Development of a Closed-Loop Testing Method for a Next-Generation Terminal Area Automation System

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Role of Air Traffic Management System

Excerpt from FAA 7110.65:

The Traffic Management System mission is to balance air traffic demand with system capacity to ensure the maximum efficient utilization of the National Airspace System (NAS).

A safe, orderly and expeditious flow of traffic while minimizing delays should be fostered through continued analysis, coordination and dynamic utilization of Traffic Management initiatives and programs.

Development History of (some) ATM Tools

- **First-generation tools provided better estimates of the current traffic condition**
  - » **TMA (B1) determined Estimated Times of Arrival (ETAs)**
- **Second-generation tools provided nominal "schedules" based upon the traffic condition**
  - » **pFAST determined runway assignments and sequences**
  - » **TMA (B2) determined meter fix delays**
  - » **D2 determined direct-to flight plan route amendments**
- **Next-generation tools will provide efficient conflict-free trajectories based upon the schedule**
  - » **aFAST and EDP will determine turn, speed and altitude commands**
  - » **EDA will determine en-route descent clearances**

Vision for Next-Generation Terminal Tools

Develop a system for the terminal area that will ultimately lead to automated air traffic control that meets all of the ATM objectives

- **Needs an operational concept that defines the role of the system in meeting the ATM objectives**
- **Needs an evolution plan that allows gradual deployment into human-centered environment**
- **Needs testing strategies that validate the system performance across a wide operating envelope**

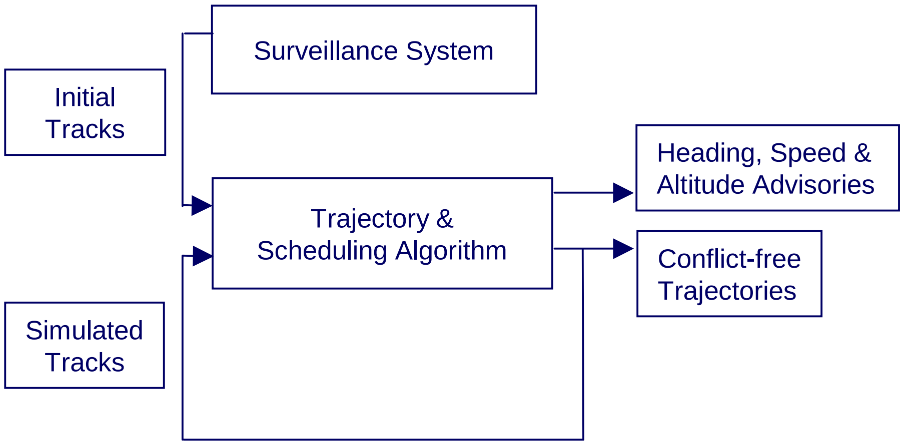
Testing Strategies of (some) ATM Tools

- **First-generation tools could be tested by statistical analysis of their predictions**
  - » Predicted times of arrival were compared with actual times of arrival
- **Second-generation tools could be tested by open-loop subjective evaluations of their advisories**
  - » Advisories were largely strategic and reactive by nature
  - » Open-loop testing allowed evaluation of the initial accuracy and overall responsiveness of advisories
- **aFAST and EDP will require fully closed-loop objective evaluations of the resulting traffic flow**
  - » Turn, speed and altitude advisories are tactical and reflect the underlying aircraft trajectories
  - » Closed-loop testing allows evaluation of the dynamic interaction between the tool and the traffic flow

Motivation for Fully Closed-Loop Testing

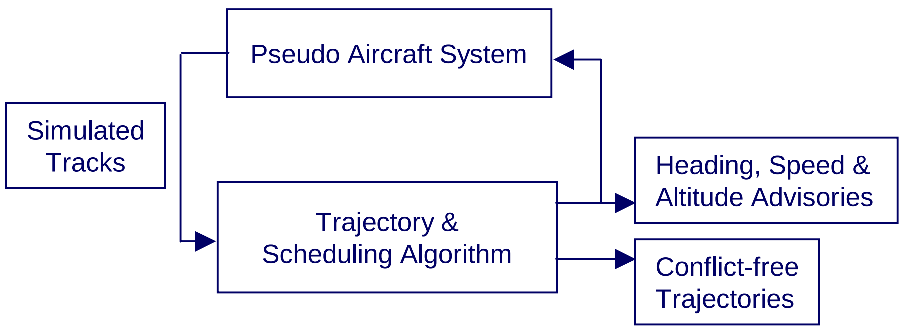
- Provides an appropriate mechanism for validating that aFAST and EDP are safe and effective
  - Uses same logic as operational system
  - Allows experimental control of errors
  - Does not require a fully mature algorithm
- Allows isolation of individual parts of the entire automation system
- Allows investigation of more regions of the operating envelope than any other method
  - Human-in-the-loop simulations are difficult to set up
  - Operational tests are costly and limited in scope
  - Fully closed-loop tests can be executed in fast-time

Fully Closed-Loop Testing Method 1:
Trajectory Feedback



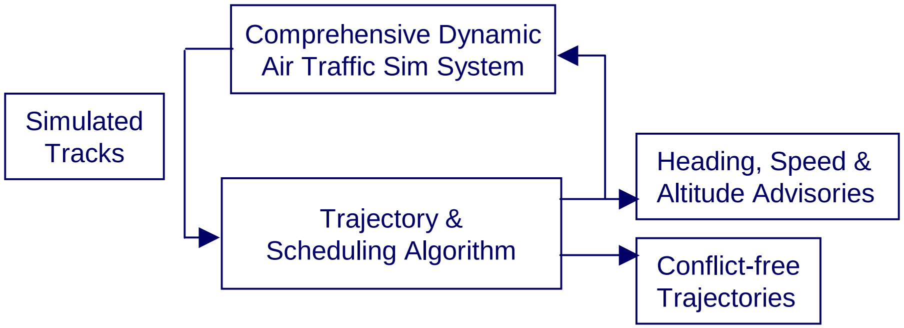
- **Uses surveillance system to generate only initial track**
- **Uses system's own solution trajectory to simulate next track**
- **Represents ideal case**
  - » **perfect state estimation**
  - » **perfect trajectory prediction**
  - » **perfect maneuver execution**
- **Is a necessary but not sufficient condition to prove system stability**

Fully Closed-Loop Testing Method 2:
Advisory Feedback via PAS



- **Uses PAS to generate all tracks**
- **Uses system's own solution advisories to fly simulated aircraft**
- **Represents near-ideal case**
  - » **perfect state estimation**
  - » **imperfect trajectory prediction**
  - » **perfect maneuver execution**
- **Is a necessary but not sufficient condition to prove system stability**

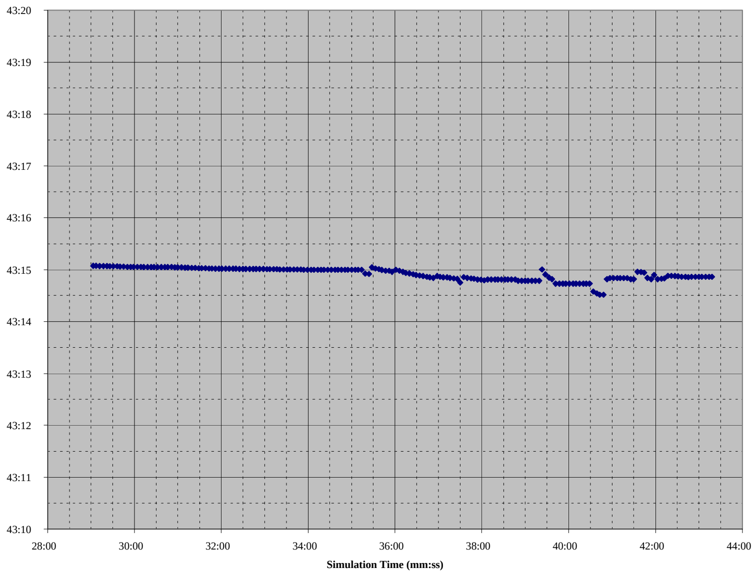
Fully Closed-Loop Testing Method 3:
Advisory Feedback via ComDATSS



- **Uses ComDATSS to generate all tracks**
- **Uses system's own solution advisories to fly simulated aircraft**
- **Models many sources of error throughout the NAS**
- **Is a necessary but not sufficient condition to prove system stability**

Validation of the aFAST Trajectory Feedback Testing Method

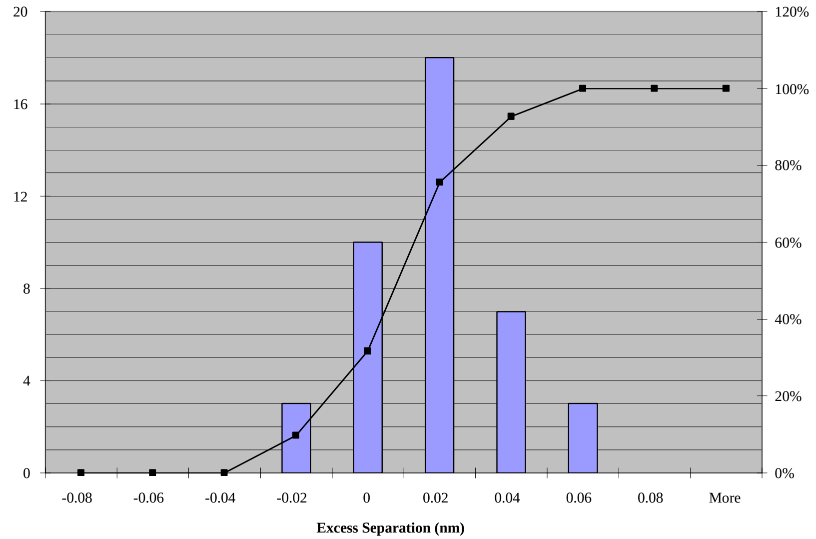
ETA Time History for a single unconstrained arrival aircraft



- **Unconstrained ETA variation bounds the precision of the observable results**
- **Peak-to-Peak ETA Variation was small**
  - » **Mean 0.41 s**
  - » **StdDev 0.15 s**
- **Cumulative ETA Change was small**
  - » **Mean 0.17 s**
  - » **StdDev 0.10 s**
- **Trajectory feedback results are valid to within less than one second**

Results of initial aFAST Trajectory Feedback Testing

Excess separation histogram for a scenario comprised of 42 aircraft to a single arrival runway



- **Excess separation represents effectiveness of aFAST turn, speed and altitude advisories**
- **Excess separation was small w.r.t. desired separation (approximately 3.0 nm)**
  - » **Mean 0.0066 nm (~0.13 s)**
  - » **StdDev 0.021 nm (~0.43 s)**
- **Mean excess separation is comparible to mean ETA peak-to-peak variation**
- **StdDev excess separation is comparible to mean cumulative ETA change**

Next Steps

- **Validate the Advisory Feedback testing methods**
  - **Tests are more difficult because PAS/ComDATSS must also be validated**
- **Use the fully closed-loop testing methods to validate the performance of aFAST and EDP**
  - **Initial tests have identified additional algorithm requirements**
  - **Complex multiple runway scenarios have not yet been attempted**
- **Compare results of fully closed-loop operation to "live" data**
  - **Comparison provides upper bound on expected delay and excess separation reduction**
  - **Live data indicates typical variability of the maneuvers of real aircraft**