Evaluation of a Flight Deck-Based Merging and Spacing Concept on En-Route Air Traffic Control Operations

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7th USA / Europe
ATM Seminar 2007
Barcelona, Spain
Overview

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  – Automatic Dependent Surveillance - Broadcast (ADS-B)

• Flight Deck-Based Merging and Spacing (FDMS)
  Concept Overview
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  – Purpose, Concept Overview, and Benefits
  – FDMS Procedures and Flight Deck Infrastructure
  – Development Effort and Related Activities

• En-Route Controller Simulation (FDMS 1)
  – Simulation Description
  – Subjective and Objective Results

• Post FDMS-1 Work
Background
Current En-Route Merging and Spacing

• Airport arrivals typically originate from numerous departure points and traverse different routes prior to merging into a single-file stream.

• Air Traffic Control (ATC) must synchronize individual arrivals and arrival flows while 1) maintaining separation standards and 2) meeting restrictions from downstream sectors during the merge.

• Controllers currently do not have the tools to achieve spacing during the en-route phase of flight prior to the top of descent.

• If spacing cannot be achieved early in the flight and miles-in-trail restrictions are in place, controllers typically resort to vectors to adjust in-trail spacing or to avoid conflicts.

• Controller interventions can be workload intensive and can also increase fuel consumption and flight time.

• Currently, controller instructions must be specific; i.e., controllers must provide specific speed and heading instructions to achieve spacing goal instead of simply designating a spacing interval for flight crews to maintain.
Automatic Dependent Surveillance-Broadcast (ADS-B)

Cockpit Display of Traffic Information (CDTI)

Call Sign Category
3-D Position
3-D Velocity and options

Call Sign Category
3-D Position
3-D Velocity and options

ATC System

Ground Receiver

ADS-B

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F084-B07-022
Flight Deck-Based Merging and Spacing Concept Overview
The Flight Deck-Based Merging and Spacing Concept was derived from research activities in the US and Europe.

Four broad CDTI categories identified*:

- Traffic situational awareness
  - Increased pilot awareness of surrounding traffic, including surface

- Airborne spacing
  - Flight crews achieve and maintain a given spacing with designated aircraft, as specified in a new instruction. Although the flight crews are given new tasks, separation provision is still the controller's responsibility and applicable separation minima are unchanged.

- Airborne separation
  - Controller can delegate separation relative to designated aircraft to the flight crew through a new clearance

- Airborne self-separation
  - Controller can delegate separation relative to all known aircraft in accordance with applicable airborne separation minima

FDMS Purpose, Concept, and Benefits

- FDMS is intended to reduce the need for downstream controller interventions by:
  1. Having the Airline Operations Center (AOC) provide minor speed adjustments early in the flight to achieve spacing in the final en-route sectors.
  2. Then giving flight crews the ability to use speed management to achieve and maintain their spacing using on-board equipment.

- When coupled with a CDA, expected benefits include:
  - Reduced: High speed/high altitude vectoring, communication, workload, fuel burn, noise, time and distance flown.
  - Increased: Accuracy and consistency in arrival spacing.

- FDMS is initially planned in UPS late-night, low density environment.
  - Ideal test bed due to low density, one airline operations.

Future complex and higher density implementations will be put into operation when ATC has the appropriate tools to utilize flight deck tools to achieve their goals.
### Initial M&S Concept

#### Set-Up
- **Airline Based En-route Sequencing and Spacing (ABESS)**

#### Conduct
- **Flight deck-based M&S (FDMS)**

#### Termination
- **Final Approach Fix (FAF)**

<table>
<thead>
<tr>
<th>Goal</th>
<th>Strategic arrival sequence and spacing at merge fix and setup for FDMS.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Airline operations center (AOC) role</strong></td>
<td>Use new tool to provide speed advisories via Aircraft Communications Addressing and Reporting System (ACARS) targeting spacing at merge fix. Send FDMS initiation message.</td>
</tr>
<tr>
<td><strong>Flight deck role</strong></td>
<td>Fly speed provided by AOC until transition to FDMS.</td>
</tr>
<tr>
<td><strong>ATC Role</strong></td>
<td>Ensure safe separation as well as to monitor operation with interventions as necessary for spacing or conflicts.</td>
</tr>
</tbody>
</table>
UPS 757/767 Flight Deck Infrastructure

CDTI

AGD
FDMS Development and Related Activities

- Led by Federal Aviation Administration (FAA) Surveillance and Broadcast Services Program Office
- Participation from Airbus, Airline Pilots Association, Aviation Communication & Surveillance Systems (ACSS), Boeing, CENA, Eurocontrol, FAA, Honeywell, Independent Pilots Association, MITRE, NASA, VOLPE, UPS, etc.
- UPS 757 / 767 aircraft currently equipped with ADS-B and a Cockpit Display of Traffic Information (CDTI) for traffic awareness
- UPS plans to implement Continuous Descent Arrivals in 2007; wants to implement FDMS to minimize interventions
- MITRE simulations replicate initial, specific UPS implementation; is not necessarily the only possible FDMS solution
Sample Past / On-Going Efforts On Similar Concepts

- Eurocontrol
  - Co-Space / Sequencing and Merging

- NASA
  - Terminal Arrival: Self-Spacing for Merging and In-Trail Separation / Concept Element-11
  - Trajectory-Oriented Operations With Limited Delegation (TOOWiLD)
  - Airborne Precision Spacing (APS) / Airborne Merging and Spacing for Terminal Arrivals (AMSTAR)

- FAA / RTCA
  - Initial and final approach spacing

- Package 1
  - Sequencing and Merging
FDMS 1 - En-Route Controller Simulation
FDMS Simulation 1

• Domain
  – En route, merge environment
• Purpose
  – Continue concept maturation and validation
  – Evaluate acceptability of FDMS
• Participants
  – Eight current or recently retired center controllers
• Procedure
  – One controller per day controlled FDMS traffic under five scenarios and then completed questionnaires
  – Controllers’ goal was to ensure spacing and separation and minimize disruptions to FDMS stream
  – Controllers told to intervene to resolve conflicts, or if they project a significant deviation below two min (14-16 miles) in trail at merge fix
• Simulation environment
  – Kansas City Center airspace and current interfaces
• Scenarios
  – Baseline, FDMS “normal”, and FDMS “non-normal” (overtake, suspension, complete termination)
Simulation Environment – Aircraft

• All aircraft between Flight Level (FL) 300 and FL400
• Thirteen UPS FDMS aircraft (757/767)
  – FDMS algorithm ran in background and provided speed commands to aircraft without pseudopilot inputs
  – Pseudopilots accepted speed or other instructions from ATC and “flew” the aircraft appropriately
• Conflict / crossing traffic
  – Three UPS, non-FDMS aircraft (A300s)
  – Fourteen non-UPS, non-FDMS, civil aircraft (all types)
Simulation Environment
ZKC High Altitude Sectors

FDMS Arrivals
Other Arrival Traffic
Subjective Data Collection

- Areas of Study:
  - Workload
  - Acceptability
  - Responsibilities
  - Traffic awareness
  - Communication requirements
  - Safety

- Four questionnaires used:
  1. Pre-simulation / demographics
  2. Baseline scenario post-run
  3. FDMS scenarios post-run
  4. Post-Simulation

- Most questions were on a seven point scale (plus Not Applicable), e.g.,

  1. Completely Unacceptable
  2. Unacceptable
  3. Somewhat Unacceptable
  4. Borderline
  5. Somewhat Acceptable
  6. Acceptable
  7. Completely Acceptable
  NA

- Other questions were yes / no or open ended
Concept Results

• All controllers stated that given appropriate training, FDMS would be acceptable

• All controllers (except for one “N/A”) stated that they had adequate information to make traffic management decisions

• Controllers agreed that FDMS somewhat improved operational efficiency

• Controllers subjectively reported that they experienced “somewhat less” communications in the FDMS scenarios

• Most controllers found it at least “somewhat acceptable” to give FDMS aircraft priority; one felt it was “somewhat unacceptable”
  – During the debrief, he explained the FAA currently operates under “first come first serve,” and that it will be difficult to change that mentality
Situational Awareness Results

- All controllers stated that their level of situational awareness was acceptable.

- Controllers agreed that it was about the same difficulty level to monitor and maintain traffic spacing as compared to controlling similar traffic levels under similar conditions.

- Controllers also agreed that it was “somewhat easy” to detect conflicts, separation violations, and spacing issues during FDMS operations.

- Some concerns expressed about controller complacency, but none felt that it presented a safety issue.

- Some concerns expressed about knowing when to intervene.
Results- Average Workload

FDMS scenarios rated lower than…
Baseline scenario and scenario where all aircraft terminated FDMS

- Controllers reported that their overall workload was acceptable for all conditions
- Most controllers reported that FDMS somewhat reduces or has no effect on their workload
Notes on Objective Results

• Results are for entire traffic flow (mixed equipage environment), not just UPS FDMS traffic
• The number and type of merge environment maneuvers, and controller audio communications were tracked and analyzed
• For objective data, the difference between means for an effect is considered significant if it has a $p$-value less than or equal to 0.05 ($p \leq 0.05$)
• Vertical bars in figures denote 95% standard error confidence intervals
## Merge Environment Maneuver Data Summary

<table>
<thead>
<tr>
<th></th>
<th>Heading Instructions</th>
<th>Altitude Instructions</th>
<th>Re-routes to PXV</th>
<th>Speed Instructions (Controller)</th>
<th>Total Controller Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline Mean</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>8.960</td>
<td>1.512</td>
<td>0.463</td>
<td>3.271</td>
<td>8.741</td>
</tr>
<tr>
<td><strong>FDMS Normal Mean</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.000</td>
<td>1.408</td>
<td>0.707</td>
<td>0.707</td>
<td>1.885</td>
</tr>
<tr>
<td><strong>FDMS Overtake Mean</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.463</td>
<td>1.996</td>
<td>0.926</td>
<td>0.423</td>
<td>3.462</td>
</tr>
<tr>
<td><strong>FDMS Suspension Mean</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.996</td>
<td>1.642</td>
<td>0.463</td>
<td>1.389</td>
<td>3.295</td>
</tr>
<tr>
<td><strong>FDMS Termination Mean</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>3.505</td>
<td>2.053</td>
<td>0.518</td>
<td>2.850</td>
<td>4.713</td>
</tr>
</tbody>
</table>

* Note increased number of Heading and Speed instructions between Baseline and Normal operations
• In order to ensure that the FDMS operations did not minimize one type of controller intervention only to increase another type, the effect of the FDMS procedure on total controller interventions by scenario was examined first.

• The total controller instruction counts were produced by summing the counts across intervention type (heading, altitude, speed, and reroutes).

• A univariate analysis of variance found significantly more total interventions in the baseline scenario than in all the other scenarios ($p < 0.01$ for all).
Controllers gave significantly more *heading instructions* in the baseline scenario than in both the normal and overtake scenarios.

Controllers gave significantly more *speed instructions* in the baseline scenario than in each of the other scenarios.

- This result is consistent with the FDMS concept, since the algorithm supplanted the controller in providing speed guidance for the FDMS traffic.
Audio Metrics Results Summary

To reduce the effect of accidental mic keyings on the data, only counts and durations for Push To Talk (PTT) keyings greater than one second were analyzed.

Controllers made significantly more calls to aircraft in the baseline scenario than all of the FDMS scenarios ($p < 0.05$ for all).

Controllers spent significantly more time on frequency in the baseline scenario than all of the FDMS scenarios ($p < 0.01$ for normal, overtake, and termination; $p = 0.021$ for suspension).

<table>
<thead>
<tr>
<th></th>
<th>PTT Keyings &gt; 1 sec (count)</th>
<th>Total Time on Frequency for Keyings &gt; 1 sec (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline Mean</strong></td>
<td>85.125</td>
<td>298.750</td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td>14.623</td>
<td>76.107</td>
</tr>
<tr>
<td><strong>FDMS Normal Mean</strong></td>
<td>64.875</td>
<td>221.125</td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td>14.237</td>
<td>44.636</td>
</tr>
<tr>
<td><strong>FDMS Overtake Mean</strong></td>
<td>65.375</td>
<td>223.500</td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td>3.688</td>
<td>16.858</td>
</tr>
<tr>
<td><strong>FDMS Suspension Mean</strong></td>
<td>72.125</td>
<td>252.875</td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td>4.249</td>
<td>19.578</td>
</tr>
<tr>
<td><strong>FDMS Termination Mean</strong></td>
<td>68.000</td>
<td>227.000</td>
</tr>
<tr>
<td><strong>Standard Deviation</strong></td>
<td>4.280</td>
<td>18.313</td>
</tr>
</tbody>
</table>
Final Results and Discussion

• Controllers reported **lower workload** in FDMS scenarios over baseline. This is consistent with the objective results, which generally showed that controllers made fewer interventions (especially vectoring) during FDMS operations – even when FDMS problems were introduced.

• Controllers also reported a **lower level of communications** with the traffic during FDMS operations. This is also supported by the objective results, which show fewer controller PTT keyings, and less total time spent on frequency.

• Controllers generally find FDMS operations in the en-route environment to be **acceptable** based on feedback from topics such as situation awareness, communications, workload, and efficiency.

• Controllers were able to sufficiently handle non-normal situations.

• The issues of controller complacency, and knowing when to intervene, still need to be examined.
Post FDMS 1 Work
Follow-On Simulations

- FDMS Simulation 2 (August – September 2006)
  - **Pilot** focus: merge environment
  - Used MITRE medium-fidelity flight simulator
  - Examined pilot acceptability, workload, situation awareness (SA), display presentation and locations
  - Results show general pilot acceptability

- FDMS Simulation 3 (February – March 2007)
  - **Pilot** focus: post-merge through landing environment
  - Used MITRE medium-fidelity flight simulator
  - Examined pilot acceptability, workload, situation awareness, display presentation and locations
  - Preliminary results show general pilot acceptability

- FDMS Simulation 4 (May – June 2007)
  - **Controller** focus: en-route descent and terminal environments
  - Used MITRE en-route and terminal simulation facilities
  - Examined operational impact, controller acceptability, workload, traffic awareness, communications, information requirements, and phraseology
  - Results still being analyzed
Next Steps

• Full data analysis and documentation of follow-on simulations
• Completion of simulations, application description, and preliminary hazard analysis
  – Including recommended communications and procedures
• On-going flight tests
• ACSS certification of equipment and UPS operational approval prior to August 2007
• Field demonstration planned by UPS in late August 2007
• Validation activities
• Initiation of activities for later implementations
  – Advanced algorithm
  – Multiple arrival streams
For Further Information…

• On MITRE FDMS simulation activities and more detailed results, contact…
  – Randy Bone at bone@mitre.org
  – William Penhallegon at penhallegon@mitre.org

• On FDMS in general and FAA flight deck application activities under the Surveillance and Broadcast Services Program Office, contact…
  – John Marksteiner at john.marksteiner@faa.gov
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