Safety Analysis Methodology for UAV Collision Avoidance Systems

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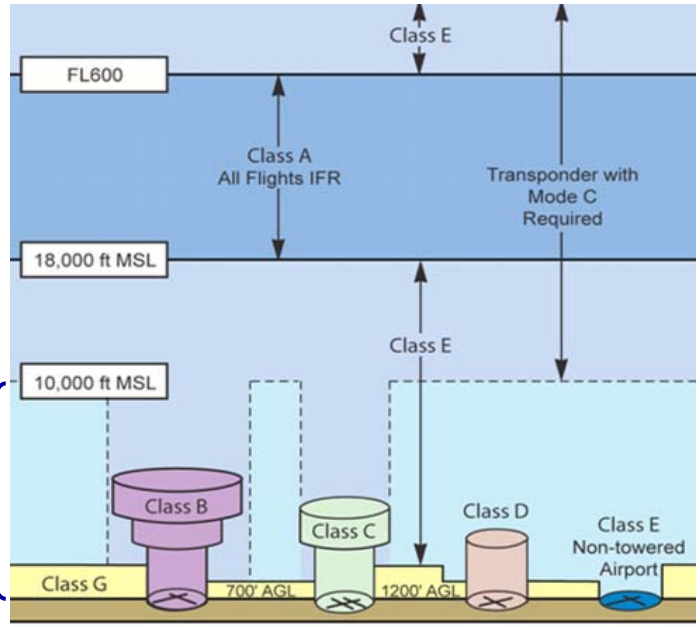
See-and-Avoid Requirement to Operate Within Civil Airspace

Federal Aviation Regulation
14 CFR Part 91.113 b

Vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft



Some aircraft without transponders

Some aircraft not in contact with ATC

Global Hawk Certificate of Waiver or Authorization

IFR flight plan plus:

- **Primary radar, or**
- **Visual observation (air or ground), or**
- **Forward and side looking cameras, or**
- **Electronic detection equipment**

On-Board UAV Collision Avoidance Systems

- **See-and-avoid systems (visual, IR, laser, radar)**
  - **Potential to satisfy see-and-avoid requirement and enable file-and-fly access**
  - **Under development (limited flight demonstrations)**

- **Traffic Alert and Collision Avoidance System (TCAS)**
  - **Existing, well-understood, certified (for manned aircraft)**
  - **Not a complete solution**

    Detects only cooperative / transponder aircraft

UAV Collision Avoidance System Concerns

- **Lack of on-board pilot to monitor and respond**
  - **Remote pilot response to resolution advisories**
    - **Communication and control latencies can induce collisions**
  - **Autonomous response to resolution advisories**
    - **Reliability requirements, ability to detect failure and intervene**
  - **Use of traffic display**
    - **Cannot aid visual acquisition; not intended to support maneuvering**

- **UAV performance characteristics**
  - **Different types of encounters with air traffic (low airspeed, high vertical rate)**
  - **Maneuvering limits may constrain response**

- **Interoperability: ATC, TCAS, see-and-avoid on other aircraft**

Global Hawk TCAS Safety Study

- **Objectives**
  - **Build agreement between FAA, ICAO, and USAF on certification process**
  - **Design and implement safety analysis infrastructure**
  - **Perform safety analysis of TCAS on Global Hawk, reach certification decision**
  - **Test-case to trailblaze certification process for future see-and-avoid systems**

- **Coordination**
  - **US Department of Defense (Air Force, Navy)**
  - **FAA (Certification, Flight Standards, Air Traffic)**
  - **Industry (Northrop Grumman, Honeywell, MITRE/CAASD, Access 5)**
  - **RTCA SC-147 (TCAS), RTCA SC-203 (UAVs)**
  - **ICAO Surveillance and Conflict Resolution Systems Panel (SCRSP)**

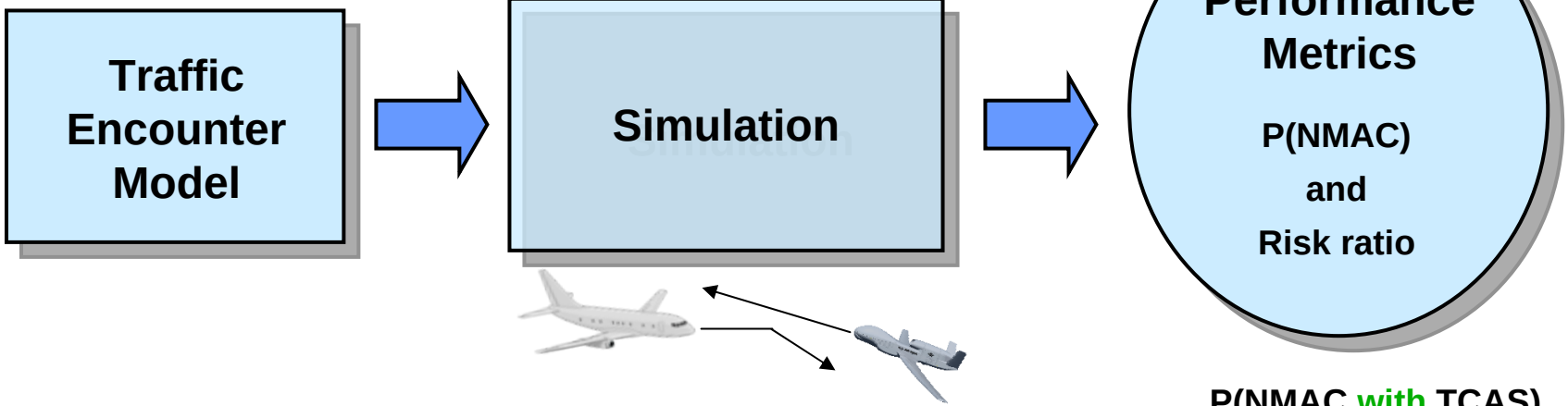
Safety Study Composition

- **Collision avoidance performance is sensitive to situation, pilot/vehicle response**
  - **Flight tests / demonstrations are useful for extracting system characteristics and limited validation, but cannot explore all situations**

- **Core: fast-time simulation over broad range of conditions**
  - **Simulate millions of representative traffic encounters**
  - **Compile statistics: safety with TCAS relative to safety without TCAS**
  - **Couple with failure mode analysis and variations in pilot/vehicle response**

- **Suitability**
  - **Process based on accepted methods that have evolved over years of TCAS development in US and Europe**
  - **General agreement that process is appropriate for TCAS, UAVs, and see-and-avoid systems (included in ICAO ACAS Manual)**

Safety Assessment Elements

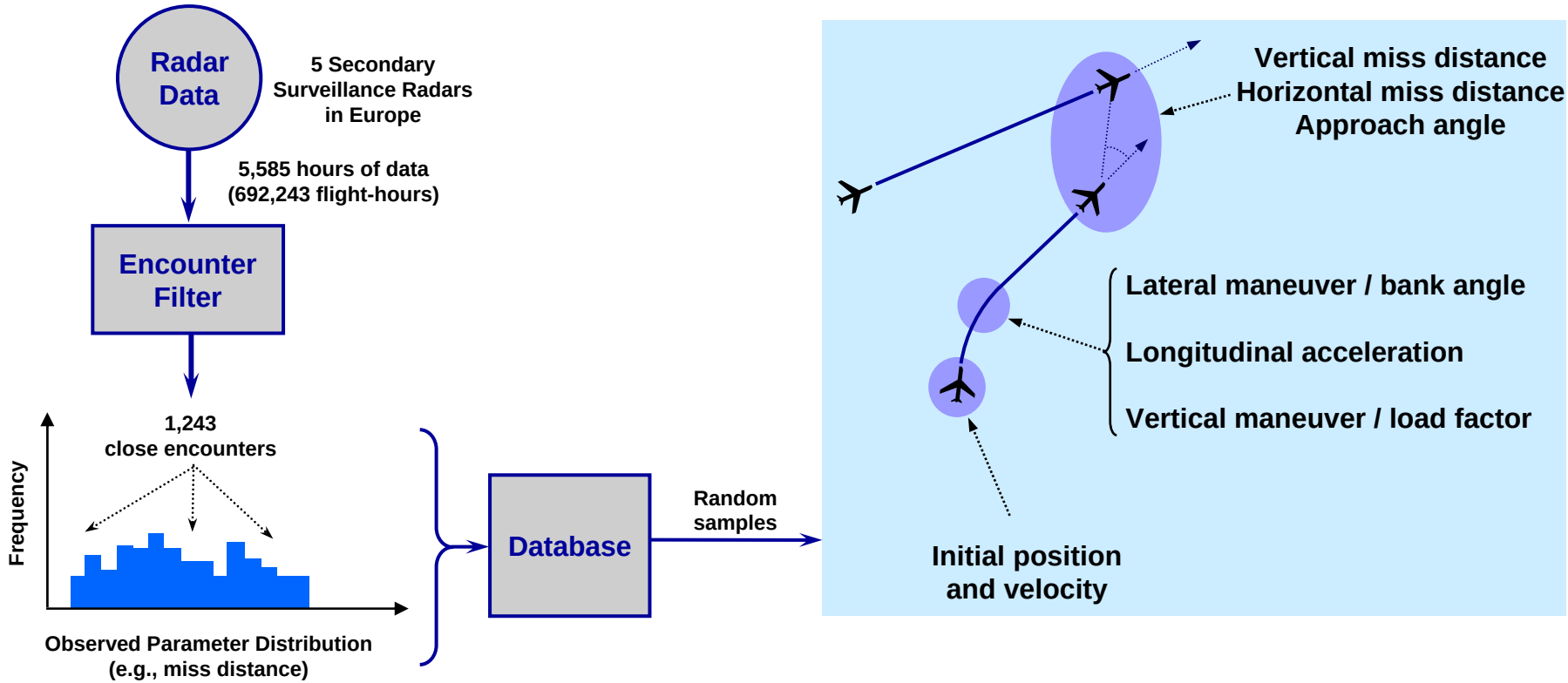


Near Mid-Air Collision (NMAC)
< 500 ft horizontal and < 100 ft vertical separation

Encounter Model Development

Large set of operationally-realistic close encounters (characteristics and likelihoods)

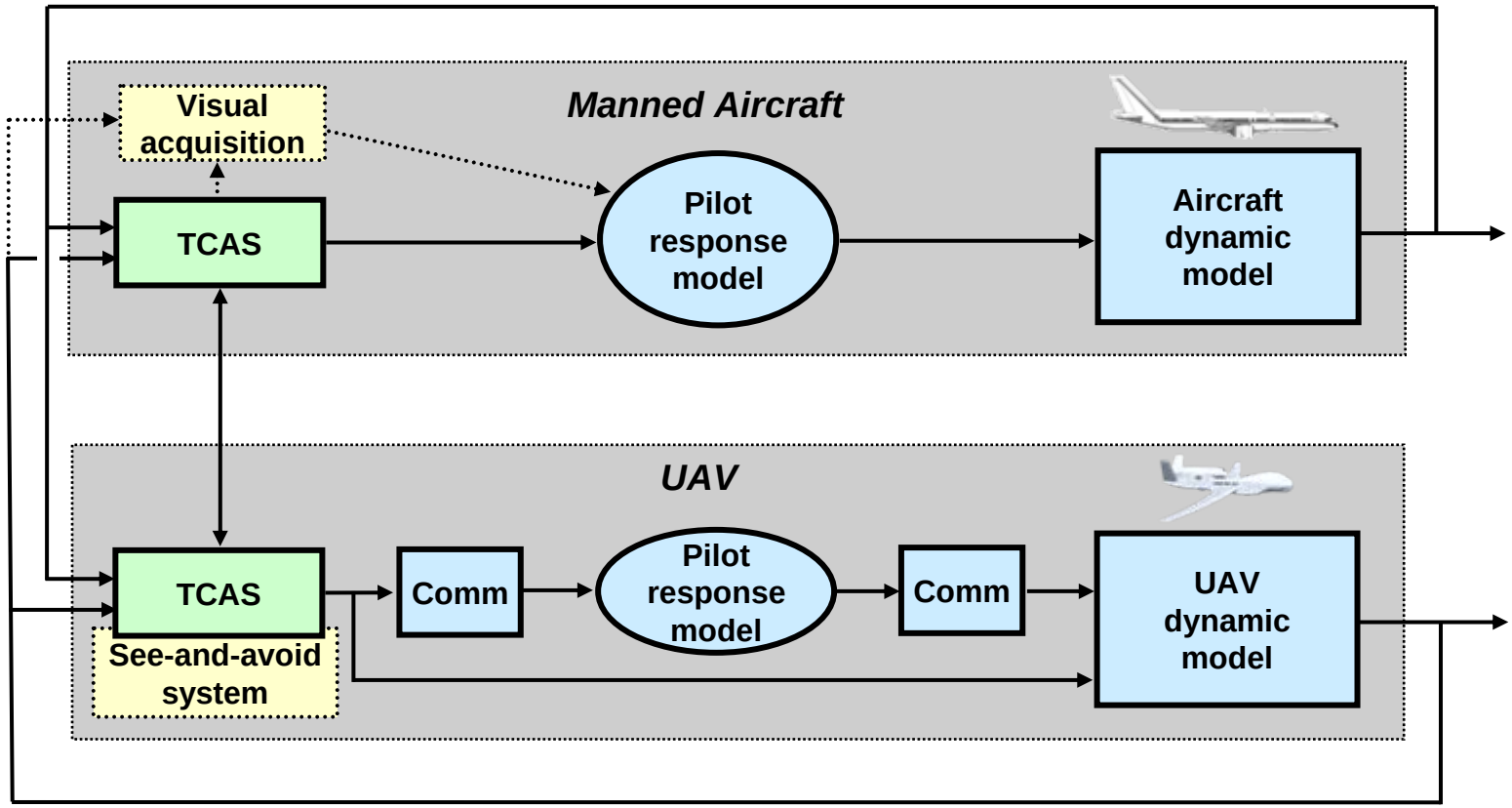
Example: Eurocontrol TCAS Study (2001)



Encounter Model Status

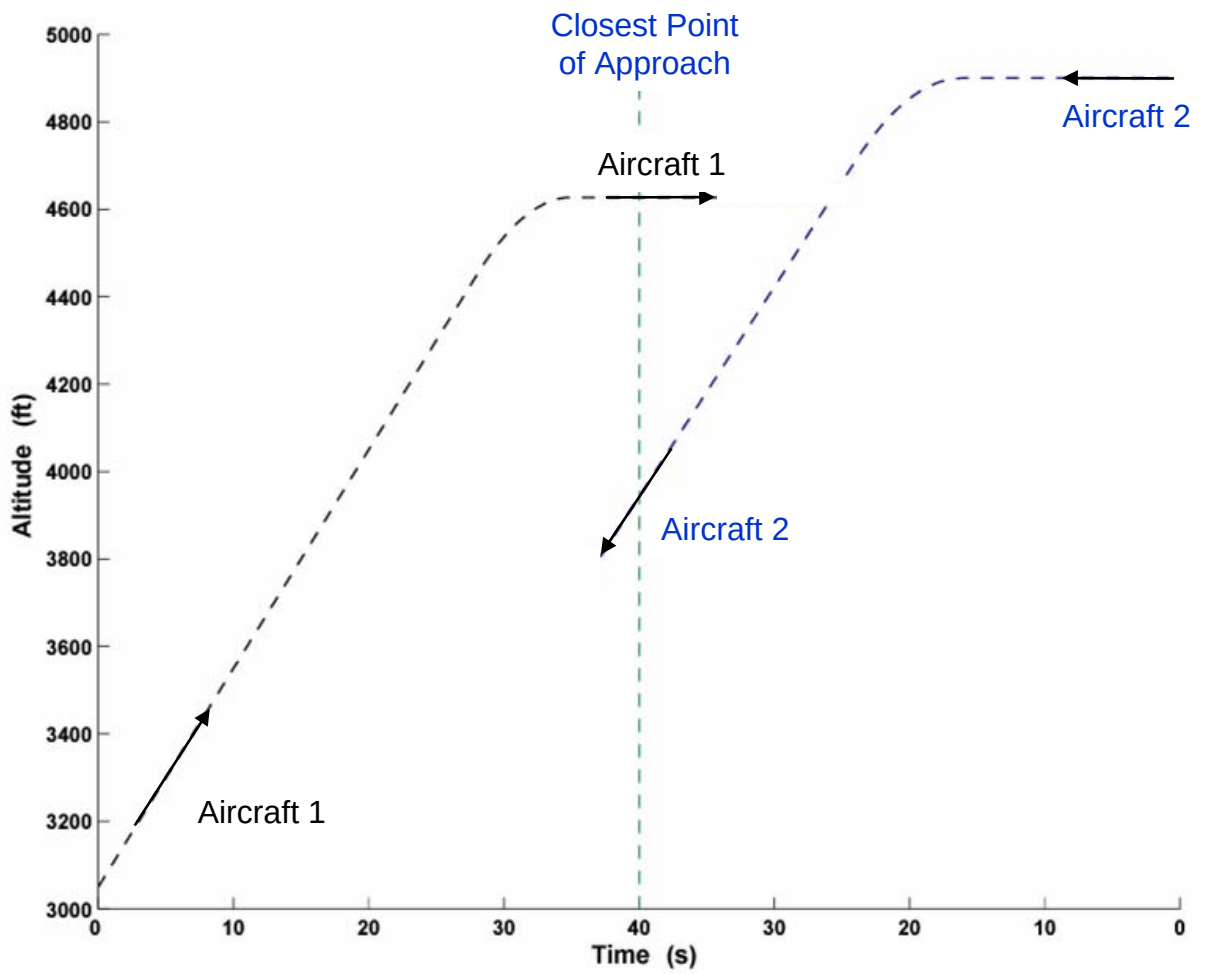
- Several encounter models are available from prior TCAS studies
  - ICAO standard model (1990s US + European data); European model (2001)
  - Currently implemented in Lincoln Lab simulation framework
- New models are needed
  - Existing models do not capture UAV flight profiles
  - Traffic data outdated (old fleet mix), limited coverage (e.g., Europe only)
- Near-term efforts
  - Currently adapting existing models for Global Hawk flight profile
  - New US encounter model

Simulation Components

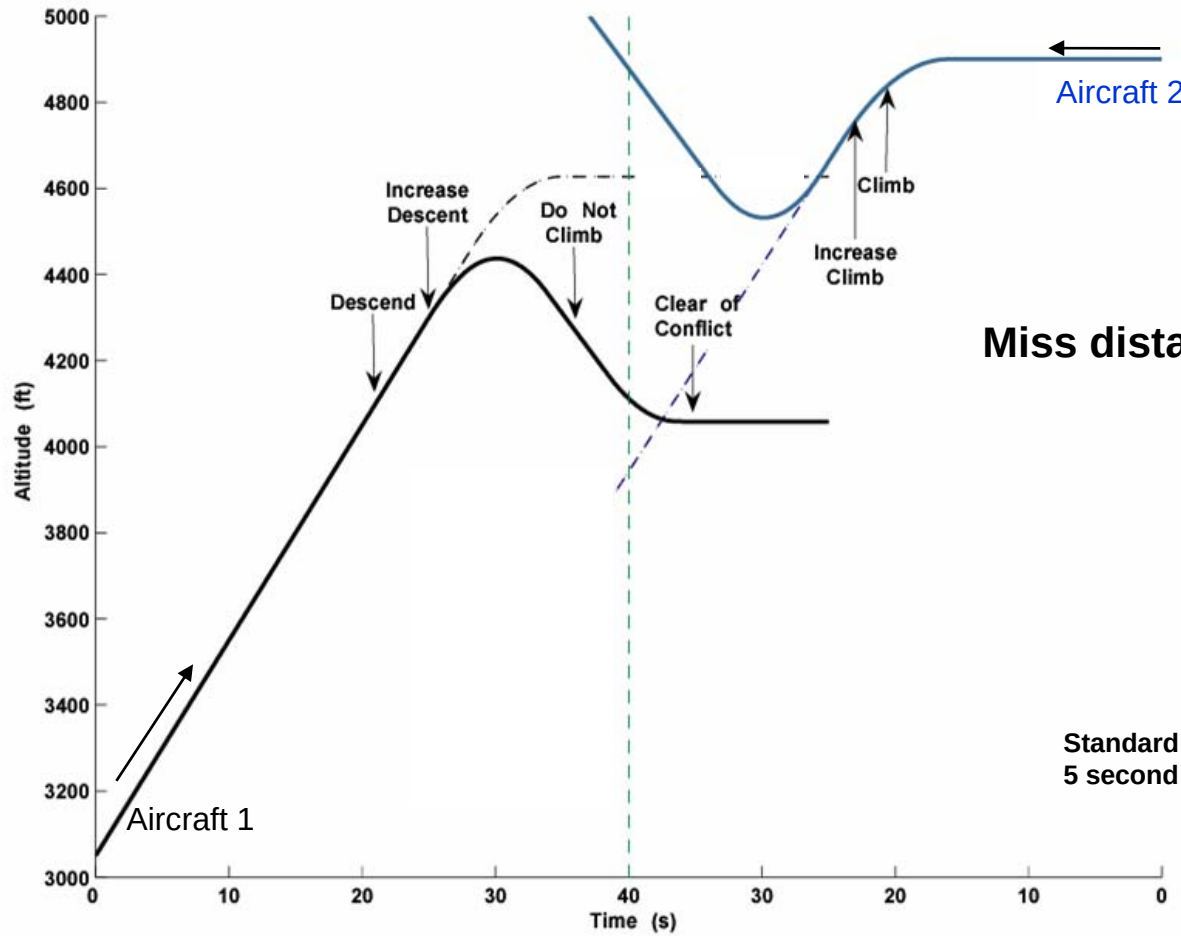


= areas of planned growth

Example Encounter Scenario: Late Descent by Aircraft 2



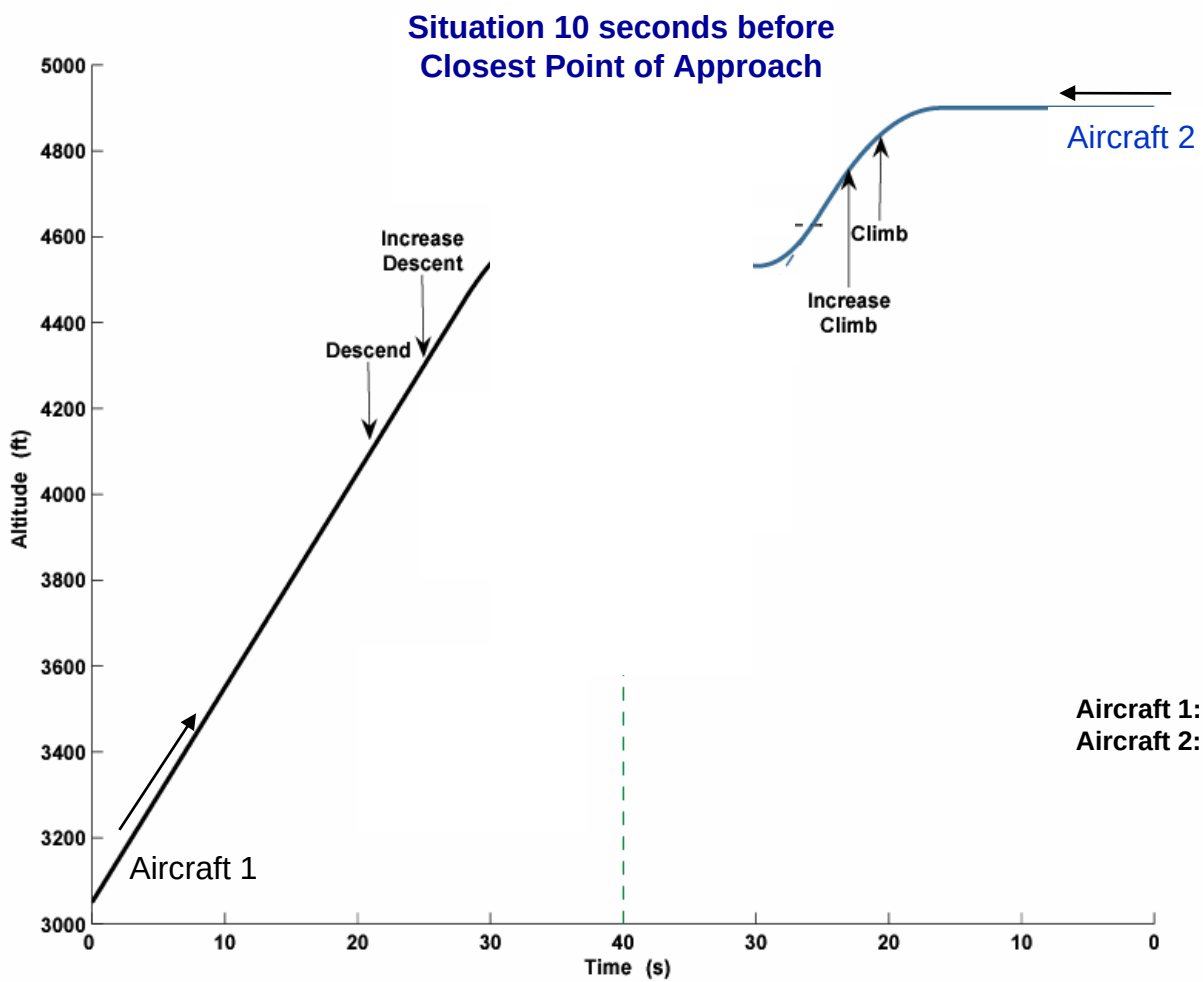
Example Encounter Scenario with TCAS



Miss distance: 725 ft

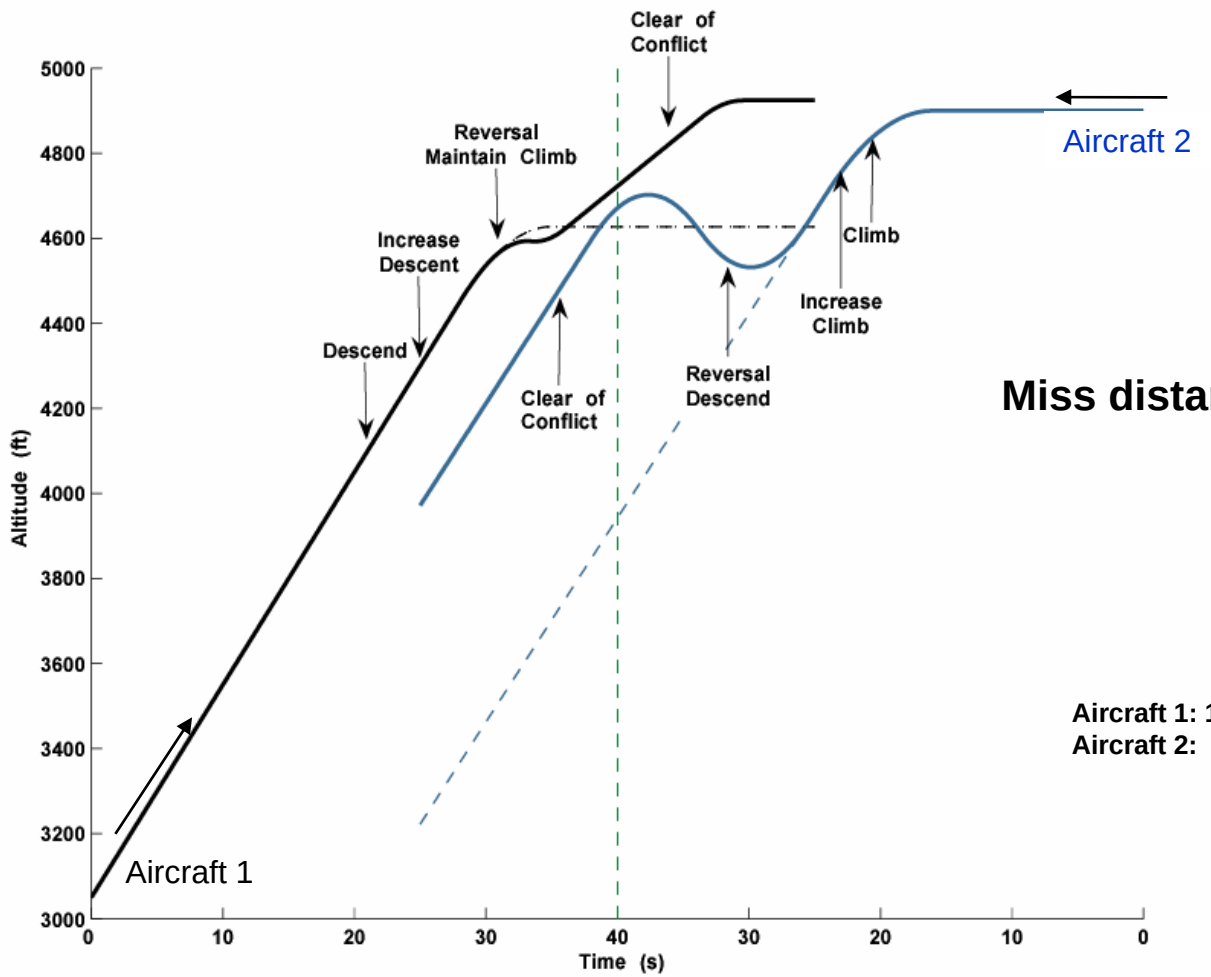
Standard pilot response model
5 second delay for both aircraft

Example Encounter Scenario with TCAS and Increased Delay for Aircraft 1



Aircraft 1: 10 second delay
Aircraft 2: 5 second delay

Example Encounter Scenario with TCAS and Increased Delay for Aircraft 1

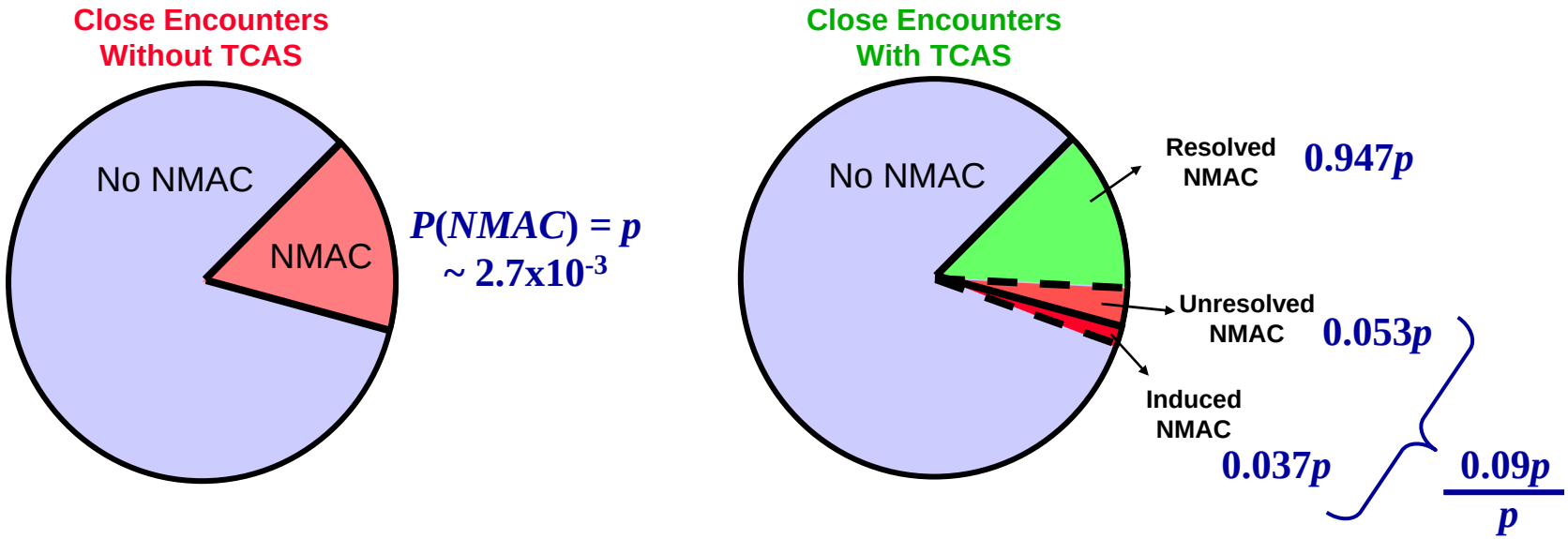


Miss distance: 60 ft

Aircraft 1: 10 second delay
Aircraft 2: 5 second delay

Statistical Analysis

Example: European Model with Conventional Aircraft

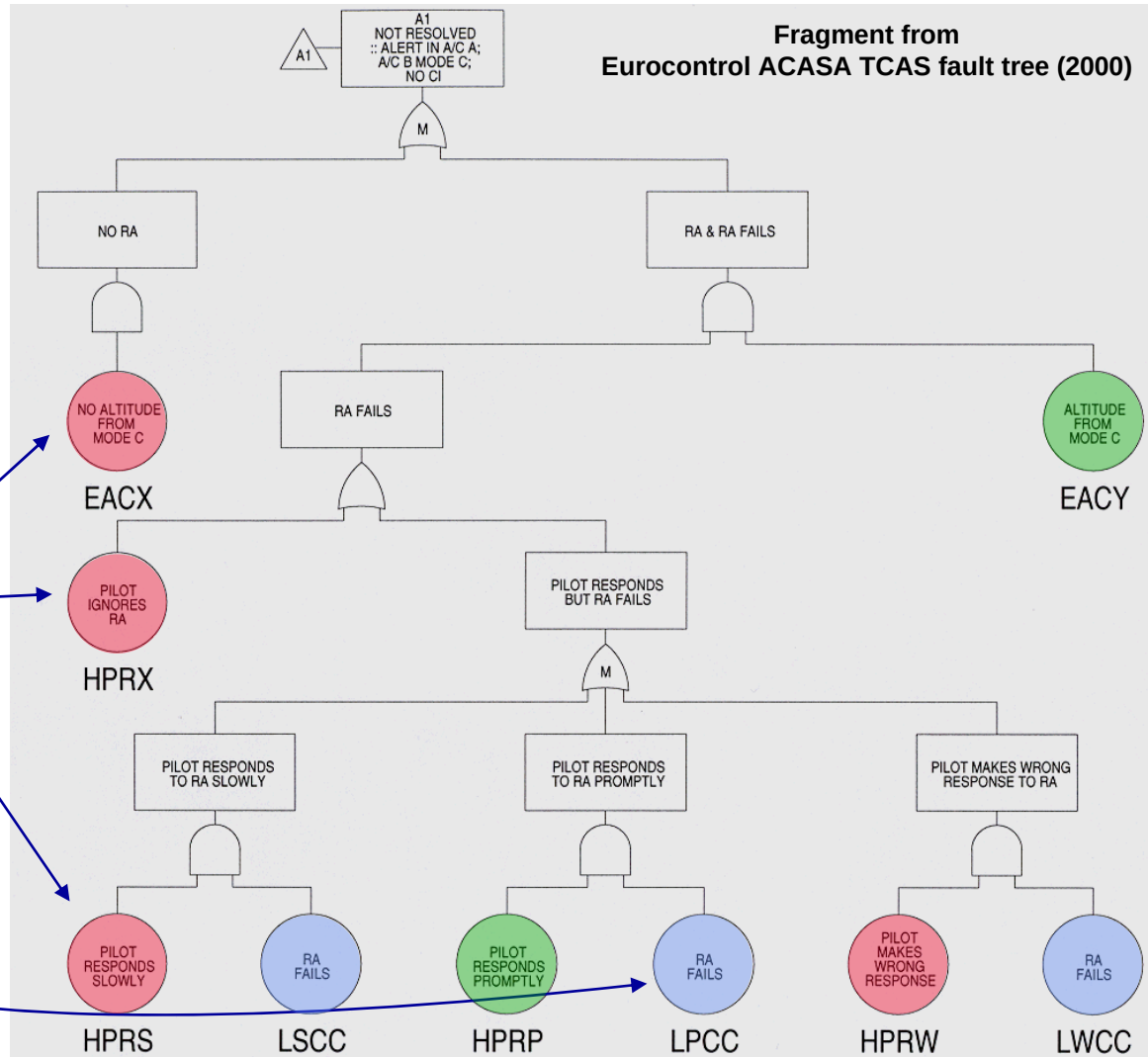


- **Logic Risk Ratio for TCAS equipage = 9%**
  - **Of which 3.7% is due to induced risk**
  - **Ideal conditions (no failures, pilots respond correctly)**
  - **Also compute logic risk ratios for other cases**

System Risk Ratio: Fault Tree Analysis

Includes consideration of
- System failures
- Mixed intruder equipage
- Variable pilot response
- ATC intervention

Eurocontrol study:
- System Risk Ratio ~ 27%



Summary

- **UAV Collision Avoidance Systems are under development to improve safety and meet see-and-avoid requirement**
  - **Complex dynamic problem**
  - **Safety concerns must be resolved with high level of confidence**
- **Safety analysis method has been defined and implemented**
  - **Certification requires broad statistical simulation and analysis**
  - **Accepted through close interaction with FAA and ICAO**
- **Initial analysis: TCAS on Global Hawk**
  - **Provide data to support certification decision-making**
  - **Extension to see-and-avoid systems also underway**