Feasibility of Mixed Equipage Operations in the Same Airspace

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Outline

- Background and Motivation
- Objective
- Method
- Results
- Conclusions
Main Points

• Objective of the study
  – To examine if mixed equipage operations of automation-separated and controller-managed aircraft are feasible in the same airspace and what might limit such operations

• From the airspace design perspective, strict airspace segregation are not always needed

• Mixed equipage operations are feasible to a limit

• Feasibility depends on
  – Density and number of the unequipped aircraft (and to a lesser degree, the density of equipped aircraft)
  – Number of aircraft that controllers need to actively monitor to ensure separation
• As a future air traffic management concept, automated separation assurance proposes to eliminate current controller workload bottleneck to airspace capacity

• As concepts such as automated separation assurance evolve, the airspace requirements to support them must be established

• A key airspace design question is whether future airspace should be segregated or integrated

• Differences between the two types of airspace
  – Segregated
    • Permit access to only to aircraft supported by automated separation
    • Allow airspace to be more homogeneous, have less complexity, and provides incentive for users to equip
  – Integrated
    • Permit mixture of all aircraft equipage
    • May utilize airspace better and increase flexibility to unequipped aircraft; may provide better transition path as aircraft equip gradually over time
Motivation

• JPDO’s concept of operations suggests segregated airspace for trajectory based operations

• Prior studies on limited mixed equipage operations of automated vs. controller-managed aircraft indicate that such operations appear to be feasible

• None of the prior studied examined ground-based automation for conflict resolution

• None of the prior studied examined implications on the airspace design
  – For example, if mixed operations are possible,
    • How many controller-managed aircraft can safely mix with automation-separated aircraft?
    • How does the density of automation-separated aircraft impact controllers in mixed equipage?
Objective

• Objective of the study: to examine if mixed equipage operations are feasible in the same airspace and what might limit such operations

• Hypothesis: mixed equipage operations are feasible with a low-to-moderate number of unequipped aircraft
  – Mixed equipage refers to mix of aircraft that are supported by automated conflict resolution (equipped) vs. aircraft that are not (unequipped)
    • Equipped = automation-separated
      – Data link, FMS, conflict resolution uplinked via data link
    • Unequipped = controller-managed
      – No data link, conflict resolution via voice
  – Note: automated conflict detection available for all aircraft
Method

- **Airspace:** Two sectors
  - ZKC90: Mostly en route traffic
  - ZID91: A mix of over-flights, arrivals, and departures

- **Participants**
  - Four certified professional air traffic controllers
  - Experience range: 11 to 25 yrs, average 20 yrs

- **12 data collection runs**

- **Each run was 45 minutes in duration**
Experimental Design

• Four Conditions
  – Condition 1 (0X)
    • No equipped aircraft, All unequipped aircraft at 1X level (more than current traffic load)
  – Condition 2 (1X)
    • About 15 equipped aircraft were constant and 1X unequipped aircraft were slowly added
  – Condition 3 (2X)
    • About 30 equipped aircraft were constant and 2X unequipped aircraft were slowly added
  – Condition 4 (3X)
    • About 45 equipped aircraft were constant and 3X unequipped aircraft were slowly added

• Number of unequipped aircraft increased linearly from 5 to 20

• Supervisor monitors controller workload and turn away aircraft when the workload is deemed excessive

0x = 0 equipped AC
1x = 15 equipped AC
2x = 30 equipped AC
3x = 45 equipped AC
Operational Concept

- Automation is responsible for detecting all conflicts involving on-trajectory flights.
- Controller is responsible for monitoring separation of all off-trajectory and transitioning aircraft.
- Ground automation resolves conflicts for all equipped aircraft.
- Ground automation detects conflicts and creates resolution maneuvers for unequipped aircraft that are on 4D trajectories and resolutions are issued via voice.
  - For lateral changes, automation generated initial heading, time-to-turn back, and waypoint to join original route.
- Controllers also has ability/option to manually construct 4D trajectories or to modify the automated resolution.
- Controllers give priority to equipped aircraft whenever a conflict occurs between equipped and unequipped aircraft.
Re-configured Controller Display

- Full data block for all aircraft
- Clutter problem
- Overwhelming traffic without automation
- Limited and dimmed data blocks
- Can access full data block if necessary
Results: Workload

- Workload increased as the number of unequipped aircraft increased over time
- Number of equipped aircraft also increased workload
- Sector 91 results show similar pattern
Results: Aircraft Turned Away

- As expected, more aircraft were turned away (not accepted) under higher traffic density conditions.
- Aircraft were turned away sooner under higher traffic density conditions.
- Consistent trend for both sectors.
- Helps us identify the limits at which unequipped aircraft can be managed in addition to the equipped aircraft.
  - Participant feedback mirrored this objective data.
Average Number of Conflicts and Separation Violations

As expected, mixed conflicts increase with higher density of equipped aircraft.

Number of separation violations low relative to very high traffic densities (e.g. 55 – 60 total A/C count in 3x condition).

At 3x condition, both automation and controllers have difficulty in finding viable, conflict-free paths due to airspace saturation.

### Average number of mixed and unequipped conflicts

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Sector 90</th>
<th>Sector 91</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Mixed conflict</td>
<td>Unequipped conflict</td>
</tr>
<tr>
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<td>11</td>
</tr>
<tr>
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<td>22</td>
<td>11</td>
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<tr>
<td>3x</td>
<td>31</td>
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</table>

### Average number of mixed and unequipped separation violations

<table>
<thead>
<tr>
<th>Condition</th>
<th>Sector 90</th>
<th>Sector 91</th>
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</thead>
<tbody>
<tr>
<td>0X</td>
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<td>0</td>
</tr>
<tr>
<td>1X</td>
<td>0.75</td>
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<tr>
<td>2X</td>
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<td>0.25</td>
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<tr>
<td>3X</td>
<td>1.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Results: Complexity

- Regression between workload and complexity variables showed a significant relationship ($R = 0.864$, $R^2 = 0.746$)

- Statistically significant complexity variables:
  - Number of variables related to unequipped aircraft
    - Horizontal proximity
    - Number of aircraft
    - Aircraft density
    - Separation criticality index
    - Percentage of climbing/descending aircraft
  - Number of mixed conflicts affected workload
  - Aircraft density and horizontal proximity of equipped aircraft

- Increased density increased proximity and reduced the number of available options for conflict resolution which resulted in higher complexity and workload under higher density conditions
Participant Feedback

- Average unequipped aircraft (in addition to equipped) that they felt could safely manage mirrors the number that they managed.
- Another criterion for safe air traffic management under mixed equipage condition:
  - Maximum of 3 off-trajectory or climbing/descending aircraft if the controllers were responsible for their separation management.
  - With better tools to handle off-trajectory and climbing/descending aircraft, the maximum number that controllers can handle will increase.
Conclusions

• From airspace design perspective, strict airspace segregation is not always needed
  – Ability to manage mixed airspace will give flexibility in the airspace design

• The results suggest that mixed equipage operations are feasible to a limit in the same airspace (integrated operations)
  – Clear division of roles and responsibilities between controllers and automation is needed to handle mixed equipage operations
  – Clear operational procedures are needed

• Feasibility is limited by
  – Density and number of the unequipped aircraft (and to a lesser degree, the density of equipped aircraft)
  – Number of aircraft that controllers need to actively monitor to ensure separation
  – E.g., Based on the sectors, traffic, tools and operational procedures defined in this study, we expect
    • approx. 12 unequipped aircraft mixed with 30 equipped aircraft to be feasible if no more than 3 unequipped aircraft are off-trajectory or climbing/descending.