

# Controlled Time-of-Arrival Spacing Analysis

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# Outline

- Background & motivation
- Simulation objectives and setup
- Experiments performed
- Summary

# Background

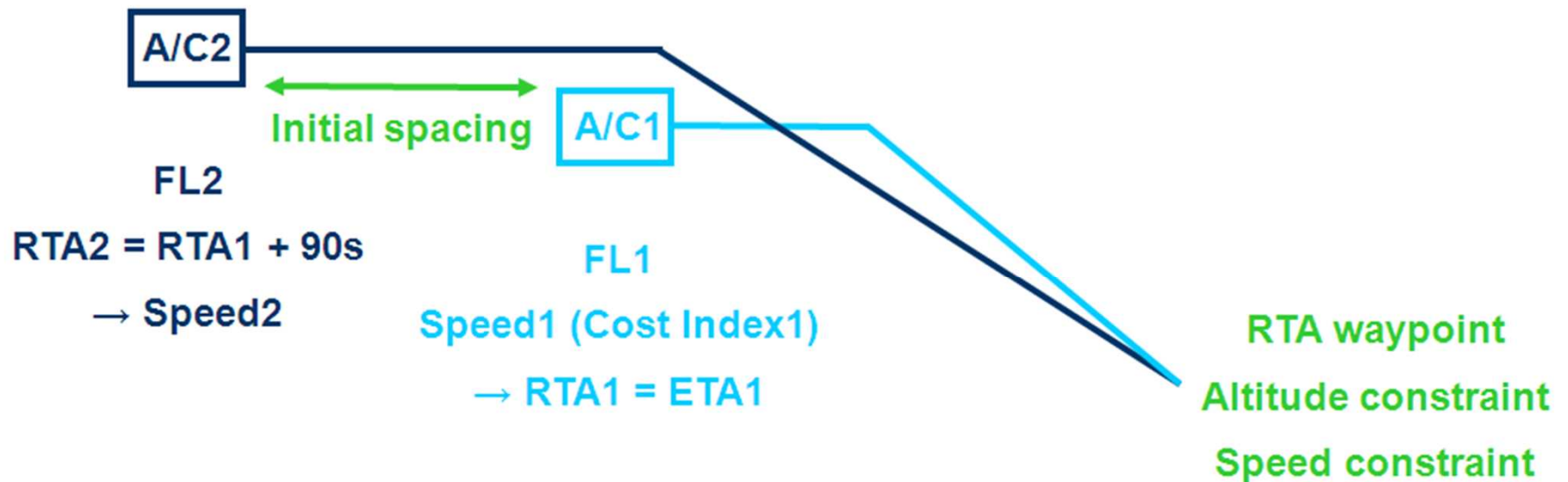
- 4D Trajectory Based Operations a key part of both SESAR and NextGen
- EUROCAE WG-85 formed to evaluate standards for airborne Time-Of-Arrival Control (TOAC)
  - “In order to provide the required capacity and the required performances, enhanced solutions must be selected, standardized and deployed to answer the mid-term implementation of Initial 4D Trajectory Management”

# Motivation

- Airborne Time-Of-Arrival Control (TOAC) is a key component of initial 4D TBO
- Use of time constraint is valuable to achieve appropriate spacing at a metering fix
  - But intermediate spacing between assignment of the constraint and crossing the fix is a concern
- Eurocontrol & GE performed simulations to examine this issue

# Simulation overview

Investigate the potential spacing reduction (longitudinal and vertical) of two aircraft flying towards a time constraint on a similar 2D route



# Simulation objectives

1. What is the magnitude and rate of spacing reductions?
2. Is standardized speed behavior needed for CTA operations?
3. Is there any relationship between initial conditions and rate of spacing reduction?
4. Is a Decision Support Tool (DST) needed for controllers to assist them in assigning CTAs to suitable aircraft pairs and to monitor the spacing between those aircraft during RTA operation?
5. Are there any airspace design implications for CTA operations?

# Simulation example

## Assumptions

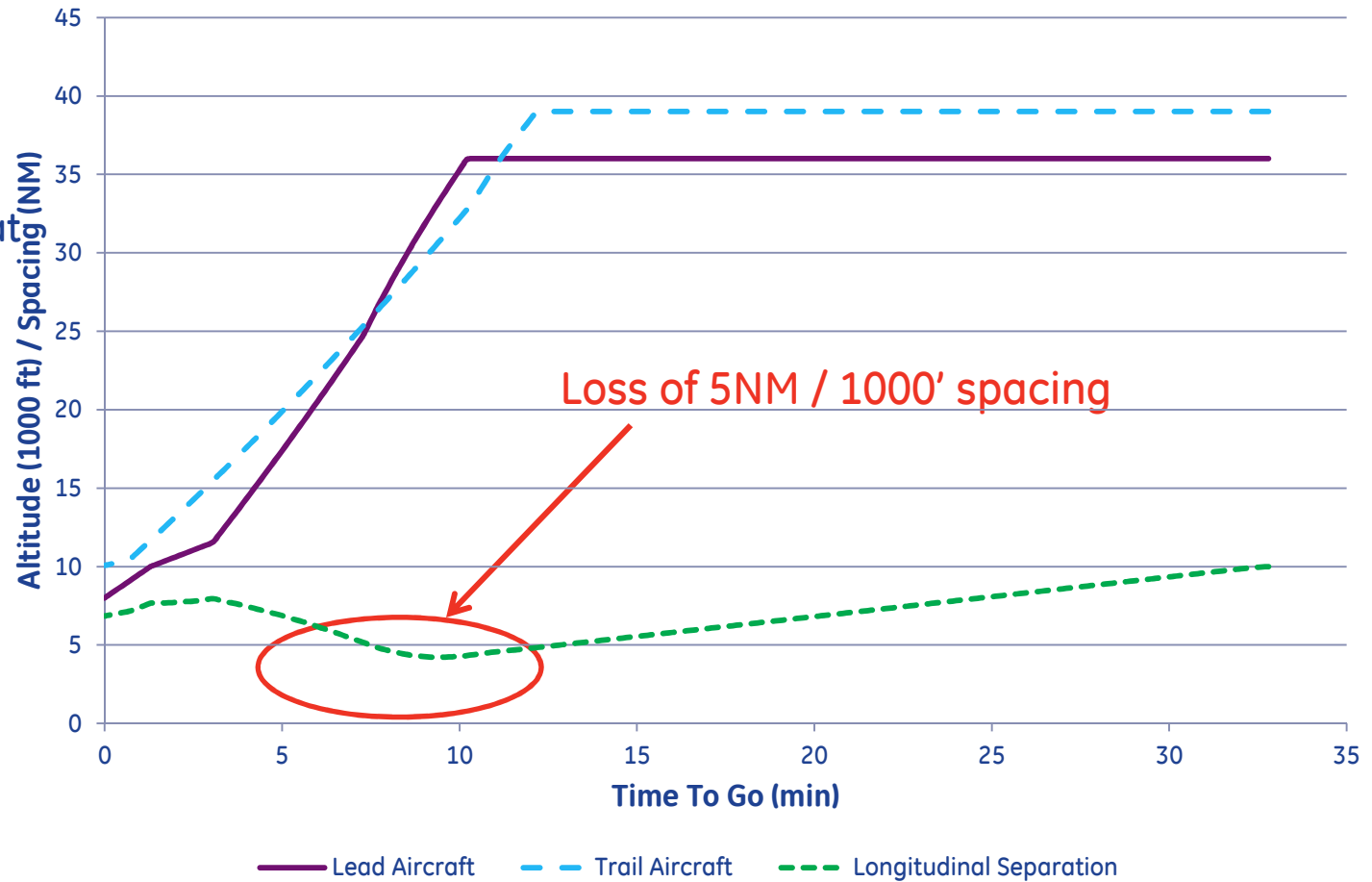
90 second target spacing at RTA wpt

8000' alt constraint at RTA wpt

250 knot speed limit below FL100

10 sec RTA tolerance

Wind errors not considered



# Simulation parameters

Variables	Unit	Values					#
Type A/C 1 (leading)	-	A320	B736	A333	B773		4
Type A/C 2 (following)	-	A320	B736	A333	B773		4
Initial Distance to RTA A/C1	NM	170	200	230			3
Wind (positive for tailwind)	kts	-80	0	80			3
Pseudo Cost Index A/C1	-	10	30	50	70	90	5
A320 and B738 Cruise FL	FL	310	330	350	370		4
A333 and B773 Cruise FL	FL		330	350	370	390	4
Initial Spacing between A/C1 and A/C2	NM		10	15	20		3
<b>TOTAL COMBINATIONS</b>	-						<b>34560</b>

NOTE: Eurocontrol parameters shown above. GE simulation parameters used aircraft types of A320, A333, B733, B738 with Cruise FLs of 310, 330, 360, 390. GE simulations did not include A320/A333 following B733/B738, yielding 25920 total combinations.



# Experiments performed

1. 90 second target spacing for all aircraft pairs, minimum separation criteria
2. Experiment 1, with 120 second target spacing for Heavy following Medium
3. Experiment 2, with trend-based separation criteria
4. Experiment 3, with 250 knot minimum speed

# 90 second spacing results

- 80% RTA Achievable
- 2.8 – 4.9% separation infringements
- Much higher probability of separation infringement for Heavy behind Medium than other aircraft pairs

Ectl results top GE bottom		Initial Spacing			
		10NM	15NM	20NM	Total
All Aircraft	<i>RTA Achievable</i>	87.6%	84.6%	74.7%	<b>82.3%</b>
	<i>RTA Achievable &amp; Spacing Lost</i>	86.4%	80.9%	73.7%	<b>80.3%</b>
Medium Behind Heavy	<i>RTA Achievable</i>	10.0%	3.1%	1.0%	<b>4.9%</b>
	<i>RTA Achievable &amp; Spacing Lost</i>	5.0%	1.8%	1.1%	<b>2.8%</b>
Medium Behind Medium	<i>RTA Achievable</i>	95.0%	86.8%	74.3%	<b>85.4%</b>
	<i>RTA Achievable &amp; Spacing Lost</i>	80.3%	75.9%	70.4%	<b>75.5%</b>
Heavy Behind Heavy	<i>RTA Achievable</i>	0.0%	0.0%	0.0%	<b>0.0%</b>
	<i>RTA Achievable &amp; Spacing Lost</i>	0.7%	0.2%	0.0%	<b>0.3%</b>
Heavy Behind Medium	<i>RTA Achievable</i>	95.7%	93.3%	80.5%	<b>89.8%</b>
	<i>RTA Achievable &amp; Spacing Lost</i>	85.1%	78.4%	69.7%	<b>77.8%</b>
Heavy Behind Medium	<i>RTA Achievable</i>	1.6%	0.3%	0.0%	<b>0.7%</b>
	<i>RTA Achievable &amp; Spacing Lost</i>	4.6%	3.1%	2.0%	<b>3.3%</b>
Heavy Behind Medium	<i>RTA Achievable</i>	86.2%	83.9%	73.5%	<b>81.2%</b>
	<i>RTA Achievable &amp; Spacing Lost</i>	100.0%	98.9%	93.9%	<b>97.6%</b>
Heavy Behind Medium	<i>RTA Achievable</i>	0.7%	0.0%	0.0%	<b>0.3%</b>
	<i>RTA Achievable &amp; Spacing Lost</i>	0.0%	0.0%	0.0%	<b>0.0%</b>
Heavy Behind Medium	<i>RTA Achievable</i>	73.6%	74.4%	70.5%	<b>72.8%</b>
	<i>RTA Achievable &amp; Spacing Lost</i>	100.0%	95.1%	91.1%	<b>95.4%</b>
Heavy Behind Medium	<i>RTA Achievable</i>	44.6%	13.8%	4.3%	<b>21.1%</b>
	<i>RTA Achievable &amp; Spacing Lost</i>	22.8%	0.6%	0.0%	<b>8.2%</b>

# 120 second spacing results

Ectl results top GE bottom		Initial Spacing			
		10NM	15NM	20NM	Total
All Aircraft	<i>RTA Achievable</i>	86.5%	84.8%	75.6%	82.3%
		86.4%	81.2%	73.3%	80.3%
	<i>RTA Achievable &amp; Spacing Lost</i>	4.9%	1.3%	0.4%	2.3%
		4.1%	1.8%	1.1%	2.4%
Heavy Behind Medium	<i>RTA Achievable</i>	69.1%	75.3%	74.1%	72.8%
		100.0%	99.3%	86.4%	95.2%
	<i>RTA Achievable &amp; Spacing Lost</i>	21.4%	5.5%	1.5%	9.2%
		13.1%	0.0%	0.0%	4.6%

- Increase spacing to 120 seconds at MF for Heavy behind Medium (keep at 90 seconds for others)
- RTA Achievability unchanged
- Significant decrease in spacing infringement from 21.1% (8.2%) to 9.2% (4.6%) for Heavy behind Medium

# Trend based alerting

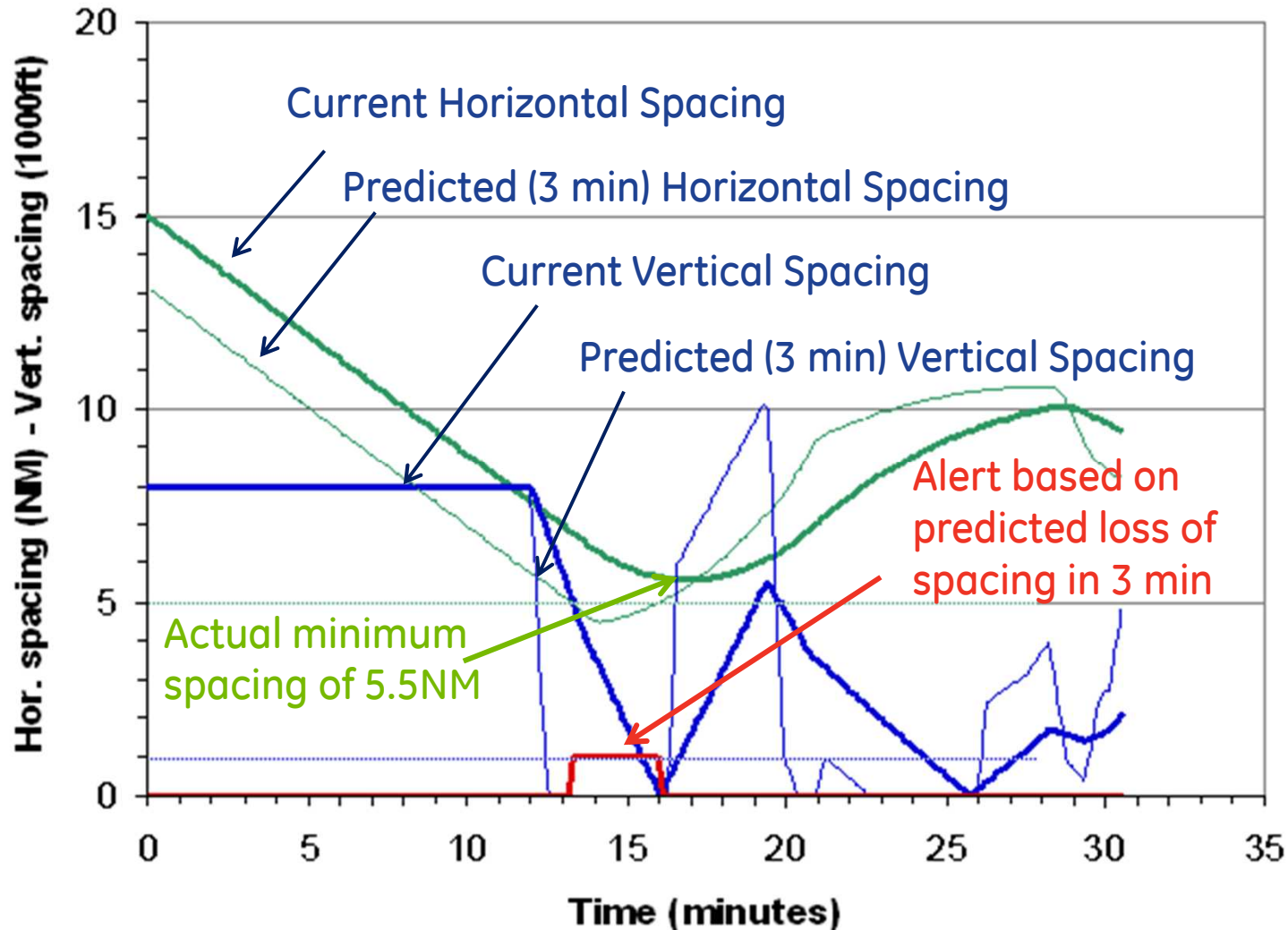
Rather than instantaneous spacing, look at how the spacing between aircraft is evolving

- Measure rate of change of vertical and horizontal spacing

Trigger an alert when:

- Spacing is decreasing at a “high-enough” rate that a loss of separation will occur in 3 minutes
- Over last 3 minutes, use min separation criteria

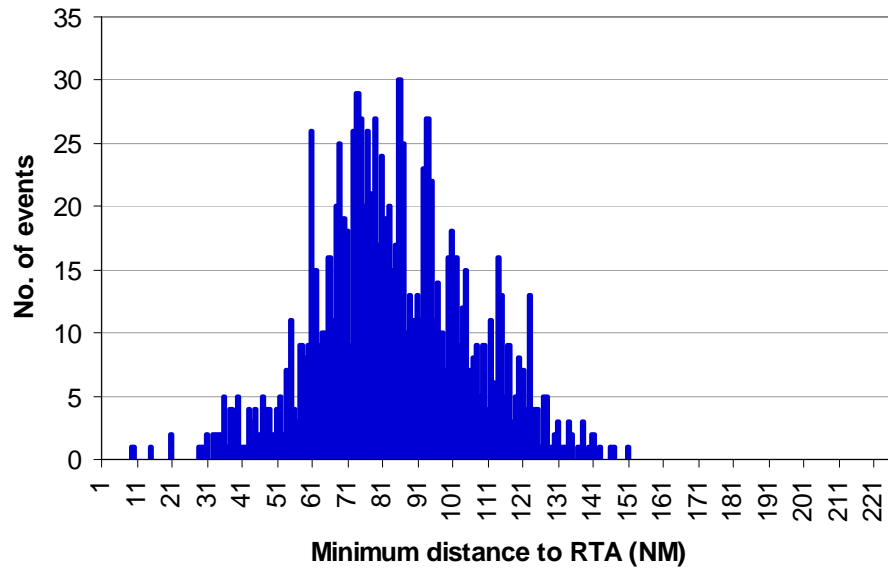
# Trend based alerting example



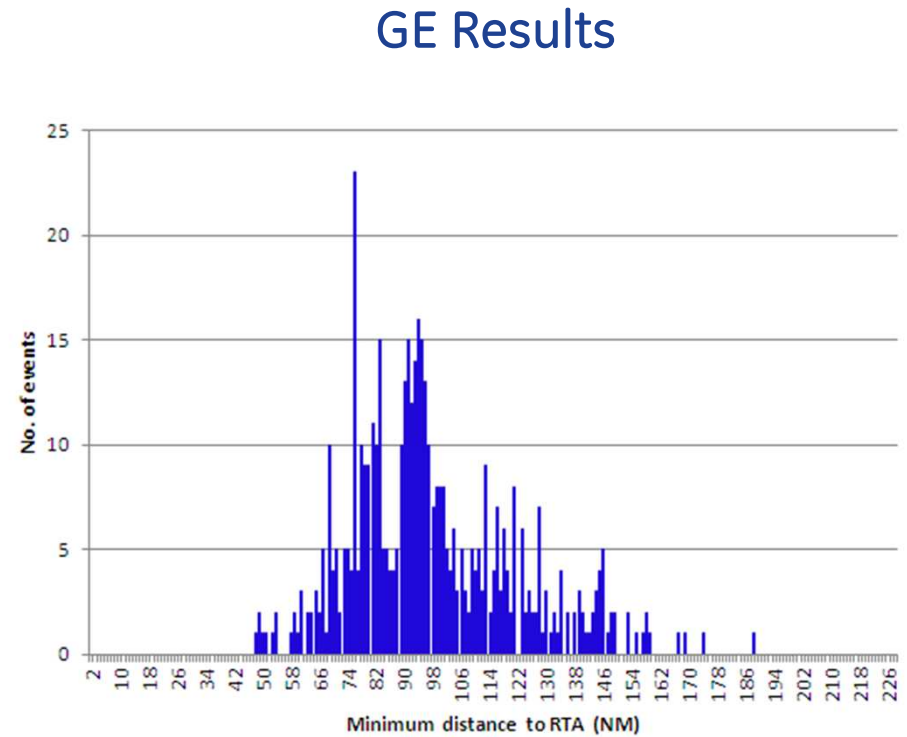
# Trend-based alerting results

RTA Achievable & Spacing Alert	Initial Spacing			
	10NM	15NM	20NM	Total
<i>All Aircraft</i>	7.7%	2.7%	0.8%	<b>3.9%</b>
	4.5%	1.5%	0.9%	<b>2.4%</b>
<i>Medium Behind Heavy</i>	0.0%	0.0%	0.0%	<b>0.0%</b>
	1.0%	0.4%	0.1%	<b>0.5%</b>
<i>Medium Behind Medium</i>	3.3%	1.0%	0.3%	<b>1.6%</b>
	3.9%	2.3%	1.6%	<b>2.7%</b>
<i>Heavy Behind Heavy</i>	2.1%	0.5%	0.1%	<b>0.9%</b>
	0.4%	0.0%	0.0%	<b>0.1%</b>
<i>Heavy Behind Medium</i>	31.3%	10.2%	2.9%	<b>14.4%</b>
	20.4%	0.6%	0.0%	<b>7.5%</b>

# Location (distance to MF) of alert

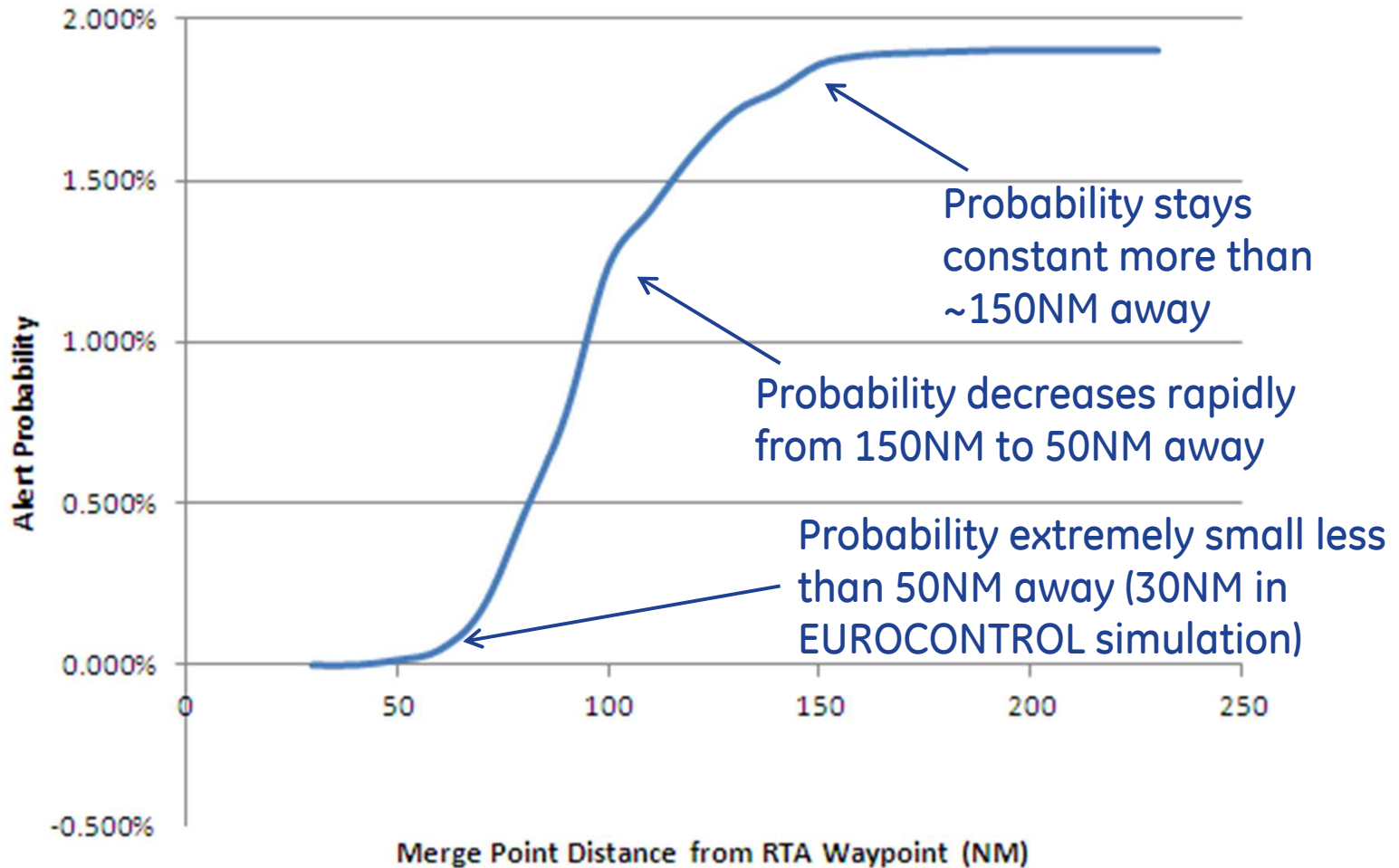


Eurocontrol Results



# Probability of alert

(GE results, excluding alerts at the Meter Fix)





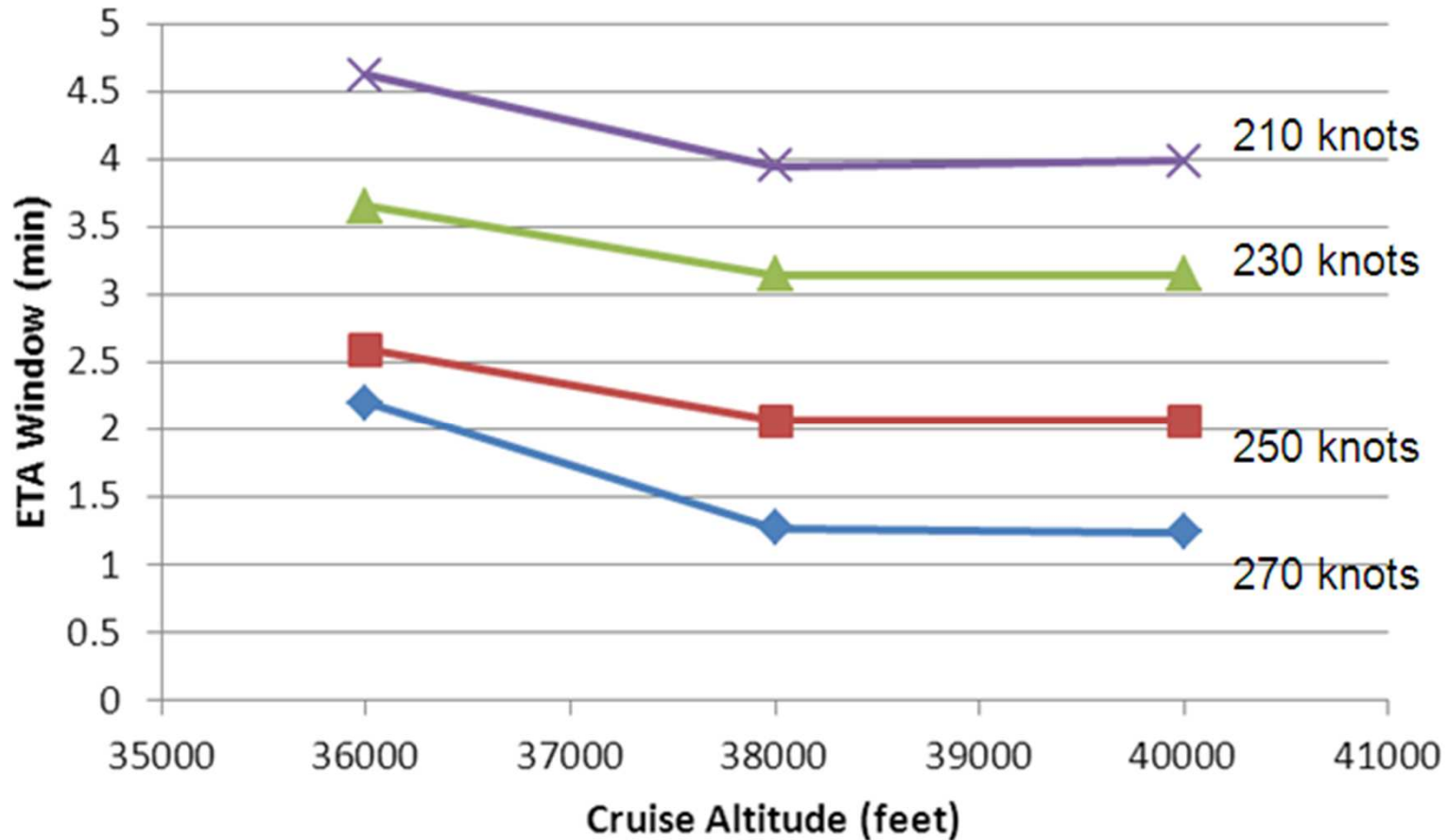
# Results with limited speeds

-3 min & 5 min look-ahead trend-based alerts

RTA Achievable & Spacing Alert	Initial Spacing			
	10NM	15NM	20NM	Total
<i>All Aircraft</i>	4.4%	1.0%	0.2%	<b>2.0%</b> ← 3 min
	5.8%	1.8%	0.7%	<b>2.9%</b> ← 5 min
<i>Medium Behind Heavy</i>	0.0%	0.0%	0.0%	<b>0.0%</b>
	0.0%	0.0%	0.4%	<b>0.1%</b>
<i>Medium Behind Medium</i>	1.9%	0.4%	0.0%	<b>0.9%</b>
	2.8%	1.0%	0.3%	<b>1.5%</b>
<i>Heavy Behind Heavy</i>	3.0%	0.7%	0.0%	<b>1.4%</b>
	3.9%	1.3%	0.3%	<b>2.0%</b>
<i>Heavy Behind Medium</i>	12.7%	2.6%	0.6%	<b>5.3%</b>
	16.8%	4.4%	1.5%	<b>7.6%</b>

# Impact of minimum speed

-significant decrease in achievable window



# Summary (1/2)

Over 30,000 scenarios evaluated

- Certain aircraft combinations required additional spacing at the metering fix
- With appropriate spacing at the metering fix (90/120 seconds), less than 2.5% of aircraft that achieved the RTA (~80% of total scenarios) reduced spacing below 5NM/1000ft
  - Heavy behind Medium highest probability

# Summary (2/2)

- Look-ahead based on trend of spacing increases “alerts” to ~4% probability
- Lower-limiting descent speed has positive effect on spacing infringement
  - 2% for 3 minute look-ahead
  - 2.9% for 5 minute look-ahead
- Most alerts occur between 50 – 150 NM from the metering fix

# Thank you.



