Separation Assurance in the Future Air Traffic System

Presented at
ENRI International Workshop on ATM/CNS

by
Heinz Erzberger
Adjunct Professor of Electrical Engineering, U.C. Santa Cruz
Consulting Professor of Aeronautics and Astronautics, Stanford University

March 2009
Outline of Presentation

- Architectures and Operational Concepts for NextGen ATM System
  - Ground Centered Separation Assurance
  - Aircraft-Centered Separation Assurance
- Algorithms for Conflict Resolution
  - Short range, tactical conflicts
  - Strategic conflicts and arrival management
- Evolutionary Steps toward Automated Separation Assurance
**Paradigm shift**: Ground-based systems connected to flight deck by data link are responsible for separation assurance.

Controllers responsible for traffic management and for handling special situations.
Analytical Model for Short Range Conflict Resolution

- Modeling of turn dynamics required for resolution of short range conflicts
- Resolution trajectories consist of heading changes followed by a straight line segment
- Objective is to achieve separation equal to or greater than required minimum separation

\[ R_A = \frac{V_A^2}{g \cdot \tan|\phi_A|} \] where $\phi_A$ is the bank angle
Conflict Resolution Analysis in Separation-Turn Angle Coordinates with Bank Angle as a Parameter

Separation during turn for a range of bank angles
Minimum sep. in straight line segment after end of turn
Time to min. sep. at 30 deg. bank angle

Aircraft B at 480 kn
A/C A 400 kn

Left turns

Right turns
Resolutions for Eight Maneuver Types

A turns left/right, B flies straight

B turns left/right, A flies straight

A turns left/right, B turns right

A turns left/right, B turns left
Window for autonomous uplink of TSAFE-Resolution advisory;

Controller resumes responsibility

If no action was taken by controller and conflict remains unresolved, or if conflict is first detected after this time, TSAFE Res. is uplinked to aircraft autonomously.

Pilot initiates maneuver expeditiously when clearance is received

Time to loss of separation

TSAFE Action Time*:

The smallest time to first loss for which resolution trajectory exists that avoids loss of separation.

**Definition of TSAFE Action Time:**
Application of Mode S Specific Services Data Link for TSAFE

- Mode S Specific Services
  - Mature technology, ICAO approved
- Com A Protocol for uplinking TSAFE Messages
  - 48 bits available for specifying resolution maneuver
  - Handshake reply by a/c verifies 24 bit parity check
- Ground Initiated Com B (GICB) Protocol for Readback of TSAFE message
  - Sends resolution maneuver received by the a/c back to ground system for verification
- Combination of handshake and readback with parity checks gives extremely low error rate
Strategic Conflict Resolution Algorithm

• Resolves three types of conflicts:
  – Loss of separation conflicts
  – Weather conflicts
  – Arrival sequencing conflicts
• An aircraft may be involved with all three types at the same time.
• Uses flight plans and aircraft performance models
• Order of resolution:
  1. Weather conflicts
  2. Sequencing conflicts
  3. Loss of separation conflicts
Resolution Algorithm

• Multiple resolutions are generated for each aircraft in a conflict
  – Left turns, right turns
  – Altitude: Temporary step-up or step-down in cruise, temporary level off during climb or descent
  – Speed change in cruise or speed profile change during descent
  – Direct-To’s

• From available successful resolutions, the resolution producing the least delay is selected (with certain exceptions)
  – Selectable delay handicap parameter gives delay advantage to horizontal resolutions
Vertical Resolution Maneuvers

- Temporary altitude, Early descent
- Temporary altitude
- Step climb in cruise
- Step descent in cruise
A specified delay generates a family of path stretches, whose locus forms an ellipse.

The algorithm starts generating resolutions with a path stretch on the symmetry axis.

It increases the vector angle if needed to avoid secondary conflicts.
Weather Cell Avoidance Algorithm

Weather cell probe provides entry and exit locations of cell for any flight plan. Shape of cell is not known.

Algorithm

Increment heading in small intervals.

For each increment locate auxiliary waypoint at midrange between entry and exit of a cell.

When vector path is first clear of cell, check return path for cell penetration.

Increase range of auxiliary waypoint along vector direction in small increments until return path is clear of cell.
Flow Chart for Algorithm

Input Conflict Pair

Resolution Maneuver Generator

Trial Planner
4D Trajectory Synthesizer

Traj. completed?

No

Check traj. for conflicts

Yes

Conflicts detected?

Yes

Res. Traj. accepted

No

Formulas and logic for calculating simplified resolution traj.

Heavy duty numerical calculations

Formulas and logic for calculating simplified resolution traj.
Conflict-Free Arrival Sequencing

Automation of descent and arrival management requires the simultaneous solution of two types of conflicts to ensure that descent trajectories are conflict free along the entire descent profile and meet in-trail time separation constraints at the arrival fix.

1. Loss of Separation Conflict
   - Location can be anywhere along flight path
   - Separation criterion is specified as a min. distance and min. altitude

2. Sequencing Conflict
   - Location of conflict at merge point, usually at the arrival fix
   - Separation criterion is specified as min. time interval between two consecutive aircraft crossing the fix
A new arrival, D, has crossed the freeze horizon and has become eligible for sequencing and deconfliction. A loss-of-separation conflict is projected between aircraft D and C at the merge point, and sequencing conflict (not shown graphically) with C is projected at the arrival fix.
Finding a Slot for a Popup
DTW SE Arrival Gate for Jets at 2x Traffic Level

New (red) arrivals are merged, scheduled and deconflicted into frozen stream.

Frozen (blue) aircraft scheduled in previous epochs.

Freeze Horizon
# Evolutionary Steps toward Automated Separation Assurance

<table>
<thead>
<tr>
<th>Level of Automation</th>
<th>Benefits</th>
<th>Controller Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Automate long range (strategic) enroute conflicts</td>
<td>Increased efficiency, reduced controller workload</td>
<td>Controller retains responsibility for separation assurance</td>
</tr>
<tr>
<td>2. Automate arrival sequencing</td>
<td>Reduced fuel consumption</td>
<td>Controller retains responsibility for separation assurance</td>
</tr>
<tr>
<td>3. Automate short range conflicts</td>
<td>Increased safety, increased capacity</td>
<td>Controller has conditional and limited responsibility for SA</td>
</tr>
<tr>
<td>4. Integrate short and long range SA</td>
<td>Greatly increased safety, efficiency and capacity</td>
<td>Controller handles special situations</td>
</tr>
</tbody>
</table>