Separation Assurance in the Future Air Traffic System

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by
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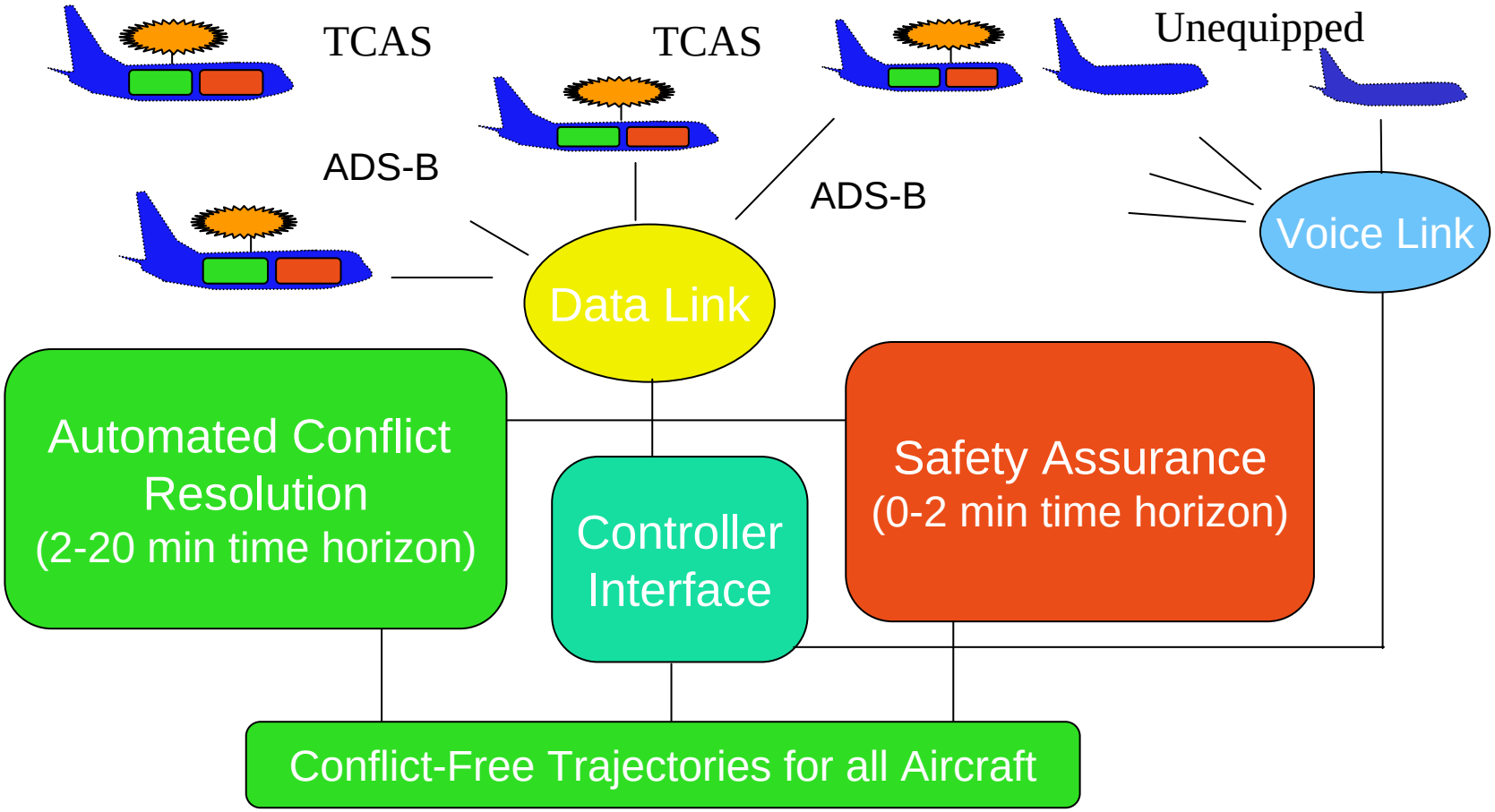
Outline of Presentation

- 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

Architecture for Ground-Based System

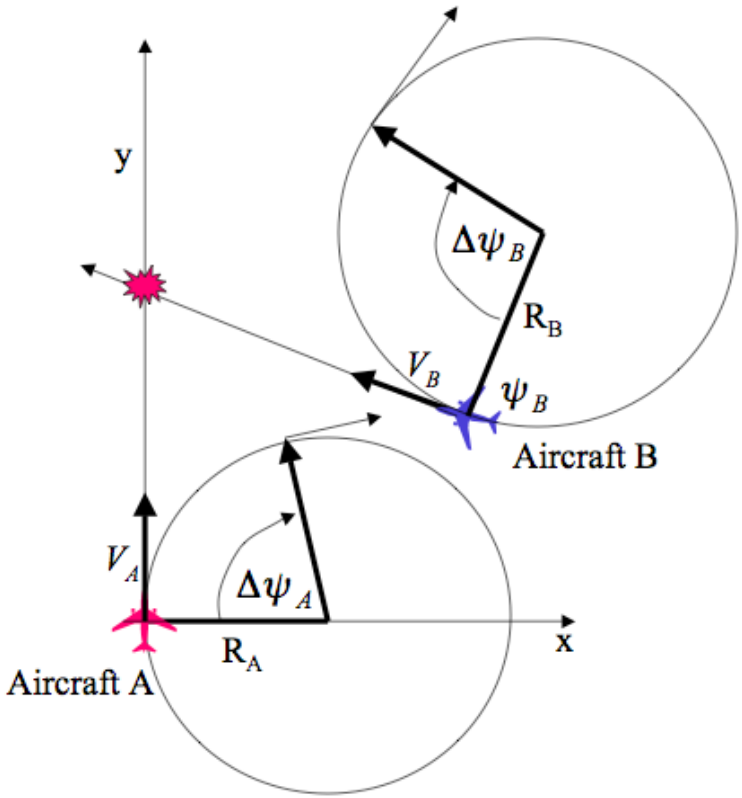
Paradigm shift: Ground-based systems connected to flight deck by data link are responsible for separation assurance

Controllers responsible for traffic management and for handling special situations



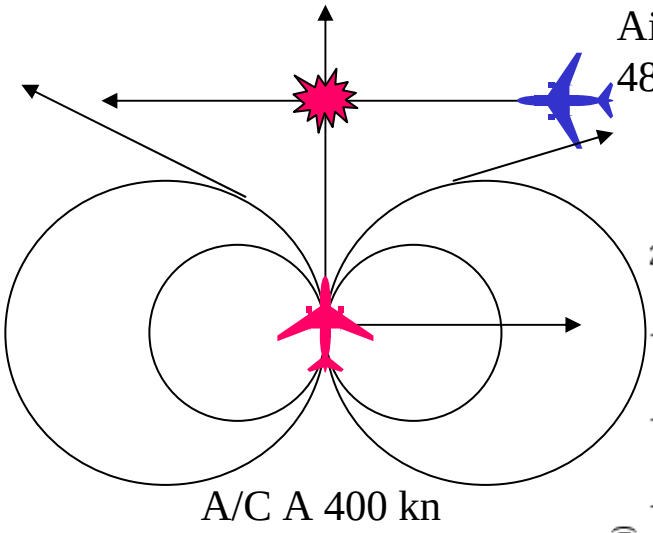
Analytical Model for Short Range Conflict Resolution

- 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



$$R_A = \frac{V_A^{\,2}}{g \cdot \tan\left|\phi_A\right|} \quad where\ \phi_A\ is\ the\ bank\ angle$$

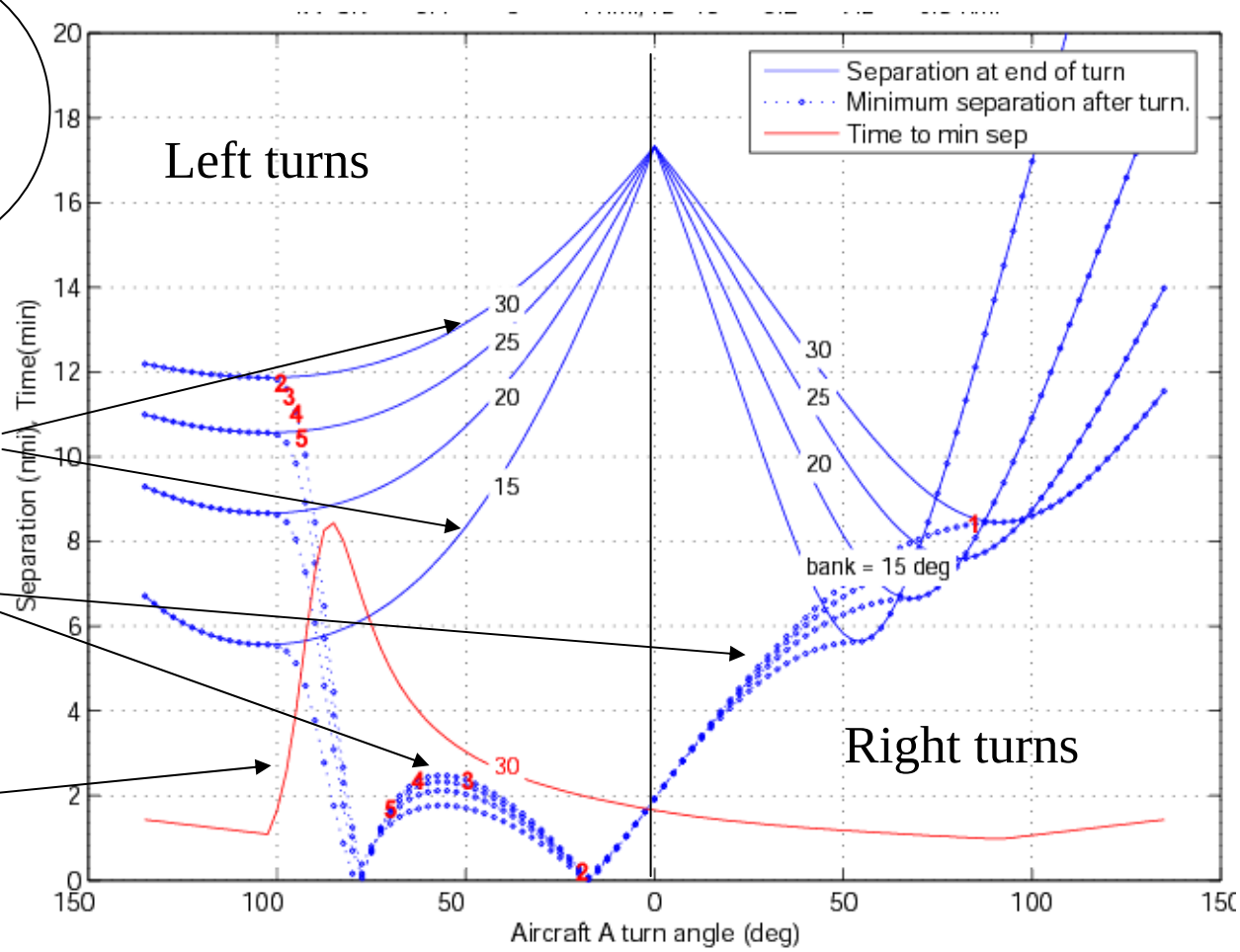
Conflict Resolution Analysis in Separation-Turn Angle Coordinates with Bank Angle as a Parameter



Separation during turn for a range of bank angles

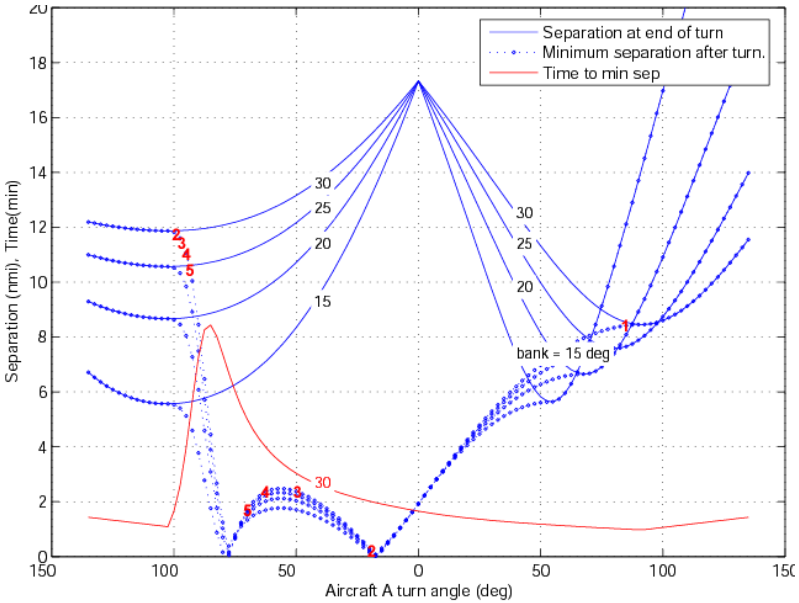
Minimum sep. in straight line segment after end of turn

Time to min. sep. at 30 deg. bank angle

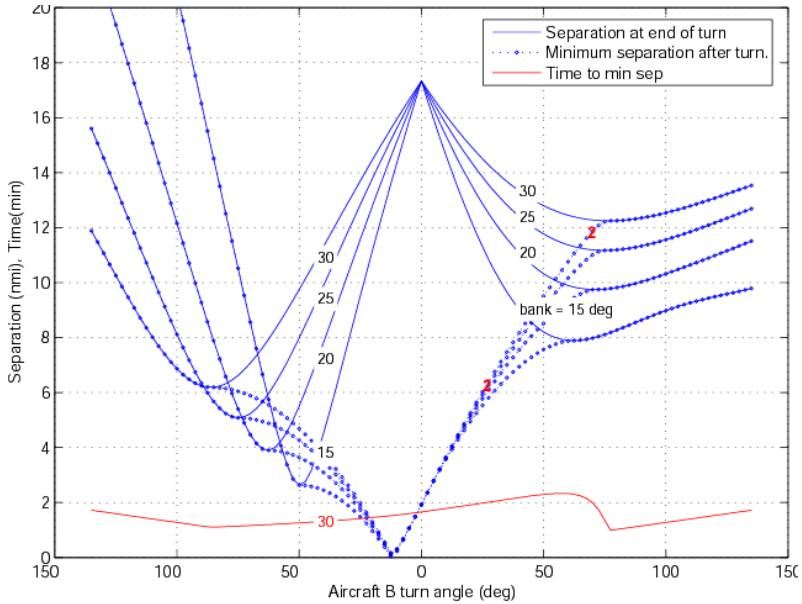


Resolutions for Eight Maneuver Types

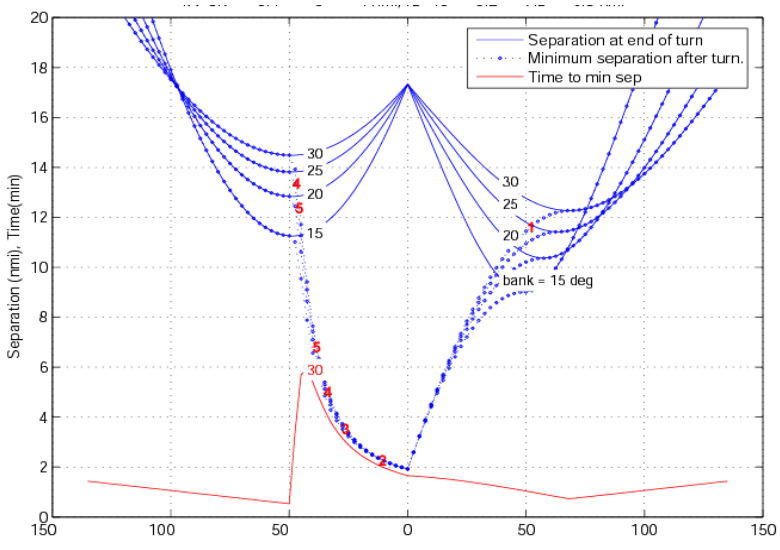
A turns left/right, B flies straight



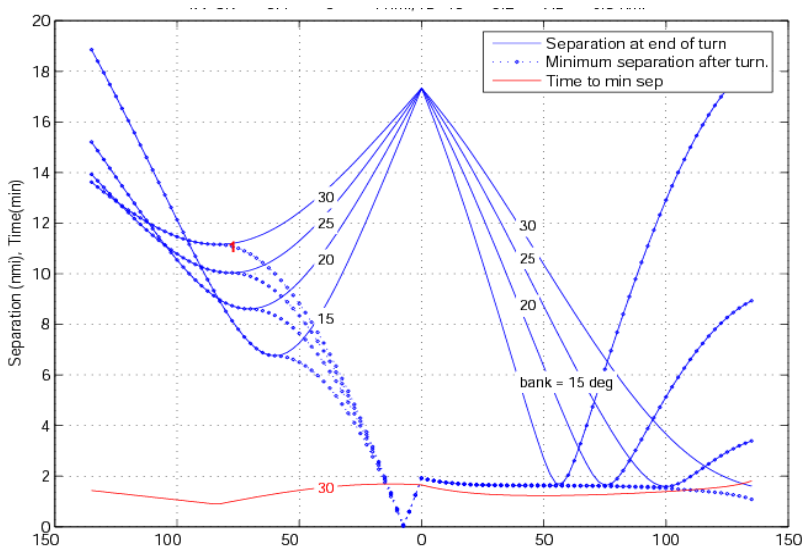
B turns left/right, A flies straight



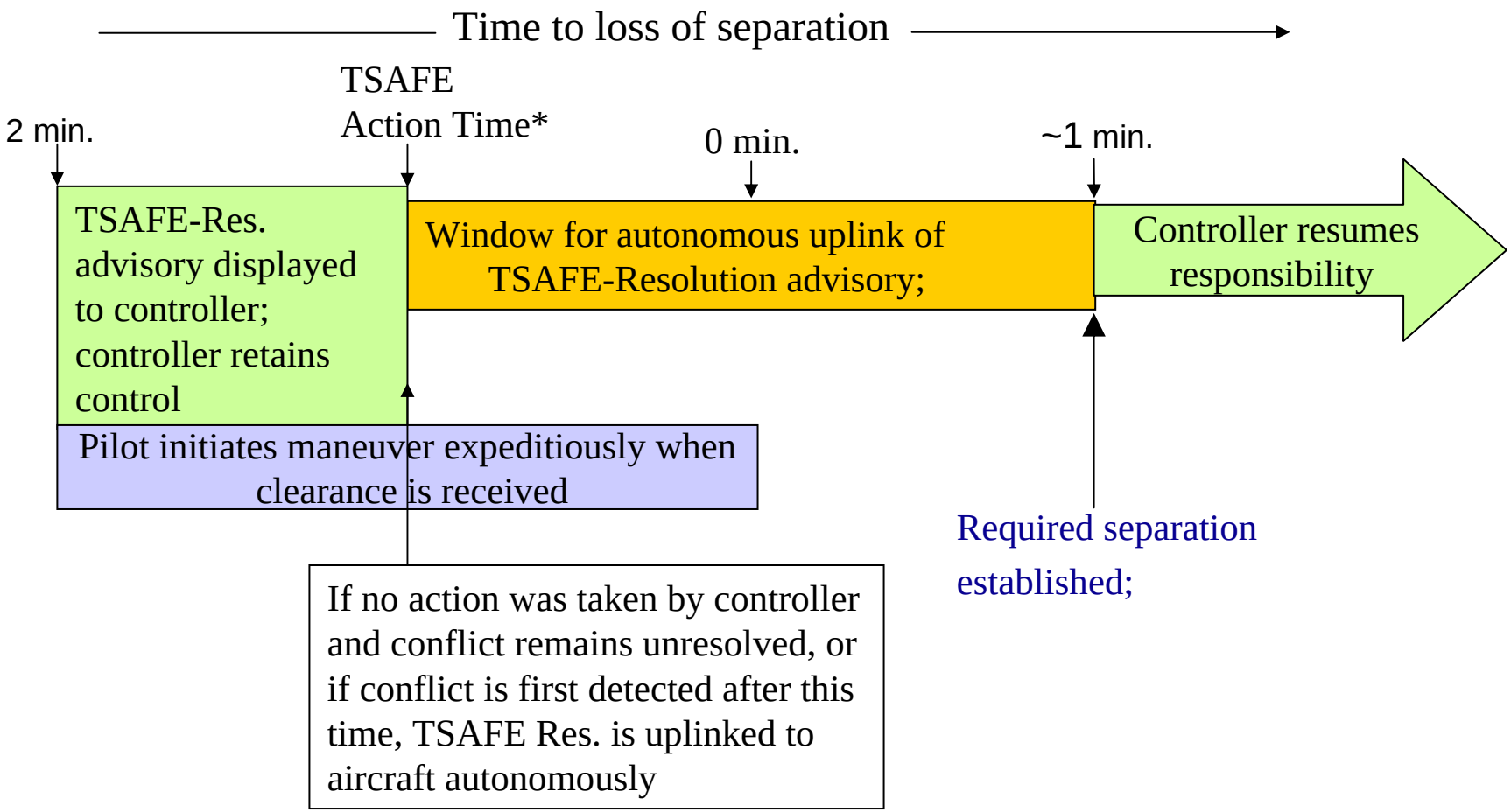
A turns left/right, B turns right



A turns left/right, B turns left



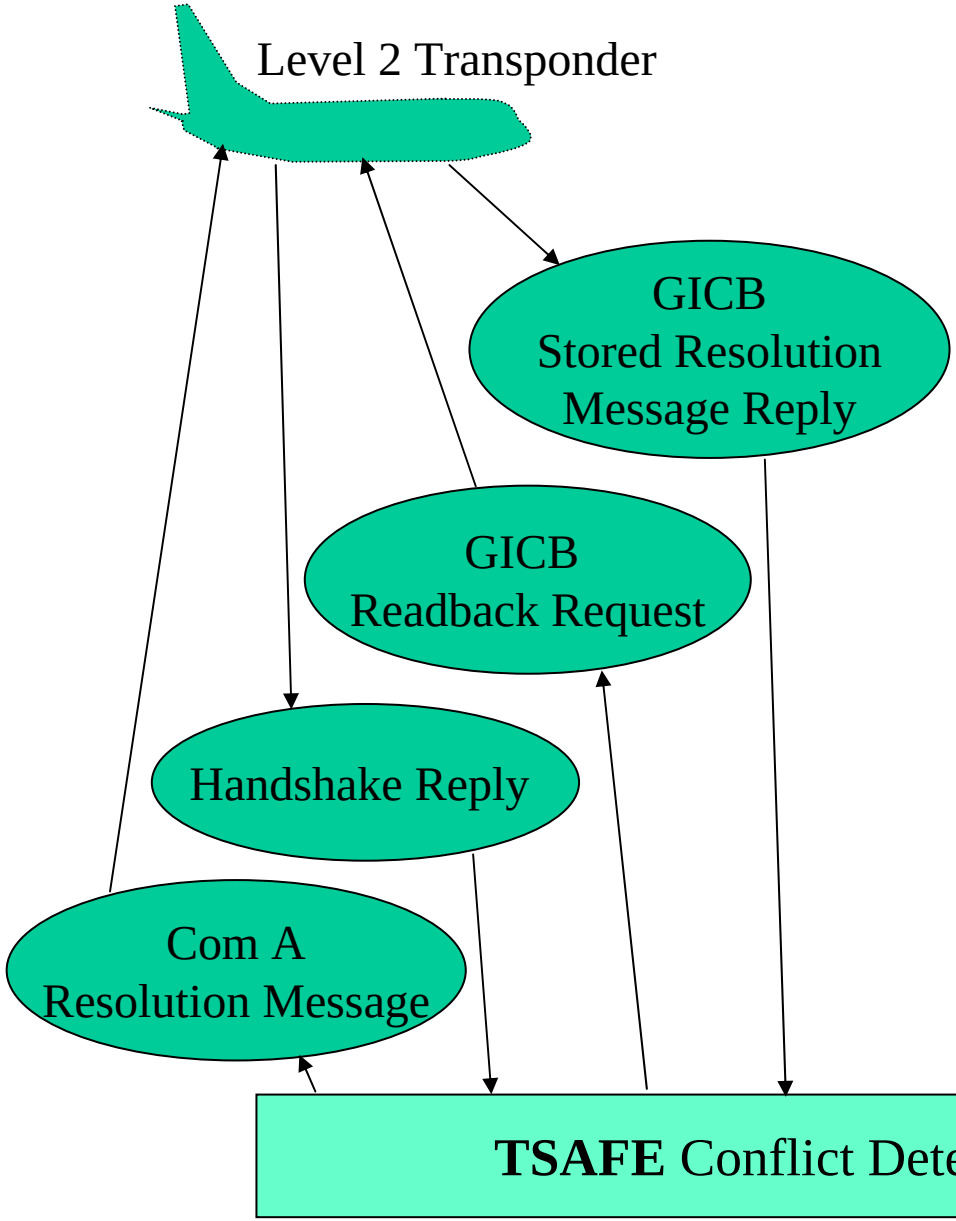
TSAFE Resolution Decision and Event Time Line



***Definition of TSAFE Action Time:**

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

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

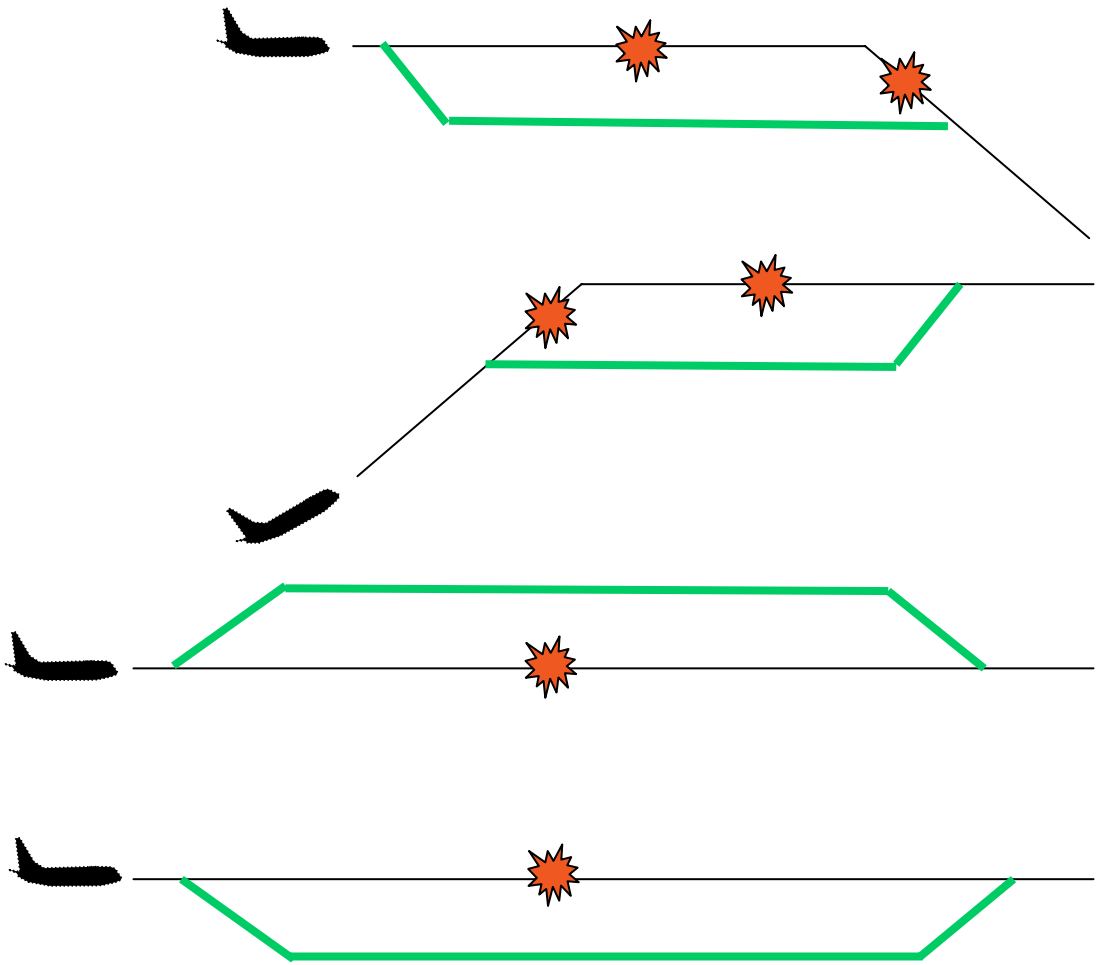
Strategic Conflict Resolution Algorithm

- 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



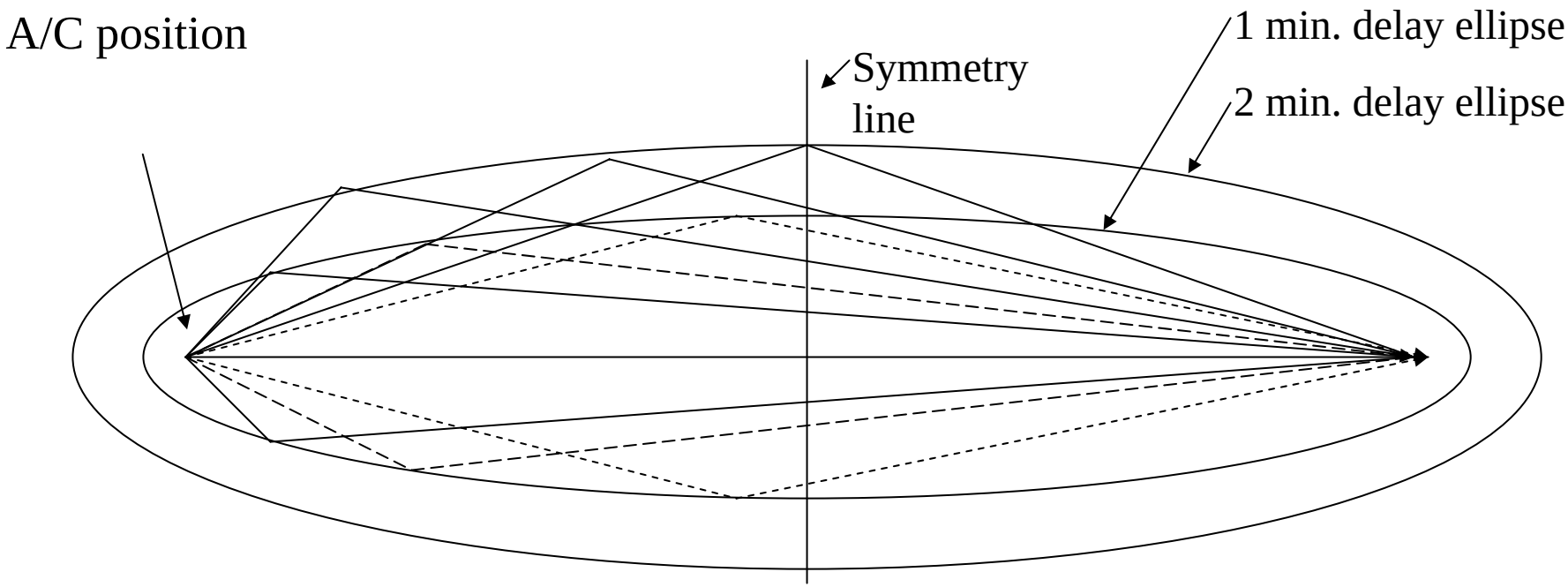
Temporary altitude,
Early descent

Temporary altitude

Step climb in cruise

Step descent in cruise

Path Stretch Vector Resolution Envelope



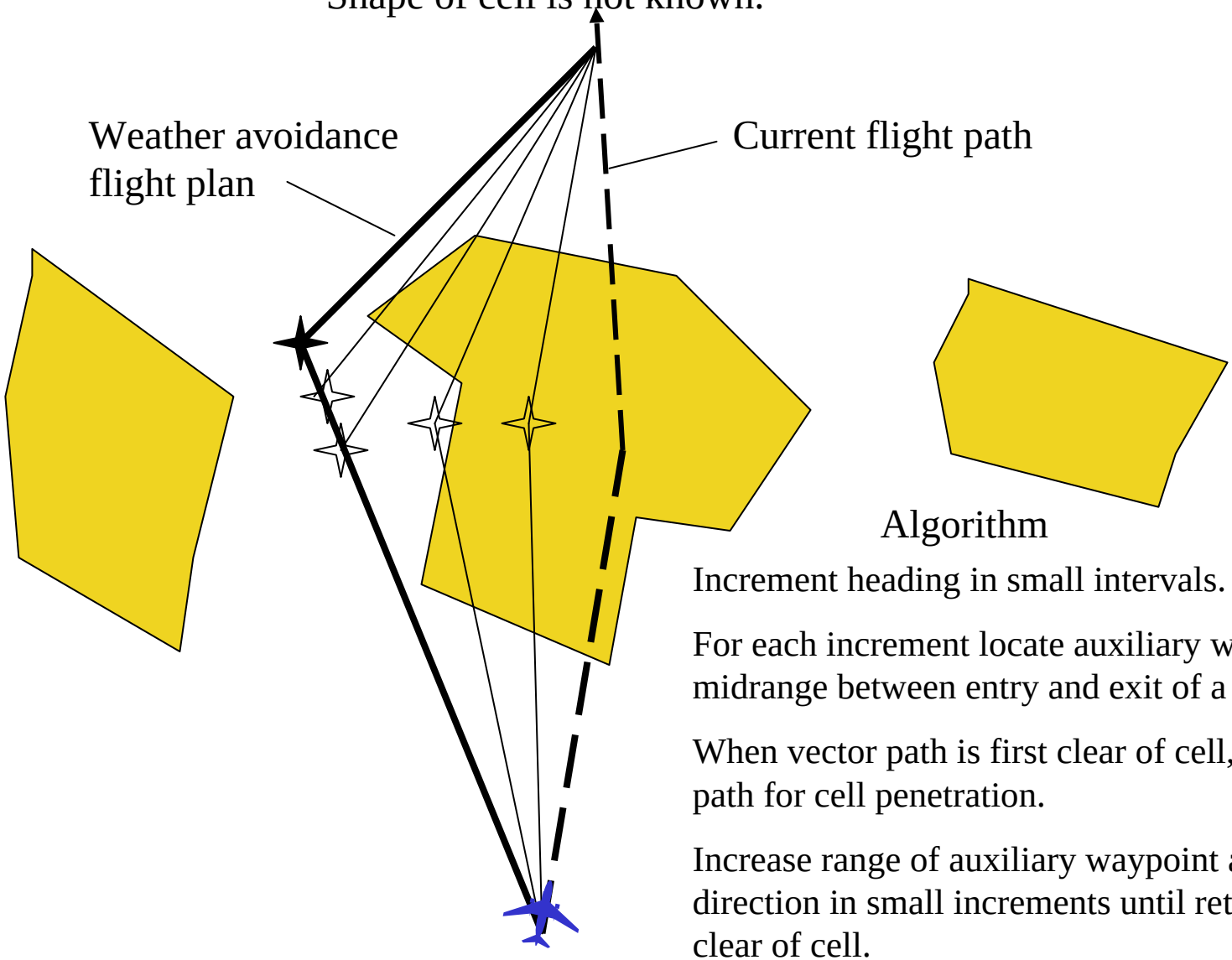
A specified delay generates a family of path stretches, whose locus forms an ellipse

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

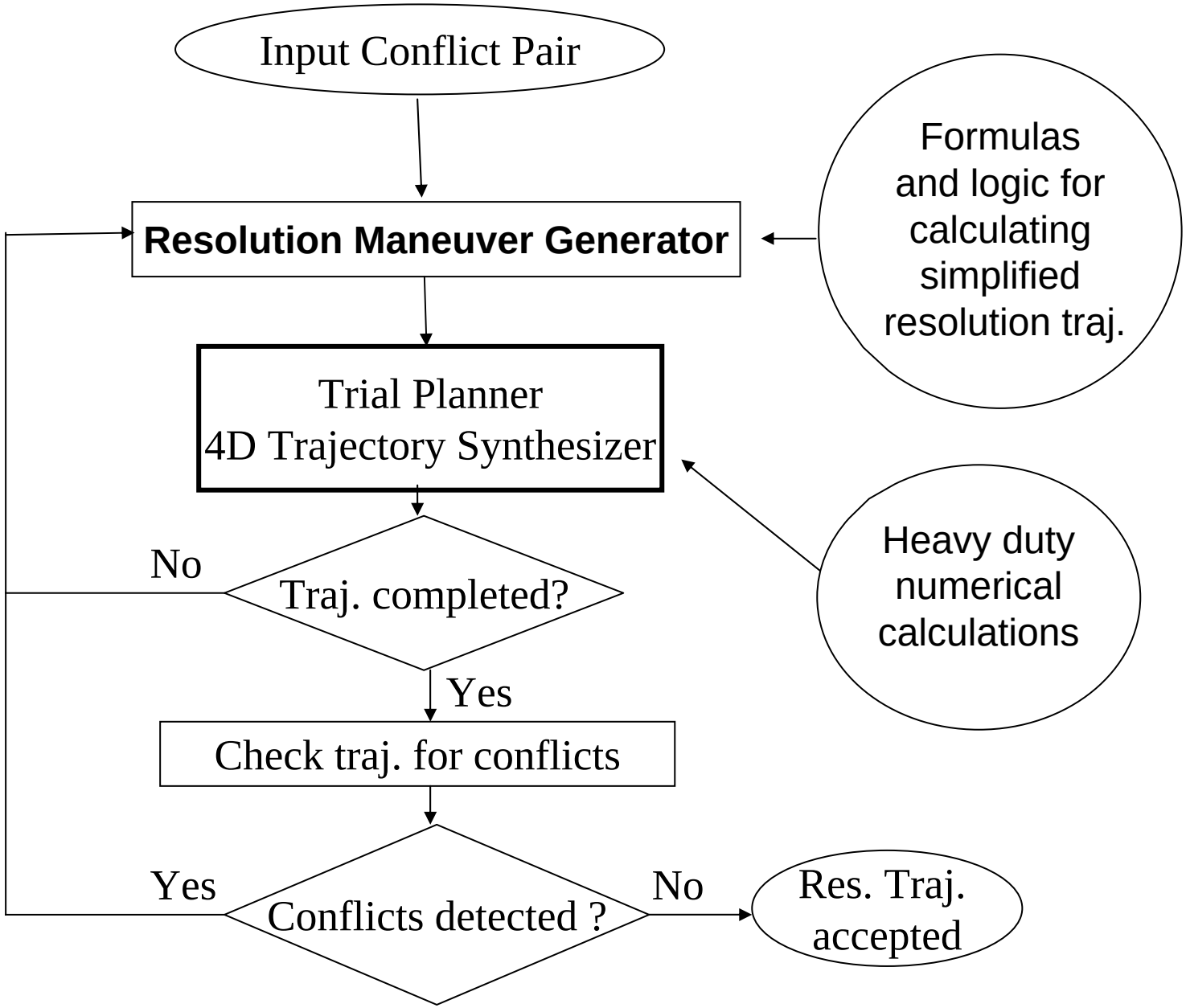
Increment heading in small intervals.

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



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

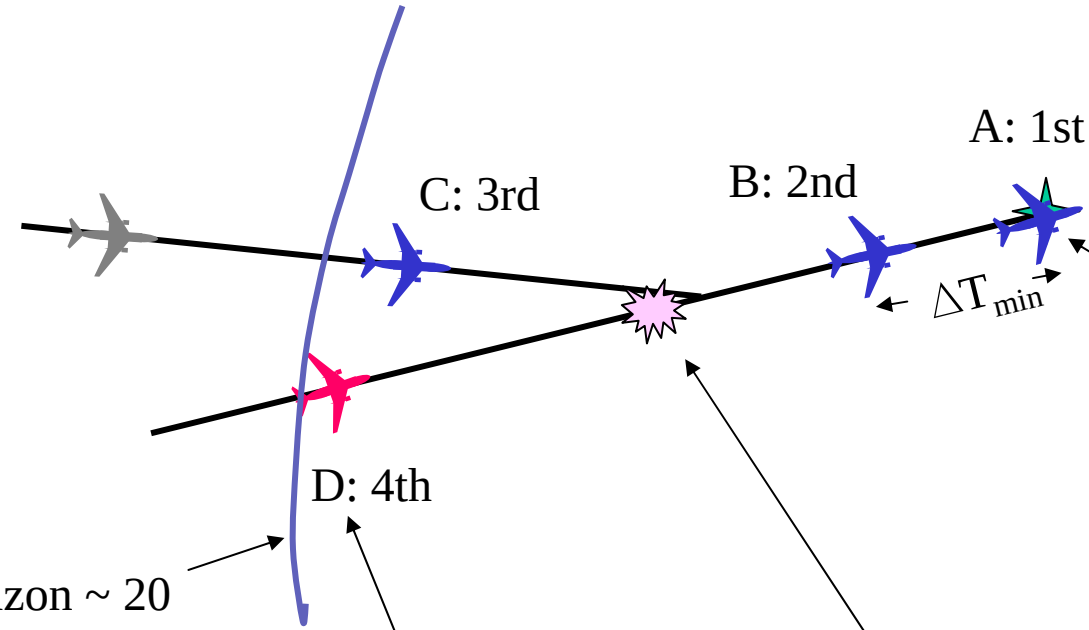
1. Loss of Separation Conflict

- 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

Sequencing and Loss of Separation Conflicts



Arrival Fix: Cross at 10,000 ft and 250 KCAS

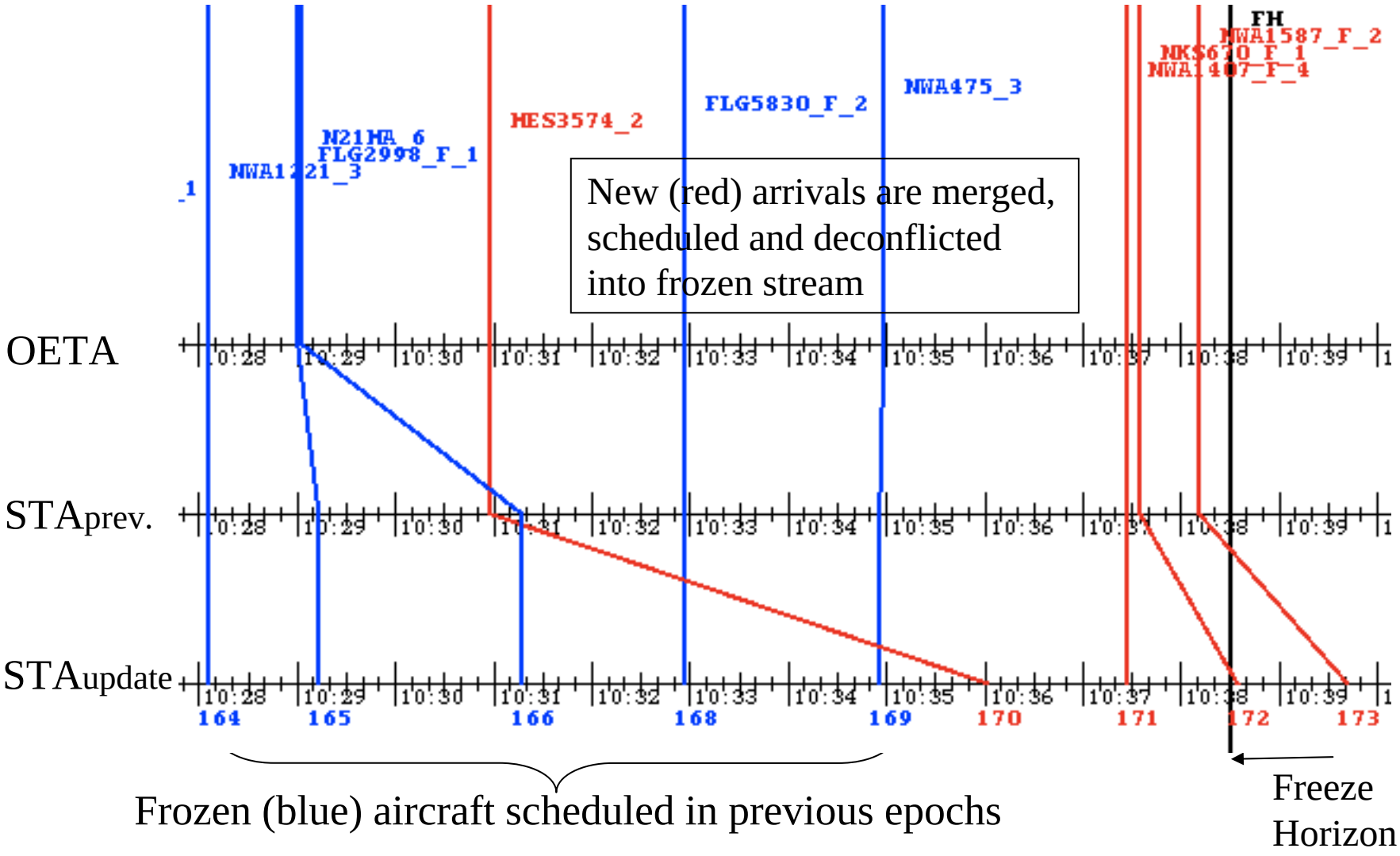
Freeze Horizon ~ 20 minutes from arrival fix

New arrival, D, has crossed the freeze horizon and has become eligible for sequencing and deconfliction

A loss-of-separation conflicts is projected between aircraft D and C at 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



Evolutionary Steps toward Automated Separation Assurance

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