CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

Monte Carlo Simulation of an ADS-B Application

Flight Deck Based Merging and Spacing

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Background

- ADS-B technology enables new air traffic management procedure development
- FAA leading a group developing flight deck based merging and spacing (FDMS)
  - Participants: FAA, Surveillance and Broadcast Services Program, MITRE, NASA, Eurocontrol, industry
- FDMS enables flight crew to maintain spacing behind a designated aircraft (traffic-to-follow)
  - Improve airport arrival traffic flow management
  - Improve runway capacity
  - Reduce flight delays
  - Reduce air traffic controller workload
  - Reduce radio communications
  - Improve use of continuous descent arrival (CDA)

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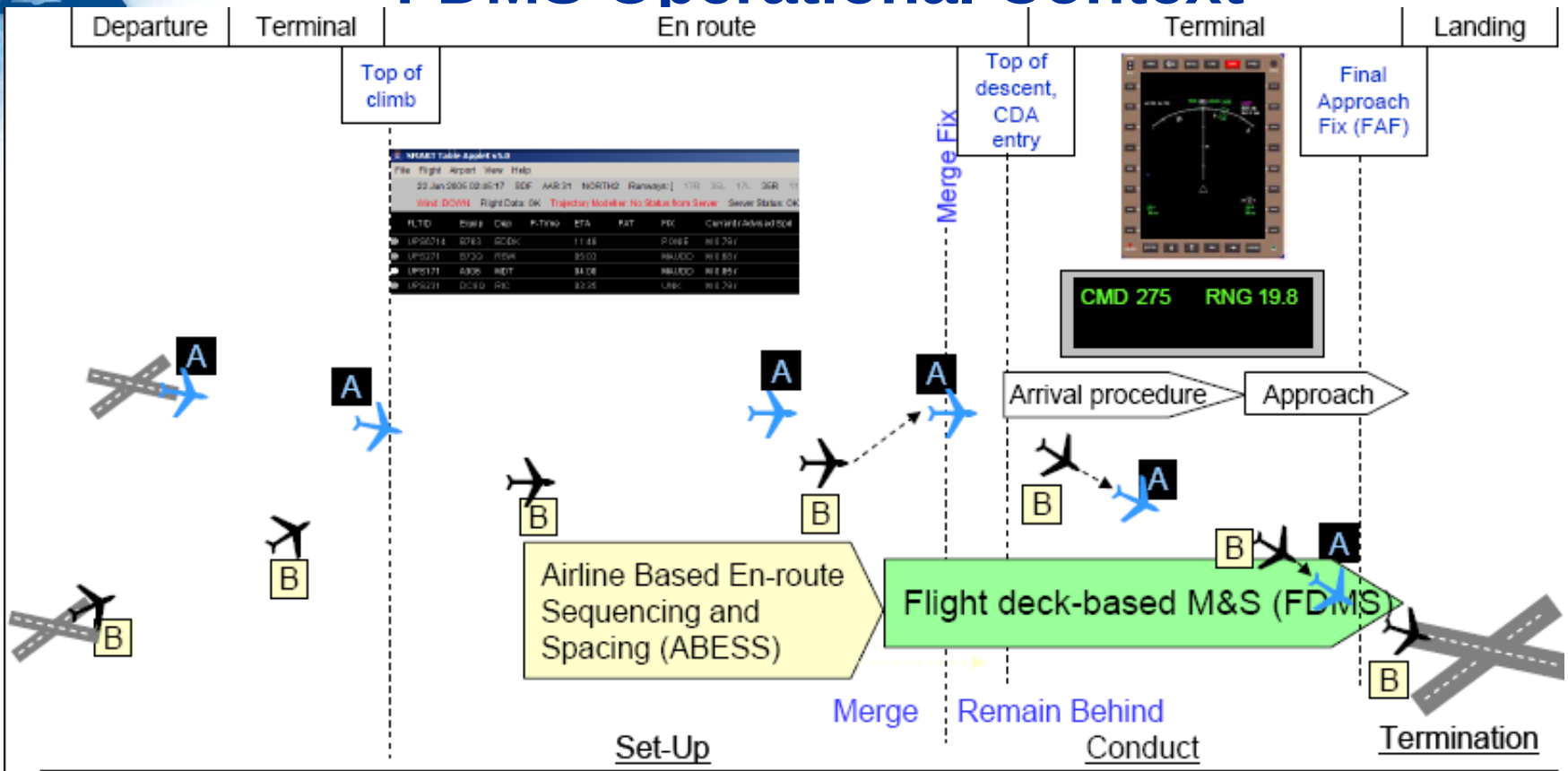
FDMS Operational Context



Goal	Strategic arrival spacing at merge fix and setup for flight deck-based M&S.	Fine-tuned arrival and landing spacing.
"New" airline operations center role	Provide speed instructions via ACARS targeting delivery of miles-in-trail at CDA entry / merge fix.	No new tasks.
Flight deck role	Fly speed provided by operations center until in ADS-B range.	Start flying M&S speed advisories when in ADS-B range and continue until the Final Approach Fix (FAF). At FAF, fly planned final approach speed until landing. Monitor for annunciated failures / conditions.
ATC Role	Ensure safe separation as well as to monitor operation with interventions as necessary for spacing or conflicts.	Ensure safe separation as well as to monitor operation with interventions as necessary for spacing or conflicts.

Speed Guidance Algorithm for Initial Development and Test Period

- **Eurocontrol Experimental Center (EEC) algorithm**
  - **Apply time-based spacing strategy**
  - **Provide suggested speed to aircrew**
  - **Two operating modes: merge behind, remain behind**
- ***Merge Behind* spacing mode**
  - **Flight segment prior to cruise altitude merge fix**
    - **Ownship and traffic-to-follow on same or different routes**
  - **Time-based spacing goal achieved at merge fix**
- ***Remain Behind* spacing mode**
  - **Flight segment after merge fix**
    - **Ownship and traffic-to-follow on same route**
      - **Individual cruise altitudes until top of descent (TOD)**
      - **Common continuous descent arrival (~2.75º flight path angle)**
  - **Constant spacing (time behind)**

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Speed Guidance Algorithm Strategy

- **Achieve a *TimeSpacing* goal with respect to designated traffic-to-follow (TTF)**
  - **Arrive at a location *TimeSpacing* (seconds) after TTF**
  - **For merge behind case, location is effectively ownship distance to merge fix plotted on TTF track**
- **Ownship basic speed guidance**
  - **Match *TTFspeed***
  - **Correct *TimeSpacingError* in *RecoveryTime* seconds**

$$\textit{SuggestedSpeed} = \textit{TTFspeed}_{(\textit{CurrentTime} - \textit{TimeSpacing} + \textit{Anticipation})} + \textit{OwnshipGroundSpeed} * \frac{\textit{TimeSpacingError}}{\textit{RecoveryTime}}$$

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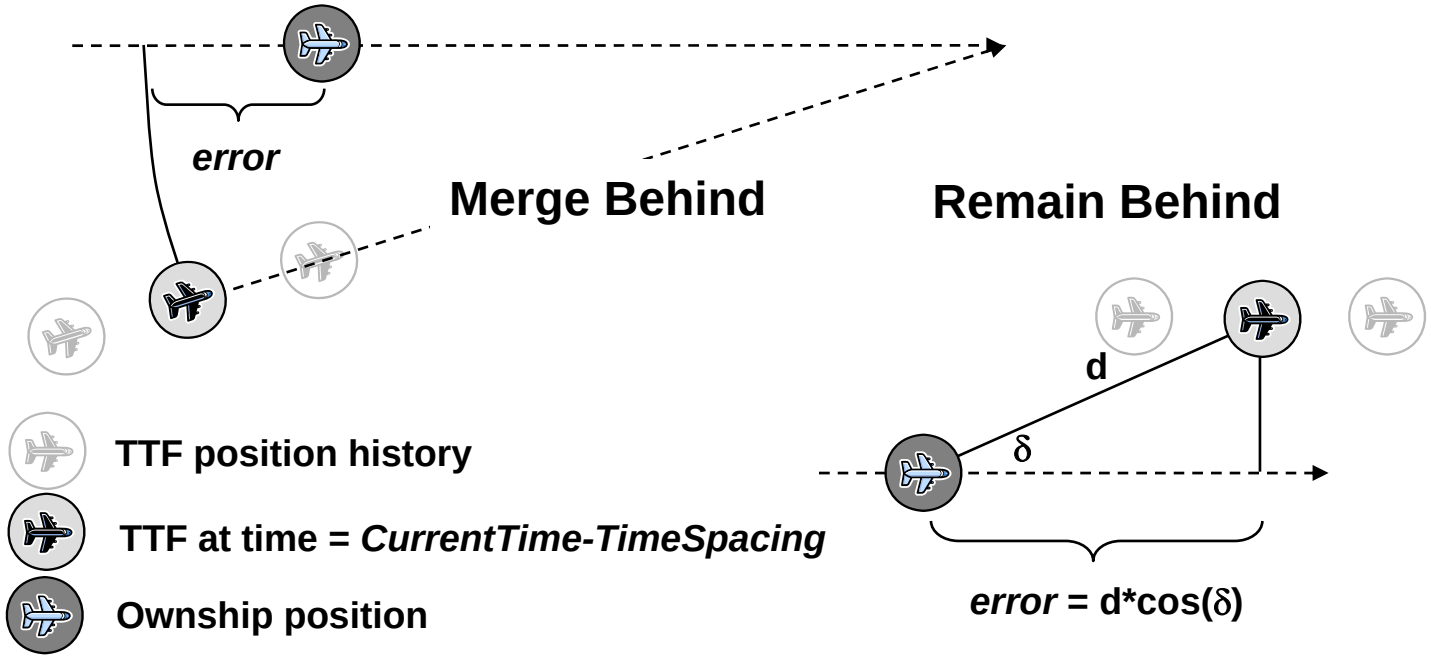
Ownship Position Error Determination



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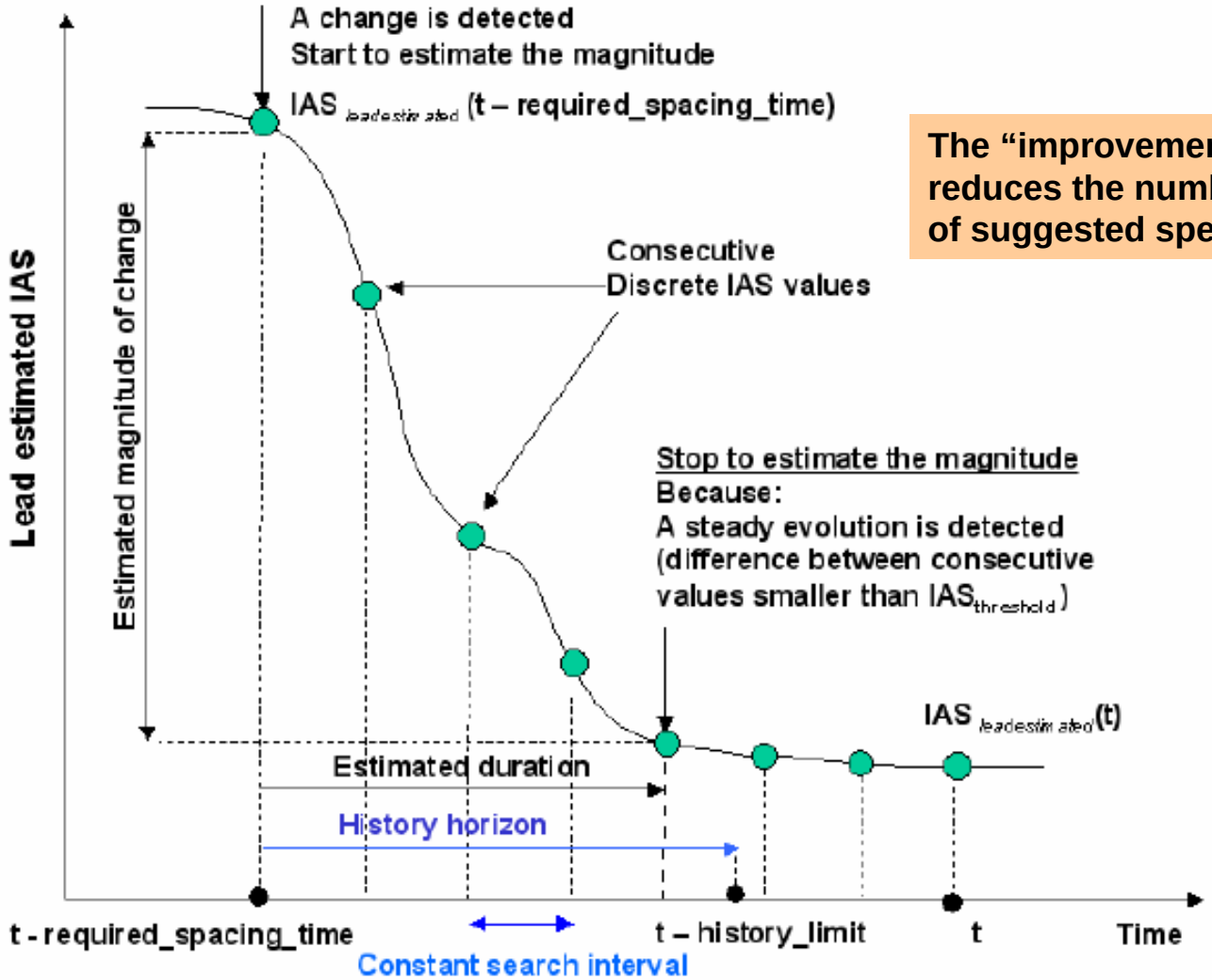
Improved Suggested Speed Calculation Estimate Changed IAS *(EEC FD-URD-2.1 Fig 4)*



The "improvement" reduces the number of suggested speeds

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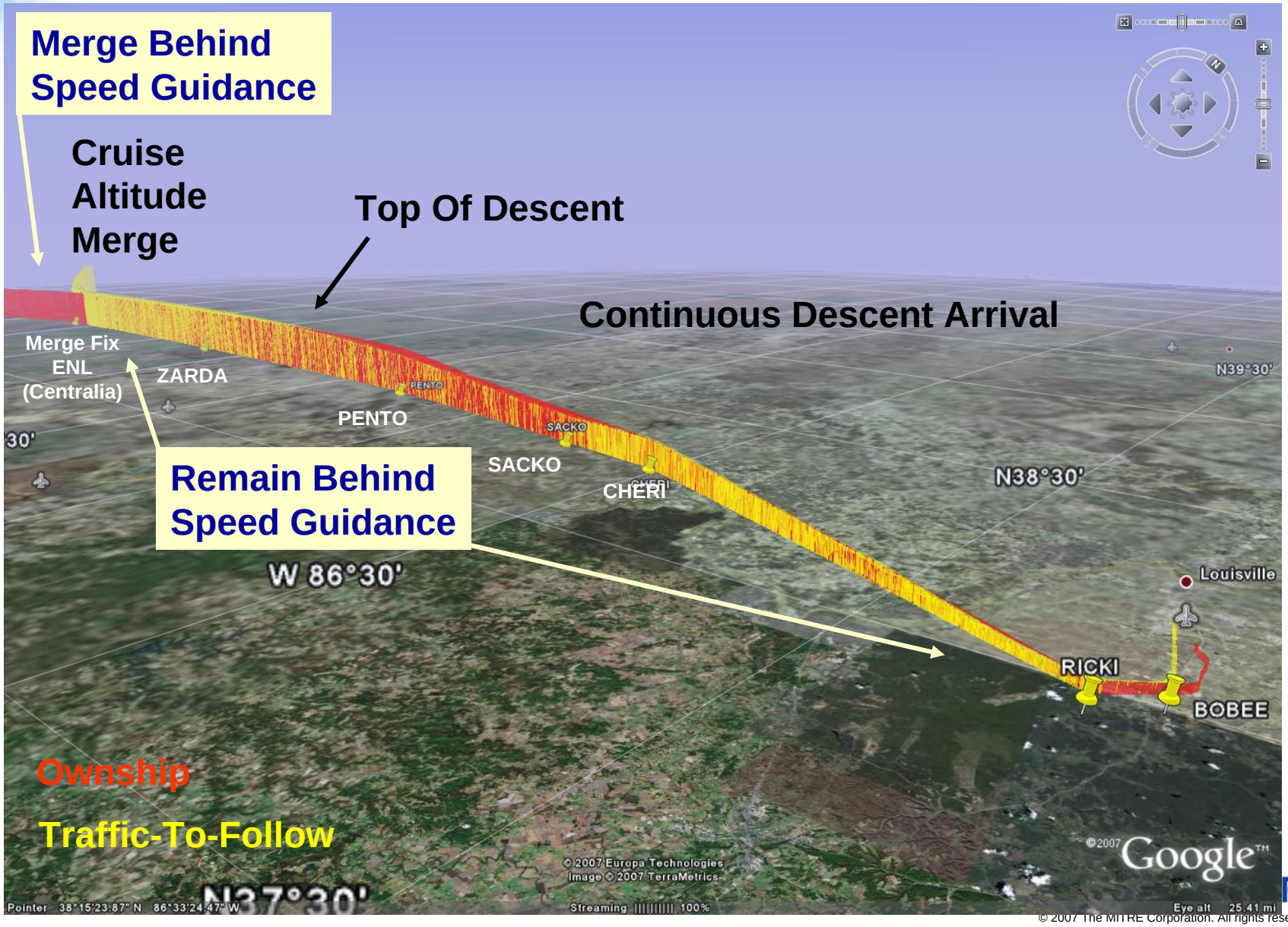
FDMS Flight Test Scenario



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Monte Carlo Simulation Objectives

- Support near-term achievement of FDMS operational capability
- Work with FDMS development group
  - Ensure Monte Carlo simulation applies accurate model of both the procedure and the avionics implementation of the EEC algorithm
  - Ensure simulation analysis findings are applied to foster the best possible performance from the algorithm
- Develop knowledge basis for adapting the EEC algorithm for FDMS
  - Establish expected performance limits
  - Establish normal operational procedures
  - Establish an acceptable algorithm configuration
    - Nominal and limiting parameter values

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Monte Carlo Analysis Plan

- **Tune algorithm parameters to support FDMS with desirable performance attributes**
  - **Stable arrival rate at the FAF**
  - **Reduced time between the arrivals of the first and last aircraft in a sequence**
  - **Acceptable performance: aircraft speed, spacing between aircraft pairs, and number of speed changes (flight crew workload)**
- **Analyze alternative methods to reduce number of suggested speeds**
- **Evaluate spacing performance**
- **Evaluate effects of wind**

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Methods to Reduce Number of Suggested Speeds Generated

- Improved Speed Law
- Below 10,000 ft MSL, do not allow speed increases
  - Algorithm shows bias for spacing too close at FAF, so reduce by eliminating commands to speed up
  - Number of suggested speeds reduced, but with greatly increased spacing error
  - Concept discarded after minimal investigation
- Limit (suppress) next speed suggestion for a minimum wait period
- Filter and round suggested speeds to 10 knots

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Analysis Test Cases
Methods to Reduce No. of Suggested Speeds

Test each method for two time of arrival at merge fix cases: 1 sec and 10 sec standard deviation

Case	EEC Speed Law	Speed Filter and Rounding (knots)	Limit (min sec between speed changes)	Merge Fix TOA Standard Deviation (sec)
Baseline	Basic	5	None	1
1	Improved	5	None	1
2	Improved	5	None	10
3	Improved	5	40	1
4	Improved	5	40	10
5	Improved	10	None	1
6	Improved	10	None	10

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Monte Carlo Simulation Parameters Remain Behind Segment

- **Time of arrival (TOA) difference at ENL**

  Mean = 120 sec Standard Deviation = 1 or 10 sec
- **Number of aircraft: 16**
- **Number of iterations per aircraft pair: 500**
- **GPS/WAAS position accuracy: NACp = 10**
- **Probability of receiving ADS-B: 0.995**
- **Algorithm parameters**
  - ***TimeSpacing* (spacing goal): 120 sec**
  - ***RecoveryTime*: 120 sec**
  - ***Anticipation*: 10 sec**

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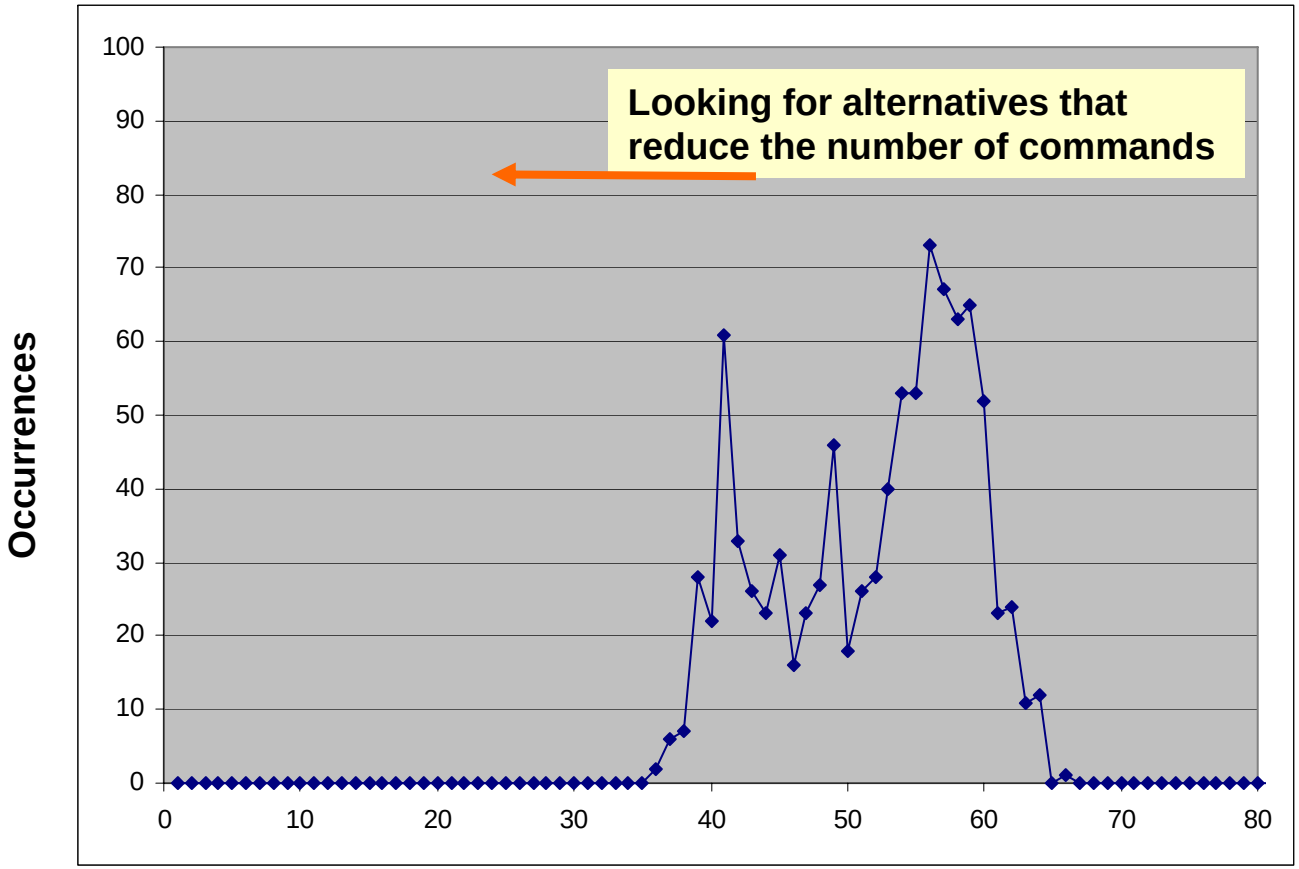
Speed Command Frequency

Baseline: Basic Speed Law
Arrival Standard Deviation = 1 sec



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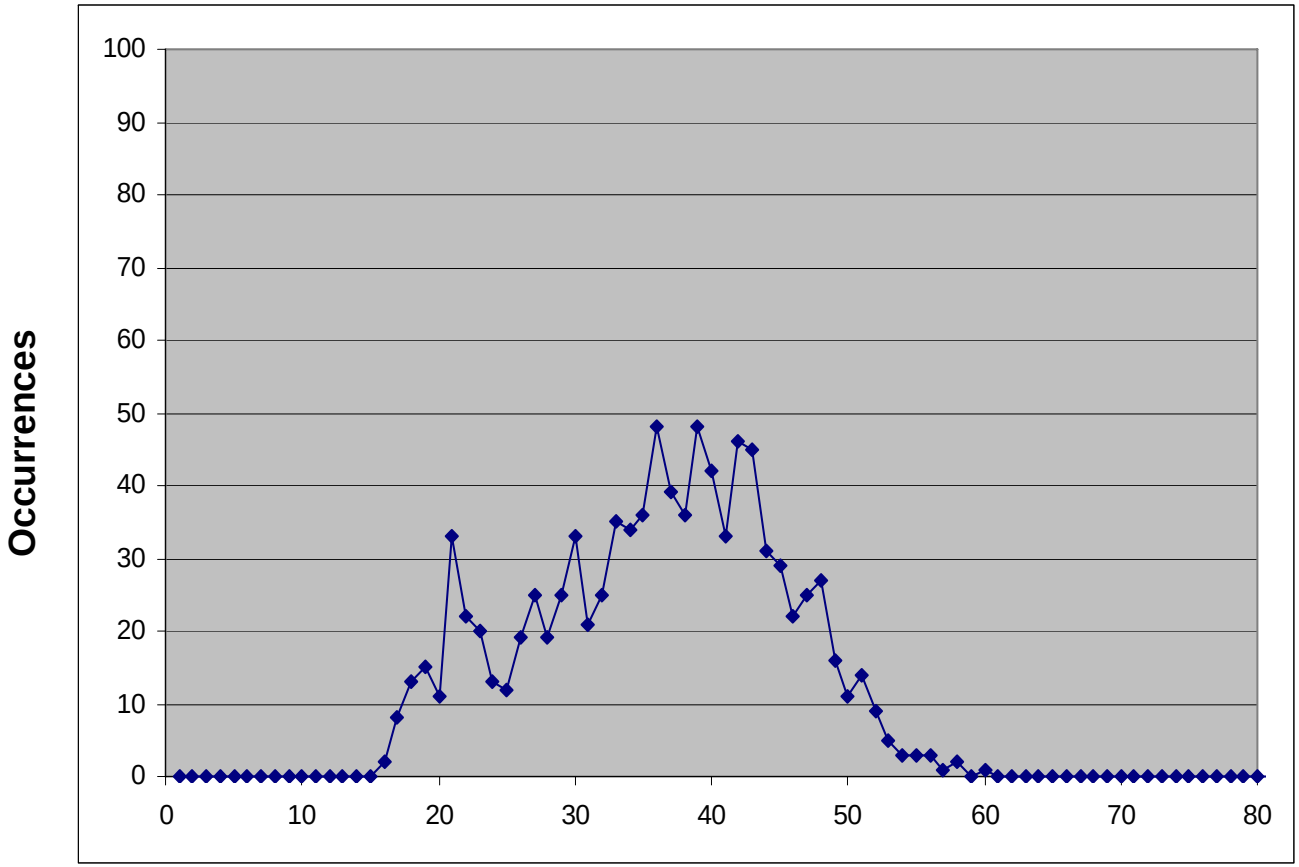
Speed Command Frequency

Cases 1 & 2: Improved Speed Law



Number of Suggested Speed Commands

Similar results for merge fix time of arrival = 1 or 10 sec standard deviation
10 sec data shown

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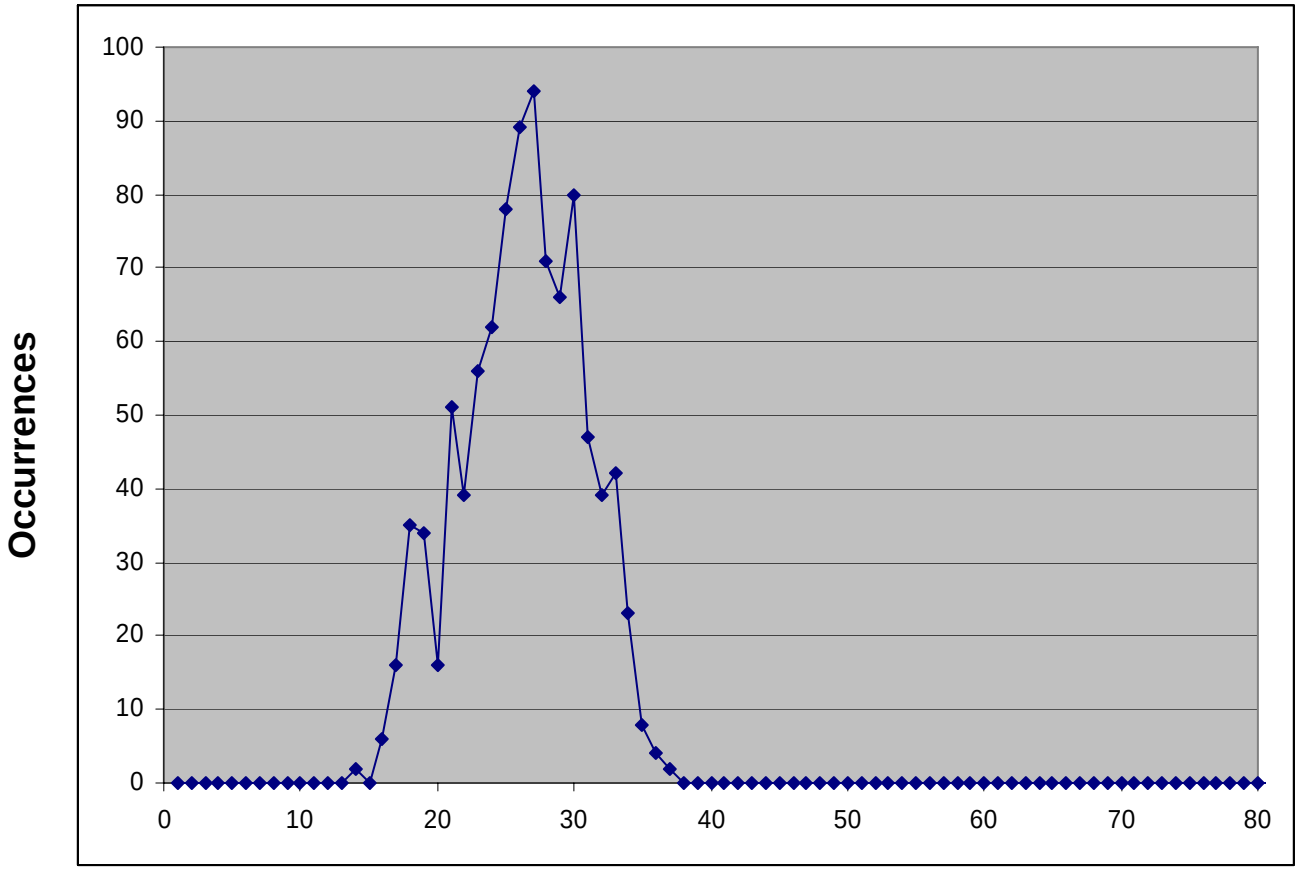
Speed Command Frequency

Cases 3 & 4: Improved Speed Law + 40 sec Limit



Number of Suggested Speed Commands

Similar results for merge fix time of arrival = 1 or 10 sec standard deviation
10 sec data shown

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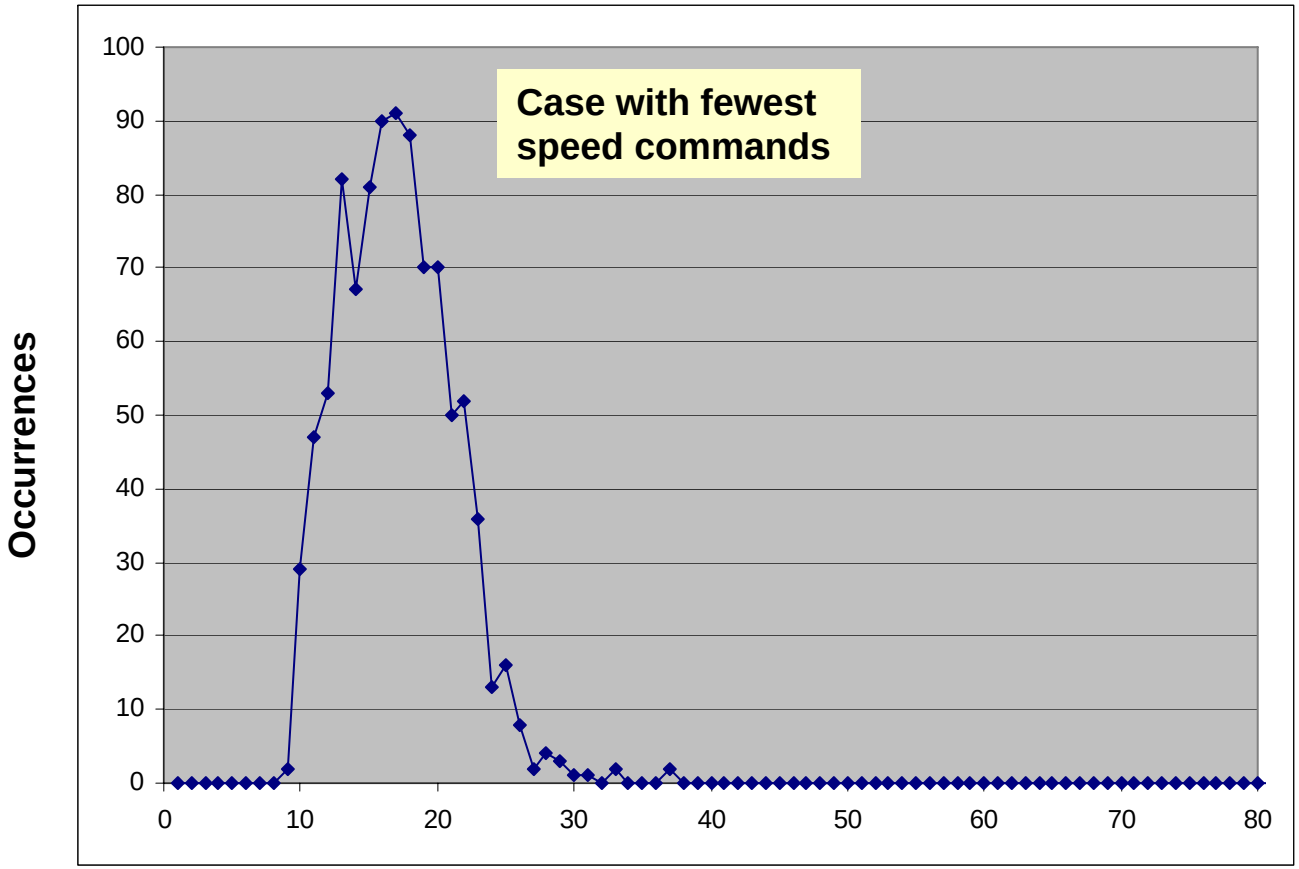
Speed Command Frequency

Cases 5 & 6: Improved Speed Law + 10 kt Rounding



Similar results for merge fix time of arrival = 1 or 10 sec standard deviation
10 sec data shown

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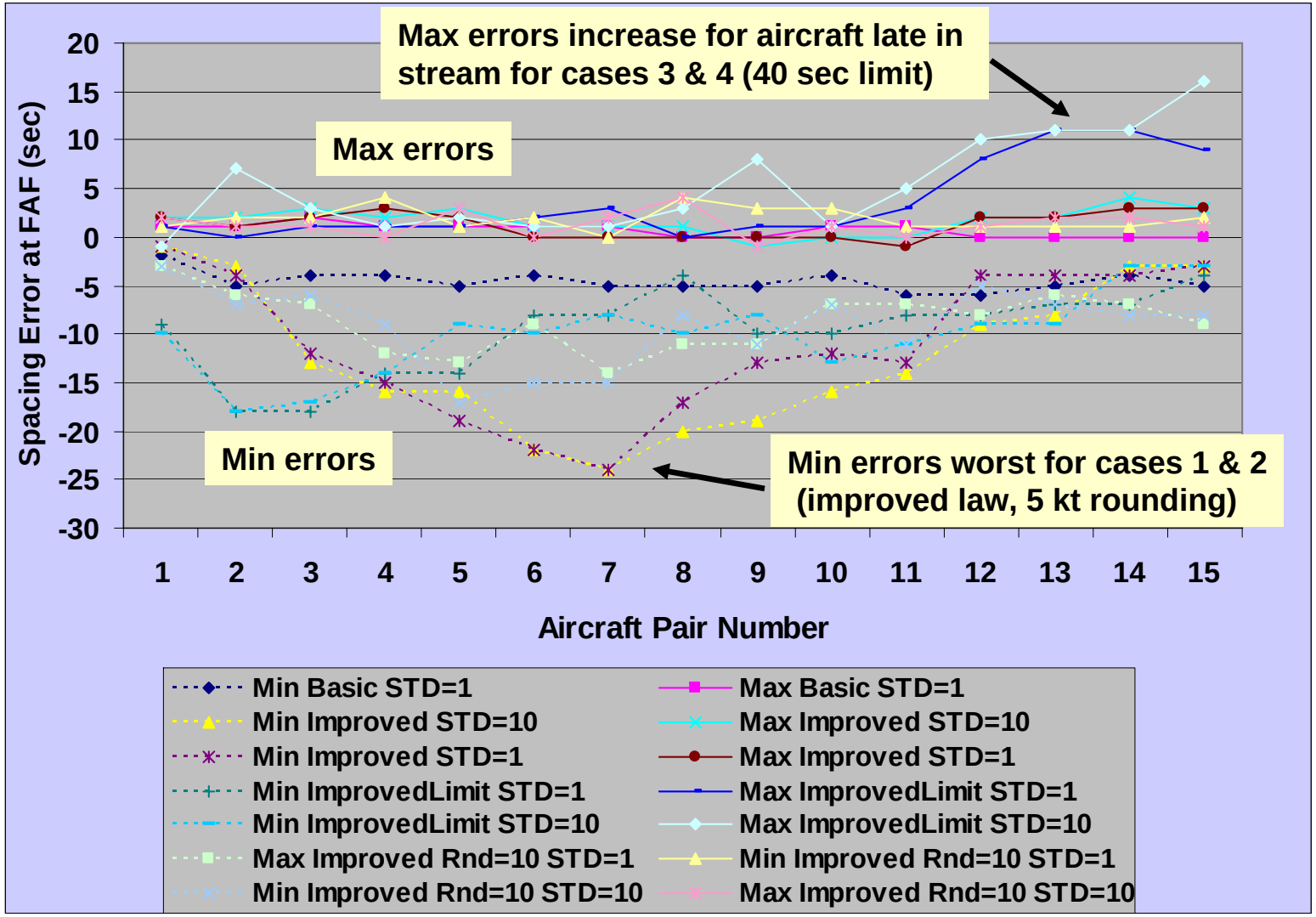
Min and Max Spacing Errors at Final Approach Fix



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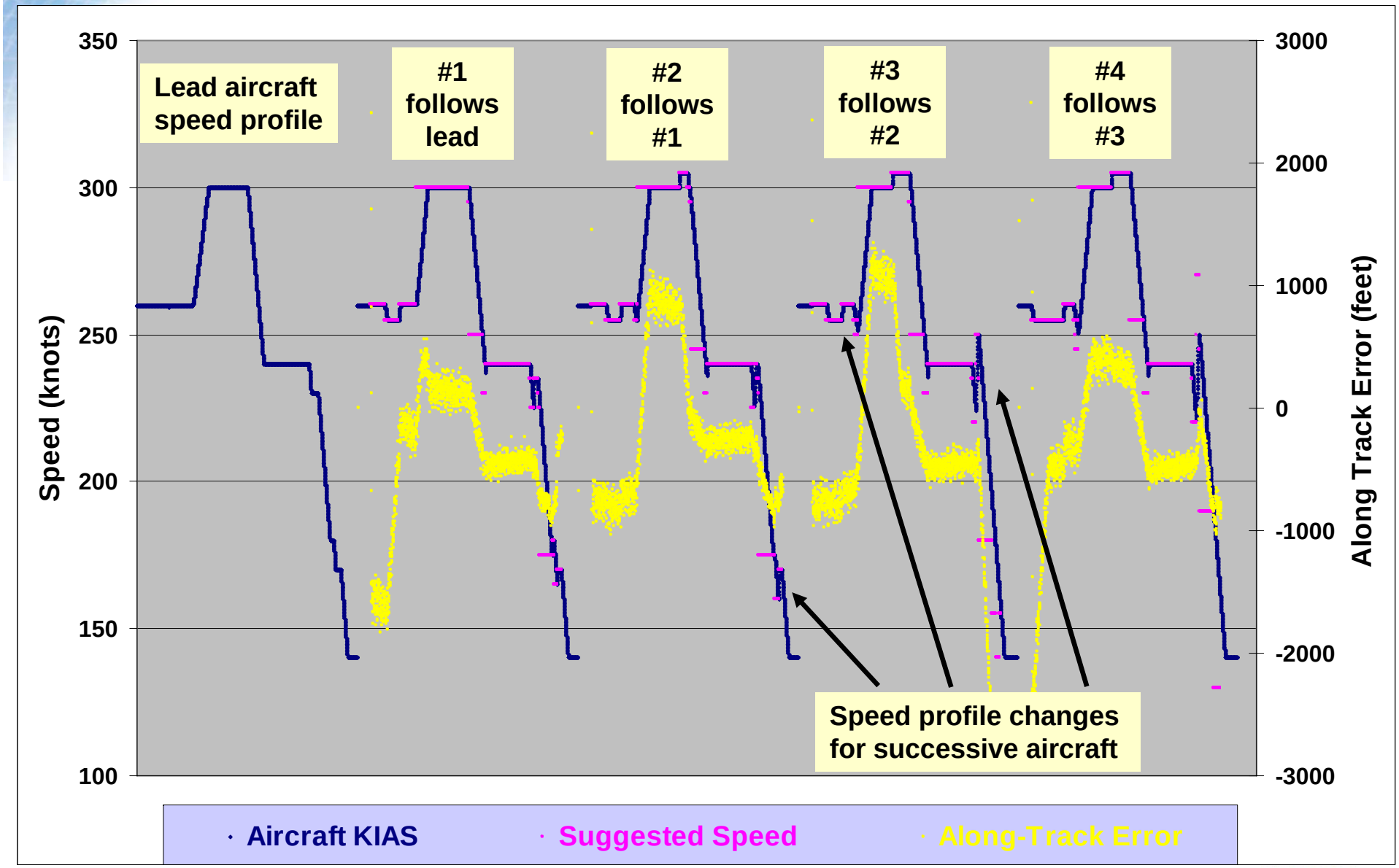
Case 1 Sample: FDMS Lead and 4 Following Aircraft Data Shown vs Position on Arrival Route



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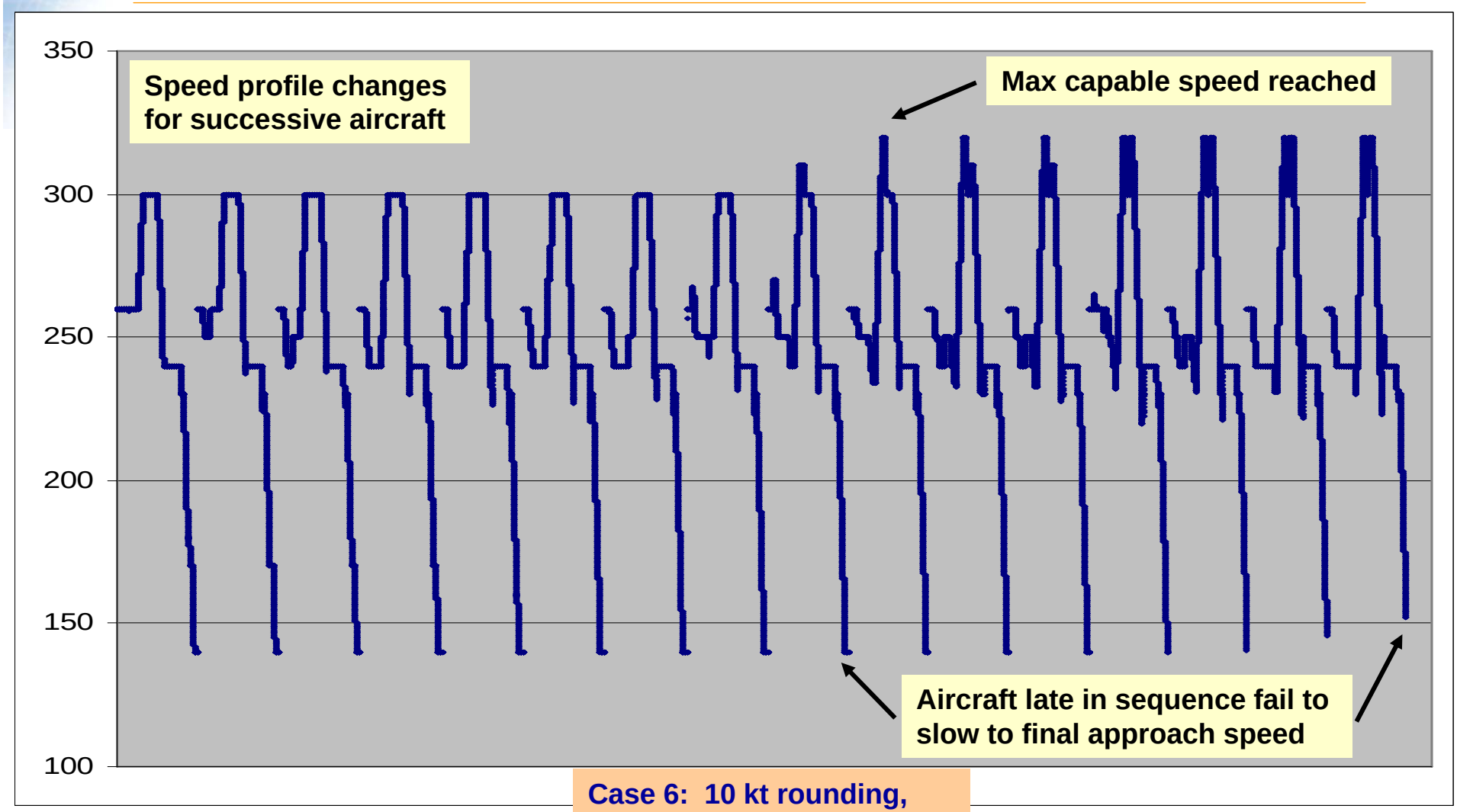
Case 6 Sample
Aircraft KIAS vs Position on Arrival Route



Case 6: 10 kt rounding, Improved Speed Law, TOA standard deviation=10

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Summary of Findings—Analysis of Methods to Reduce No. of Suggested Speeds

- **10 kt filtering & rounding (F&R) performs better than 5 kt F&R alone or with command limiting**
  - **Average < 1 change per minute (27 minute procedure)**
- **Speed profile flown by successive aircraft deteriorates compared to target speed profile**
- **In many cases, later aircraft in a sequence are driven to an unacceptably high speed at FAF**
- **Increased spacing variation at merge waypoint**
  - **Produces unacceptable high speed sooner (at earlier iteration in sequence)**
  - **Introduces target speed profile deviations sooner**

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Conclusions

- 10 kt filtering & rounding appears desirable as a strategy to reduce number of speed changes
- Operational tests with the interim speed guidance algorithm should limit the number of aircraft in a sequence to no more than eight
- Pilots will abandon following speed guidance to decelerate in preparation for landing
  - The effect where aircraft late in a sequence are driven to increased speeds will be replaced by increased time separation at FAF
- Spacing performance is acceptable for worst case spacing variation at merge waypoint tested so far (10 sec standard deviation)

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Future Investigation Plans

- **Continue to improve understanding of algorithm performance and errors throughout the procedure**
  - **What is the effect of increasing spacing variance at the merge fix?**
- **Experiment by varying algorithm gain parameter over the CDA**
- **Experiment with a strategy to compute suggested speed based on *nominal profile speed* plus error correction adjustment**
- **Evaluate performance for merge behind segment**
  - **Independently**
  - **Coupled with remain behind segment**
- **Evaluate performance in varying wind fields**

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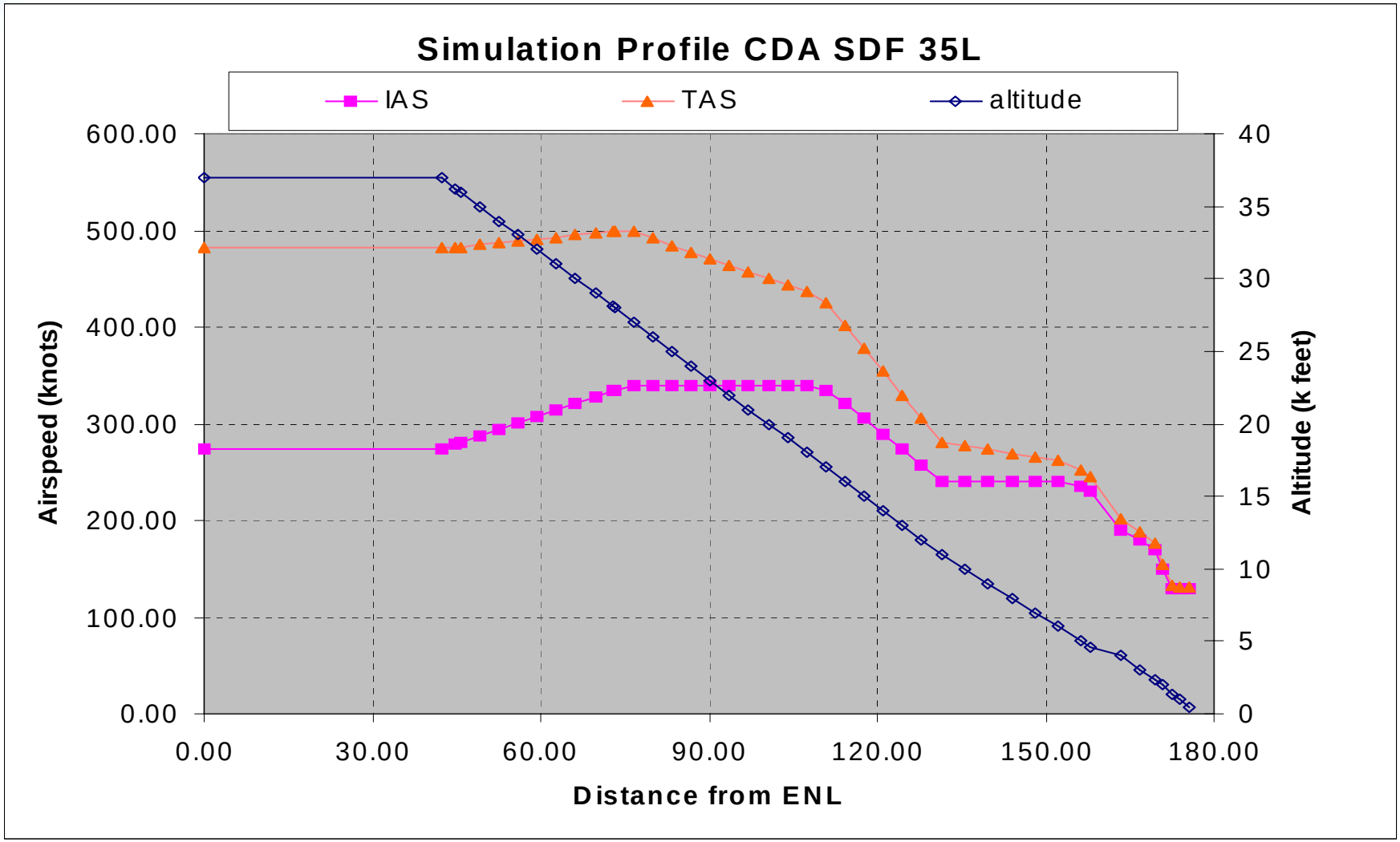
Continuous Descent Arrival Nominal Airspeed Profile



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