Flight Demonstration of the Separation Analysis Methodology for Continuous Descent Arrival

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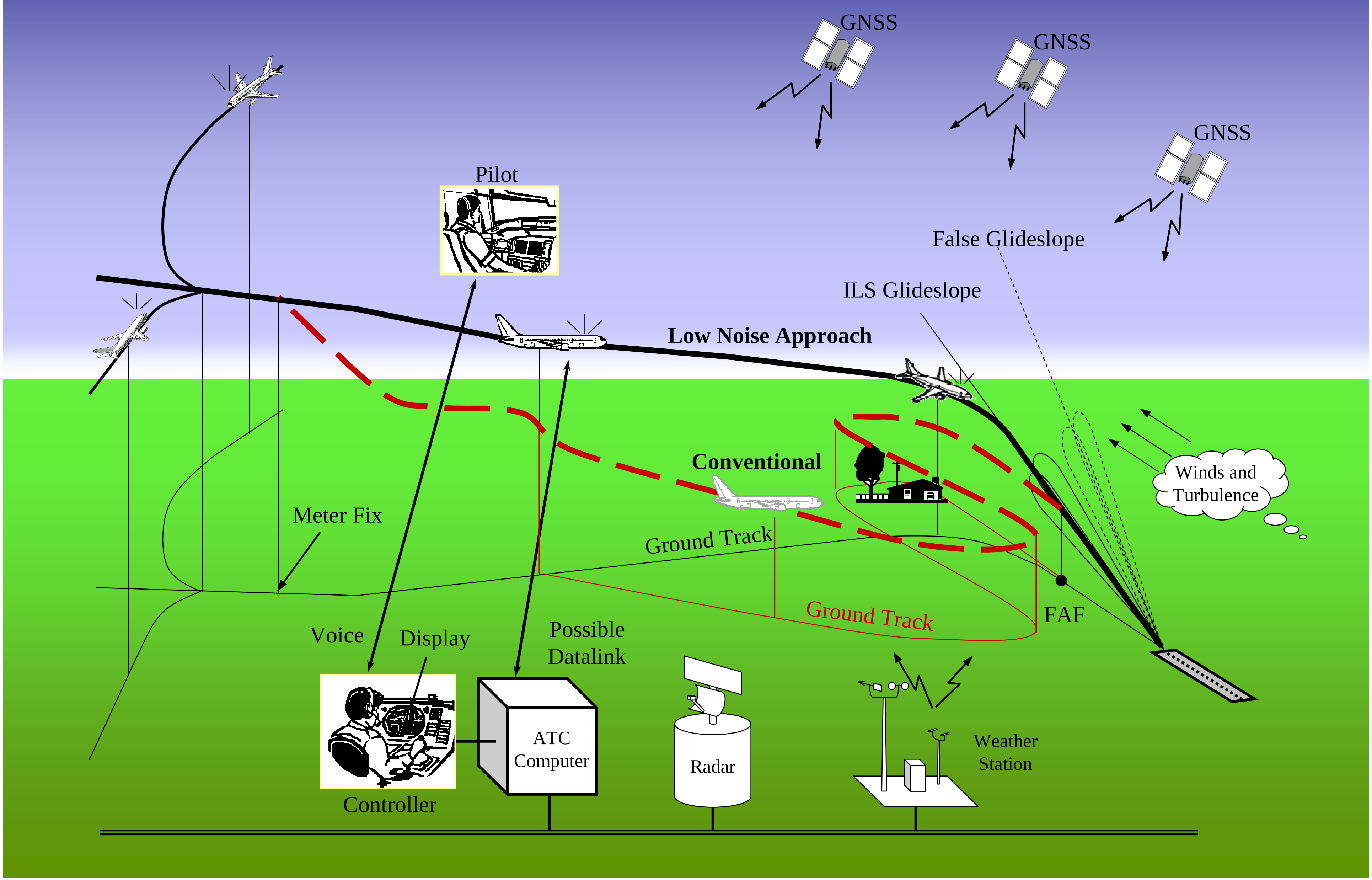
Problem Definition

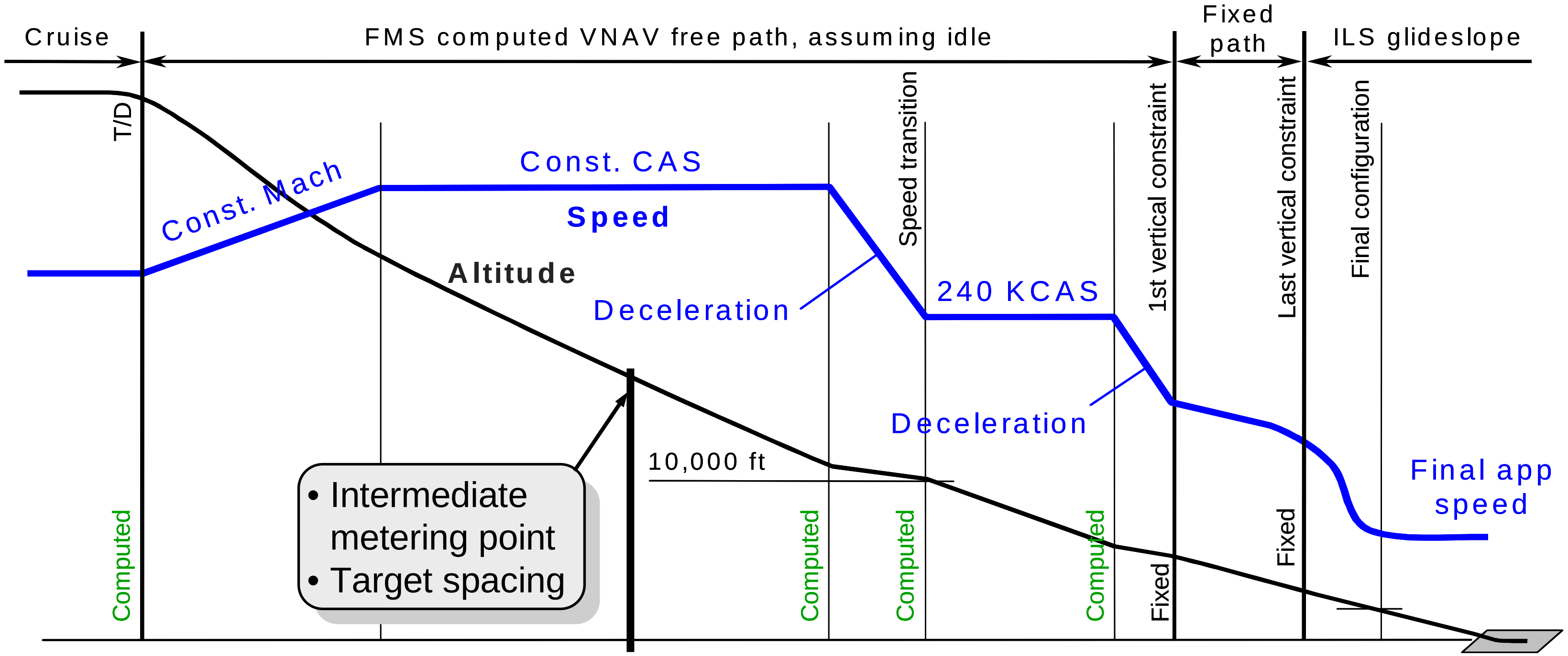
- **Continuous Descent Arrivals (CDA)**
  - Leverage on GPS based RNAV/RNP and FMS
  - Descend (at idle) along a higher profile without level segment
    - Optimized to reduce noise, fuel burn, emissions, & flight time
- **Implementation Challenges**
  - Aircraft trajectory variations due to operational uncertainties
  - Difficult for controllers to predict and maintain separations
  - Without proper decision support tools, controllers need to add arbitrarily large buffers, reducing airport throughput
    - More than 50% reduction observed in a study at Amsterdam Schiphol*
- **Objectives**
  - Develop methodology and tools for air traffic controllers to efficiently manage the separation for CDA

*Erkelens 2000, Research Into New Noise Abatement Procedures for the 21st Century

Continuous Descent vs. Conventional



Research Approach



- Provide a Target Spacing at the intermediate metering point
  - To assure separation minima at a high probability throughout the remainder of the procedure without controller intervention
  - Intervene only when separation violation is predicted, low probability
- Model trajectory variations – Mote Carlo simulation or radar data
- Probability based separation analysis methodology

Modeling Aircraft Trajectory Variations

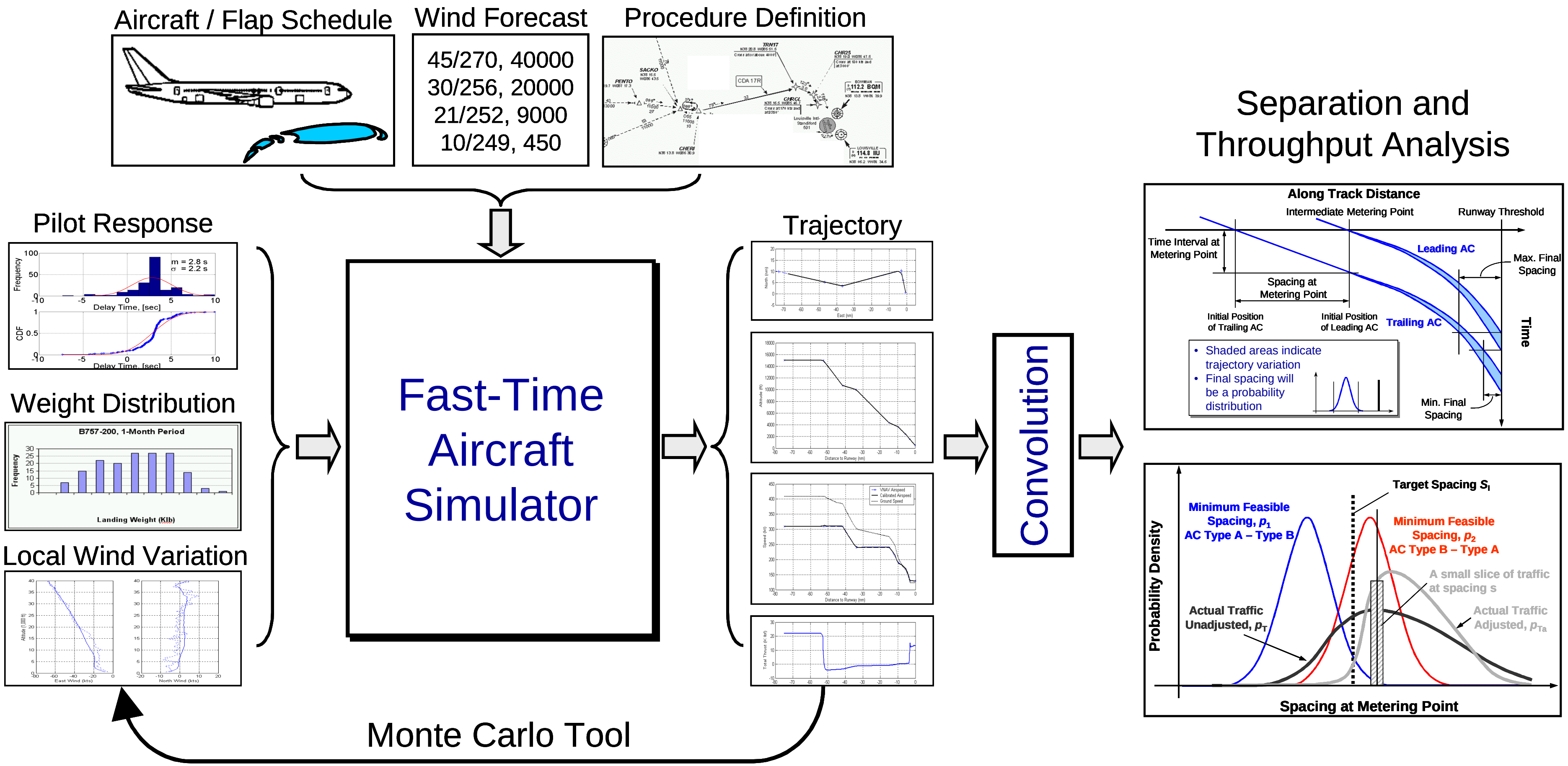
❑ Factors Contributing to Aircraft Trajectory Variations

- Aircraft type – differences in dynamics and performance
- CDA descent path logic – due to difference in FMS
- Pilot technique – pilot response randomness
- Aircraft weight – due to demand and operational conditions
- Weather conditions – predominantly winds, both wind variations between flights and forecast uncertainties
- Other factors

❑ Modeling Approach

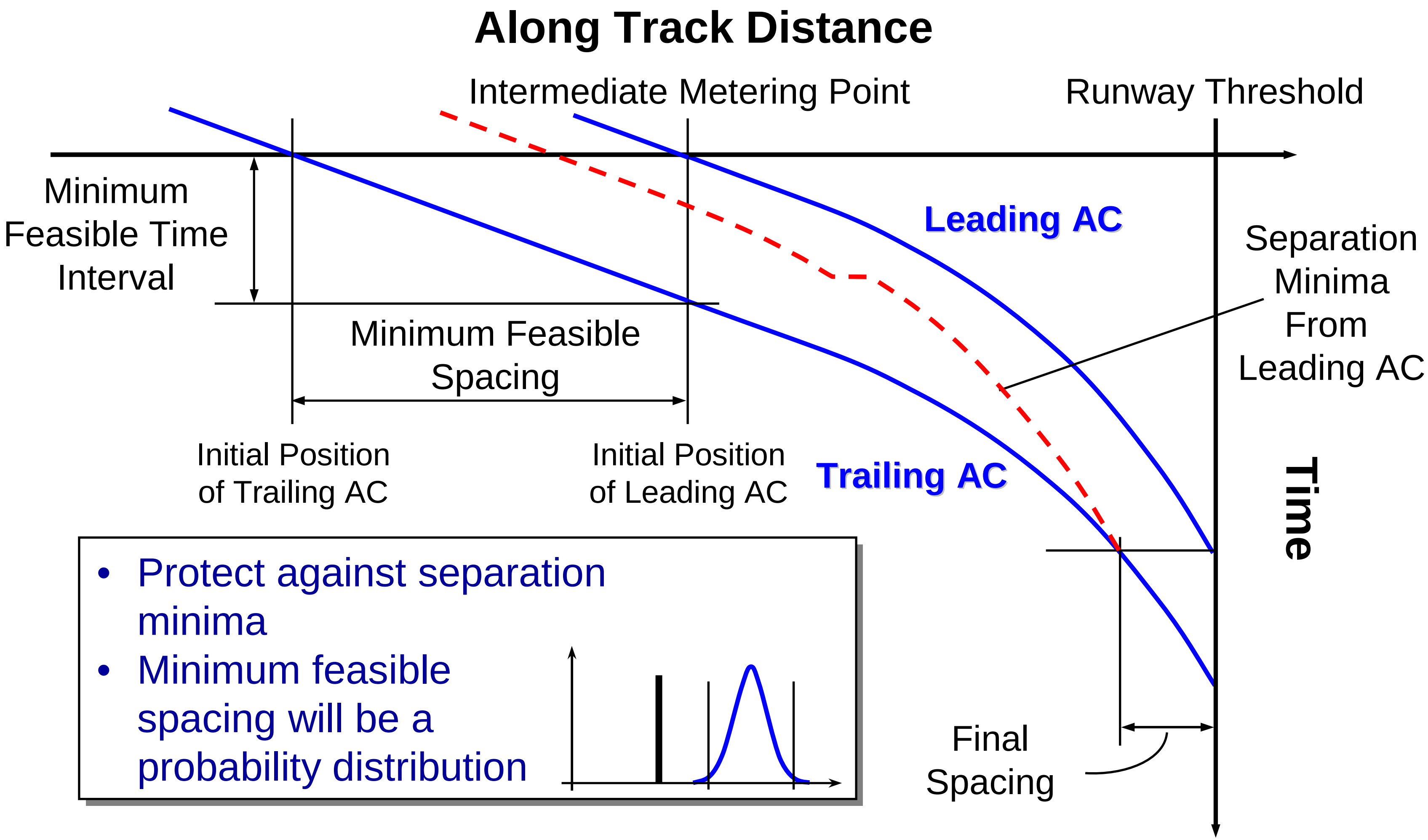
- Aircraft type & FMS logic modeled as part of the aircraft simulator
- Pilot response and aircraft weight modeled random variable
- Winds:
  - Nominal profiles – reflect statistical expectations
  - Wind changes between consecutive flights – non-linear/non-stationary
    - Mode decomposition and autoregressive model

Tool for the Analysis of Separation And Throughput (TASAT)



- Leading and trailing position simulated separately to signify wind change between flights

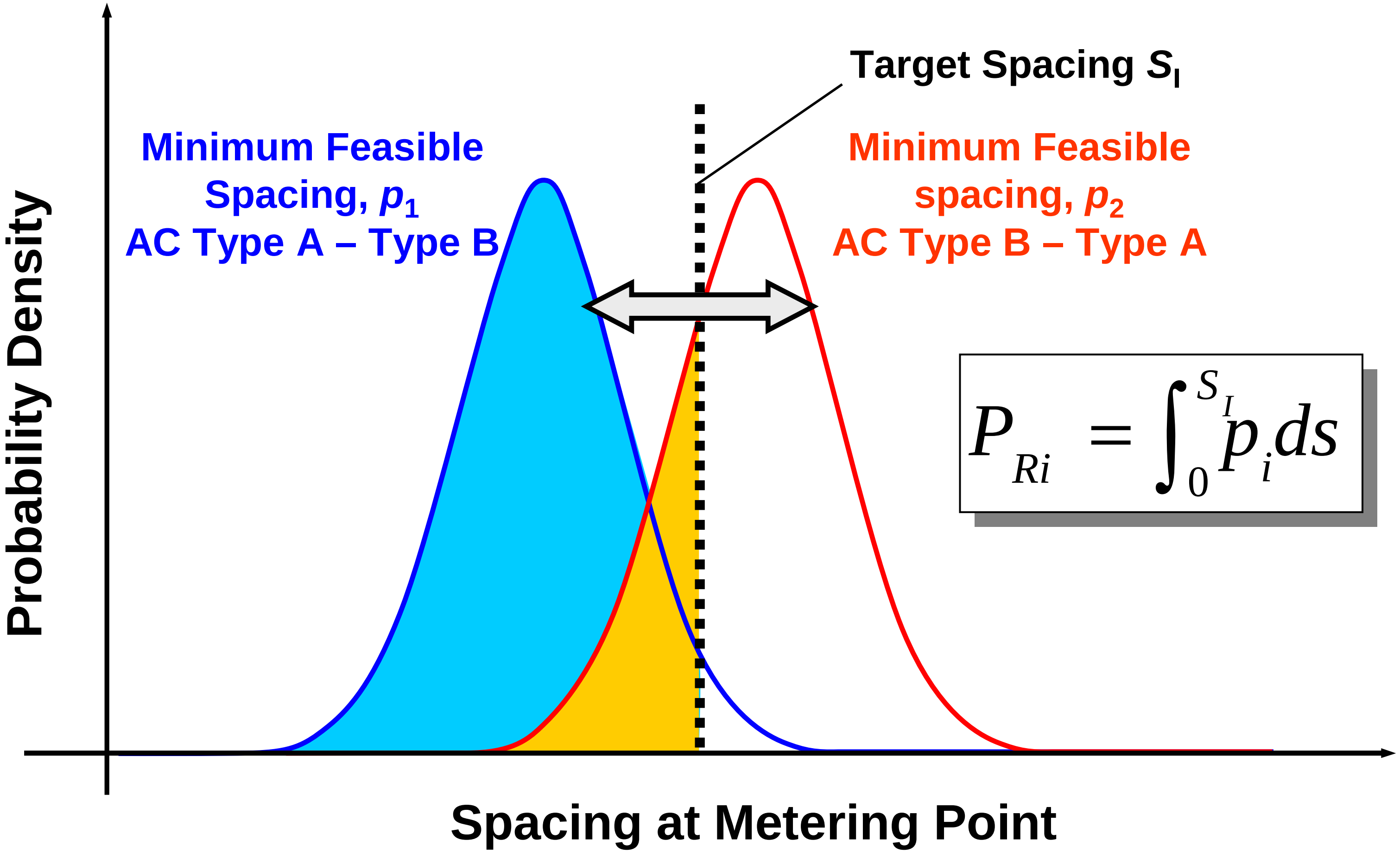
Minimum Feasible Spacing for A Pair of Trajectories



- Protect against separation minima
- Minimum feasible spacing will be a probability distribution

Conditional Probability Method

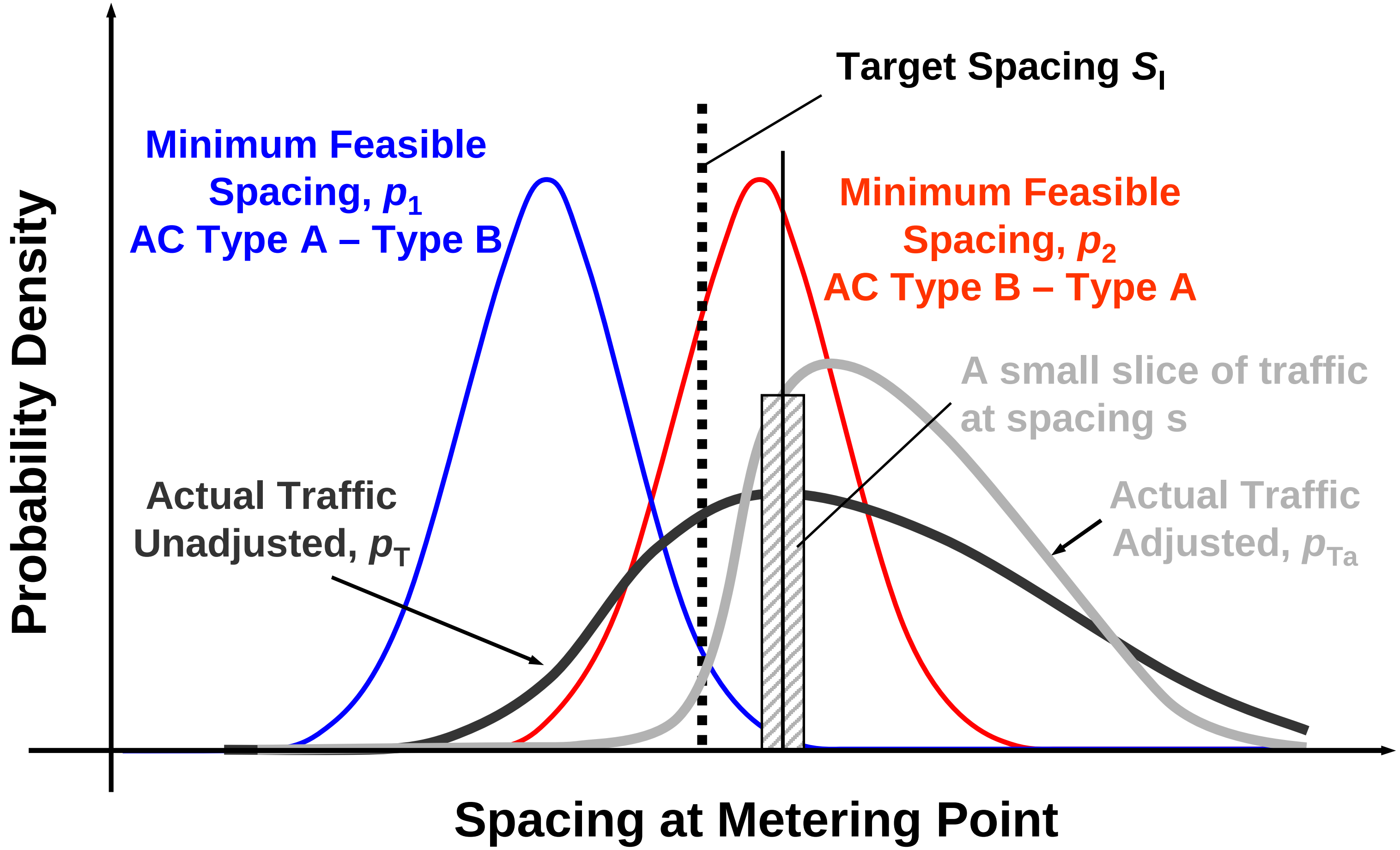
- **Conditional Probability for Given Target Spacing**
  - Integral of minimum feasible spacing pdf from zero to the target spacing



$$P_{Ri} = \int_0^{S_I} p_i ds$$

Total Probability Method

- **Total Probability for Traffic Distribution Subject to Target Spacing**
  - Weighted average of conditional probability for each traffic slice at s



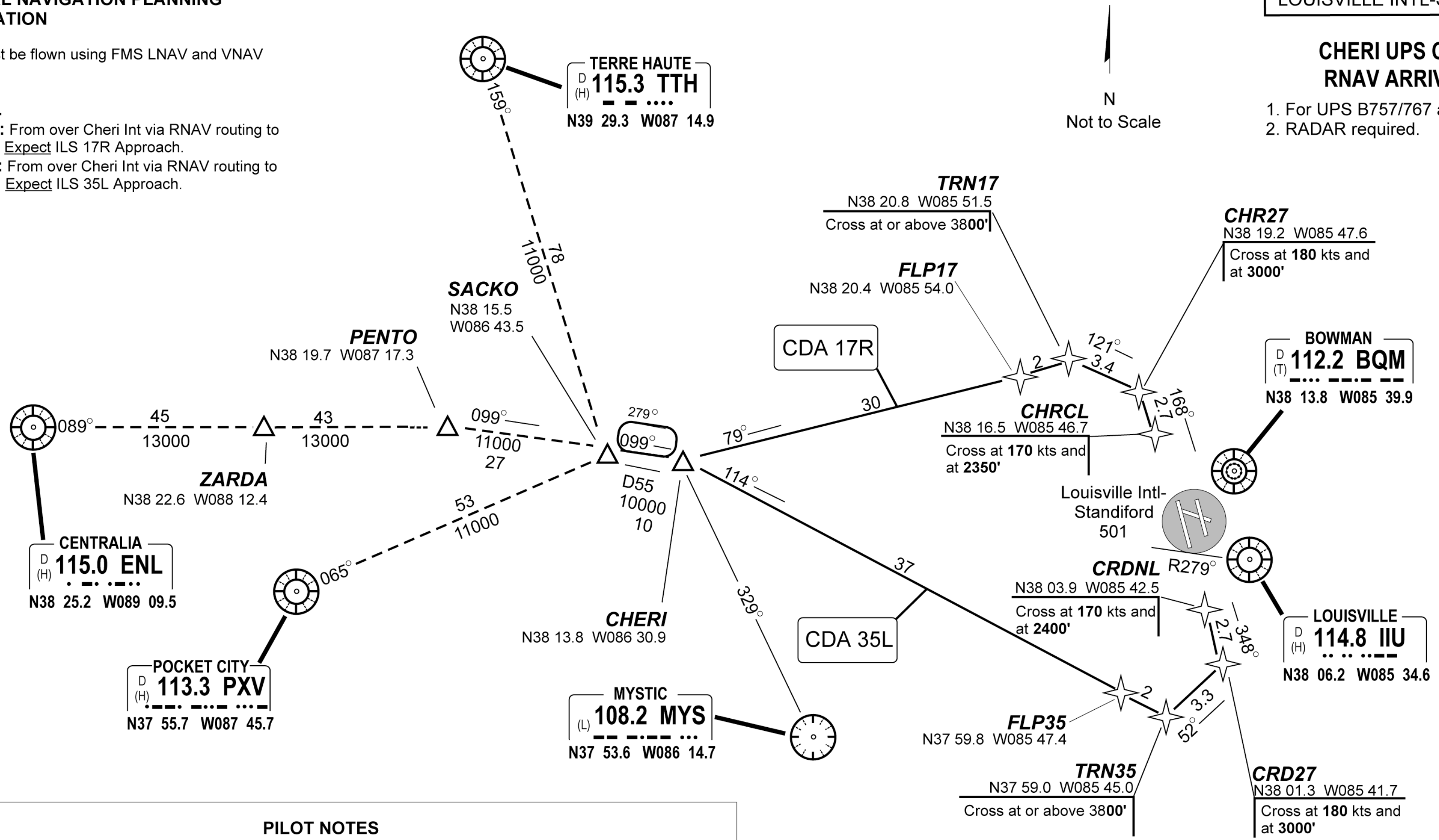
VERTICAL NAVIGATION PLANNING INFORMATION

Arrival must be flown using FMS LNAV and VNAV guidance.

ARRIVAL
CDA 17R: From over Cheri Int via RNAV routing to Chrcl Wpt. Expect ILS 17R Approach.
CDA 35L: From over Cheri Int via RNAV routing to Crdnl Wpt. Expect ILS 35L Approach.

CHERI UPS CDA RNAV ARRIVAL

1. For UPS B757/767 aircraft only.
2. RADAR required.



PILOT NOTES

1. KSDF ATIS will indicate if CDA procedures are in effect for UPS B757/767 arrivals.
2. Load the CDA17R or CDA35Lwith the filed transition and the corresponding ILS. Close the discontinuity between the arrival and the ILS final approach fix.
3. Verify speed/altitude constraints from the FMS match the Jeppesen CDA chart.
4. **Set FMS descent speed to .82/335.**
5. MCP altitude window should be set to lowest assigned ATC altitude clearance. The 3800í altitude at the TRN17/35 waypoints is not an ATC restriction--it initiates the speed slowdown.
6. Enter any ATC speed or route changes in the FMS and use power or speed brakes to re-acquire the VNAV path. Flight level change or vertical speed should not be required.
7. For best VNAV path performance maintain speed close to commanded speed.
8. **Select flaps to 1 no later than FLP17/FLP35 and flaps to 5 prior to TRN17/TRN35.**
9. Arm APPROACH after receiving ATC clearance for the ILS.
10. After glide slope capture, set speed window to match CDA profile.
11. **No later than 1 mile prior to final approach fix, select gear down and flaps 20.**

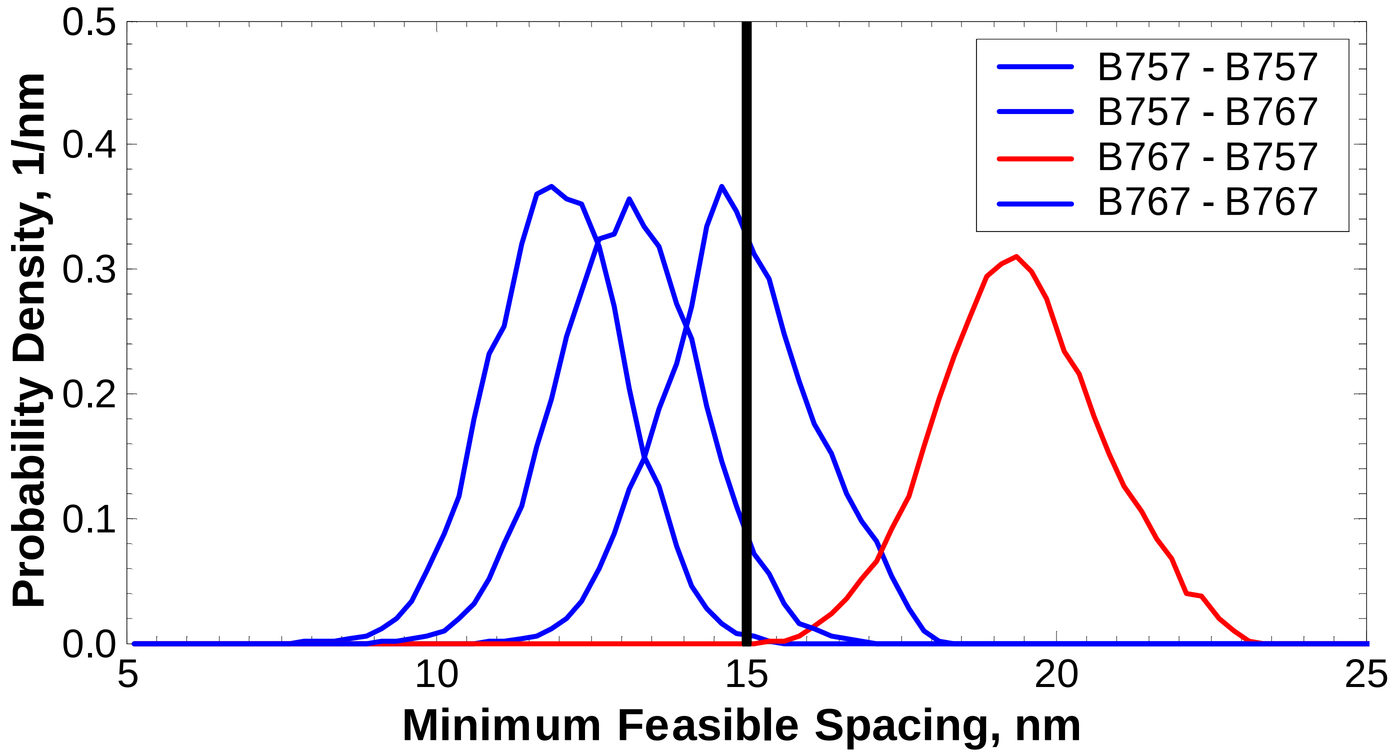
ATC CLEARANCE INFORMATION

1. The filed ATC clearance is the CHERI2 arrival and ends at the IIU VOR
2. Clearance from Indianapolis Center will be a routing to CHERI and pilotís discretion to 11,000 feet. Indianapolis will make every attempt to begin the descent from the original cruise altitude.
3. Indianapolis will switch the flight to Louisville Approach in the vicinity of SACKO intersection.
4. Louisville Approach will give clearance for the CDA17R/35L arrival and pilotís discretion to 3,000 feet.
5. **If clearance for the CDA and lower altitude is not received from Louisville Approach prior to CHERI, proceed via the filed routing to IIU VOR and maintain last assigned altitude.**

CHANGES: New Page.

Simulation Predictions for CDA to KSDF35L

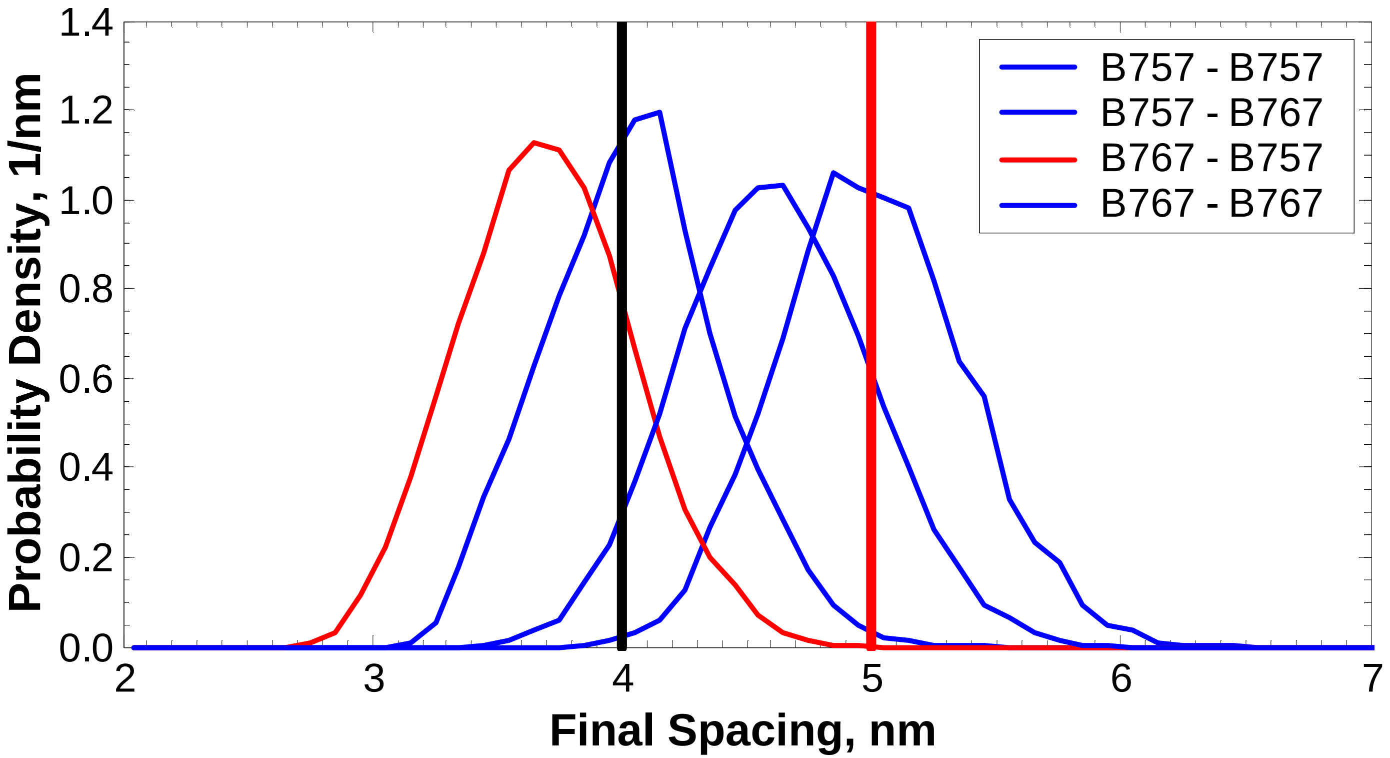
- **PDFs of Minimum Feasible Spacing at SACKO (-60.8 nm)**
  - Dashed vertical line – 15 nm target spacing used in flight test



- Conditional probability: integral from 0 to target spacing

Simulation Predictions for CDA to KSDF35L

- **PDFs of Final Spacing Given 15 nm at SACKO**
  - Separation minima: 5 nm for B767 - B757, 4 nm for others



- Conditional probability: integral from separation minima to ∞

Simulation Predictions for CDA to KSDF35L

❑ Conditional Probability (P_R) & Traffic Throughput (C)

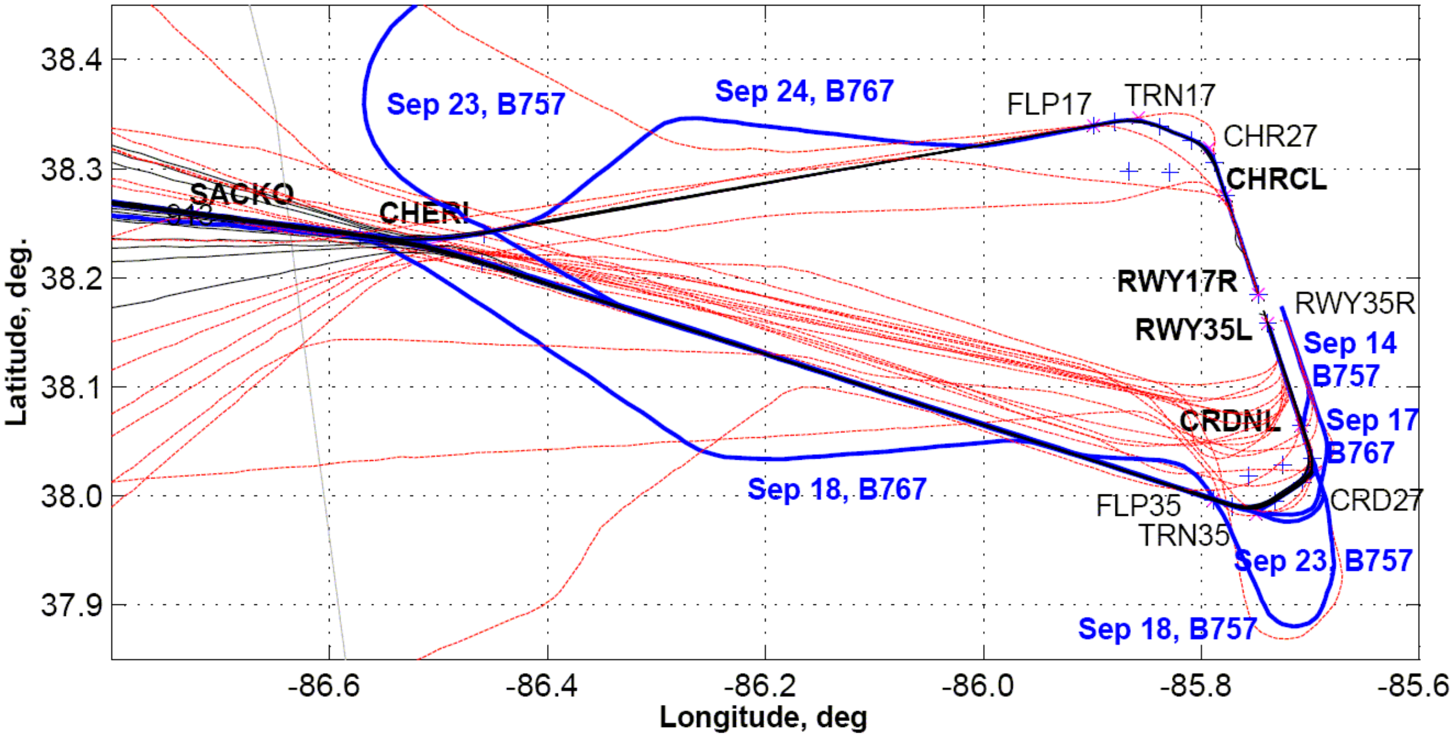
Aircraft Type/Sequence	Ideal Case C_i 1/hr	Ideal Case $E(s_i)$ nm	S_I = 15 nm P_{Ri}	S_I = 15 nm C_i 1/hr	S_I = 15 nm β_{fi} nm
B757 – B757	32.04	14.88	55.5%	31.78	0.05
B757 – B767	37.42	11.96	99.9%	30.08	1.01
B767 – B757	24.84	19.41	0.0%	31.78	-1.30
B767 – B767	34.24	13.11	95.2%	30.08	0.62
Average	**31.40**	14.84	62.7%	**30.91**	0.09

β – final separation buffer, $E(s_i)$ – average spacing

- Ideal case
  - Separation for each pair set to corresponding minimum feasible spacing
  - No capacity loss, final separation buffer ~0
- 15 nm target separation is close to system capacity, still yielding a average conditional probability of 62.7% (68.2% for CDA to 17R)

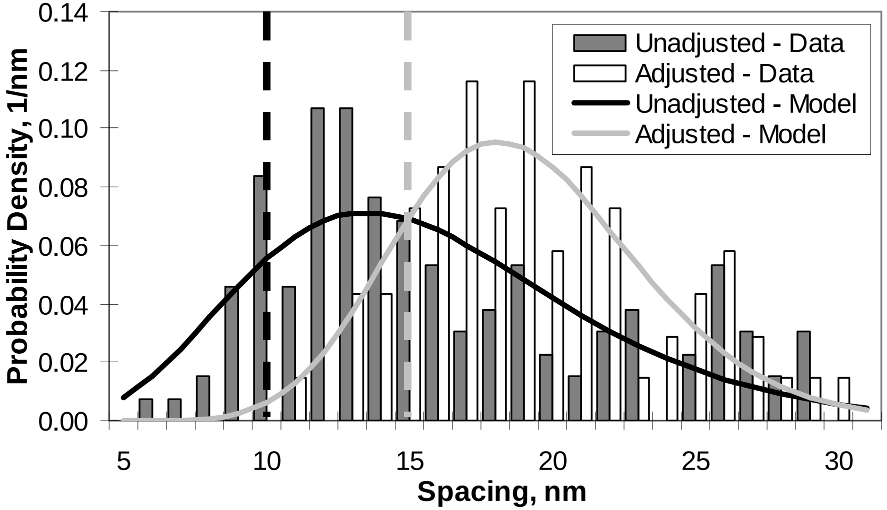
Flight Test – Ground Track

- **125 CDA flights (100 to 35L, 25 to 17R)**
  - 1 late joining
  - 4 laterally vectored due to spacing less than 15 nm at SACKO
  - 2 laterally vectored due to events not related to CDA



Flight Test – Observed Total Probability

❑ Traffic Spacings at SACKO



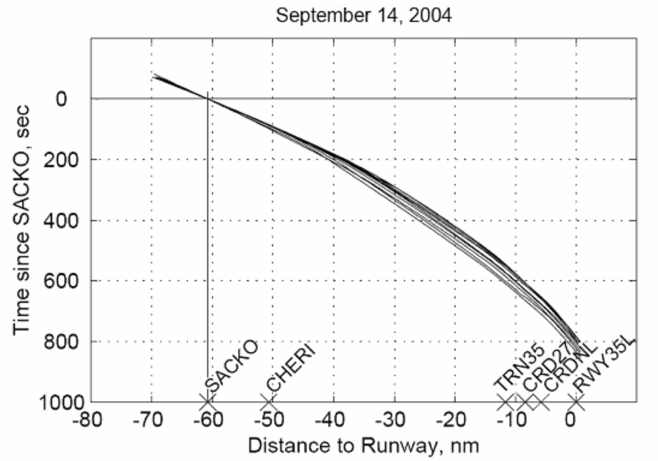
- Unadjusted traffic: 10 nm miles in trail (MIT), data from regular operations
- Adjusted traffic: 15 nm target spacing, data from CDA flight test

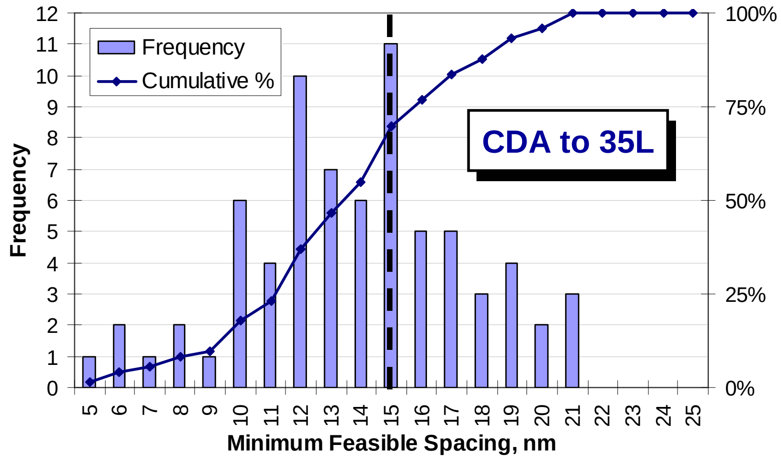
❑ Observed Total Probability

- 60 Consecutive Flight Pairs involving CDA to both 35L and 17R
- 4 laterally vectored; 3 had speed adjustment; 4 visual separation with final spacing less than IFR separation minima (could be vectored)
- Equivalent to an overall total probability of 81.7%

Post-Flight Test Separation Analysis

- Sample ARTS Trajectories & Minimum Feasible Spacings





- Conditional Probability Consistent with Simulation Predictions

For 15 nm target spacing

	Simulation Results		
	Average	Weighted Average	Flight Test Results
CDA to 35L	62.7%	68.6%	69.9%
CDA to 17R	68.2%	72.5%	72.2%

Post-Flight Test Separation Analysis

- **Estimated Total Probability Assuming 50-50 Traffic Mix**
  - Estimated using observed traffic distribution and simulated trajectories
  - CDA to 35L: 53.5% for unadjusted, 79.6% for adjusted

Sequence	P_T (S_I = 10 nm)	P_{Ta} (S_I = 15 nm)
B757–B757	52.0%	83.6%
B757–B767	72.1%	96.4%
B767–B757	25.5%	45.4%
B767–B767	64.3%	92.8%
Overall	53.5%	79.6%

  - CDA to 17R: 58.7% for unadjusted, 85.0% for adjusted
- **Total Probability Higher than Conditional Probability**
  - Average 79.6% vs. 62.7%, given 15 nm target spacing for 35L
- **Very Close to Flight Test Result**
  - 79.6% and 85.0% vs. observed total probability of 81.7%

Summary

- **Developed Tool for the Analysis of Separation And Throughput**
- **Model Accuracy and Utility of the Tool Verified by Flight Test**
- **Current Applications**
  - KSDF 2004 CDA flight test project; NEMA & London Gatwick in UK; LAX, and ATL in US; several other projects in Europe and US.
- **Future Directions**
  - Enhancing the aircraft performance model and the wind model
  - Improving the pilot response delay model
  - Developing a generic model of spacing in the arrival traffic stream under different miles-in-trail restrictions
  - Tradeoff analysis optimizing the target spacings for noise abatement and upper stream traffic efficiency
  - Using the separation analysis principle to solve the traffic coordination problem for merging arrival routes (in progress)
  - Time based separation analysis (being developed and tested at KATL with Delta)