INVESTIGATION OF CONFORMANCE MONITORING APPROACHES IN ATC ENVIRONMENTS

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BACKGROUND

- **New technologies enable enhanced surveillance and communication of aircraft states**
  - E.g. ADS-B & CPDLC
- **Future ATC concepts propose use of enhanced dynamic and intent states for tactical and strategic functions, e.g. airborne self-separation, ground-based TFM**
  - NASA DAG-TM
  - Eurocontrol Air Traffic Management Strategy for the Years 2000+
  - Boeing Air Traffic Management Concept
    - "Trajectory-based" traffic planning & separation management
- **"Trajectory-based" control solutions most effective if aircraft follow expected trajectory**
- **Need to check for adherence to expected trajectory to assess validity of control solutions: "conformance monitoring"**

CONFORMANCE MONITORING

- **Current FAA and Eurocontrol systems use position relative to active flight plan**
- **Enhanced surveillance & communication of states may enable more effective conformance monitoring systems with concomitant positive impacts on system operation**
  - ❑ Air-based monitor using broadcast states as baseline for self-separation
  - ❑ Ground-based monitor using assumed trajectory for TFM
- **Added interest in conformance monitoring in light of events of September 11, 2001**
  - ❑ Detection of ‘rogue’ aircraft deviating from cleared or nominal procedure trajectories
- **Research goal: investigate conformance monitoring approaches in current and future ATC environments with varying levels of aircraft dynamic and intent state information**

RESEARCH APPROACH

① **Define framework to represent aircraft state availability in different operational environments**

② **Develop models of conformance monitoring functions using state framework**

③ **Design conformance monitoring algorithms as functions of:**

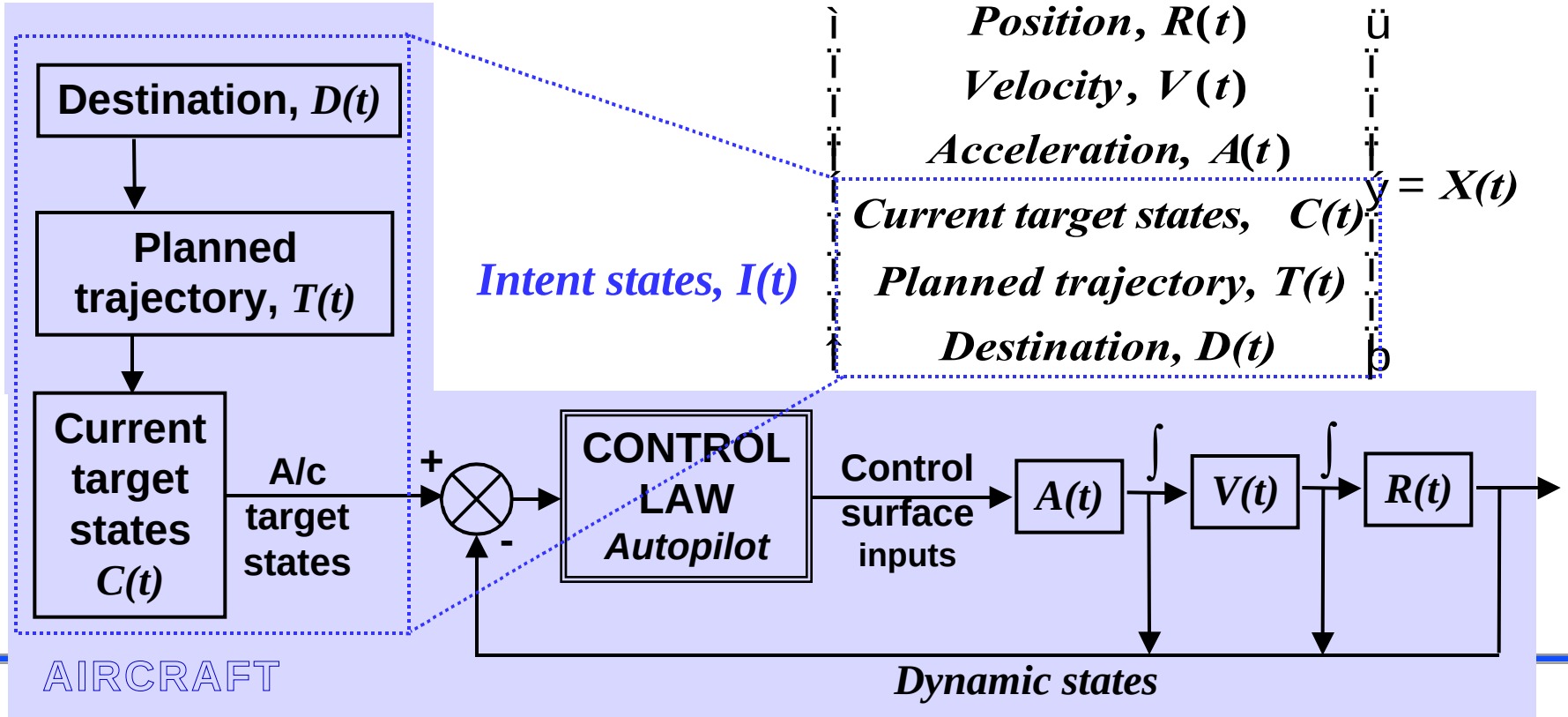
- ❑ Operational scenarios of interest
- ❑ State availability environments
- ❑ Metrics of interest

④ **Design and conduct experimental studies to refine/analyze approaches under various current and future ATC environments**

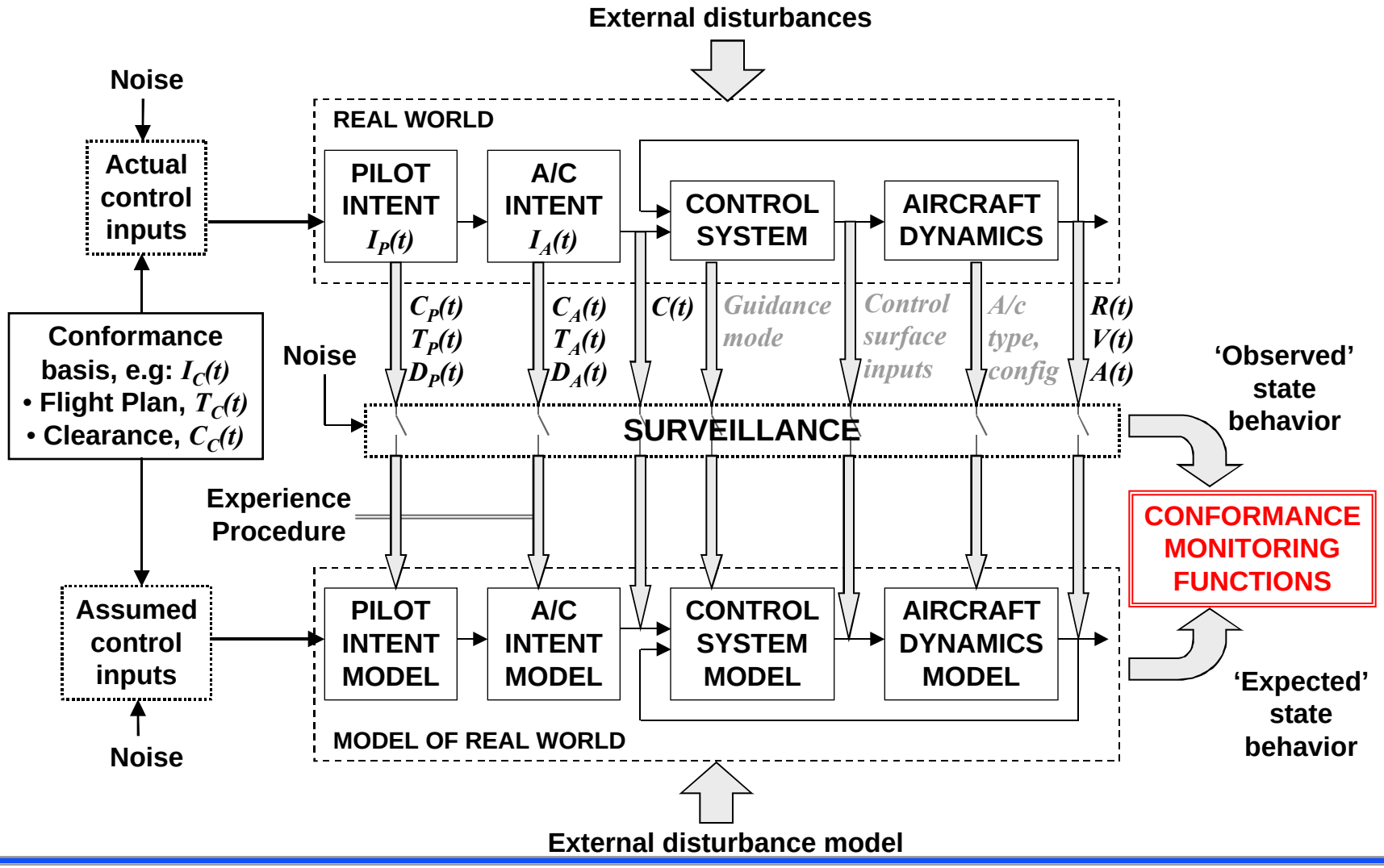
⑤ **Assess implications of approaches (e.g. for ADS-B message contents)**

① AIRCRAFT STATE REPRESENTATION: SURVEILLANCE STATE VECTOR

- **Surveillance state vector approach formalizes relationship between dynamic and intent states in a way consistent with:**
  - ❑ Traditional control systems driving to a target state
  - ❑ The way the FMS uses a linked series of target states to generate a trajectory to control the route to the desired destination

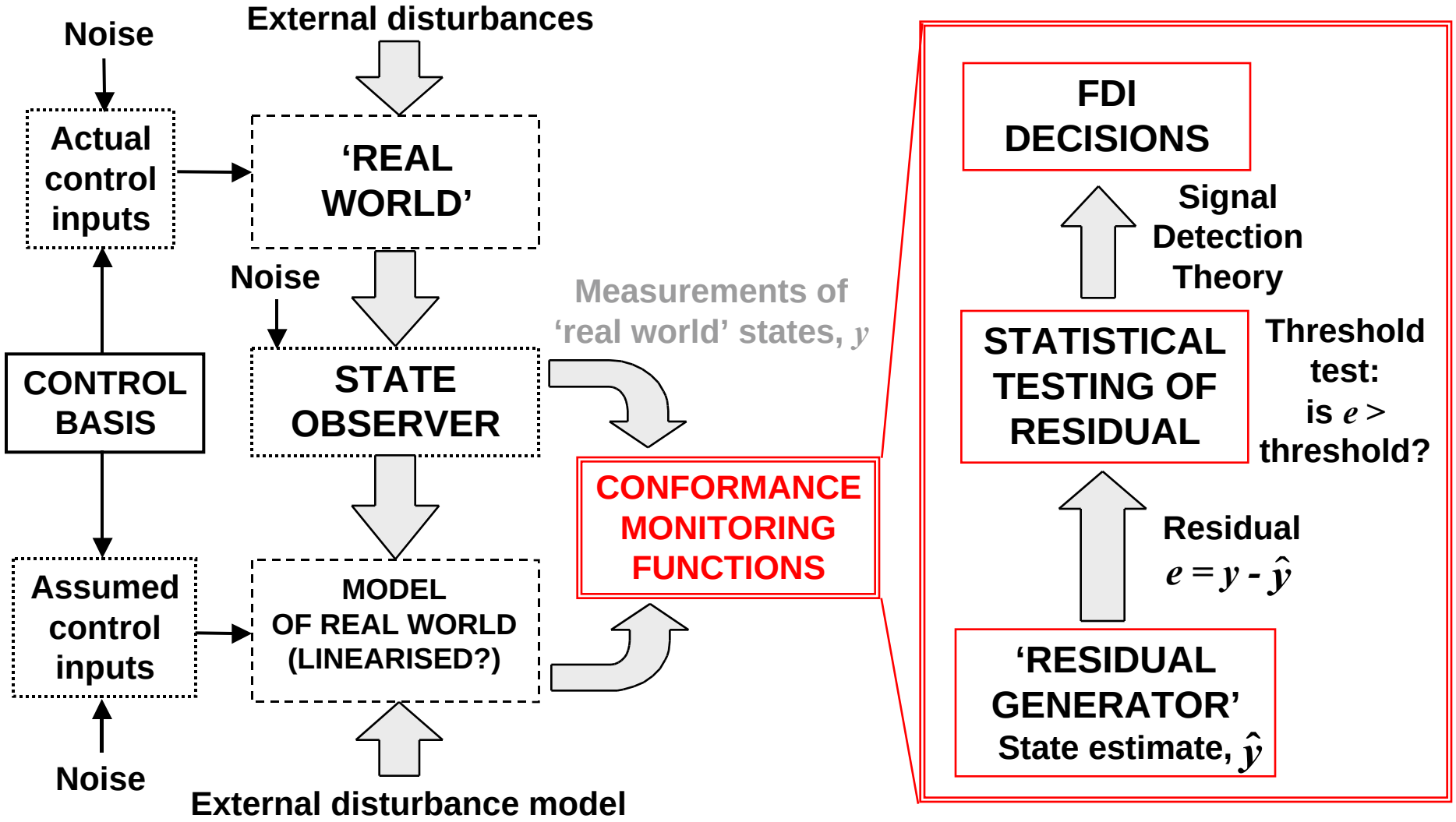


② PROPOSED CONFORMANCE MONITORING APPROACH



Note: Subscript C = controller, P = pilot, A = aircraft

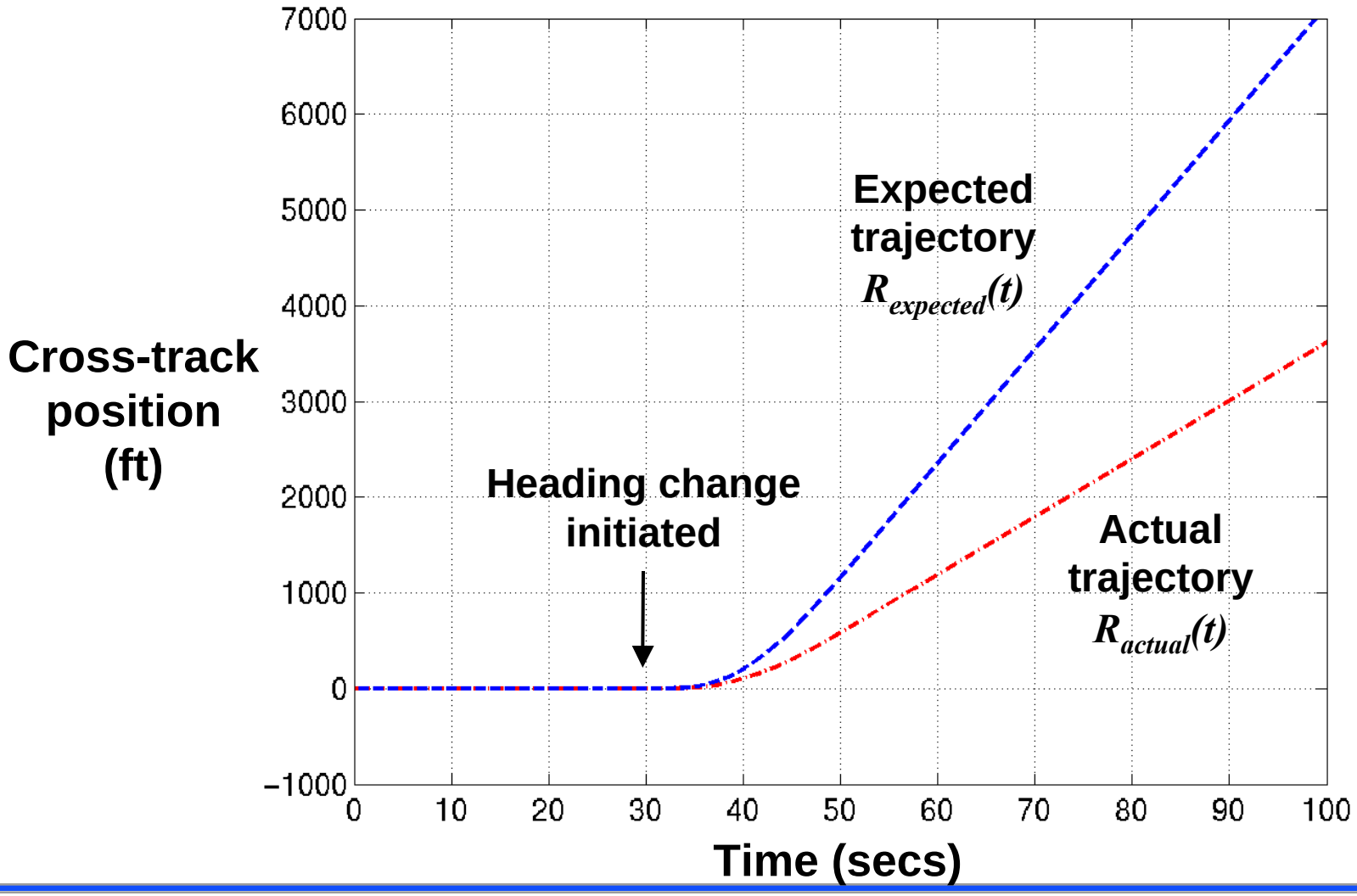
PARALLELS TO CLASSIC FAULT DETECTION & ISOLATION (FDI)



③ USING FDI APPROACHES TO DESIGN CONFORMANCE MONITORING ALGORITHMS

- **Fault detection: detecting when *observed* system behavior is different to *expected* behavior based on assumed system model**
  - ❑ Analogous to conformance monitoring function
- **Fault isolation: isolating where the failure has occurred for system reconfiguration purposes**
  - ❑ Run models of ‘degraded’ system behavior to establish failure location
  - ❑ Analogous to intent inferencing function using modified system behaviors
- **Steps to pursue FDI approach to conformance monitoring:**
  - ❑ Define conformance monitoring scenarios of interest
  - ❑ Construct models of expected system performance under scenarios
    - ➪ Linearised models or Flight simulator
  - ❑ Develop residual generator
    - ➪ Depends on form of system model
  - ❑ Develop decision logic
    - ➪ Statistical testing algorithms

EXAMPLE SCENARIO: HEADING CHANGE 20 deg expected, 10 deg actual

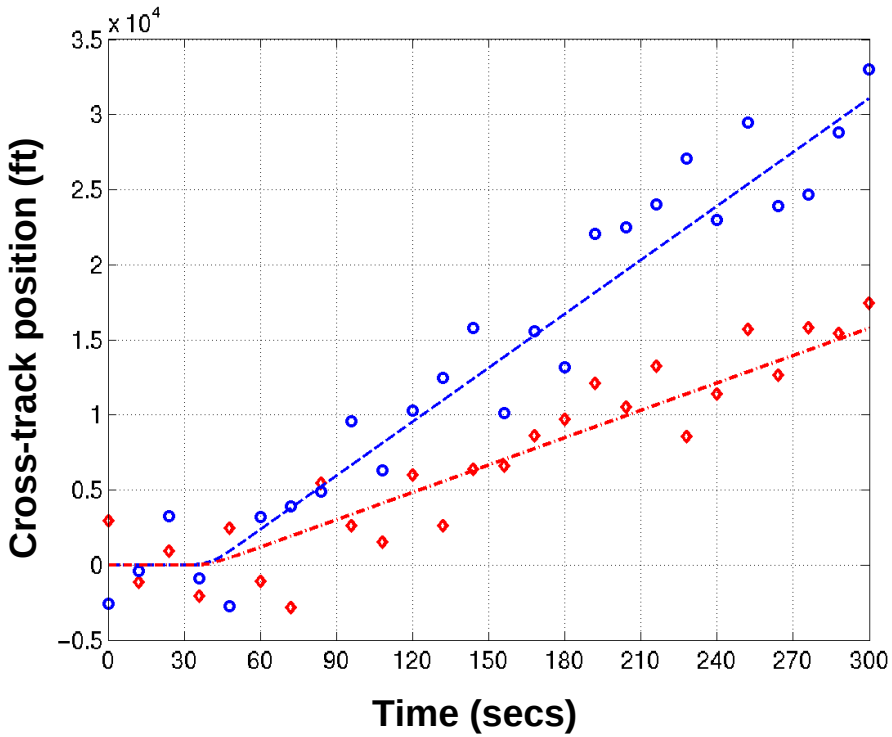


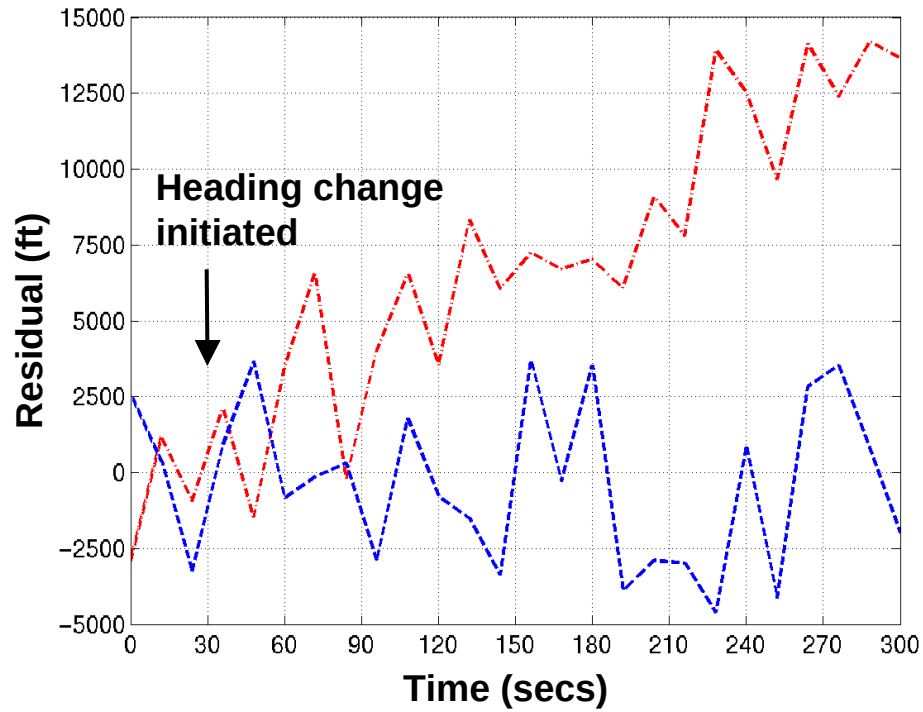
SIMULATION

- **MATLAB/Simulink model developed of heading capture guidance system coupled to large commercial aircraft dynamics**
  - ❑ 'Actual behavior' model
  - ❑ 'Expected behavior' model used by monitoring system
- **Assume deviation in control input only**
  - ❑ Aircraft flies route perfectly (No wind effects or tracking errors)
  - ❑ Known guidance system/dynamics models & time of maneuver
- **Uncertainty in behavior introduced to monitoring system via modeled noise and update rate of surveillance systems:**
  - ❑ Long range/low update radar (eg ARSR, 12 sec update, 2500 ft sd error[1])
  - ❑ Medium range/medium update radar (eg ASR, 5 sec update, 500 ft sd error[1])
  - ❑ GPS position reporting via ADS-B (1 sec update, 100 ft sd error*)
  - ❑ Heading reporting via ADS-B (1 sec update, 1 deg sd error*)

[1] Radar noise values based on angular accuracy performance at max operating ranges
*** GPS/heading noise values based on published data**

MONITORING USING ARSR RADAR (12 sec update, 2500 ft sd)





Expected trajectory

Actual trajectory

Surveilled expected trajectory

Surveilled actual trajectory

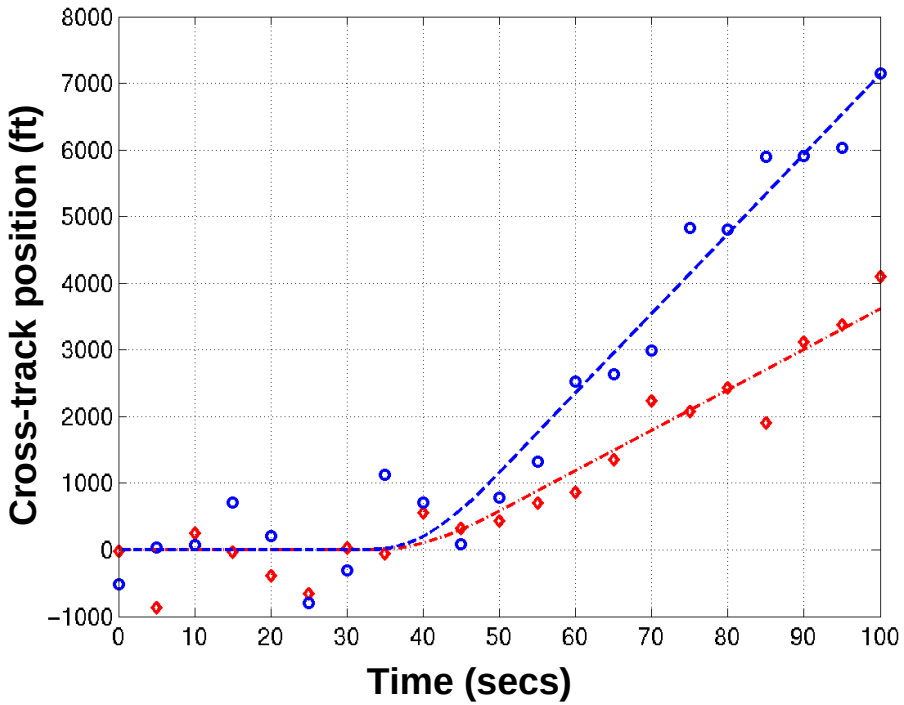
Expected residual

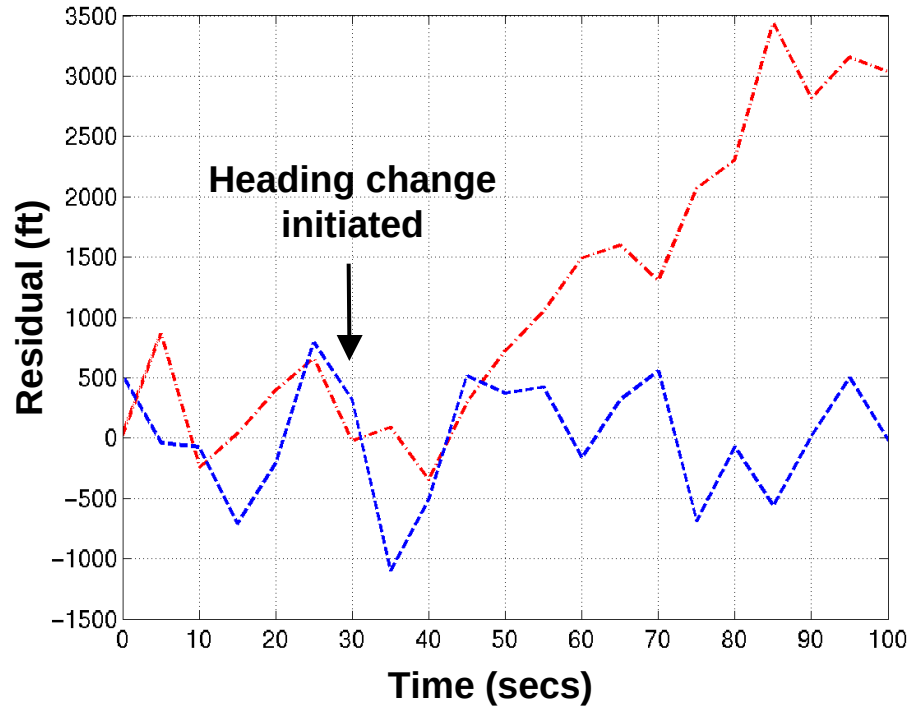
Actual residual

Residual = Expected trajectory - surveilled

Note: Presented results based on one simulation run

MONITORING USING ASR RADAR (5 sec update, 500 ft sd)





Expected trajectory

Actual trajectory

Surveilled expected trajectory

Surveilled actual trajectory

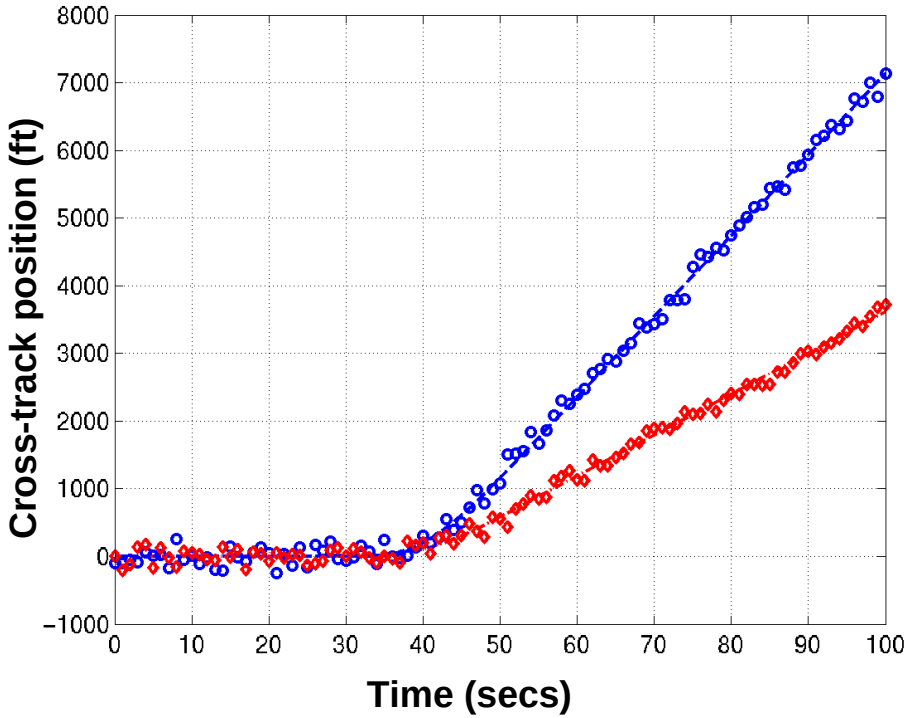
Expected residual

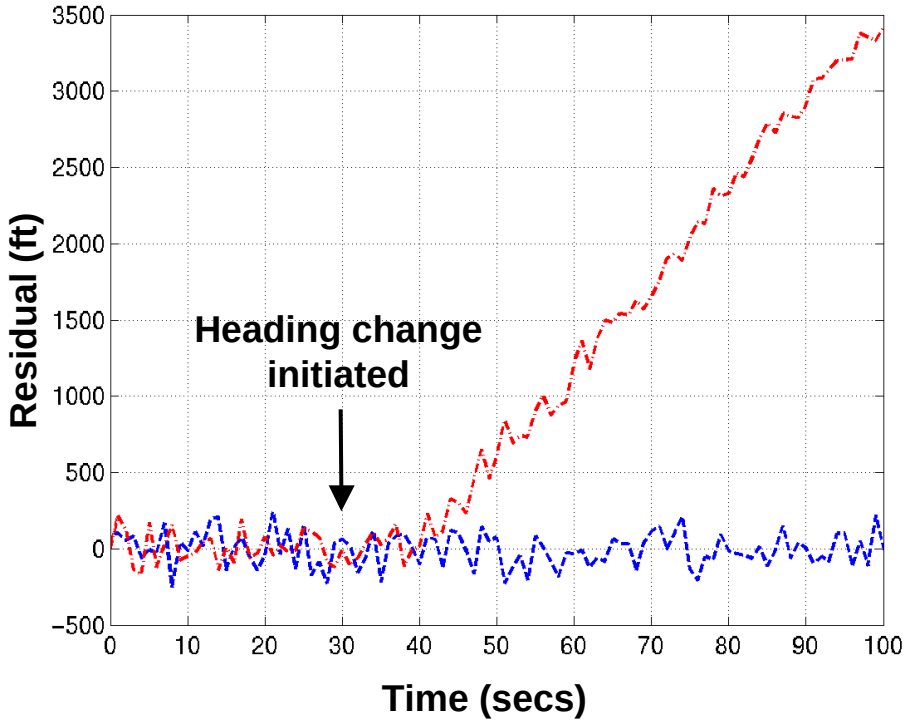
Actual residual

Residual = Expected trajectory - surveilled

Note: Presented results based on one simulation run

MONITORING USING GPS POSITION REPORTED VIA ADS-B (1 sec update, 100 ft sd)





Expected trajectory

Actual trajectory

Surveilled expected trajectory

Surveilled actual trajectory

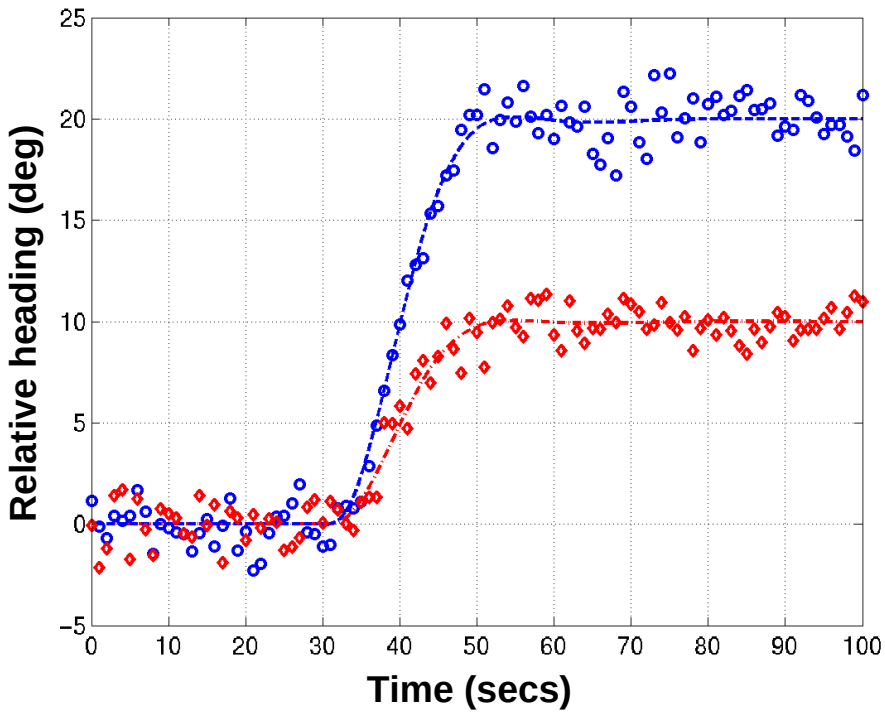
Expected residual

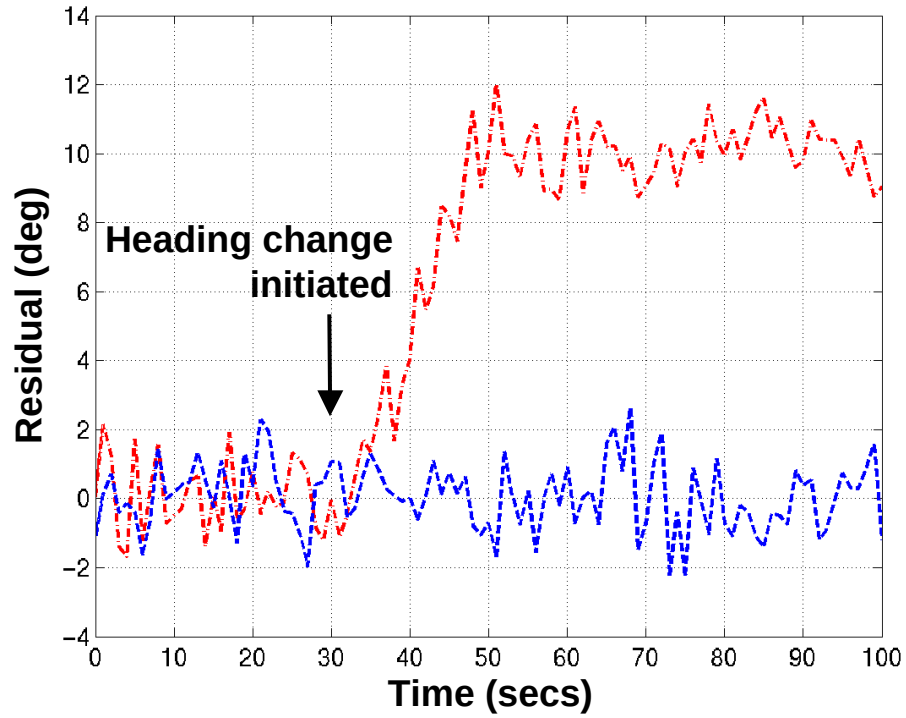
Actual residual

Residual = Expected trajectory - surveilled

Note: Presented results based on one simulation run

MONITORING USING HEADING REPORTED VIA ADS-B (1 sec update, 1 deg sd)





Expected trajectory

Actual trajectory

Surveilled expected trajectory

Surveilled actual trajectory

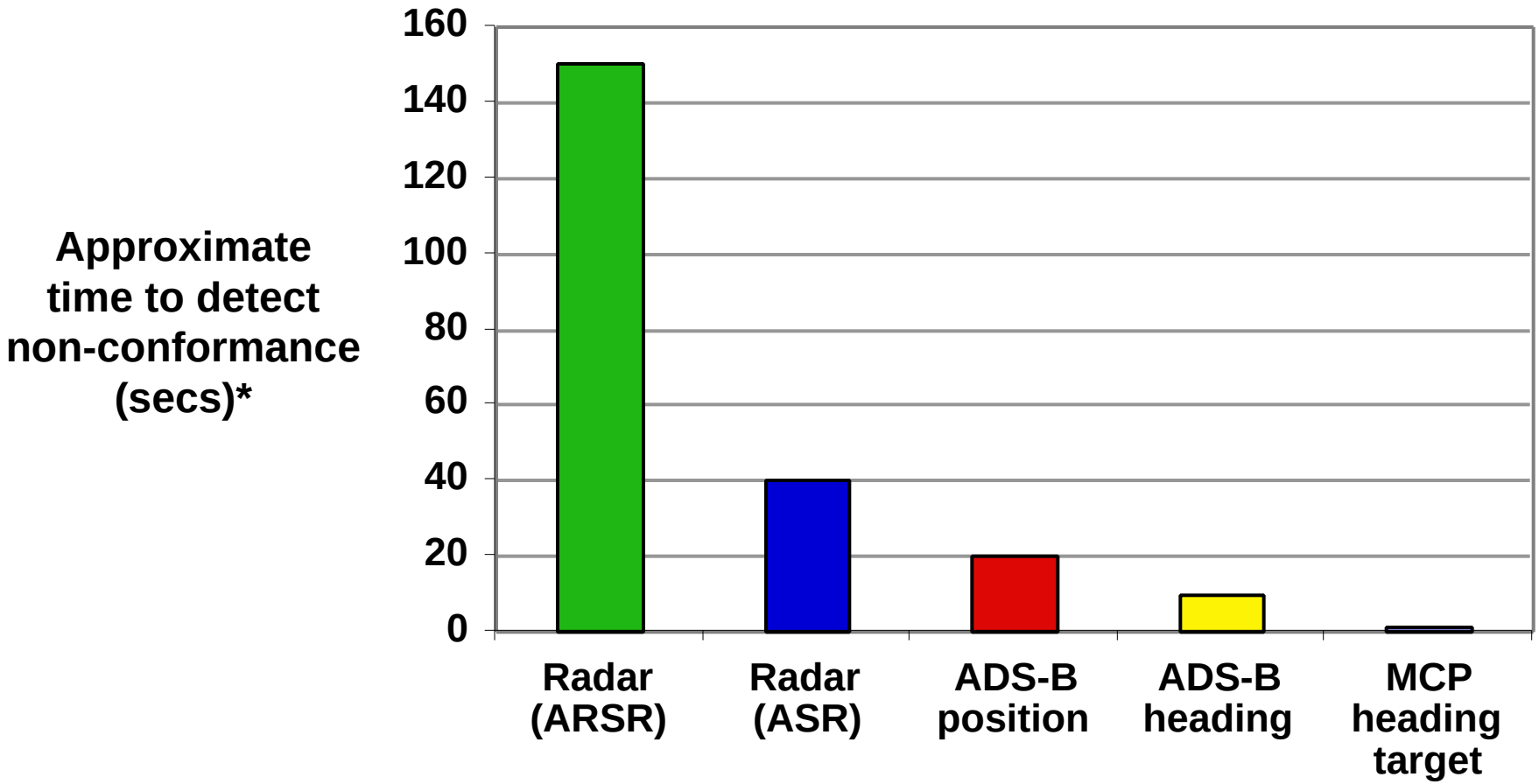
Expected residual

Actual residual

Residual = Expected trajectory - surveilled

Note: Presented results based on one simulation run

IMPACT OF STATE QUALITY AND AVAILABILITY ON TIME TO DETECT NON-CONFORMANCE IN CHOSEN SCENARIO



* assuming 'sensible' threshold placement

CONCLUSIONS

- **Conformance monitoring identified as important function in future ATC environments where enhanced state availability provides opportunity to develop more effective algorithms**
- **Parallels of conformance monitoring to FDI demonstrated**
- **FDI approach implemented for simple example to demonstrate approach and the importance of state quality and availability**
- **Future work:**
  - ❑ Develop approaches for integrating higher order intent states into conformance monitor
  - ❑ Define (more challenging) scenarios of operational interest
  - ❑ Design conformance monitoring algorithms (residual generator and decision logic) and conduct experimental studies to analyze
  - ❑ Assess implications for future ATC operations (e.g. ADS-B message-sets)