Arrival Management with Required Navigation Performance and 3D Paths

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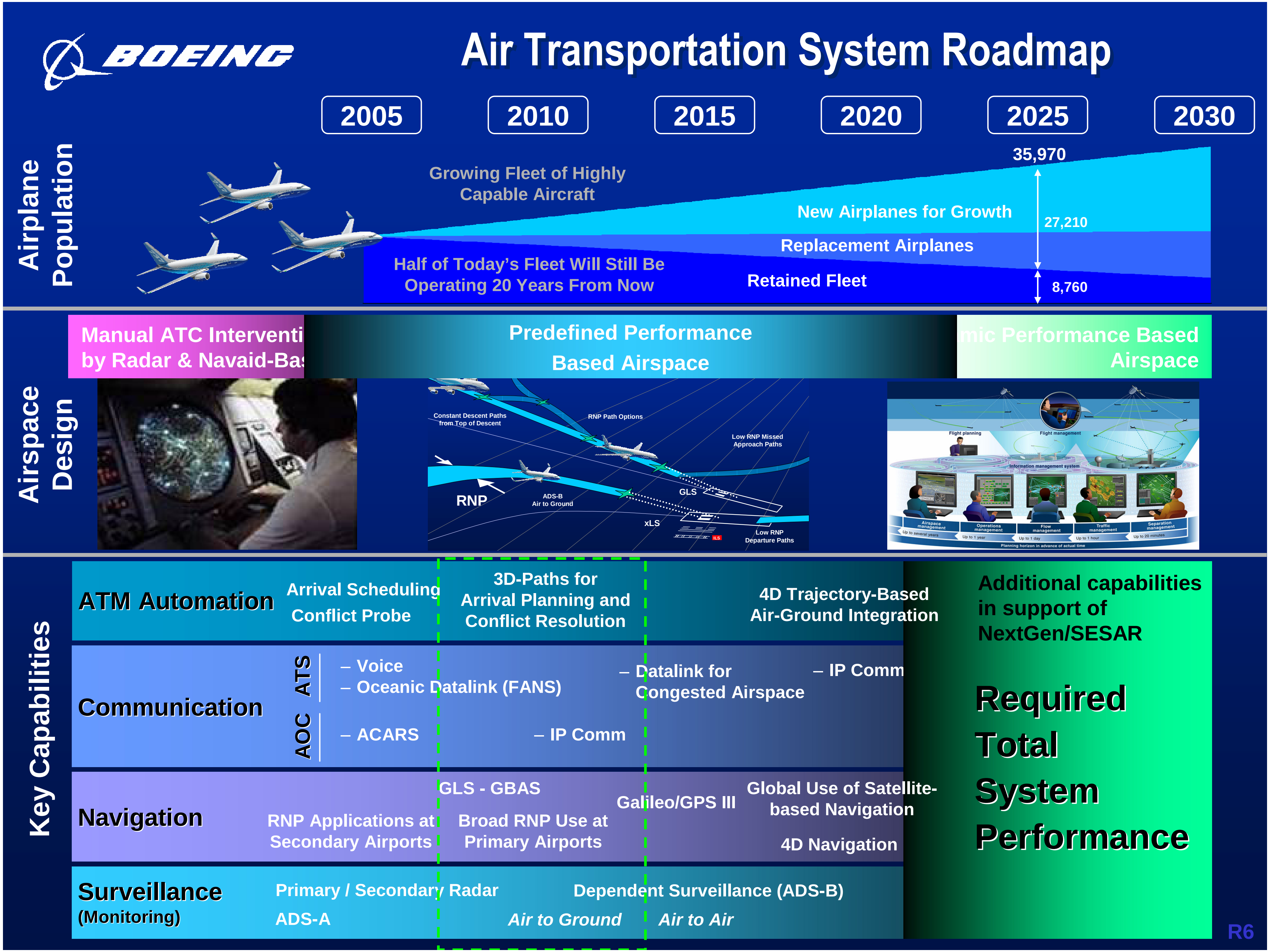
Overview

- Air transportation system roadmap to NextGen and SESAR
- Required Navigation Performance (RNAV/RNP) and 3D Paths – concept overview
- Arrival management modeling and analysis methodology
  - Arrival management performance analysis overview
  - Arrival management model in Boeing's Trajectory Analysis and Modeling Environment (TAME)
  - Key system performance parameters
  - Scenario and simulation methodology
  - Analysis results
- Conclusions



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Air Transportation System Roadmap
2005
2010
2015
2020
2025
2030
Airplane Population
Growing Fleet of Highly Capable Aircraft
35,970
New Airplanes for Growth
27,210
Replacement Airplanes
Half of Today's Fleet Will Still Be Operating 20 Years From Now
Retained Fleet
8,760
Airspace Design
Manual ATC Interventi
by Radar & Navaid-Ba
Predefined Performance Based Airspace
mic Performance Based Airspace
Constant Descent Paths from Top of Descent
RNP Path Options
Low RNP Missed Approach Paths
RNP
ADS-B Air to Ground
GLS
xLS
Low RNP Departure Paths
Flight planning
Flight management
Information management system
Key Capabilities
ATM Automation
Arrival Scheduling
Conflict Probe
3D-Paths for Arrival Planning and Conflict Resolution
4D Trajectory-Based Air-Ground Integration
Additional capabilities in support of NextGen/SESAR
Communication
ATS
– Voice
– Oceanic Datalink (FANS)
– Datalink for Congested Airspace
– IP Comm
AOC
– ACARS
– IP Comm
Required Total System Performance
Navigation
GLS - GBAS
RNP Applications at Secondary Airports
Broad RNP Use at Primary Airports
Galileo/GPS III
Global Use of Satellite-based Navigation
4D Navigation
Surveillance (Monitoring)
Primary / Secondary Radar
ADS-A
Dependent Surveillance (ADS-B)
Air to Ground
Air to Air
R6

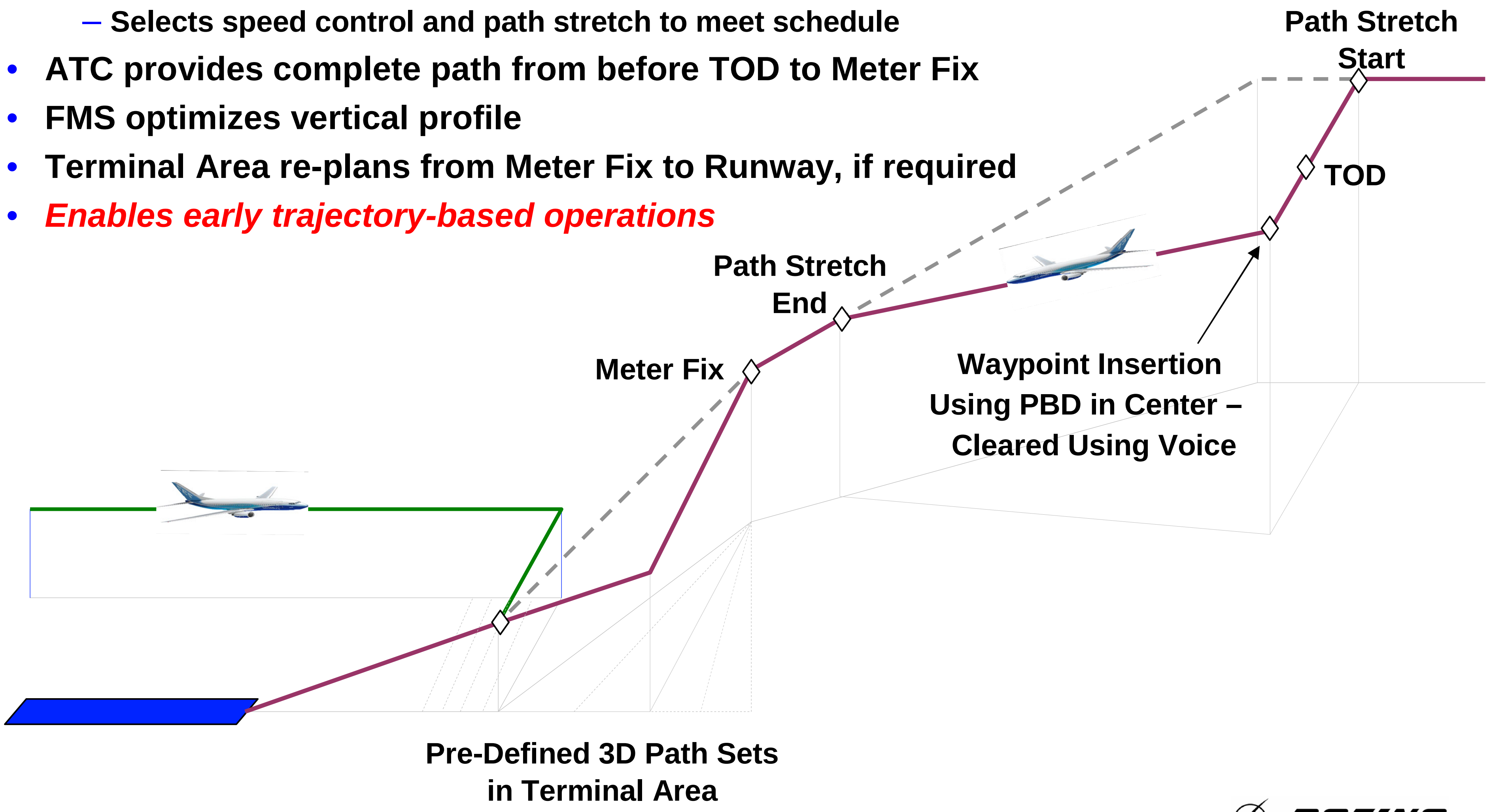
Required Navigation Performance (RNAV/RNP) and 3D Paths– Concept Overview

- **The objective is FMS-based operations – the first step towards 4D trajectory-based operations**
  - Path stretching is required when speed control is insufficient to achieve spacing
  - ATC uses advanced automation tools to select path and speed to space traffic
  - Paths need to be defined to enable FMS-based execution by the aircraft
  - Alternative clearance mechanisms include
    - En-route: “Place/Bearing/Distance” or lateral offsets
    - Arrival transition: “Place/Bearing/Distance”
    - Terminal Area: Pre-defined sets of 3D paths, published and available in both air and ground navigation databases
  - Automation also supports vectoring of non-equipped aircraft

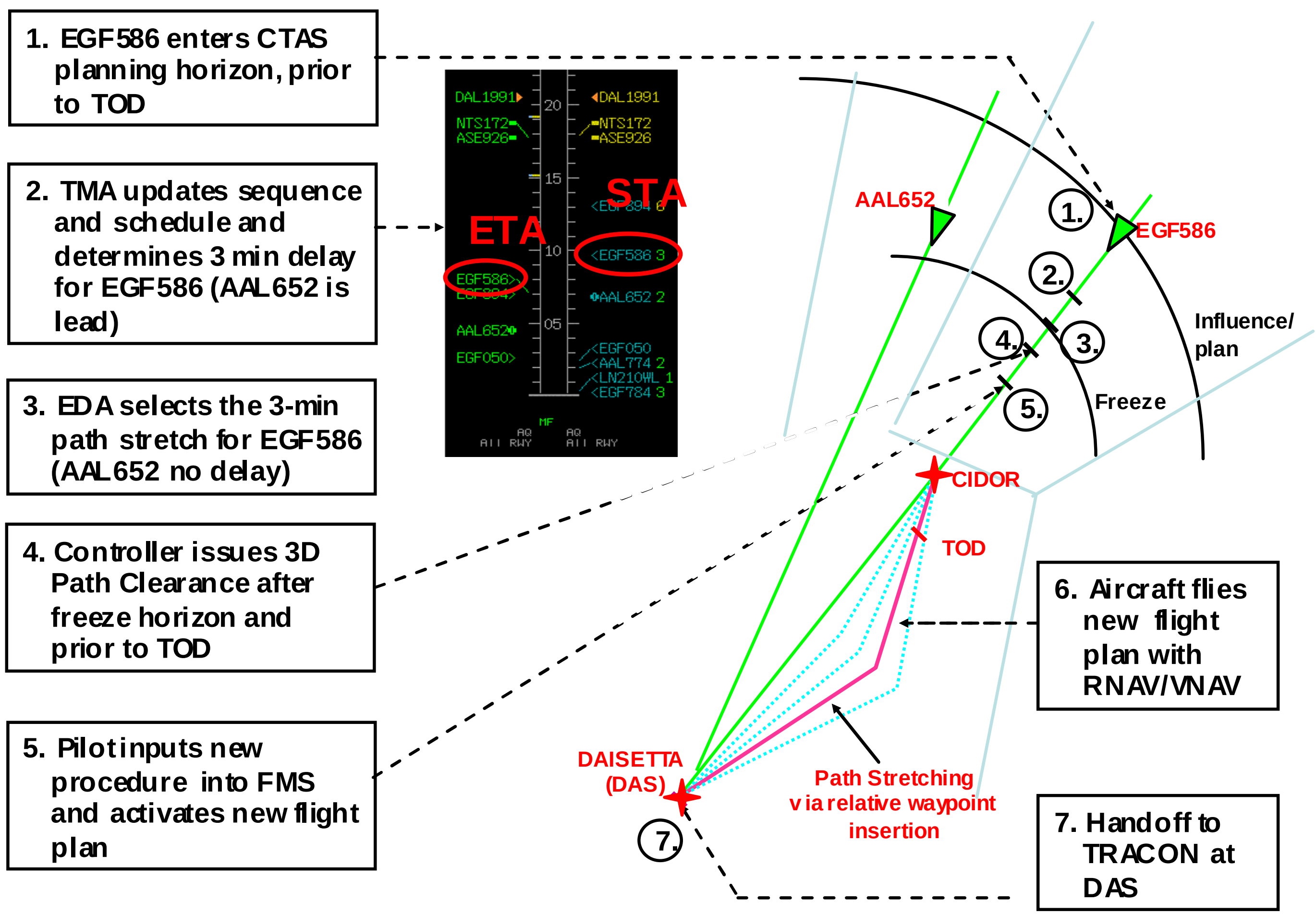
- **Clearance delivery**
  - Voice-based 3D path clearances to equipped aircraft
  - Non-equipped aircraft receive traditional speed, altitude and heading clearances

3D Paths in Arrival Management

- **Ground automation maximizes airport throughput**
  - **Computes schedule at runways and meter fixes**
  - **Selects speed control and path stretch to meet schedule**
- **ATC provides complete path from before TOD to Meter Fix**
- **FMS optimizes vertical profile**
- **Terminal Area re-plans from Meter Fix to Runway, if required**
- ***Enables early trajectory-based operations***



Arrival Management Event Sequence

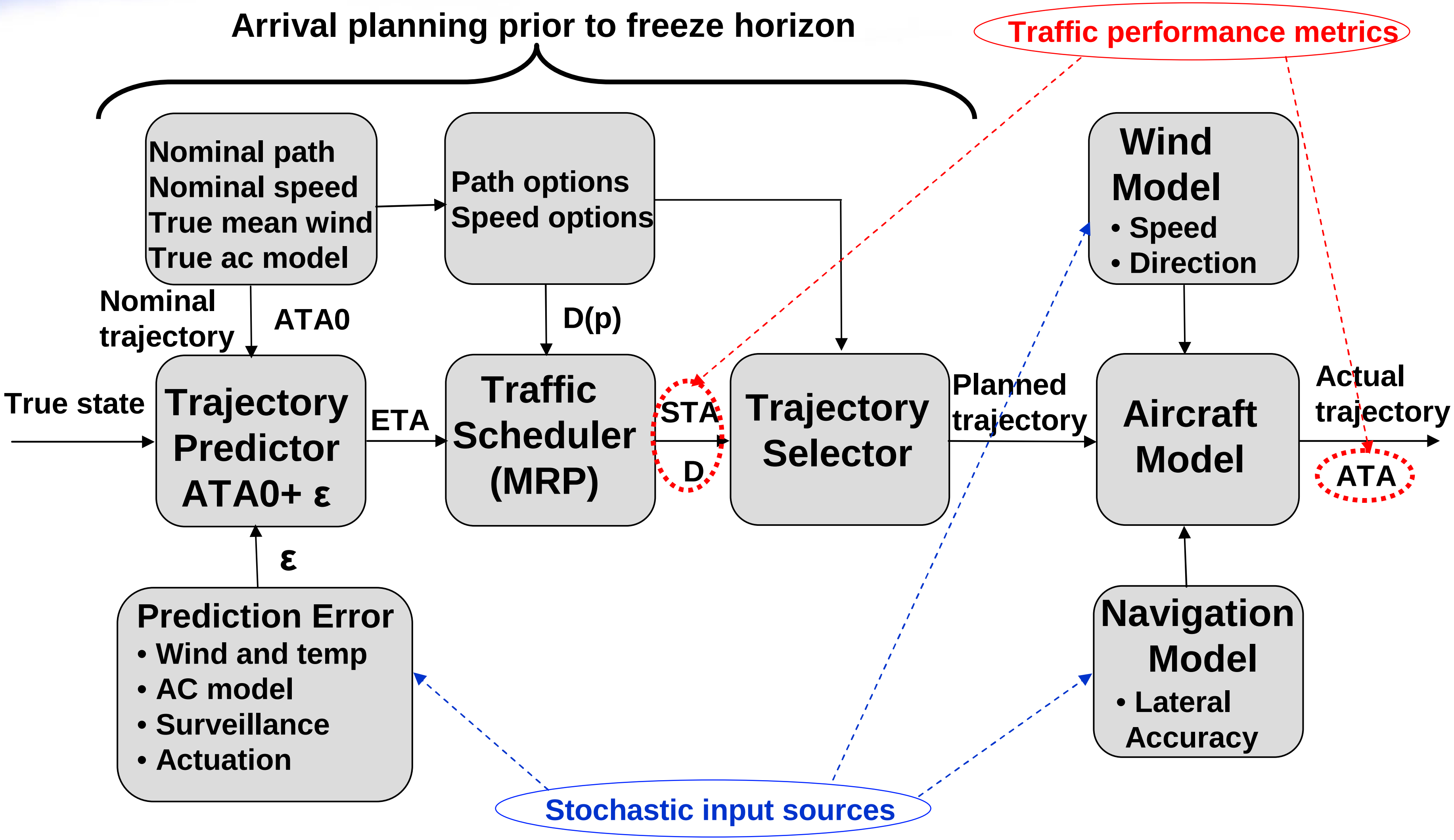


NASA CTAS automation used as an example to illustrate required arrival management functions

AM Performance Analysis Overview

- **Throughput is directly influenced by variability in spacing at the Meter Fix and Runway Threshold**
- **Spacing variability is influenced by several key parameters**
  - Wind prediction accuracy (mean wind and gusts)
  - Navigation accuracy
  - Surveillance accuracy
  - Timing variability introduced by operators
  - Aircraft trajectory prediction model
- **Goal is to understand the relationship between these key parameters and traffic metrics**
  - Delivery accuracy at Meter Fix and Runway (ATA-STA)
  - Inter-arrival time statistics
  - Delay
- **Based on Boeing's Trajectory Analysis and Modeling Environment (TAME)**
  - Monte-Carlo traffic simulation and analysis framework based on MATLAB

Arrival Management Model in TAME

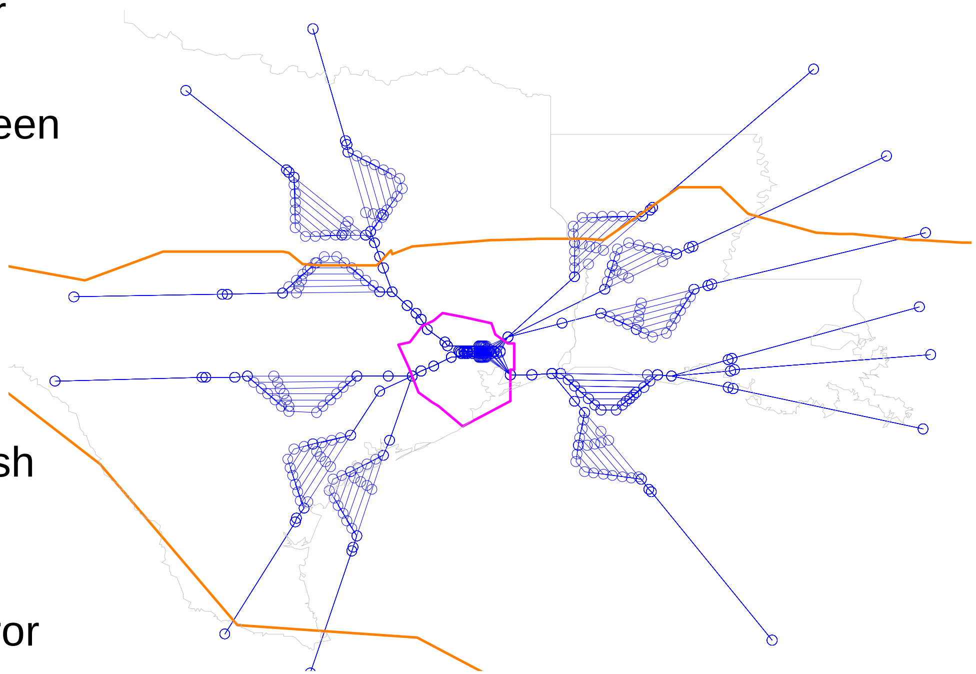


Key System Performance Parameters

- **Lateral navigation performance**
  - Based on Actual Navigation Performance (ANP) metric
  - Levels chosen to represent range of present GPS and radio navigation capabilities
- **Wind model**
  - Mean wind is represented by speed and direction as function of altitude
  - Wind gusts are sized by specifying speed and direction variability of Gaussian processes
  - Wind field does not vary laterally across the scenario
- **Trajectory prediction error**
  - Single aggregated model parameter ε with mean and standard deviation
  - Standard deviation sized by data from NASA CTAS prediction performance flight test results
  - Mean of ε represents difference between predicted and actual mean wind and can be sized differently for traffic to each meter fix

Scenario and Simulation Methodology

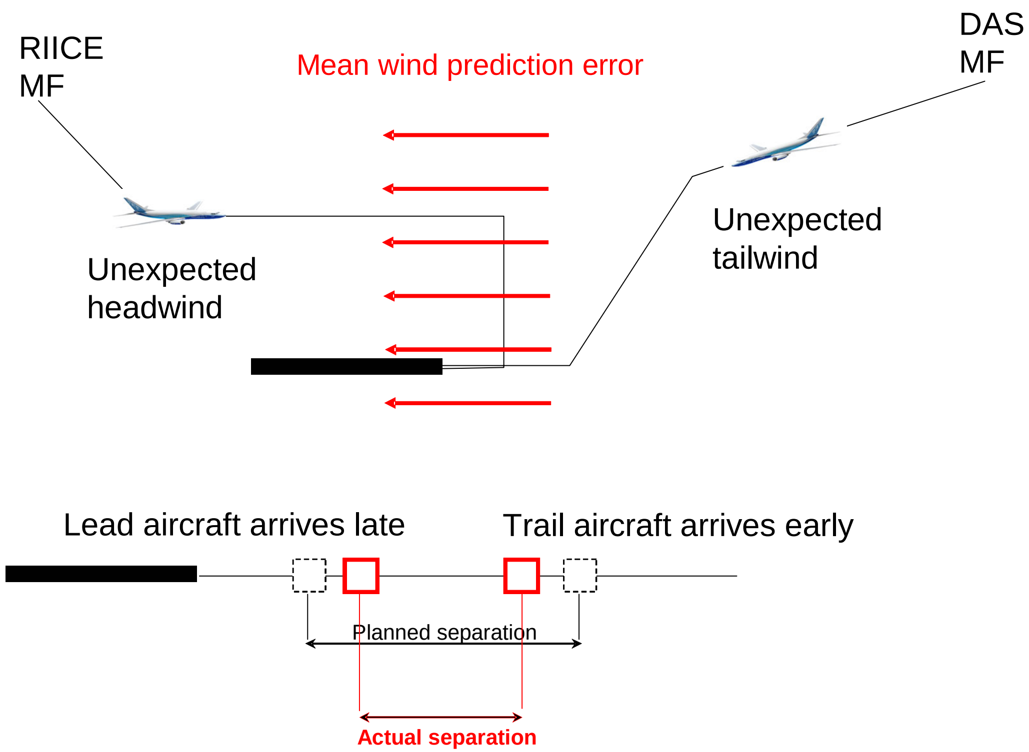
- **Airport and airspace arrival scenario**
  - Houston Intercontinental Airport (IAH)
  - Path stretch using lateral offsets in Center
  - Fixed path options in Terminal Area
  - Descent speeds in 5 kts increments between 250 and 290 kts
  - Cruise speeds in 0.05 Mach increments between 0.7 and 0.8
  - Hold at cruise when necessary
  - 4 meter fixes feeding 3 arrival runways
  - Traffic is an OAG-based 75 min arrival rush

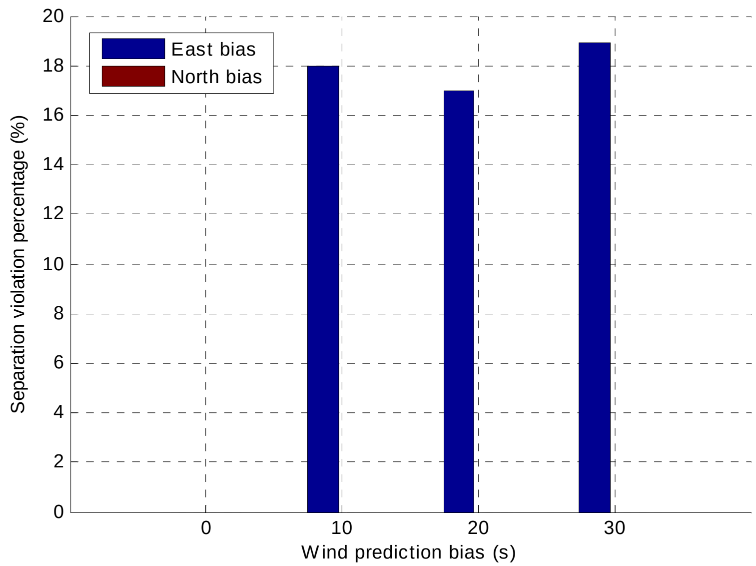


- **Simulation methodology**
  - Studied effect of mean wind prediction error (wind bias) using deterministic simulation
  - Studied stochastic effects using Monte-Carlo simulation methodology

Effects of Mean Wind Prediction Error

- If traffic is balanced, we expect ~25% rate of in-trail separation violations
- Test case: Traffic from North-East and North-West merging to a single East-West runway





Error in mean wind prediction is a significant issue for strategic traffic planning

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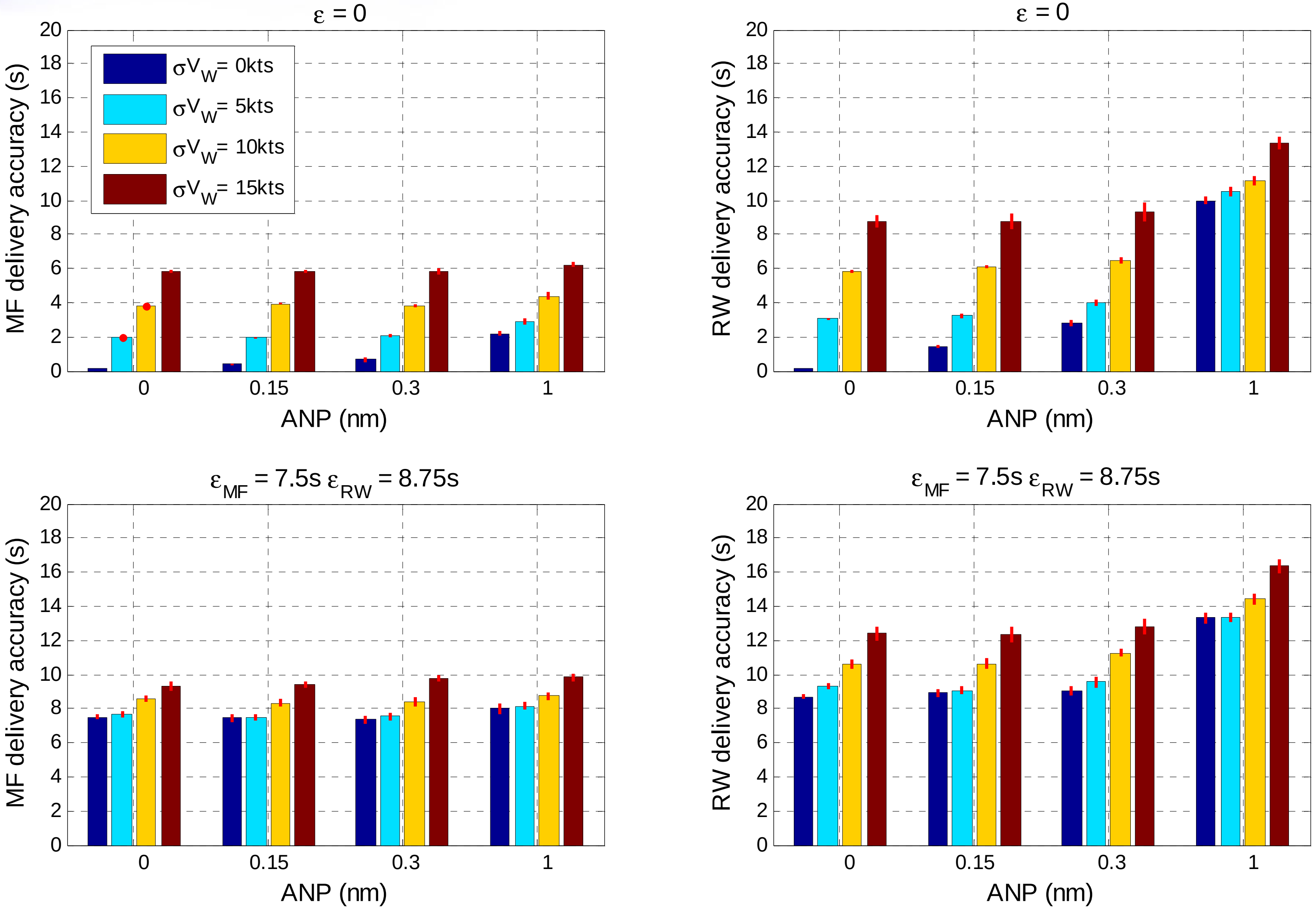
Meter Fix and Runway Delivery Accuracy Results

Monte-Carlo simulation convergence is ensured via t-tests



- **Trajectory prediction and wind effects dominate delivery accuracy**
- **Error grows from the Meter Fix to the Runway**

The Need for Spacing Buffers

- **Buffers are needed to accommodate spacing variability due to prediction uncertainty**
- **Buffers were sized to ensure that the probability of meter fix separation loss is less than 0.5%**
- **Buffers lead to reduced throughput and thus produce higher delay**

Buffer analysis for ANP =0.15 nm, σ_{Vw}=10 kts, ε_{MF}=7.5 s

	No buffers	25 s (2 nm) MF buffer
Probability of meter fix separation loss	15.2%	0.5%
Average arrival delay	69 s	178 s

Conclusions

- **The 3D Path operational concept is based on integrating advanced navigation with advanced ground automation capabilities**
  - Step towards the trajectory-based vision of NextGen and SESAR
  - Strategic traffic plans with accurate navigation performance
  - Implementation is technically feasible in 2008-2012
- **Arrival management performance analysis conclusions**
  - Trajectory and wind prediction performance dominate delivery accuracy
  - Lateral navigation performance effects are influenced primarily by turns
  - A second planning stage for the TRACON will be required for maximum throughput
  - 2 nm separation buffers at the meter fix are sufficient to accomodate delivery variability for expected concept performance levels
- **The TAME toolset provides fast-time technical performance analysis capability for a variety of arrival management concepts**

Backup

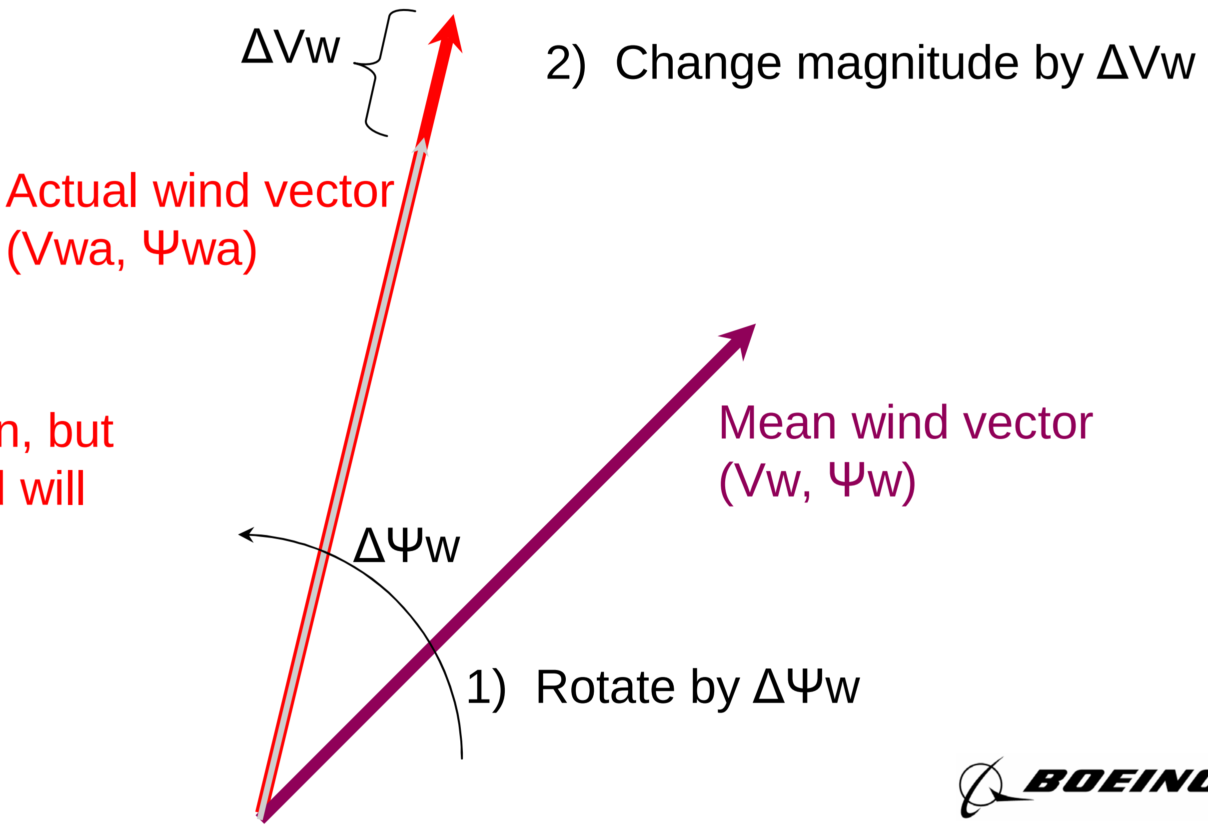
Wind error model details

Modify mean wind vector by magnitude error ΔVw and direction error ΔΨw, each drawn from independent filter guaranteeing a zero mean Gaussian time distribution with standard deviation σ and period T (NOT VARYING BY ALTITUDE)

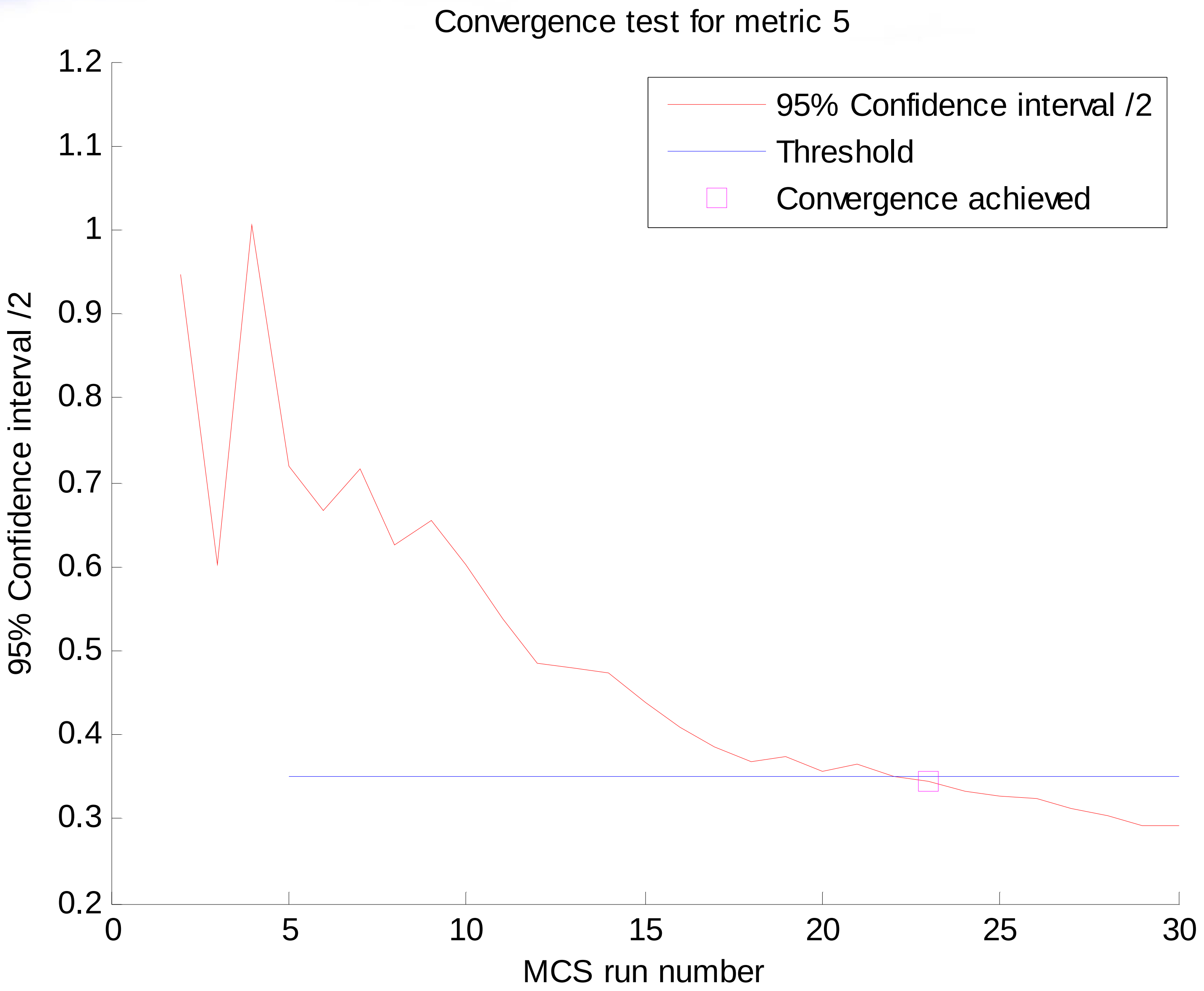
<u>Model:</u>

Vwa=Vw+ΔVw
Ψwa= Ψw+ Δ Ψw
Vxa=Vwa cos(Ψwa)
Vya=Vwa sin(Ψwa)

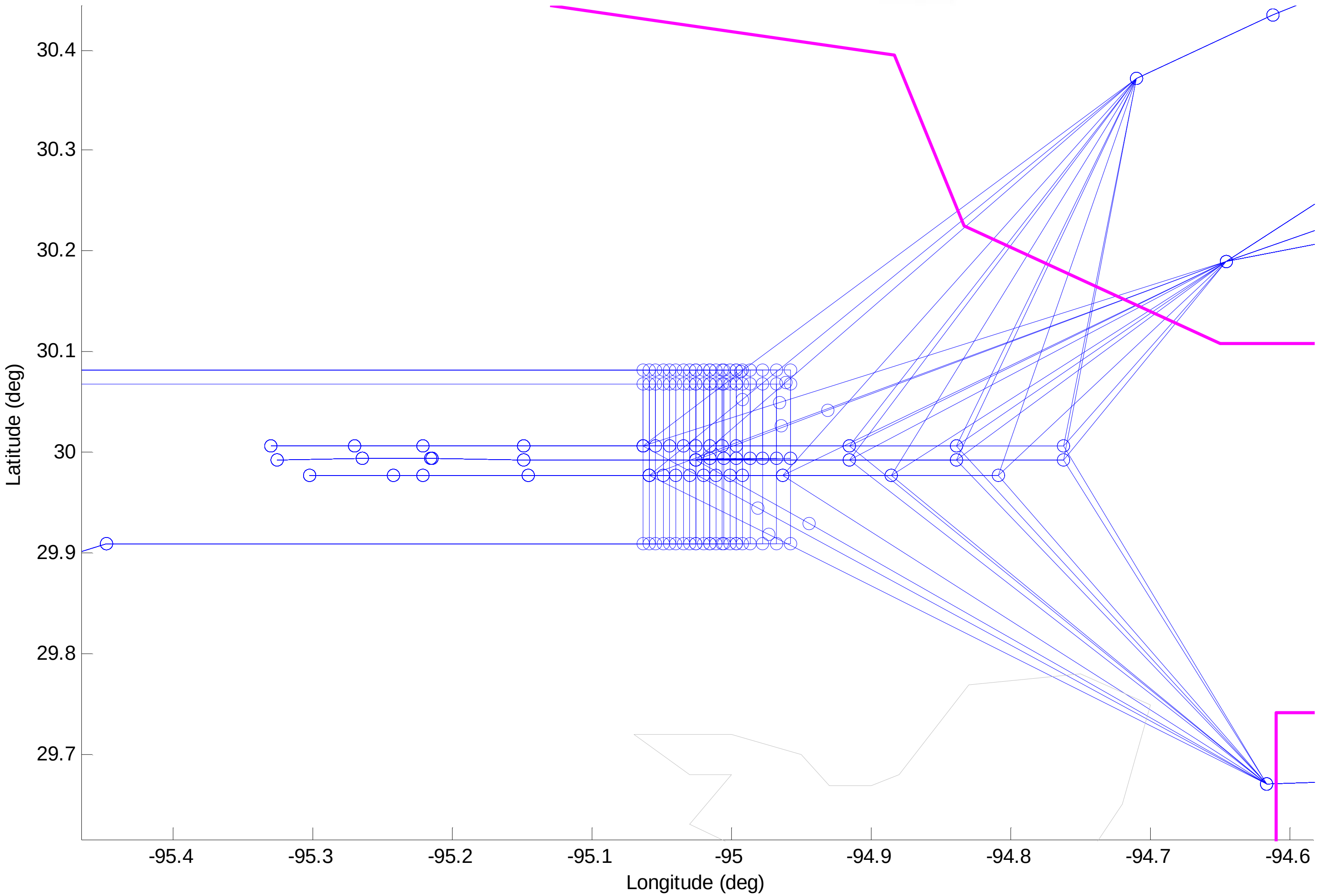
This is NOT vector addition, but statistically the actual wind will average to the mean wind



Monte-Carlo Convergence Process



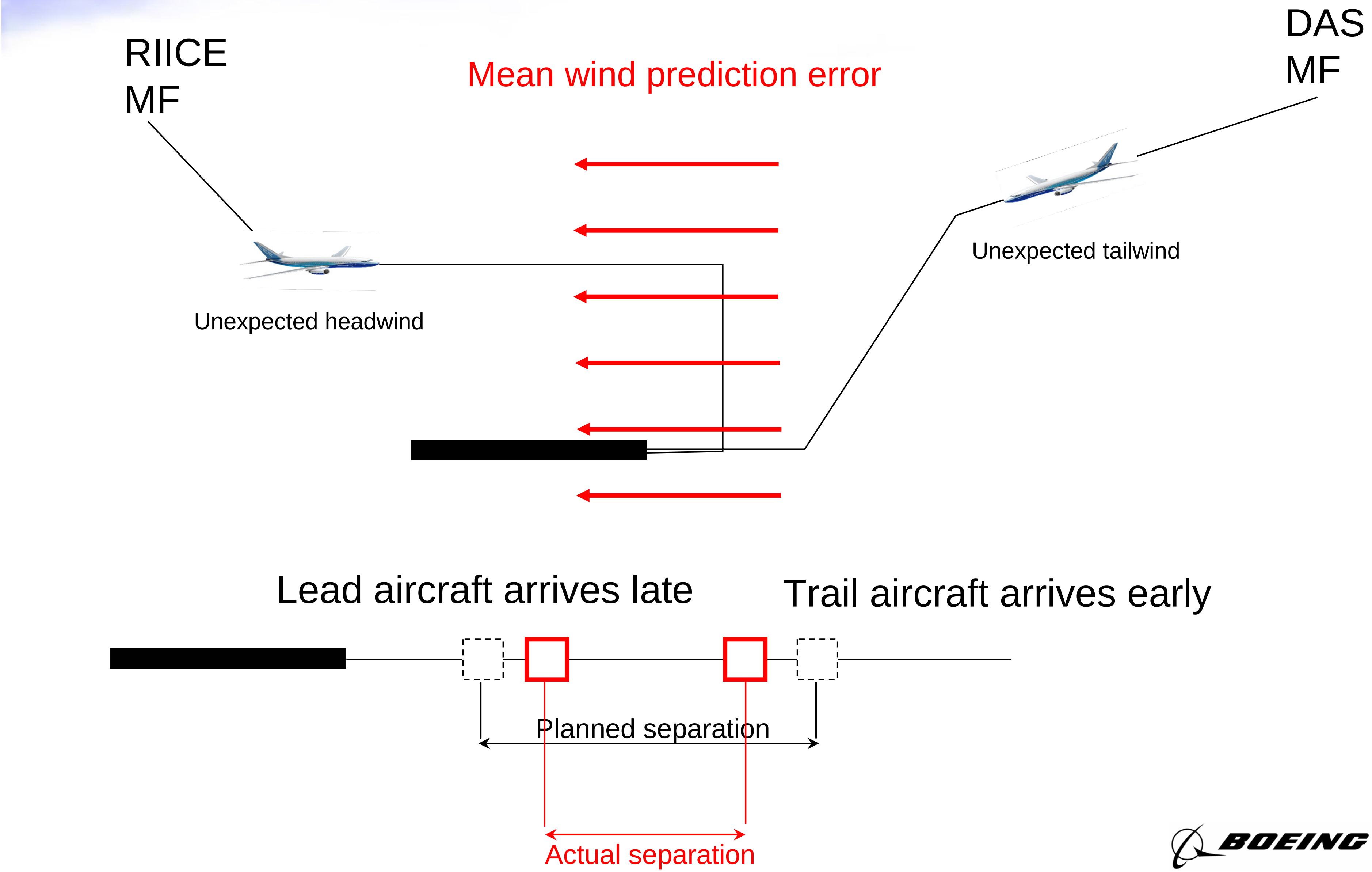
IAH TRACON paths



ANP vs RNP table

Assumes ANP effect dominates RNP (low FTE)

ANP (nm)	RNP (nm)
0	0
0.15	0.1
0.3	0.16
1.0	0.51


RIICE
MF
Mean wind prediction error
DAS
MF
Unexpected tailwind
Unexpected headwind
Lead aircraft arrives late
Trail aircraft arrives early
Planned separation
Actual separation