An Automated Airspace Concept for the Next Generation Air Traffic Control System

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Demand for air travel continues to increase

Substantial increase in traffic expected in next 20 years. Today’s airspace system is not expected to be able to accommodate future demand.

Data source: ICAO scheduled services of commercial carriers (courtesy, John Hansman, MIT)
Insufficient capacity?

- Spatial capacity
- Practical capacity as presently operated
  - Competition for prime runways (& airspace) at prime time
  - Cognitive capacity for keeping aircraft separated

- Increases in demand are expected to exacerbate these demand/capacity mismatches

- Many approaches to alleviating the problem
  - Automated separation assurance
Air Traffic Control functions

• Keep aircraft safely separated
  – Monitor separation
  – Detect potential conflicts
  – Resolve them
  – Transfer separation responsibility

• Minimize delay
Elements of a Future Airspace System

Data Link

Trajectory-Based Automation (2-20 min time horizon)

Safety Assurance (0-3 min time horizon)

Collision Avoidance (0-1 min time horizon)

Voice Link

Humans

Trajectory Database
Trajectory Modeling
## Conflict Analysis

<table>
<thead>
<tr>
<th>SHOW</th>
<th>ACIDS</th>
<th>RM</th>
<th>TM</th>
<th>VS</th>
<th>HS</th>
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## Conflict Detection

<table>
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AAL2212 JFK
350 C
8752 499

COM4 CVG
350 ↑ 278
CRJ1 432

(25 nm)
Conflict Resolution

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<td>RES</td>
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AAL2212 JFK
350 C
B752 499

COM4 0641 11
350 ↑ 276
CRJ1 432

(25 nm)
Technical Challenges

• Allocation of functions between automation and human operators
• Allocation of automation between cockpit and ground
• Automation of conflict detection and resolution
• Fault tolerance and Safety assurance
Human/Automation Allocation

- Human detects conflict with automation support, human resolves
- Automation detects conflict, human resolves
- Automation detects conflict, suggests resolution, human (modifies and) resolves
- Automation detects conflict, automation resolves
Probing the low end of the automation spectrum

• Experiment
  – Real-time lab simulation, Fort Worth Center traffic data
  – 5 airspace sectors combined, 90 min traffic sample
  – Traffic levels comparable to today’s operations
No one detects conflicts, no one resolves

Aircraft Count

Elapsed time (min)

Aircraft count

Minimum Separation Metric

Unique aircraft pairs

Elapsed time (min)

< 5 nmi

5-10 nmi
Human detects conflicts, human resolves

Aircraft Count

Minimum Separation Metric

Elapsed time (min)
Automation Detects, Human Resolves
One controller doing work of 5 to 10 people. No loss of separation.
Probing the high end of the automation spectrum

- Which aircraft moves, what maneuver, when, constraints
- Airborne and ground-based implementations
- Surveillance, intent, data exchange, coordination
- Metrics
Auto Resolution Example
Auto Resolution Example
Auto Resolution Example
## Auto Resolution Results Summary

<table>
<thead>
<tr>
<th>Traffic level, Cleveland Center</th>
<th>1X</th>
<th>~2X</th>
<th>~3X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic count (24 hours)</td>
<td>7000</td>
<td>17800</td>
<td>26000</td>
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<tr>
<td>Conflicts detected and resolved</td>
<td>532</td>
<td>1572</td>
<td>3099</td>
</tr>
<tr>
<td>% flights in conflict</td>
<td>12</td>
<td>20</td>
<td>23</td>
</tr>
<tr>
<td>Mean delay (sec)</td>
<td>21</td>
<td>22</td>
<td>25</td>
</tr>
</tbody>
</table>

100% of en-route conflicts resolved.

Cost of resolution rises acceptably with traffic level.
Auto Resolution Delay Characteristics

Delay Statistics (sec)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
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</thead>
<tbody>
<tr>
<td>1x</td>
<td>21</td>
<td>31</td>
</tr>
<tr>
<td>2x</td>
<td>22</td>
<td>39</td>
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<tr>
<td>3x</td>
<td>25</td>
<td>48</td>
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</tbody>
</table>

minutes of delay (+/- 15 sec)
Safety Assurance

- Tactical, safety-critical conflict analysis (0-3 min)
- Simple, safe maneuvers to clear the conflict
- Multiple trajectories for each aircraft
Multiple Trajectory Models - Vertical

- fast climb
- slow climb
- dead reckoning

predicted altitude

 altitude entered

predicted time
Tactical Safety Assurance vs Today’s Conflict Alerting

69 Operational Errors

- Tactical safety assurance
- Today’s conflict alerting

Alert lead time, sec

- > 30
- > 60
- > 90
Collision Avoidance

• Tactical, safety-critical conflict analysis (0-1 min)
• Urgent maneuvers to avoid collision
Technical Challenges

- Allocation of functions between automation and human operators
- Allocation of automation between cockpit and ground
- Automation of conflict detection and resolution
- Fault tolerance and safety assurance
Initial Safety Analysis

- Identify failure and recovery modes
- Identify risk of failures and risk of collision if failure occurs.
- Analyze safety criticality requirements of key architectural components
- Interoperability of tactical safety assurance automation and TCAS.

Traffic Density = 0.002 AC/nmi³
Activity Level: 20 million flight hours/year

Challenges Ahead

- Interoperability of layered separation assurance functions
- Modeling, measuring human awareness
- Failure and uncertainty modeling
- Understanding, building the safety case
- Consistent objective metrics
- Comparison of airborne and ground-based methods
- Testing in today’s operations
- Transition strategy
Concluding Remarks

• Today’s airspace operations are not expected to be able to support anticipated growth in air traffic demand.

• Automation of primary separation assurance functions is one approach to expand airspace capacity.

• Primary technical challenge: develop technology and procedures to deliver a safe, fail-operational automated separation assurance capability.