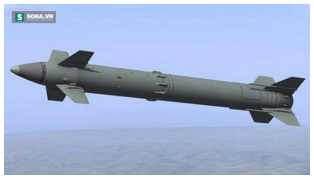
External Tracker

- Single Tracker
- Dual/Multiple Tracker



Example: Tor-M1 Air Defense System

- Short range tactical surface to air missile
- Max Range: 12 km
- Max Altitude: 9 km
- Solid propellant
- Guidance system: command
- Tracking: radar+optic
- Guidance law: Three point
- Kill radius: 15 m
- Control system: reaction jet + aerodynamic control



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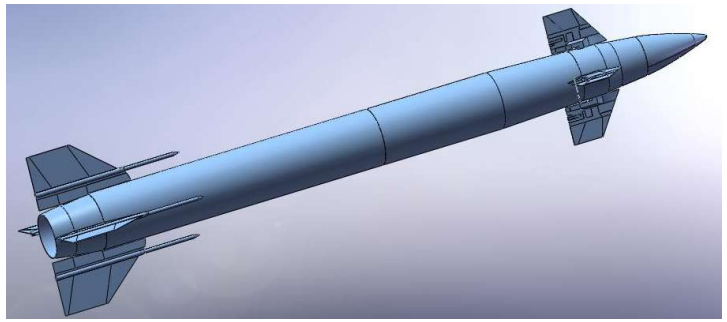

video