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

Background

- 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?

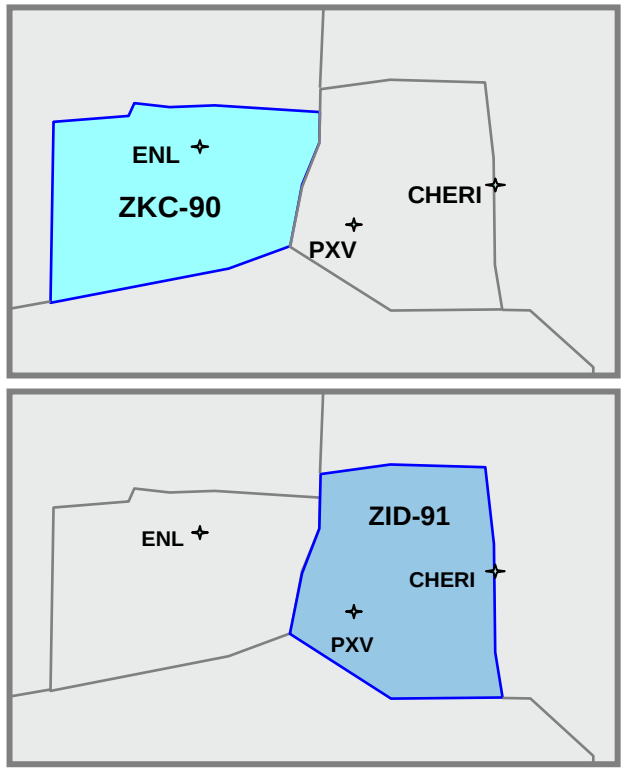
Objective

- 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

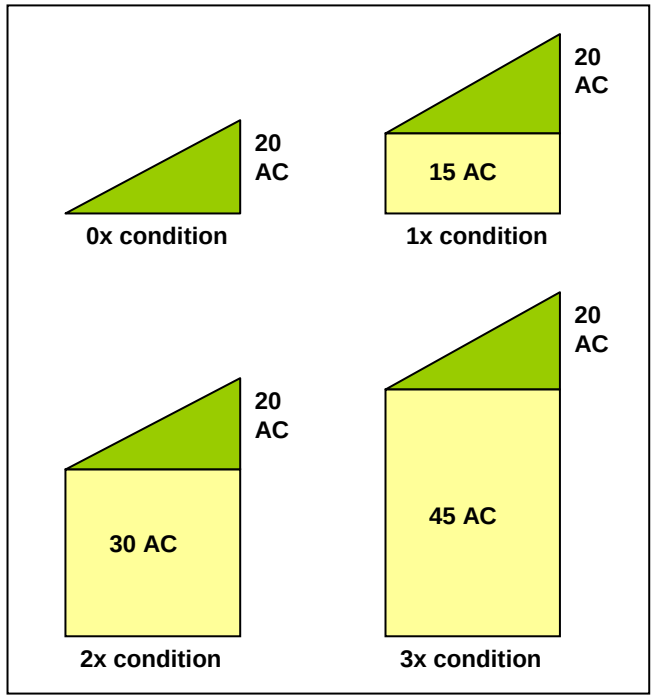
Method

- 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

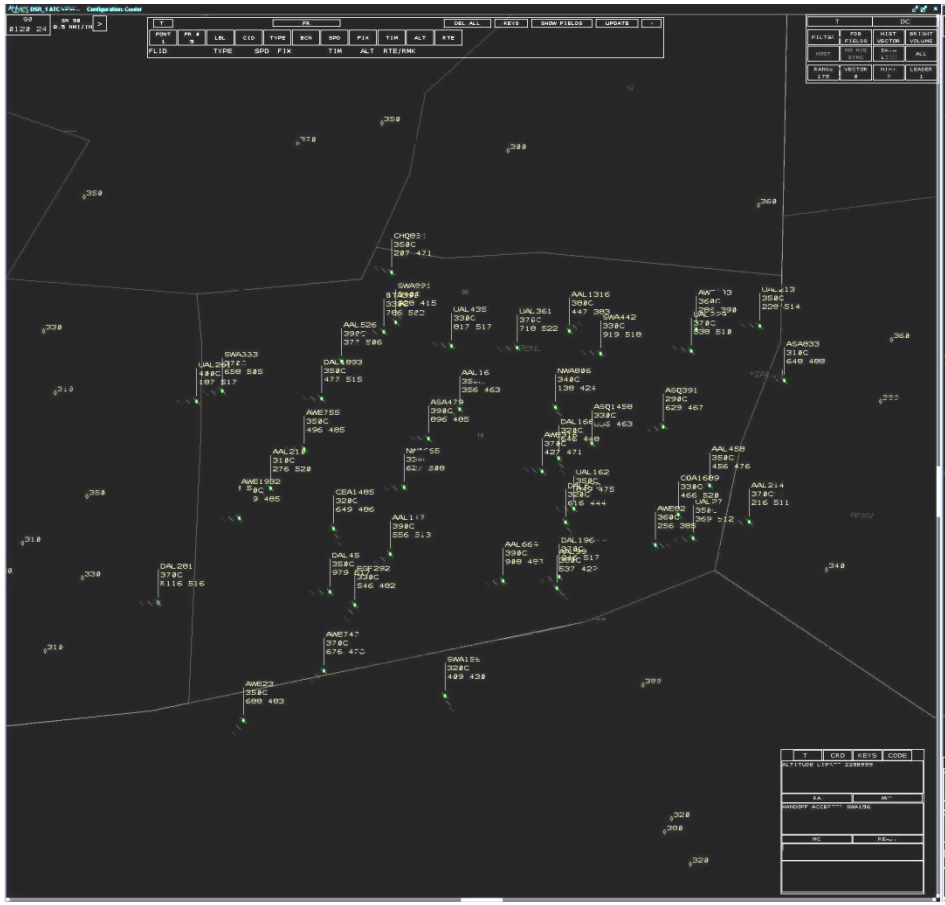


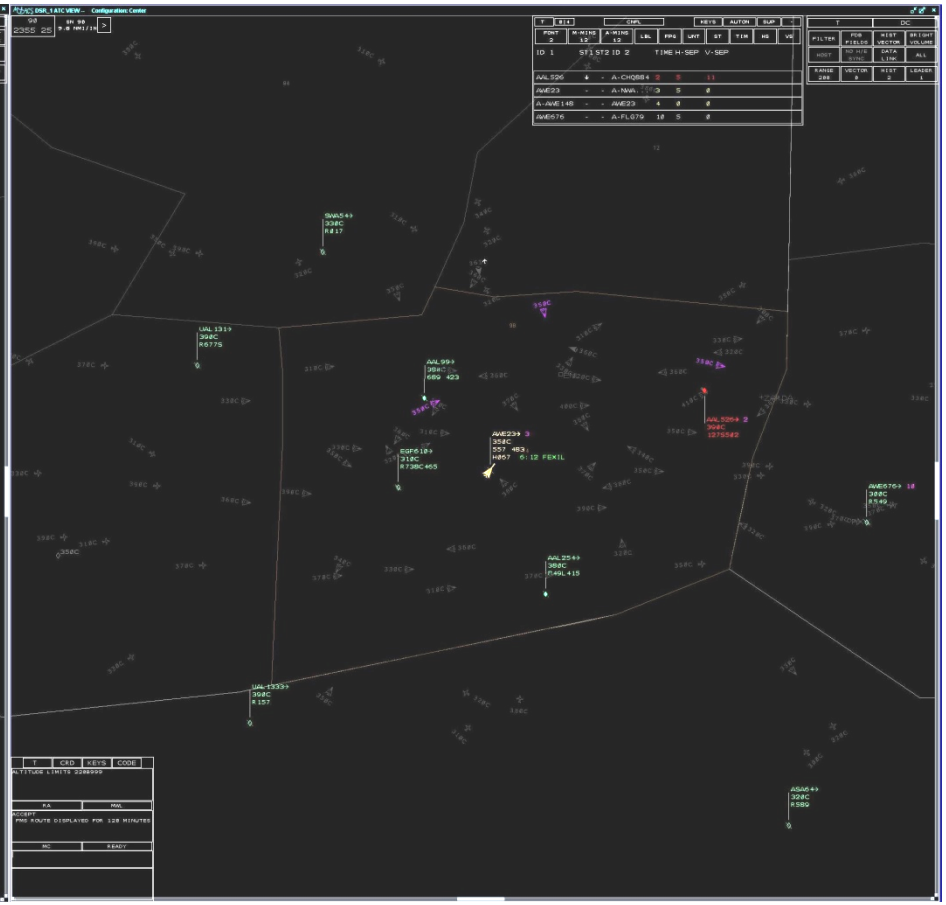
0x = 0 equipped AC
1x = 15 equipped AC
2x = 30 equipped AC
3x = 45 equipped AC

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

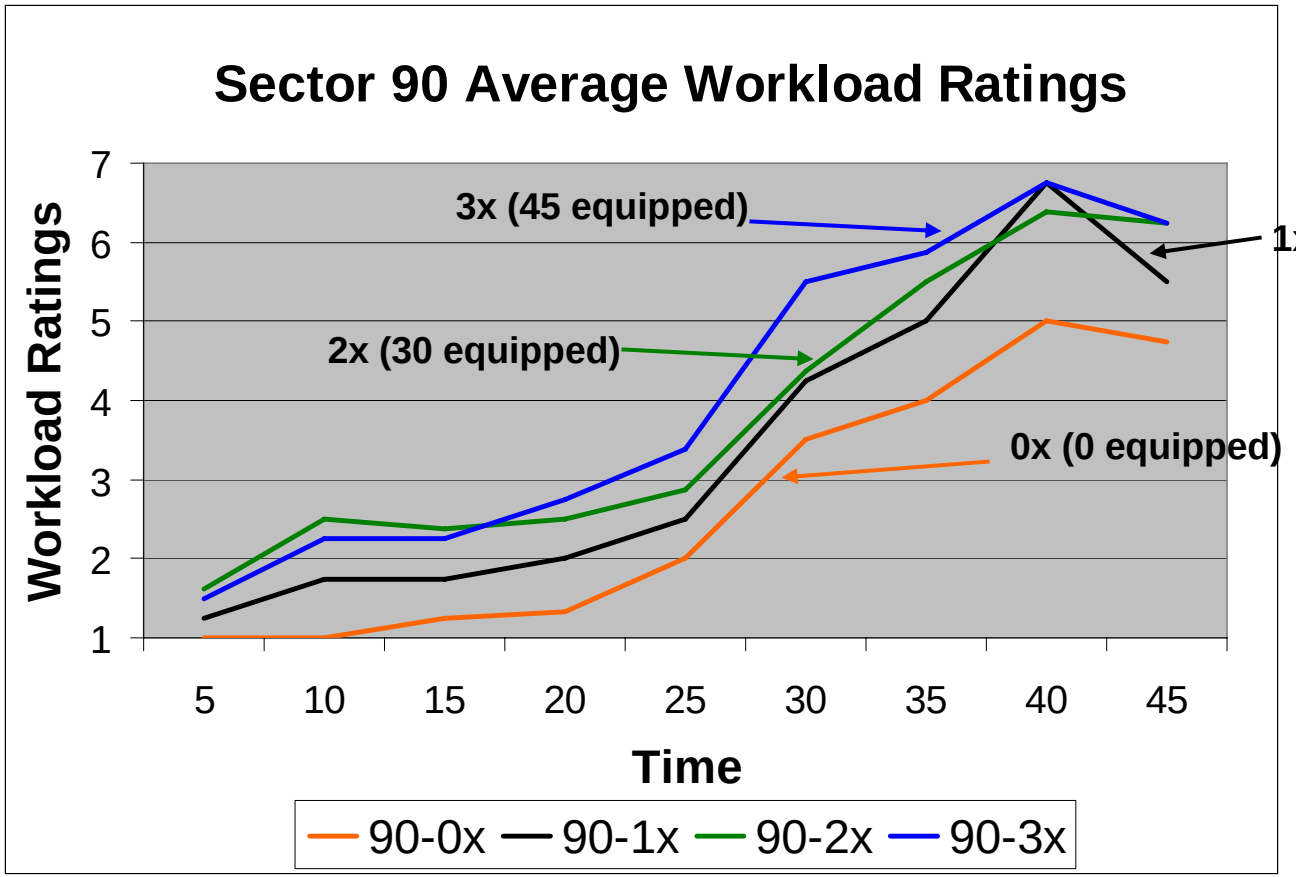




- Full data block for all aircraft
- Clutter problem
- Overwhelming traffic without automation

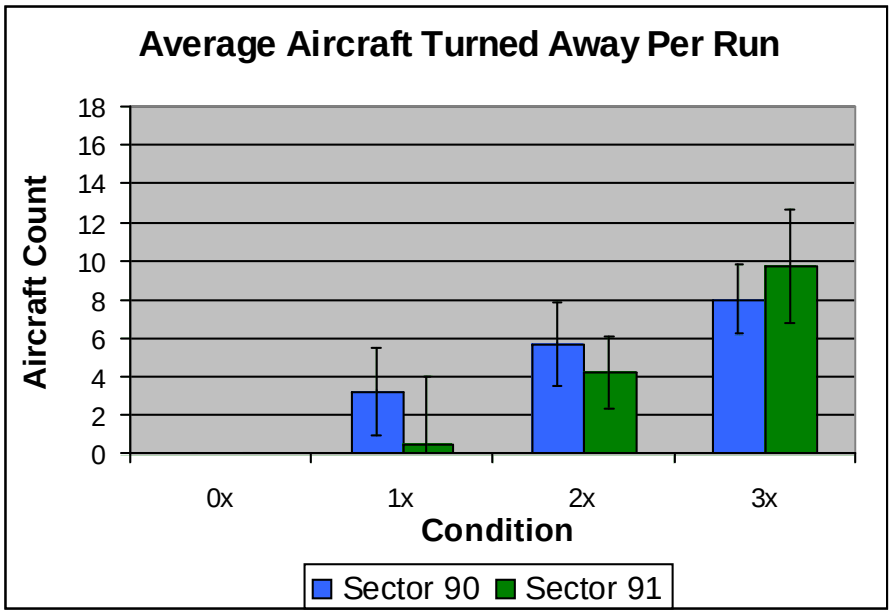
- Limited and dimmed data blocks
- Can access full data block if necessary

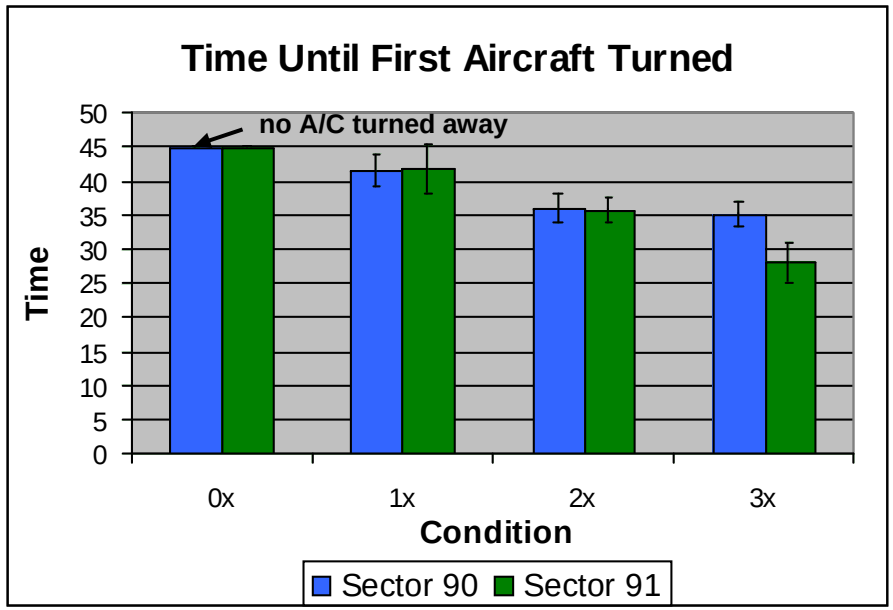
Results: Workload



- **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

Average number of mixed and unequipped conflicts

Scenario	Sector 90		Sector 91	
	Mixed conflict	Unequipped conflict	Mixed conflict	Unequipped conflict
0x	0	11	0	7
1x	14	10	14	7
2x	22	11	26	7
3x	31	10	45	7

Average number of mixed and unequipped separation violations

Condition	Sector 90	Sector 91
0X	0	0
1X	0.75	0
2X	0.75	0.25
3X	1.0	2.0

- 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

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.