Autonomous Coordinated Airspace Services for Terminal and Enroute Operations with Wind Errors

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Increasingly Complex Airspace
Foundational Autonomy Research
Development of an Autonomous Airspace Service

4D separation, arrival management and weather avoidance

Coordinated operations across 20 enroute centers

Operations in the presence of uncertainty and errors

Terminal Area Operations
Current Development
Current Development

Coordinated Terminal Area and Enroute Operations
Current Development
Current Development

Trajectory Prediction Errors in the Terminal Area
Current Development
Current Development

Handling Novel Operations
(Aviation 2018 Talk by Bosson)
Current Development
Current Development

Focus of this Presentation
Cloud-Based Service
Exercising New Capabilities

TRACON and Enroute Airspace Simulation
Exercising New Capabilities

TRACON and Enroute Airspace Simulation

Coordination Rules
Exercising New Capabilities

TRACON and Enroute Airspace Simulation

Errors in the TRACON

Coordination Rules
Exercising New Capabilities

TRACON and Enroute Airspace Simulation

Coordination Rules

Errors in the TRACON

Detection Only
Exercising New Capabilities

TRACON and Enroute Airspace Simulation

Errors in the TRACON

Coordination Rules

Detection Only

Arrival Conformance
Dallas (D10) TRACON

Simulated Traffic in D10;
350 Flights at Present Day Demand Levels
Coordinated Enroute and Terminal Operations

Center Boundary

Terminal Boundary
TRACON Visibility and Control

Green = Controlled
Blue = Visible
Enroute Visibility and Control

Green = Controlled
Blue = Visible
Losses of Separation Near Boundaries
Coordination Rules

Use Enroute Separation

Enroute Ensure Conflict Free Across Boundary

Terminal Assumes “Frozen” Enroute Trajectories
Conflicts Detected with Less than 1 Minute to Loss of Separation

![Bar Chart]

- **Number Less Than 1 Minute**
  - No Coordination: 12
  - Coordination: 2
Wind Field Errors

Actual Winds
(Constant 25 knots from the South)

Predicted Winds
(150% Actual Magnitude)
Example Trajectories

Latitude v. Longitude

Along-Track Distance (nmi)

Altitude (ft)

Look-Ahead Time (minutes)

Actual

Predicted

Turn Occurs

40

20

4

8

12

16

10,000

6,000

2,000

4

8

12

16

4

8

12

16

4

8

12

16
Detection Buffer
Missed Alerts

Missed Alerts (%)

Time to First Loss (minutes)

Baseline

50%

No Buffer

1nmi Buffer
False Alerts

Time to First Loss (minutes)

False Alerts (%)

Baseline
50%

1nmi Buffer
No Buffer
Errors and Arrival Scheduling

Along-Track Distance (nmi)

Look-Ahead Time (minutes)

Actual Time

Predicted Time

Time to Metering

Time at Metering Point
Arrival Schedule Conformance Monitoring

Predicted Time

Scheduled Time

Conformance Bounds

Time t0

Time t1

Time t1’ (After Conformance Resolution)
Number of Resolutions

- Baseline: 299
- 50% Error: 122 (Baseline: 299, Increase: 299)
- 50% Error and Monitoring: 1562 (Baseline: 299, Increase: 299)
Total Delay

![Bar chart showing total delay in hours for baseline, 50% error, and 50% error and monitoring conditions. The chart indicates the baseline delay is 5.2 hours, 50% error delay is 5.2 + 1.7 = 6.9 hours, and 50% error and monitoring delay is 5.2 + 1.7 = 6.9 hours. The delay for monitoring is 5.2 hours.]
Number of Schedule Changes

- Baseline: 2
- 50% Error: 73
- 50% Error and Monitoring: 40
Conclusions

- Coordinated operations in multiple types of airspace were demonstrated in the presence of trajectory prediction errors.
- Simple rules were demonstrated that enabled coordination across control boundaries.
- Arrival schedule conformance monitoring reduced delay significantly at the cost of significantly more resolutions.