A Human-in-the-Loop Evaluation of Flow-Based Trajectory Management in Mixed Equipage Airspace

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Outline

• What is flow-based trajectory management?
• FBTM mixed equipage simulation
• Conclusions
What is Flow-Based Trajectory Management?

Flow-based Trajectory Management is a distributed, tool-supported process for addressing local airspace problems by modifying trajectories of one or more aircraft.

• Technical challenge:
  – Develop an efficient process for managing trajectories of in-flight aircraft within a planning horizon that extends beyond the controller’s field-of-view.

• Concept has evolved through a series of studies:
  – From a multi-sector planner (MSP) position supporting radar controllers (Corker, et al., ATM-2007)
  – To multi-sector planning operations for local area flow management (Smith, et al., ATIO 2010)
  – To a concept for flow-based trajectory management (FBTM)
1. A problem is predicted within the next 45 minutes in en route Area 1. Traffic management unit (TMU) personnel discuss its impact and possible solutions with the Area 1 supervisor.
2. The **TMU** identifies several inbound aircraft within an east-bound flow that could be rerouted to reduce the impact on the affected sectors.
Plan Development and Coordination

3. The aircraft would be rerouted through Area 2. **TMU confirms with Area 2 supervisor that this is acceptable.** TMU may also check with Area 4.
Plan Coordination

4. **TMU** then confirms with the **Area 3 supervisor** that the Area 3 controllers can execute plan.
5. **TMU** prepares and sends 3 trajectory clearance requests to **Sector A**. The **controller** reviews each request and issues it to the aircraft if able.
Execution and Follow-through

6. The **Area 1 team** manages the reduced flow through the two problem sectors. **TMU** monitors solution effectiveness.
Multi-Sector Planning: a Distributed Process

Or, an *integrated* process performed by a *distributed* team:

- **Area supervisor** and **traffic management** monitor local traffic situation.
- **TMU** plans trajectory changes, coordinating with **supervisors** and **others**.
- **Area supervisors** support plan development, and manage execution by **controllers**.
- **TMU** prepares and sends trajectory clearance requests to **controllers**.
- **Controllers** review trajectory requests and execute if suitable.
Multi-Sector Planning: a Tool-Supported Process

Supported by integrated tools for situation assessment, plan development and coordination, execution and follow through:

- Area supervisor and traffic management monitor local traffic situation.
- TMU plans trajectory changes, coordinating with supervisors and others.
- Area supervisors support plan development, and manage execution by controllers.
- TMU prepares and sends trajectory clearance requests to controllers.
- Controllers review trajectory requests and execute if suitable.
Planner Automation Tools

Planning Station
Integrated tools support situation assessment (load tables, load graphs, traffic display with weather and filters), multi-trajectory trial planning, and ground-to-ground coordination of plans and clearance requests.

Station can be configured for either TMU or area operations.
Controller Automation Tools

Controller Station

Integrated tools support development and exchange of ground-to-ground clearance requests, request evaluation, and delivery of requested clearance.

Equivalent capabilities are provided to radar controller and radar associate.
Flow-Based Trajectory Management in Mixed Equipage Airspace

• Why?
  – Changing expectations for NextGen mid-term operational environment

• Motivation:
  – Is full air-ground Data Comm environment necessary for these operations?
    Or can they be introduced before full equipage (Data Comm) airspace exists?

• Answer two key questions:
  – Could FBTM functions be *feasible* in this environment?
  – Might FBTM functions provide *benefit* in this environment?

• *Technical challenge:*
  – *How to support FBTM in mixed equipage airspace?*
Mixed Equipage Simulation

• **Approach:**
  – Conduct a simulation to evaluate mixed equipage operations
  – Leverage prior multi-sector planner research and simulations
  – Adapt tools and concept for unequipped aircraft (non-Data Comm)

• **Mixed equipage changes to FBTM tools and procedures:**
  – **Functionality:**
    • Trajectories clearances that can be delivered by voice
    • Complexity metric includes equipage weighting
  – **Display:** Data block symbols and color coding denote equipage category
  – **Team Composition:** Radar associate present on each sector

  – **Policy:** *Simulation provides a chance to explore “best-equipped, best-served” approach for flow and trajectory management.*
Flow-Based Trajectory Management with Mixed Equipage

- Unequipped and equipped aircraft will travel through problem sectors.
- Planner re-routes unequipped aircraft \textit{first} using named waypoints.
- Equipped aircraft can be re-routed later if necessary.

- Controllers were also asked to favor equipped aircraft in mixed equipage conflicts.
Test Plan

• Kansas City Center (ZKC) Airspace:
  – 4 high altitude sectors, assigned to 2 areas in two adjacent rooms.
  – Each test sector has a radar controller and radar associate.

• Participants:
  – Active and retired FAA facility staff
  – 3 TMU positions, 2 area supervisors, 8 controllers

• Run variations:
  – 2 traffic scenarios x 2 weather patterns x 2 equipage alternatives per aircraft

• 3 Equipage Levels:
  – 10%, 50% and 90% of aircraft equipped for air-ground Data Communications

• Schedule:
  – Eight 60 minute runs
  – 1 week study, with 1 day of training, 2 days data runs and discussion
Scenario

• Convective weather affects local facility and downstream facility traffic.

• Supervisory traffic management coordinator (STMC) discusses situation with Command Center, then supervisors.

• TMCs develop reroute plan to manage airspace complexity.

• Unequipped aircraft add more to sector complexity (controller workload), so TMCs reroute the unequipped aircraft first, which also provides benefit to the equipped aircraft.
Results: System Performance with FBTM

- Planning operations maintained workload within limits at all 3 equipage levels.
- Higher equipage levels resulted in lower workload with higher throughput.

Mean workload rating, by position and equipage level

Mean number of aircraft through sector per run, by equipage level
Results: Service for Equipage at Local Area Level

- FBTM *planning operations* support “best-equipped best-served” policy across equipage levels.

**Total number of aircraft through ZKC test sectors, by equipage, across all 8 runs**

<table>
<thead>
<tr>
<th>Equipage Level</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unequipped</td>
<td>1688</td>
</tr>
<tr>
<td>Equipped</td>
<td>1938</td>
</tr>
</tbody>
</table>

**Mean path length change per aircraft, by equipage level, for aircraft flying through the test area**

<table>
<thead>
<tr>
<th>Equipage Level</th>
<th>Change in Path Length (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% Equipped</td>
<td>4.00 ± 0.50</td>
</tr>
<tr>
<td>50% Equipped</td>
<td>5.00 ± 0.50</td>
</tr>
<tr>
<td>90% Equipped</td>
<td>6.00 ± 0.50</td>
</tr>
</tbody>
</table>

- Unequipped
- Equipped
Results: Service for Equipage at Sector Level

- *Controllers* provided priority service in conflict resolution across equipage levels.

![Bar chart showing mean number of aircraft of each type maneuvered to resolve mixed equipage conflicts per run, by equipage level. The chart includes bars for 10%, 50%, and 90% equipped aircraft, with a clear indication of the mean number of maneuvered aircraft for each category. The chart legend indicates that blue bars represent unequipped aircraft, while red bars represent equipped aircraft. The vertical axis represents the mean number of A/C maneuvered, while the horizontal axis categorizes the equipage levels.]
Results: Tool Performance

- Tools were effective and satisfactory for mixed equipage operations.

<table>
<thead>
<tr>
<th>Sender</th>
<th>Uneq.</th>
<th>Eq.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>All positions (TMC, supervisor or controller)</td>
<td>1026</td>
<td>569</td>
<td>1595</td>
</tr>
<tr>
<td>Controllers from participant-staffed sectors only</td>
<td>89</td>
<td>18</td>
<td>107</td>
</tr>
</tbody>
</table>

- TMCs and controllers developed most of their clearance requests for unequipped aircraft.

- Only 10 out of 229 CCs sent to test sectors were rejected.

- TMCs gave both clearance coordination and trial planning functions for both equipage types usability and usefulness ratings of 5.5 to 6, on a 1-6 scale.
Results: Some Participant Feedback

- Post-run and post-simulation data show mixed equipage concept to be acceptable, with tools for trajectory coordination effectively used by all positions.

Some comments:

- Supervisors:
  - Thought complexity management strategy was a “win-win” solution since moving an unequipped aircraft out of a sector has greater impact, and also rewards equipped aircraft with better service.

- TMCs:
  - Wanted the FBTM tools integrated with current capabilities (traffic situation display) to they could see how they would work together to make the “ideal TMU tool set.”

- Controllers:
  - Priority handling of equipped aircraft was easy; prioritized resolution advisories would have made it even more practical.
  - Data Comm reduced workload, increasing safety and ability to handle more aircraft.
Conclusions

• FBTM operations are feasible and show benefit with mixed equipage.
• Trajectory clearances can be used with non-Data Comm aircraft.
• “Best-equipped, best-served” policy appears promising

Next Steps:

• NASA AOL continuing development of integrated NextGen operational concepts, with “FBTM” functions as one component of our concept prototyping environment.