Multisensor Fusion During Transition to ADS-B

June 10, 2009
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Outline

- Two System of Systems Examples in the NAS
  - PRM-A (Precision Runway Monitoring-Alternate)
  - Multisensor Fusion
- Multisensor Fusion Preliminary Study Results
  - Promising benefits support transition to ADS-B surveillance
  - Continuing study recommended
- Controller Tools & Procedures Enabled by Improved Surveillance
  - Ghosting
  - Minimizing Fuel Consumption
- Conclusion
- Backup

Theme: Making better use of what we have in the NAS (National Airspace System)
# Two Examples of “System of Systems” Architectures in the NAS

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<tr>
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<th>Function</th>
<th>Systems/Roles</th>
<th>Initial Site</th>
<th>Benefits</th>
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<tr>
<td>PRM-A (Precision Runway</td>
<td>Monitoring Simultaneous Closely Spaced</td>
<td>■ Existing Avionics/Transponders&lt;br&gt;■ Existing Extended Coverage ASDE-X</td>
<td>Detroit TRACON</td>
<td>■ Faster Update Rate&lt;br&gt;■ Improved Accuracy&lt;br&gt;</td>
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<tr>
<td>Monitoring -Alternate</td>
<td>Parallel Approaches</td>
<td>system/ terminal-area multilateration...a new sensor for terminal automation</td>
<td></td>
<td>■ Improved separation while MLAT coverage expands and ADS-B equipage builds&lt;br&gt; ■ Smooth transition to ADS-B&lt;br&gt; 1.Radars&lt;br&gt; 2.Radars+MLAT&lt;br&gt; 3.Radars+MLAT+ADS-B&lt;br&gt; ■ Increased Capacity&lt;br&gt; ■ Potential Backup among sensors</td>
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<td>(to radar))</td>
<td></td>
<td>■ Existing STARS automation system/ multisensor fusion tracking and FMA</td>
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<td></td>
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<td>(Final Monitor Aid) display</td>
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<tr>
<td>Multi-sensor Fusion</td>
<td>Terminal Automation</td>
<td>■ Existing Avionics/Transponders&lt;br&gt;■ Existing overlapping short range*</td>
<td>Philadelphia TRACON</td>
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<td></td>
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<td>(terminal) and long range (enroute) radar/ sensors&lt;br&gt;■ Existing ADS-B</td>
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<td></td>
<td></td>
<td>Ready STARS*: automation system/ multisensor fusion tracking and display</td>
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*Includes the DASR (ASR-11) +DAAS (DoD STARS) system of systems

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**Systems Working Together to Improve the NAS**
PRM-A Introduction

- High-traffic airports with closely-spaced multiple parallel runways increase capacity via simultaneous independent parallel approaches
  - FMA (Final Monitor Aid) monitoring in terminal ATC ensures safety
  - Denver (DEN) & Cincinnati (CVG) use Mode-S ASR-9 (~5 sec. update)
- Runway spacing closer than 4300 feet needs faster update rates (1 second) from a specialized PRM sensor like the eScan phased array
- PRM-A at the Detroit TRACON, sponsored by Northwest Airlines, was implemented using three existing NAS Systems:
  - Existing Avionics (ATCRBS & Mode-S Transponders)
  - ASDE-X, while performing airport surveillance as usual, has expanded multilateration coverage to 25NMi along each approach so it can also be a sensor for PRM-A
  - STARS, while performing terminal approach control mission as usual, also serves as a processing and display system for PRM-A

PRM-A safely increases arrival capacity
PRM-A Interfaces

- A new NAS interface was established and implemented in both ASDE-X and STARS

ASDE-X

- Reports every ~ 1 second
- Status ASTERIX Cat 19
- Existing Flight Data Interface

Other Sensors; including future ADS-B (SW delivery in August)

STARS

- MFT*

PRM-A OT&E regression testing and flight inspection at Detroit completed last week... final OT&E finishes today- looking good!

- IOC is scheduled for 2009 July

- Potential future sites include: ATL, CLE, MSP, PHL, STL, SFO

PRM-A safely increases arrival capacity
**PRM-A Display on STARS**

- **FMA** is a separate display mode, available in nationally-deployed STARS.
- Used to monitor simultaneous parallel approaches to >4 runways, safely increasing airport capacity.
- Permits “stretch” up to 8x perpendicular to approach course to make lateral deviations more evident to controllers.
- **Caution and Warning Alerts** Change color
  - Yellow (aircraft approaching NTZ)
  - Red (in NTZ)
- **Wrong Runway** and Surveillance lost alerts.
- Alerts augmented by voice identifying flight and type of alert.
- **Compatible with**
  - CRDA (Ghosting; example later)
  - Integration with Approach Manager
  - Mechanisms available for other conformance monitoring.

**Non-Transgression Zones (NTZ)**

- Icon representing Target ensemble in this illustration.
Multisensor Fusion Introduction

- Multisensor Fusion Tracker*
  - Correlates aircraft position reports from multiple sensors of various types
    - Long Range Radars ~12 seconds
    - Short Range Radars ~5 seconds
    - Multilateration (MLAT) ~1 second (PRM-A)
    - ADS-B ~1 second
  - Maintains a single system track for each target
  - Utilizes an Interacting Multiple Model (IMM) algorithm with two Extended Kalman filters; one optimized for constant velocity, another for maneuvers
  - Includes compensation for static and dynamic sensor alignment errors

- Current ATC Applications of MFT
  - NAS: STARS (since 1996**, now in 154+ FAA and DoD systems), ERAM
  - AutoTrac International ATC systems

* For more background and detail, see “Fusion Tracking in Air Traffic Control”, Winter 2008 ATC Journal
** STARS has always had MFT, but until mandated by SBS for ADS-B, could only use the MFT output to locate the target symbol on the display during coasting, identified by “TRK”.
Multisensor Fusion Benefits

- World-wide user community facilitates continuing refinement and adaptability to a wide range of sensors and environments*
- Handles asynchronous and semi-periodic reports
- Makes the best of whatever sensors are available vs.
  - Geographic Location (sensors fill each other’s coverage gaps)
  - Time (short term – missing reports, etc.)
  - Time (long term – seamlessly accommodates new radar and emerging sensors MLAT, ADS-B)

* For more background and detail, see “Fusion Tracking in Air Traffic Control”, Winter 2008 ATC Journal
Areas of high traffic density already have multiple overlapping radar coverage that will continue through NextGen mid-term.

- As shown:
  - All Long Range (200 nmi) radars
  - Proposed Reduced Population of Short Range (60 nmi) radars, given ADS-B

- Future
  - LRR SLEP further increases coverage
  - NAS Enterprise Surveillance Roadmap shows new terminal radars in 2014 – 2018
Existing NAS SRR Coverage in New England

- Individual SRRs support 3NMi separation to 60 NMi (colored circles)
- BCT, for example, receives reports from 8 radars:
  - Every ~5 seconds from 4 SRR (green numbers show how many SRRs are within 60 NMi)
  - Every ~12 seconds from 4 LRR (not shown; LL analysis shows each could support 3NMi separation to 100 NMi)

"Analysis of Terminal Separation Standards and Radar Performance", Steven Thompson & Steven Bussolari, MIT LL

Overlapping coverage from existing NAS radars in high traffic areas increases the aggregate update rate
Radar Infrastructure is needed to support mixed equipage in the NAS for at least the next decade – we can make better use of it NOW.

Charts from:
Surveillance and Broadcast Services
February 21, 2007
MFT (Multisensor Fusion Tracker)
- MFT Fuses asynchronous reports from multiple sensors, as noted above
- While each radar reports at it’s normal 5 or 12 second interval
  - The aggregate, effective rate improves because multiple sensors are seeing the aircraft at different times
  - Pilots, who see their transponder’s busy interrogation indicator in terminal areas, already know!
- Coverage, accuracy, and robustness all benefit
- Correction of radar registration errors before fusion is crucial

Fused Track Display to AT Controllers
- Until recently, NAS requirements prevented using tracker output to locate the symbol on the display; only single radar view is certified for 3 NMI separation
- But SBS had foresight in mandating fused track display from ADS-B and radar, including extrapolation (necessary to deal with the asynchronous nature of multiple radars and ADS-B)

Fused Track Display benefits NAS even before ADS-B is fully deployed
How MFT Improves Separation During Transition to ADS-B (2 of 2)

- MFT, even with just radars, will improve accuracy and update rate, thereby expanding the airspace supporting 3NMi separation
  - A preliminary study was conducted to quantify the benefits
  - Promising results are summarized in the following charts

- Further improvement will be achieved during longer time scales
  - Near-Term: As MLAT coverage expands (e.g. for PRM-A sites beyond Detroit, plus WAM)
  - Mid-Term: As SBS is deployed and ADS-B equipage expands
  - Far-Term:
    - Integrated surveillance
    - Advanced phased array sensors

MFT is the key to improving separation using available and emerging NAS Sensors
Multisensor Fusion Study

- **STARS CCP-607 Data Collection Task**
  - Evaluating separation performance of ADS-B/Radar Fusion Tracking and extrapolation
  - Collecting tracker data for MIT-LL, JHU/APL, and the FAA SBS Separation Standards Working Group to analyze

- **We also independently conducted a separate preliminary study to quantify the benefits of radar-only fusion**
  - Built upon CCP-607 on a non-interfering basis
  - Used the same environment, including:
    - STARS hardware, software, and PHL adaptation
    - Evaluation tools
    - STARS/ATCoach simulator running the same scenarios to simulate coordinated multisensor reports
    - Aircraft equipage combinations
  - Differences from CCP-607
    - Did not run fusion of one short range radar and ADS-B
    - We ran additional sensor combinations (presented later)
    - Analyzed absolute, not relative, tracker accuracy, using Monte-Carlo techniques
    - Did not explore residual radar bias effects
Multisensor Fusion Evaluation

Process and Data Flow

- AT Coach Simulated Target Reports
- Comm. Gateway
- Radar Data Processor with MFT
- Situation Data Display with Extrapolation

Data Collection

Actual STARS R-21 Build Software and Hardware

Radar & ADS-B

Radar & ADS-B (CAT33)

Track Reports

Extrapolated Track Reports

JHU/APL CRABS* Tool

Data Analysis

*Comprehensive Real-time Analysis of Broadcast Systems

Preliminary Results Reported Here (NOT CCP-607 Funded)

CCP-607
Scenarios 1 & 2
Developed by MIT-LL

MIT-LL Scenarios were designed to stress the MFT in the radar environment

Scenario 1: Holding Pattern
Intended to induce tracker transients and lag

Scenario 2: Slow Radial Flight Toward a Radar
The slow radial flight path scenario includes aircraft flying about 110 kts toward the PHL radar location. One aircraft overtakes the other by flying at 120 knots. Intended to minimize per-scan geometry change.

NOTE: Aircraft #2 is not flying radially nor is $D_2$ a radial distance. $D_2$ places Aircraft #2 5 NM in trail of Aircraft #1 on a parallel course, as depicted.
Scenarios 3 & 4
Developed by MIT-LL

Scenario 3: Fast Flight
Tangential to a Radar
Both flying 400 kts. Point of closest approach is 20 nautical miles from PHL radar.
Intended to produce high angular rates.

Scenario 4: Merging Aircraft
Intended to represent an operationally challenging ATC procedure.
PHL TRACON All-Scenario View

- Multiple scenarios run in parallel
- Specified Radar Noise modeled
- ADS-B NACp=8
- Display Update Interval = 1 second
Equipage and Sensor Combinations

- Four aircraft equipage combinations used in all 4 scenarios
  - For each pairing of aircraft in each scenario
    - AC1 radar-only, AC2 radar-only (baseline)
    - AC1 radar-only, AC2 radar & ADS-B
    - AC1 radar & ADS-B, AC2 radar-only
    - AC1 radar & ADS-B, AC2 radar & ADS-B

- Two sensor combinations used with all 4 scenarios + all 4 equipage combinations
  - Fusion with one short-range radar & ADS-B (Not used in this study)
  - Fusion with All Sensors
  - 3 Additional Combinations (Colors match results – next chart)

<table>
<thead>
<tr>
<th>Sensor Combination</th>
<th># points reported</th>
<th>#points extrapolated</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>“All” Sensors</td>
<td>143,283</td>
<td>119,378 [0.83]</td>
<td>Equipage combinations make ~ half of reports radar only</td>
</tr>
<tr>
<td>Multi Radar no ADS-B</td>
<td>83,890</td>
<td>119,045 [1.41]</td>
<td></td>
</tr>
<tr>
<td>Single Radar (PHL)</td>
<td>25,328</td>
<td>118,065 [4.66]</td>
<td></td>
</tr>
<tr>
<td>ADS-B Only</td>
<td>59,138</td>
<td>59,782 [1.01]</td>
<td>Non ADS-B AC NOT SEEN</td>
</tr>
</tbody>
</table>
Multisensor Fusion Cumulative Error Distribution, Including Extrapolation

Required Hor. Position Error @
ADS-B* NACp  9  8  7

MSSR*

95% tile

Improvement from fusing 4 radars vs. just 1

Note: Results are normalized to 120K to facilitate comparison

Absolute Position Error including modeled sensors through actual SW, including extrapolation

MFT, even with just radars, will improve accuracy and update rate

* Equipage combinations cause about half of the reports to be radar-only. This curve would look much better if all AC were ADS-B equipped.
Recommendations for Further Work

- Extend CCP-607 work, including analysis of relative errors between AC pairs and varying residual radar biases, to include 3 Additional Sensor Combinations
  - Multi Radar no ADS-B
  - Single Radar (PHL)
  - ADS-B Only

- Determine how far beyond traditional limits the improved accuracy can extend 3 NMI separation

- Include the MLAT sensor
  - Expect performance approaching ADS-B within PRM-A coverage areas (e.g. the approaches to DTW*)
  - Expect intermediate performance in radar gap filling applications (WAM)*
  - Sensor Diversity- backup for GPS with better accuracy than radar

*See previous chart
Controller Tools & Procedures Enabled by Improved Surveillance

- Ghosting
  - Converging Runway Display Aid (CRDA)
  - Relative Position Indicator (RPI)

- Procedures that reduce fuel consumption
  - Time Based Metering (to arrival fix)
  - Constant Descent Approach (to FAF)
  - Minimizing downwind through RNP
and Relative Position Indicator (RPI)

CRDA Qualification Regions

CRDA Display Includes Ghost Targets to assist controller interleaving Approaches to intersecting runways

Figure 2-5. RPI Aids in Precise Arrival Slot Creation (from “Analysis of Potential Delay Reduction from Implementation of the Relative Position Indicator (RPI) at Operation Evolution Partnership (OEP) Airports” MITRE Product MP80060, June 2008)

- Extension of existing Converging Runway Display Aid (CRDA)
- Target Image “allows the West Feeder controller to make a more informed decision about where to preserve slots for traffic from the east.”
Time Based Metering (ZBW Arrivals)

Time Based Metering (to arrival fix)

- Speed restrictions replaced with required time of crossing (RTC) as necessary
  - Operators meet RTC with most efficient speed/altitude profile
- ATC automation manages crossing times
  - Calculates estimated time of crossing ETCs from downlinked FMS data
  - When congestion occurs, provides calculated RTC to airline dispatch
  - Airline dispatch uplinks RTC to crew via ACARS or voice (Future via DataComm)

DAL211 RTC = 17:55
FDX702 RTC = 17:57
AAL152 ETC = 17:51
CDA (ODP) Ghost Positions (Conceptual)

- Step down descents replaced with continuous idle descent
  - Aircraft cleared for the CDA approach at altitude from the arrival (or transition) fix
  - CDA enabled FMS required for accuracy
- ATC automation monitors descent based on each airline/aircraft profile
  - Ghost positions projected and displayed to controller
  - ATC maintains lateral and vertical spacing for CDA traffic through standard means
RNP Ghost Positions (Conceptual)

Minimizing downwind via RNP
- Aircraft fly 3-5nmi base using RNP
  - Aircraft cleared for the RNP approach
  - RNP enabled FMS required for accuracy
- ATC automation monitors approach
  - Ghost position projected and displayed to controller
  - ATC maintains spacing for RNP traffic through standard means
Conclusion

- We have added PRM-A and Multisensor Fusion, two important capabilities, to the NAS
  - Work with existing radar sensors and aircraft transponders
  - Improve position update rate and accuracy
  - Seamlessly accommodate expanded MLAT and ADS-B
  - Safely support improved separation and increased Terminal Area capacity

- Promising multisensor fusion preliminary study results
  - Show that fusion of existing overlapping radars, using SBS-sponsored MFT enhancements, improves accuracy now, aiding transition to ADS-B
  - We recommend continuing analysis by MIT-LL and JHU/APL to
    - Confirm these preliminary findings
    - Quantify expanded 3 NMI separation
    - Include the MLAT sensor

- Additional recommended Terminal ATC tools facilitate near-term fuel efficiency and capacity improvements

Making better use of what we have will accelerate NextGen
???

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Back Up
STARS Overview

- **STARS (Standard Terminal Automation Replacement System)** Overview
  - Multisensor Fusion Tracker (MFT) fuses reports from up to 16 aircraft location sensors:
    - Short Range (Terminal) and long Range (Enroute) Radar,
    - Multilateration from ASDE-X,
    - ADS-B from SBS; software on track for August delivery to FAA
  - 154 FAA and DoD systems deployed, including half of the 35 OEP airports

- Work with existing equipage
No new display types; any TCW can be switched to “CSP” (Closely Spaced Parallel) mode where it will present an FMA/PRM-like display making the best of any available CSPA sensors and equipage.
Author Bios

- **Tony Jagodnik** is a Senior Engineering Fellow in Raytheon’s Network Centric Systems, Systems Engineering Center, with 42 years of engineering experience. He is Technical Director of the Standard Terminal Automation Replacement System (STARS) program for FAA and DoD. Under the Volpe CNS/TM IDIQ program, Tony is the Task Area Manager for Air Traffic Management Systems (Including TDDS) and Traffic/Fleet Management Automation, Display, and Control Systems. Tony was also the Raytheon Lead Systems Engineer of the NEO (Network Enabled Operations) Spiral Zero program for JPDO, demonstrating information exchange among multiple legacy DoD, FAA, and DHS automation/surveillance/communication systems. Tony’s formal education includes a BSEE from Case Institute of Technology (1967) and an MSEE from Massachusetts Institute of Technology (1969).

- **Joe Stella** is a Senior Principal Engineer at Raytheon’s Network Centric Systems, Systems Engineering Center. He has 29 years of engineering experience. His areas of expertise include the optimization of system performance through the application of mathematical modeling and simulation, design and definition of system requirements, and algorithm design and implementation. For the past 11 years he has been involved with the STARS ATC program, where he has made significant contributions towards improving the performance of the STARS MFT (Multisensor Fusion Tracker). His education includes a BS in Physics and a MSEE from the University of Lowell.

- **Robert Stamm** is a Senior Principal Systems Engineer in Raytheon's Network Centric Systems, Systems Engineering Center. He has over 28 years of systems and software architecture experience. Bob’s work includes leading several advanced STARS prototype systems for fusion tracking of radar, multilateration and Automatic Dependent Surveillance – Broadcast sensors. Bob is currently the Principal Investigator for NEO Spiral 2. He also works for the STARS Program. Bob’s career also includes medical imaging research and development work at Brookhaven National Laboratories work on Air and Vessel Traffic Control systems along with enterprise management research and development at both Computer Associates International and Raytheon. Bob holds a MS Degree in Computer Sciences, Polytechnic University of New York, a BS Degree in Computer Science from Empire State College, State University of New York and a BS in Biological Sciences from the State University of New York at Stony Brook.