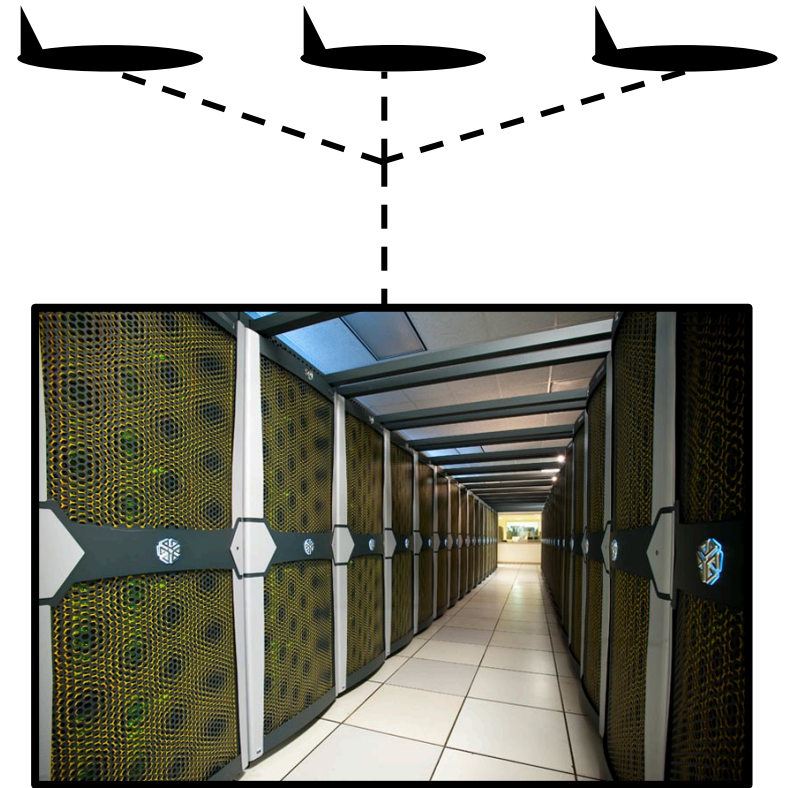
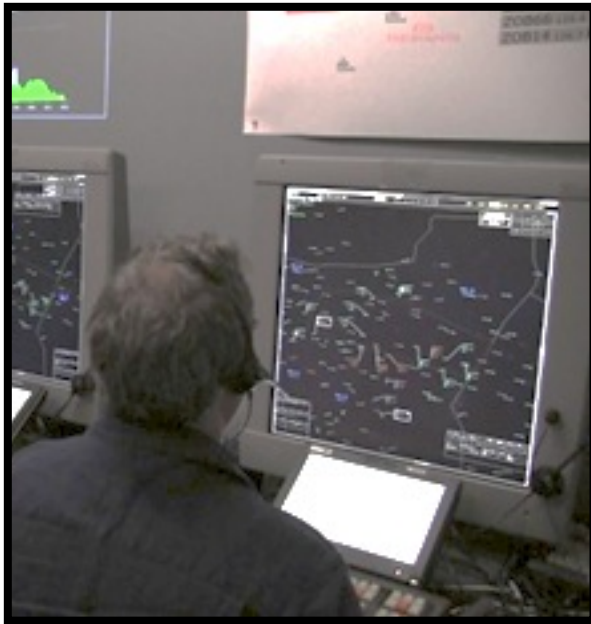


Automated Separation Assurance with Weather and Uncertainty

Todd Lauderdale and Heinz Erzberger

NASA Ames Research Center

Automated Separation Assurance



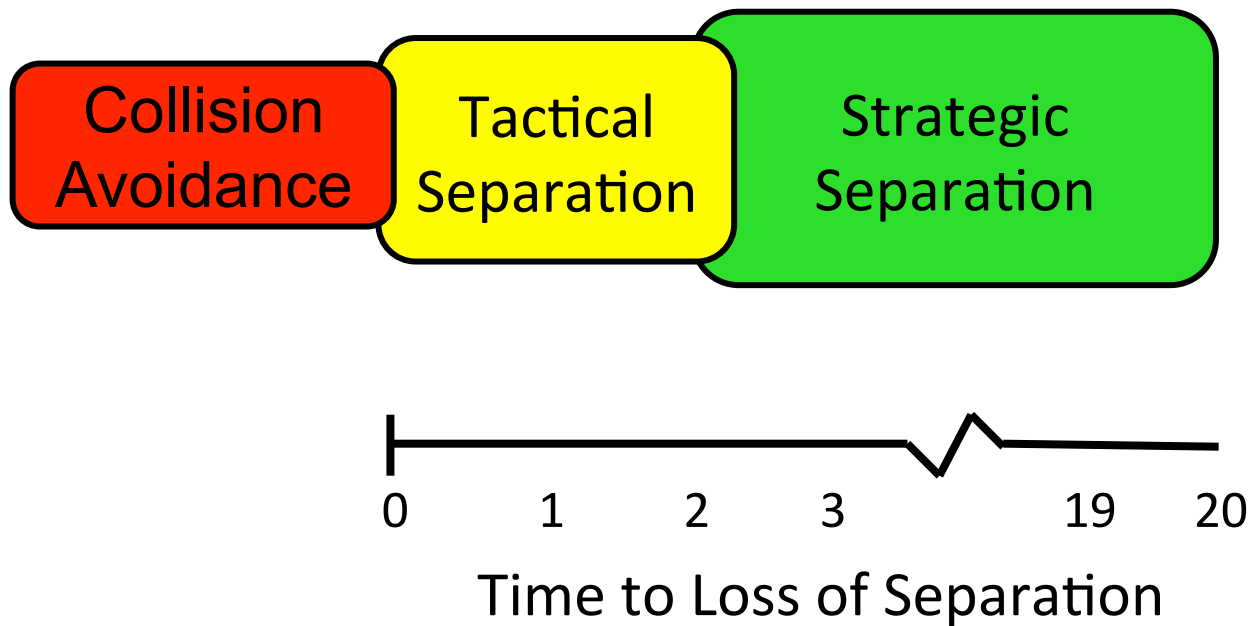
Take Away

- A long-term research focus guided us towards:
 - Automated weather avoidance
 - Robust handling of trajectory prediction errors
- This provided us with near-term benefits

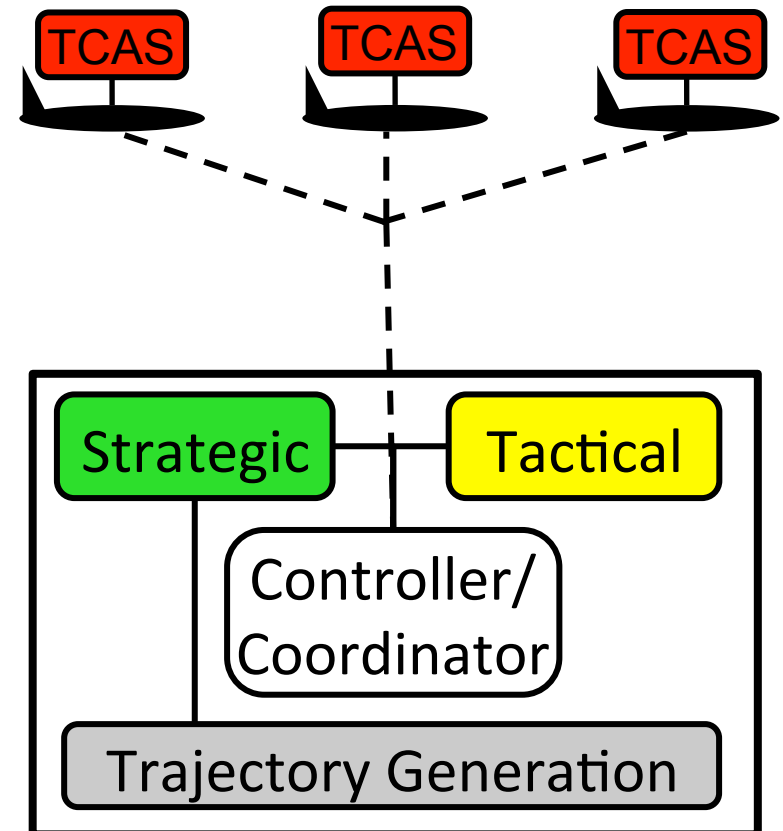
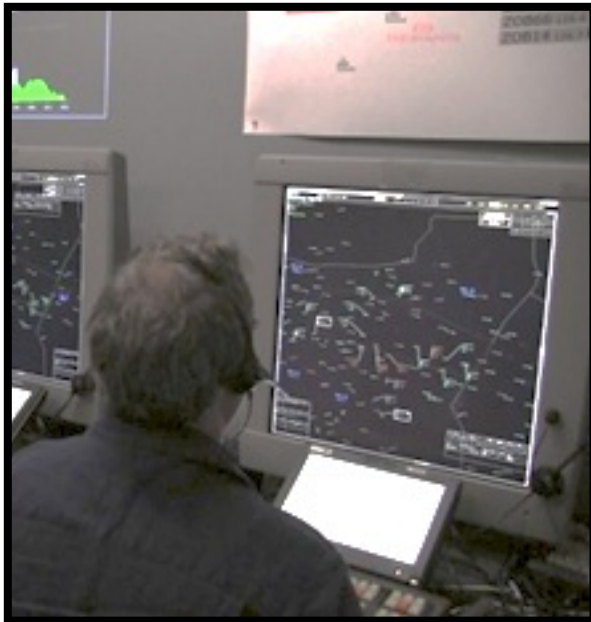
Outline

- Algorithm background
- Trial planning
- Weather avoidance
- Handling trajectory prediction errors

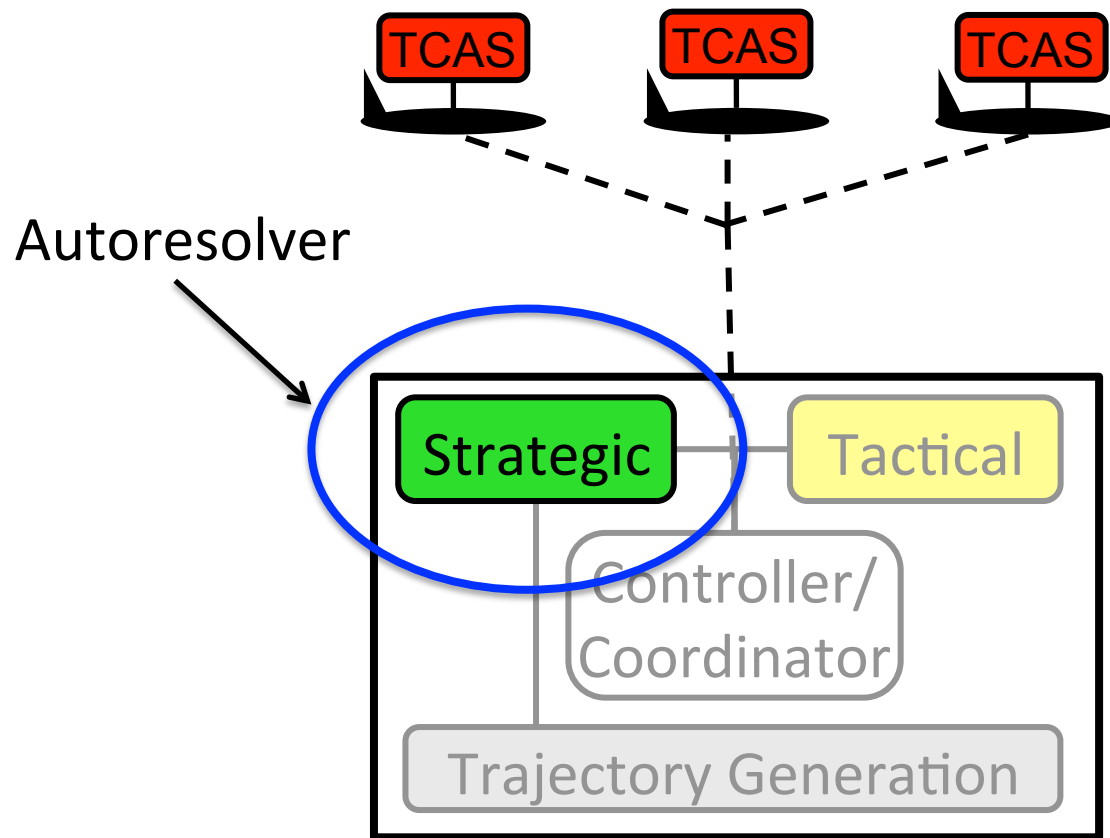
A Layered Approach to Separation Assurance



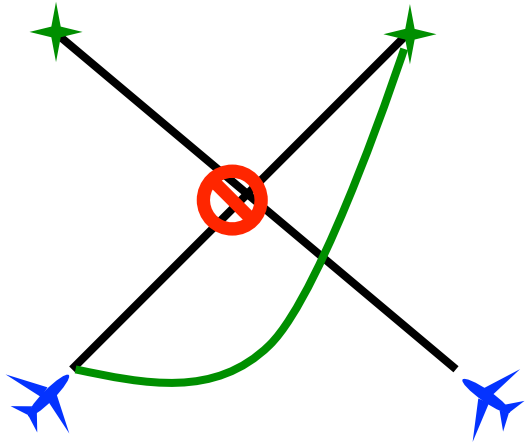
Advanced Airspace Concept



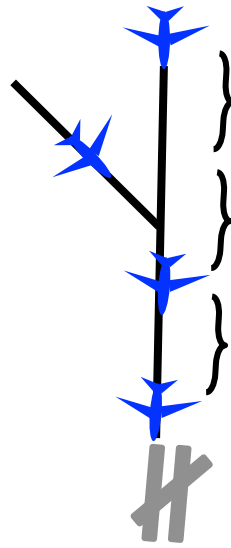
Advanced Airspace Concept - Autoresolver



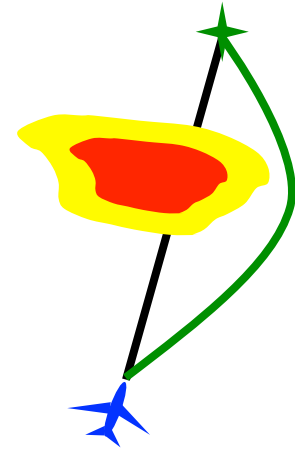
Integrated Solutions



Conflicts

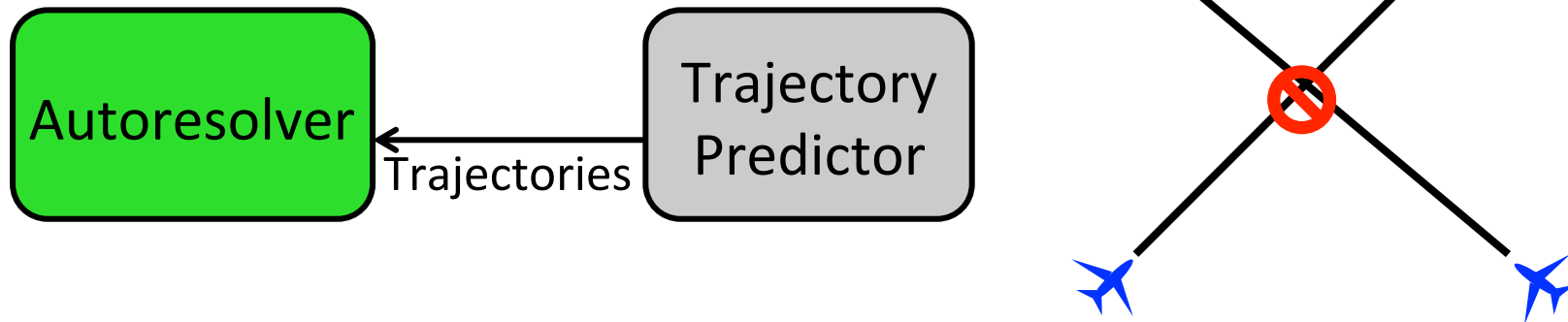


Arrival Merging
and Spacing



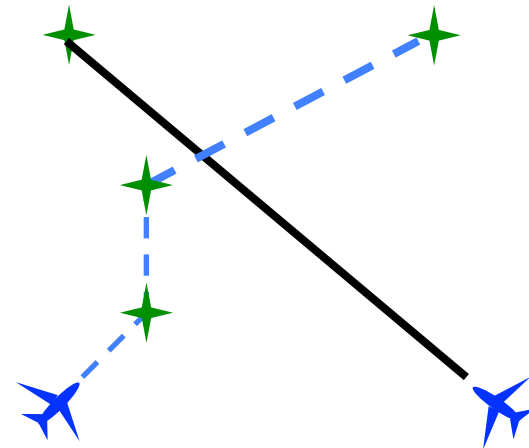
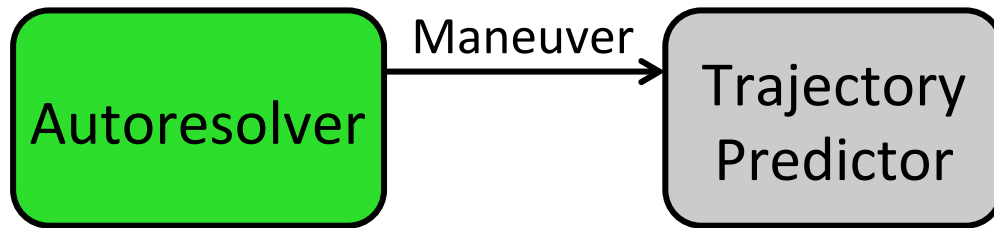
Weather Avoidance

Trial Planning



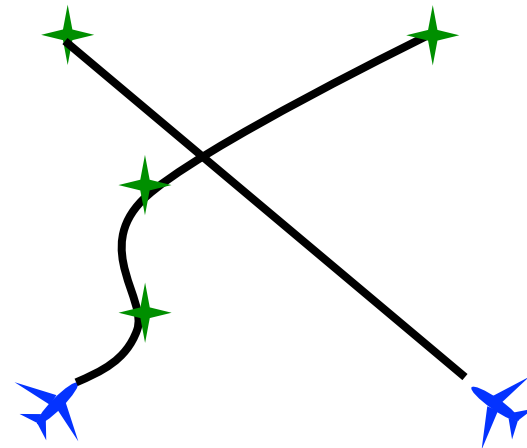
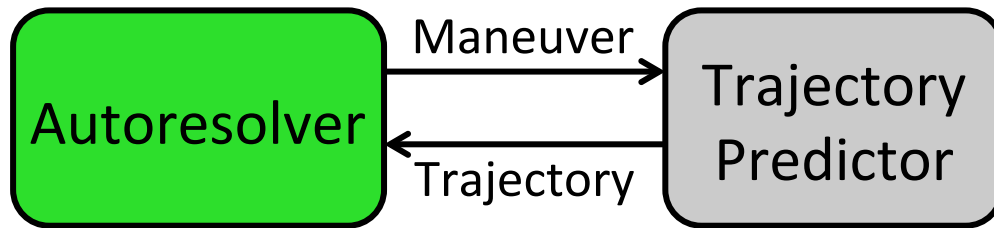
A loss of separation is predicted

Trial Planning



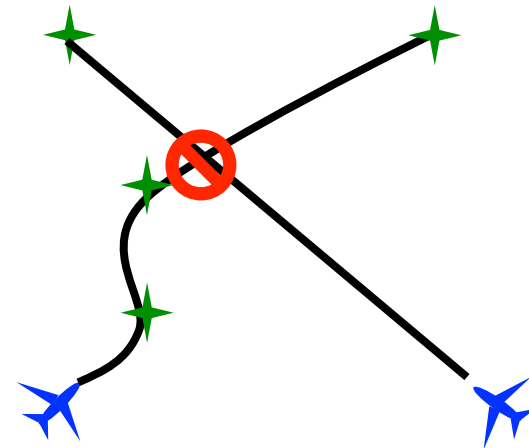
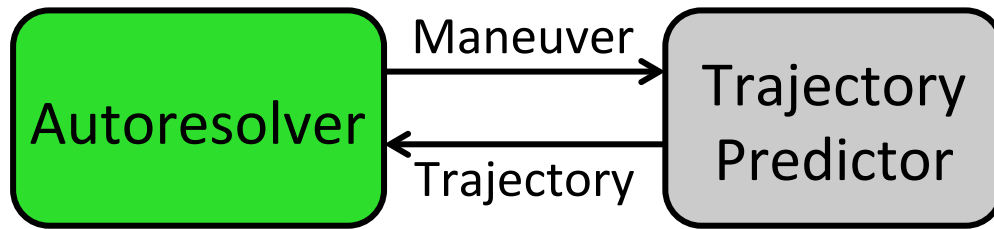
Use simplified calculations to generate a maneuver

Trial Planning



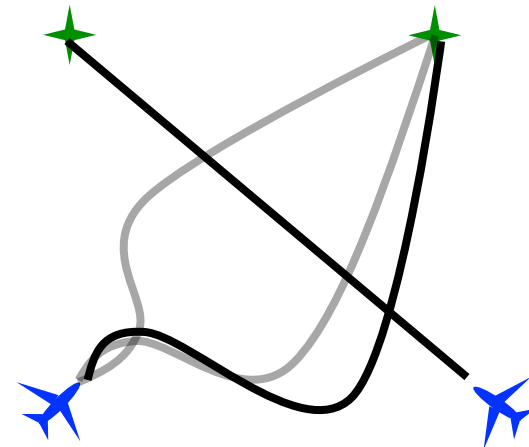
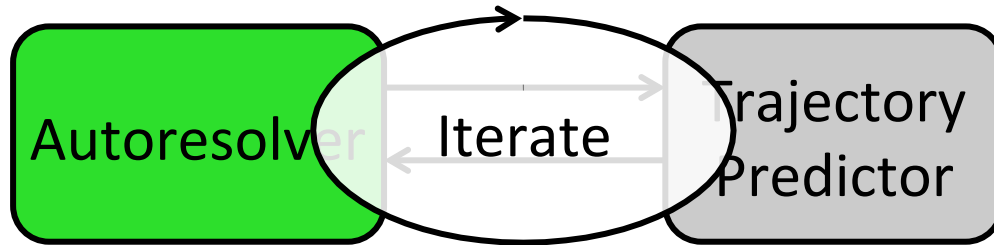
Use independent trajectory prediction system to create high-fidelity trajectory

Trial Planning



Determine properties of trajectory including conflict-free status

Trial Planning

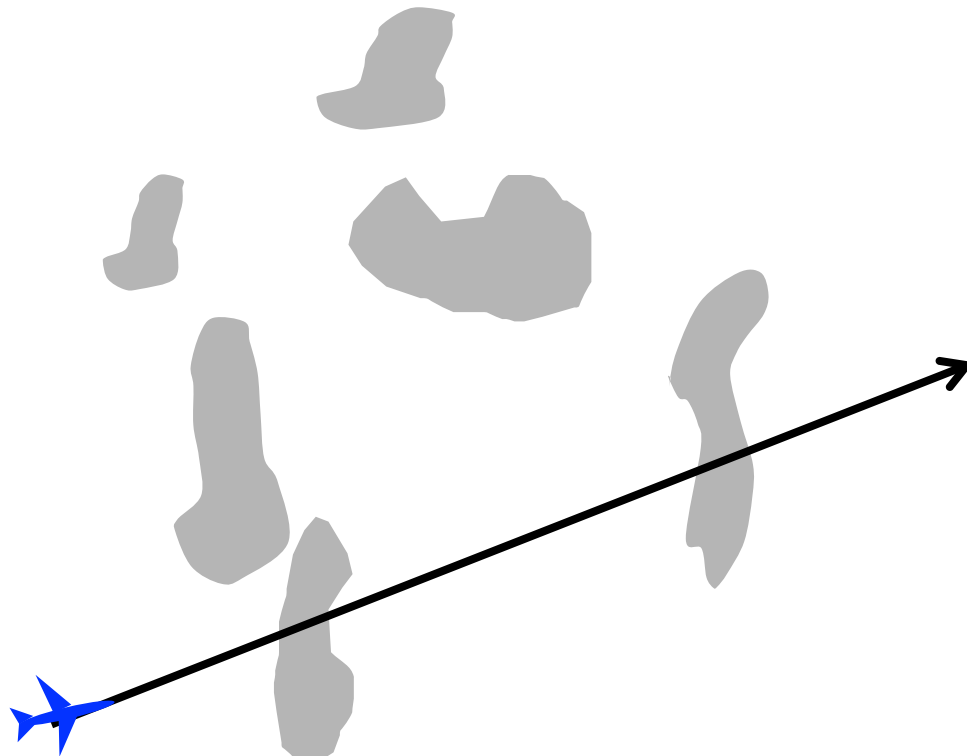


Iterate to find preferred successful resolution

Trial Planning Summary

- Separate process of generating resolution maneuvers and predicting the results
- Resolutions are selected based on best available information
- Can leverage improved predictions immediately to improve performance

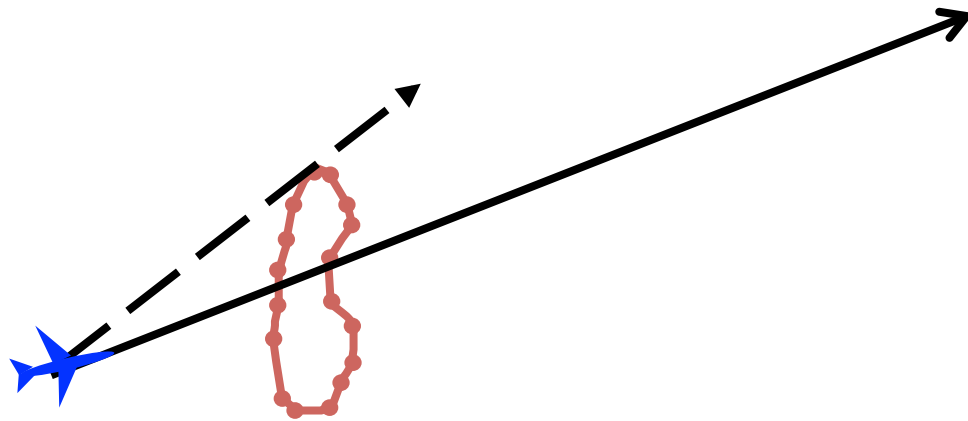
Complex Weather



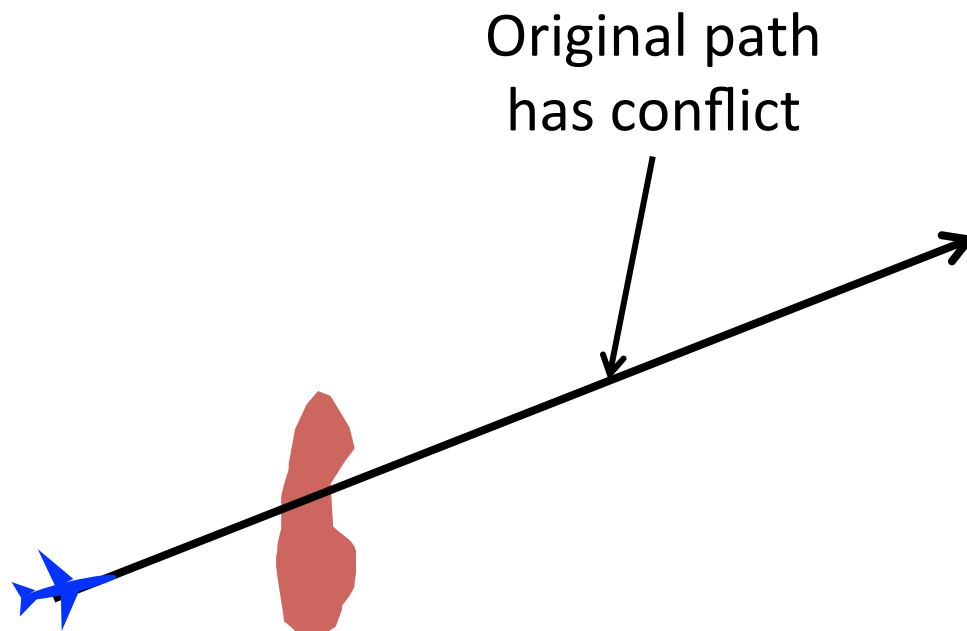
Weather Avoidance Algorithm

- Assumptions
 - At most two auxiliary waypoints
 - Create only horizontal resolutions
 - Attempt to minimize deviations
- Use geometric algorithm instead of gridded search algorithm

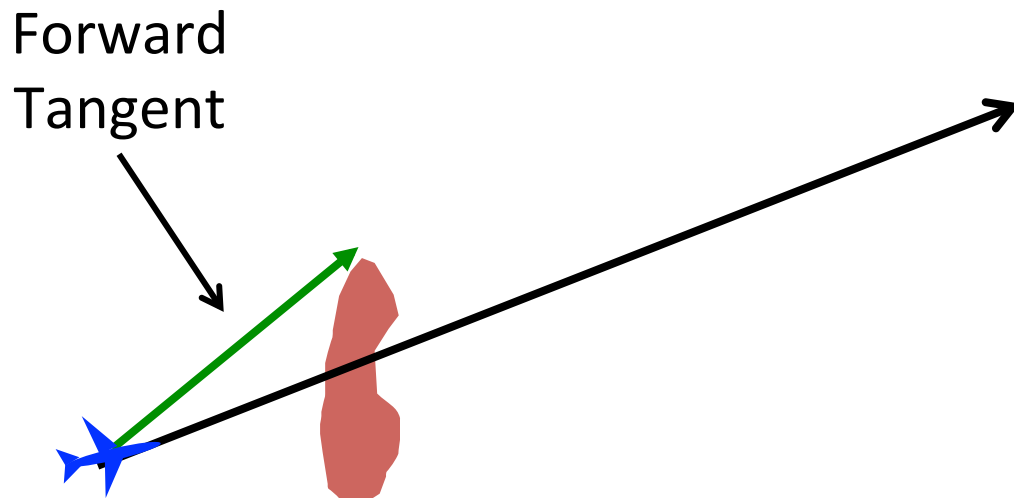
Finding Tangencies



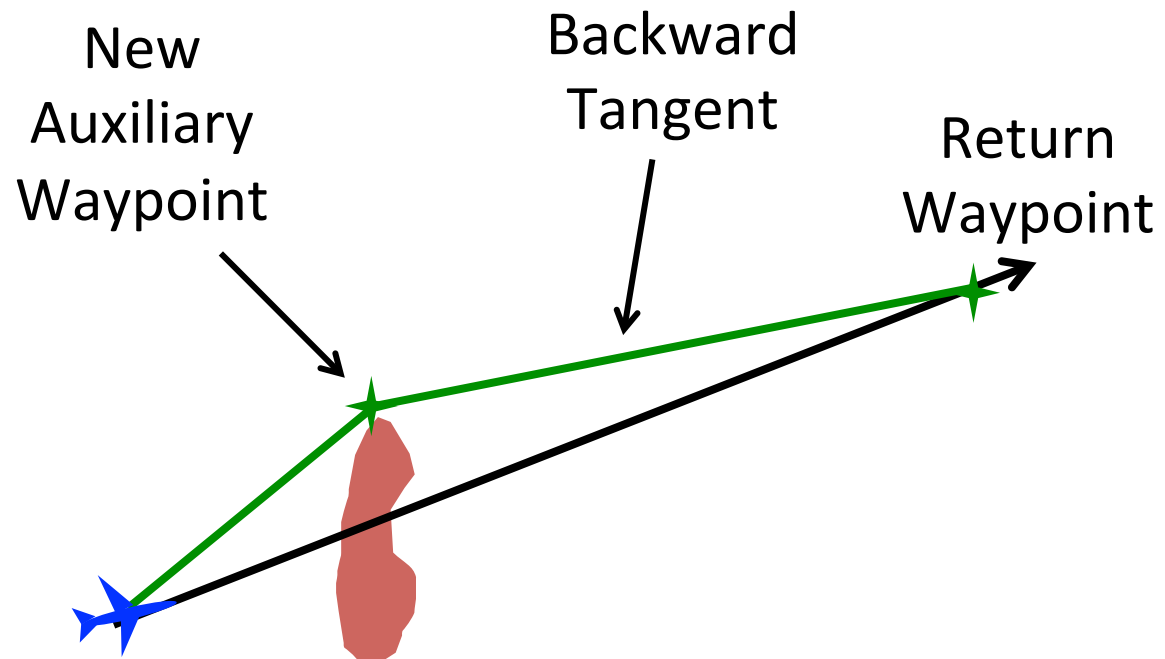
Simple Example



Simple Example

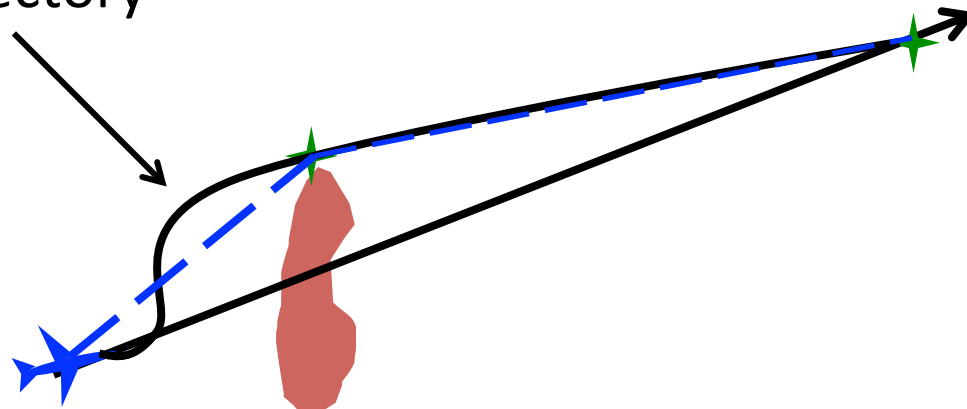


Simple Example

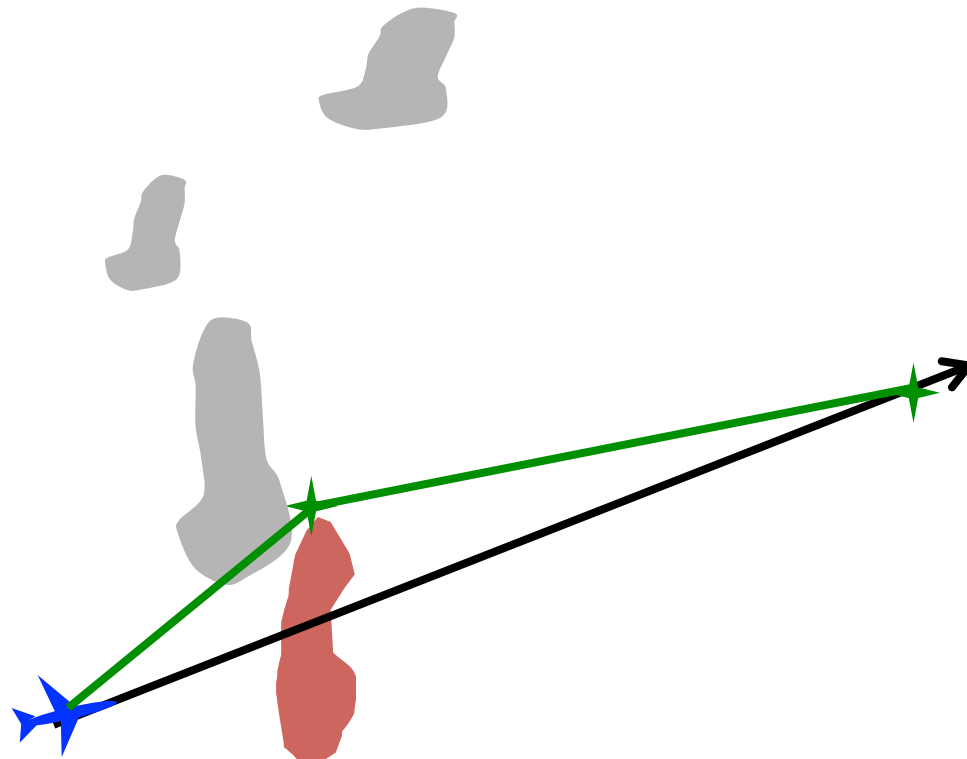


Simple Example

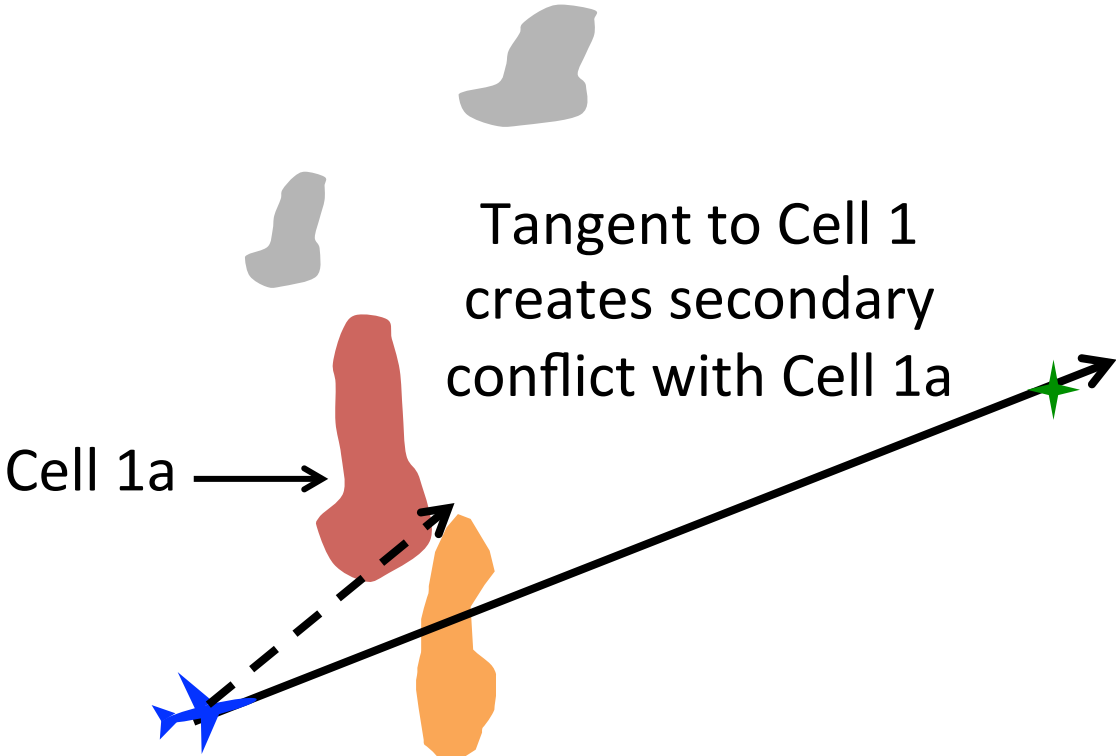
High-Fidelity
Trajectory



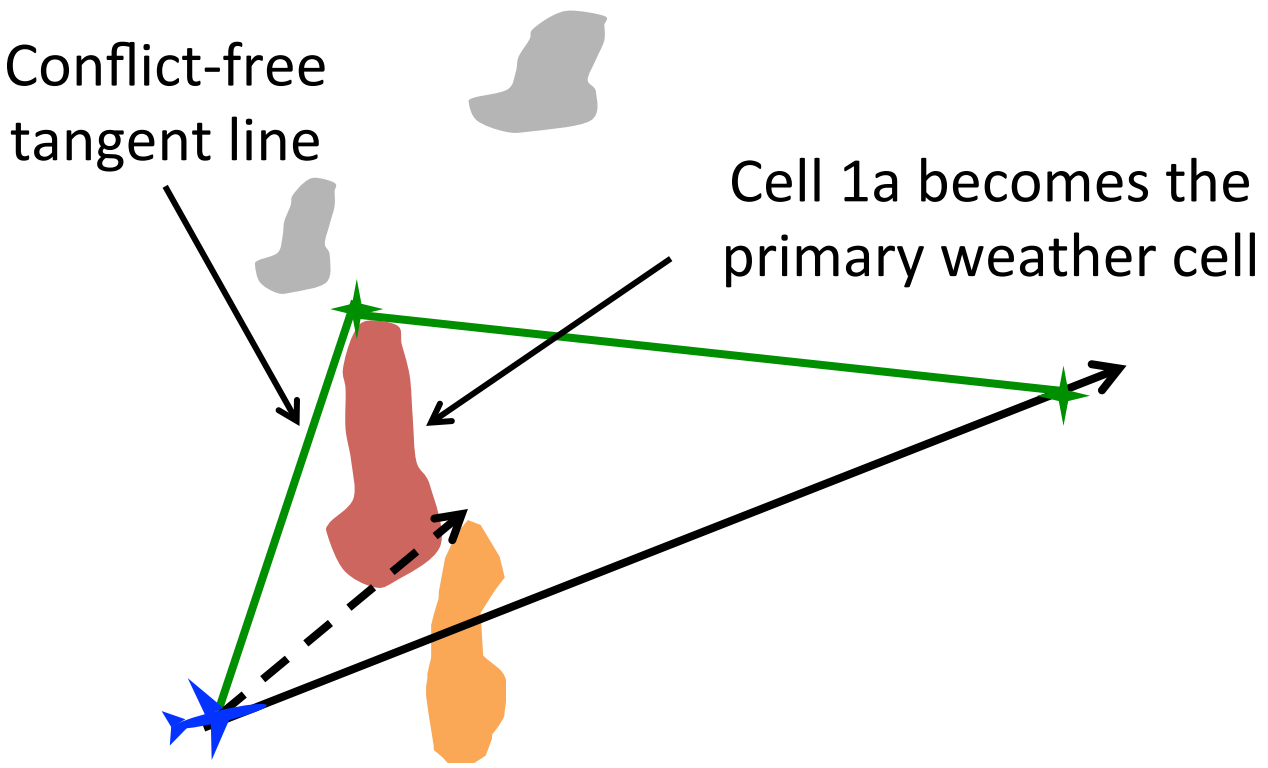
New Outbound Conflict



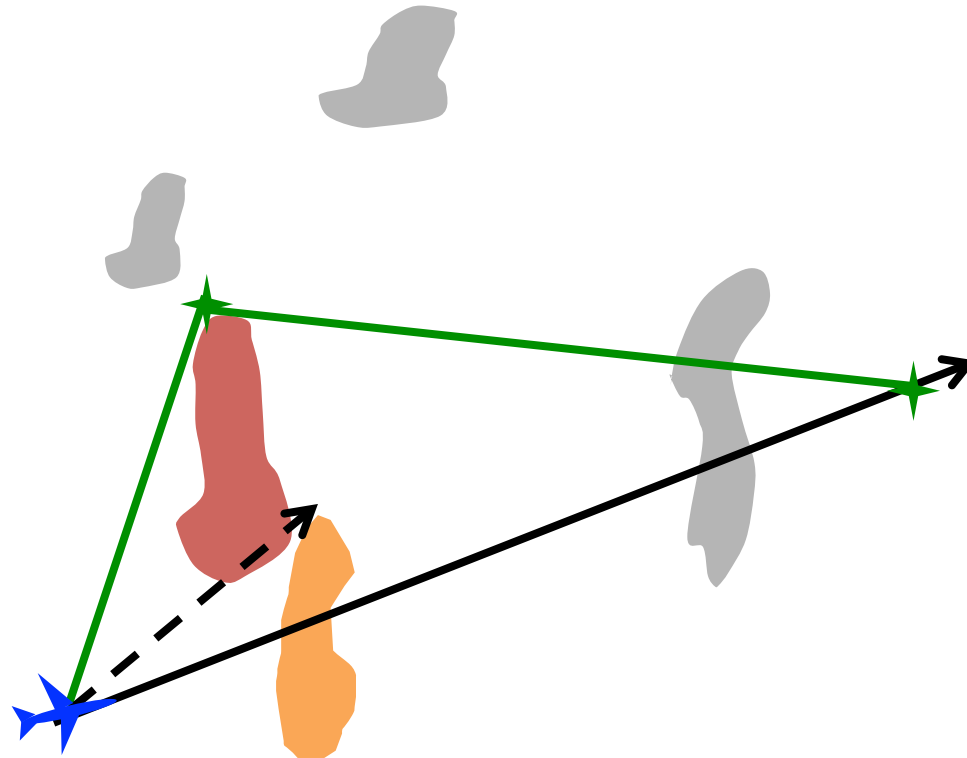
New Outbound Conflict



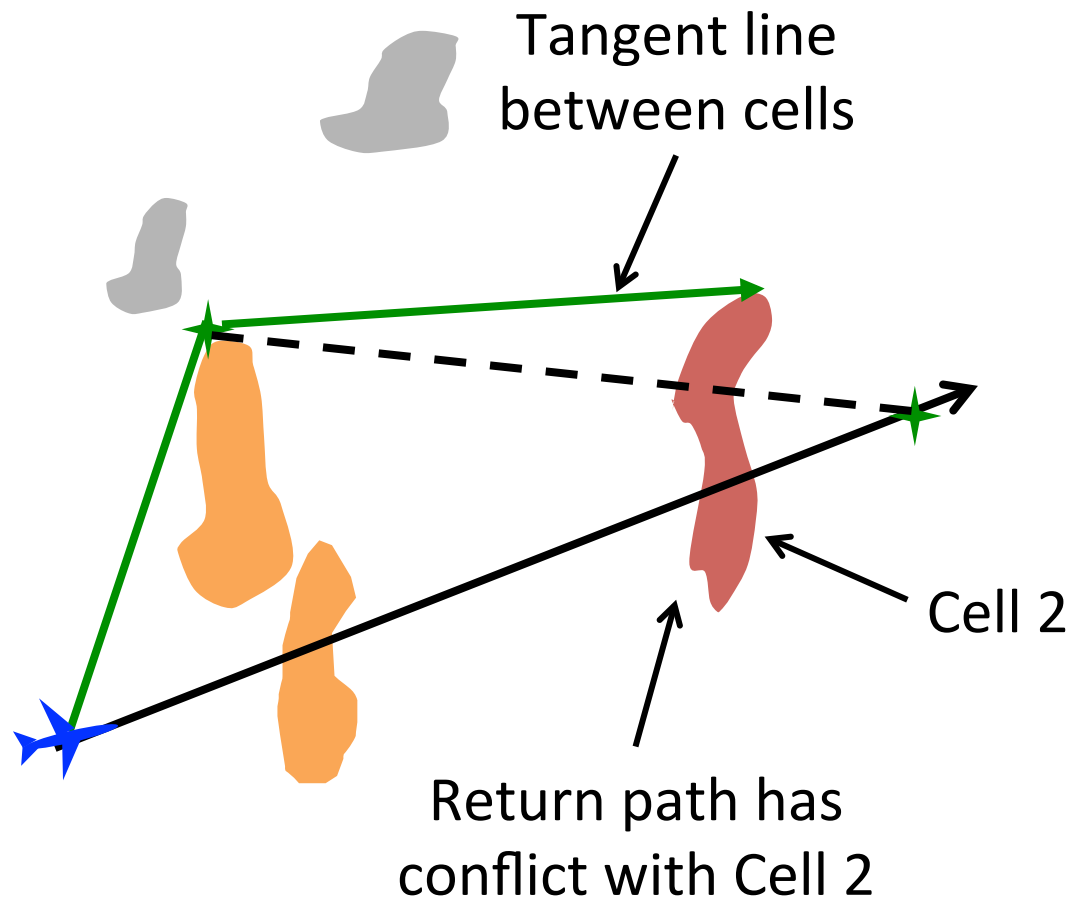
New Outbound Conflict



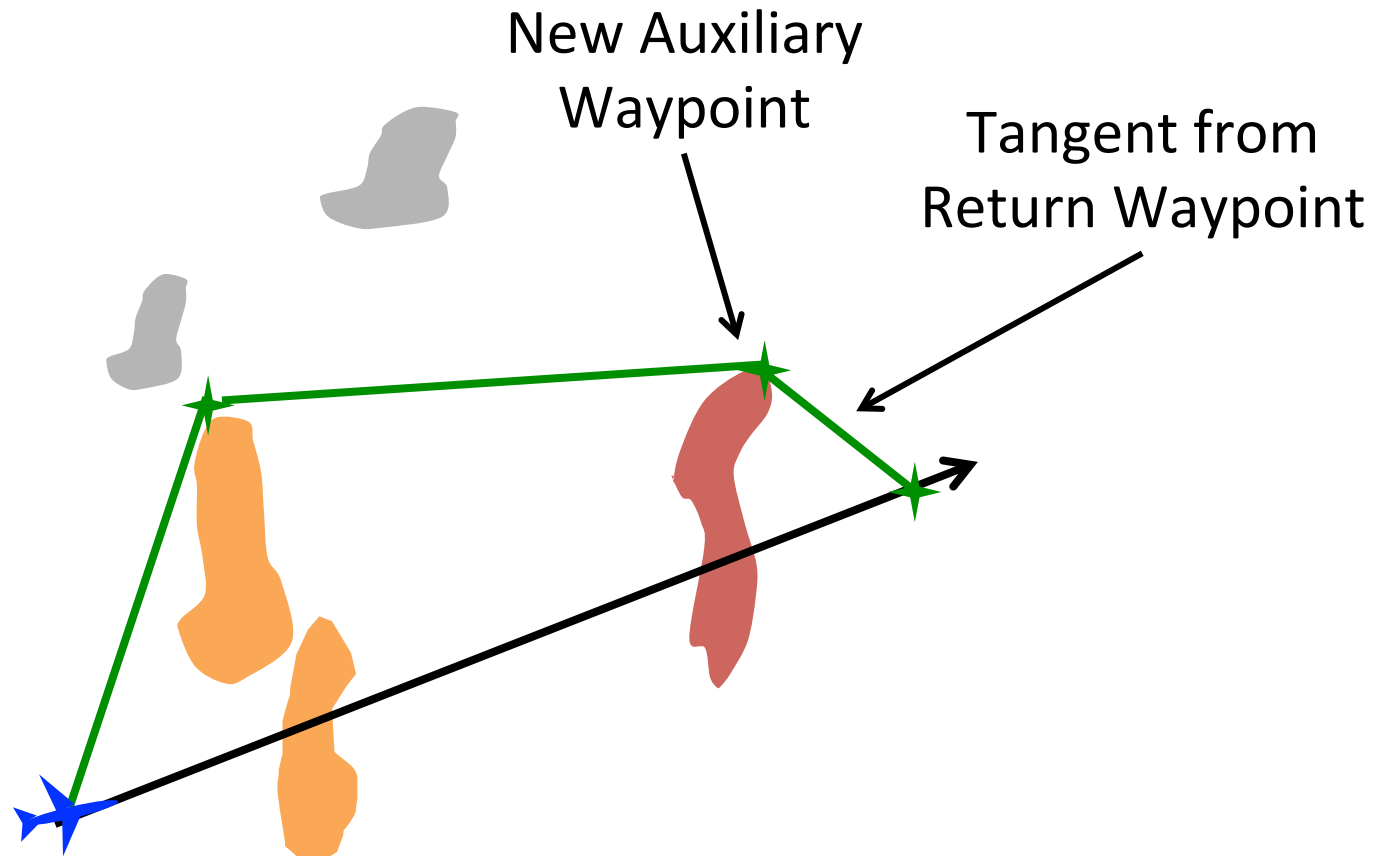
New Inbound Conflict



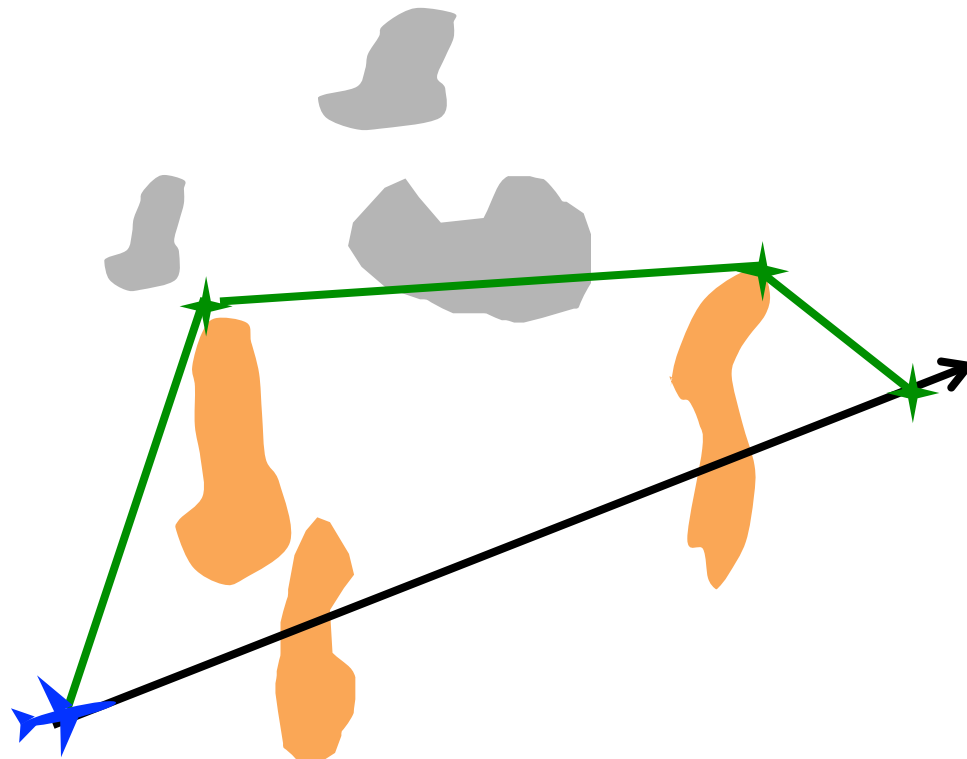
New Inbound Conflict



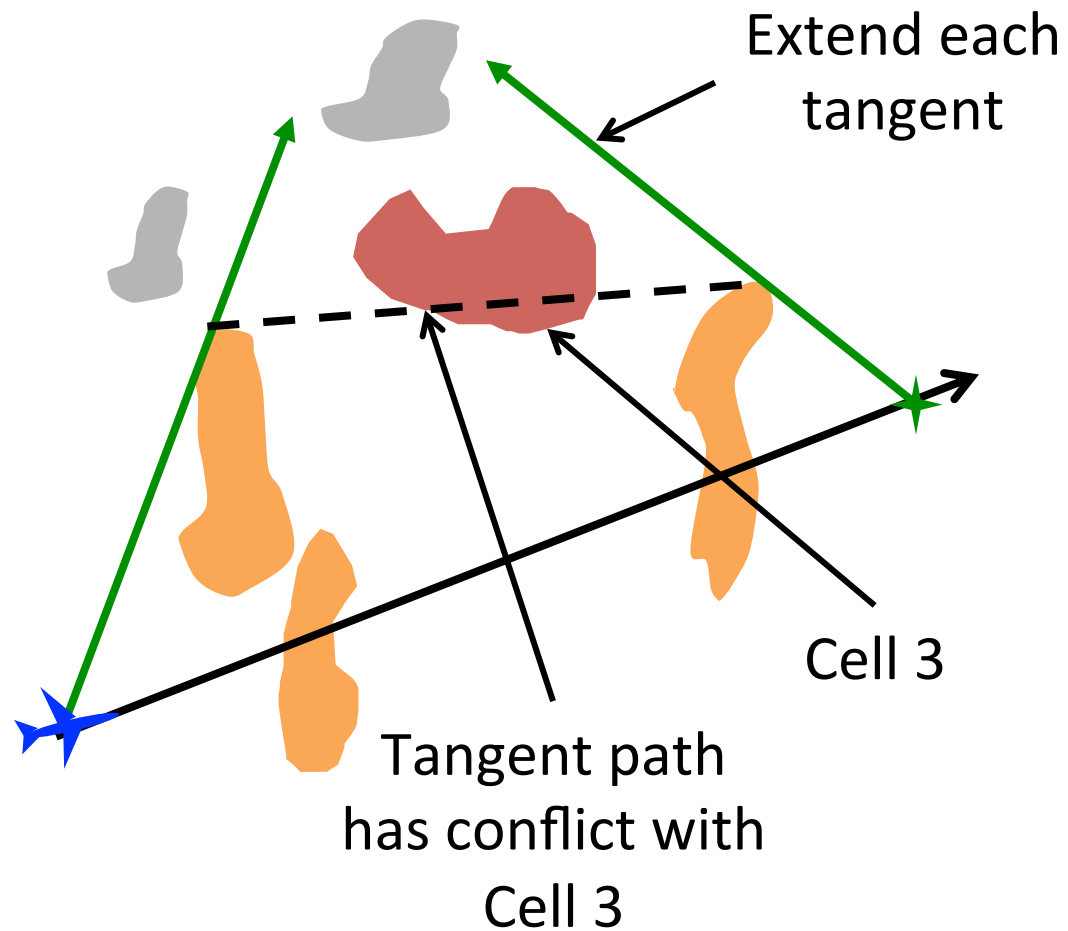
New Inbound Conflict



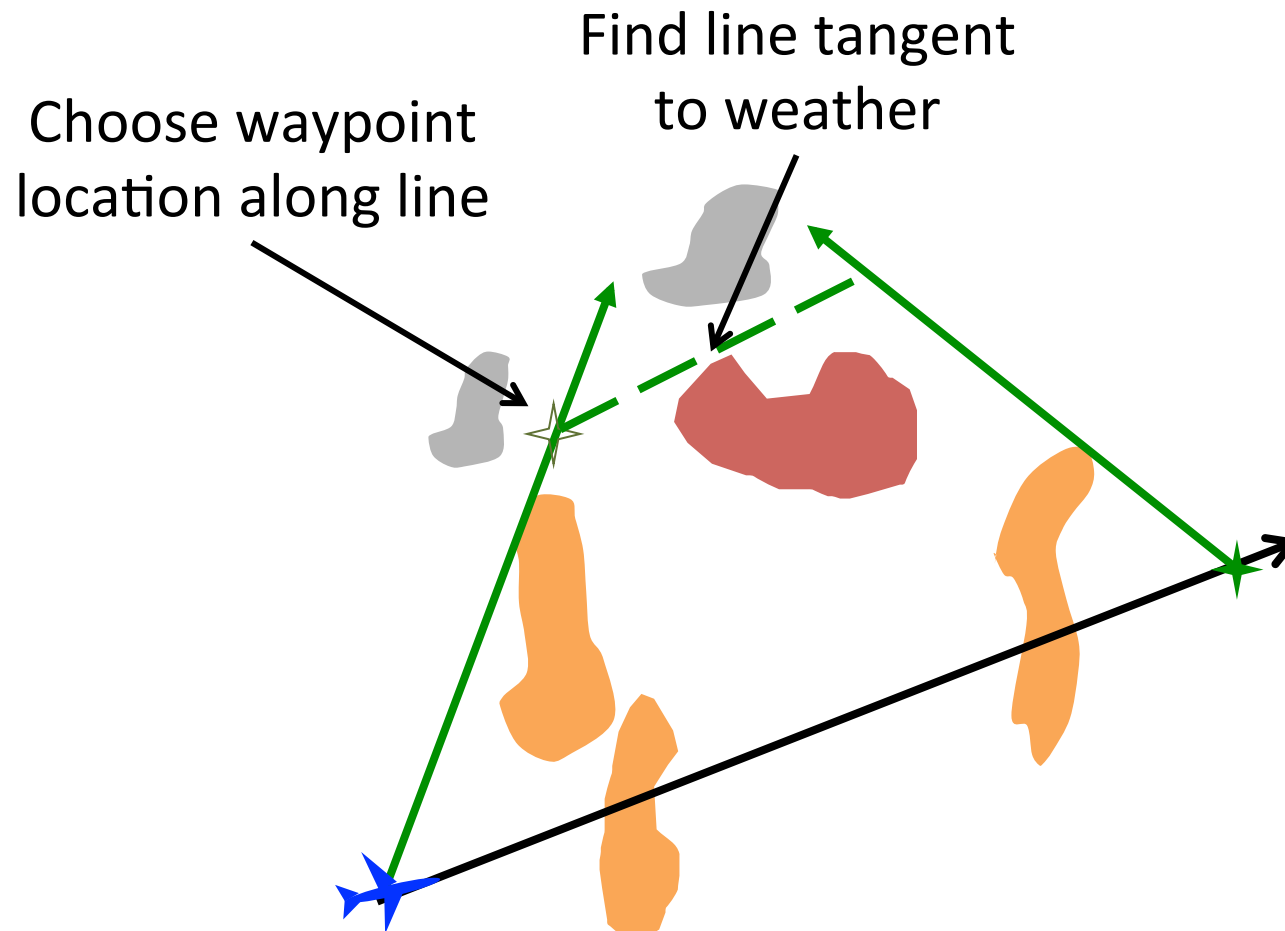
New Middle Segment Conflict



New Middle Segment Conflict

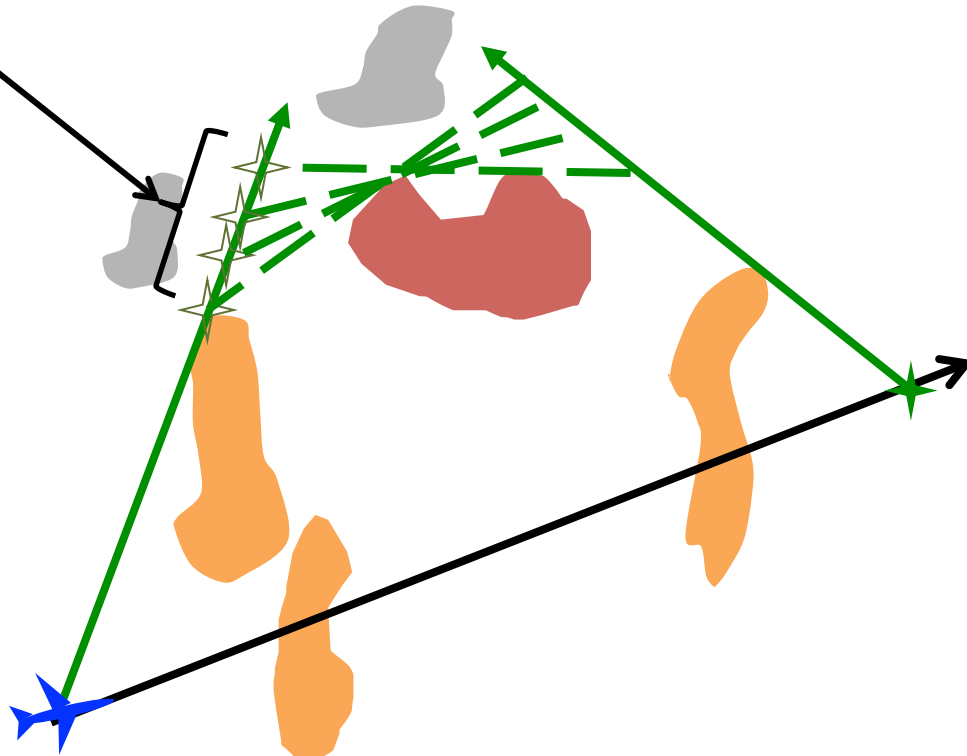


New Middle Segment Conflict



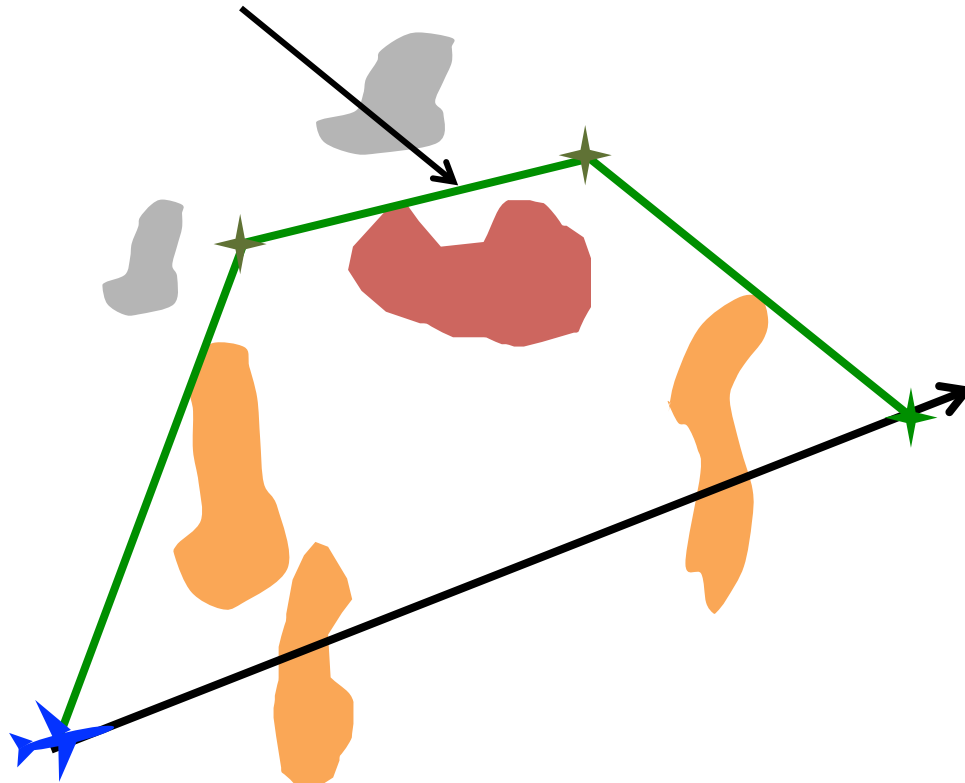
New Middle Segment Conflict

Iterate waypoint
location up to 50 nmi

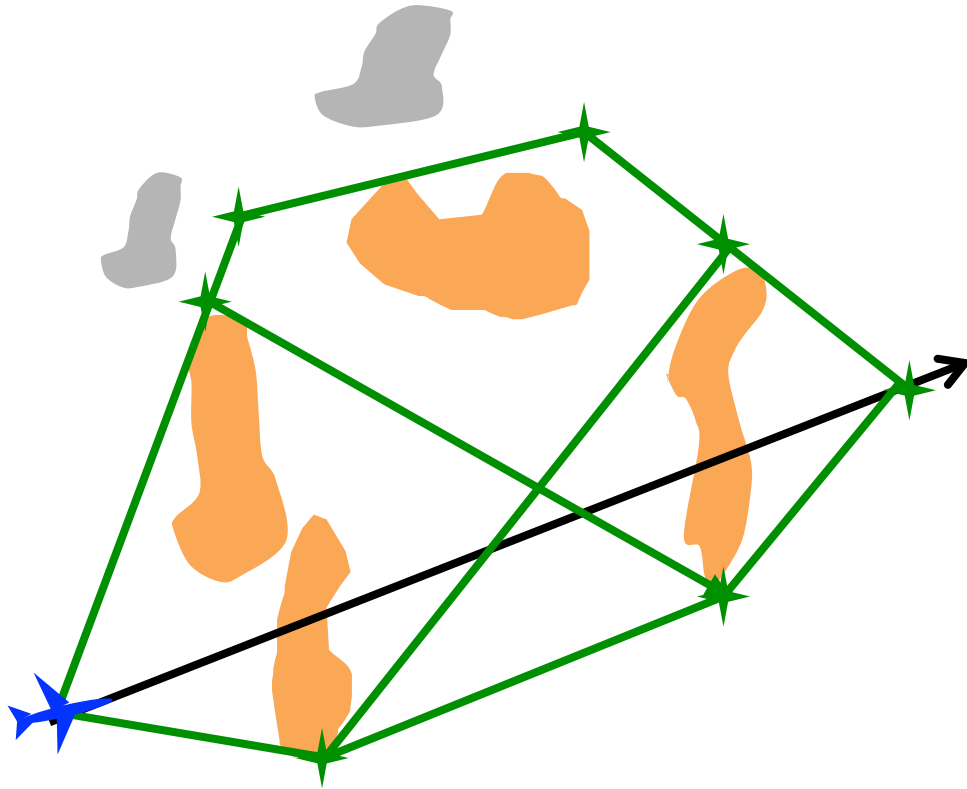


New Middle Segment Conflict

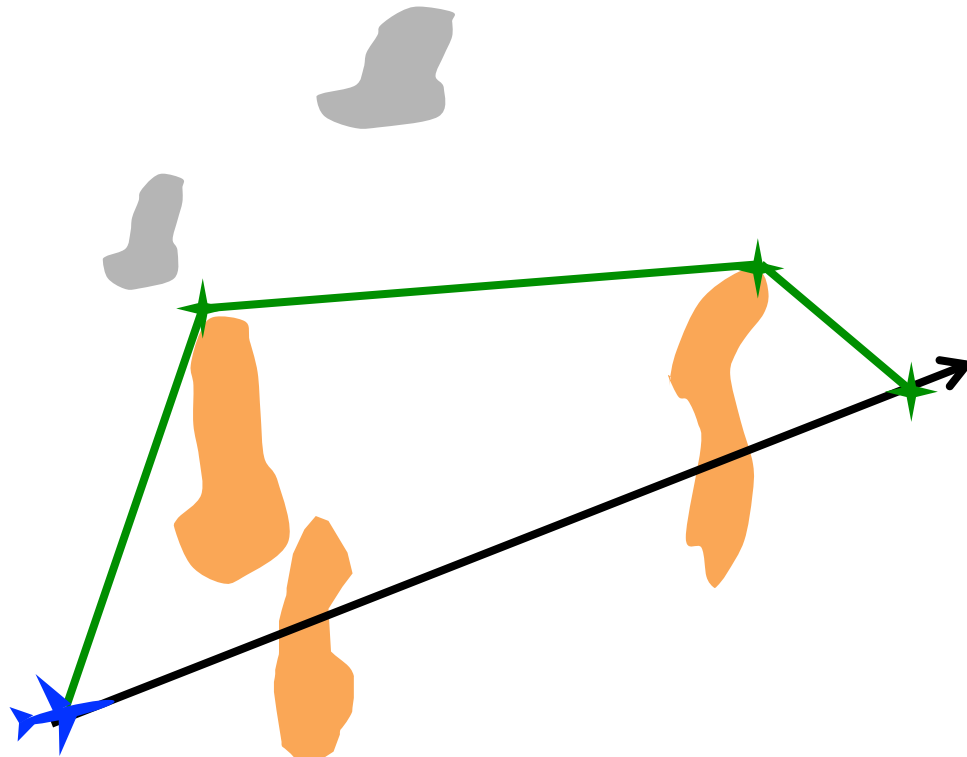
Select shortest
conflict-free path



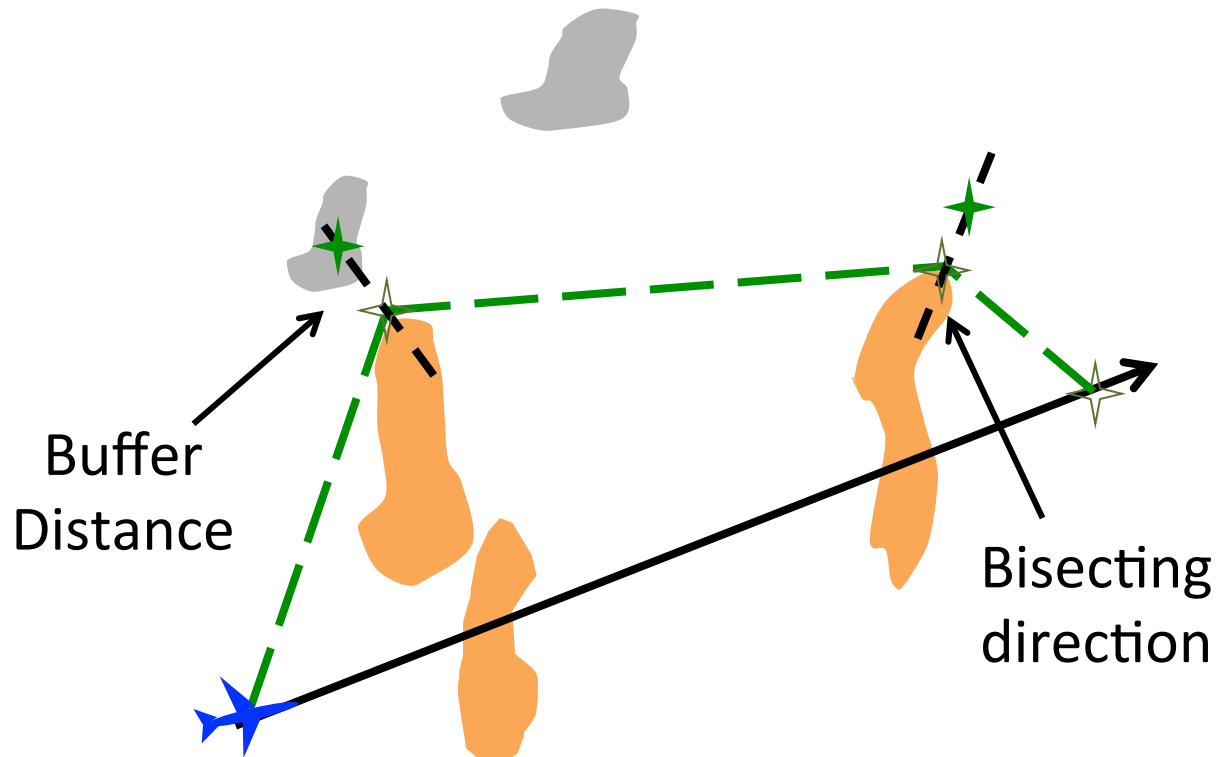
Discover Other Routes



Handling Weather Uncertainty

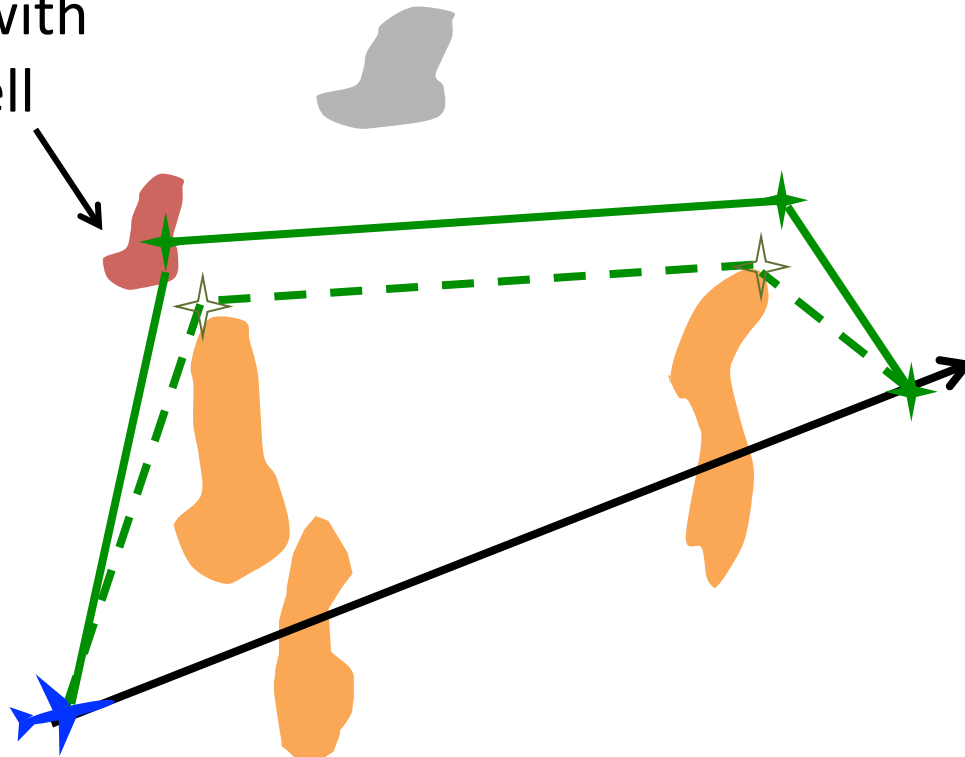


Handling Weather Uncertainty

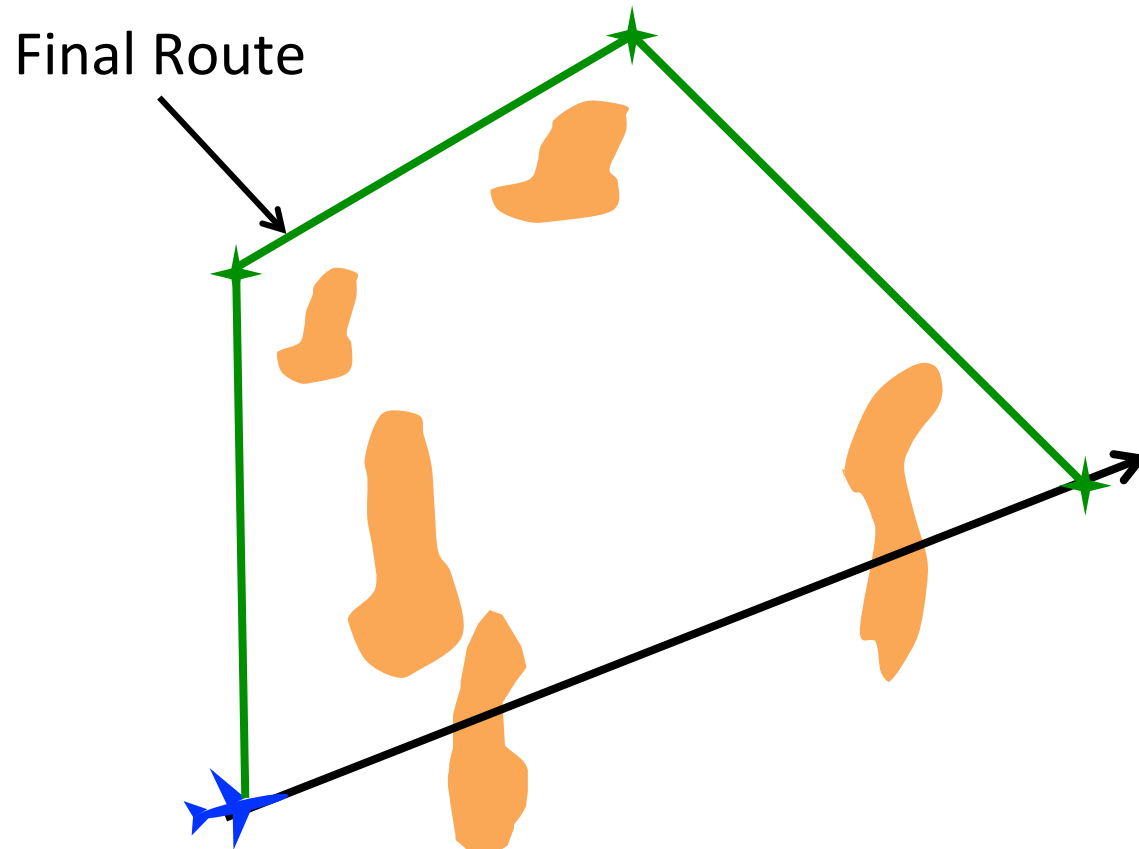


Handling Weather Uncertainty

Buffer creates
conflict with
new cell



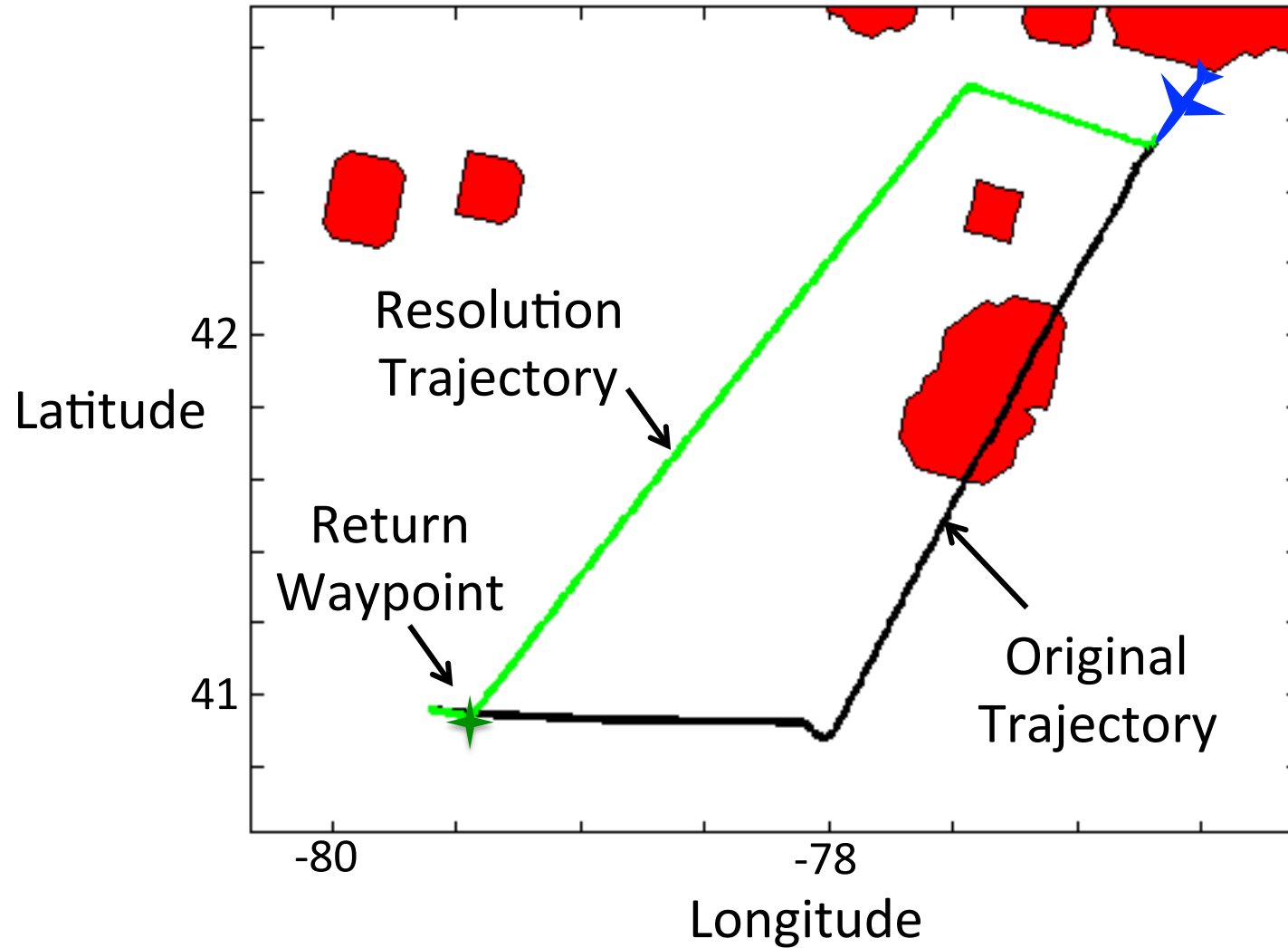
Handling Weather Uncertainty



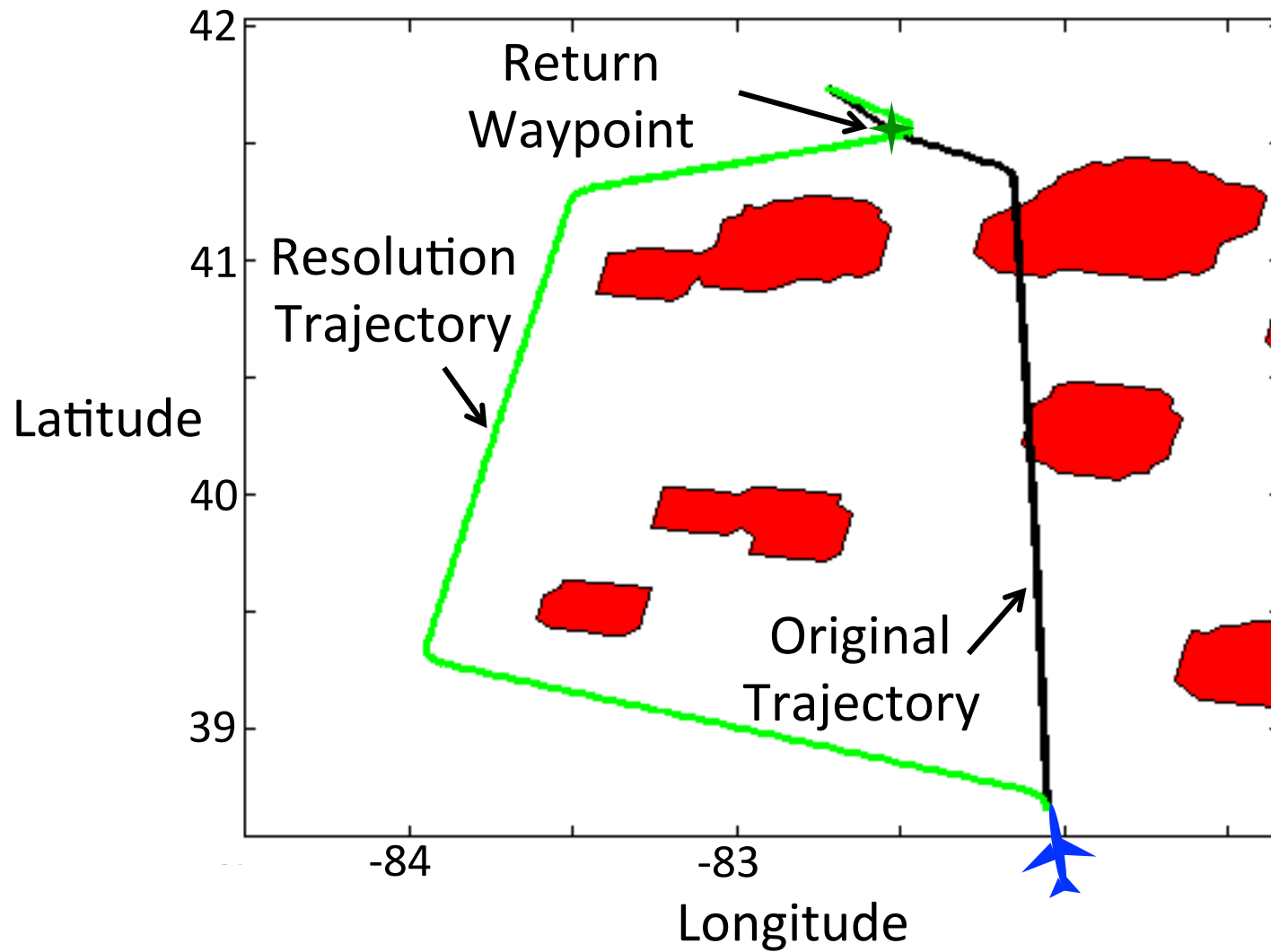
Prototype Development

- Airspace Concept Evaluation System (ACES) simulation used as development platform
- Used Convective Weather Avoidance Model (CWAM) polygons derived from weather radar
- Used in operational trials as part of the Dynamic Weather Routes trial with American Airlines

Simulation Example



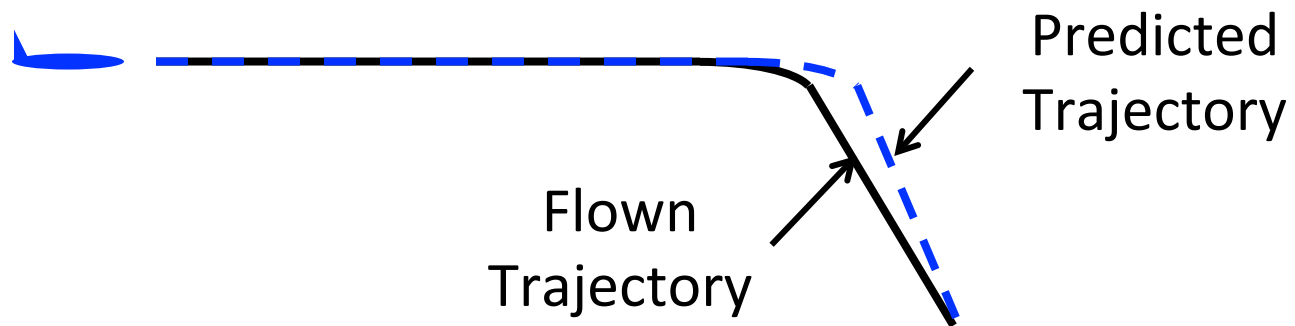
Simulation Example



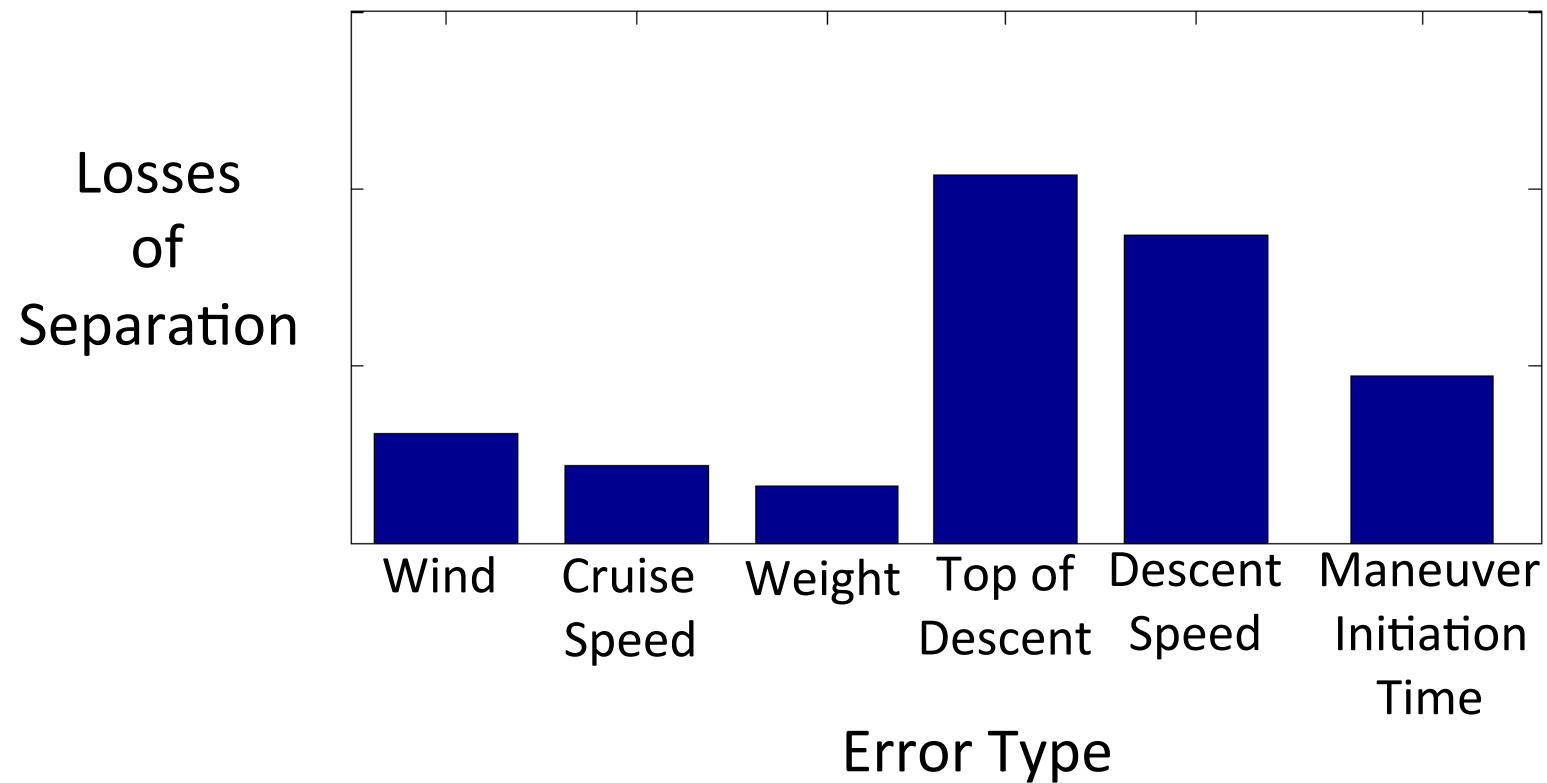
Weather Algorithm Summary

- Simple geometric algorithm
- Uses constraints inherent to airspace operations to restrict the solution space
- Provides geometrically reasonable resolutions
- Proving effective in field study

Trajectory Prediction Errors



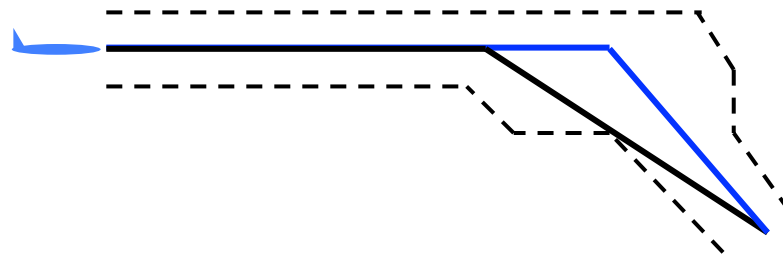
Impact of Different Error Types



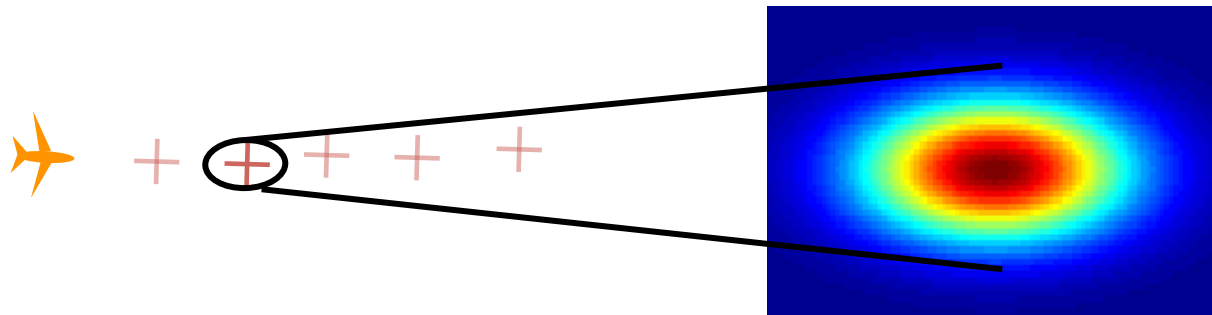
[Lauderdale et. al. ATM 2011]

Methods to Increase Robustness

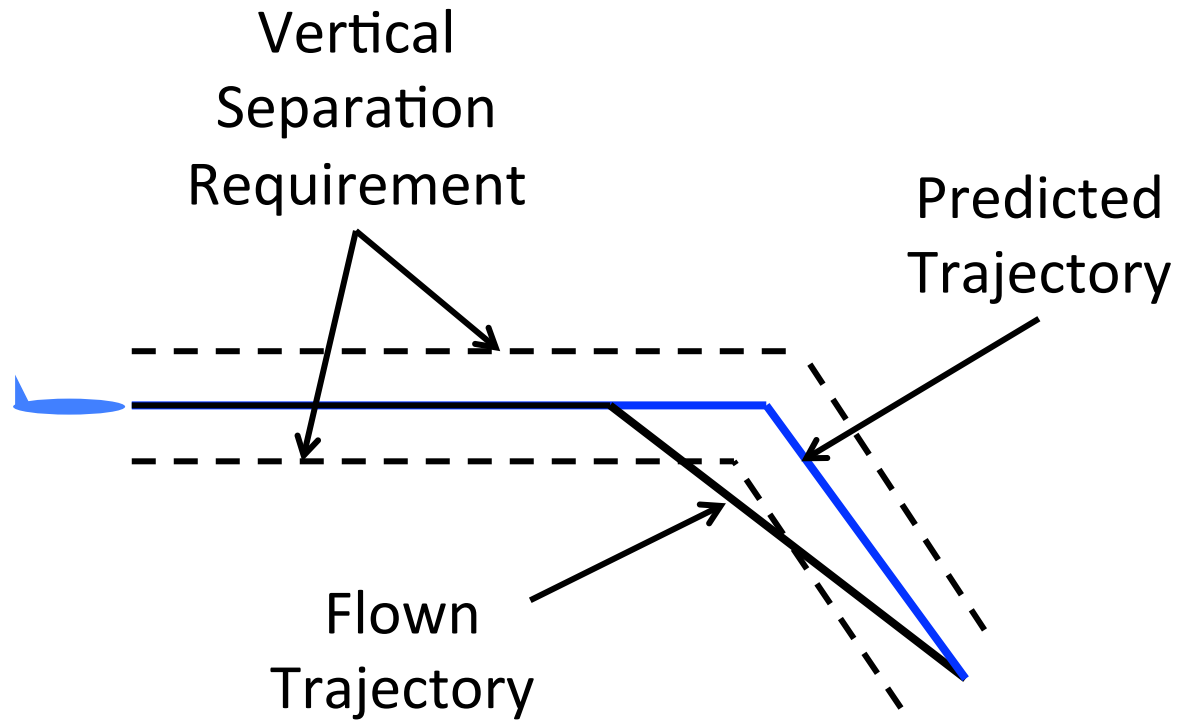
- Increase vertical separation requirements around Top of Descent



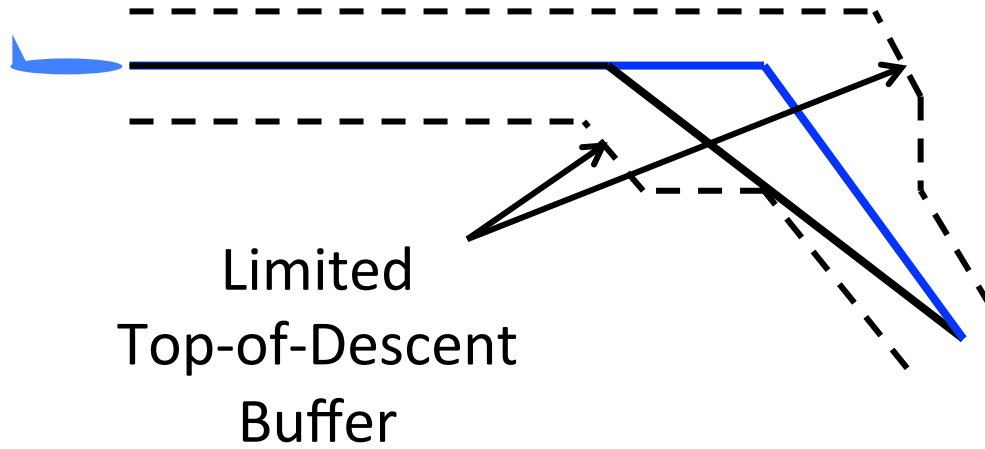
- Use probabilistic conflict detection



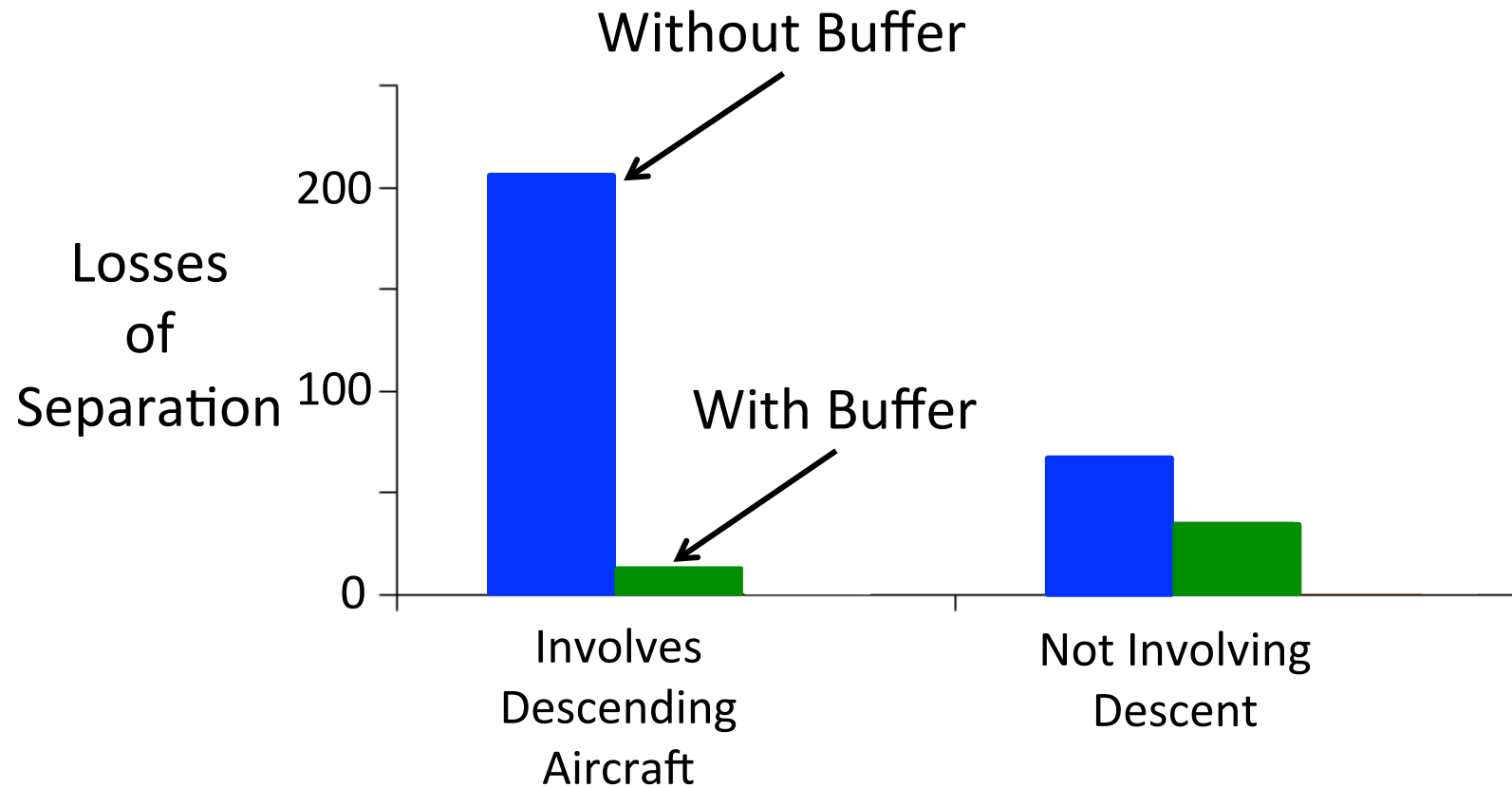
Vertical Buffers



Vertical Buffers



Impact of Vertical Buffers



[Cone, A. and Lauderdale, T. ATIO 2012]

Prediction Error Summary

- Robustness to prediction errors is necessary
- Have shown that top-of-descent errors have large impact
- Simple, target buffers can be used to mitigate this impact
- Other methods to efficiently handle errors are being studied

Final Thoughts

- Long-term research focus can lead to near-term benefits
- Trail planning effectively separates resolution generation and trajectory prediction
- Geometric weather avoidance is effective for ATM applications
- Trajectory prediction errors must be handled efficiently, especially for arrival aircraft