

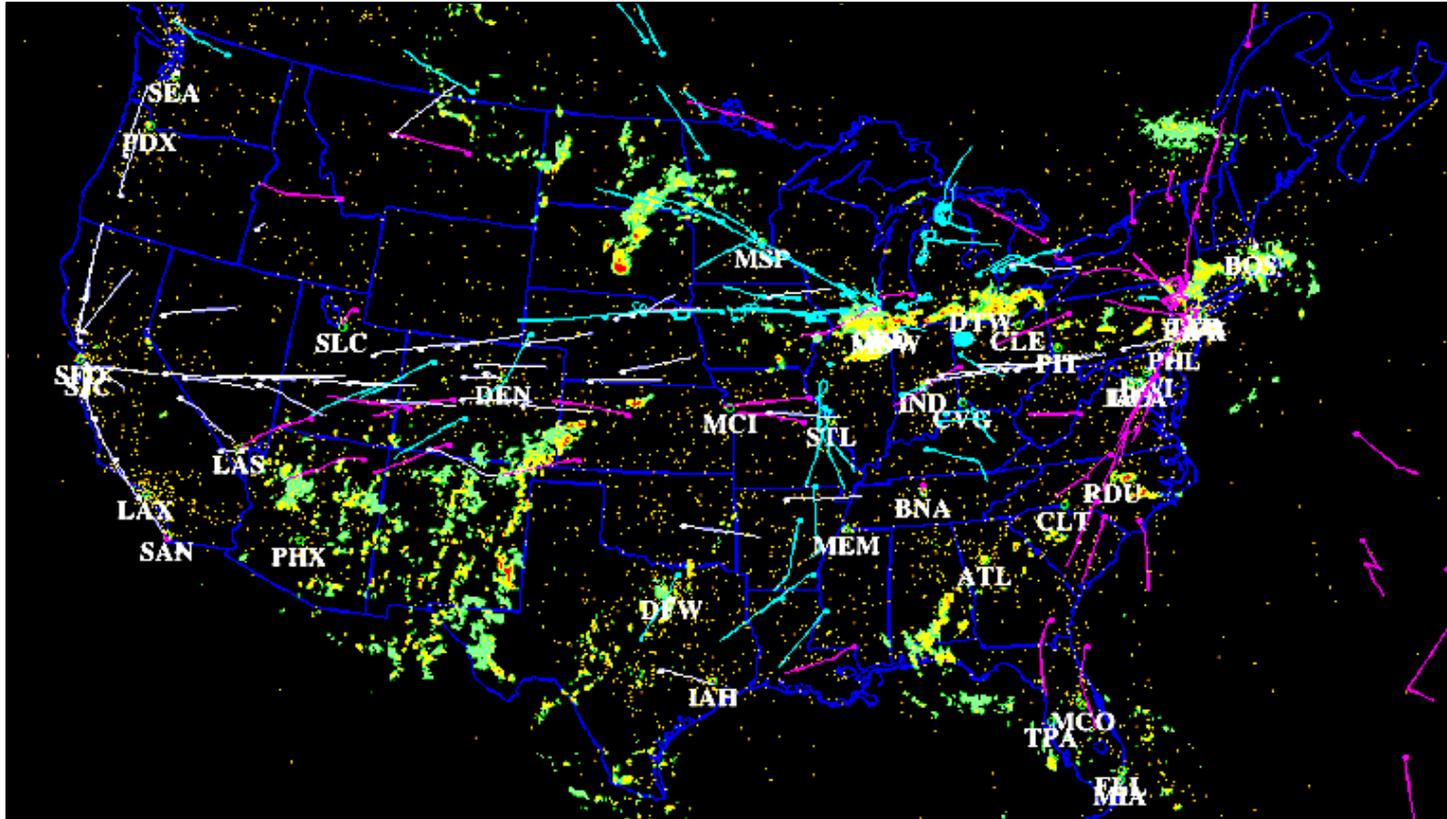


Automated Methods to Maintain Aircraft Separation

Todd Lauderdale
NASA Ames Research Center

November 14, 2011

The Air-Transportation System

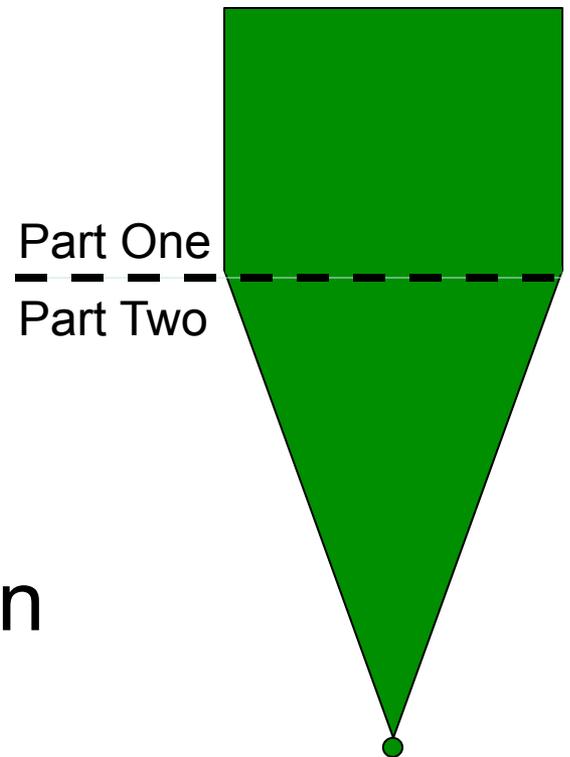


The Air-Transportation System



Talk Outline

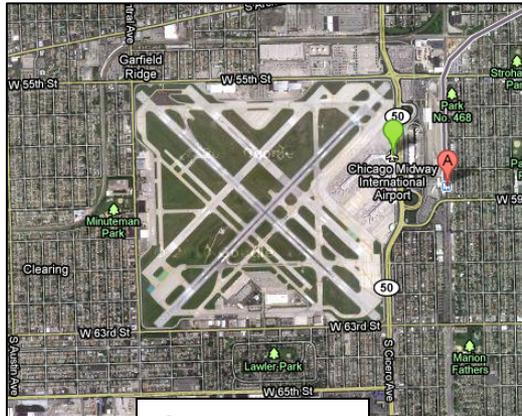
- A large optimization problem
- Decomposing the problem
- Areas of research
- Separation assurance
- Strategic resolution
- Robust separation automation



Benefits of Efficient Operations

- People and property arrives as quickly as possible
- Reduced environmental impact (fuel burn and noise)
- In 2007 delays cost over \$32 billion (UC Berkeley)

Challenges



Google Maps



National Weather Service

- Airport growth is constrained and expensive
- Humans must be able to maintain safety
- Weather and other uncertainties

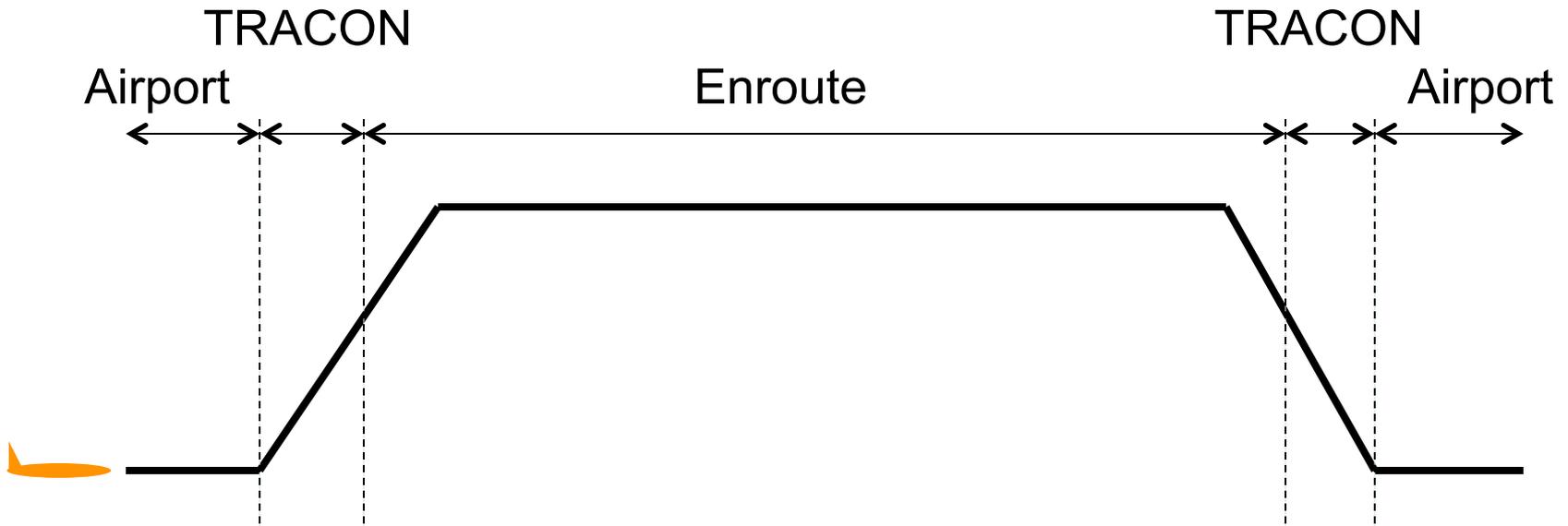
Large Optimization Problem

- Constraints:
 - Cannot occupy the same space
 - Performance limits
 - Restricted airspace
- Controls:
 - Departure times
 - Routes
 - Speeds

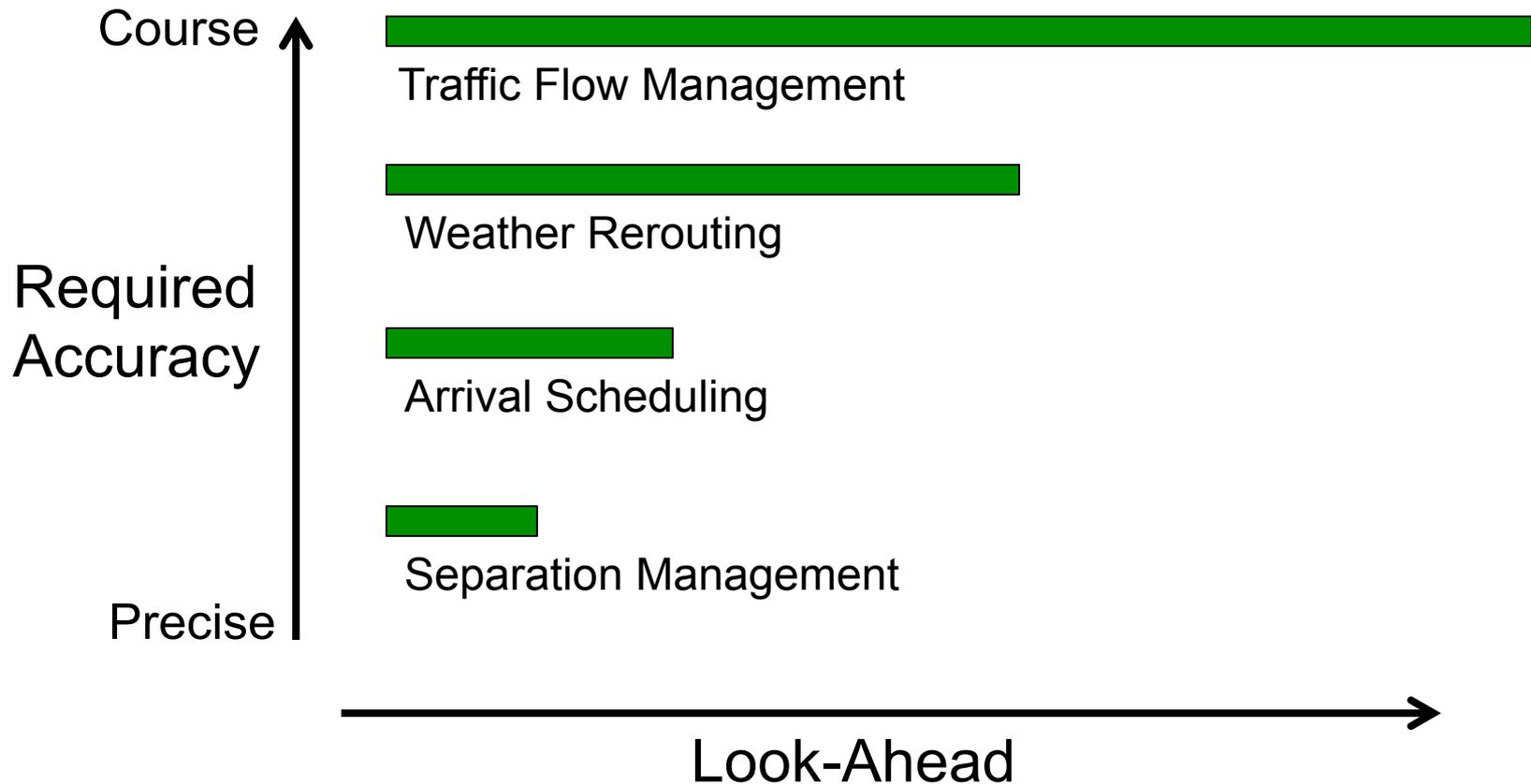
Decomposing the Problem

- Different regions have different constraints and functions
- Different accuracies are important at different time scales
 - To deal with arrival constraints hours away, aircraft can be dealt with in the aggregate
 - An impending aircraft collision must be dealt with very precisely

Regions of Control



Optimization Time Scales



Airport Operations



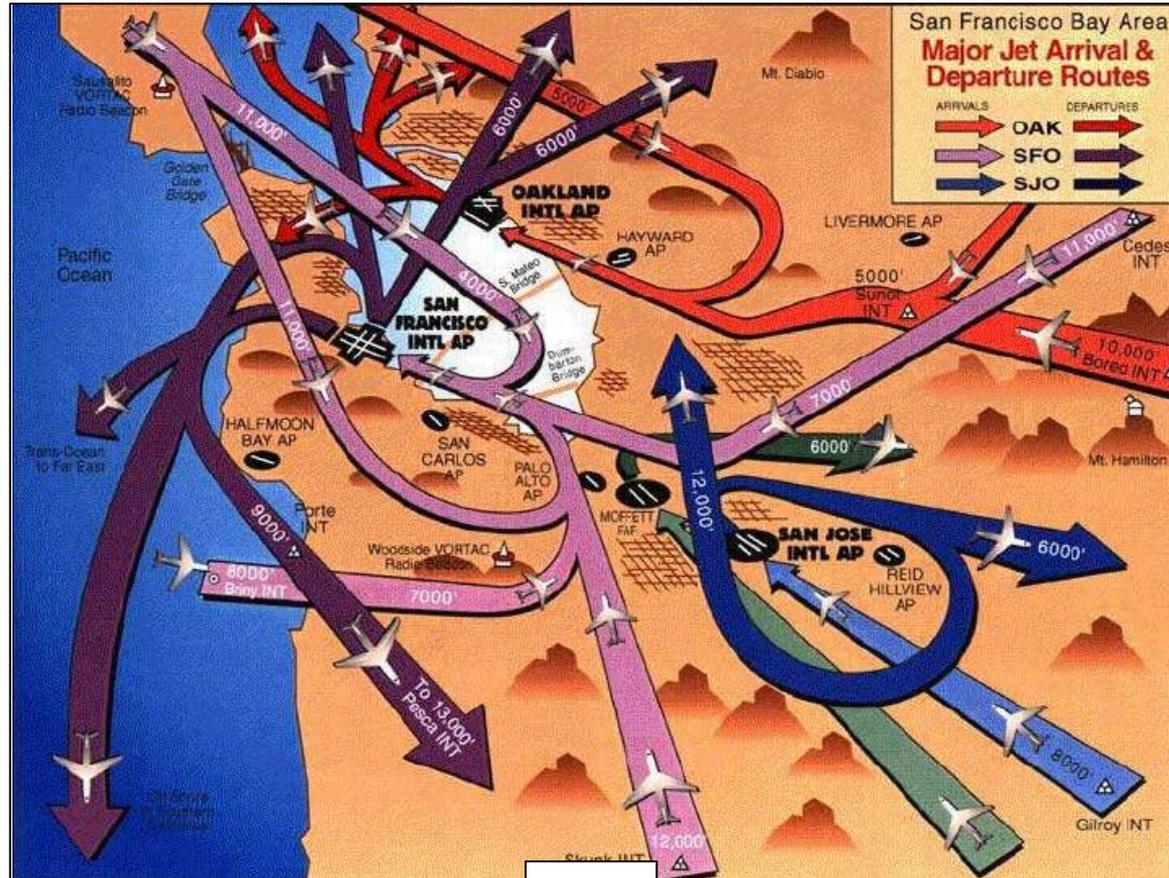
Airport Surface Operations Research

**NASA Ames Research Center
April 21, 2009**

Airport Research

- Issues:
 - Departure scheduling for taxi and takeoff
 - Efficient use of parallel runways
- Methods:
 - Efficient scheduling algorithms
 - Procedures for low visibility

Around the Airport (TRACON)



FAA

TRACON Research

- Issues:
 - Main task is delivering aircraft to airport runways as closely as allowed
 - Continuous descents
 - Maintaining separation
- Methods:
 - Efficient scheduling algorithms
 - Design of human computer interfaces
 - Trajectory prediction

Enroute Operations



Traffic Flow Management

**IMPACT OF CONVECTIVE WEATHER
ON
NEW YORK AREA ARRIVALS**

CREATED USING

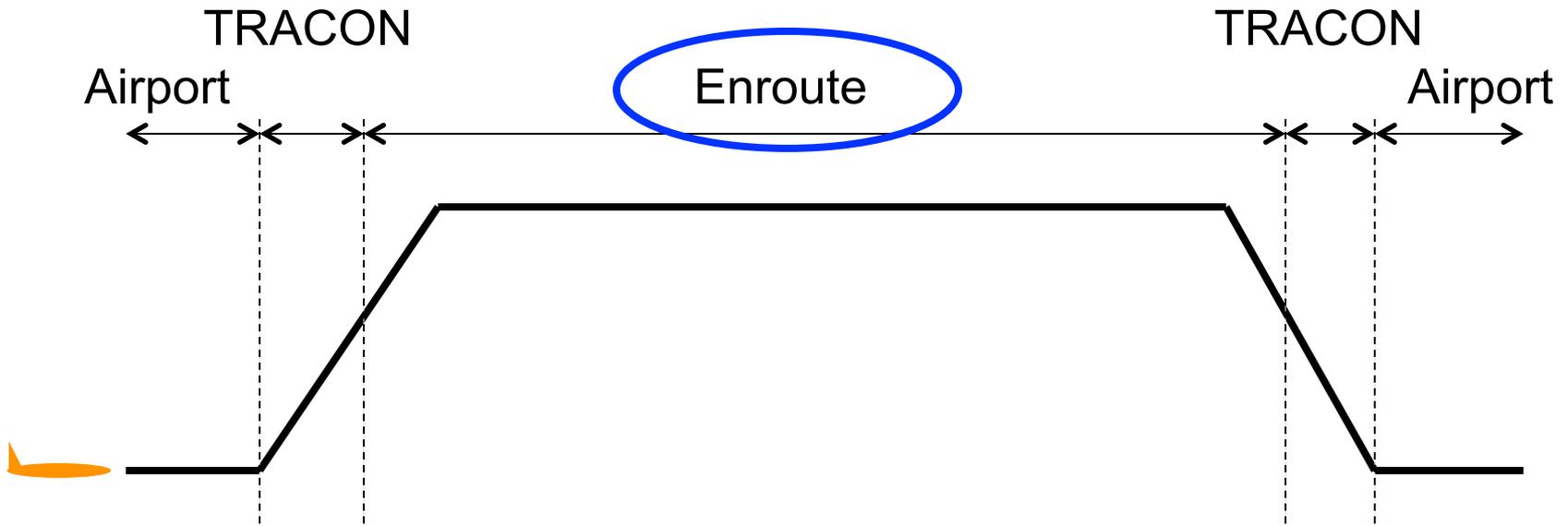
**FUTURE ATM CONCEPTS
EVALUATION TOOL
(FACET)**

**CREATED FOR
AVIATION SYSTEMS DIVISION (AF)
NASA AMES RESEARCH CENTER**

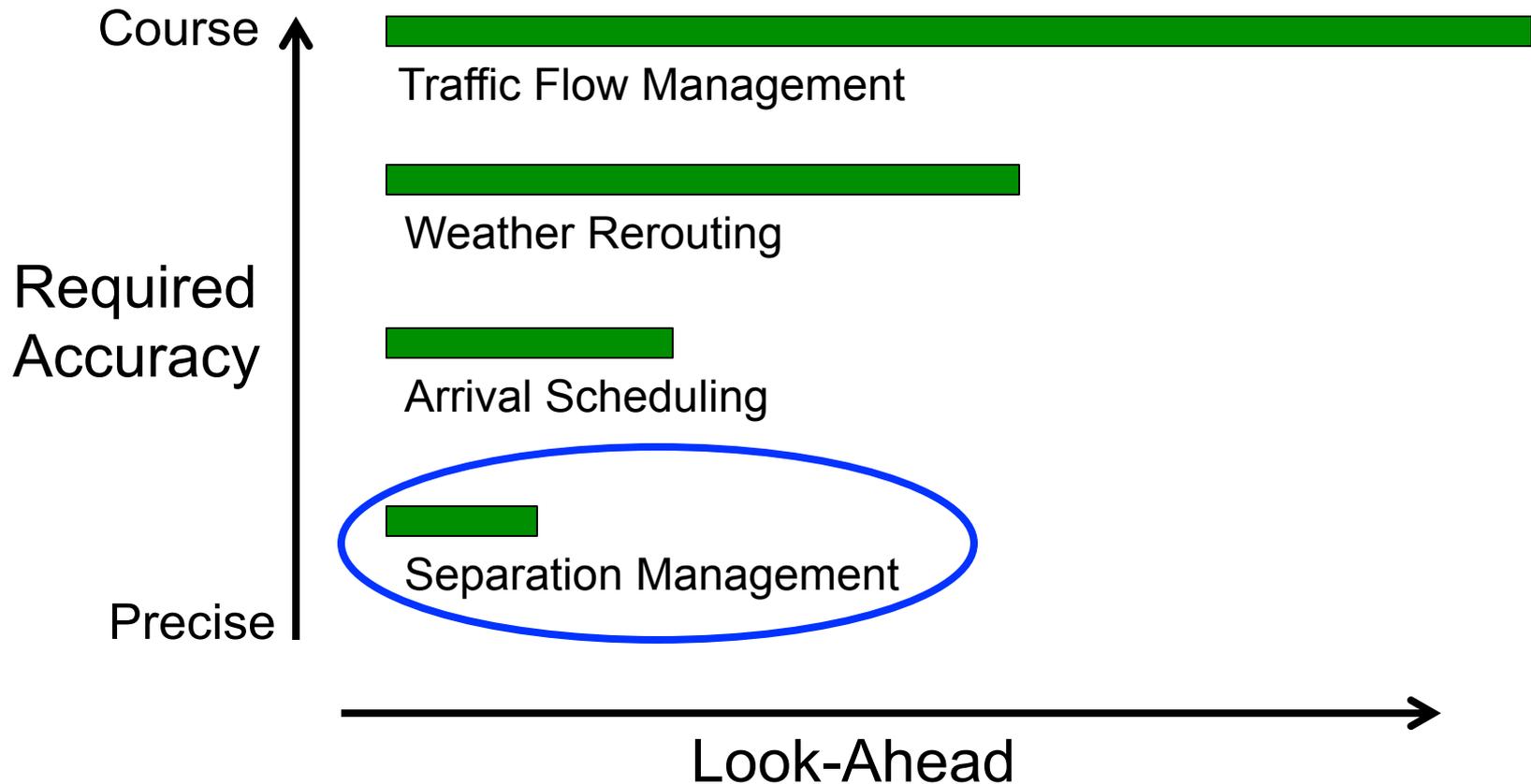
System-Wide Research

- Issues:
 - Maintain airport and airspace constraints
 - Efficient departure scheduling
 - Flow around weather
 - Airspace design
- Methods:
 - Linear programming
 - Voronoi diagrams
 - Data mining

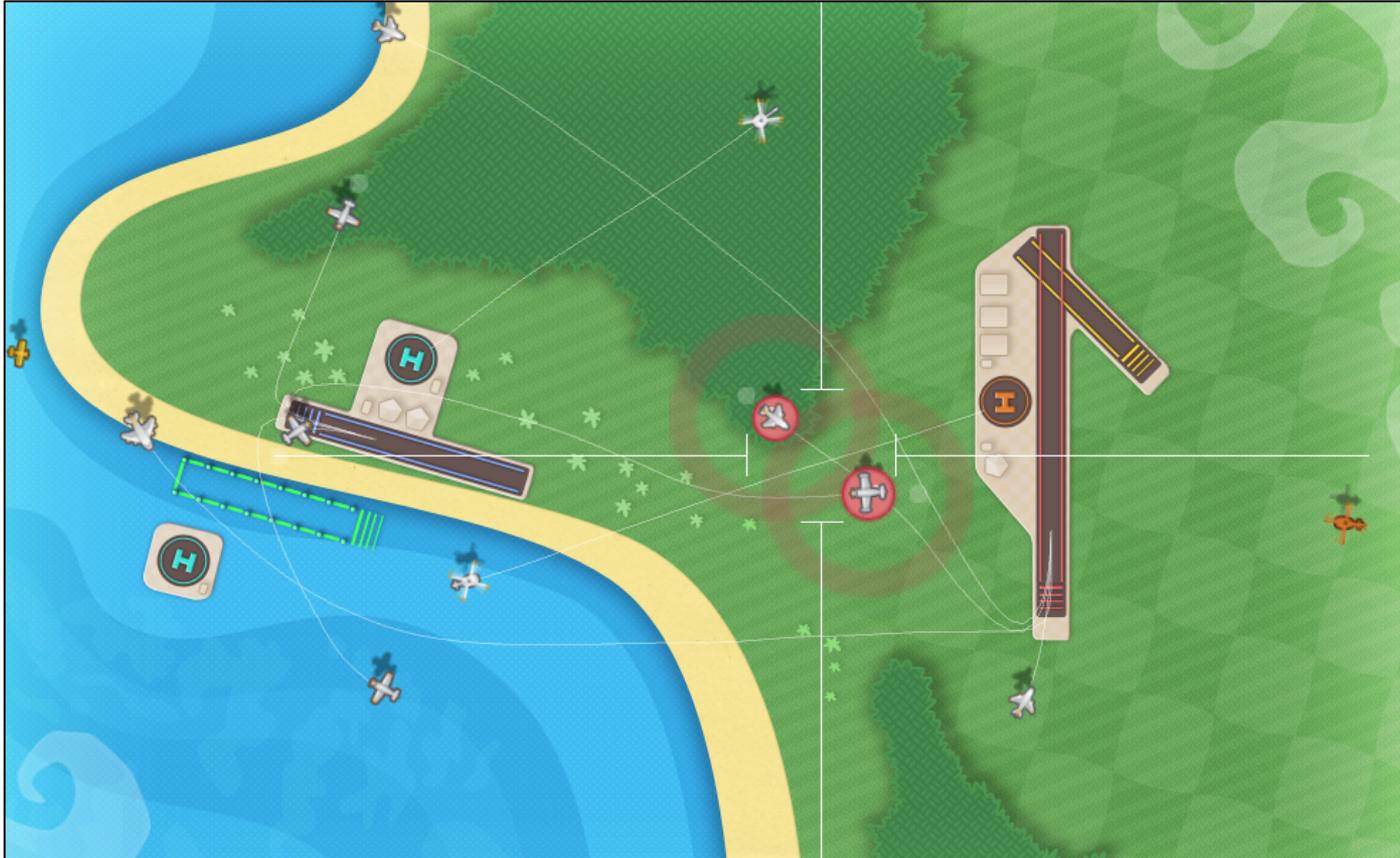
Regions of Control



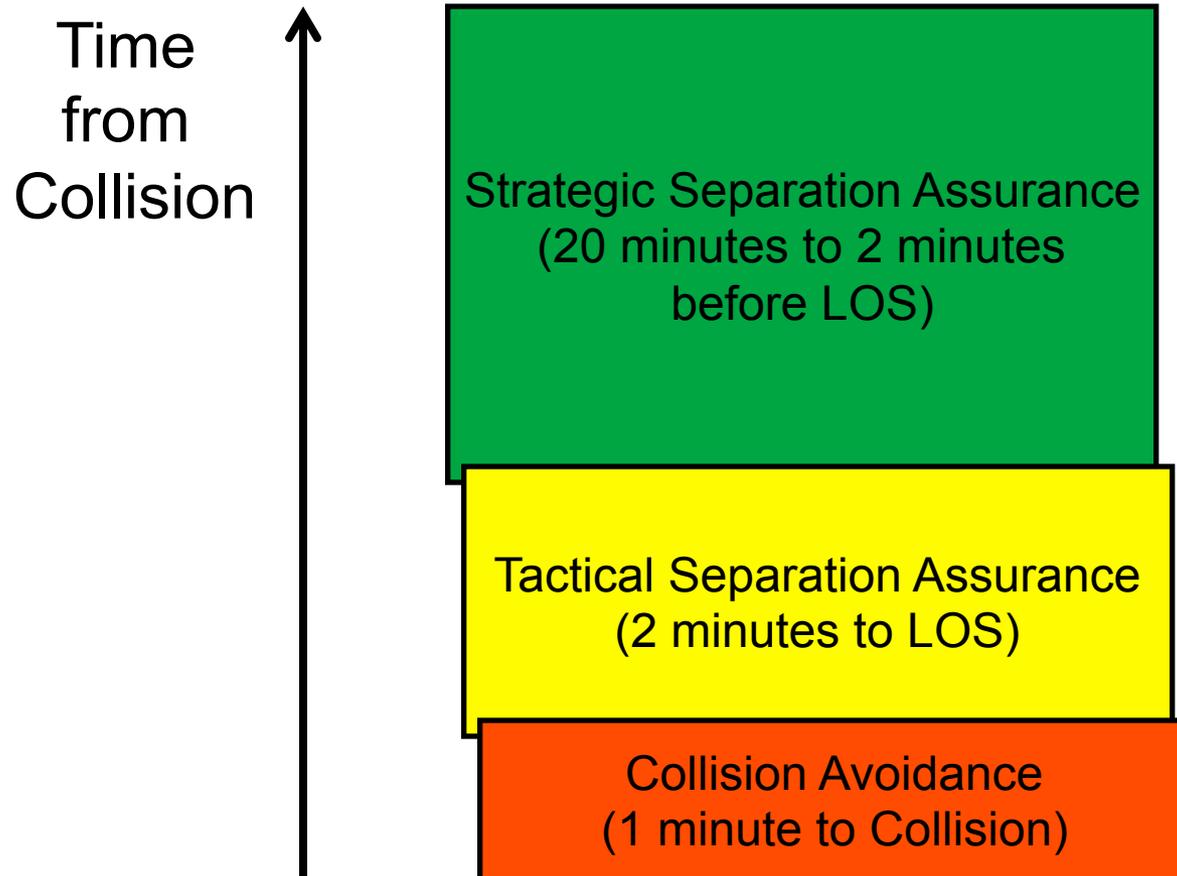
Optimization Time Scales



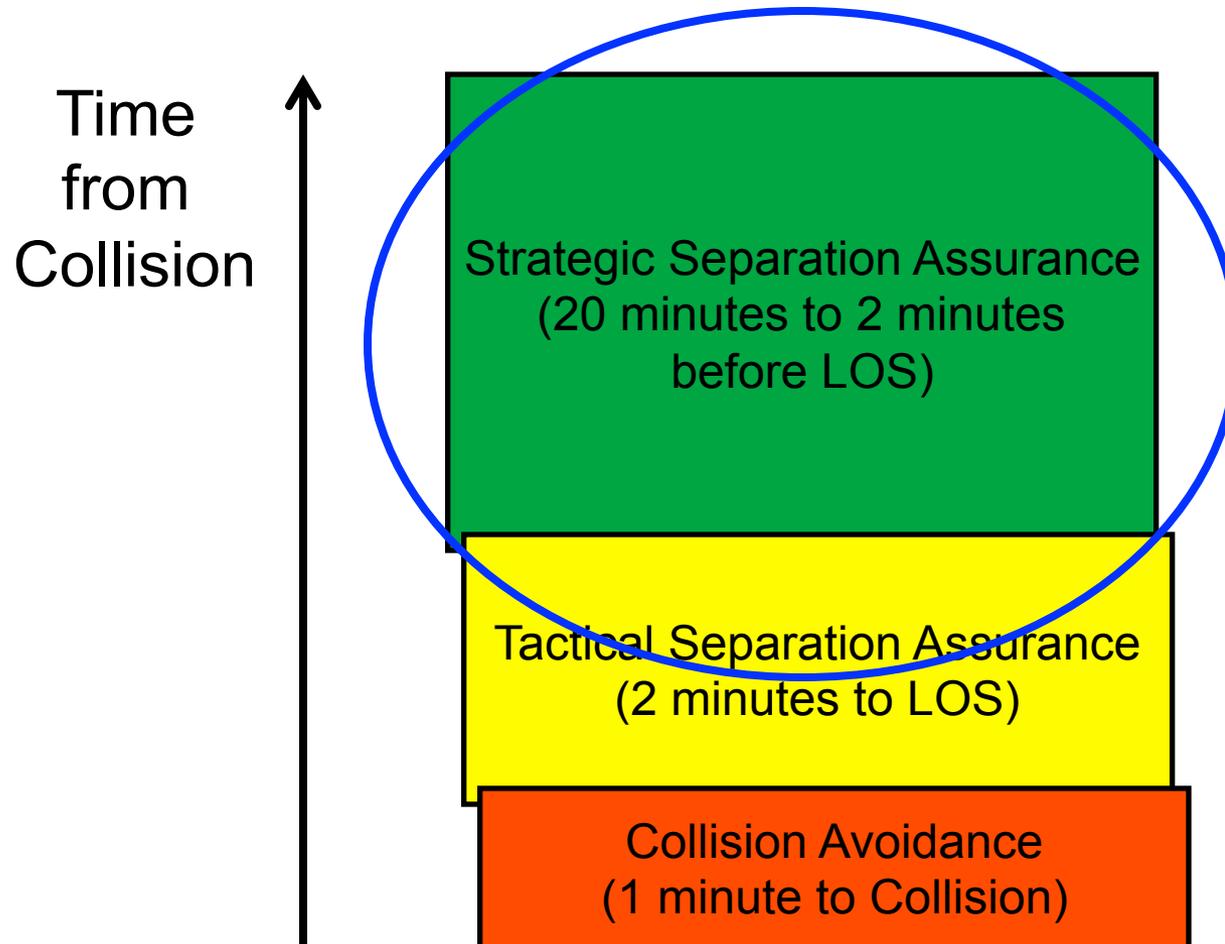
Maintaining Aircraft Separation



Maintaining Aircraft Separation



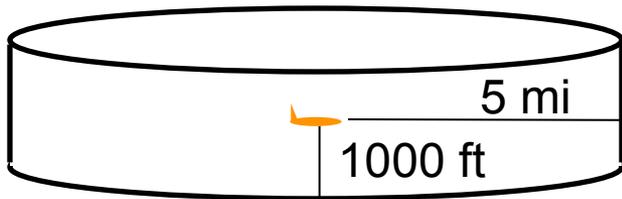
Maintaining Aircraft Separation



Part Two

- Enroute
- Separation Assurance
- Strategic

Separation Assurance

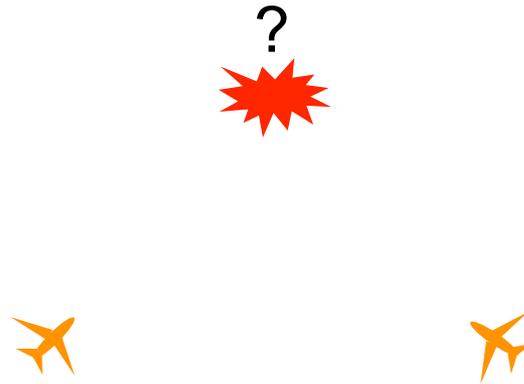


- Aircraft must remain 5 mi and 1000 ft from one another
- Currently performed by Air-Traffic Controllers (minimal tools)

Automated Separation Assurance

- Want the system to be safe
- Want to impact the system as little as possible (efficiency)
- Want to provide resolutions to aircraft which are understandable to pilots
- Needs to be robust to uncertainty

Identifying Issues



Need to identify if two aircraft will be within 5 mi and 1000 ft in the future

Predicting Aircraft Trajectories

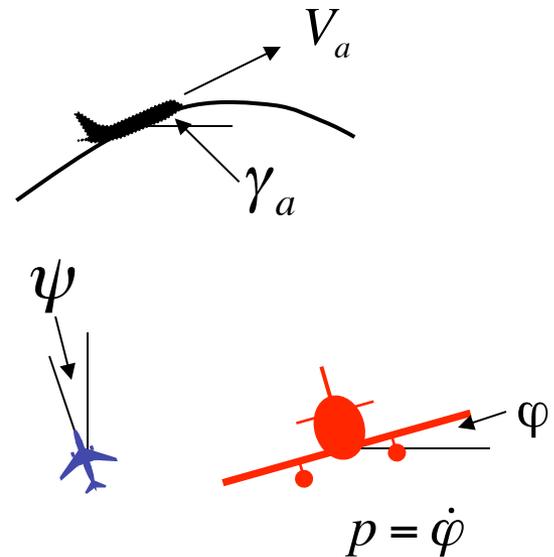
- Create models of aircraft performance using physics
- Models can be either kinematic or kinetic

V_a - Airspeed

γ_a - Flight Path Angle

ψ - Heading

p - Roll Rate



Example Kinetic Model

$$\dot{V}_a = \frac{T - D}{m} - g \sin(\gamma_a)$$

$$\dot{\gamma}_a = \frac{L \cos(\varphi) - mg \cos(\gamma_a)}{mV_a}$$

$$\dot{p} = L_p p + \tau$$

$$p = \dot{\varphi}$$

$$\dot{\psi} = \frac{g \tan(\varphi)}{V_a}$$

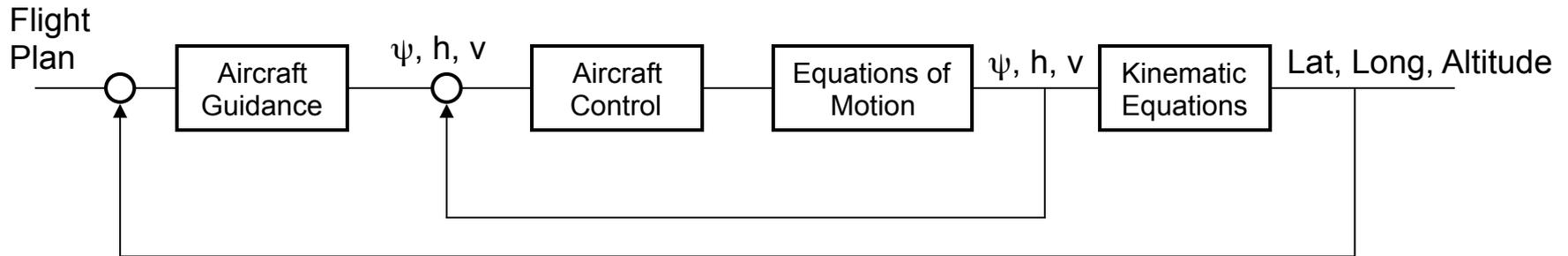
T - Thrust

D - Drag

L - Lift

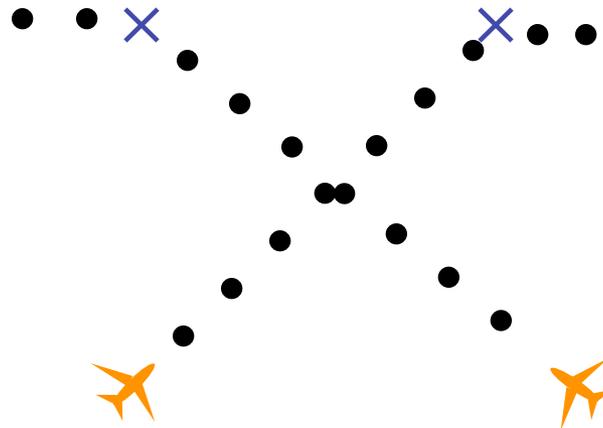
τ - Roll Force

Aircraft Controller



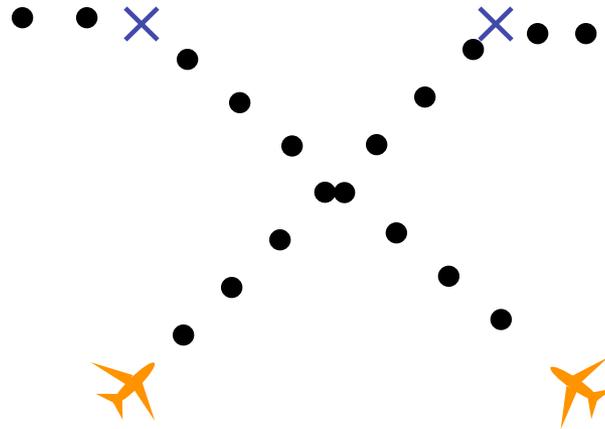
- Inner loop control for aircraft stability and desired attitude
- Outer loop guidance for aircraft lateral navigation between waypoints

Predicted Trajectories

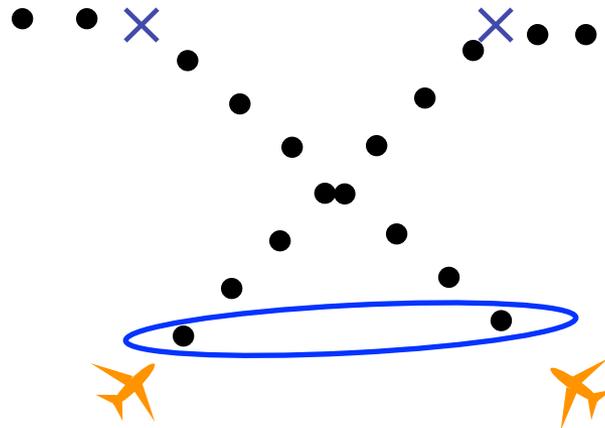


Numerical integration provides discrete predictions of future locations

Geometric Conflict Detection

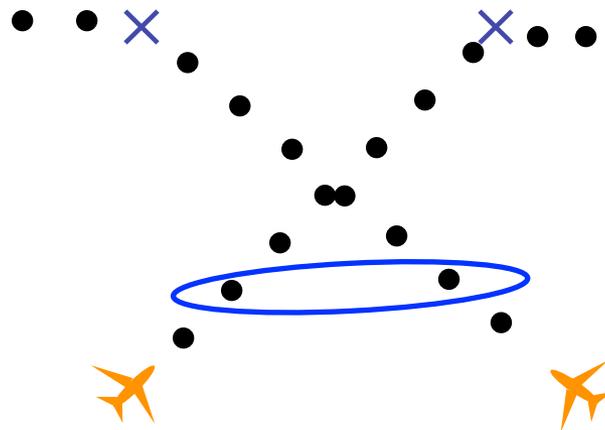


Geometric Conflict Detection



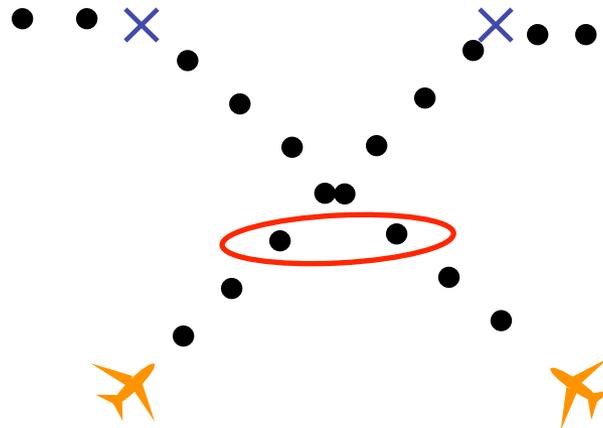
- Check vertical and horizontal distance
- There are temporal and spatial buffers to deal with uncertainty

Geometric Conflict Detection



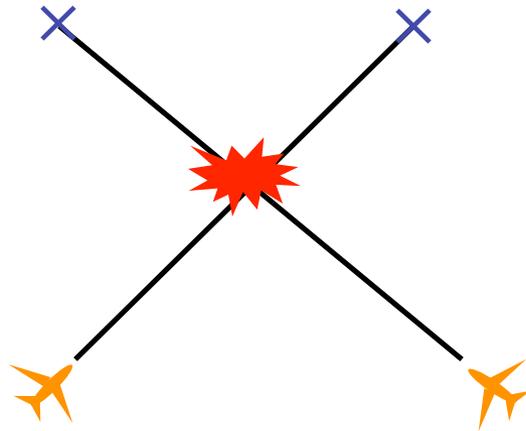
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Geometric Conflict Detection



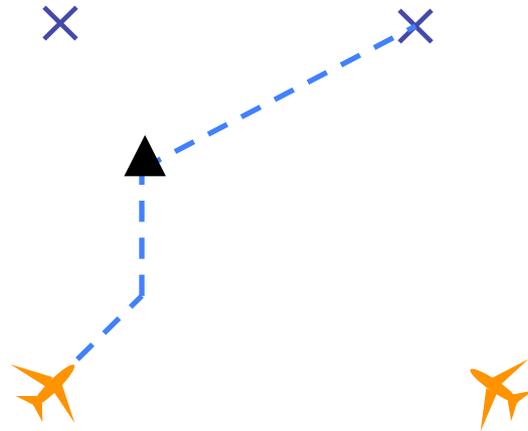
- Check vertical and horizontal distance
- There are temporal and spatial buffers to deal with uncertainty

Trial Planning



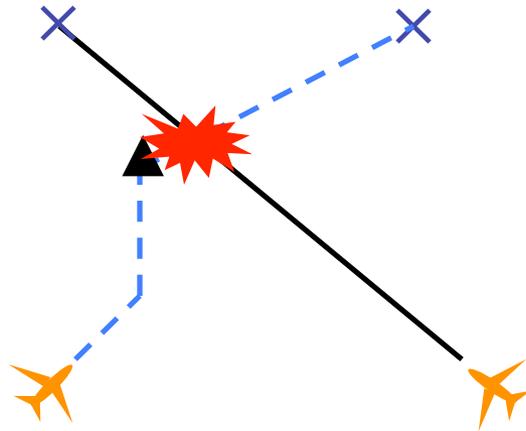
A loss of separation has been predicted

Trial Planning



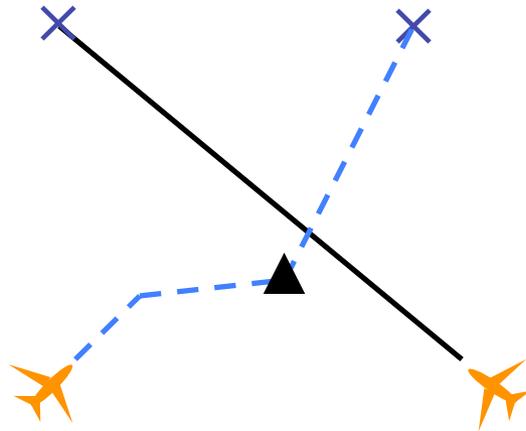
Generate a maneuver and predicted how the aircraft will fly it

Trial Planning



This maneuver is predicted to not solve the problem

Trial Planning

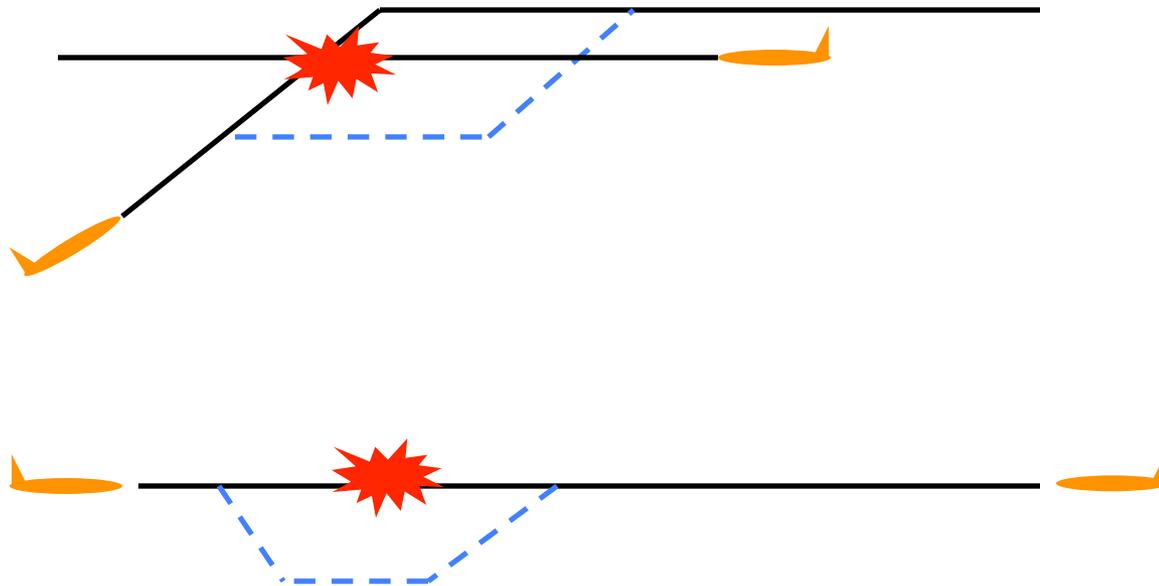


The problem is predicted to be resolved by this maneuver

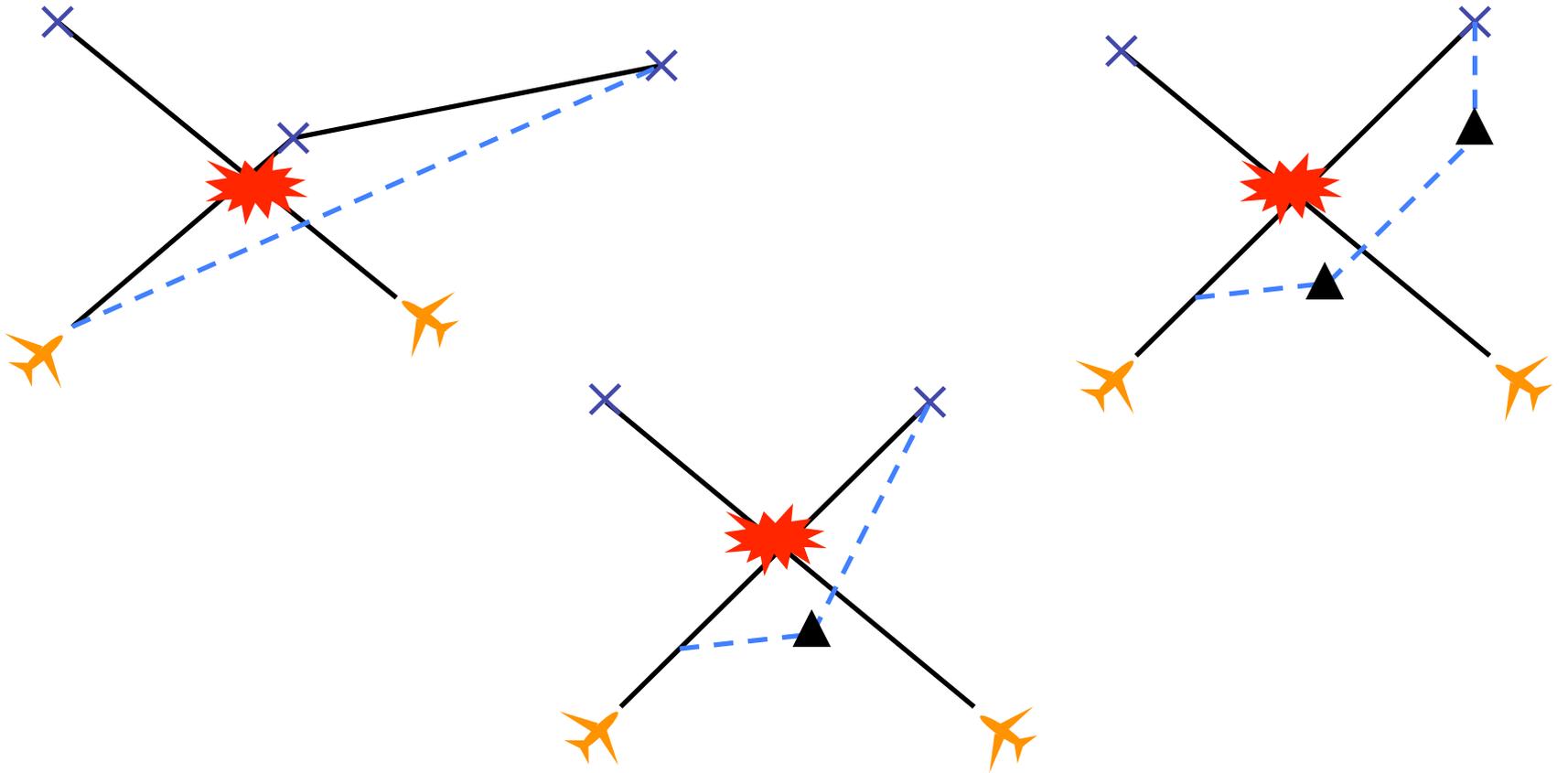
Maneuver Types

- Maneuvers can be difficult to communicate
- Want to use common current maneuvers
- Have three types of maneuvers:
 - Altitude maneuvers
 - Horizontal maneuvers
 - Speed maneuvers

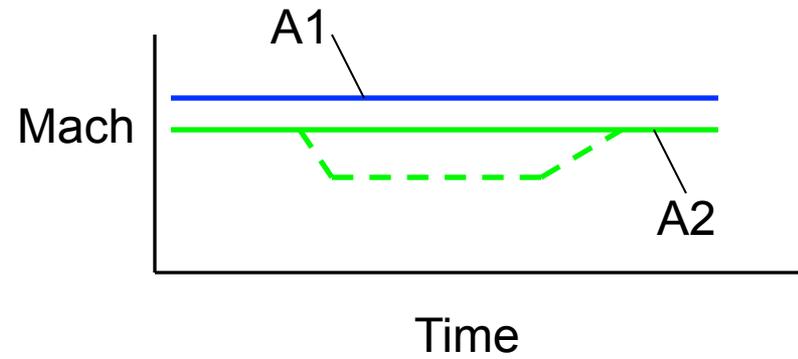
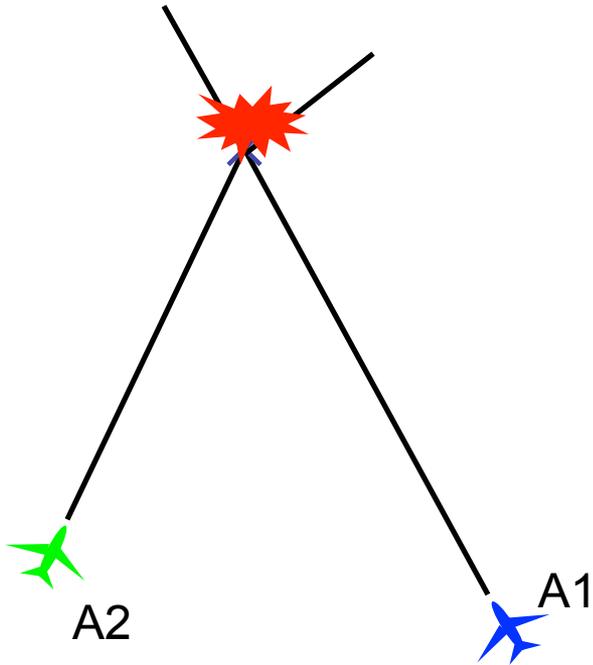
Altitude Maneuvers



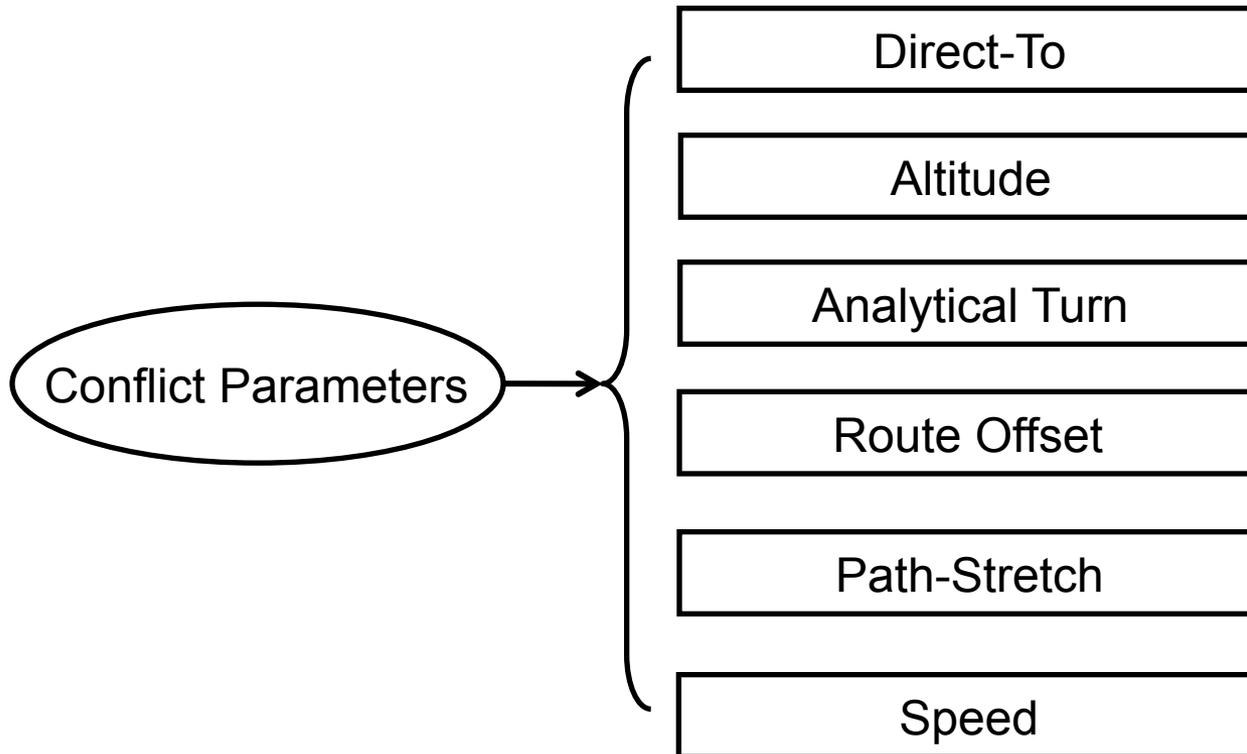
Horizontal Maneuvers



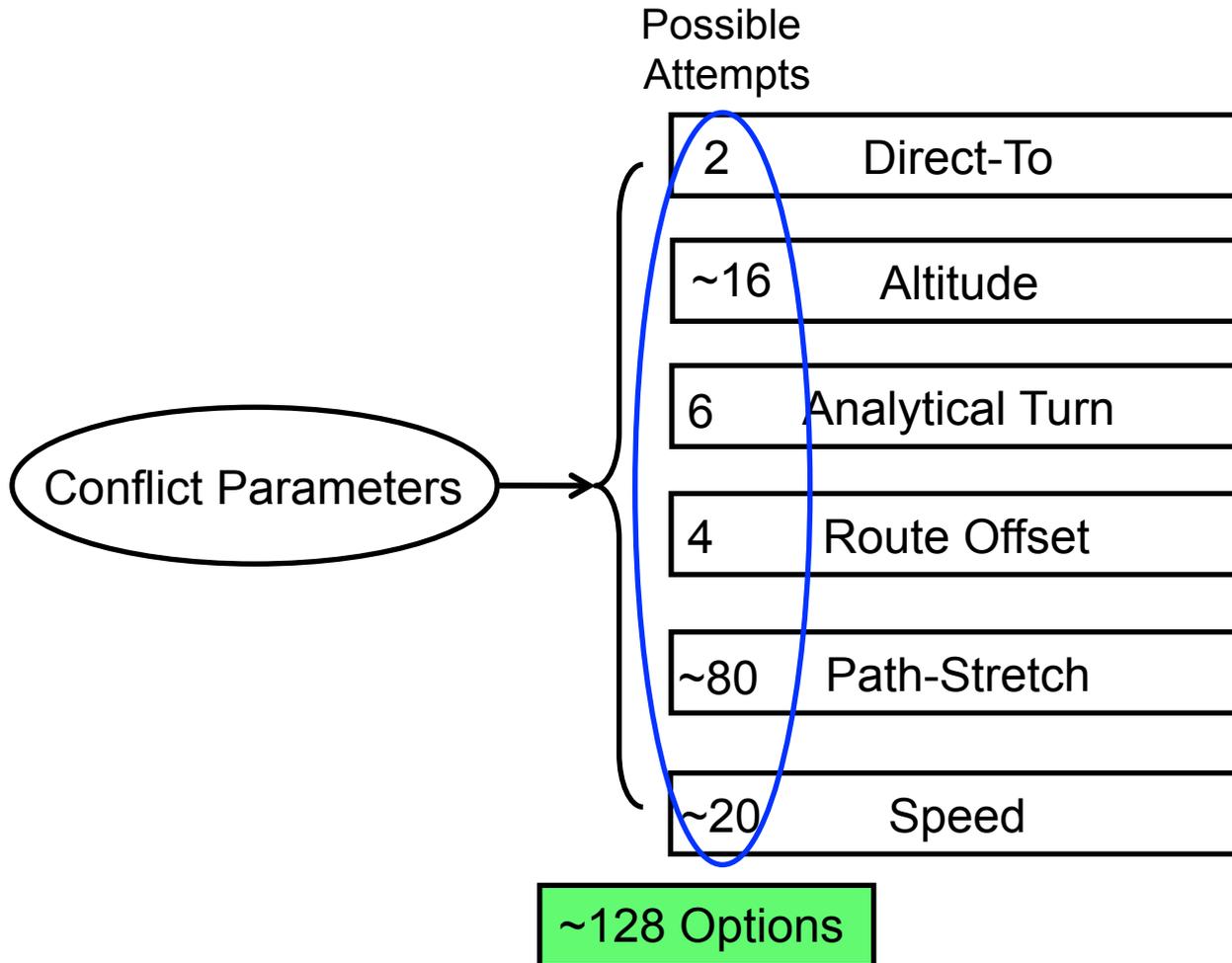
Speed



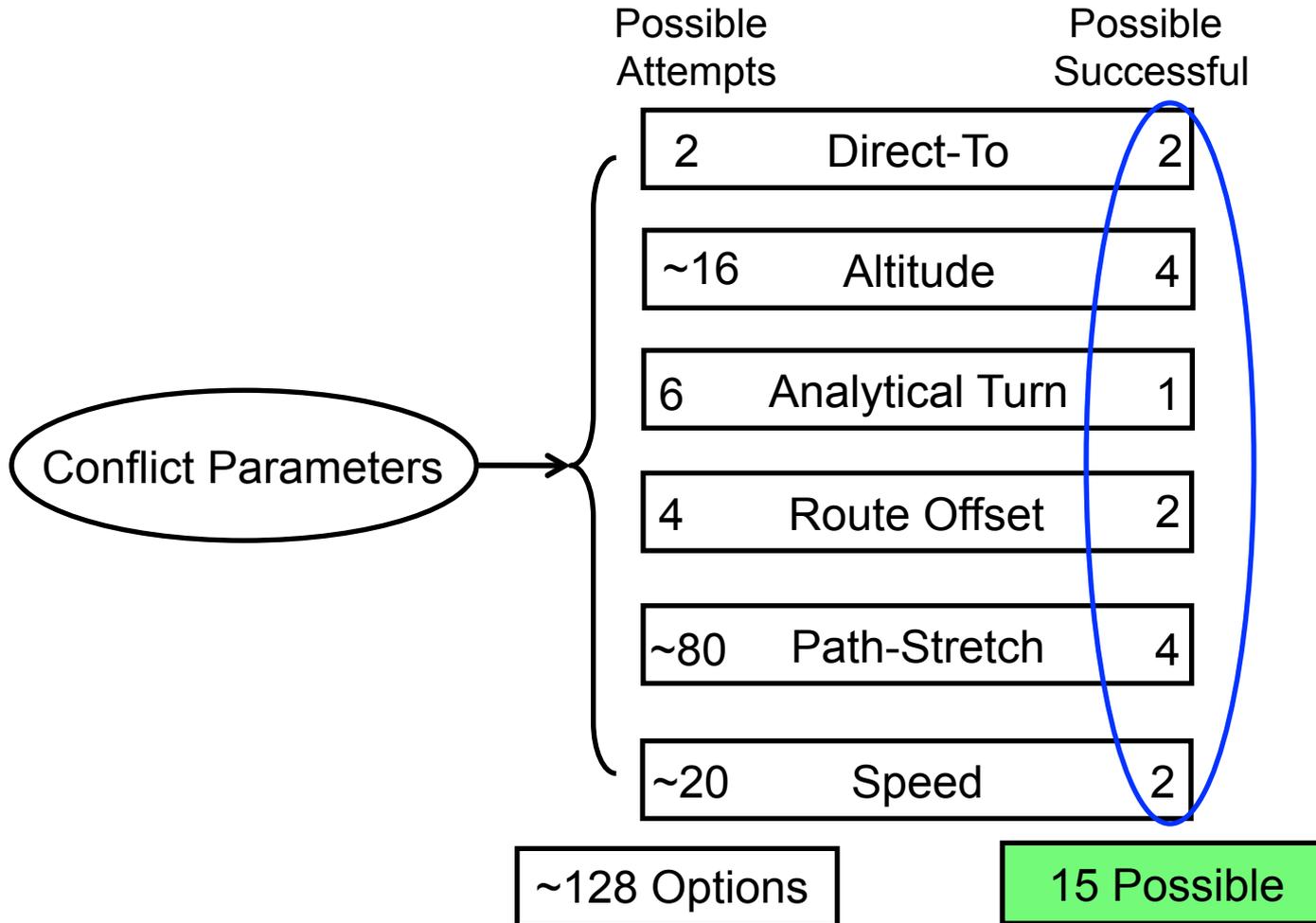
Resolution Search



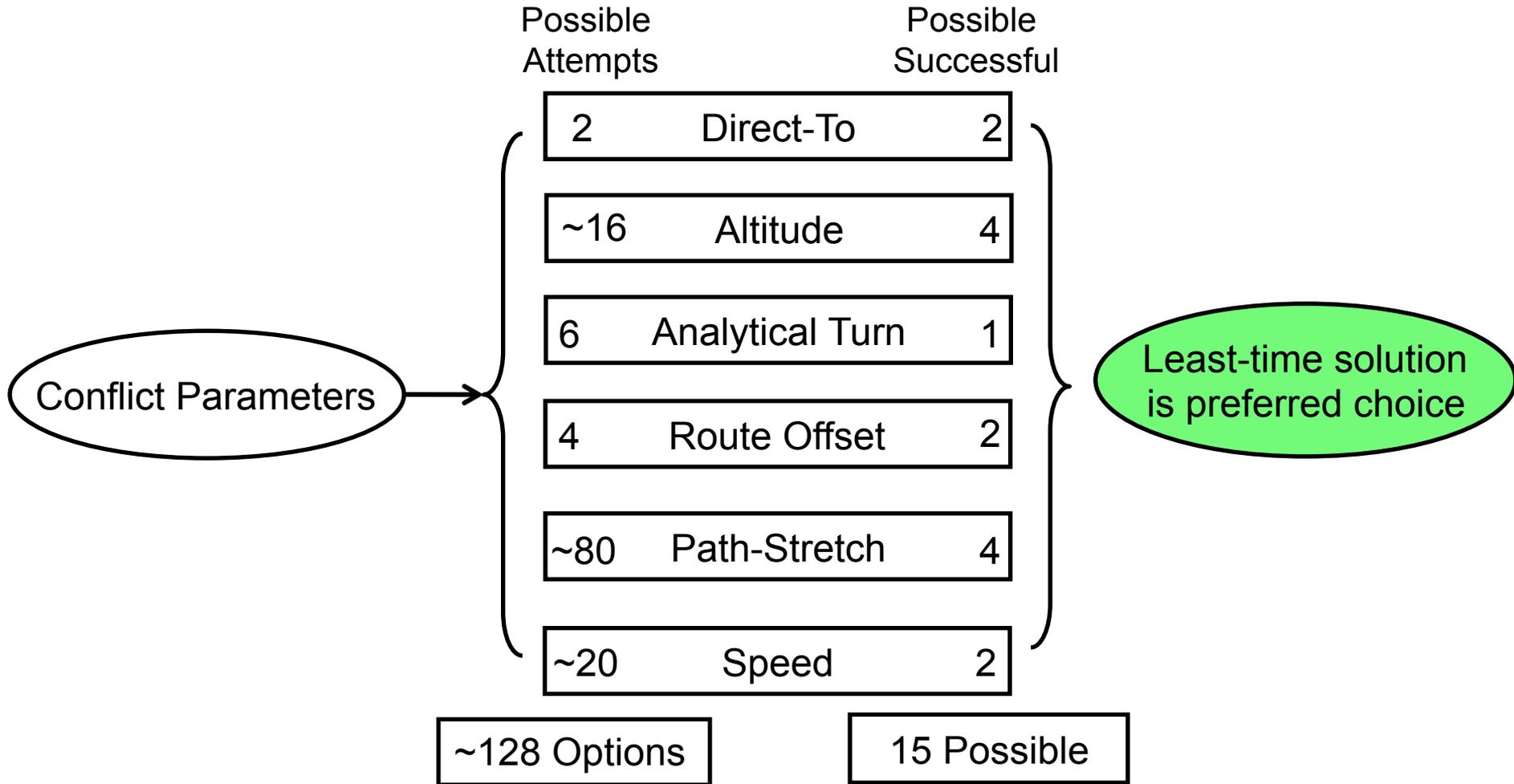
Resolution Search



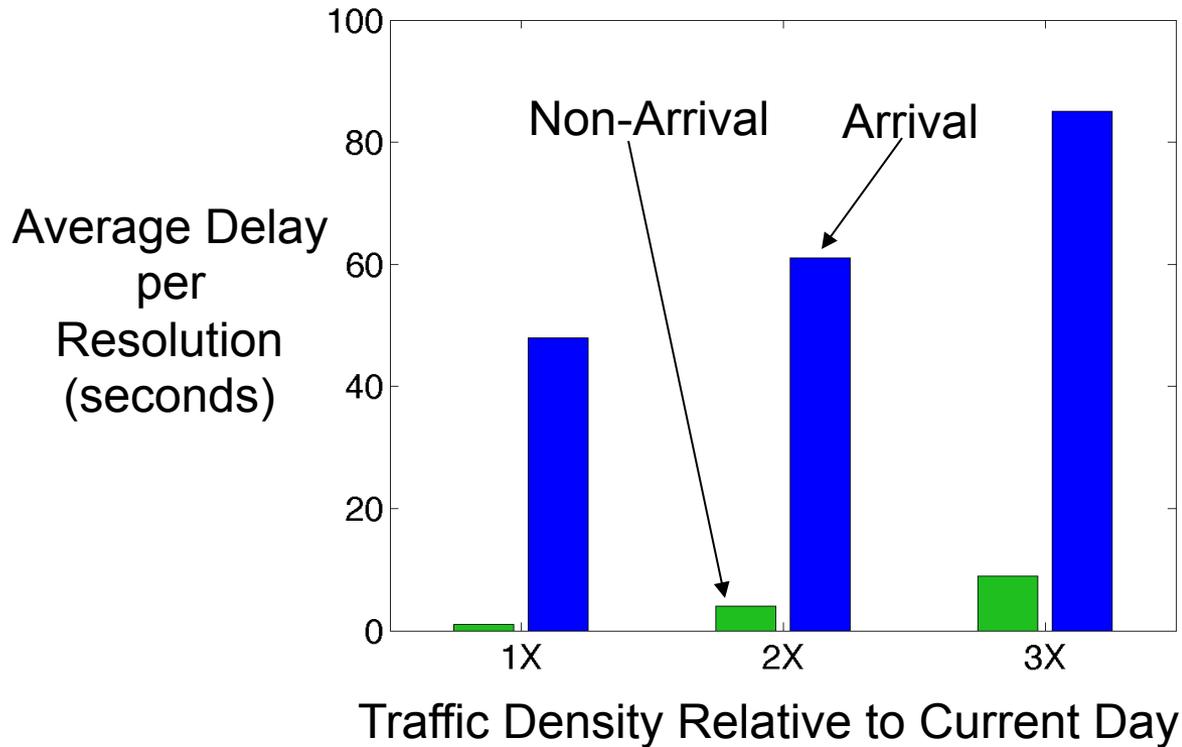
Resolution Search



Resolution Iterations

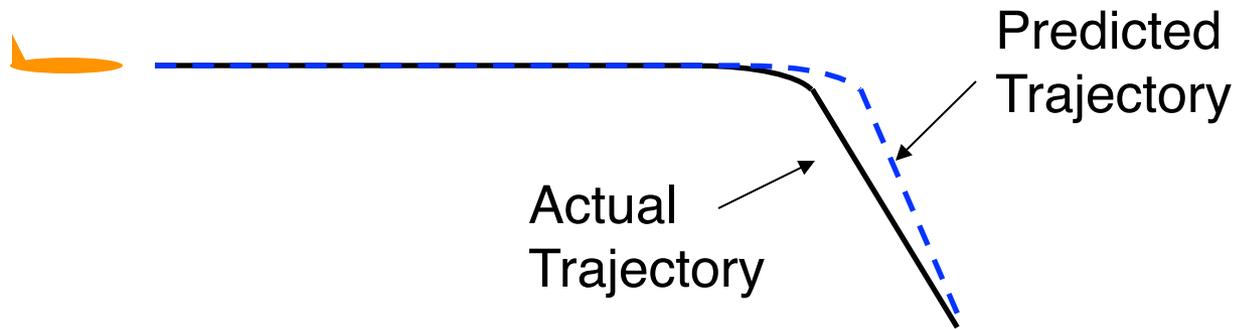


Results with No Uncertainty



Resolved 100% of conflicts

Uncertainty in Simulations

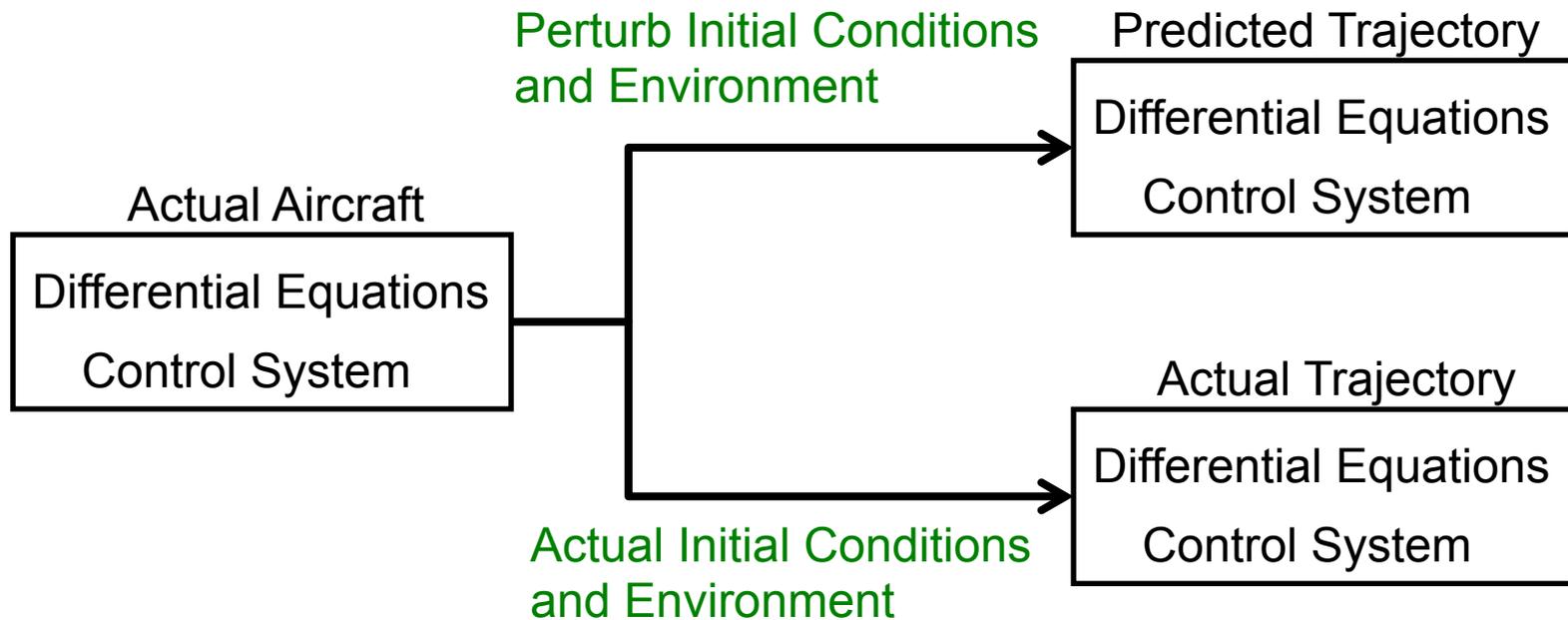


Any trajectory prediction will have some error

Major Sources of Uncertainty

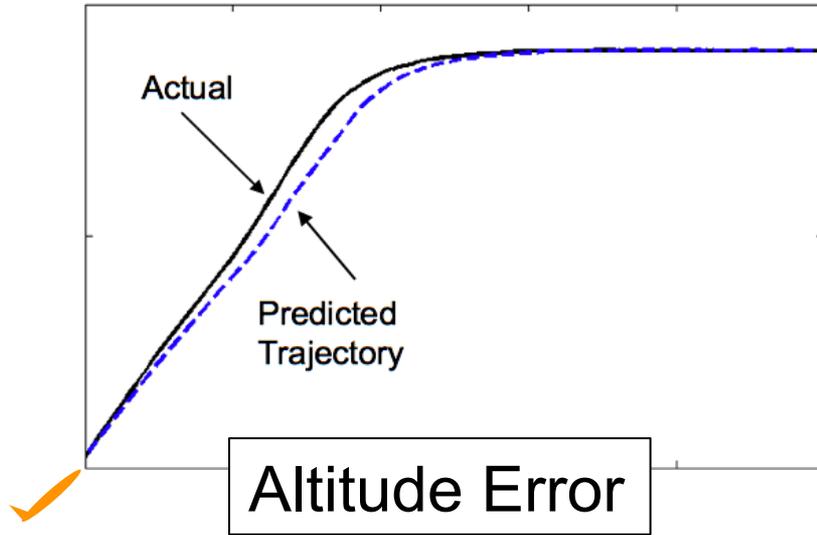
- Wind error
- Aircraft weight error
- Pilot intent error
- Communication delay
- Control system modeling

Adding Uncertainty in Simulation

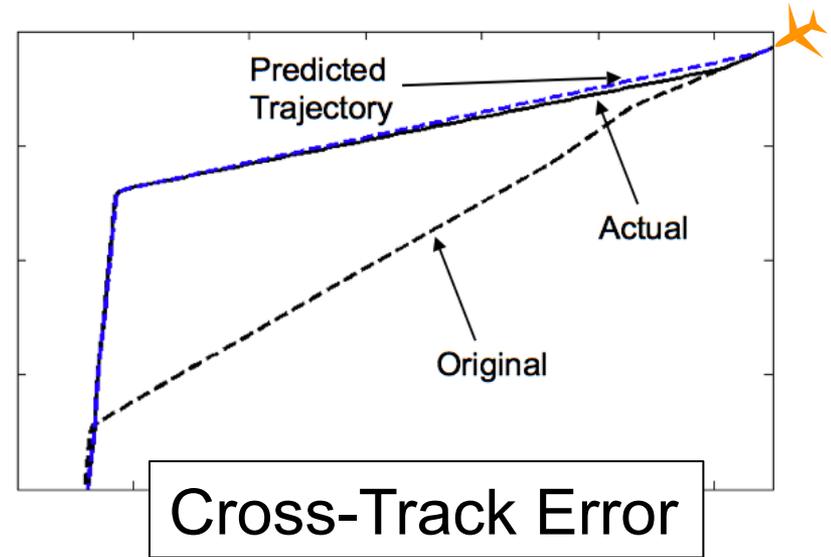
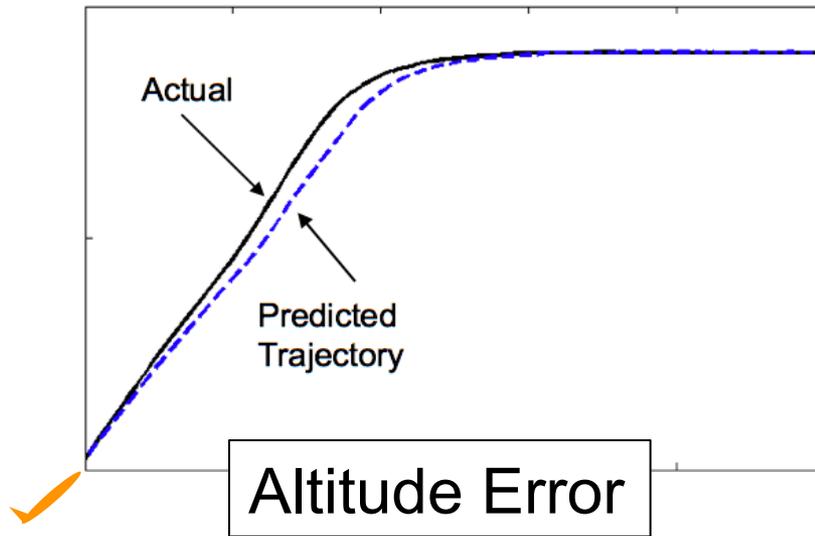


Create an exact copy at the same time to have a truth trajectory

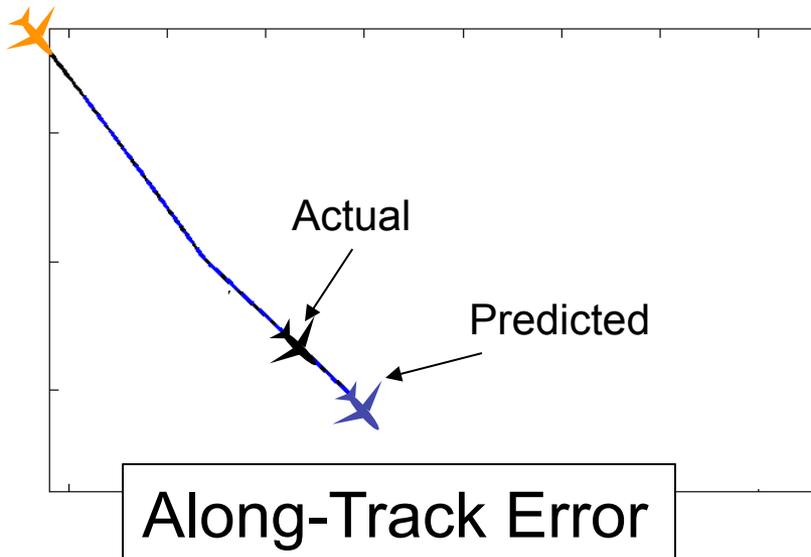
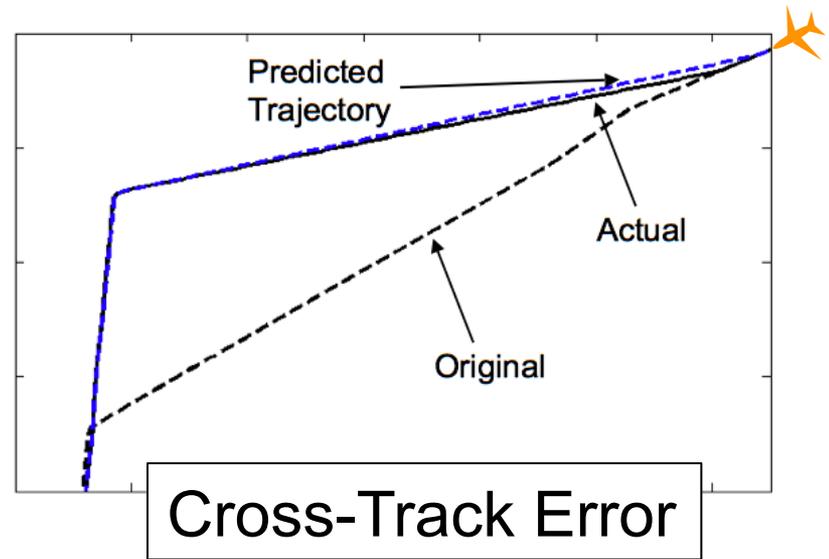
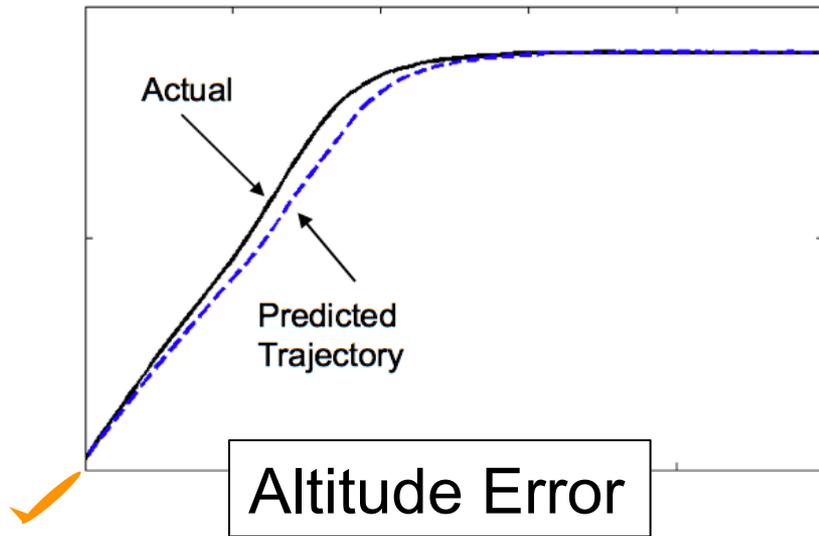
Resulting Prediction Errors



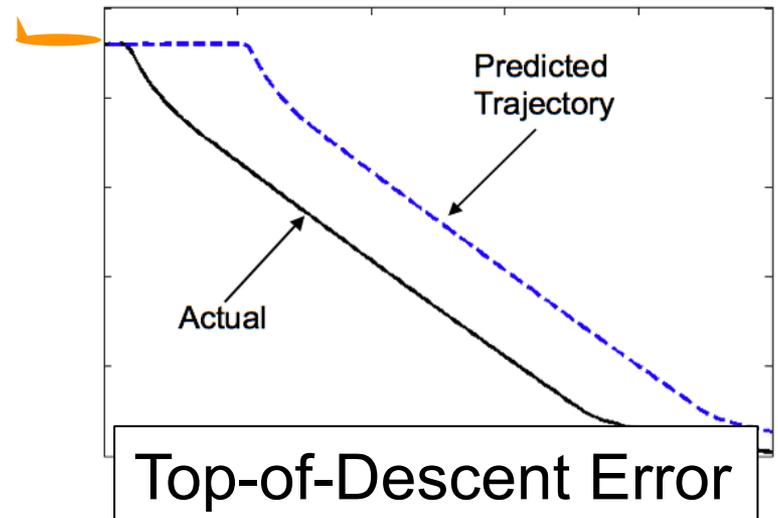
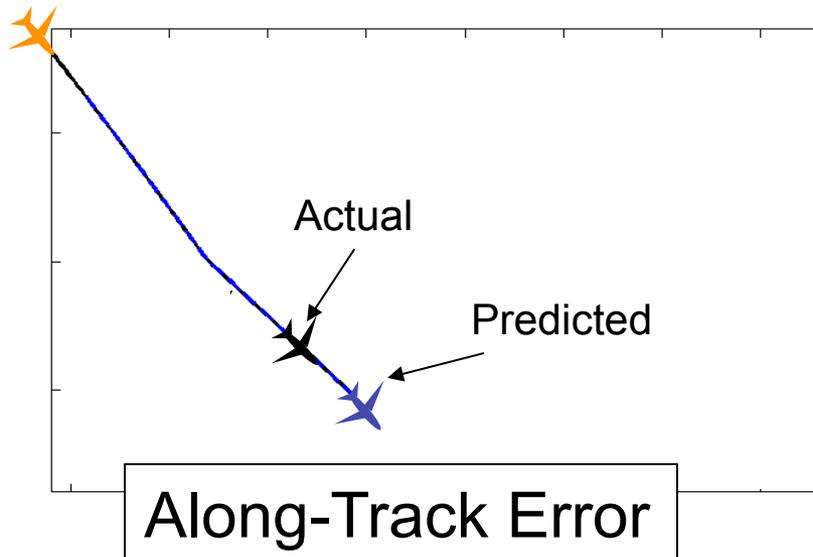
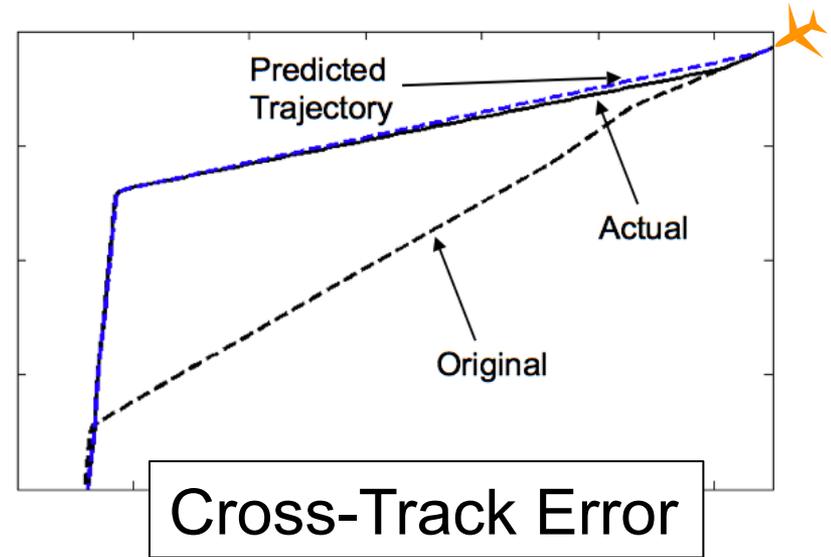
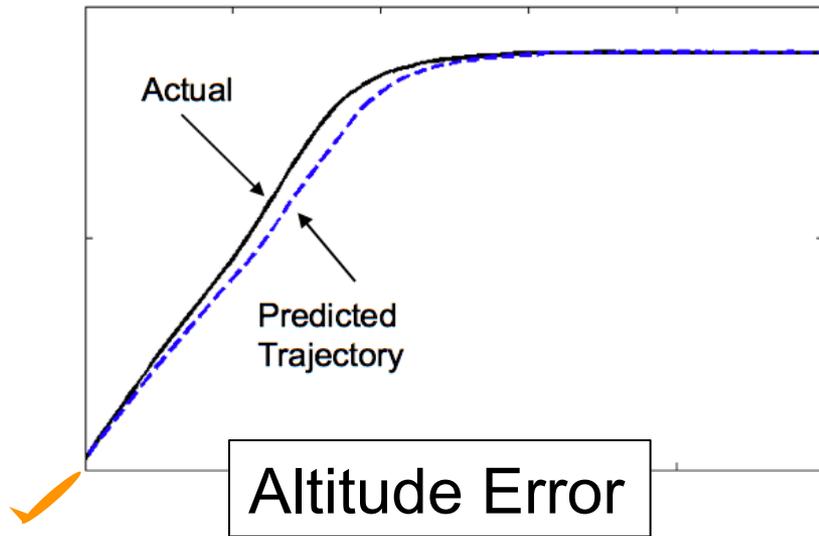
Resulting Prediction Errors



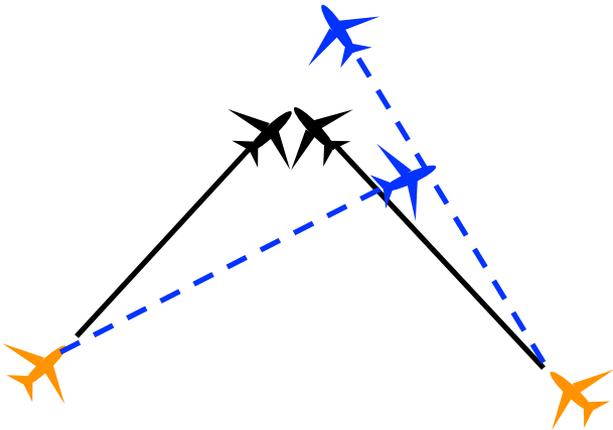
Resulting Prediction Errors



Resulting Prediction Errors

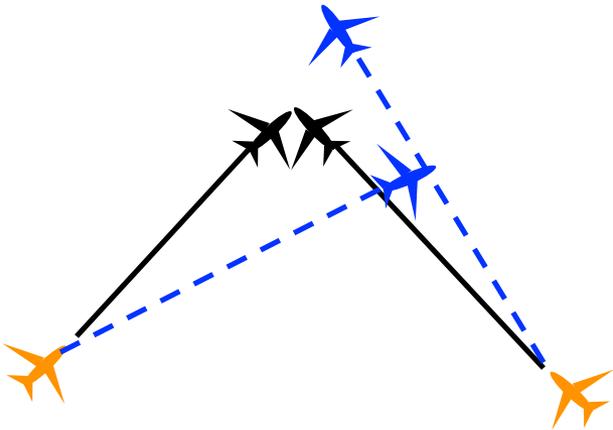


Missed and False Alerts

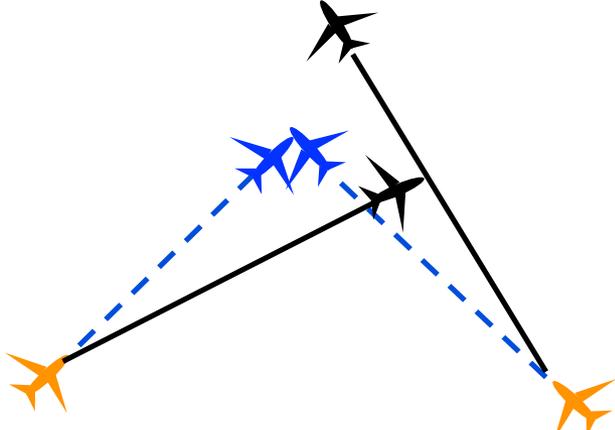


Missed Alert

Missed and False Alerts

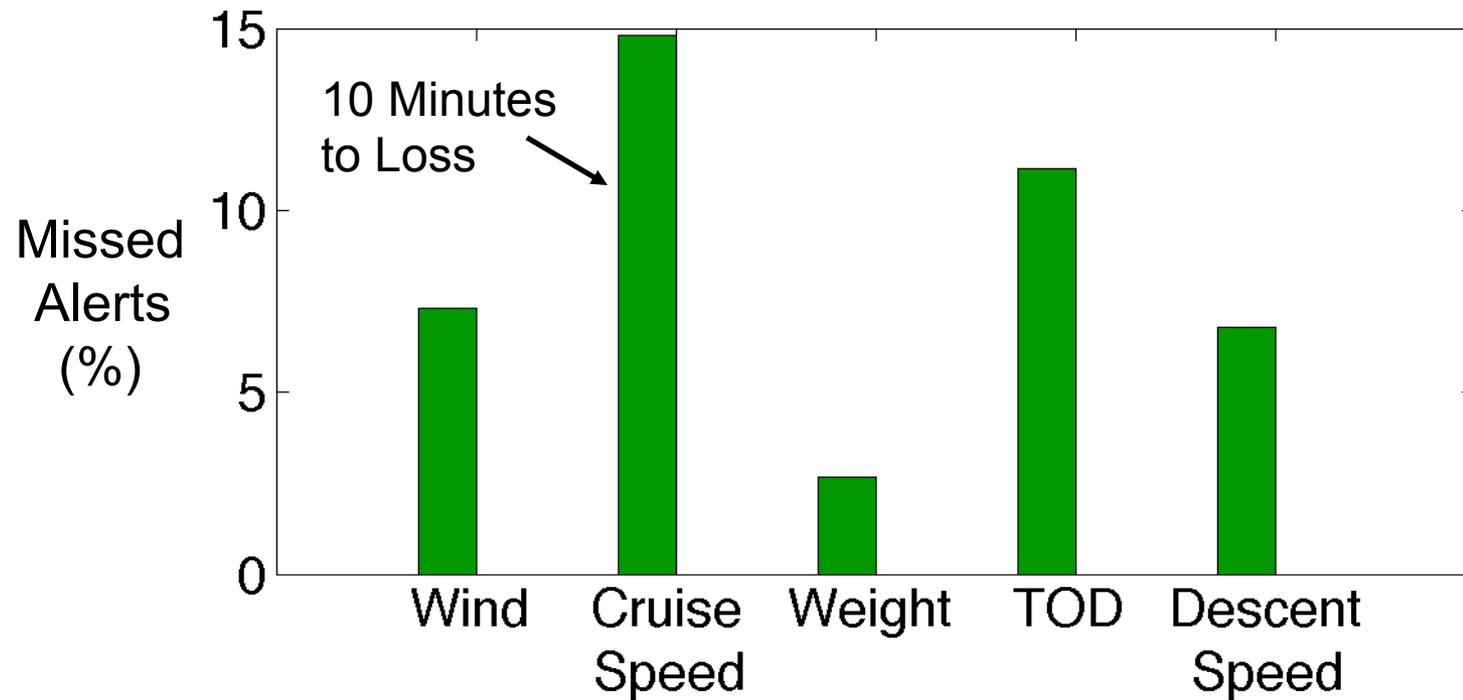


Missed Alert

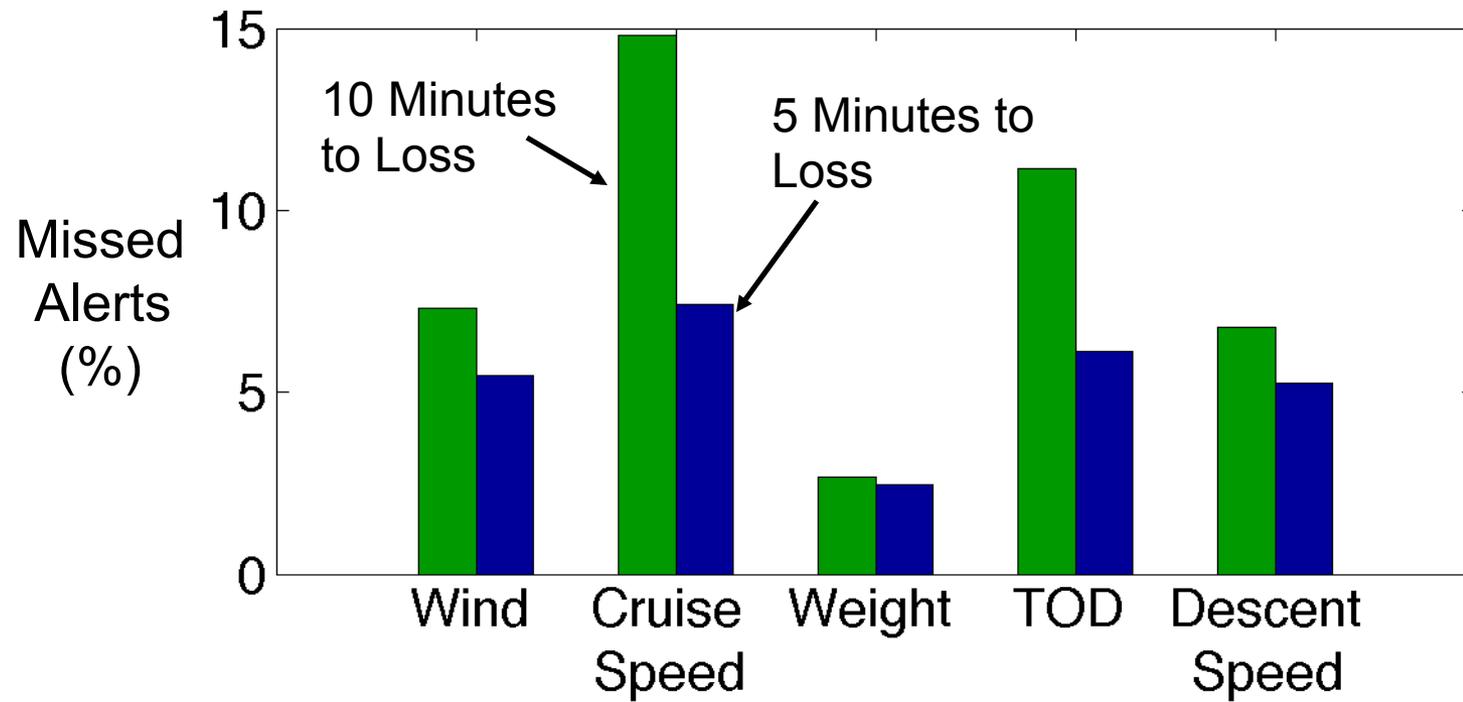


False Alert

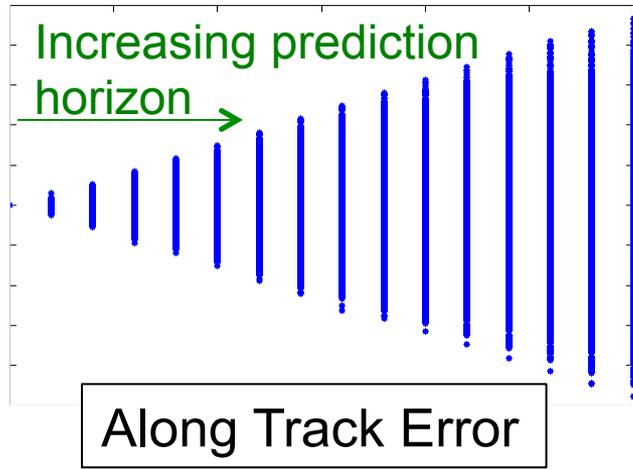
Missed Alerts with Errors



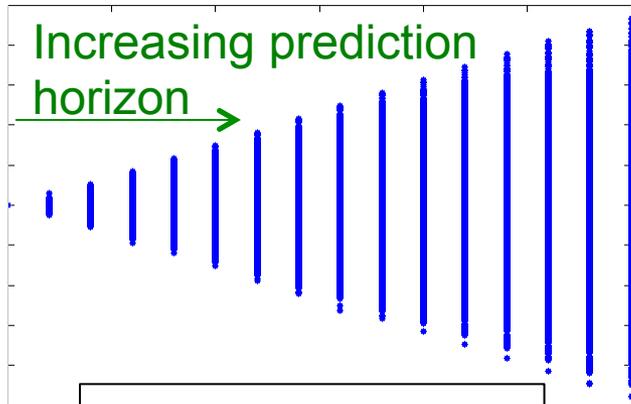
Missed Alerts



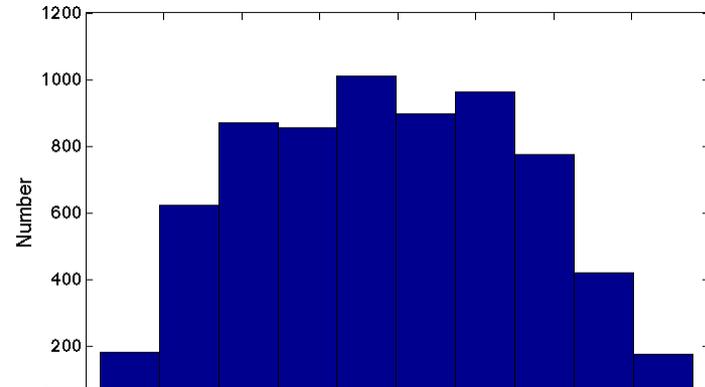
Prediction Errors



Prediction Errors

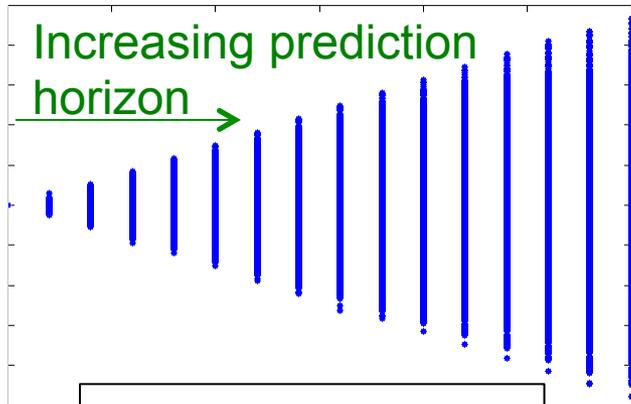


Along Track Error

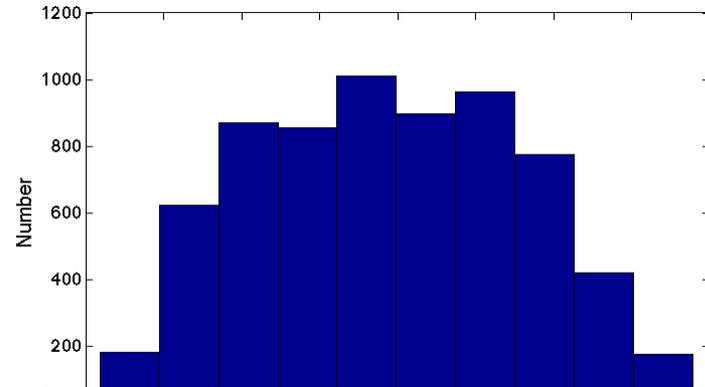


Along Track Error Histogram
at 24 Minutes

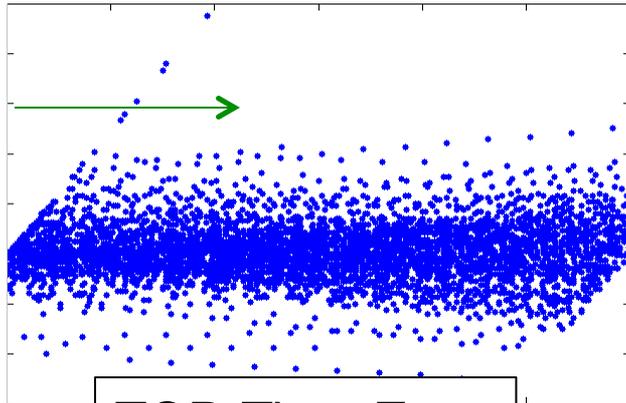
Prediction Errors



Along Track Error

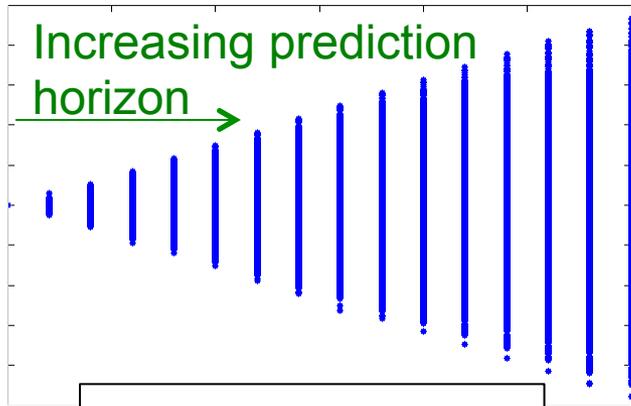


Along Track Error Histogram
at 24 Minutes

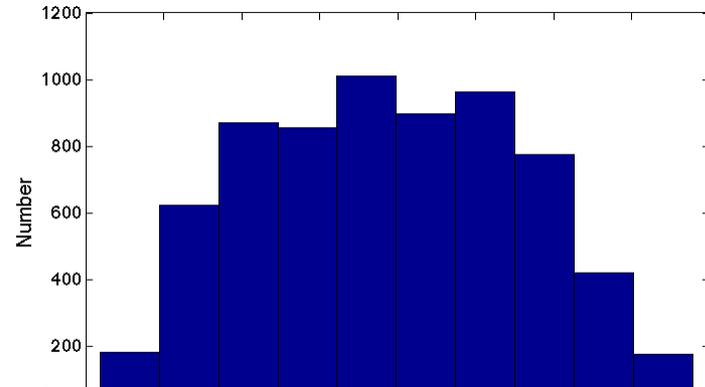


TOD Time Error

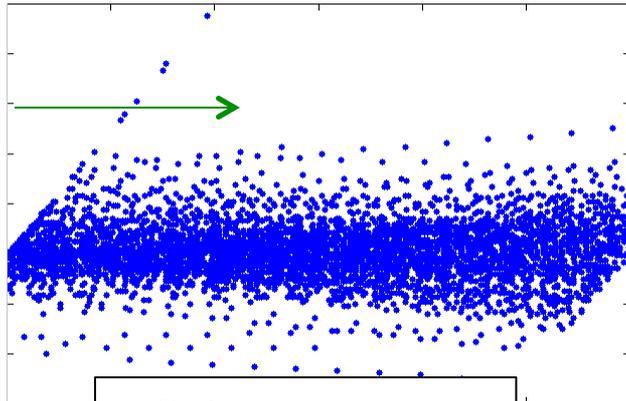
Prediction Errors



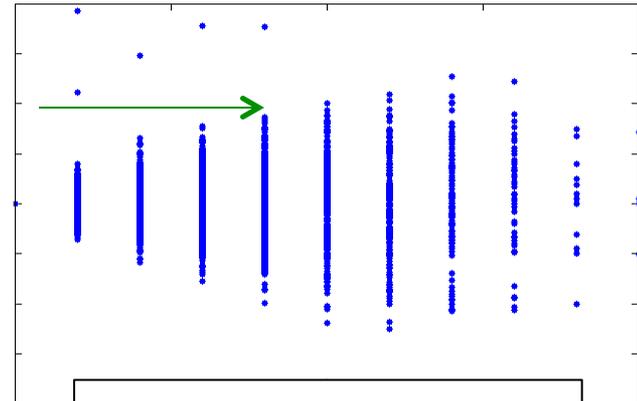
Along Track Error



Along Track Error Histogram at 24 Minutes



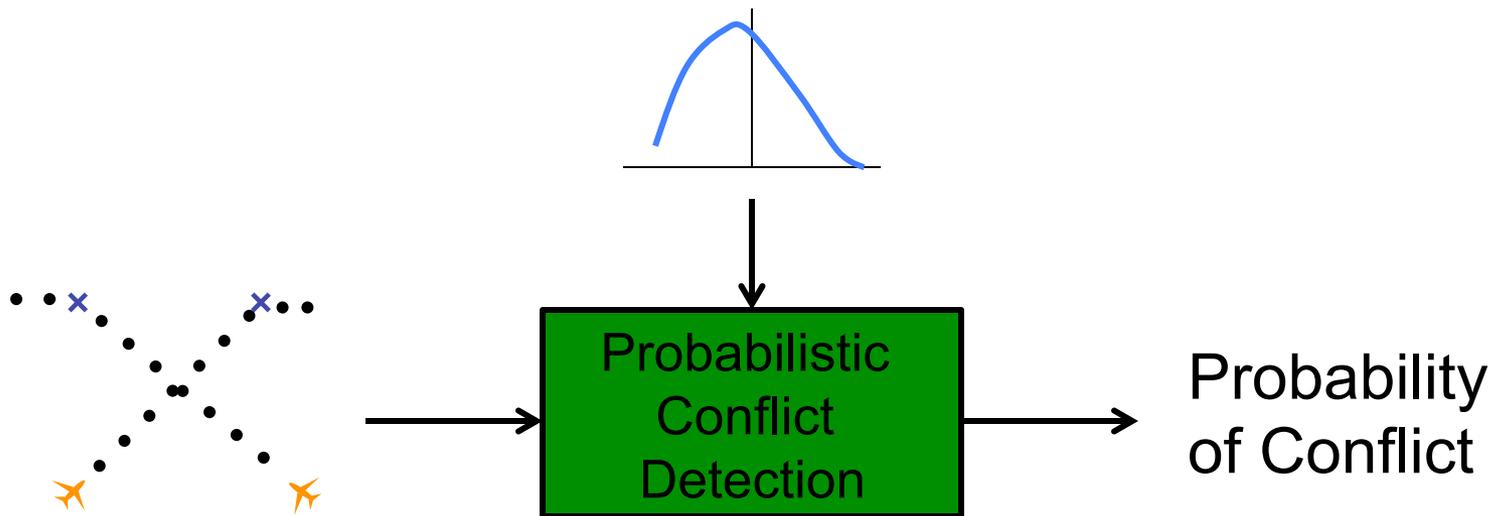
TOD Time Error



Climb Altitude Error

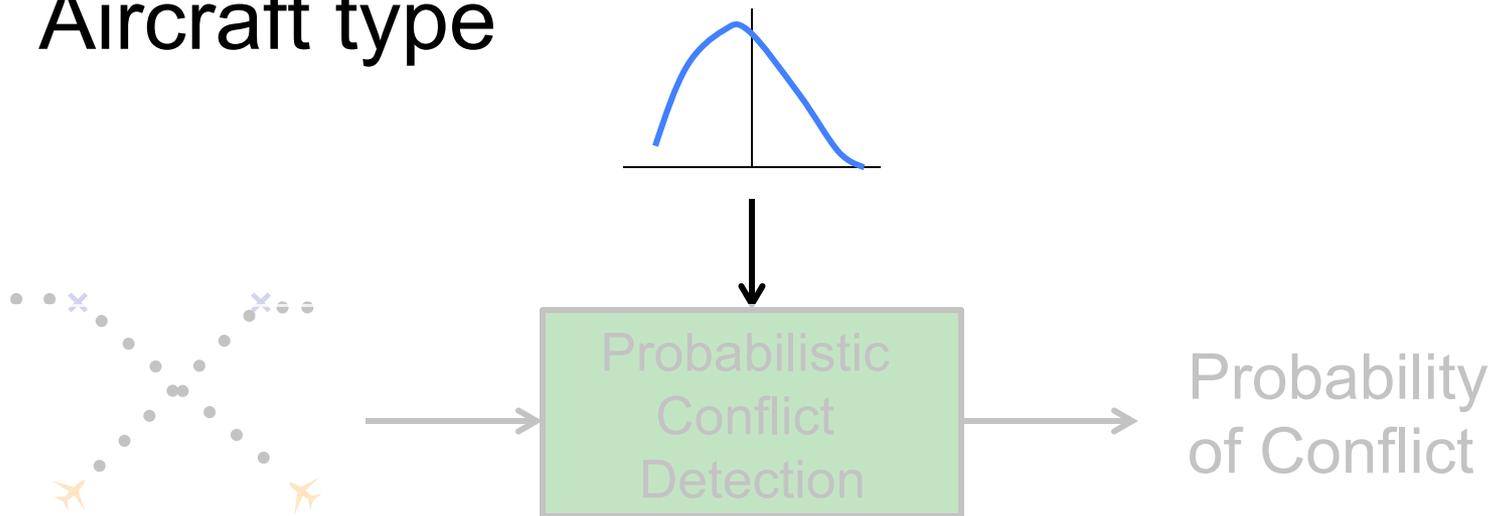
Probabilistic Conflict Detection

- Use knowledge of prediction errors to improve conflict detection performance
- Remove arbitrary buffers and time thresholds

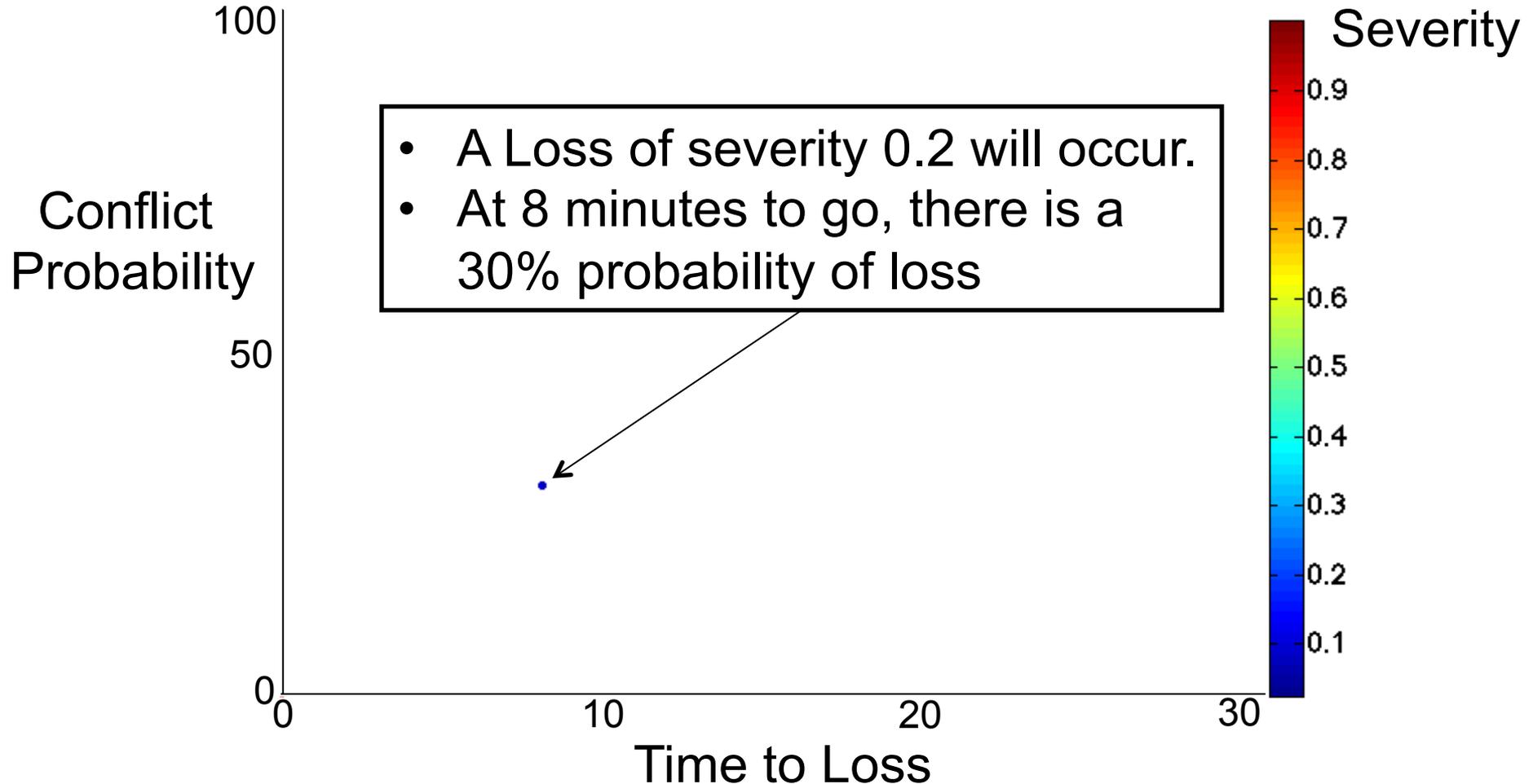


Factors in Position Uncertainty

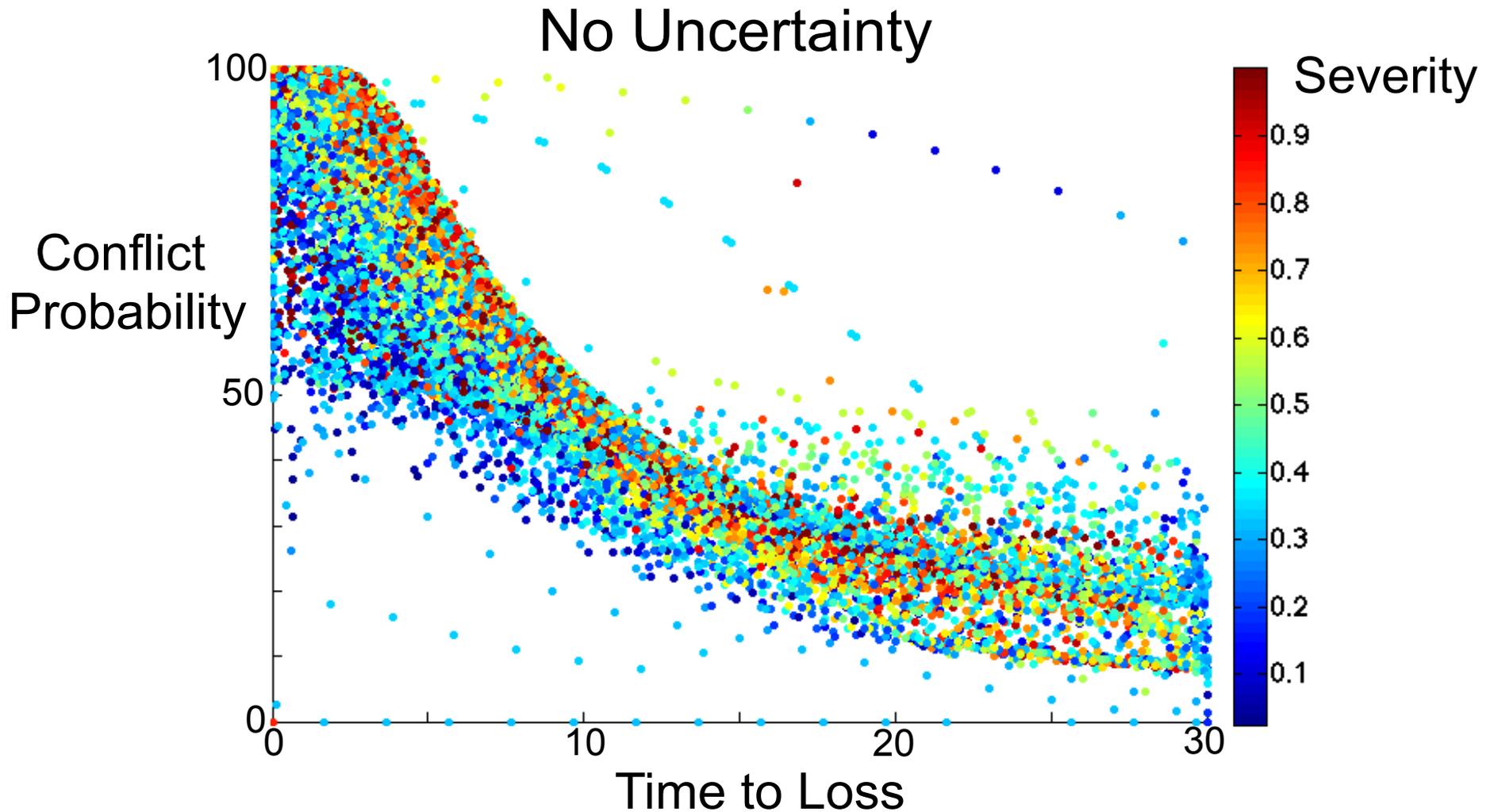
- Prediction time extent
- Currently changing state
- Distance from next state change
- Distance from top of descent
- Aircraft type



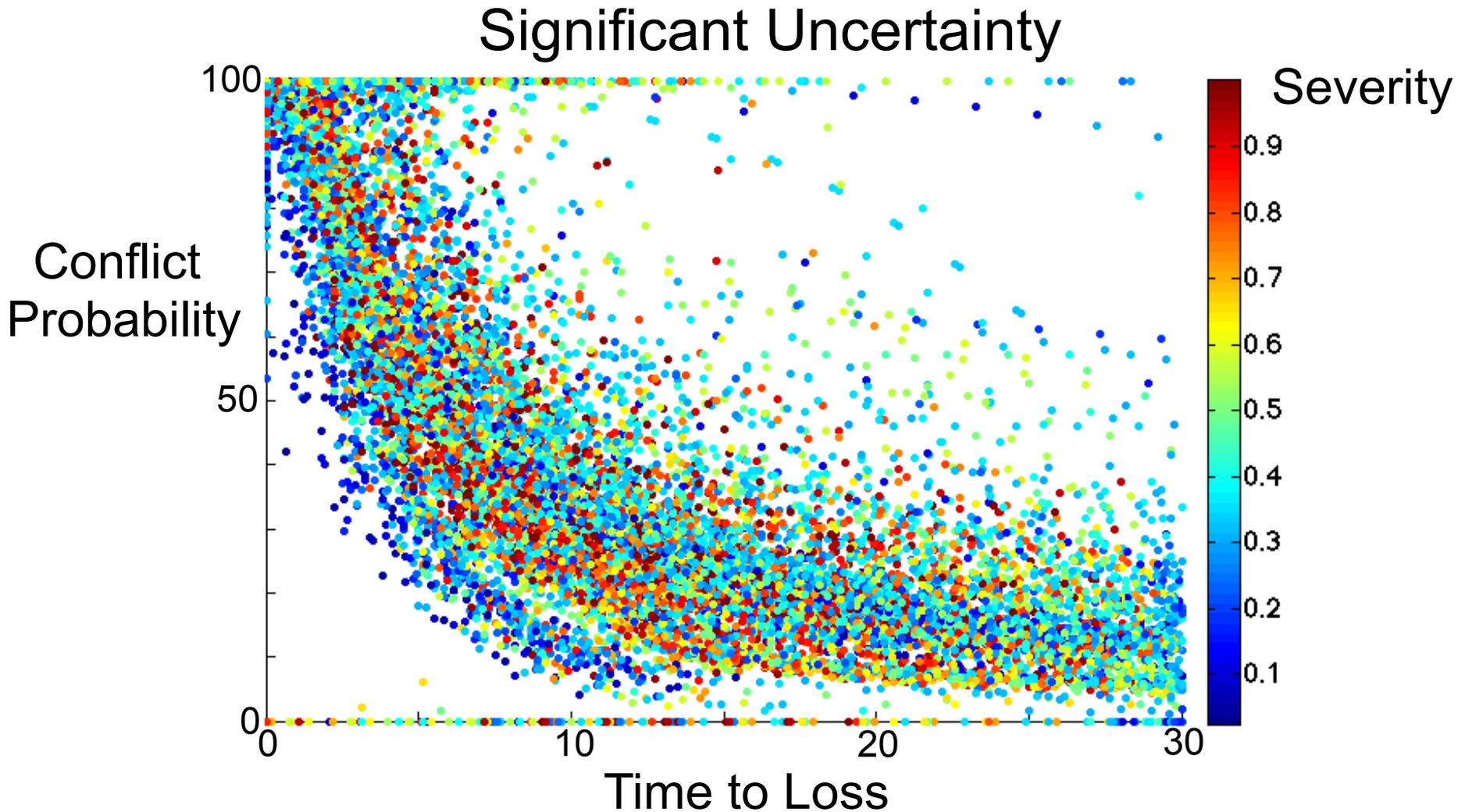
Probability of Conflict



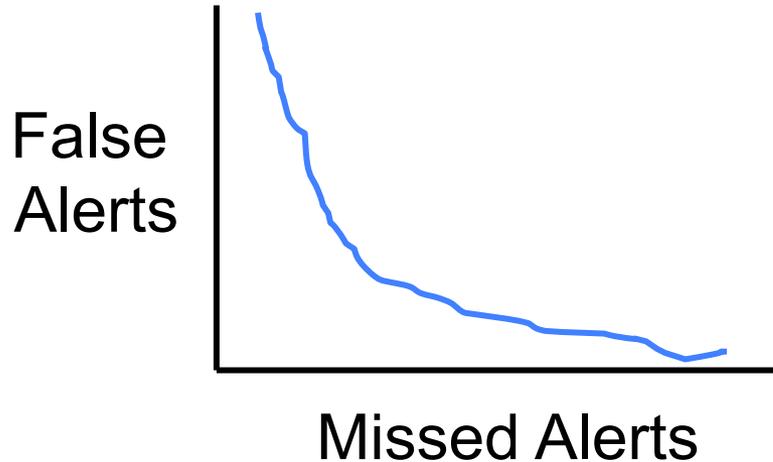
Probability of Conflict



Probability of Conflict

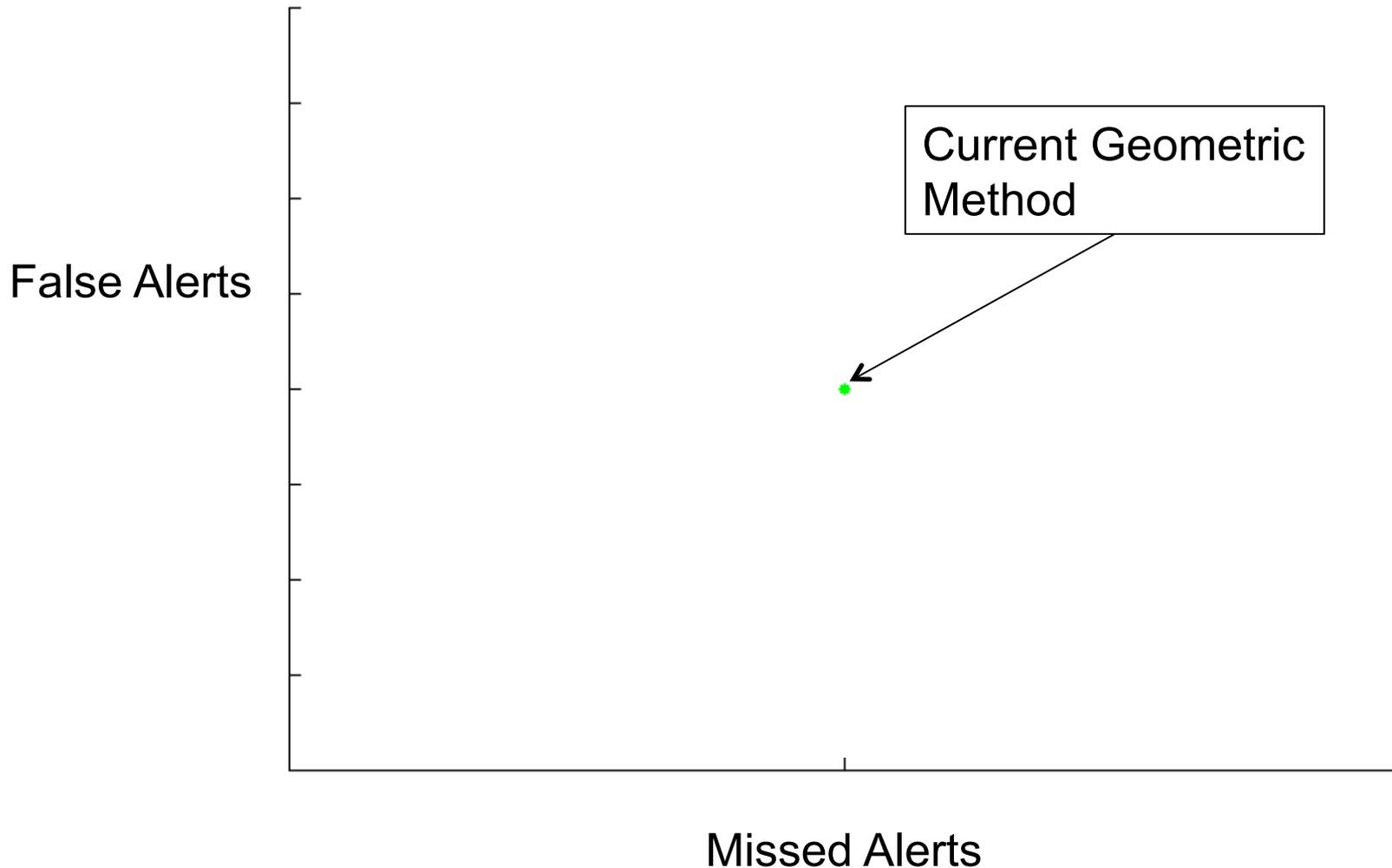


Trade-off with False Alerts

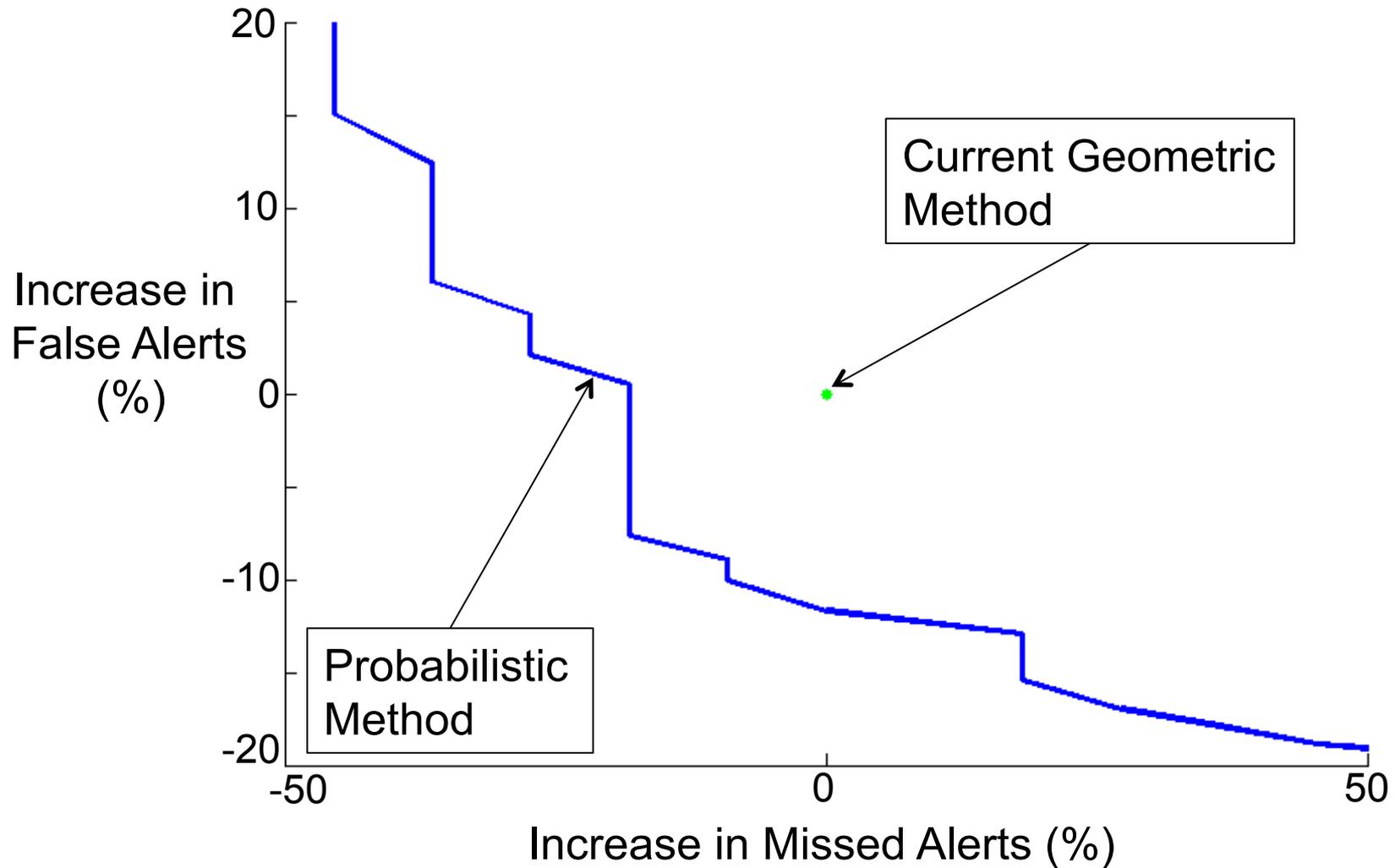


- Easy to have zero missed alerts if almost everything is declared a conflict
- This leads to a high number of false alerts

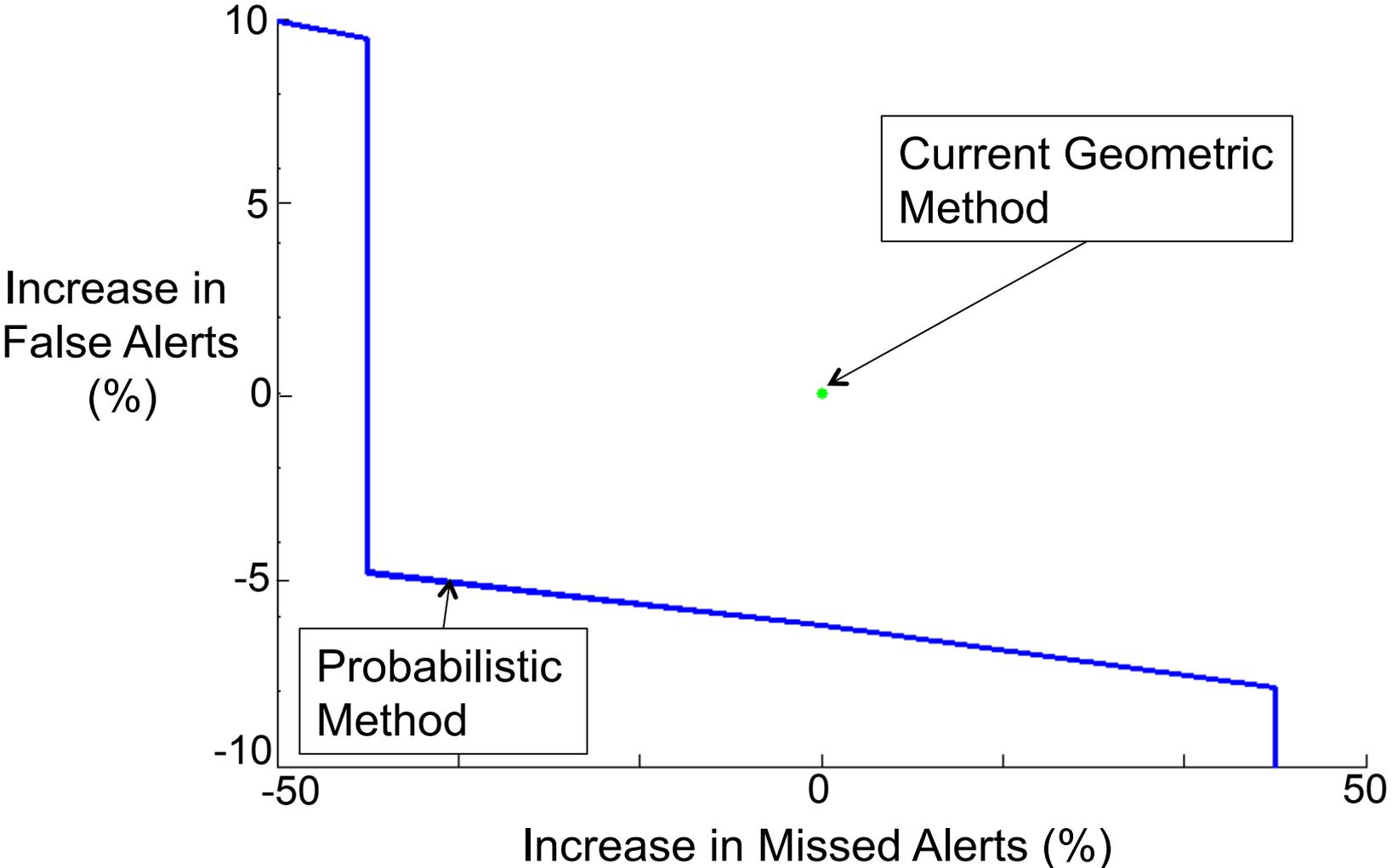
Large Error Comparison



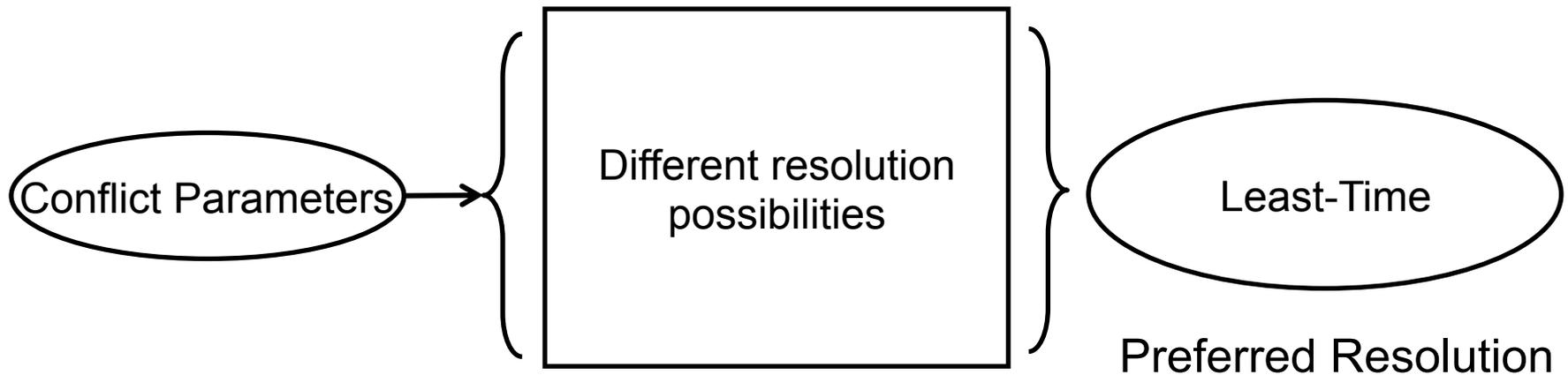
Large Error Comparison



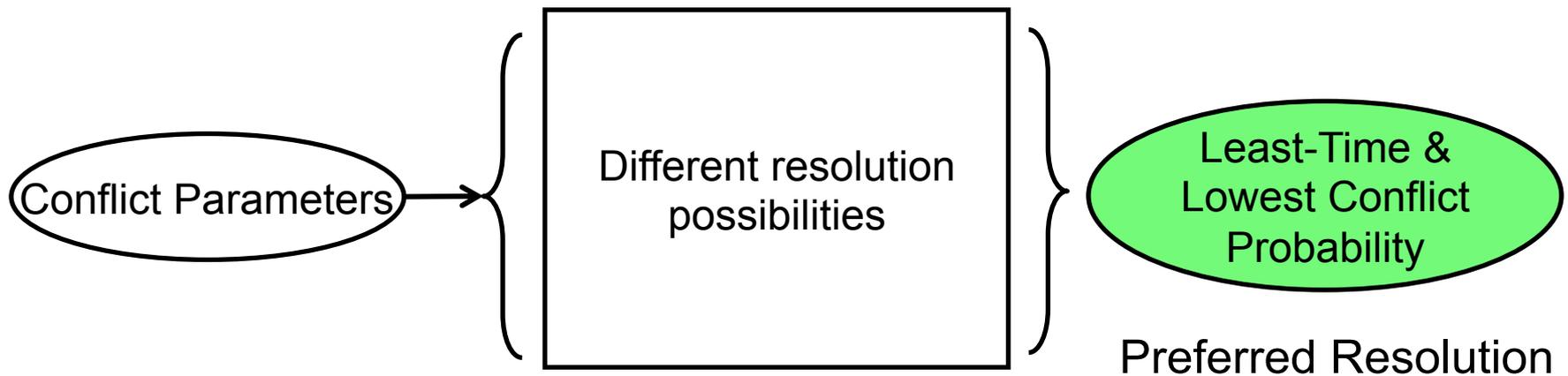
Small Error Comparison



Improving Resolution Robustness



Improving Resolution Robustness



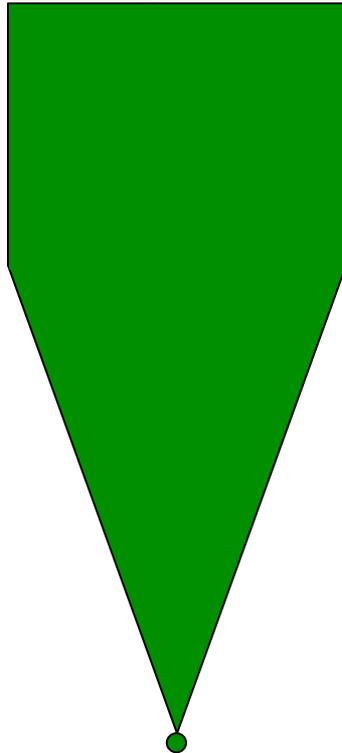
Use probability of conflict reoccurring for resolution choice

Automated Separation Assurance

- Have shown that automation works well under perfect conditions
- Currently being adapted as a tool for controllers
- Have made progress in improving the robustness to errors

A Large Optimization Problem

Efficient Modernized
Transportation



Robust Strategic
Enroute
Separation Assurance

Individual Research Topics

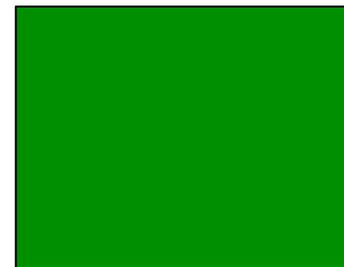


Dependencies

Research Areas



Dependencies



Efficient Modernized
Transportation

Questions

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