



Relative Significance of Trajectory Prediction Errors on an Automated Separation Assurance Algorithm

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Separation Assurance Automation

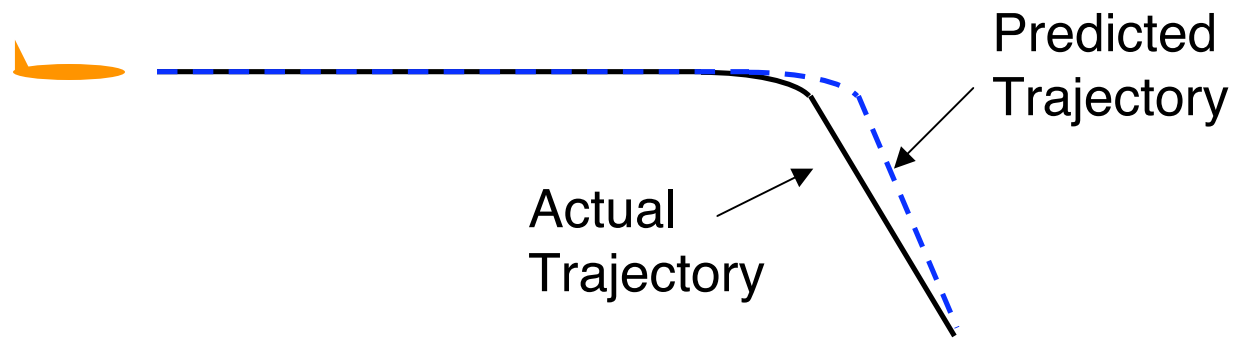
- Should detect all conflicts with sufficient time to resolve them
- Should not suggest resolutions which result in near-term losses of separation
- Should not resolve false conflicts

Separation Assurance Automation

- Should detect all conflicts with sufficient time to resolve them
- Should not suggest resolutions which result in near-term losses of separation
- Should not resolve false conflicts

If we could perfectly predict the future positions of all aircraft this would be fairly easy

Prediction Errors



- Any trajectory prediction will have some error
- Different error sources impact trajectories in different ways

Impact of Errors

- Error Correlation
 - Wind errors affect all aircraft in a certain area
 - Cruise speed errors are independent of each other
- Type of impact
 - Cruise speed errors result in along-track errors
 - Descent profile errors result in altitude errors

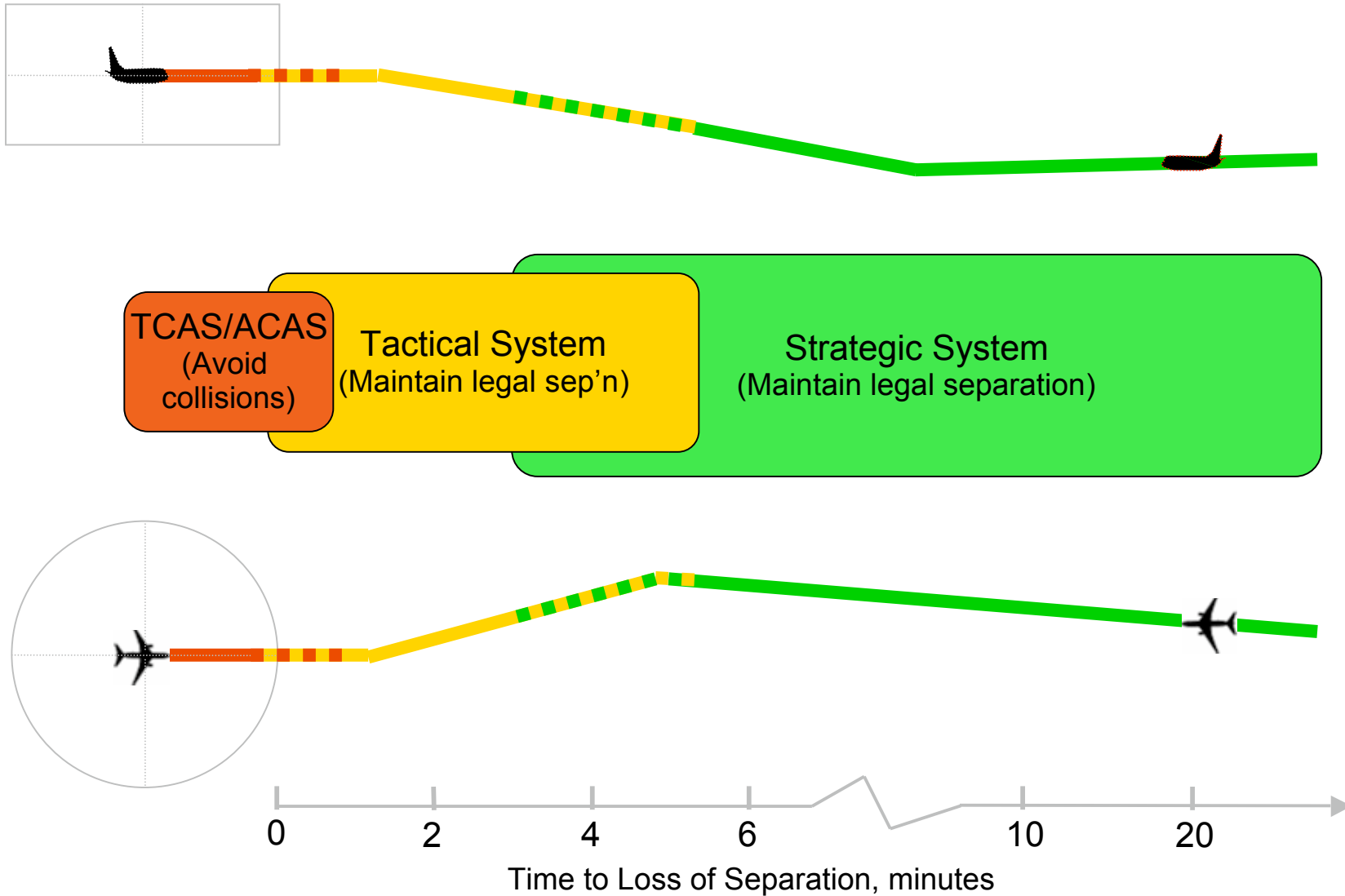
Outline

- Automated separation assurance
- Simulation environment
- Error sources studied
- Conflict detection results
- Conflict resolution results

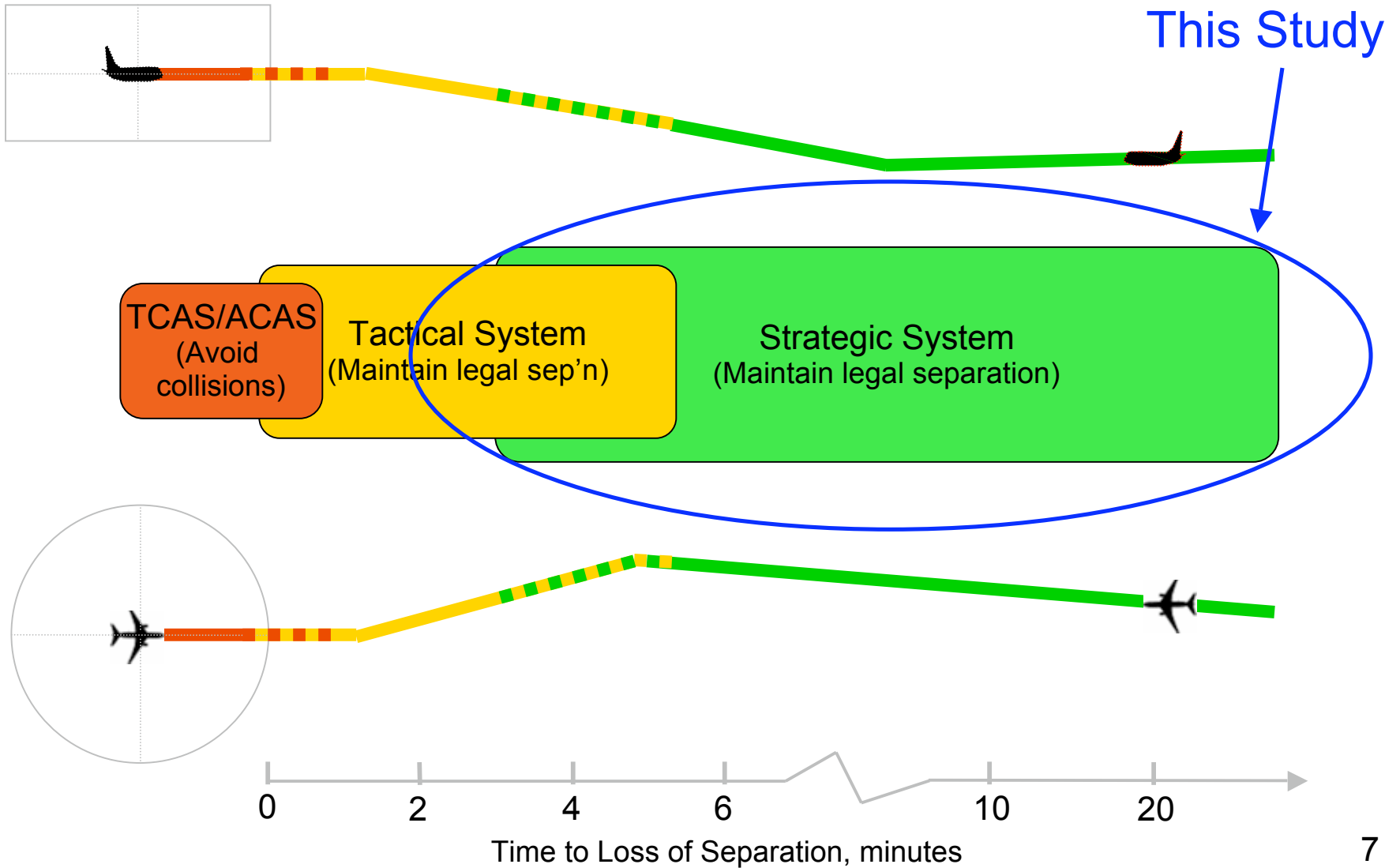
Automation Objectives

- To be robust to trajectory prediction errors
- To be as efficient as possible given a certain amount of prediction error

Layered Approach



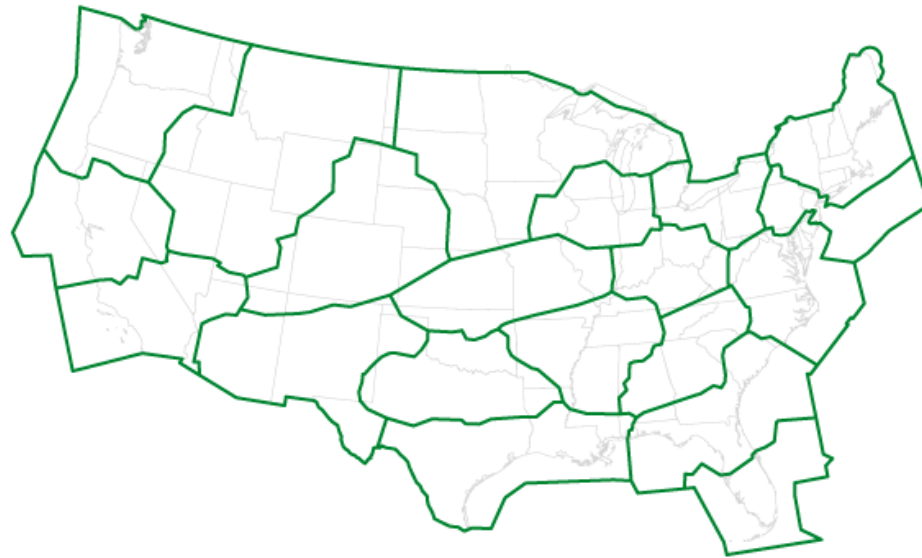
Layered Approach



Study Objectives

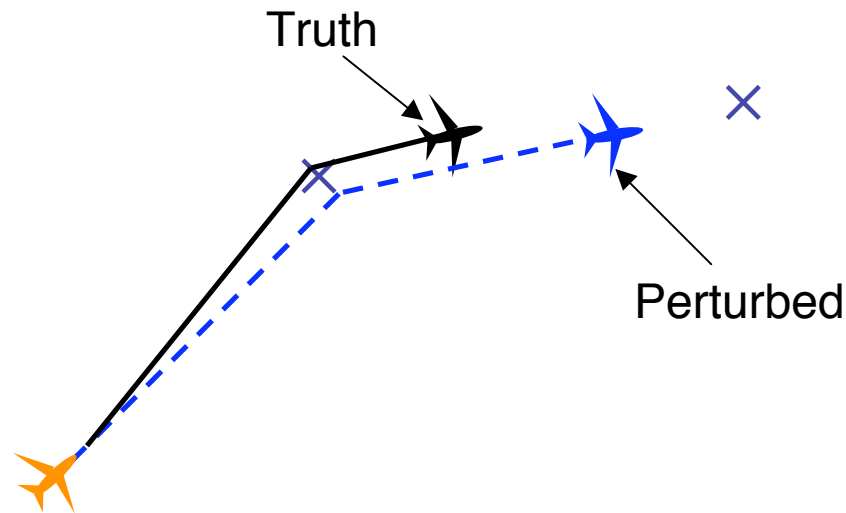
- Understand how different sources of trajectory prediction errors affect conflict detection and resolution
- Compare the relative effects across error sources
- Highlight algorithmic improvements to mitigate these errors

Airspace Simulation



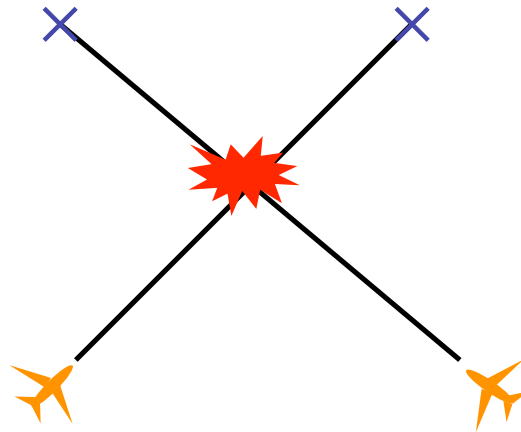
- Airspace Concept Evaluation System (ACES)
- United States airspace fast-time, gate-to-gate simulation
- 4D trajectory from departure fix to arrival fix

Key Simulation Feature



Every time conflict detection is performed, both a truth and a perturbed prediction are created

Separation Assurance Algorithm



- Advanced Airspace Concept (AAC) Autoresolver
- A strategic separation assurance and problem-solving tool
- Many recent zero-prediction-error studies

Error Studies

- Perform two separate studies:
 - Detection study
 - Resolution study
- Use 3 hours of United States traffic with over 10,000 flights
- Study a single source of error at a time

Error Sources Studied

- Wind prediction
- Cruise speed prediction
- Weight
- Top of descent
- Descent speed
- Resolution maneuver initiation time

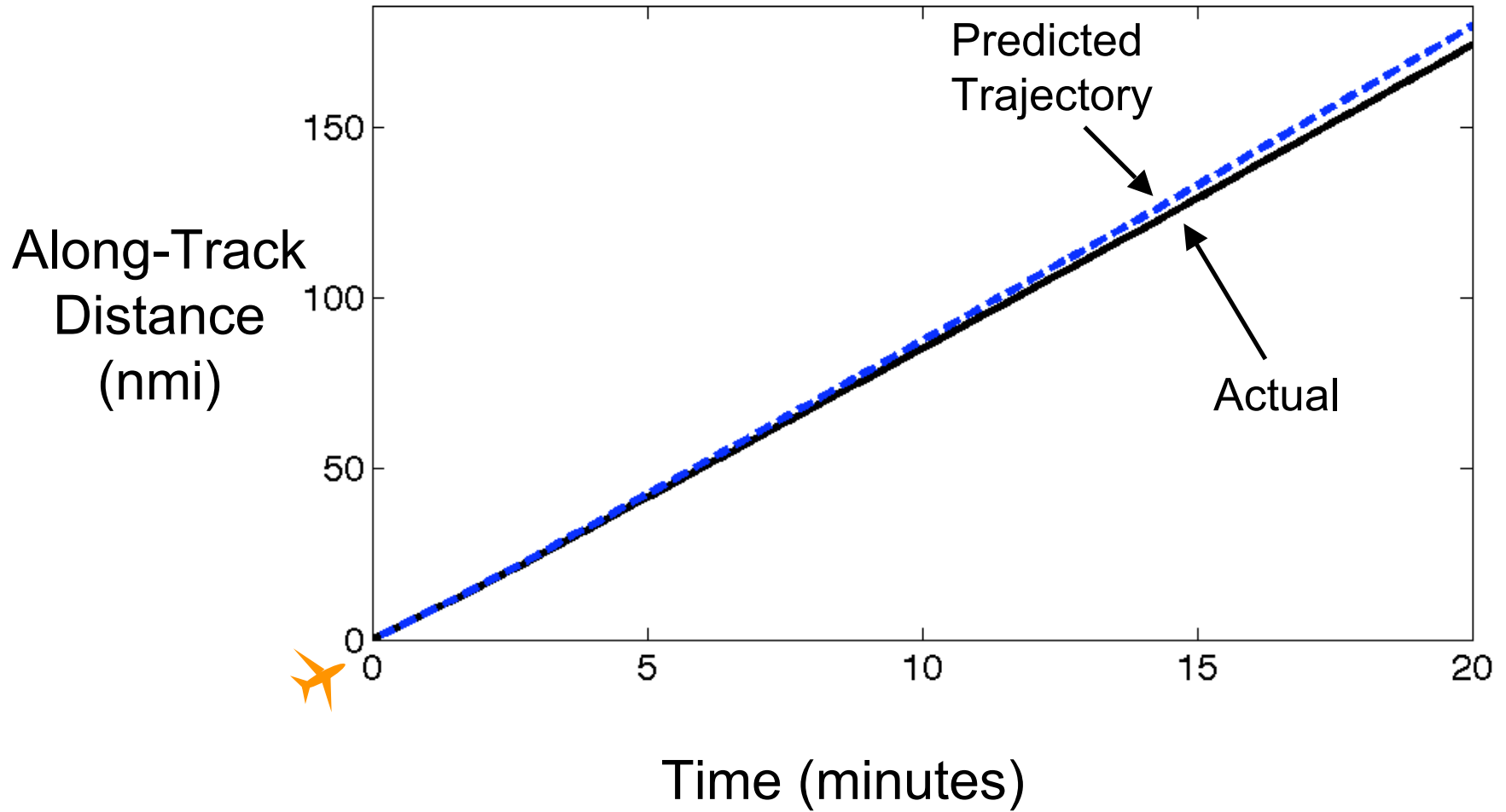
Error Amounts

Error Type:	Applied:	Values:
Wind	Simulation-Wide	-10%,10%, 25%
Cruise Speed	Per Aircraft	±2%, ±5%
Weight	Per Aircraft	±10%, ±20%
Maneuver Timing	Per Maneuver	±20 sec, ±40 sec
Top of Descent	Per Aircraft	±5 nmi, ±10 nmi
Descent Speed	Per Aircraft	±5%, ±10%

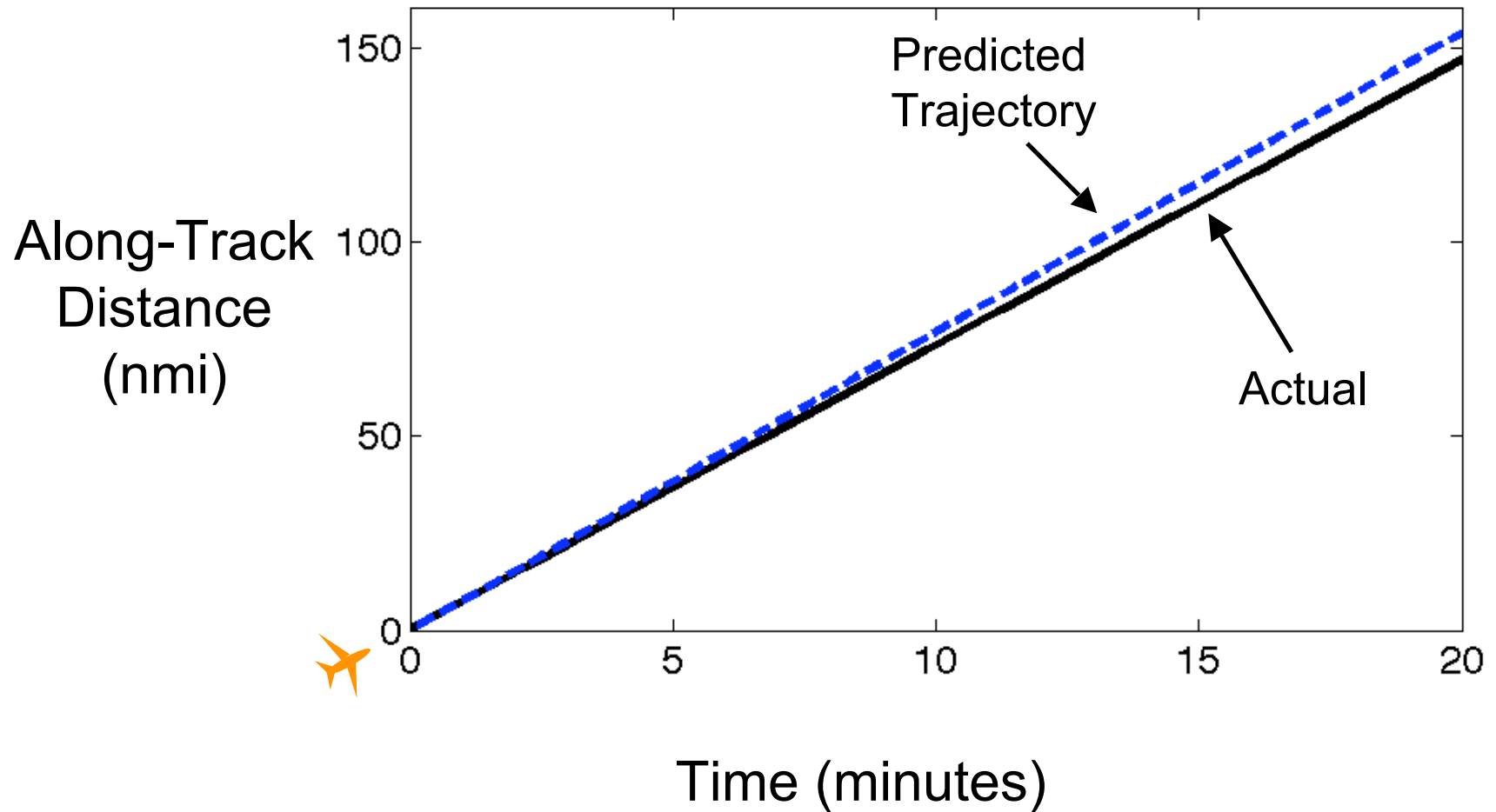
Generally slightly larger than values found in previous studies

Trajectory Error Examples

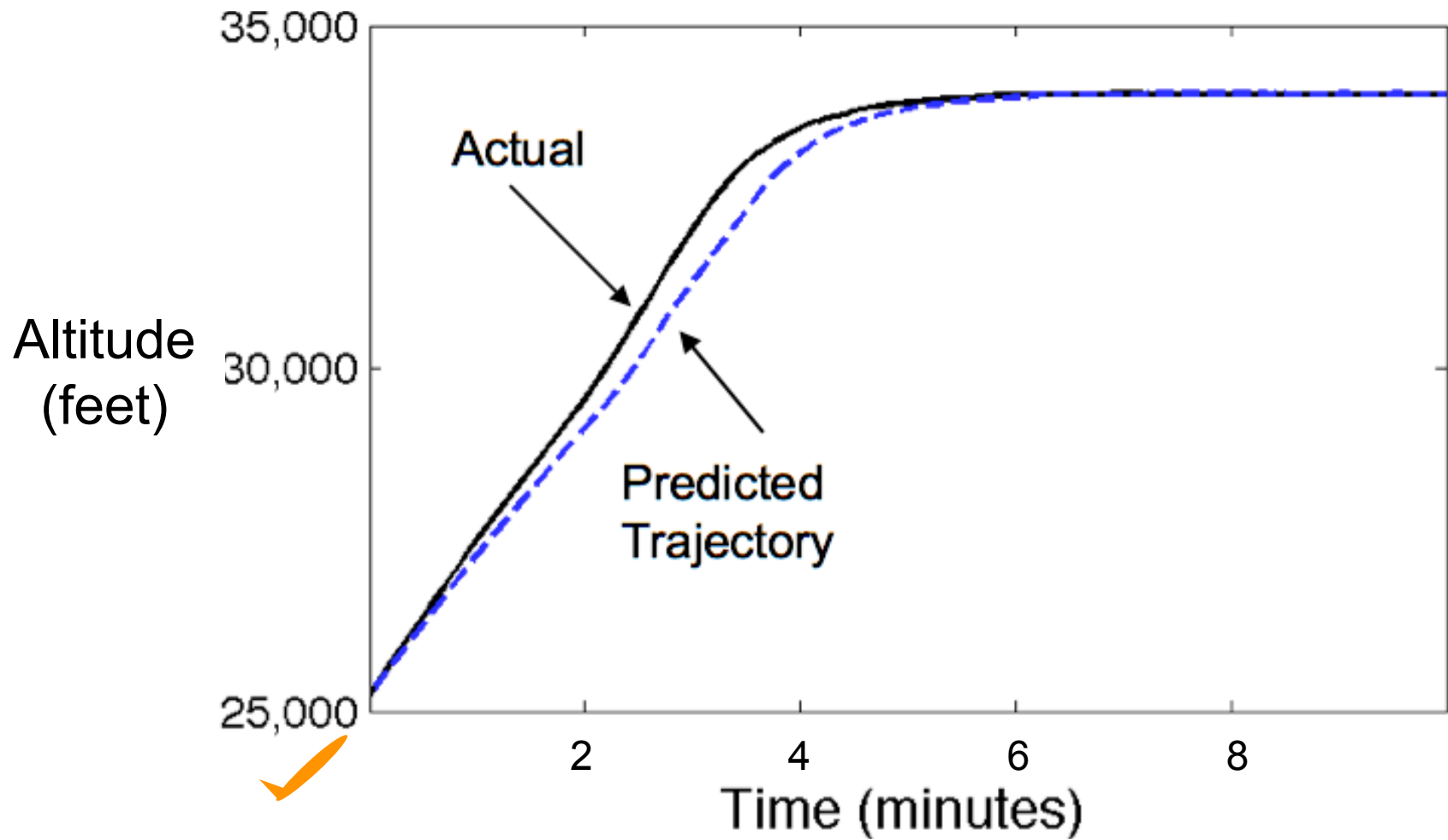
Wind Errors



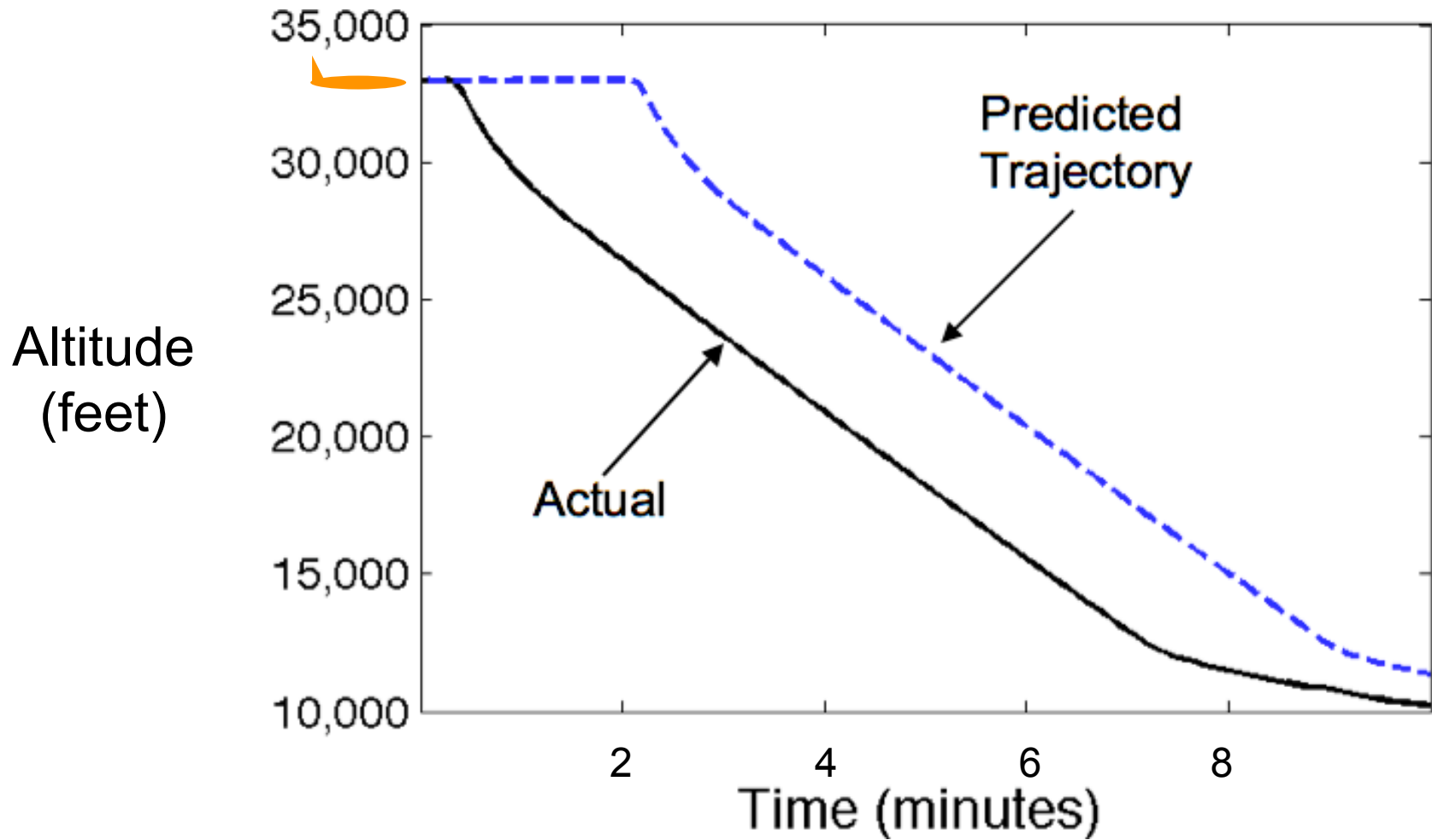
Cruise-Speed Errors



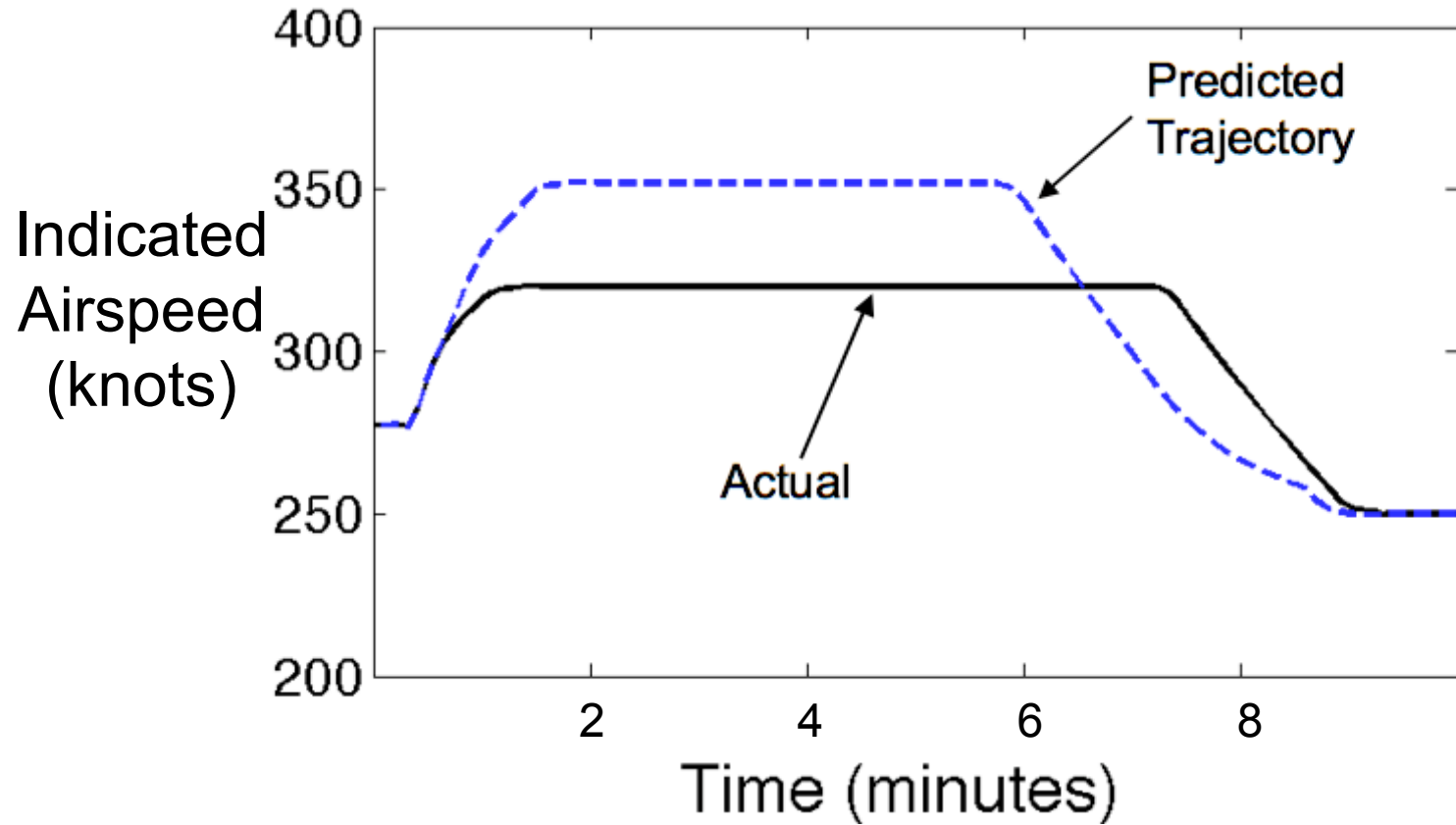
Weight Errors



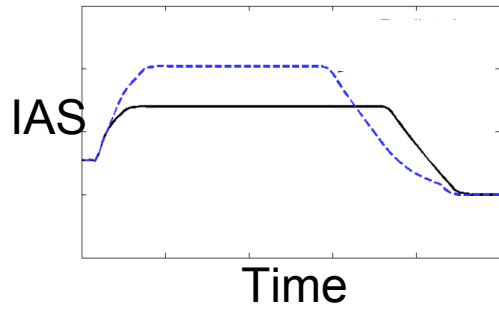
Top-of-Descent Errors



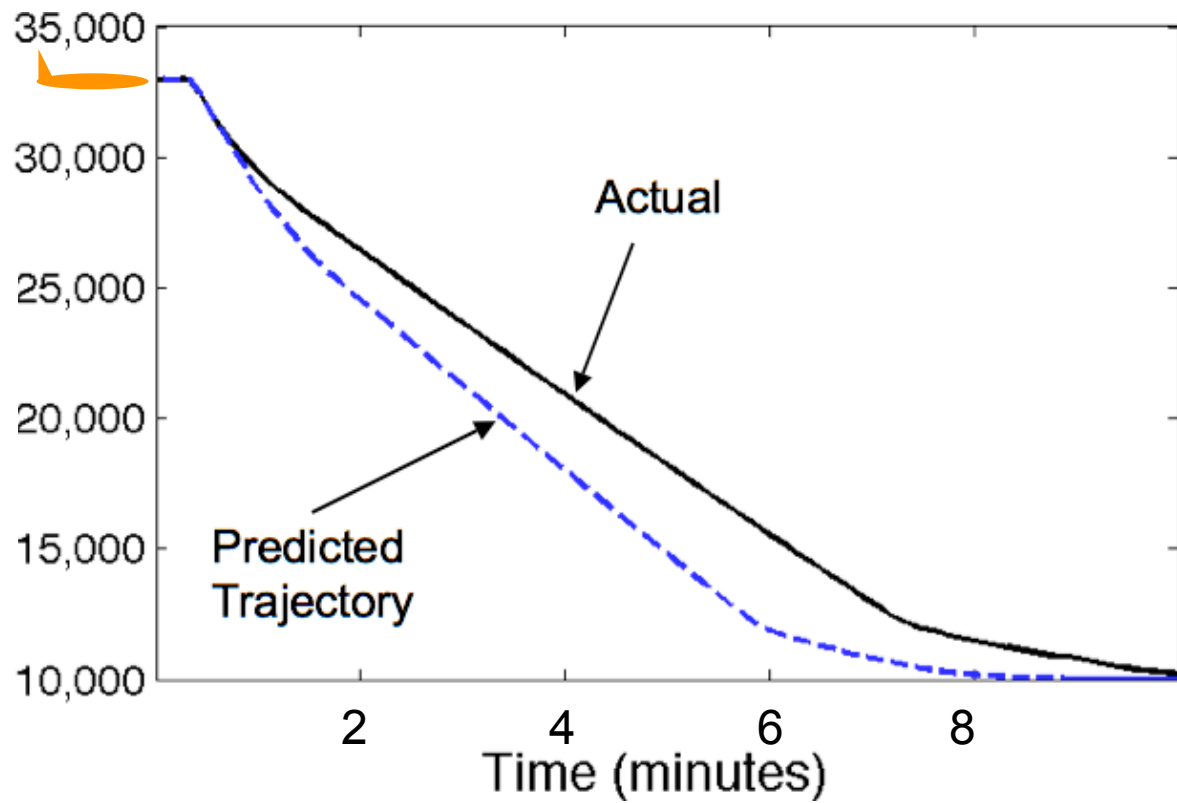
Descent-Speed Errors



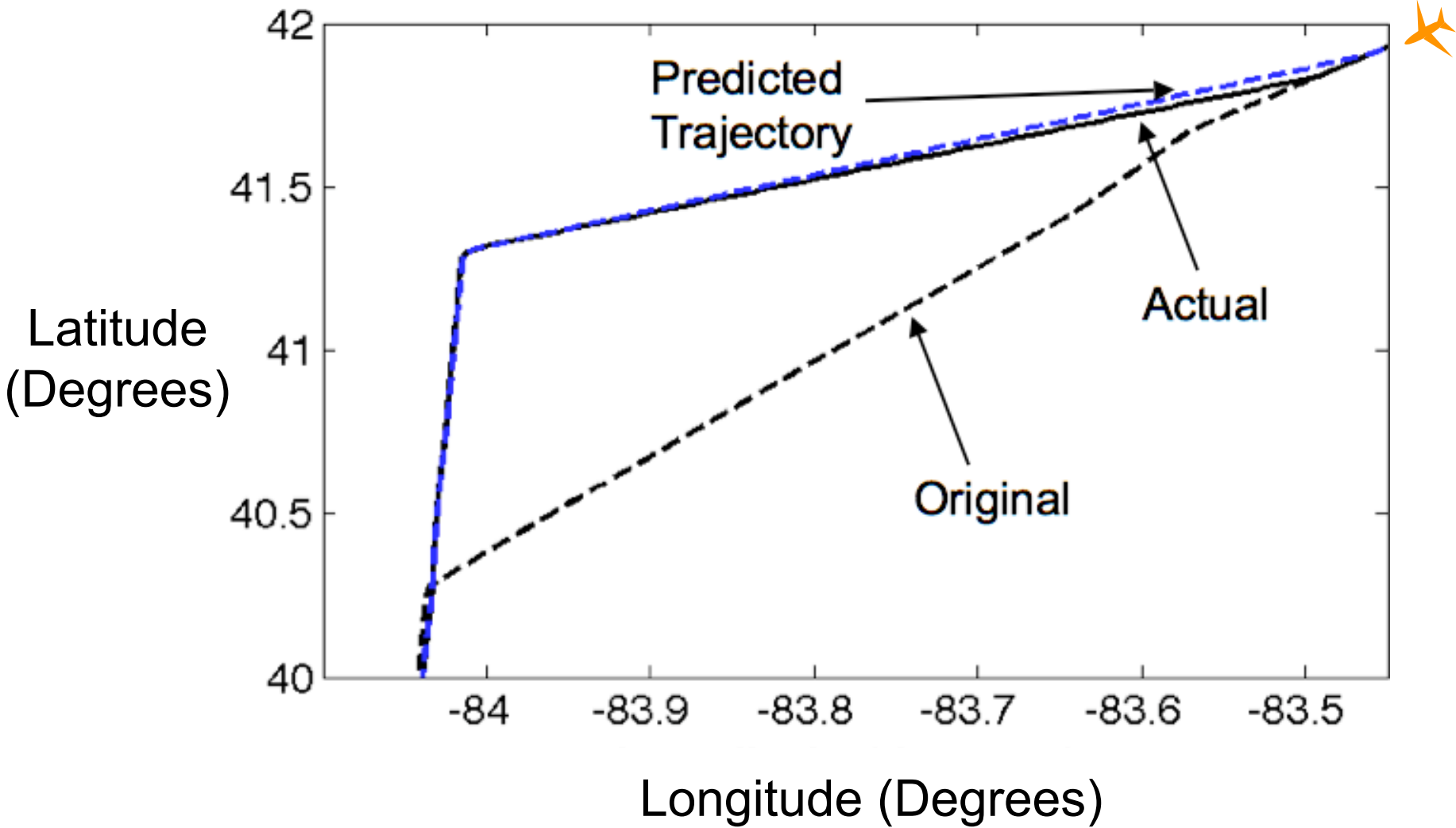
Descent-Speed Errors



Altitude
(feet)

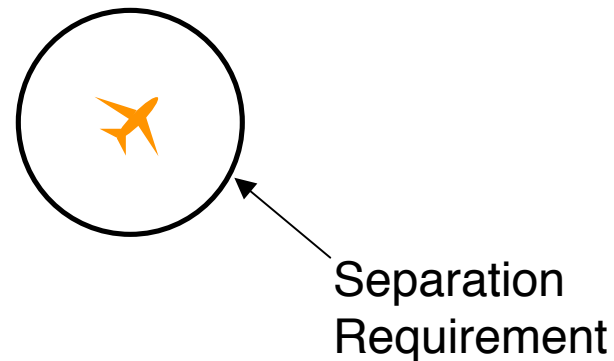


Resolution-Maneuver-Initiation-Time Errors



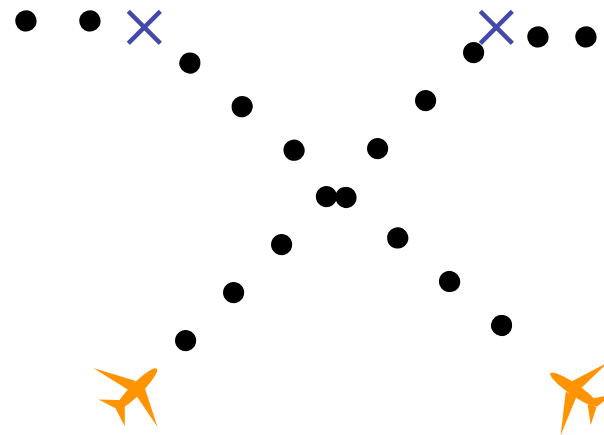
Detection Study

Detection Study



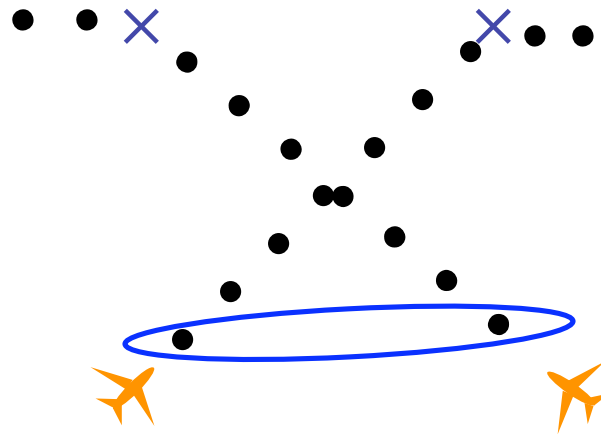
- Ran simulation with no resolutions performed
- Performed deterministic conflict detection
- Over 1800 losses of separation

Conflict Detection Algorithm



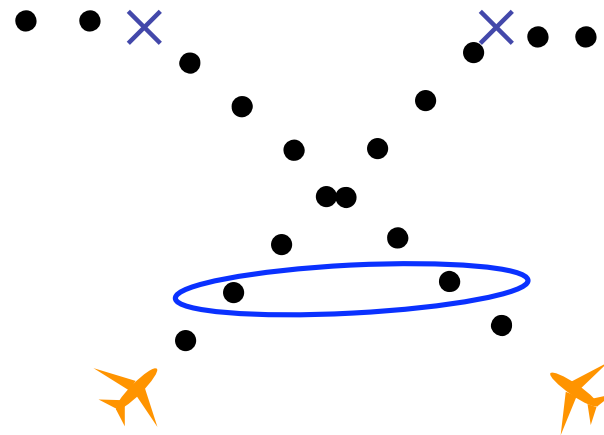
- Predicted trajectories are composed of discrete points

Conflict Detection Algorithm



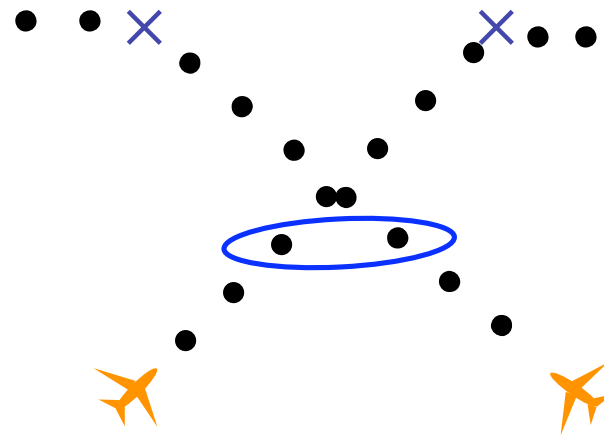
- Predicted trajectories are composed of discrete points
- Compare points of all trajectories for violations

Conflict Detection Algorithm



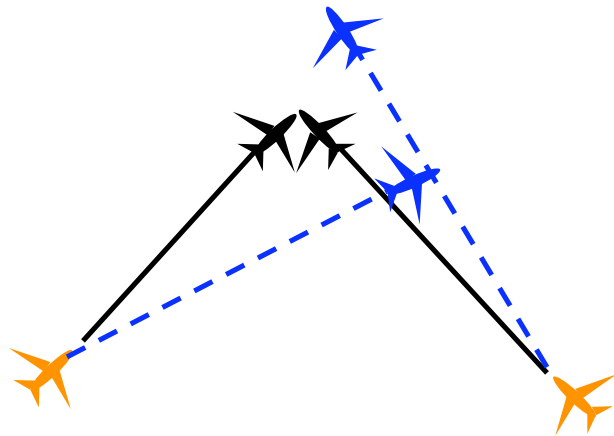
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Conflict Detection Algorithm

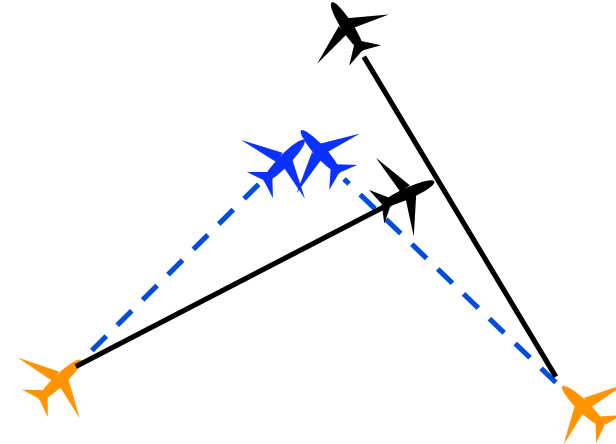


- Predicted trajectories are composed of discrete points
- Compare points of all trajectories for violations

Missed and False Alerts



Missed Alert

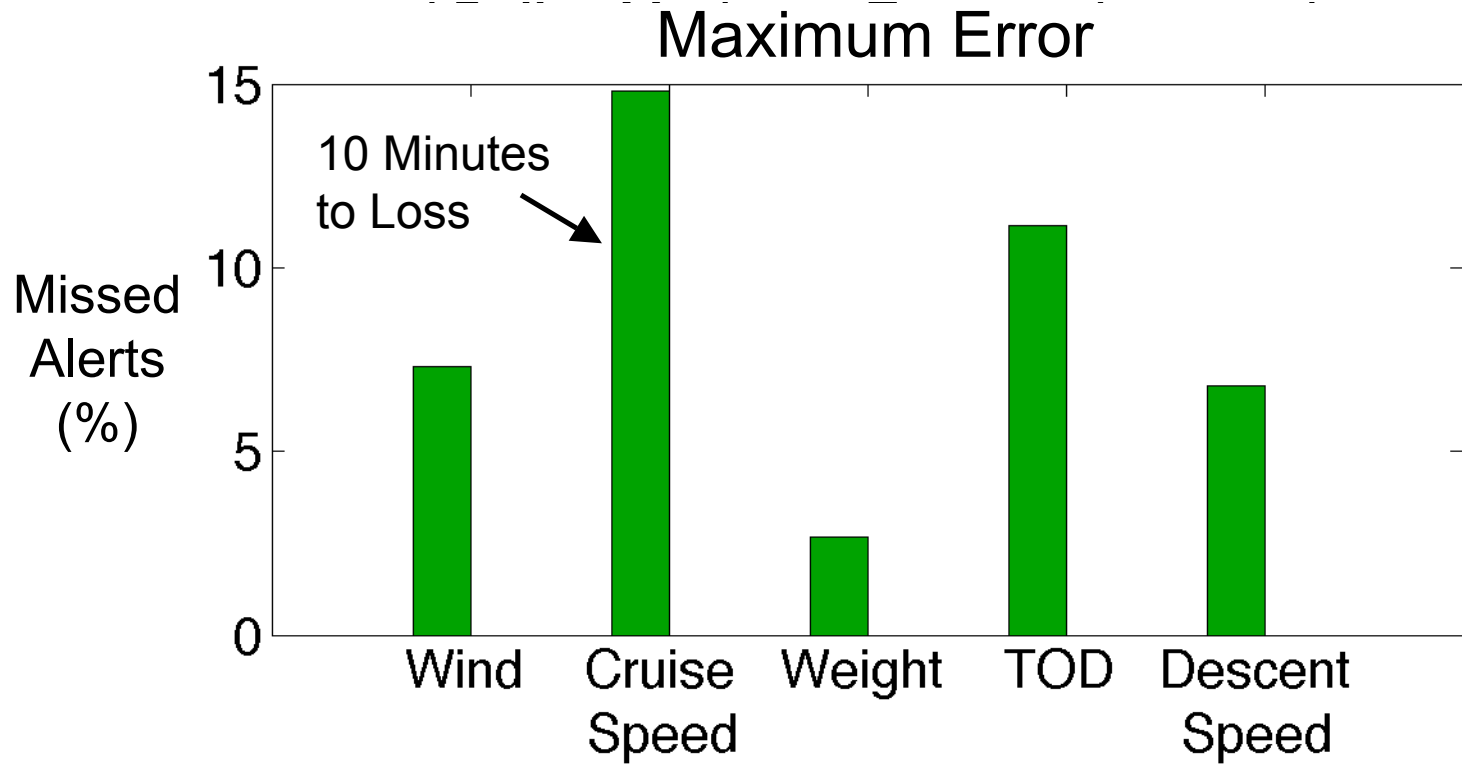


False Alert

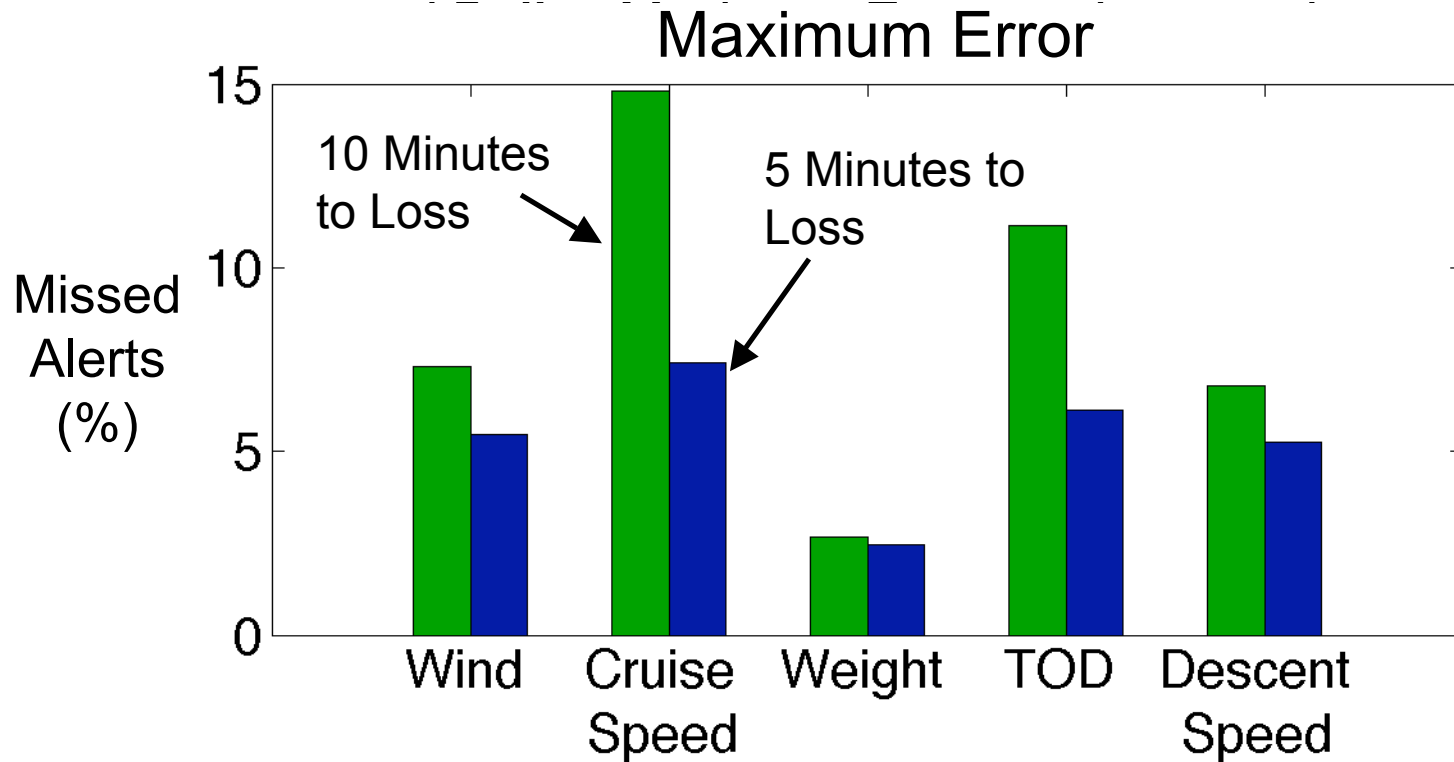
- Missed alert: Perfect trajectories include a loss and perturbed trajectories do not
- False alert: Perfect trajectories do not have a loss and perturbed trajectories do

Detection Results

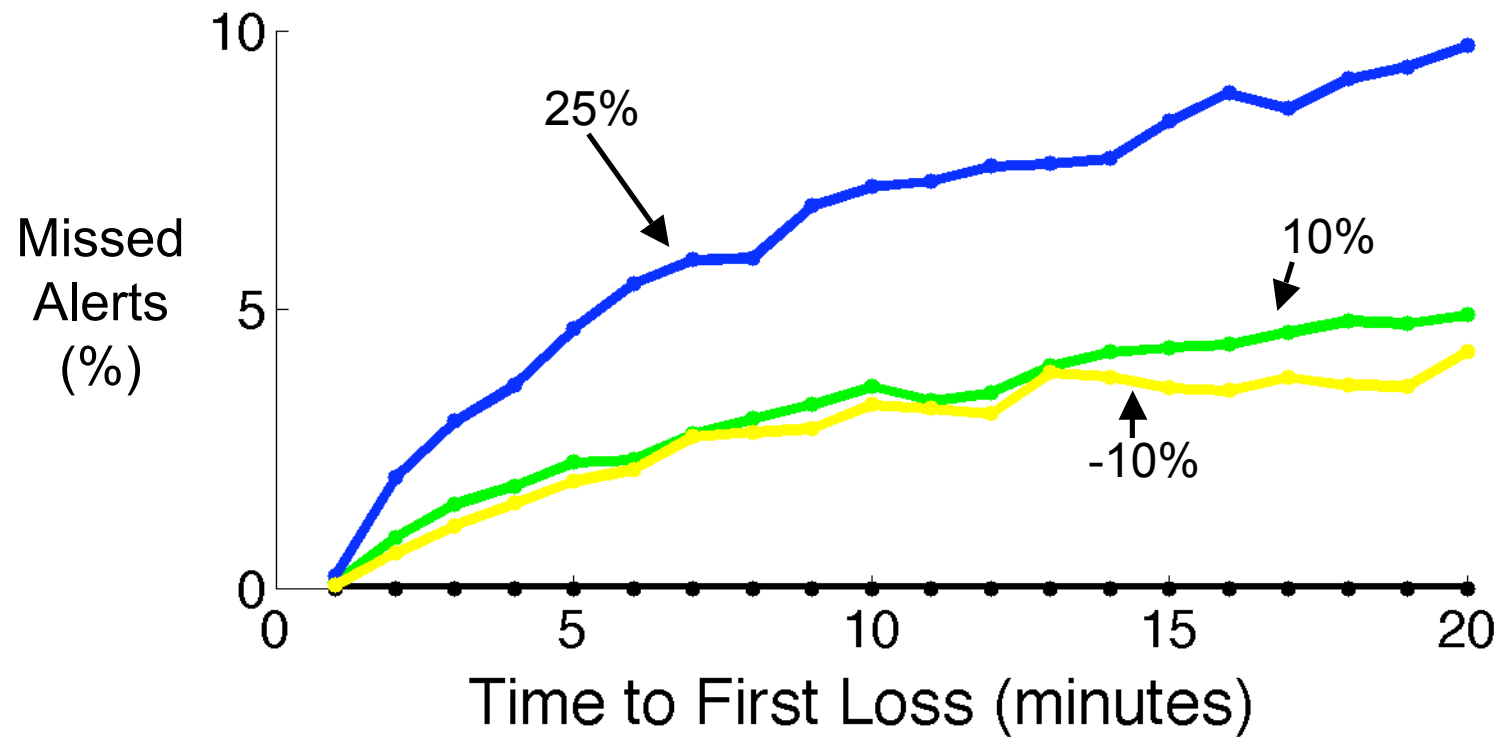
Missed Alerts



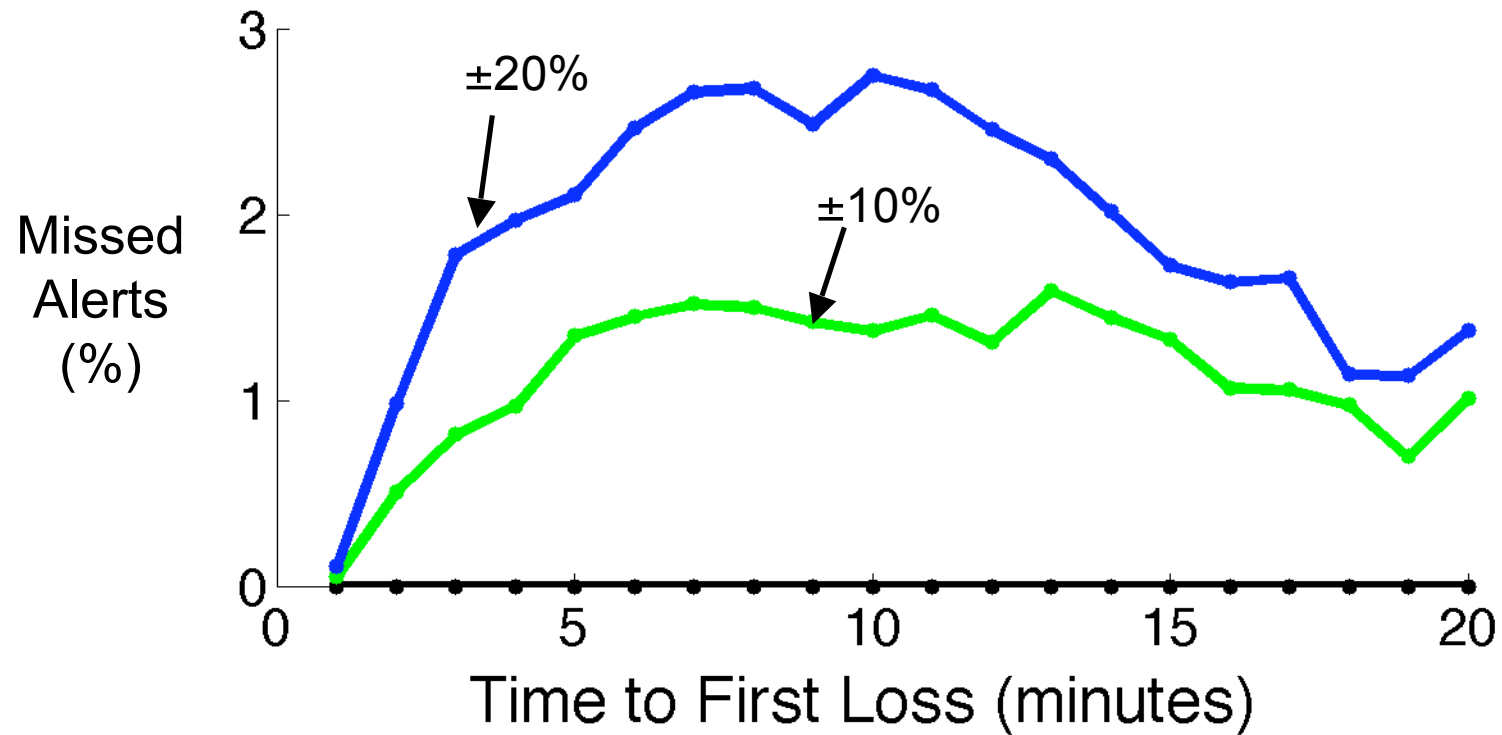
Missed Alerts



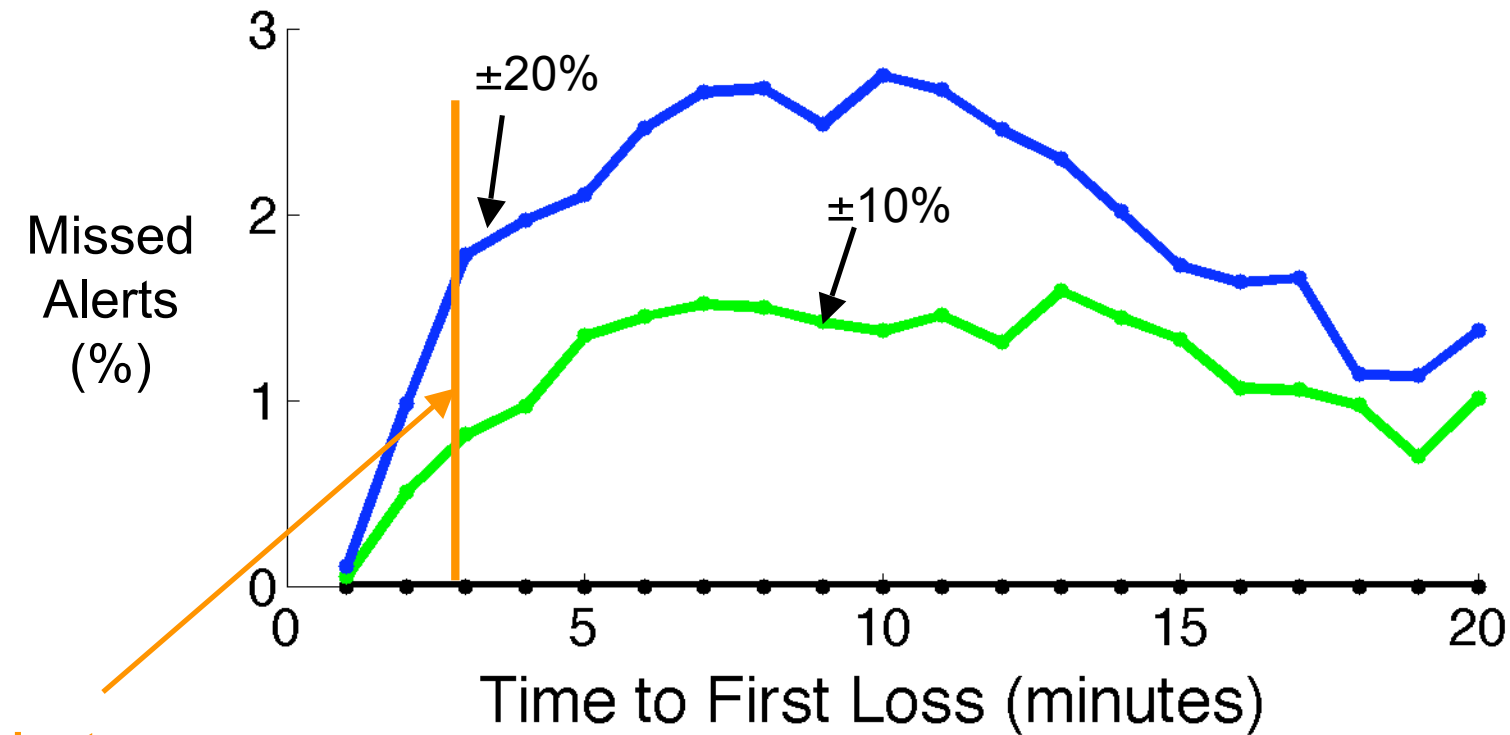
Wind Errors



Weight Error

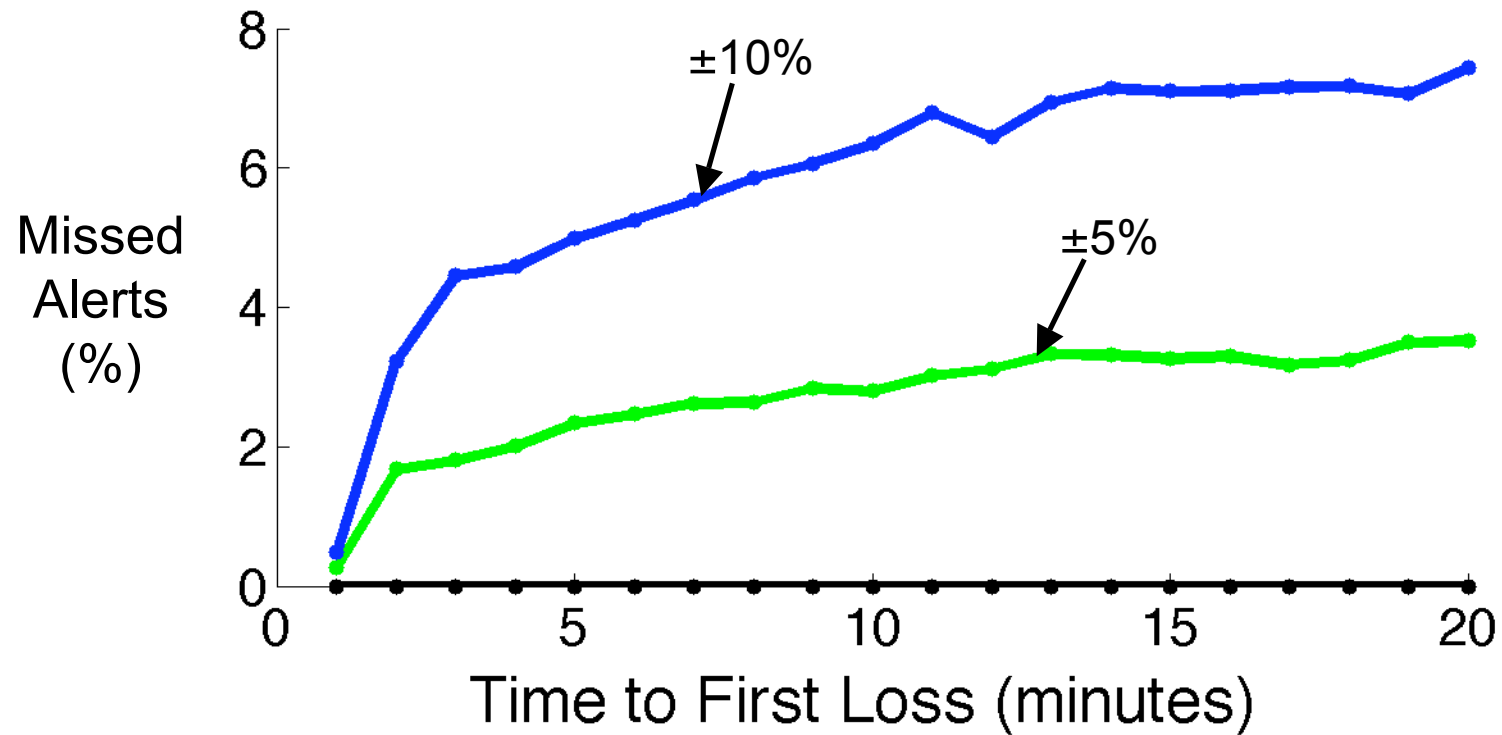


Weight Error

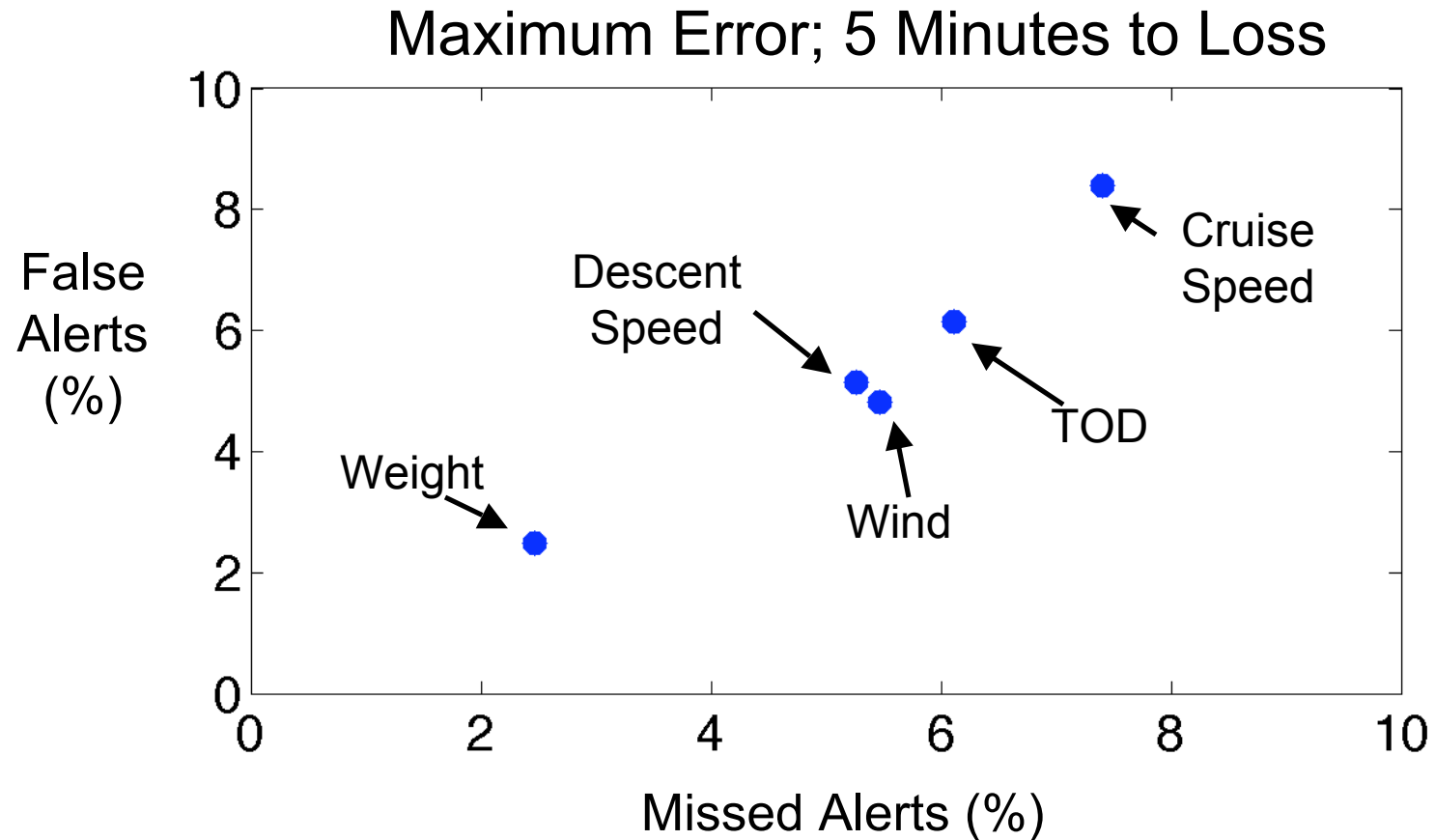


Late
Inflection

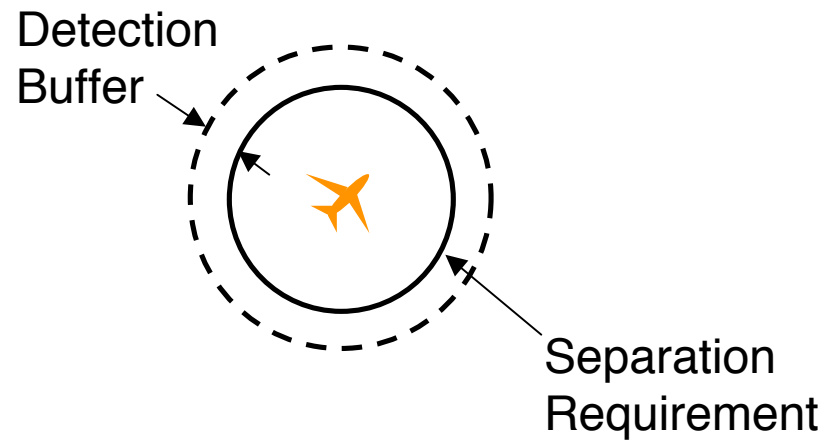
Descent-Speed Errors



Missed Alerts and False Alerts

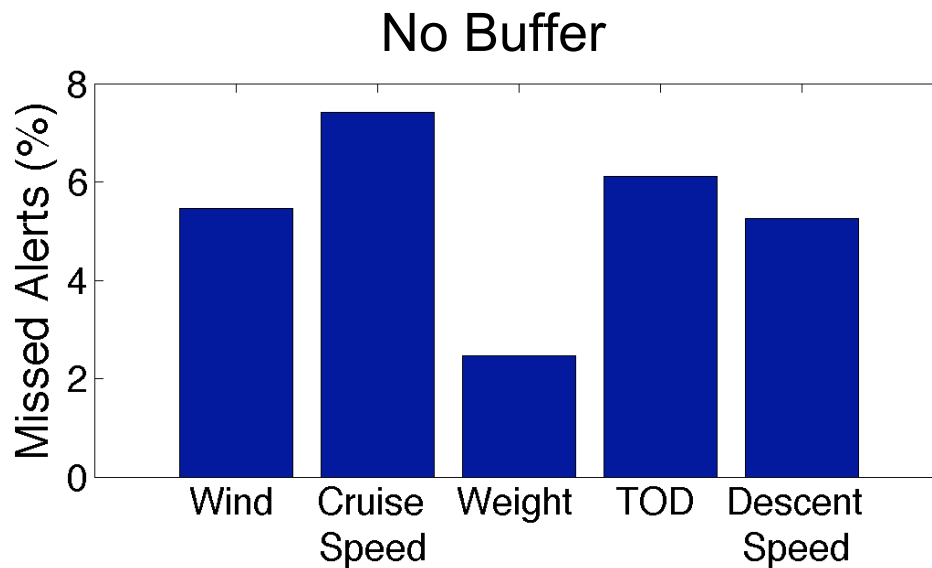


Missed Alert Reduction Strategy



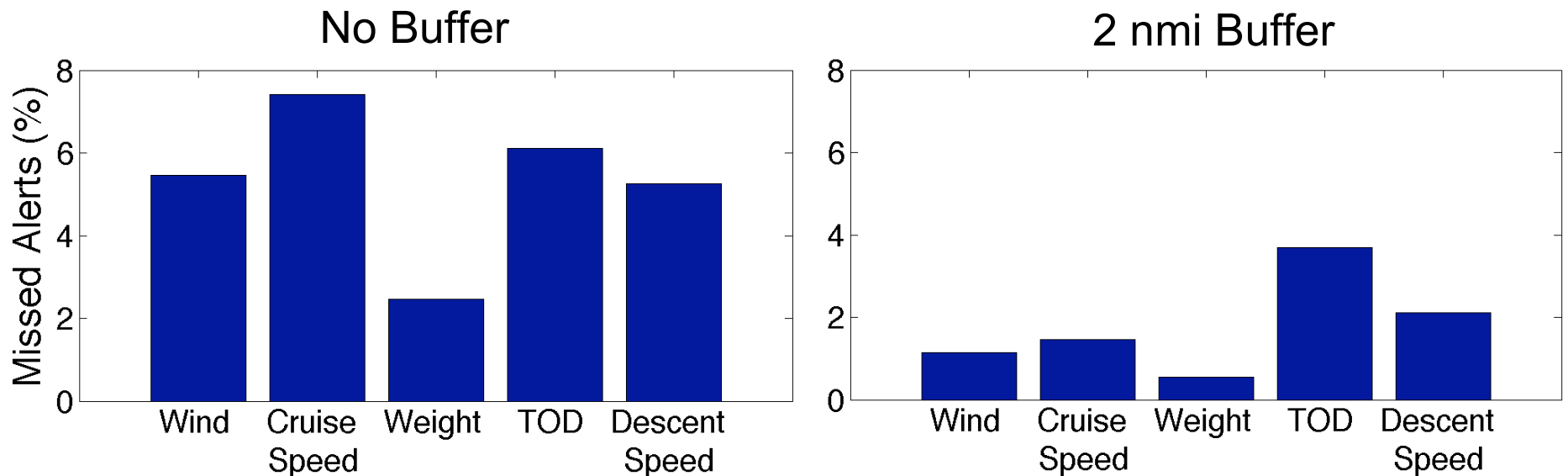
- Same no-resolution simulations
- Increased horizontal detection area

Missed Alerts and Buffer



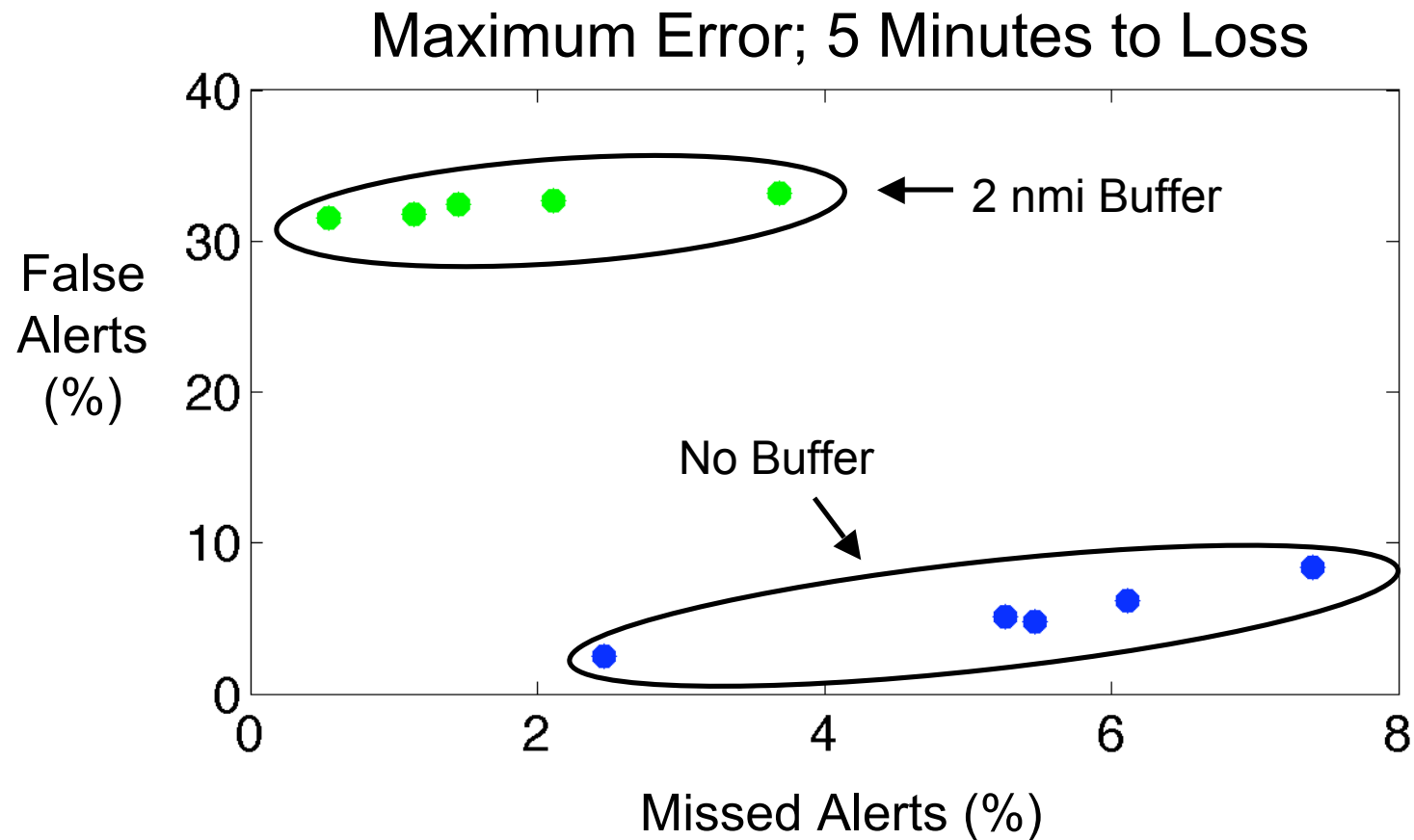
- With no buffer cruise-speed errors result in most missed

Missed Alerts and Buffer



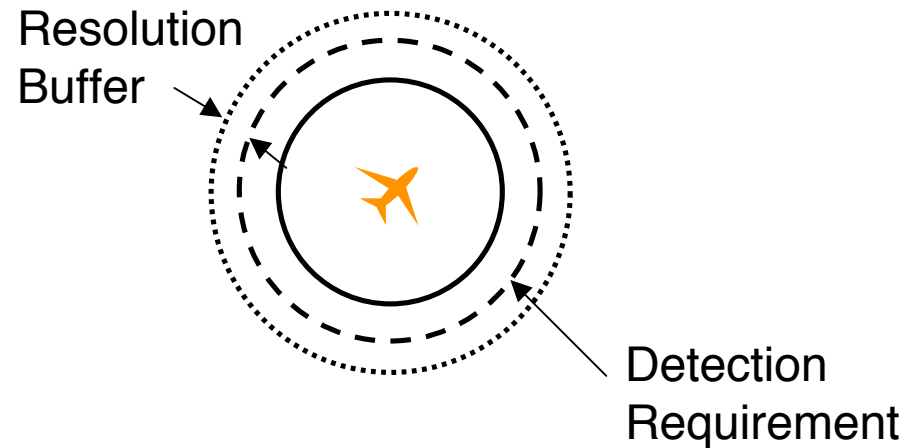
- With no buffer cruise-speed errors result in most missed
- With buffer TOD and descent-speed errors result in the most missed

Missed Alerts and False Alerts



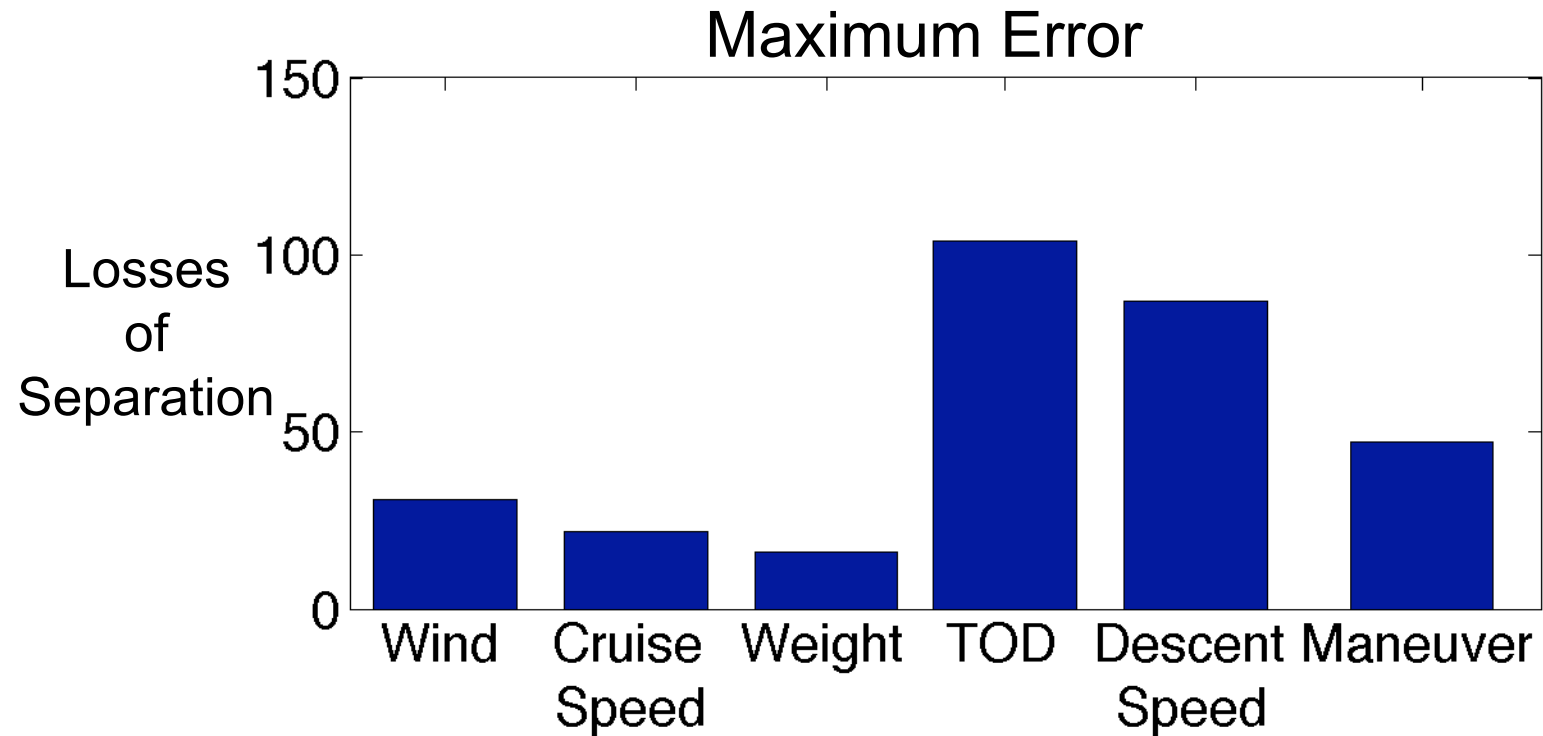
Resolution Study and Results

Resolution Study

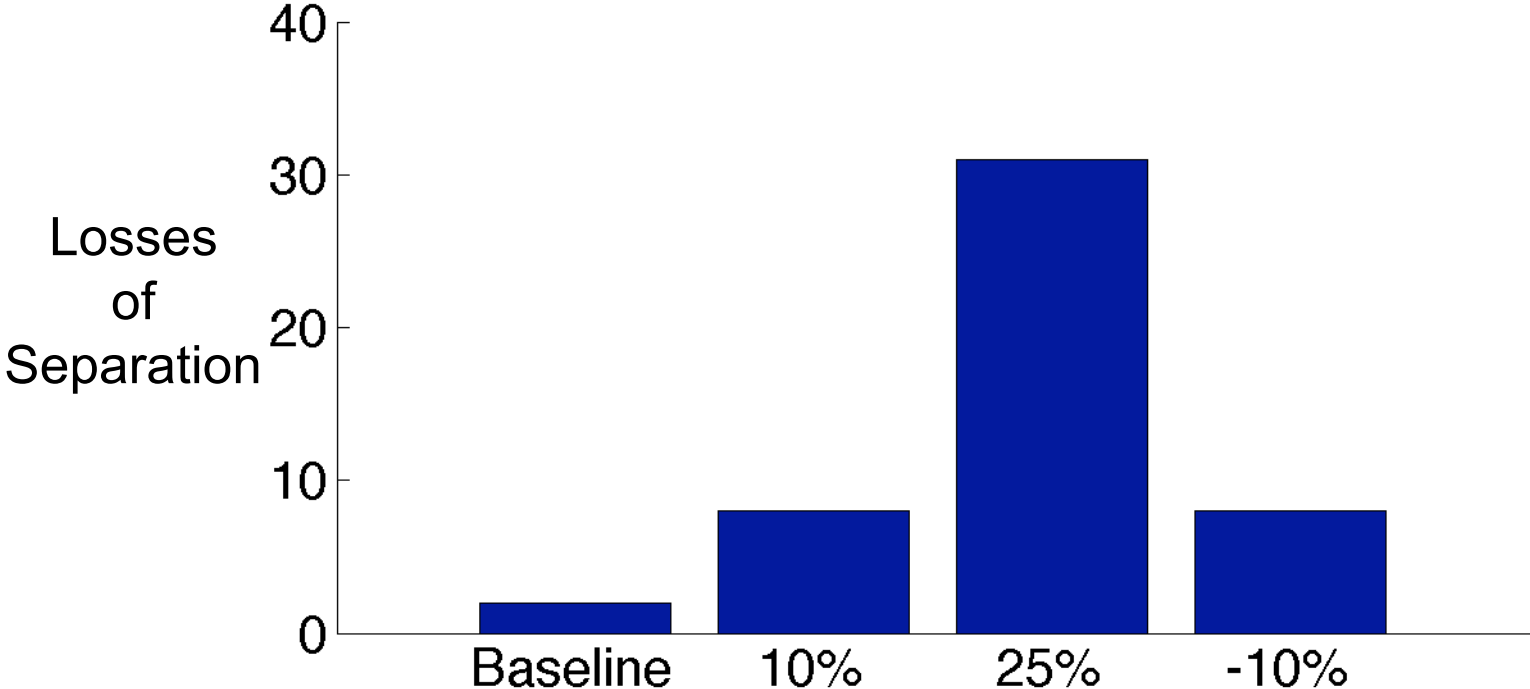


- 1 nmi detection buffer and 8-minute look-ahead
- 12-minute look-ahead for successful resolutions
- Over 4000 conflicts resolved
- No metering

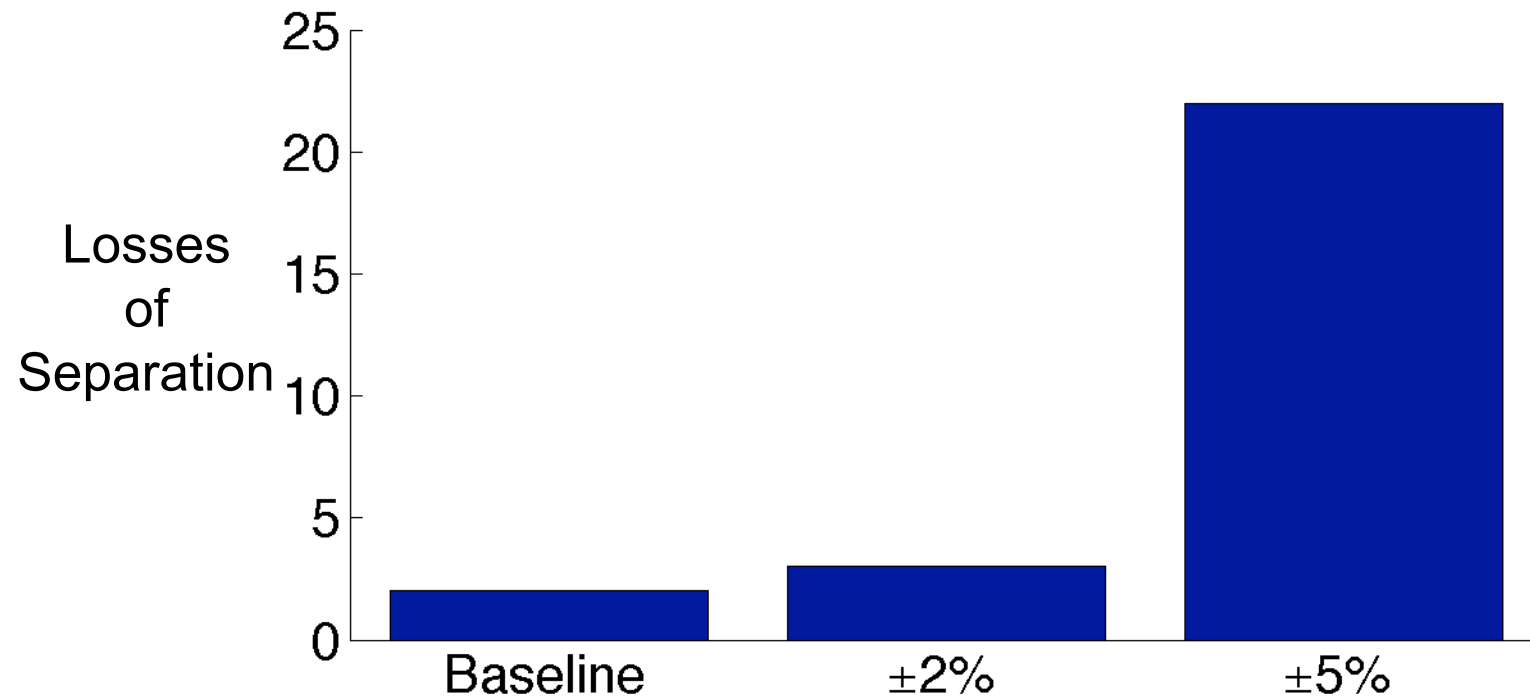
Losses of Separation



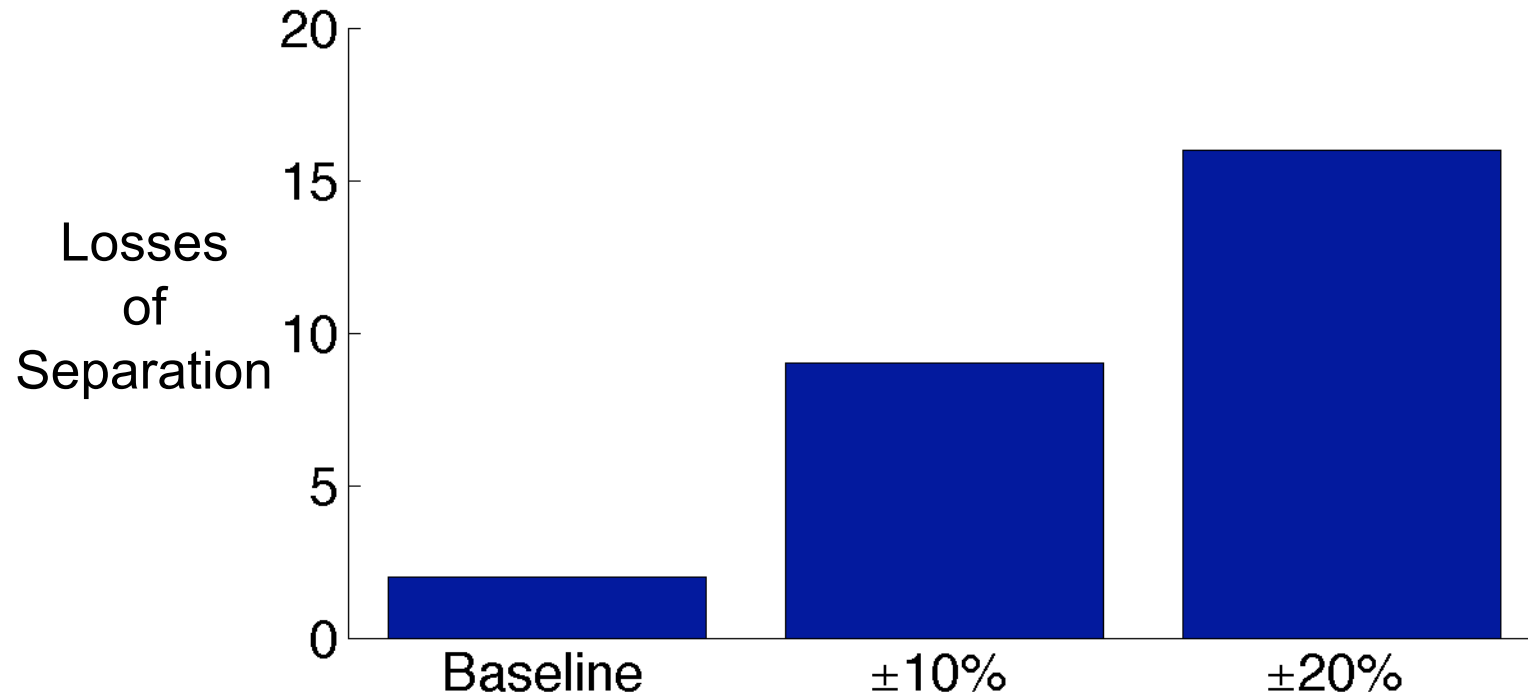
Wind Errors



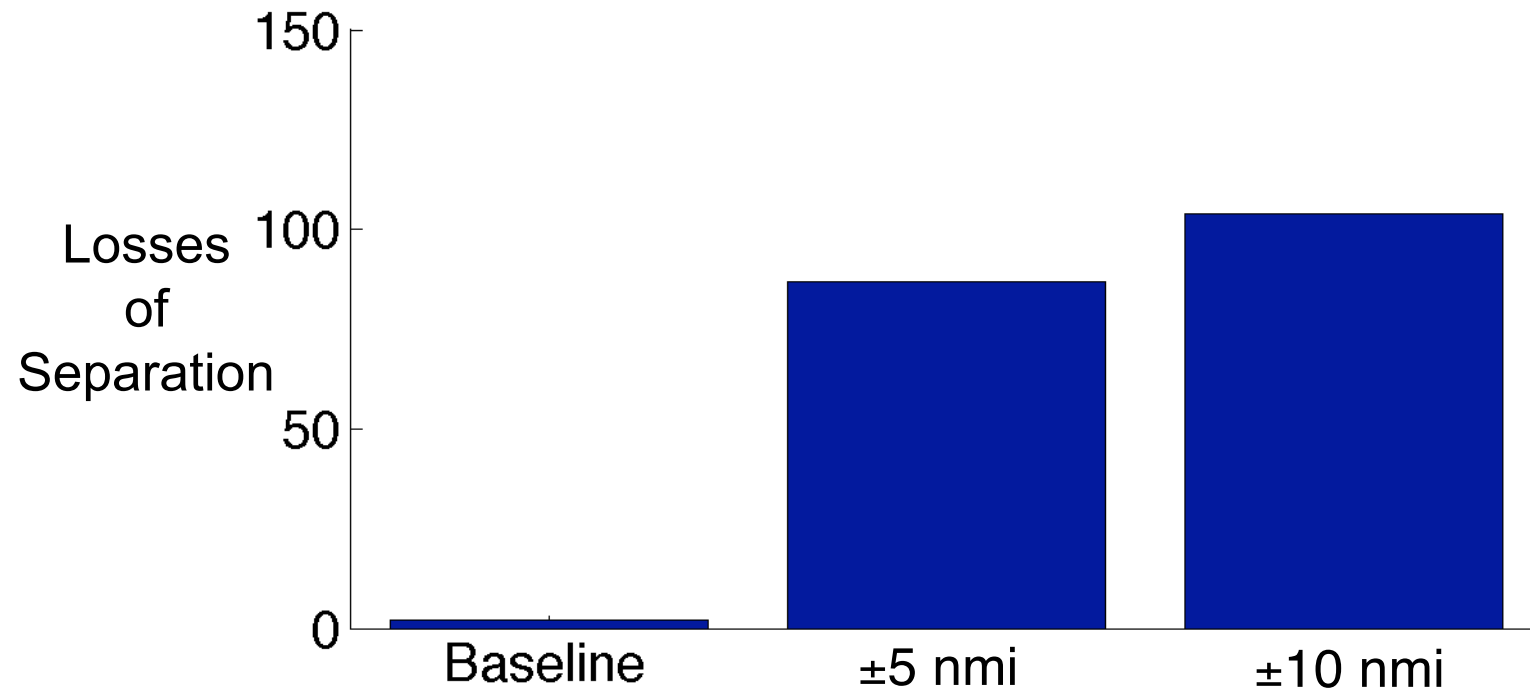
Cruise-Speed Errors



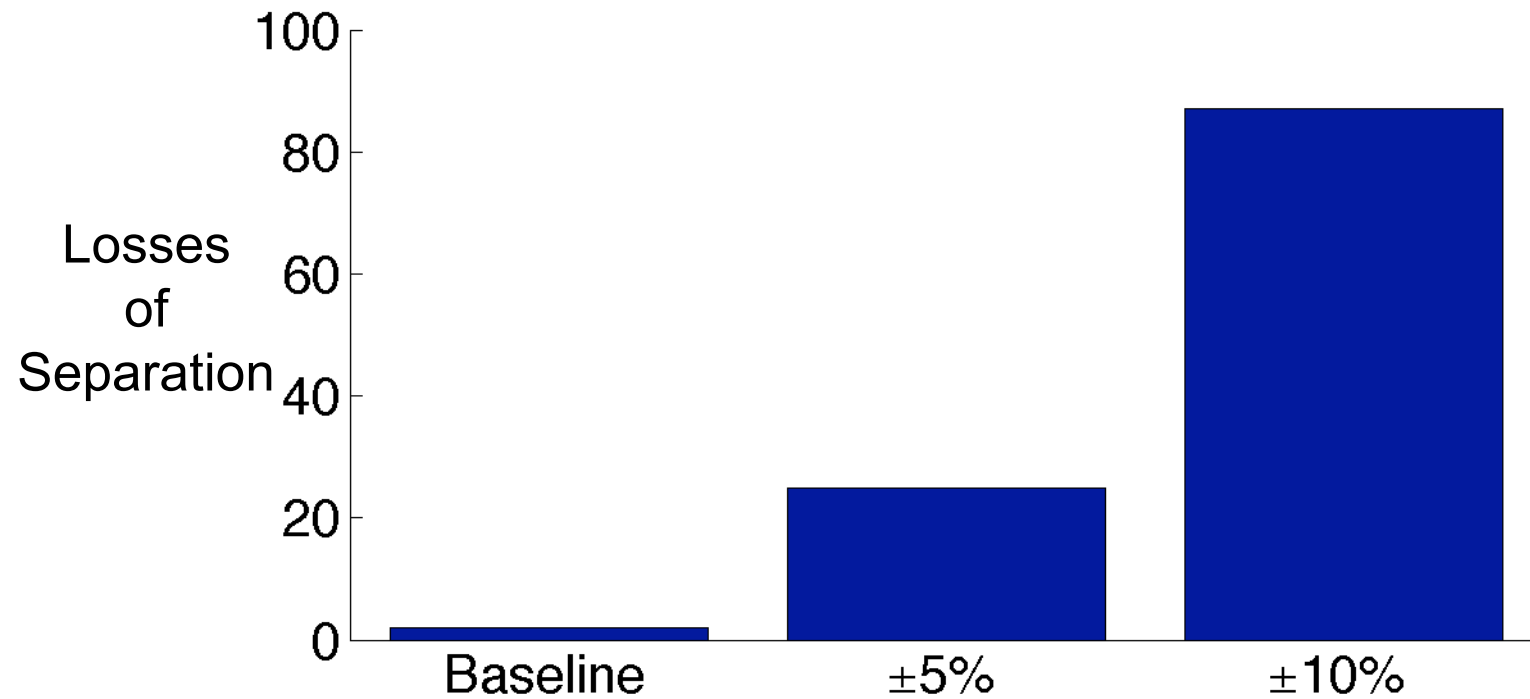
Weight Errors



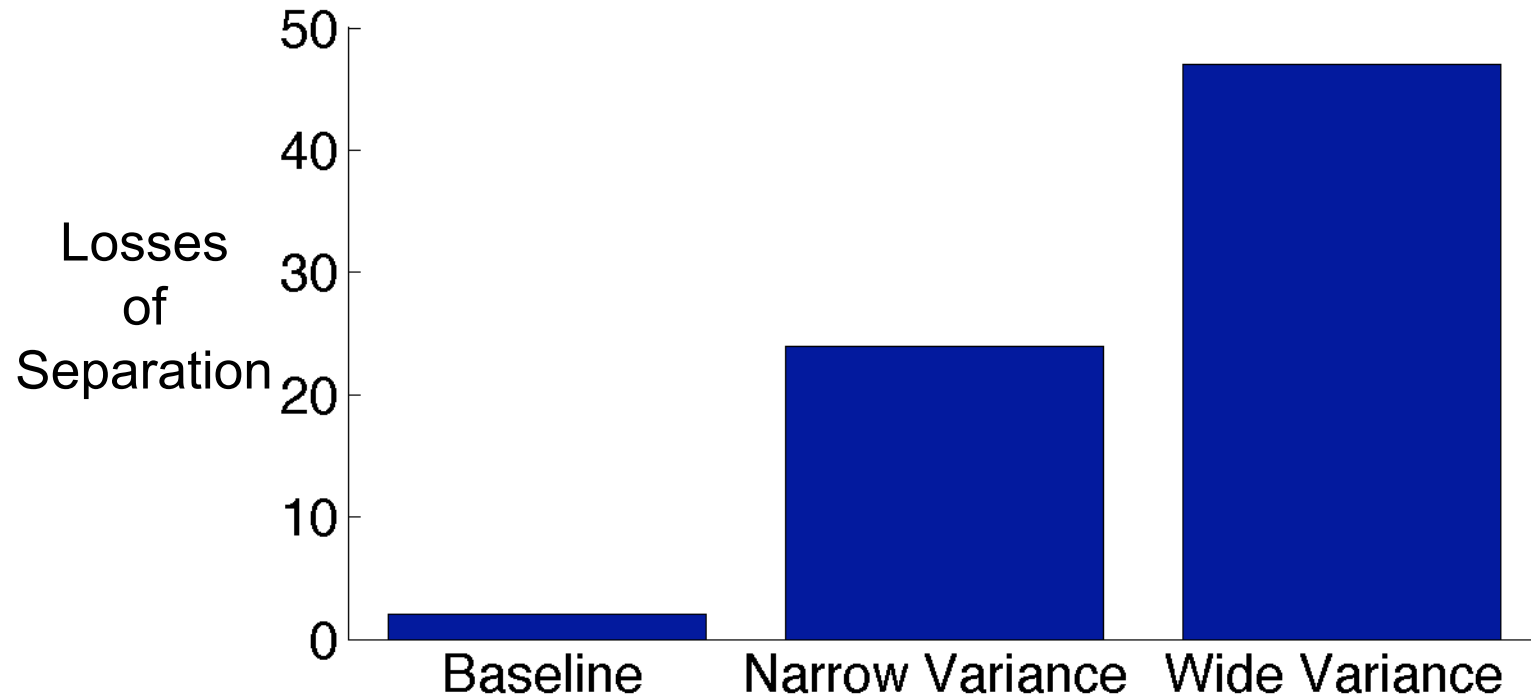
Top-of-Descent Errors



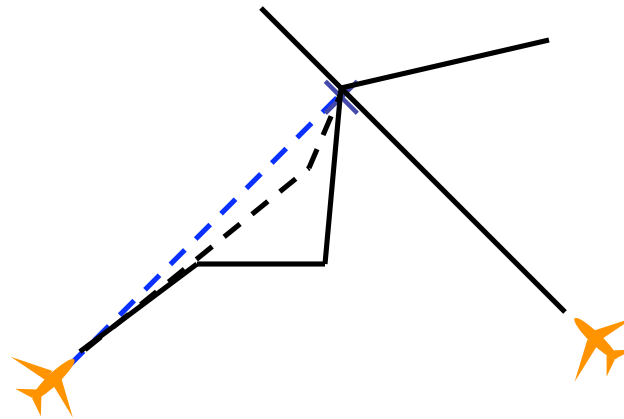
Descent-Speed Errors



Maneuver-Initiation-Time Errors

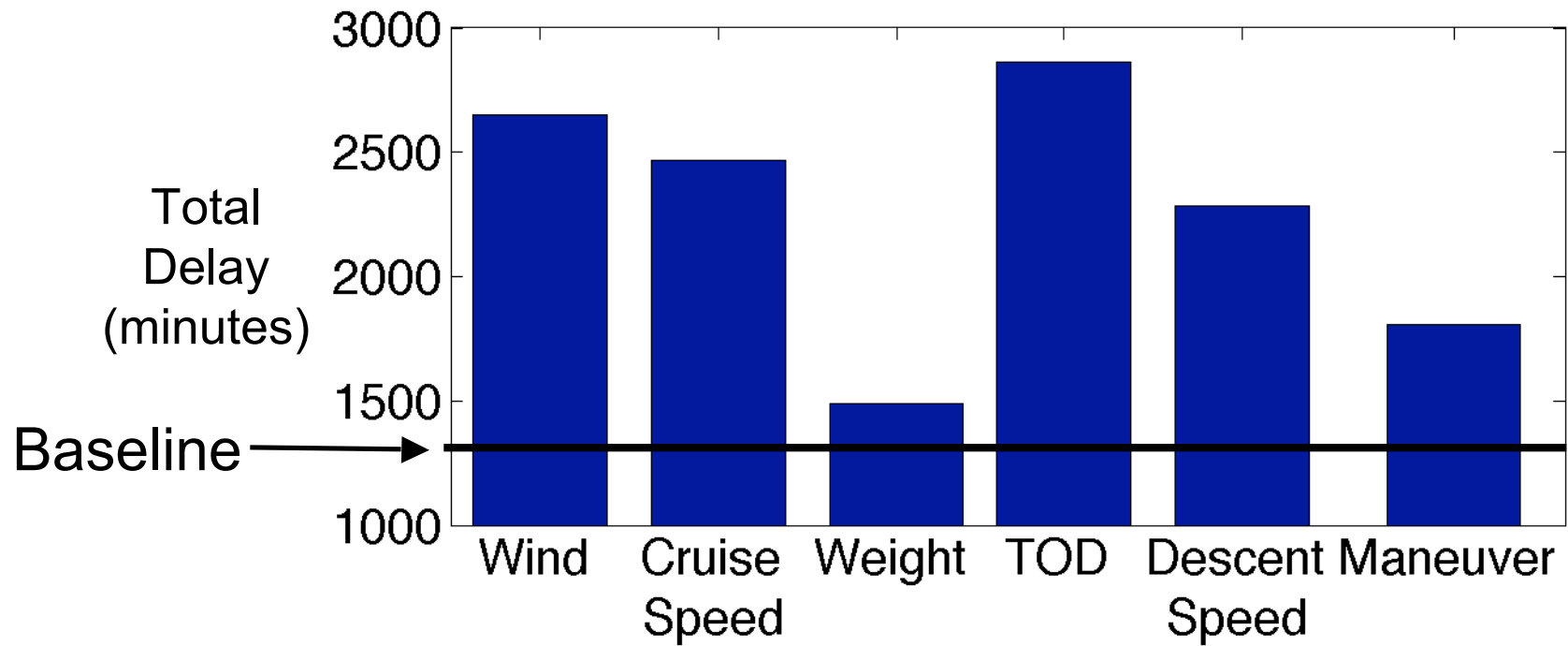


Delay



- Prediction errors result in re-planning of resolutions and resolving non-conflicts
- This results in additional system-wide delay

Delay Summary



Conclusions

- Over 95% of all losses were resolved for all cases
- Prediction errors result in increased losses and delay for all error types
- Descent prediction errors result in many late predictions and the largest number of losses
- The algorithms need to handle descent uncertainty better

Future Work

- Modify detection and resolution algorithms for zero losses
- Study other error sources such as horizontal intent errors
- Experiment with combinations of errors
- Optimize algorithms to maximize throughput for a set level of prediction error