Lecture 15

Flying Qualities & Automatic Control

YFQ-44a

Flying Qualities

- **Flying qualities of an airplane are related to the stability and control characteristics and can be defined as those stability and control characteristics important in forming the pilot's impression of the airplane**

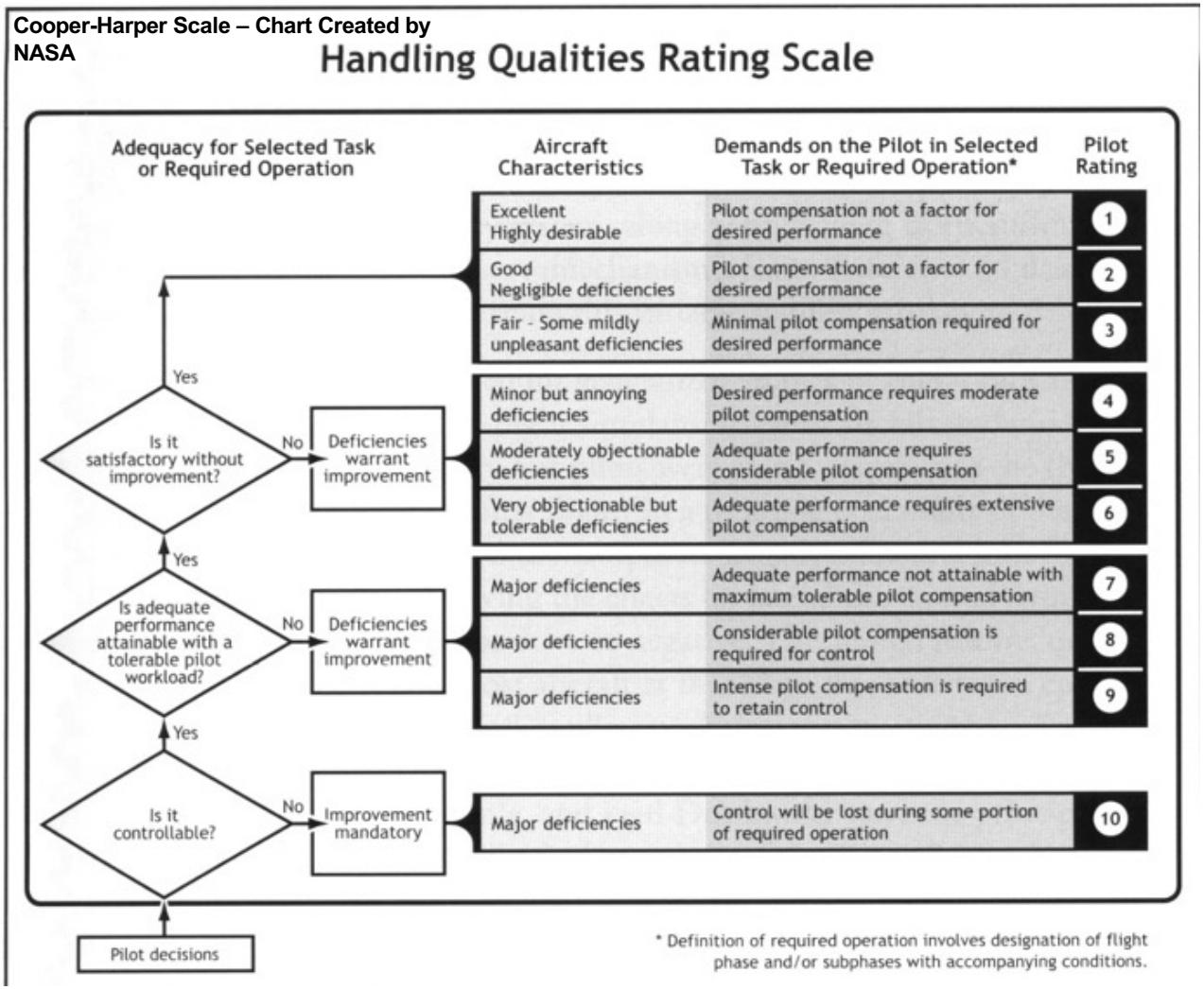
- **The pilot forms a subjective opinion about the ease or difficulty of controlling the airplane in steady and maneuvering flight**
  - **Longitudinal motion**
  - **Lateral-directional motion**
  - **Stick force and stick gradients (force per g)**
  - **Pilot-induced oscillations**

Kawasaki C-1 – Photo by Maryu

Cooper-Harper Scale

- **Flying qualities research provides the designer information early in the design process**
- **Extensive research programs have been conducted to quantify the stability and control characteristics of the airplane with the pilot's opinion**
- **Flying qualities expected by the pilot depend on the type of aircraft, as well as the phase of flight**

Cooper-Harper Scale – Chart Created by NASA



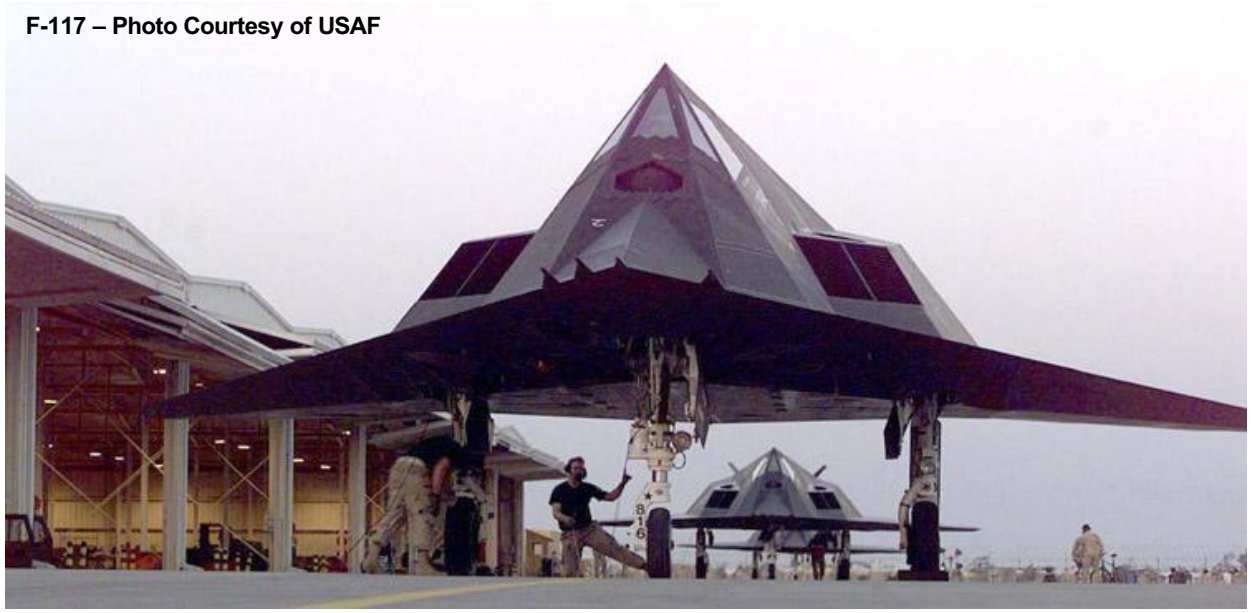
Stability Augmentation

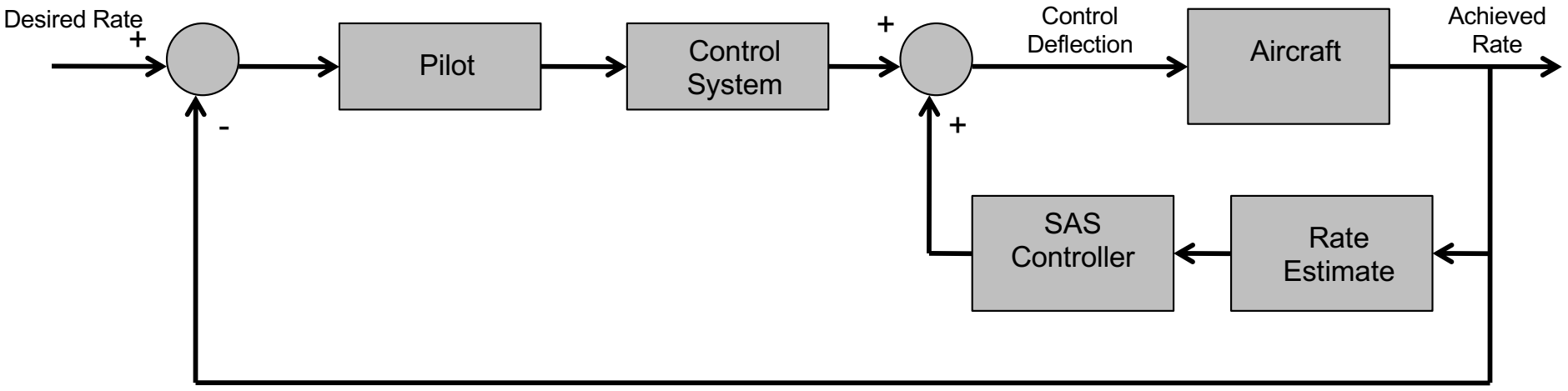
- **If an aircraft has insufficient static stability, automatic control systems can produce stability augmentation**
- **This allows for aircraft to have relaxed static stability to improve control and maneuverability**

F-16 was world's first aircraft designed with relaxed stability. It had negative static stability at subsonic speeds and relied on SAS to fly.

F-16 – Photo Courtesy of USAF

Stability Augmentation





Automatic Control

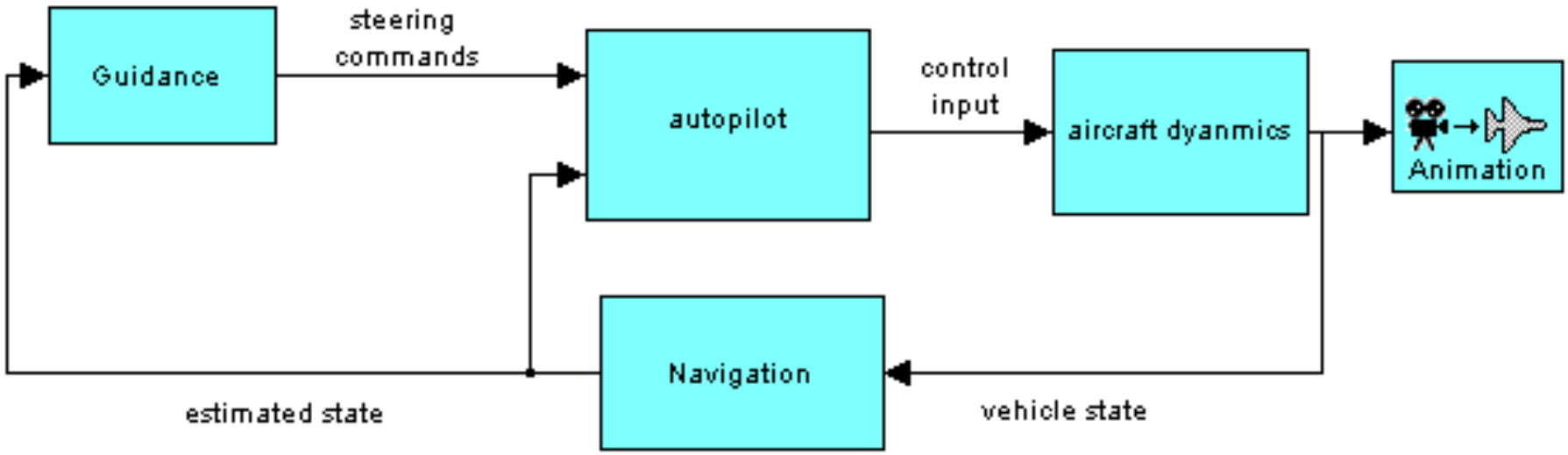
- **Many modern aircraft have autopilot systems**
- **Autopilots are automated systems that help steer or guide a vehicle**
- **Typical autopilot functions:**
  - **Airspeed-hold**
  - **Altitude-hold**
  - **Heading control**
  - **Bank angle control**
- **Autopilot control systems determine proper aircraft control settings (elevator, aileron, rudder, throttle) to achieve desired commands**
- **Feedback control systems are designed (such as PID controllers), and gains are chosen to ensure stability, provide desired response and command tracking**

Typical Simulation Architecture with GN&C

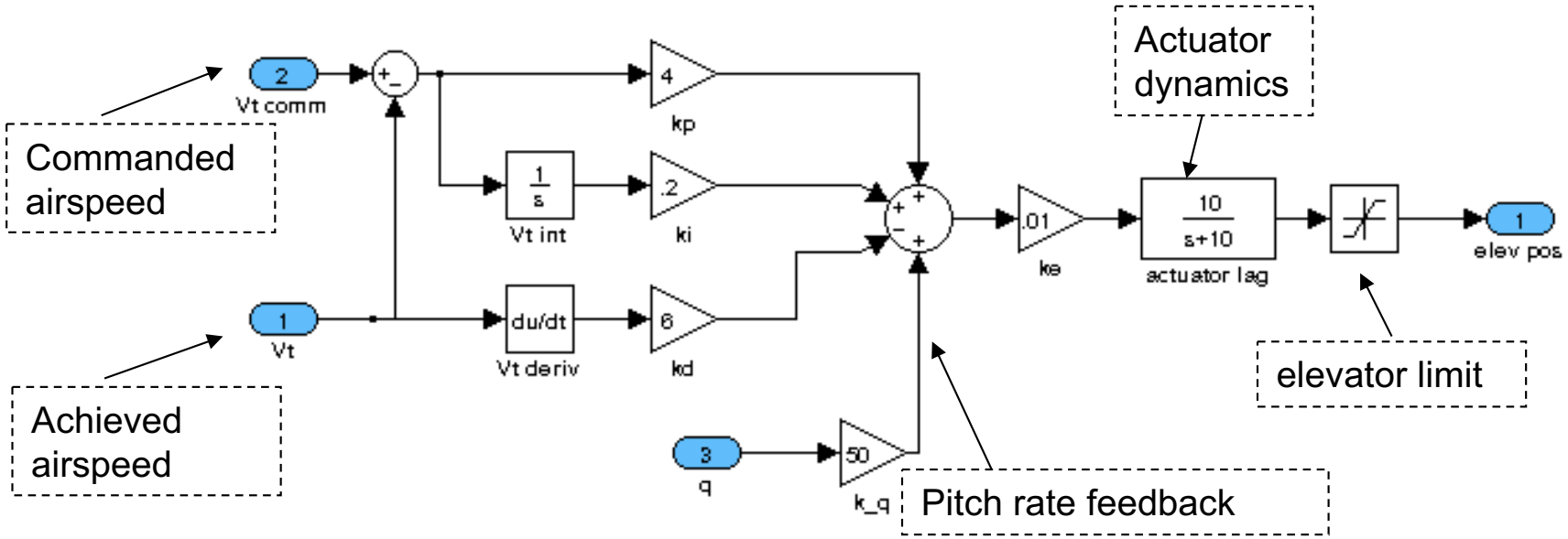
Guidance: Issues steering commands to keep the vehicle on the desired trajectory

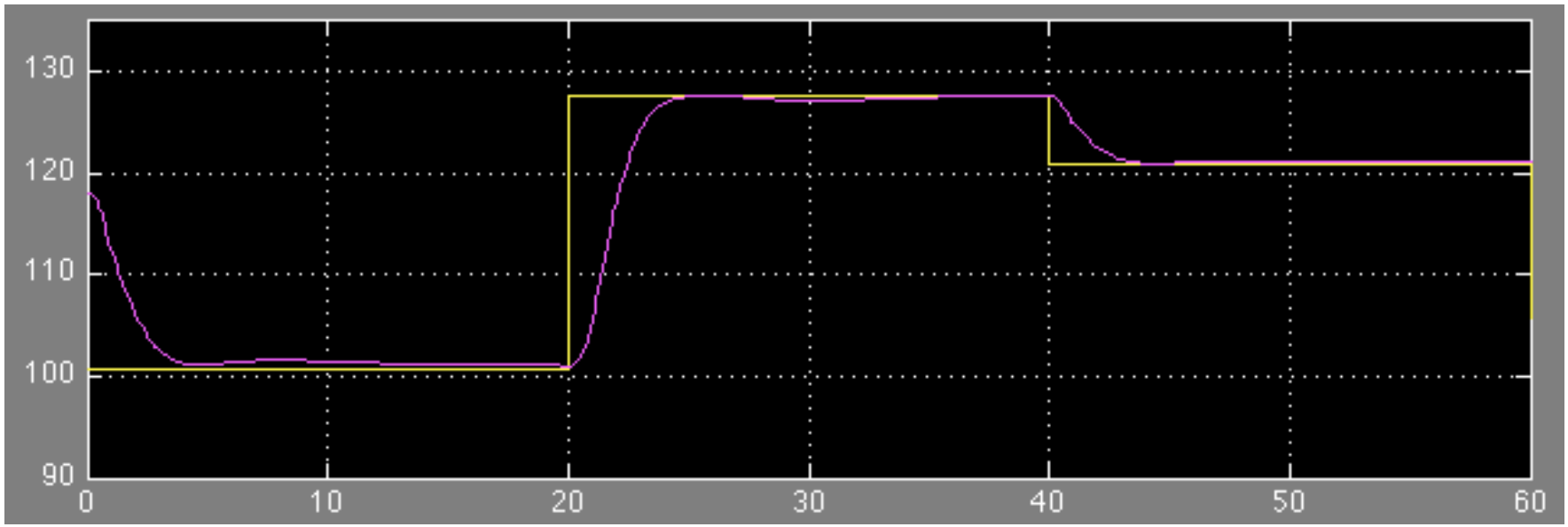
Autopilot (control system): Executes guidance commands, stabilizes vehicle dynamics.

Navigation: estimates vehicle's state information so guidance and control systems know what to do.



Example Autopilot – Airspeed Hold





Guidance Systems

- **Autonomous vehicles have outer loop guidance systems that determine what vehicle commands the autopilot should attempt to follow**

- **Typical guidance problems:**
  - **Waypoint navigation**
  - **Proportional Navigation**
  - **Formation flight problems**

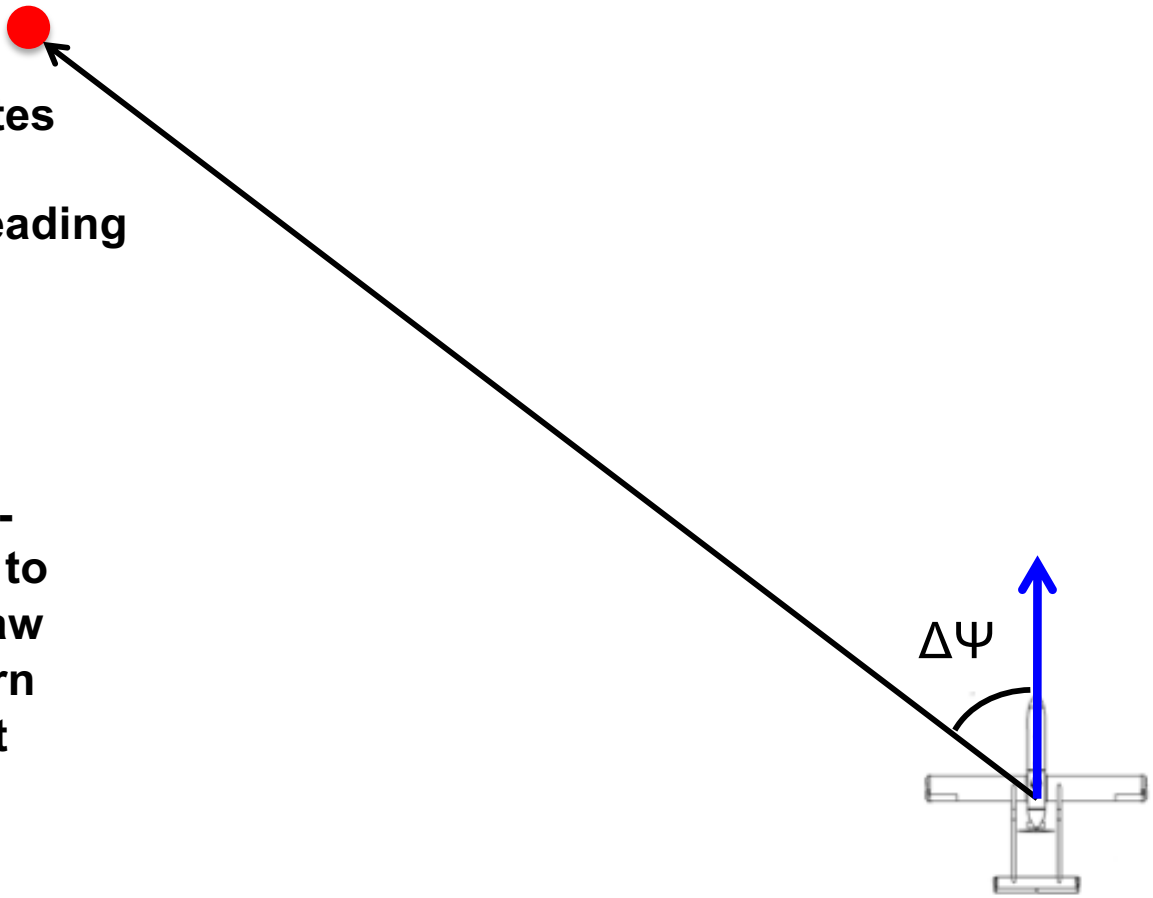
Waypoint Guidance

- **Waypoint target coordinates are compared to vehicle present position, and a heading to target is computed**

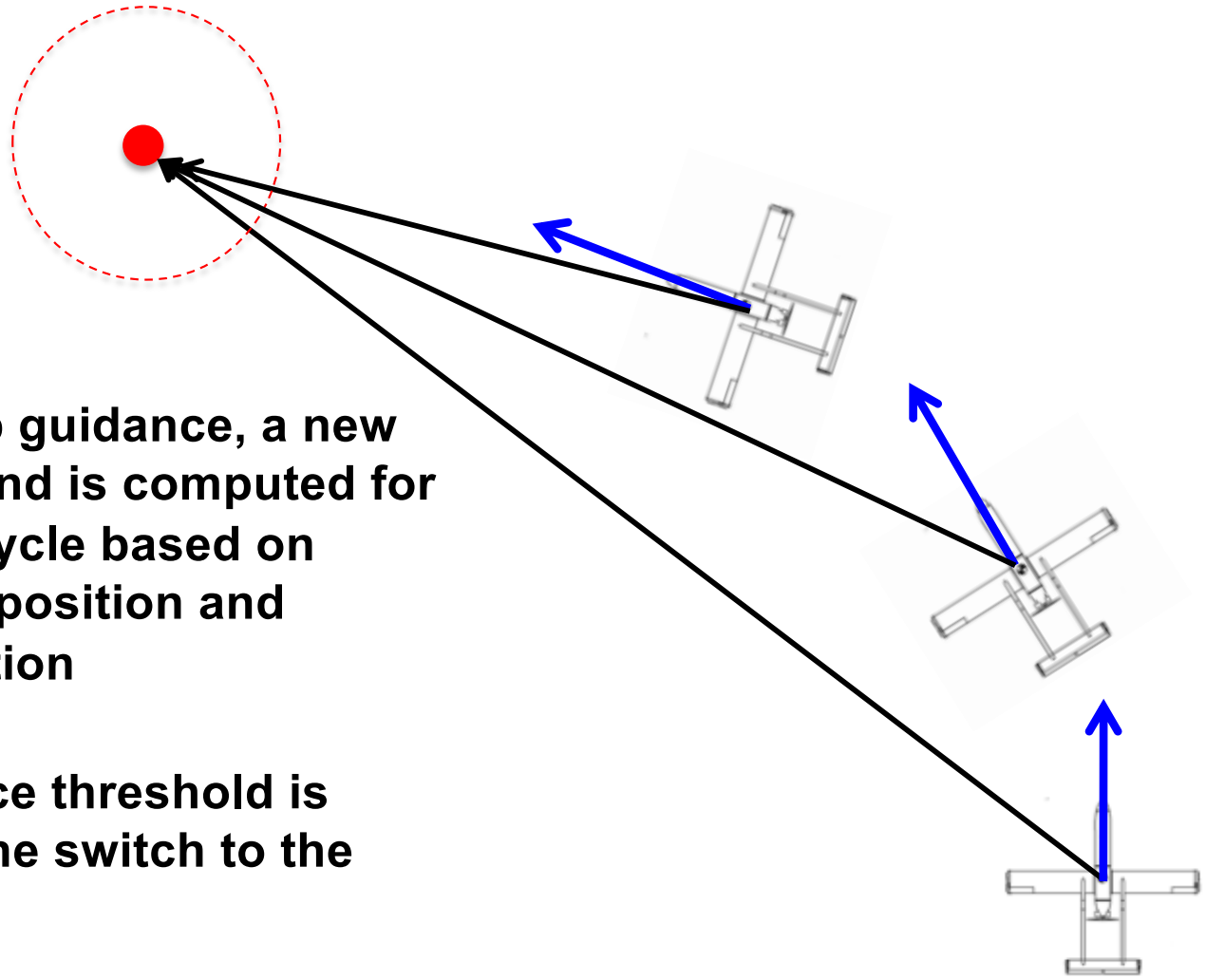
- **Angle difference between vehicle's current velocity vector and the heading-to-target vector can be used to drive a simple guidance law where the commanded turn rate is proportional to that angle**

$$\dot{\Psi} = K\Delta\Psi$$

- **Guidance turn rate commands can be converted into a bank angle command that the vehicle autopilot will execute**

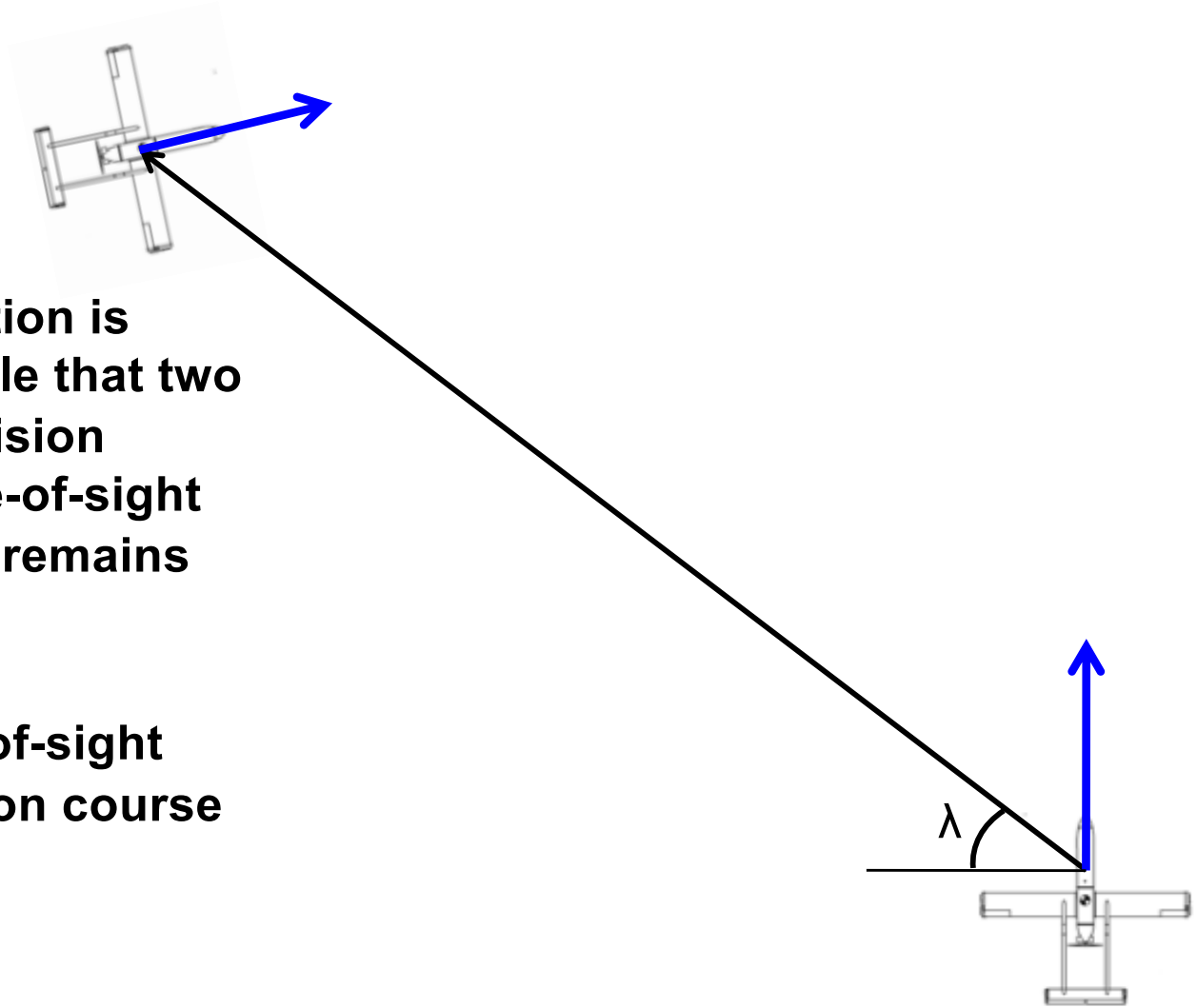


Waypoint Guidance



- **With closed-loop guidance, a new turn rate command is computed for each guidance cycle based on updated vehicle position and velocity information**
- **Usually a distance threshold is used to trigger the switch to the next waypoint**

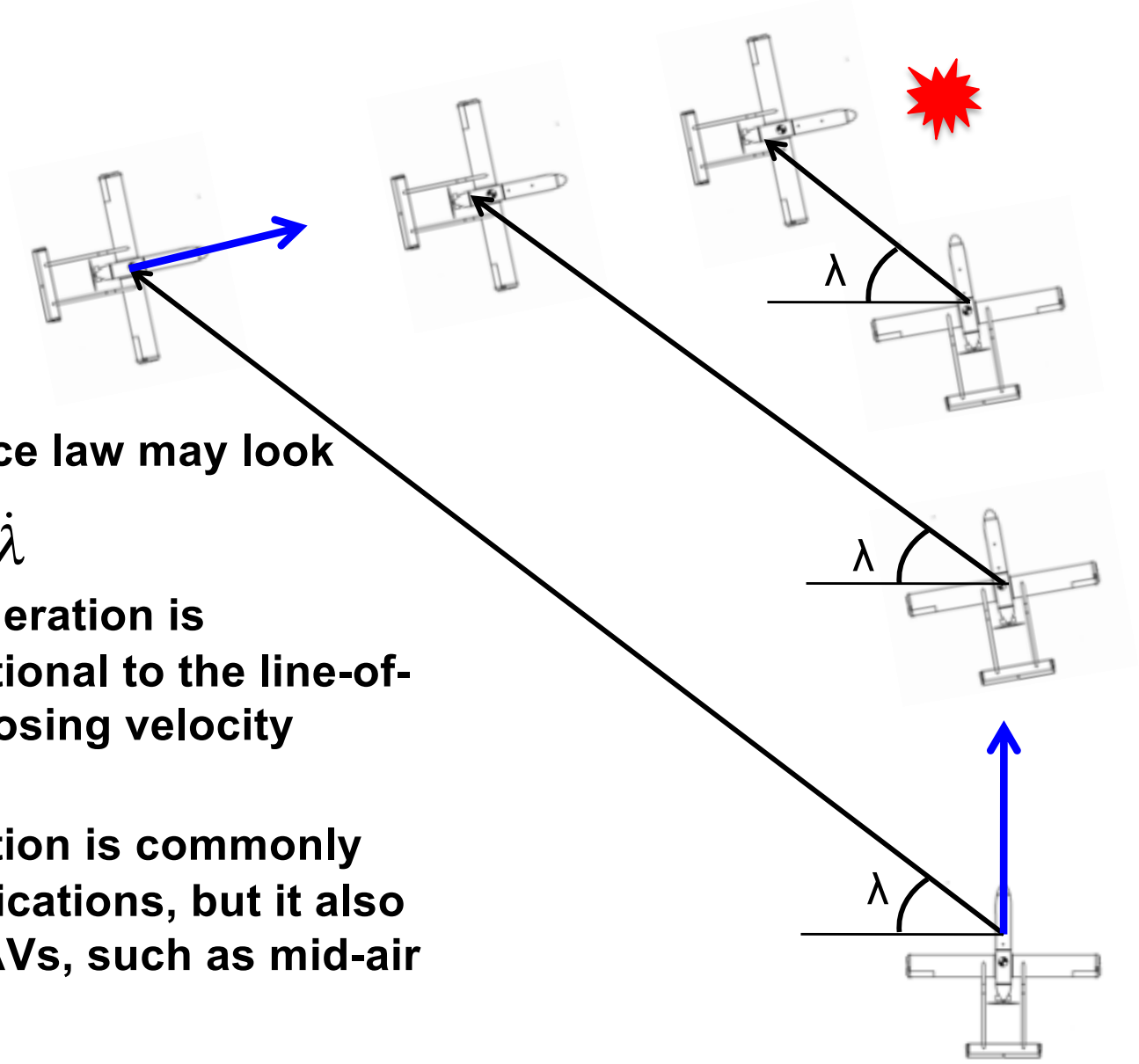
Proportional Navigation



- **Proportional Navigation is based on the principle that two objects are on a collision course when the line-of-sight angle between them remains constant.**

- **By keeping the line-of-sight rate at zero, a collision course can be maintained.**

Proportional Navigation



- **A typical PN guidance law may look like:**

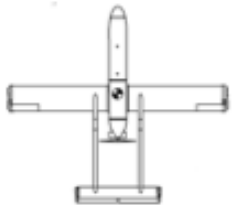
$$a_{comm} = KV_C\dot{\lambda}$$

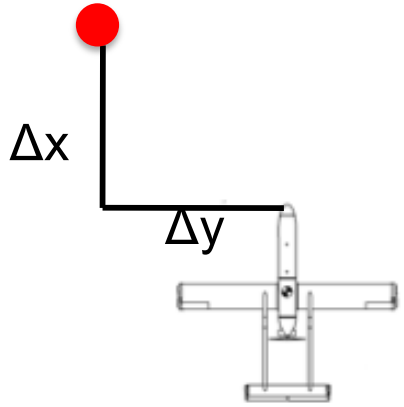
where a lateral acceleration is commanded proportional to the line-of-sight rate and the closing velocity

- **Proportional navigation is commonly used in missile applications, but it also can be used with UAVs, such as mid-air rendezvous**

Formation Flight Problems

- **Some of the most challenging UAV GN&C problems today involve multiple UAVs flying in formation**
- **One application is for UAVs to fly in close formation to take advantage of the drag benefits when flying in the upwash of the lead vehicle**
- **The Guidance system tries to find the optimum location behind lead vehicle to maximize the performance benefits by tracking the throttle setting at different relative positions**
- **Autopilot uses throttle control and fine steering control to maintain the desired x and y position behind the lead vehicle**





References

1. Raymer, D.P.,*Aircraft Design: A Conceptual Approach*, AIAA Education Series
2. McCormick, B.W.,*Aerodynamics, Aeronautics and Flight Mechanics*, 2nd edition, Wiley & Sons, 1995
3. E. Field, MAE 154S, Mechanical and Aerospace Engineering Department, UCLA, 2001
4. B.L. Stevens, F.L. Lewis, *Aircraft Control and Simulation*, John Wiley & Sons, 1992
5. P. Zarchan, *Tactical and Strategic Missile Guidance*, AIAA, 2007