National Aeronautics and Space Administration

Relative Effects of Trajectory Prediction Errors on the AAC Autoresolver

Todd Lauderdale

Airspace Systems Program
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Separation Assurance Automation

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

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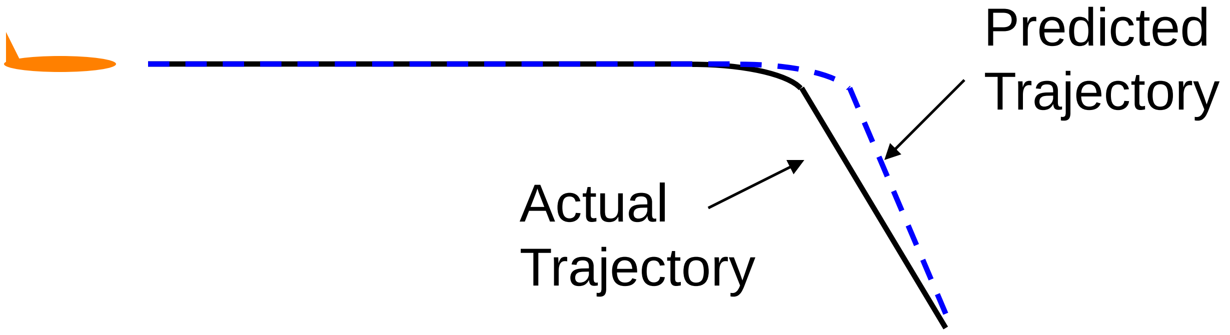
If we could perfectly predict the future positions of all aircraft this would be fairly easy

Prediction Errors



Any trajectory prediction will have some error

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

Automation Objectives

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

Study Objectives

- To understand how different sources of trajectory prediction errors affect the AAC Autoresolver
- To compare the relative effects across error sources
- To highlight algorithmic improvements to deal with errors

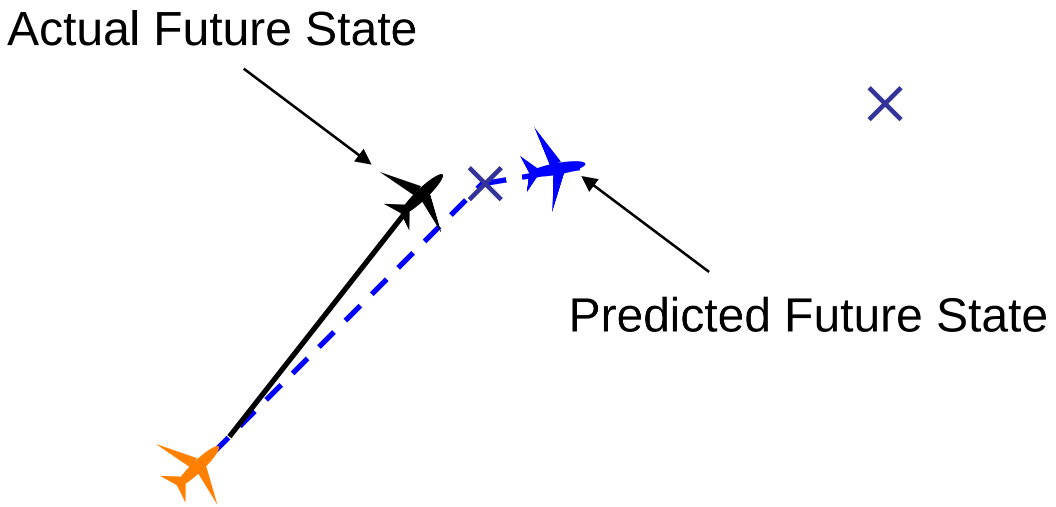
Error Sources Studied

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

Simulation Environment

- Airspace Simulator: Airspace Concept Evaluation System (ACES)
- Separation Assurance Algorithm: Advanced Airspace Concept (AAC) Autoresolver

Key Simulation Feature



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

Error Studies

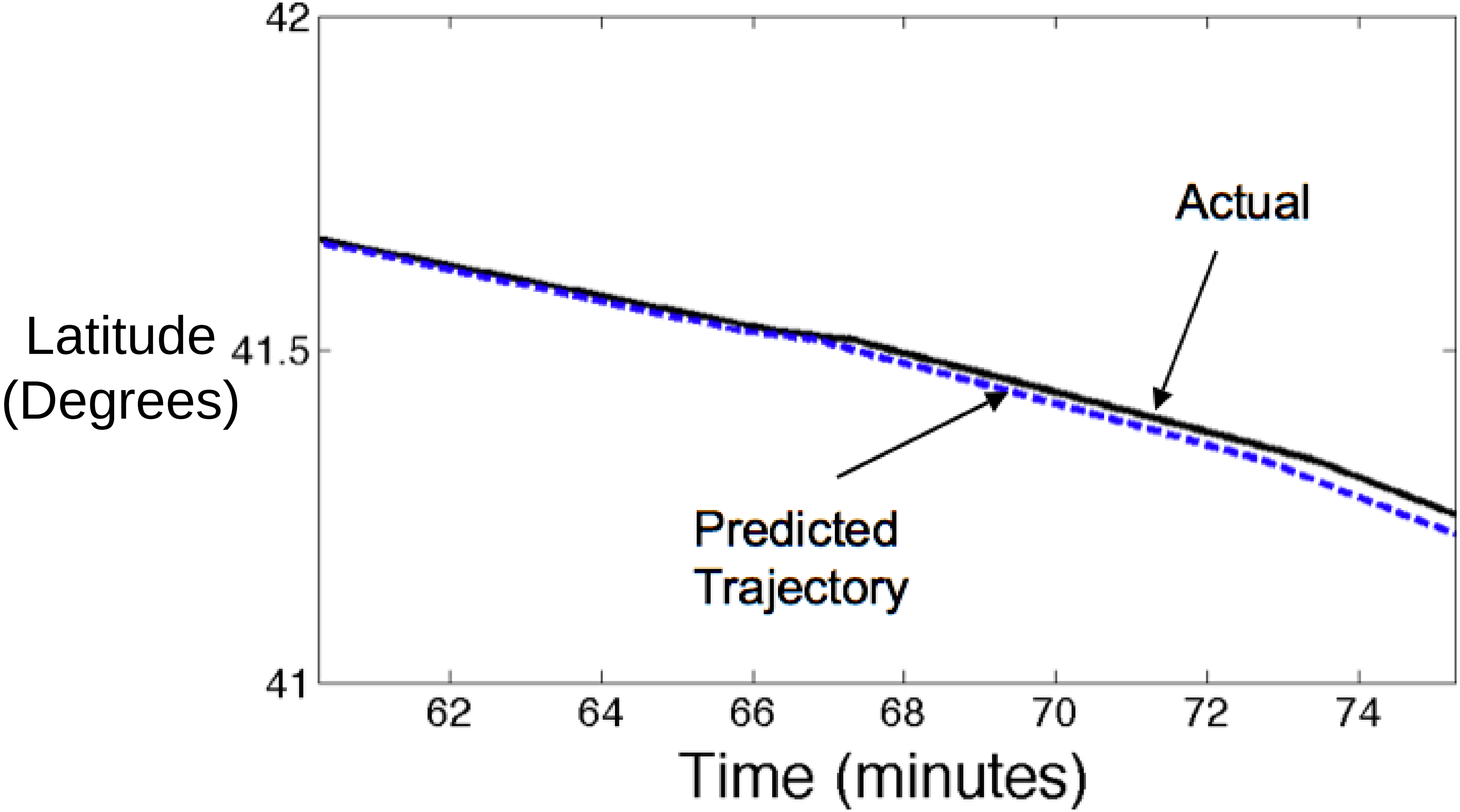
- Perform two separate studies:
  - Detection study
  - Resolution study
- Vary the amount of error from single source
- Use 3 hours of nationwide traffic

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%

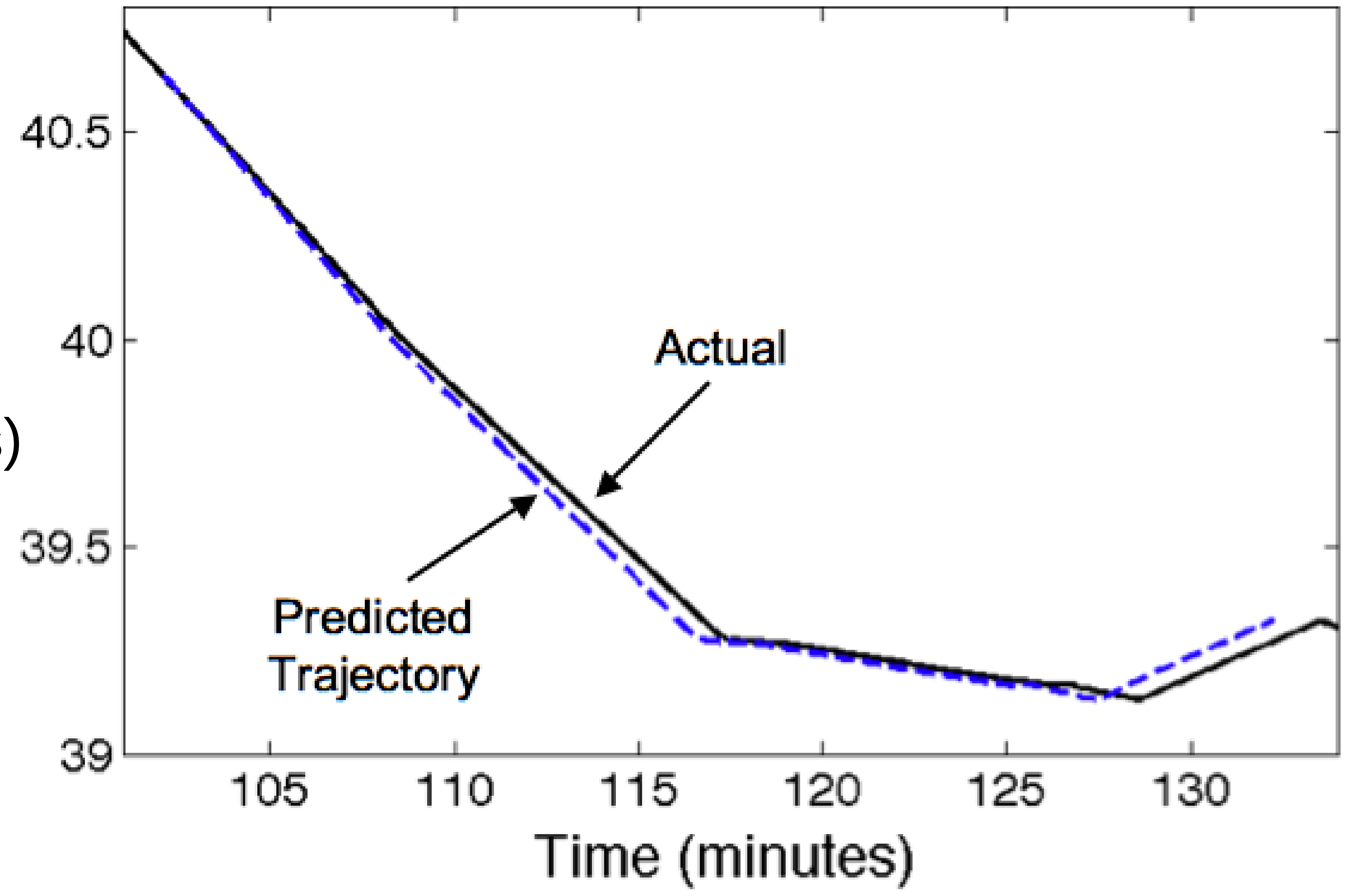
Generally slightly larger than values found in previous studies

Wind Errors


Latitude
(Degrees)
42
41.5
41
62
64
66
68
70
72
74
Time (minutes)
Actual
Predicted
Trajectory

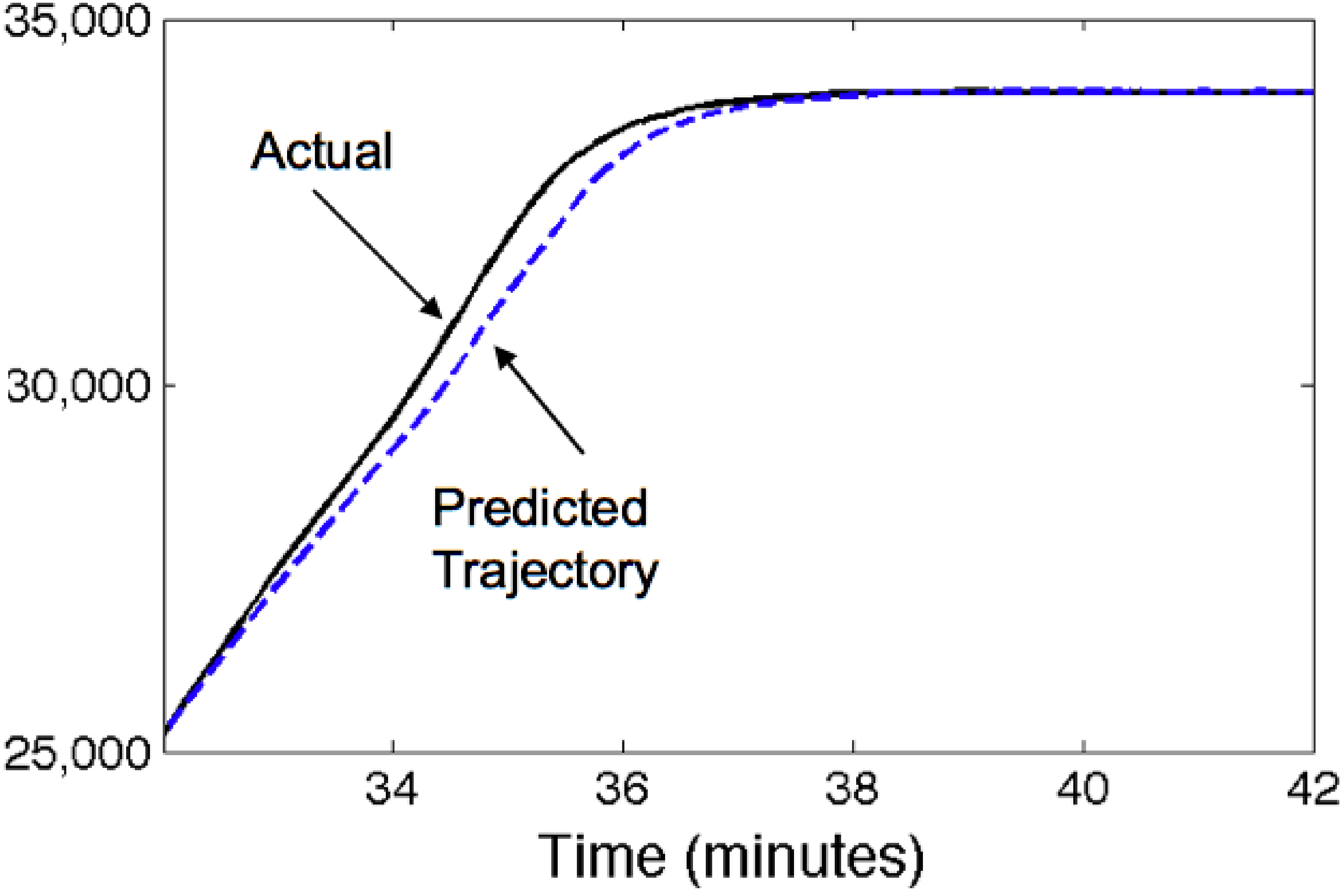
Cruise-Speed Errors

Latitude (Degrees)

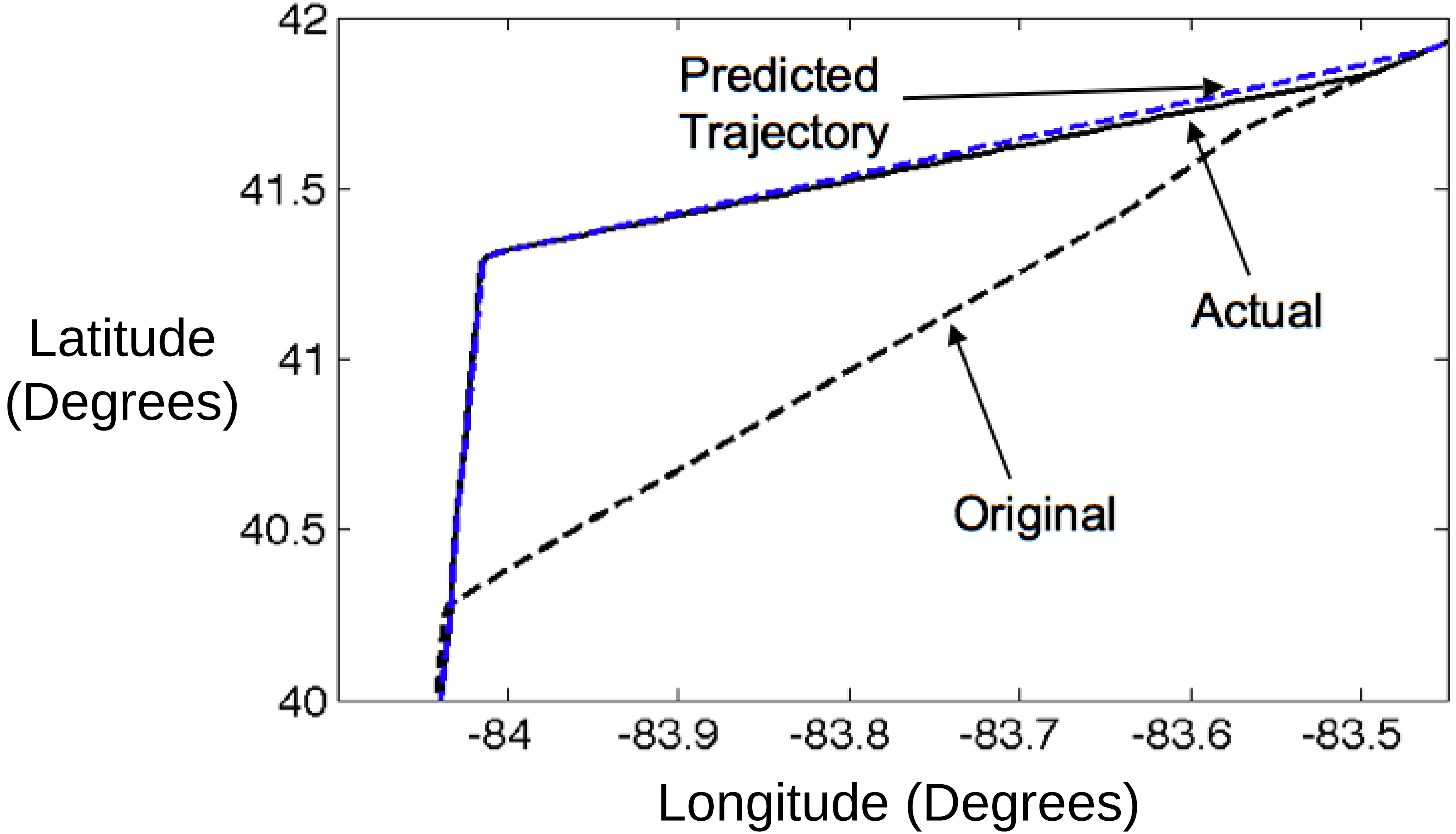


Weight Errors

Altitude
(feet)

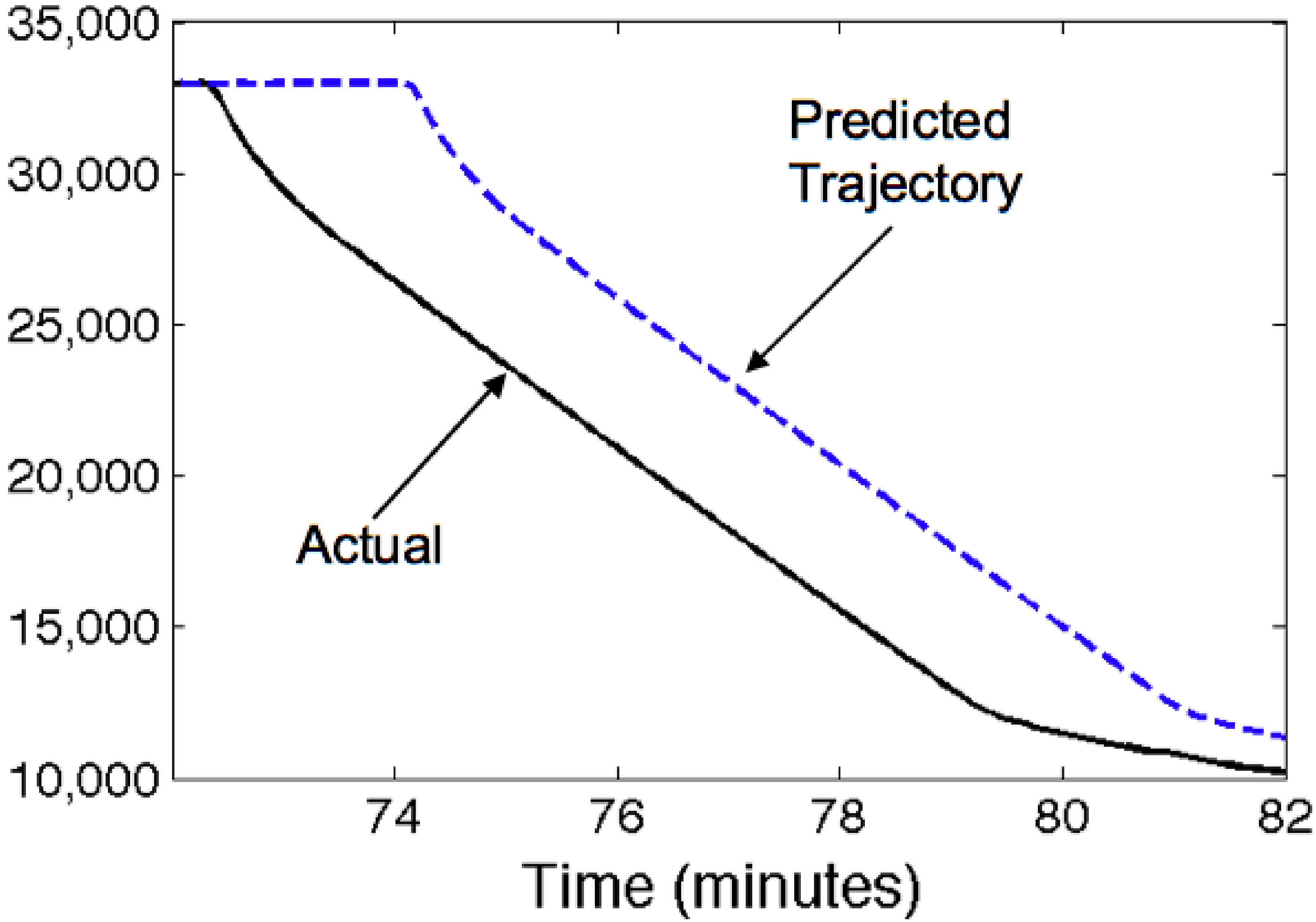


Maneuver-Initiation-Time Errors

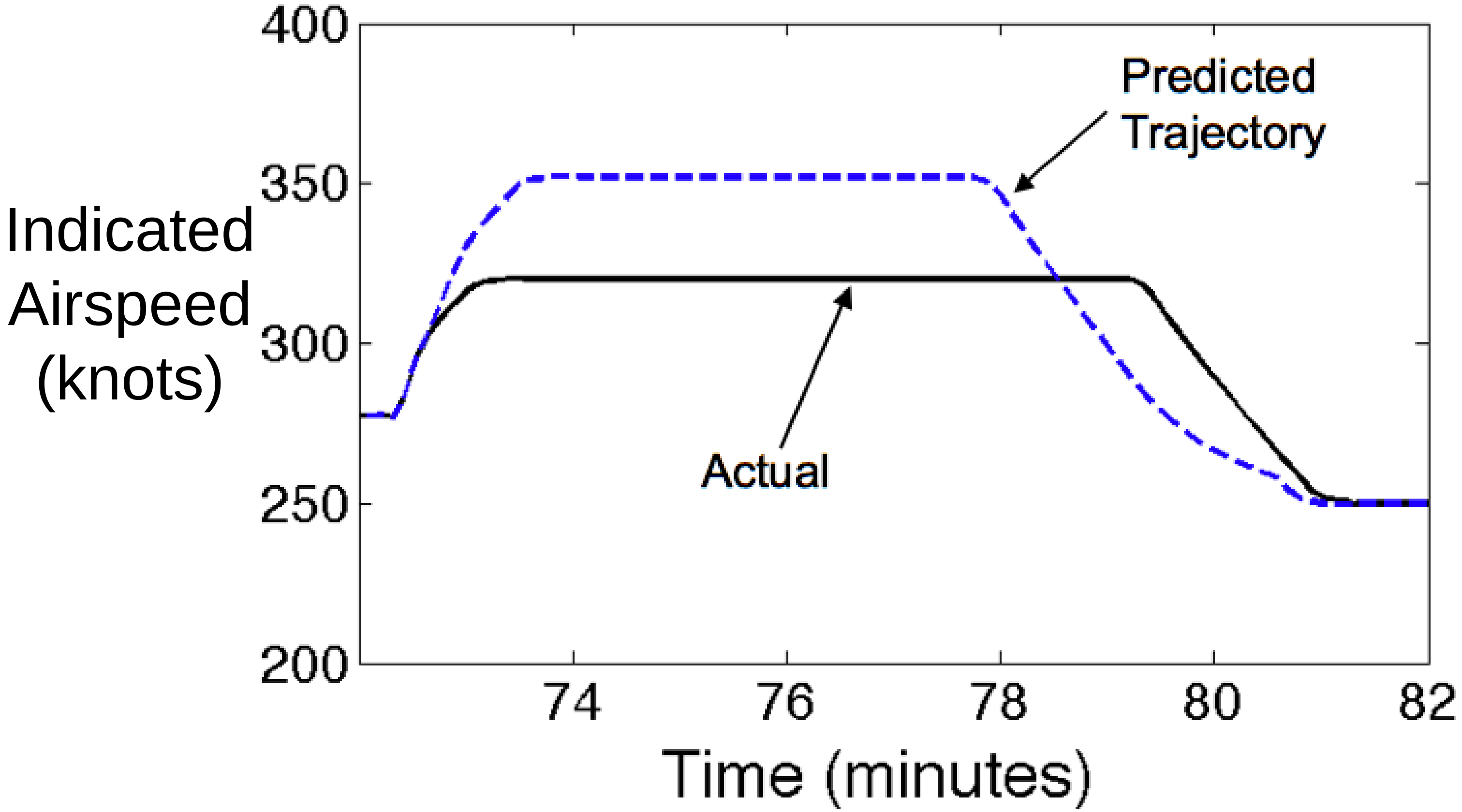


Top-of-Descent Errors

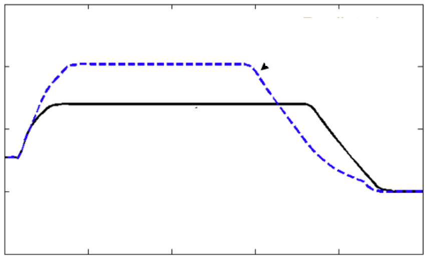
Altitude
(feet)

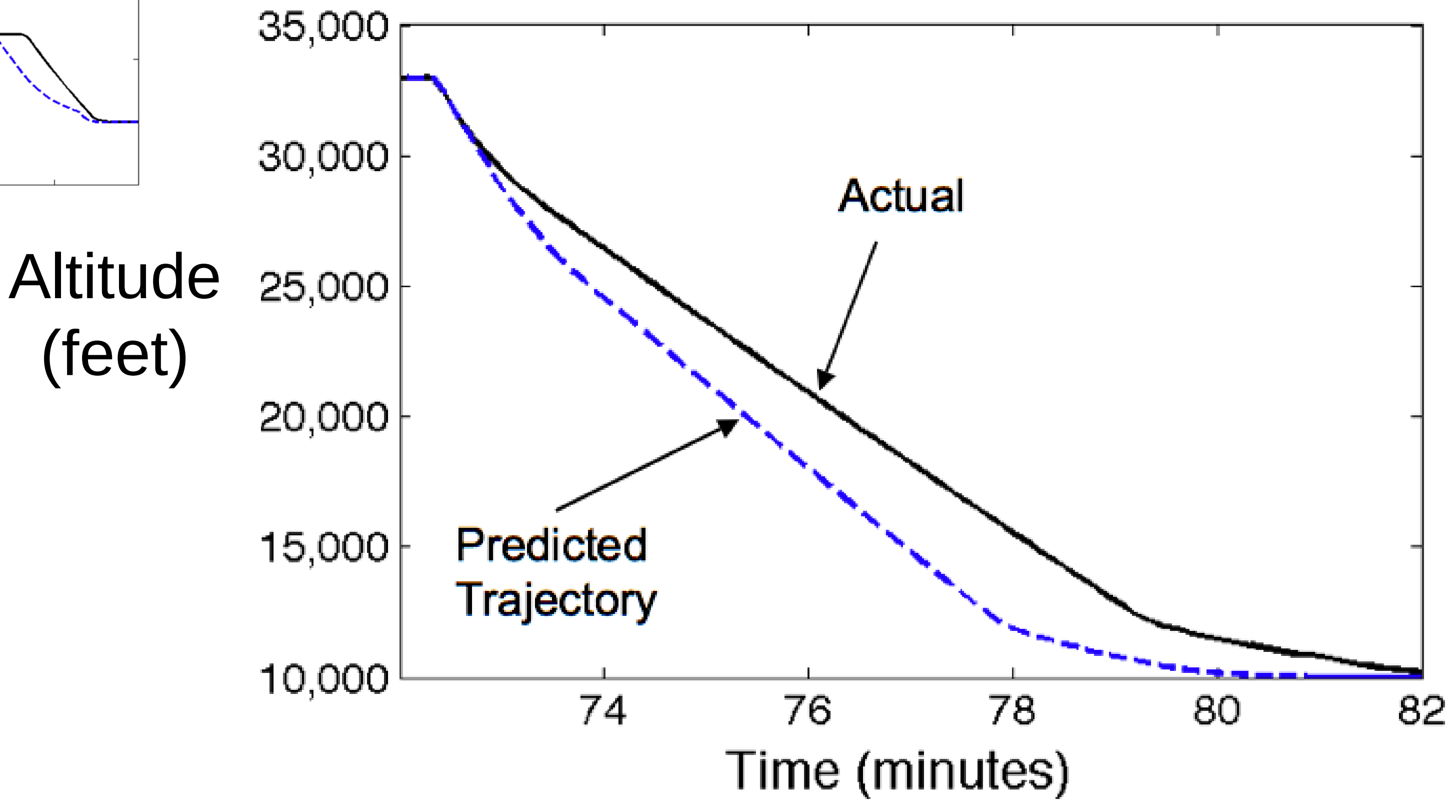


Descent-Speed Errors

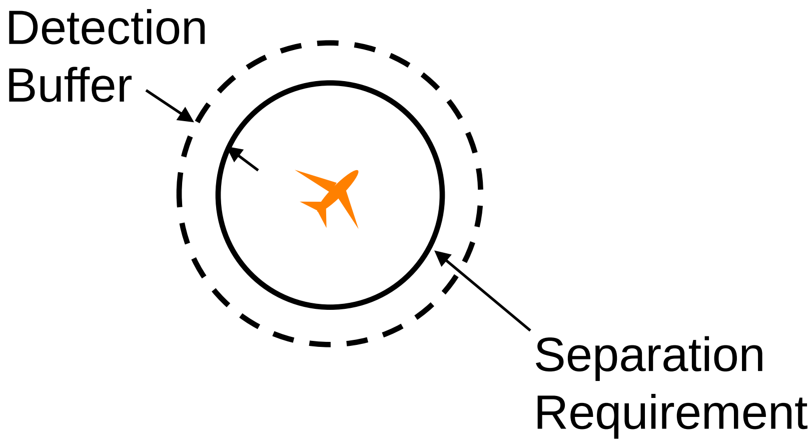


Descent-Speed Errors



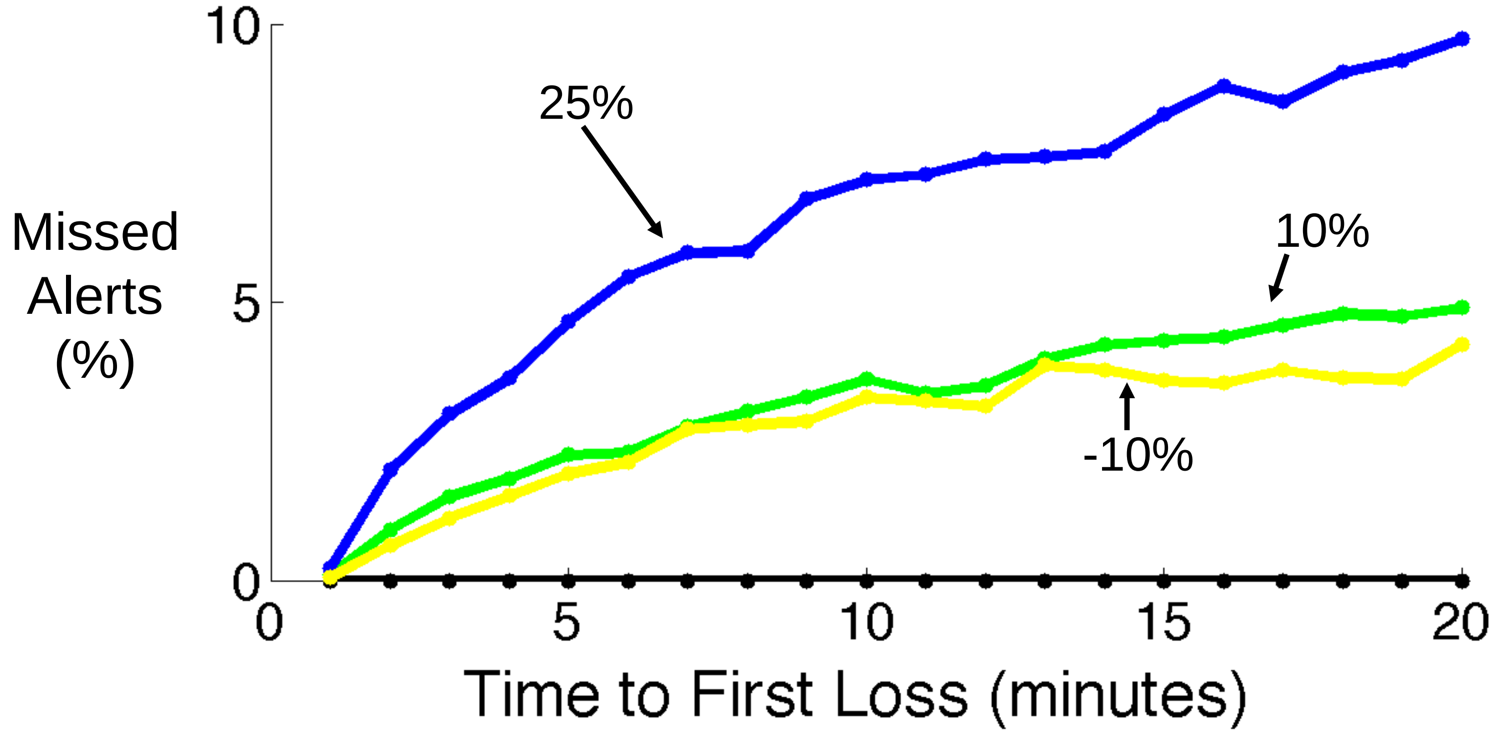


Detection Study



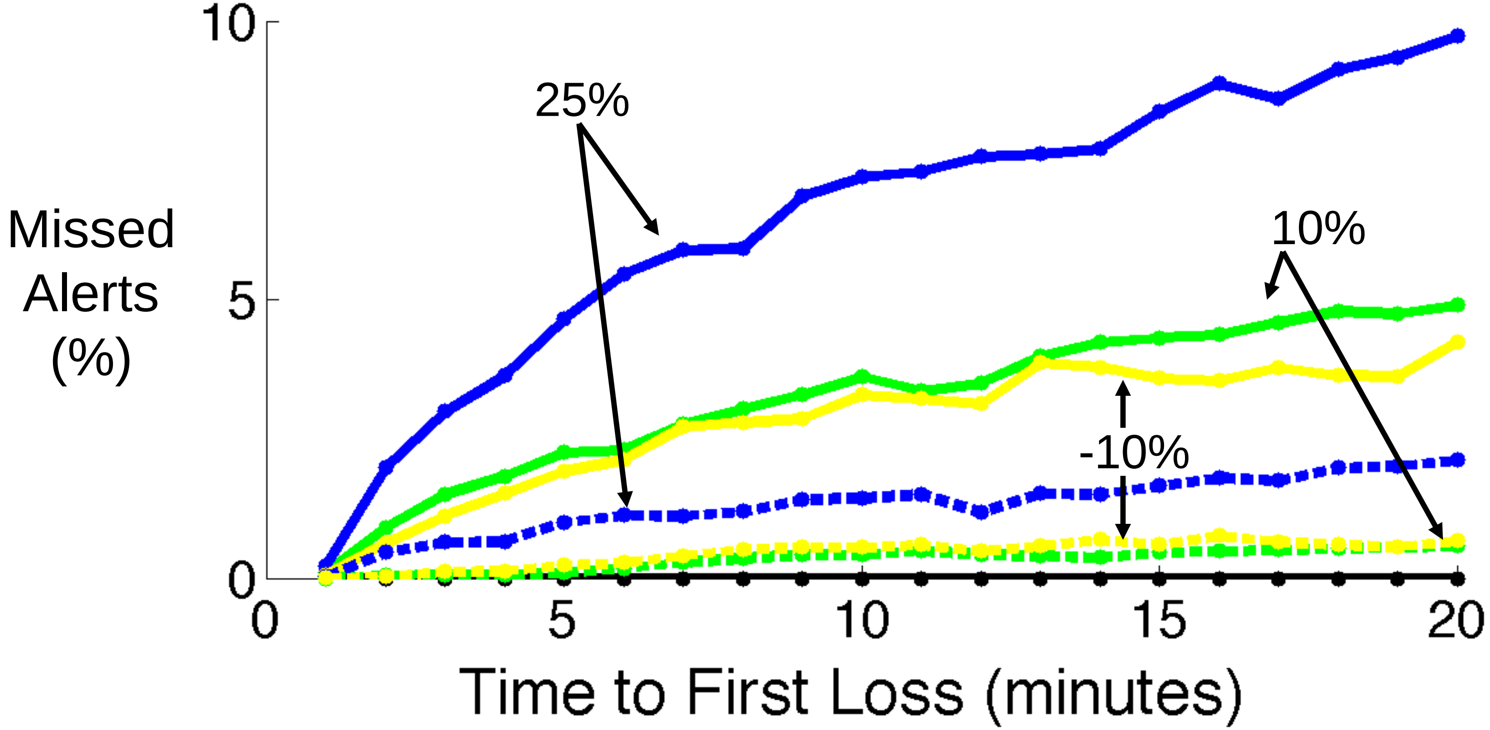
- Looked at geometric detection with and without a horizontal buffer
- Open-loop simulations with over 1800 losses of separation

Wind Errors



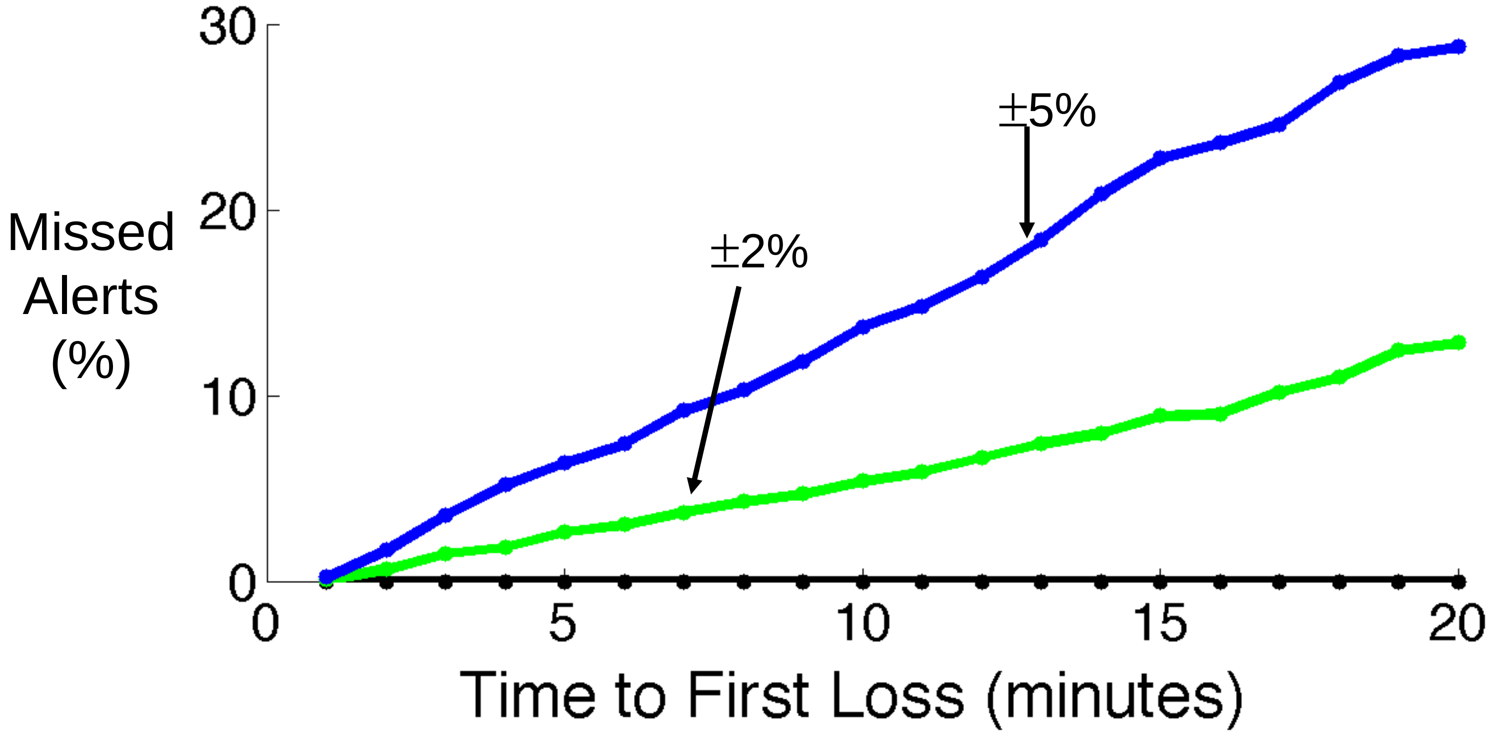
- Symmetric between positive and negative values

Wind Errors



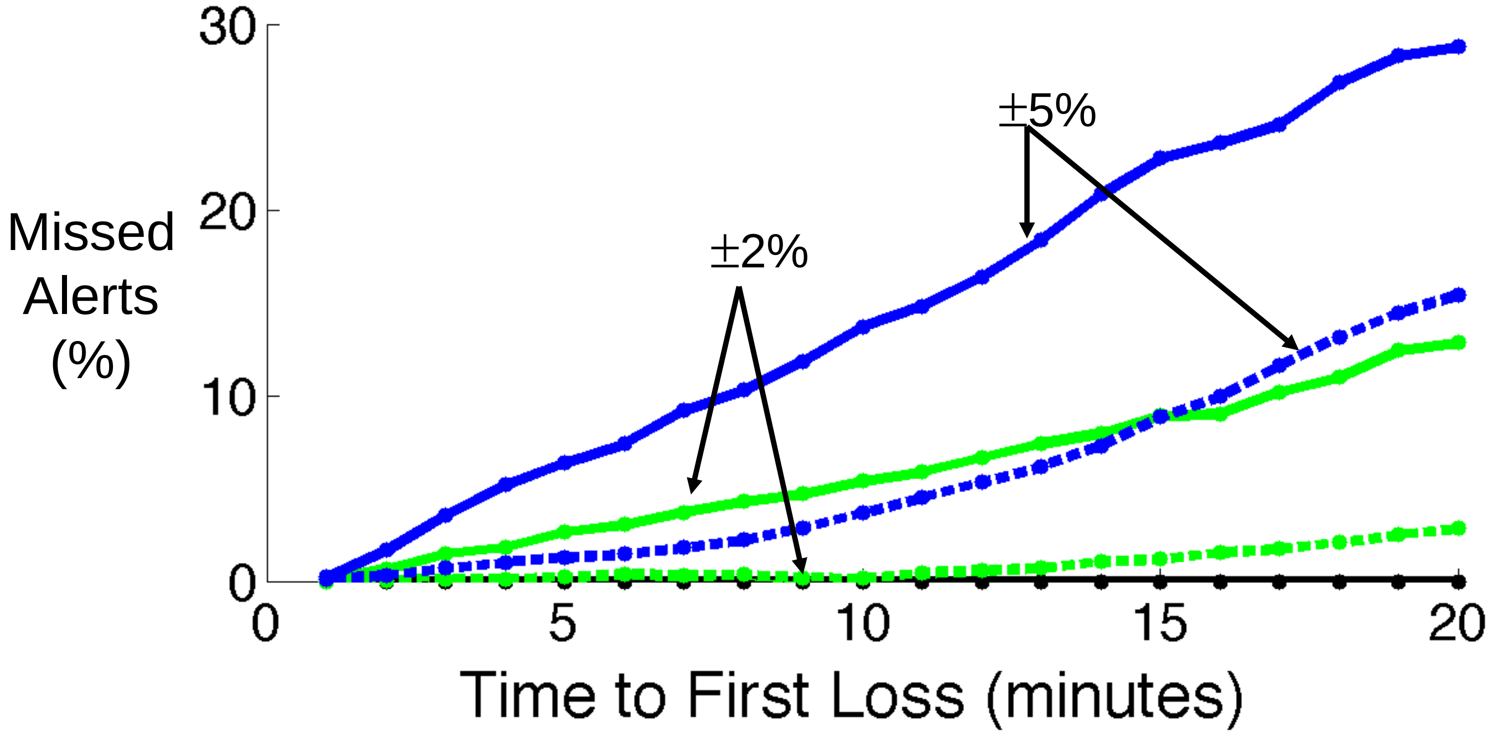
- Symmetric between positive and negative values
- Buffer is quite effective

Cruise-Speed Error



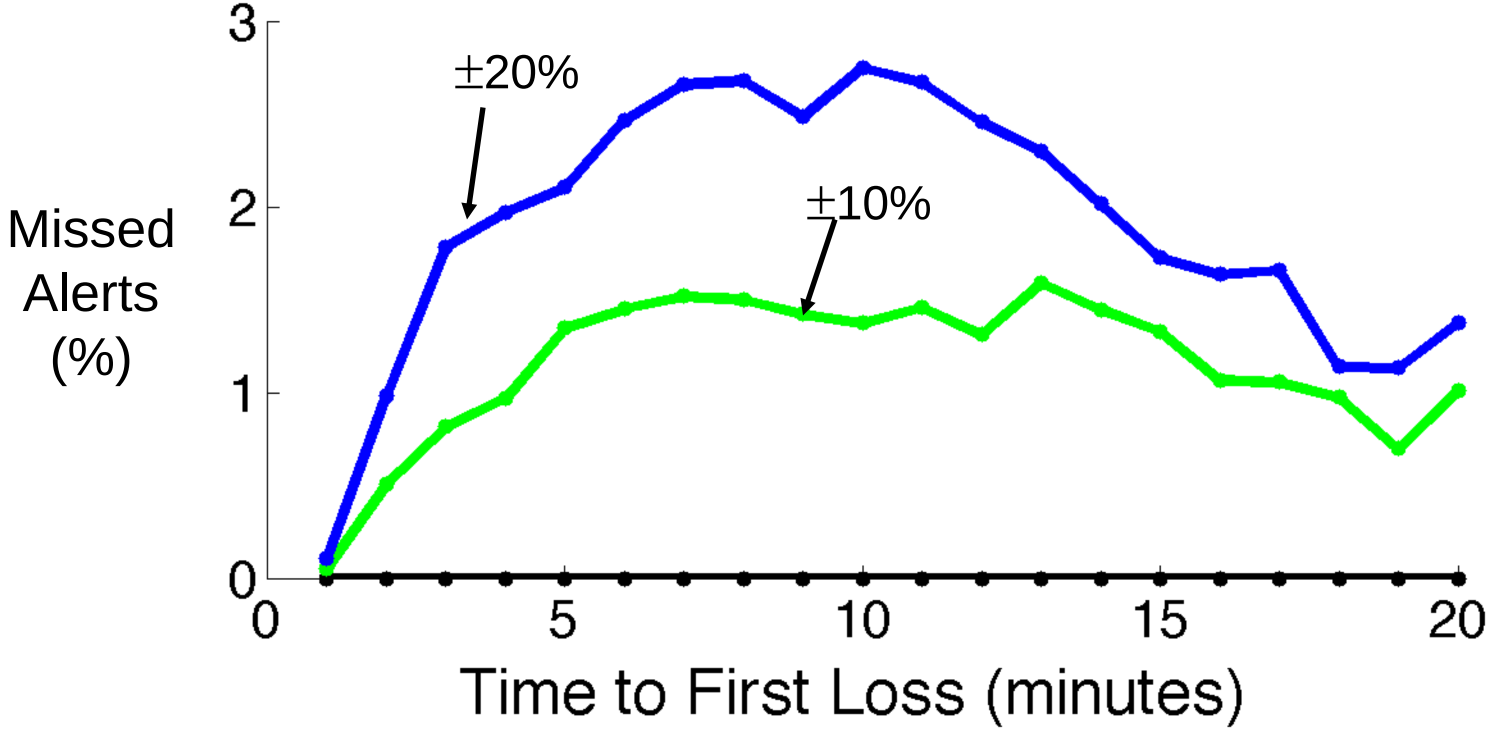
- Linear increase to large amount

Cruise-Speed Error



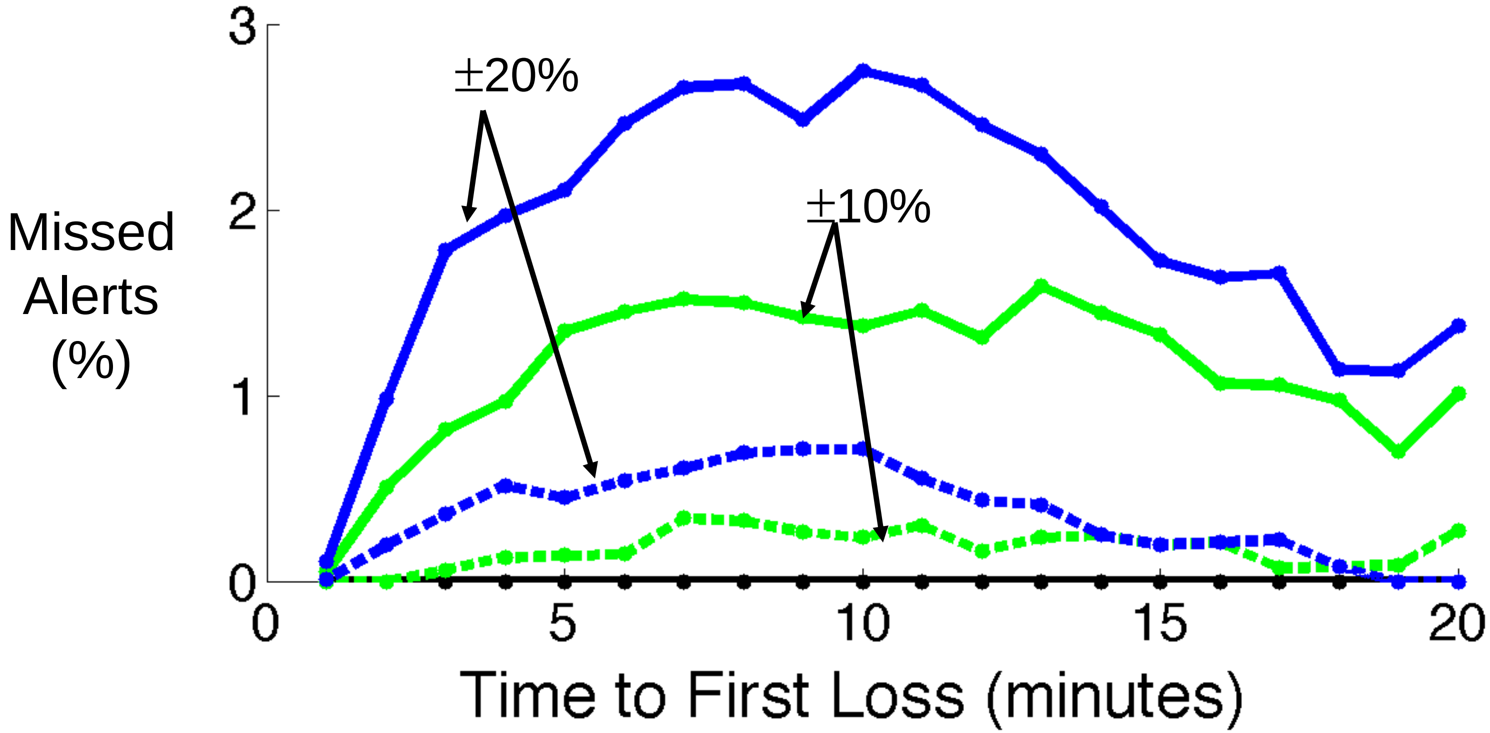
- Linear increase to large amount
- Buffer effective

Weight Error



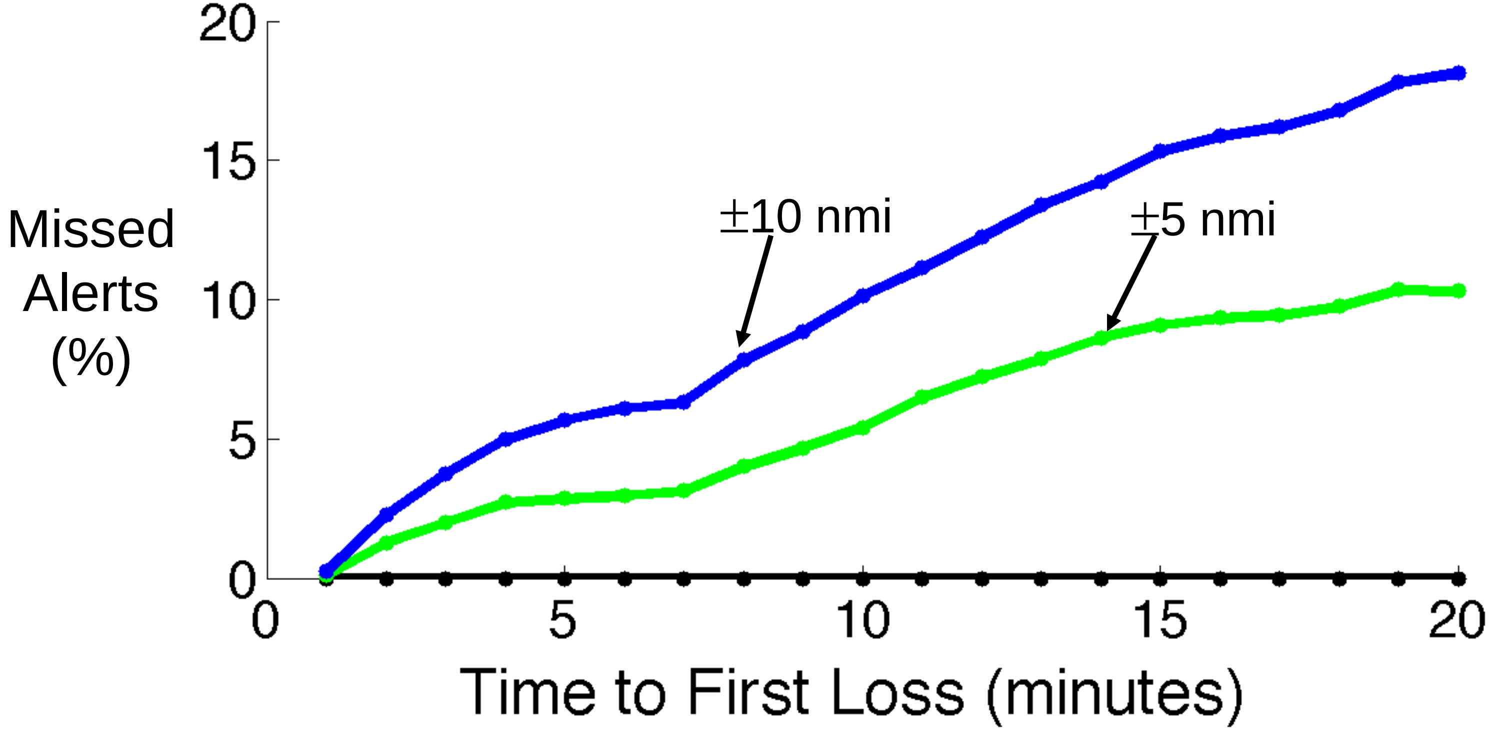
- Decrease as a function of time and small total value

Weight Error



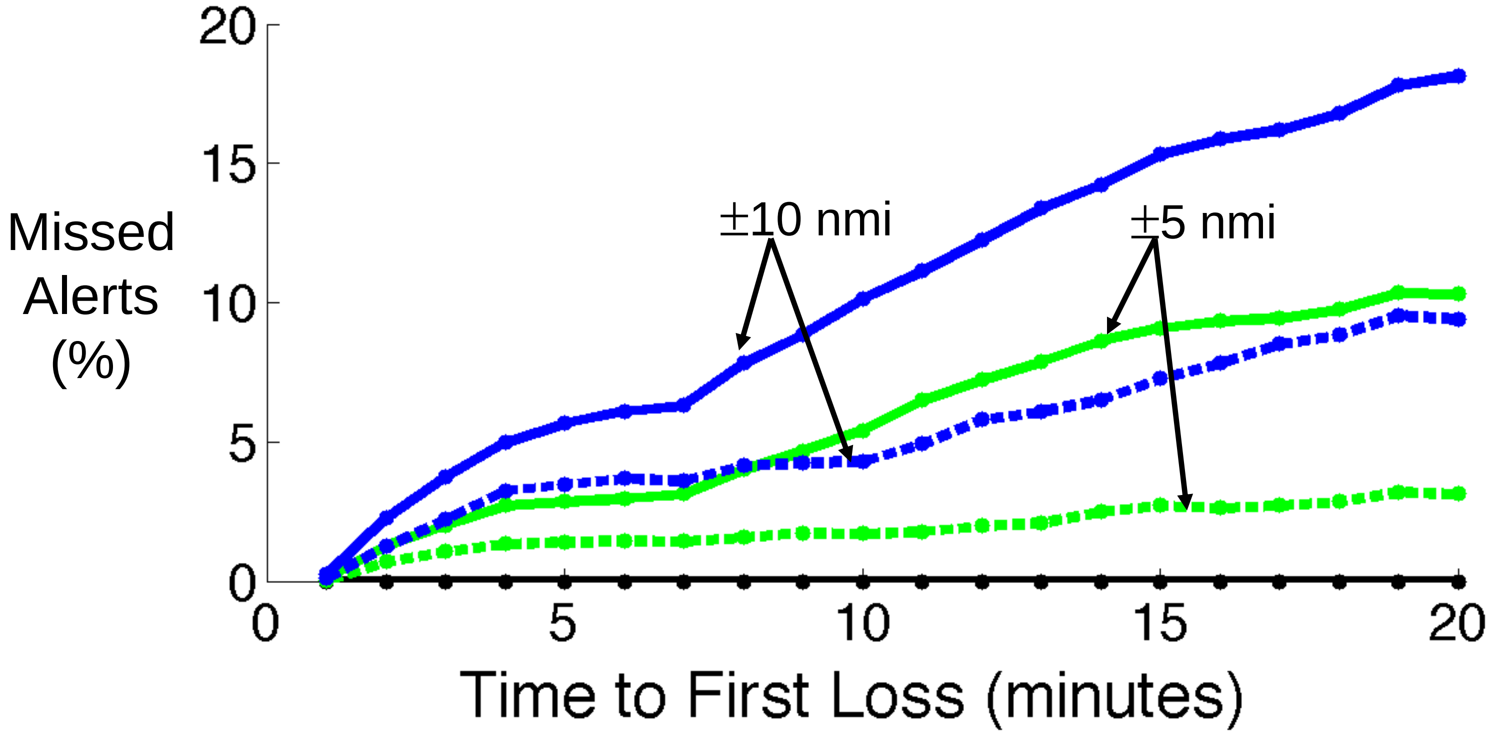
- Decrease as a function of time and small total value
- Buffer less effective for large errors

Top-of-Descent Errors



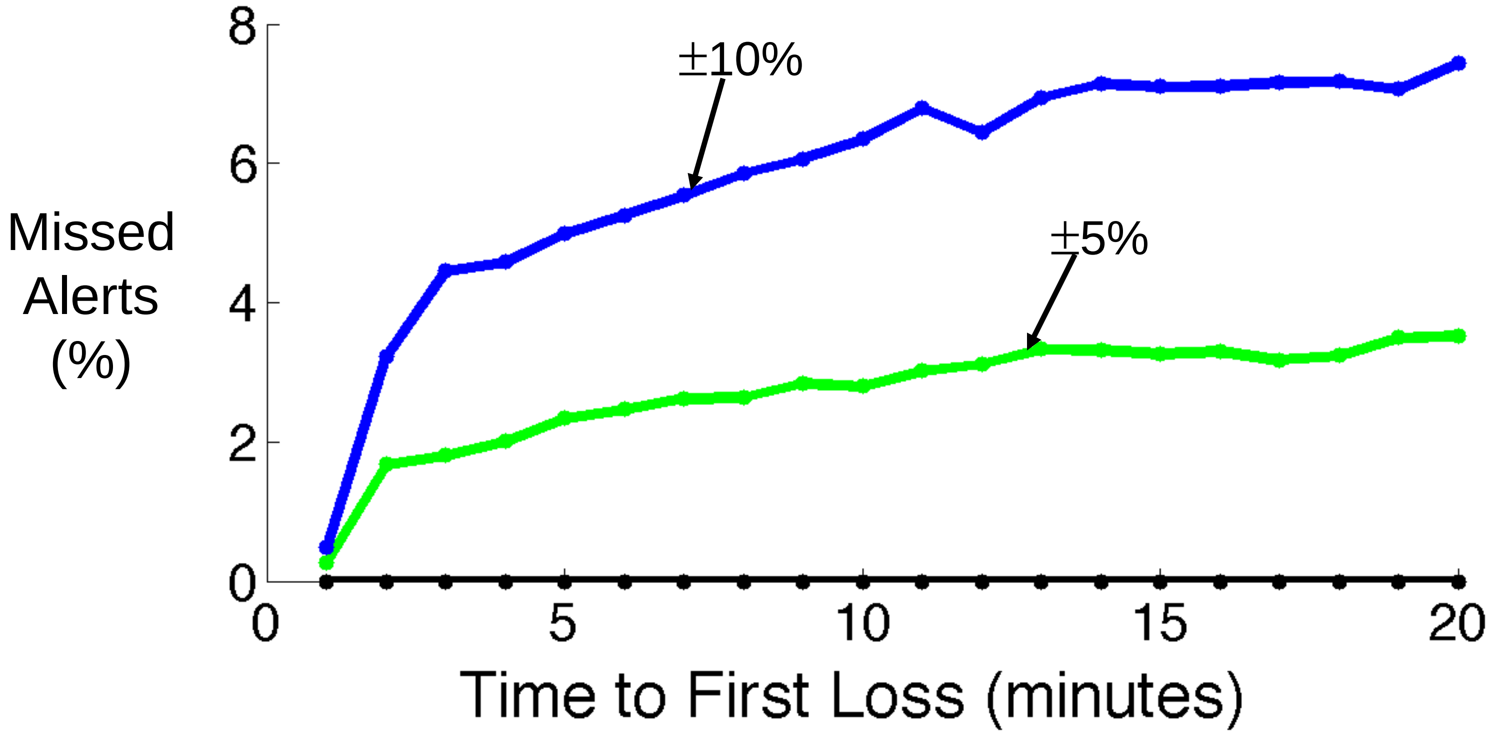
- Relatively large number of missed alerts

Top-of-Descent Errors



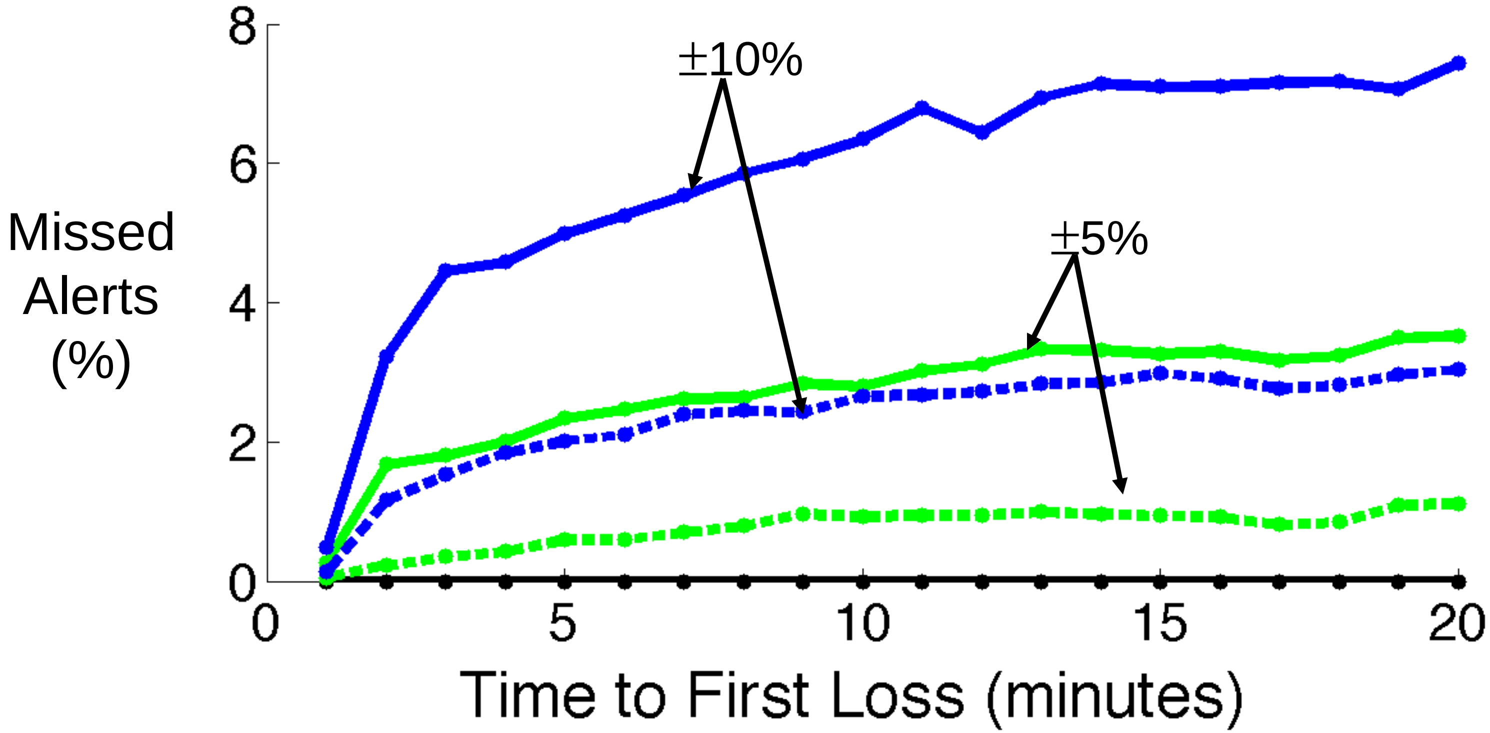
- Relatively large number of missed alerts
- Buffer not very effective

Descent-Speed Errors



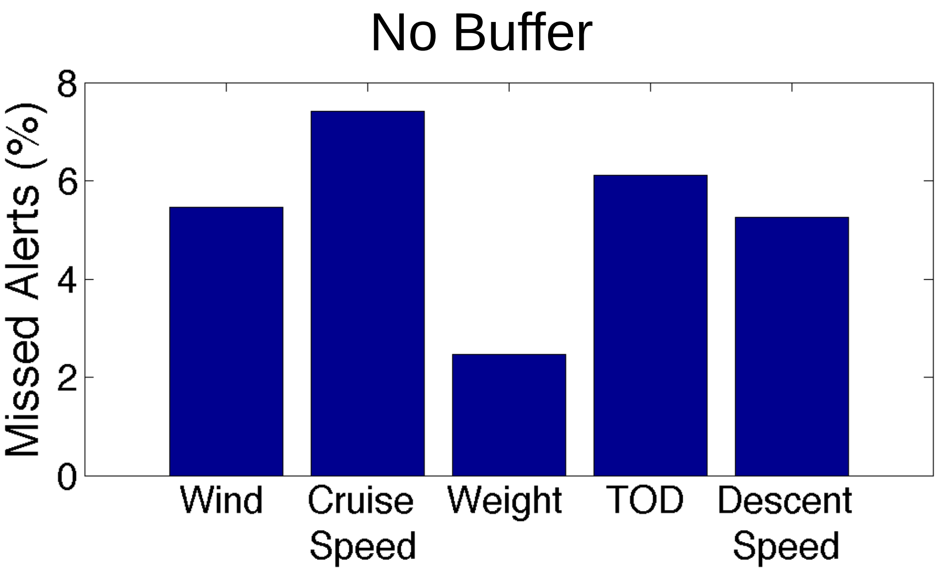
- Moderate amount of missed alerts and steep curve near 1 minute to loss

Descent-Speed Errors



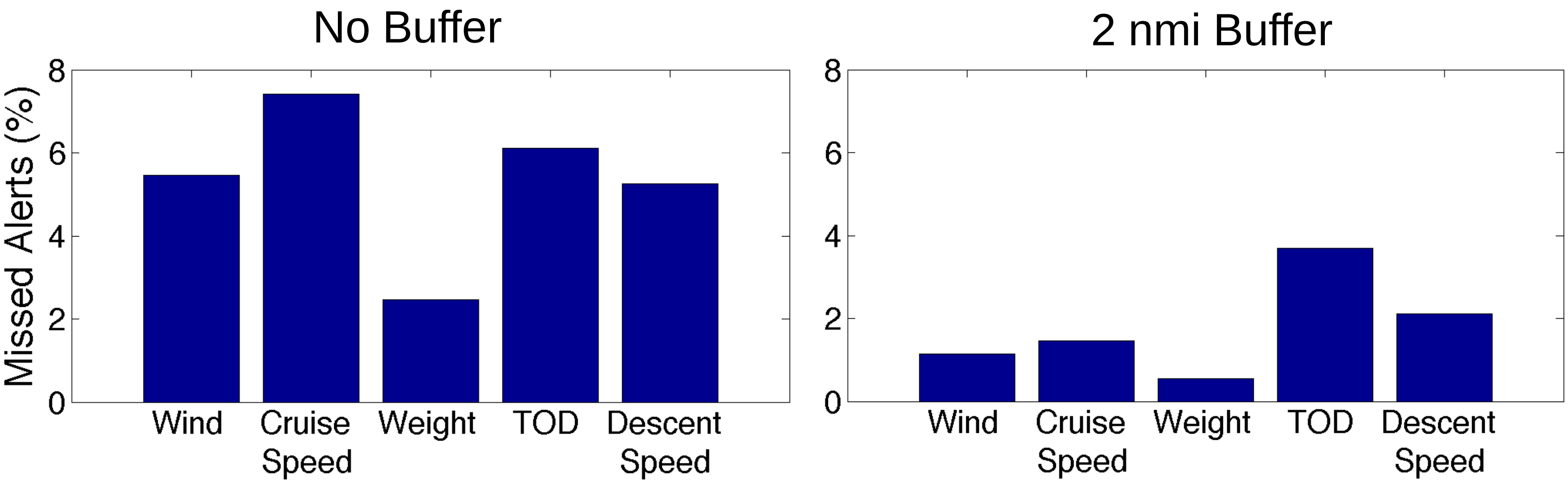
- Moderate amount of missed alerts and steep curve near 1 minute to loss
- Buffer not very effective

Missed Alert Summary



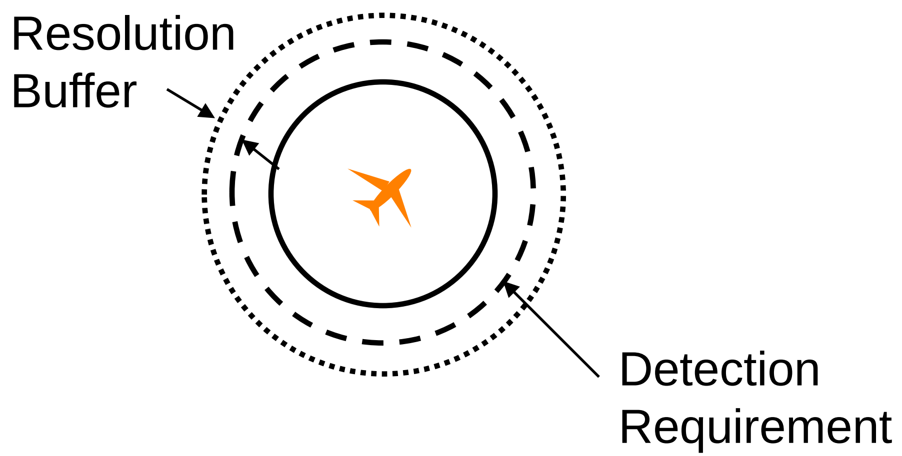
- Cruise-speed and top-of-descent errors result in most missed alerts

Missed Alert Summary



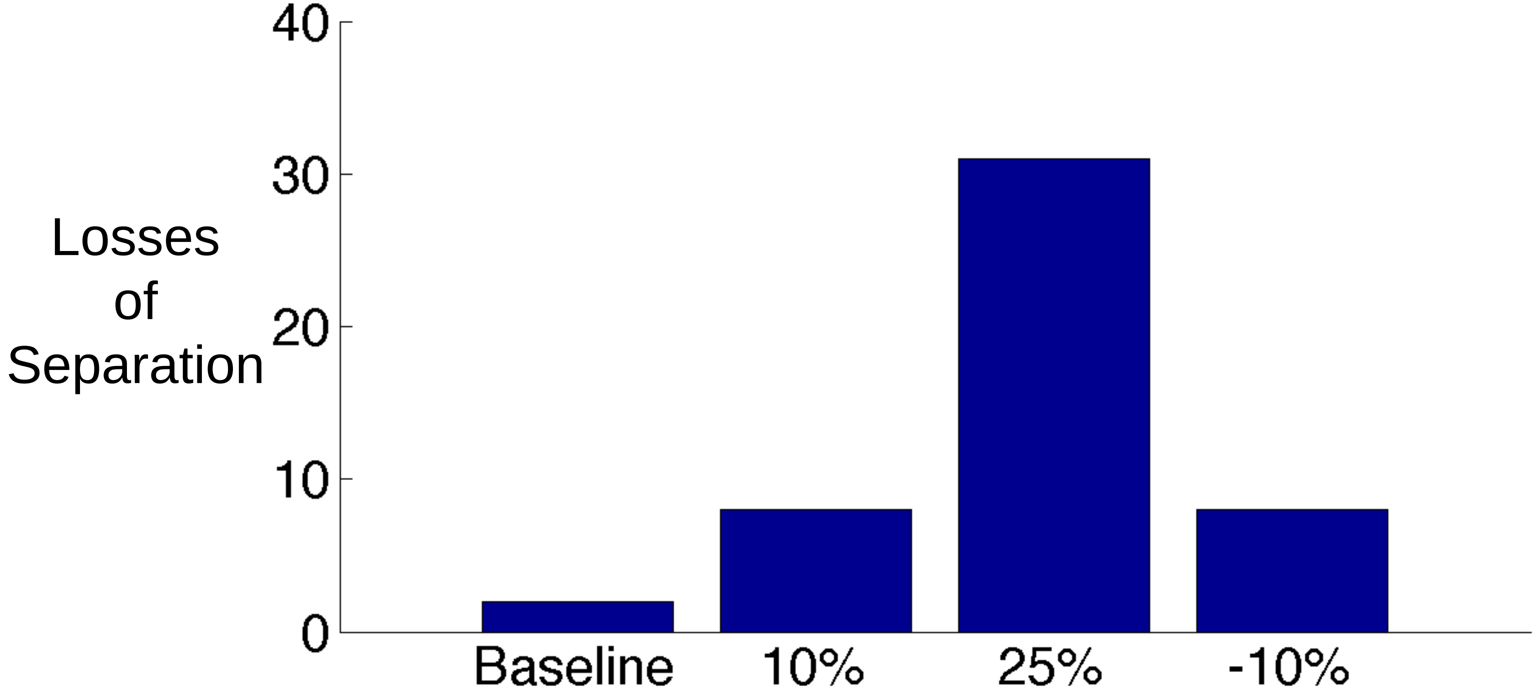
- Cruise-speed and top-of-descent errors result in most missed alerts
- Buffer is least effective for top-of-descent and descent-speed errors

Resolution Study



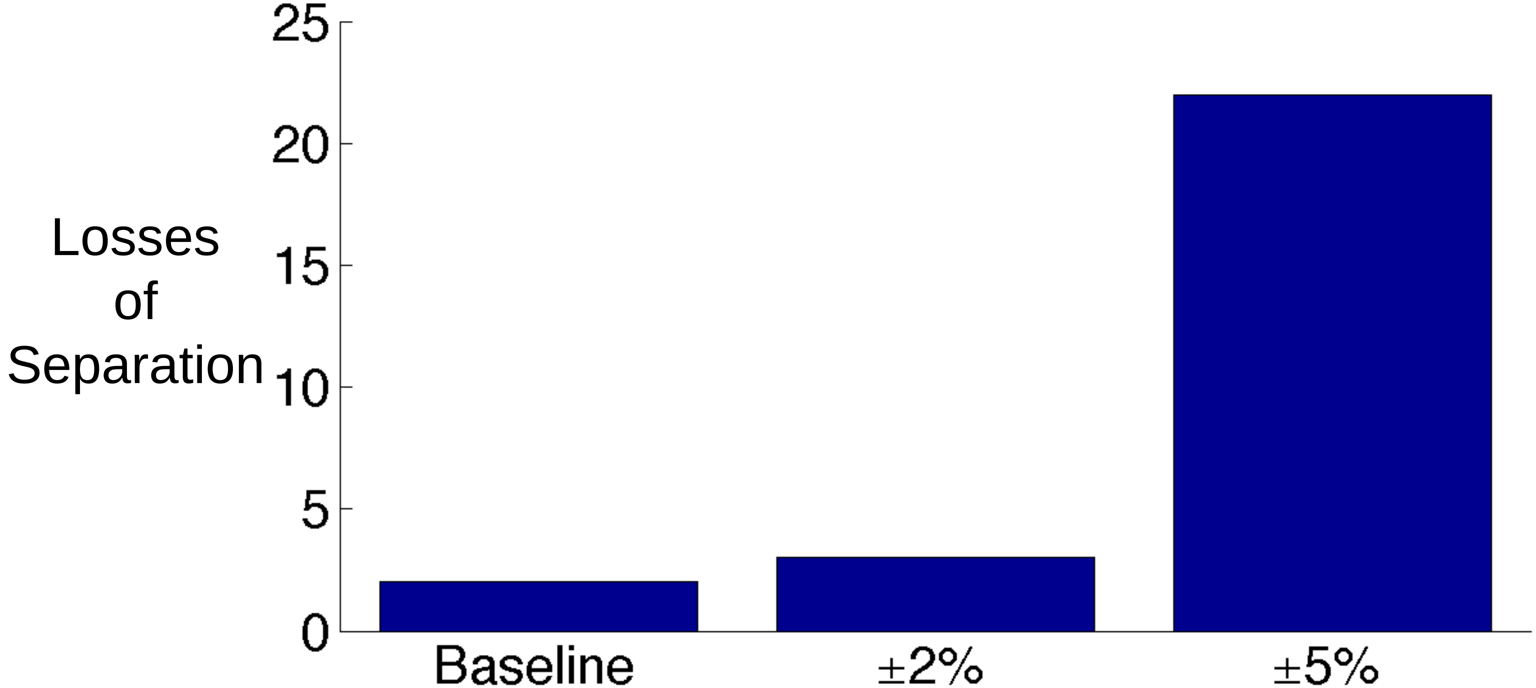
- 1 nmi detection buffer
- 8-minute look-ahead for conflict detection
- 12-minute look-ahead for successful resolutions

Wind Errors



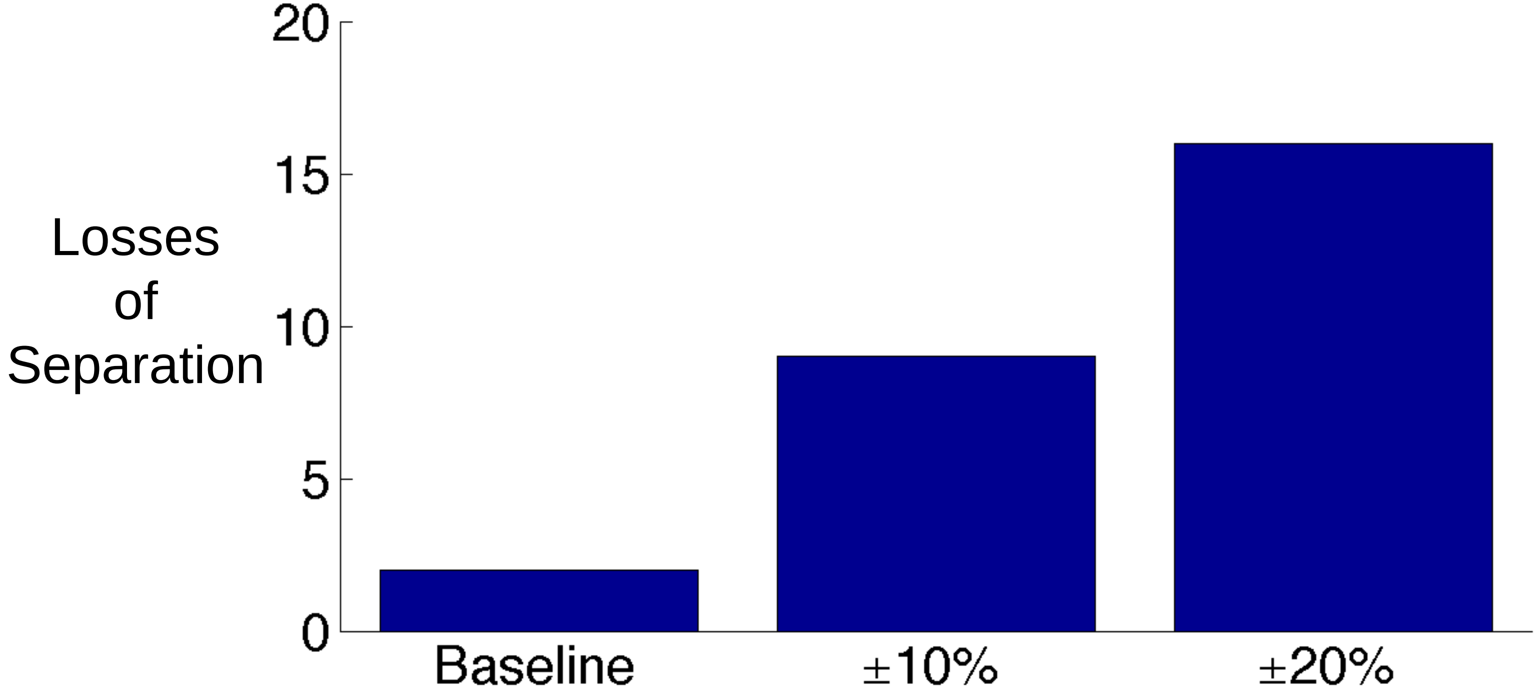
- Losses increase with increase wind error
- Symmetric with positive and negative magnitude

Cruise-Speed Errors



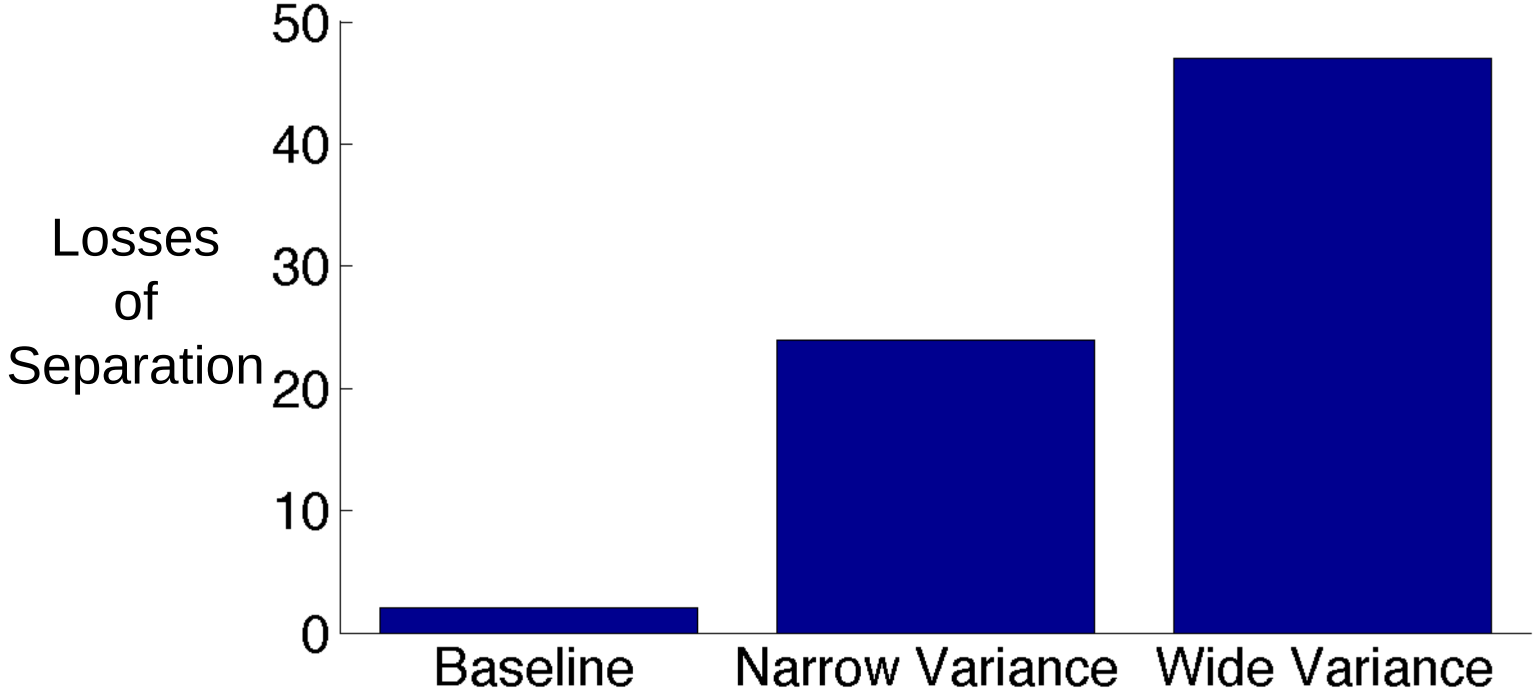
- Produces fewer losses than largest wind error
- Small errors are handled well by the algorithm

Weight Errors



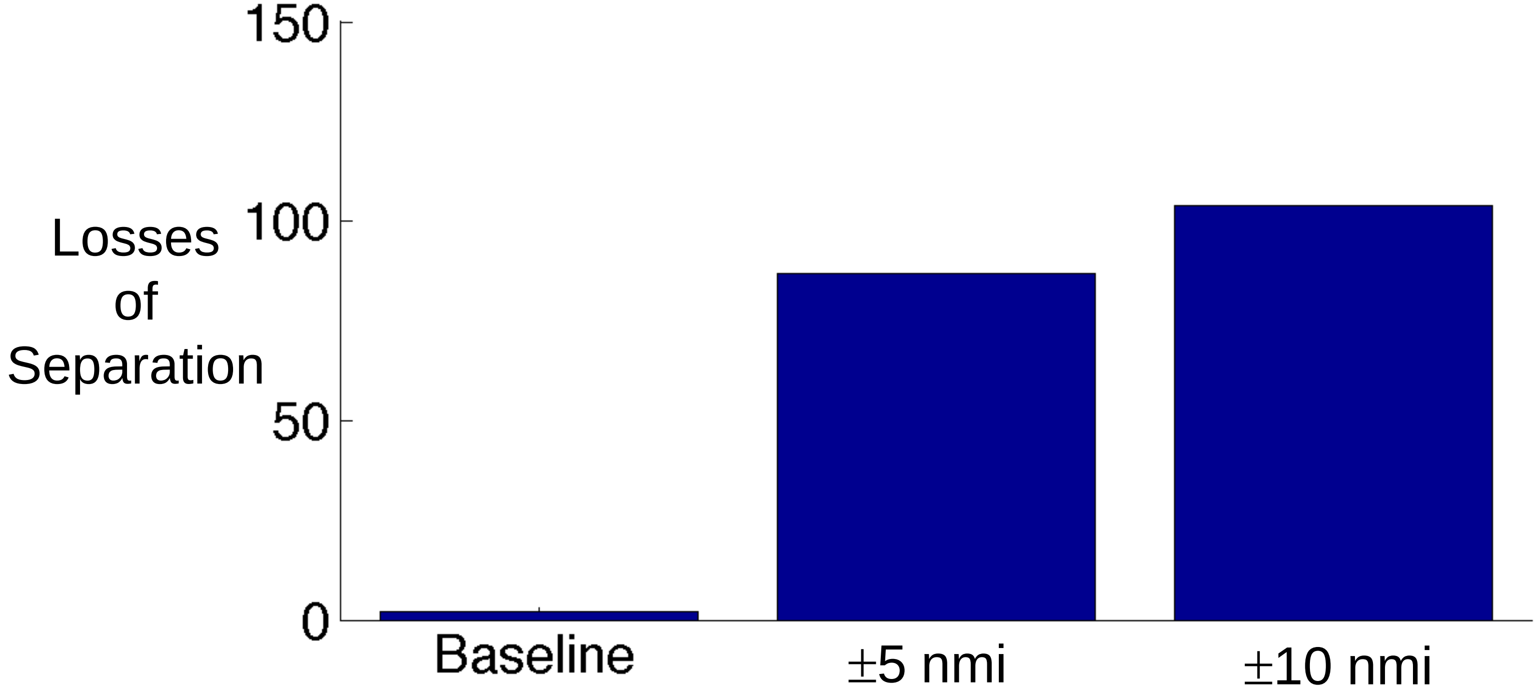
- About the same number of losses as the cruise speed case
- Linear increase with amount of error

Maneuver-Initiation-Time Errors



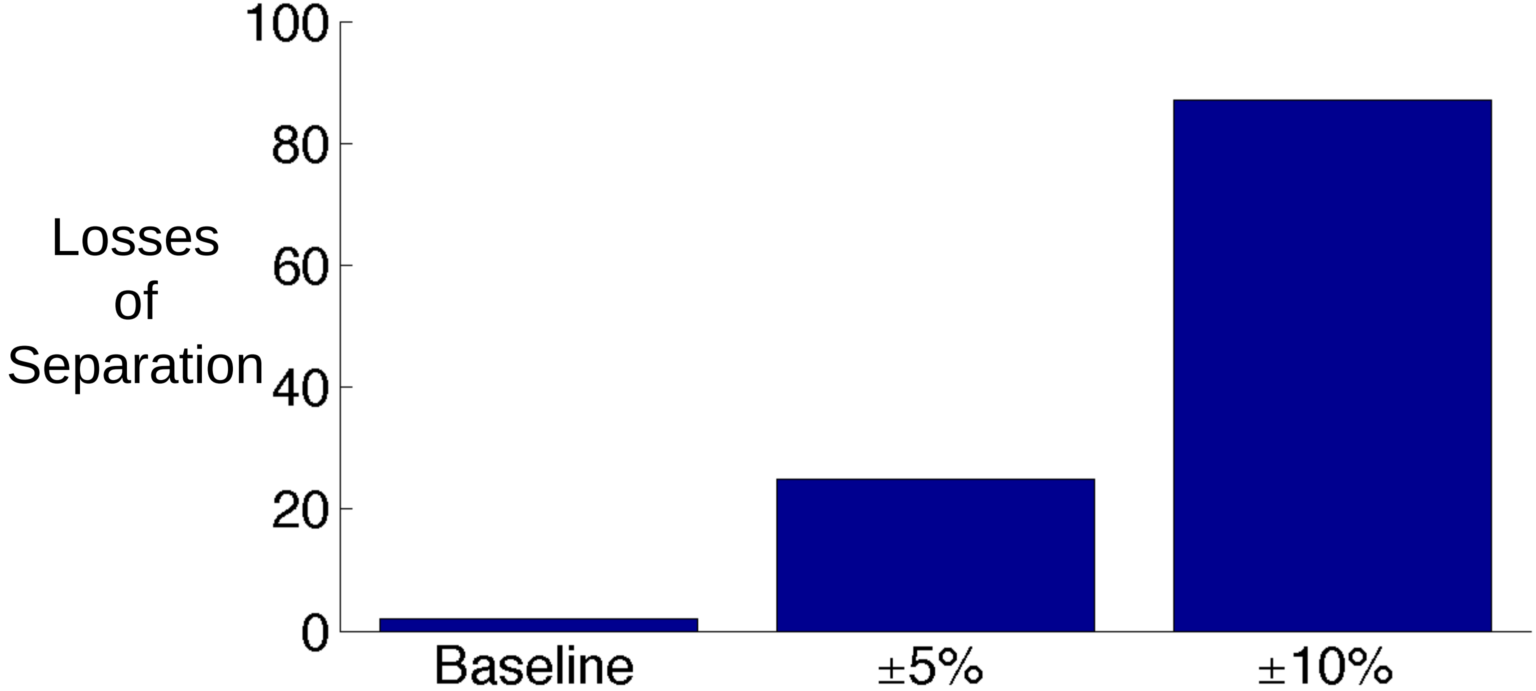
- Causes more errors than the previous cases
- Only impacts aircraft which are maneuvering

Top-of-Descent Errors



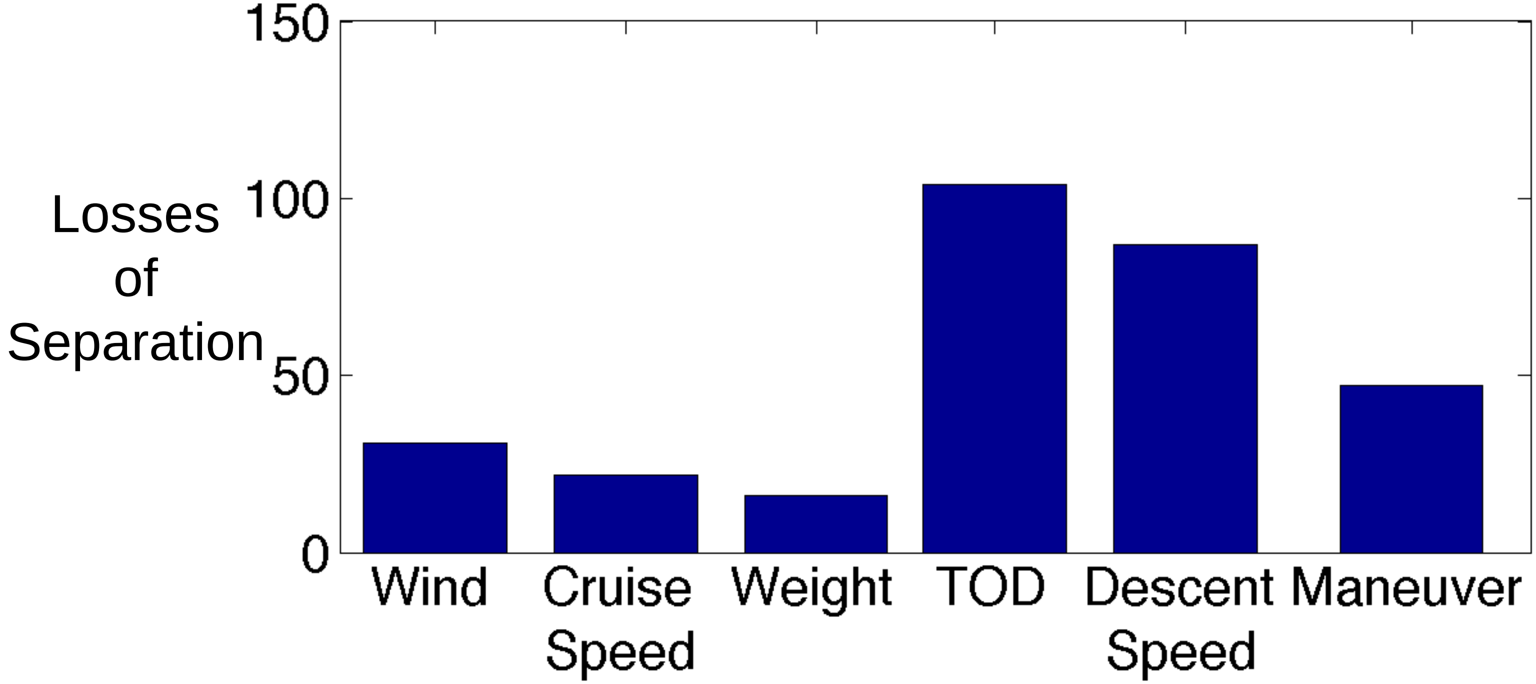
- Results in the most losses of separation
- Not as dependent on the error amount

Descent-Speed Errors



- Large number of losses for the large error case
- Losses are dependent on error amount

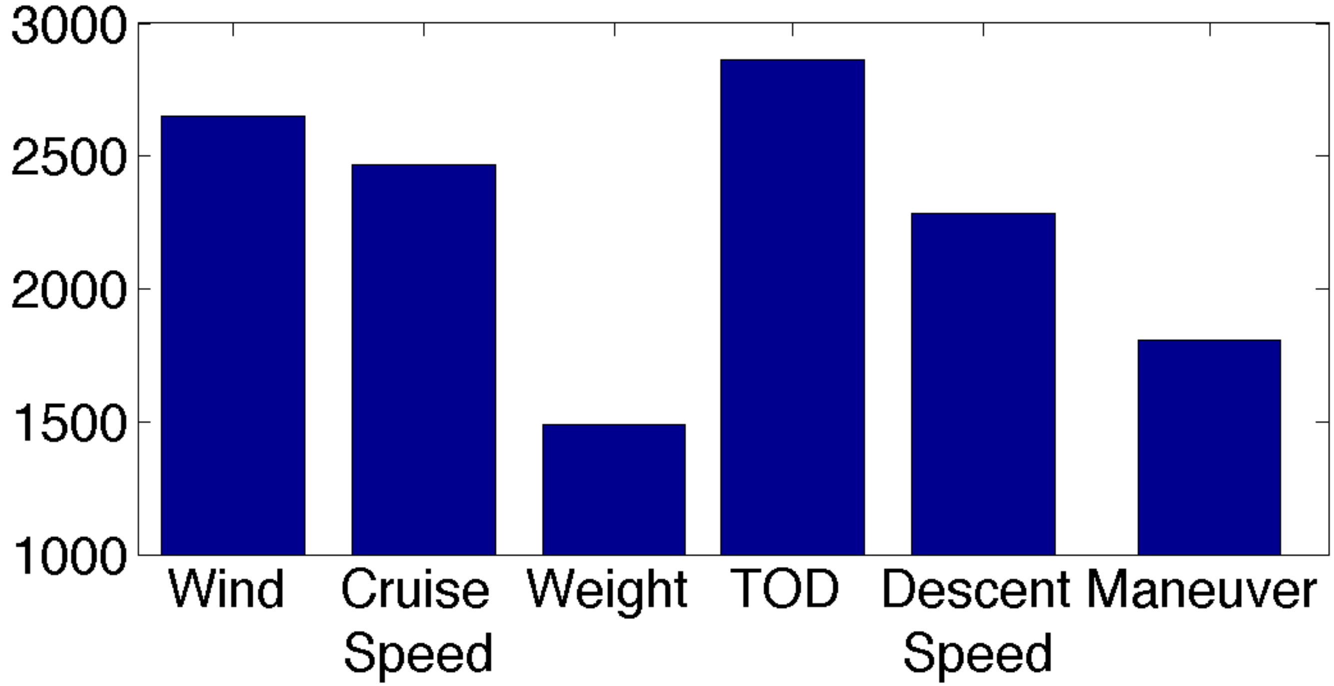
Losses of Separation



- Descent prediction errors result in significant amount of losses of separation
- Wind, weight, and cruise speed errors are less important

Delay Summary

Total
Delay
(minutes)



- Top-of-descent errors result in large delays
- Wind and cruise speed errors also contribute a lot to delay

Conclusions

- Over 90% of all losses were resolved for all cases
- Prediction errors result in increased losses and delay
- Descent prediction errors result in many late predictions and the largest number of losses

Future Work

- Identify algorithm improvements for robustness
- Experiment with combinations of errors