Presentation on Wake Turbulence Re-Categorization Phase I Methodology and Safety Case

June 20, 2011

TU Berlin
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Outline

- Background
- Methodology
- Safety
- Summary

Problem Statement

- Demand for airport capacity increases every year
- Current ICAO wake separation standards are widely viewed as being outdated
- Many ANSP's globally have developed their individual variations from the ICAO standard
- International cooperation exists for addressing ICAO wake standards for the introduction of new large aircraft into service

EUROCONTROL / FAA Cooperation

- In November 2006, ICAO requested the FAA and EUROCONTROL to lead an effort to harmonize wake separation standards for all aircraft
- Study being performed under a EUROCONTROL / FAA Memorandum of Cooperation
  - 20+ Coordinated Action Plans
- Action Plan 14 deals with Wake Turbulence
  - Agree on strategy and sharing of work
  - Promote global harmonization
  - Jointly approach ICAO

Program Participants

Joint effort led by FAA and EUROCONTROL

- Federal Aviation Administration FAA
  - ATO Air Traffic Operations
  - AVS Aviation Safety
- EUROCONTROL
  - Airspace Department
  - Performance and Methods/Safety Assessment
  - Performance and Methods/Validation
- Supporting Organizations
  - Department of Transportation Volpe Center
  - Det Norske Veritas
  - International Subject Matter Experts

Recategorization is a Three Phase Effort

- Phase 1 is Static 6 Category Separation
  - Results to be presented in this talk
- Phase 2 is static pair-wise separation
- Phase 3 is dynamic pair-wise separation
- All three phases are required steps towards NextGen and SESAR

Proposed Implementation of RECAT

- Not a Big Bang Implementation
- RECAT and Today's ICAO categories are safe
- Both categorizations can co-exist
- Performance Based Transition
    - Each ANSP can transition to RECAT when needed
    - Transition Decision by one ANSP has No Impact on Adjacent ANSP
- No Required Changes to ICAO Flight Plan

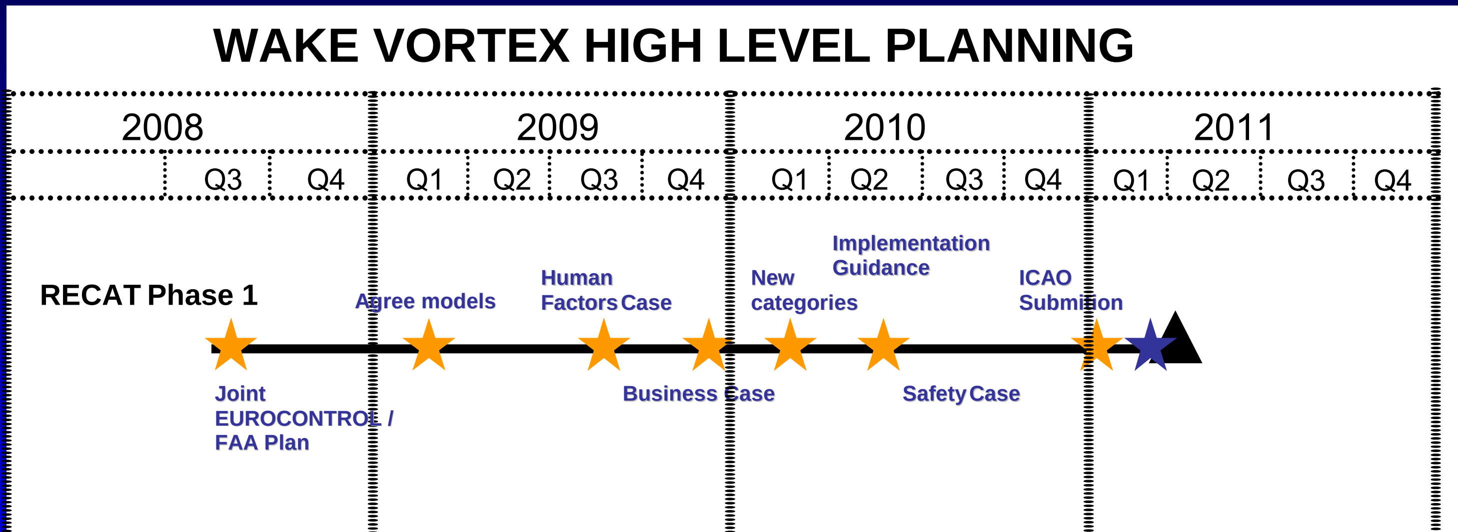
Background (1 of 2)

- Current predictions indicate a doubling of air traffic by 2025
- Current ICAO, US and European separation standards are different, but all are safe
  - In the US or Europe there has never been an accident caused by wake vortex under IFR separations and procedures
- Wake research and improved sensors provide an opportunity to increase capacity and harmonize separation standards while providing the same or increased safety over existing standards

Background (2 of 2)

- ICAO effectively has 3+1 categories (Light, Medium, Heavy, A380)
- US has 6 categories (Small, Small+, Large, B757, Heavy, A380)
- Many European ANSP's use variations from ICAO categories, e.g. NATS UK utilizes 6 categories
- NextGen and SESAR will incorporate dynamic pair-wise separation, using individual aircraft pair separations based on current weather and operational parameters
  - RECAT 6 Categories is the first step to NextGen and SESAR
  - Static Pair-wise (Phase 2) is the next step

Importance of Phase I

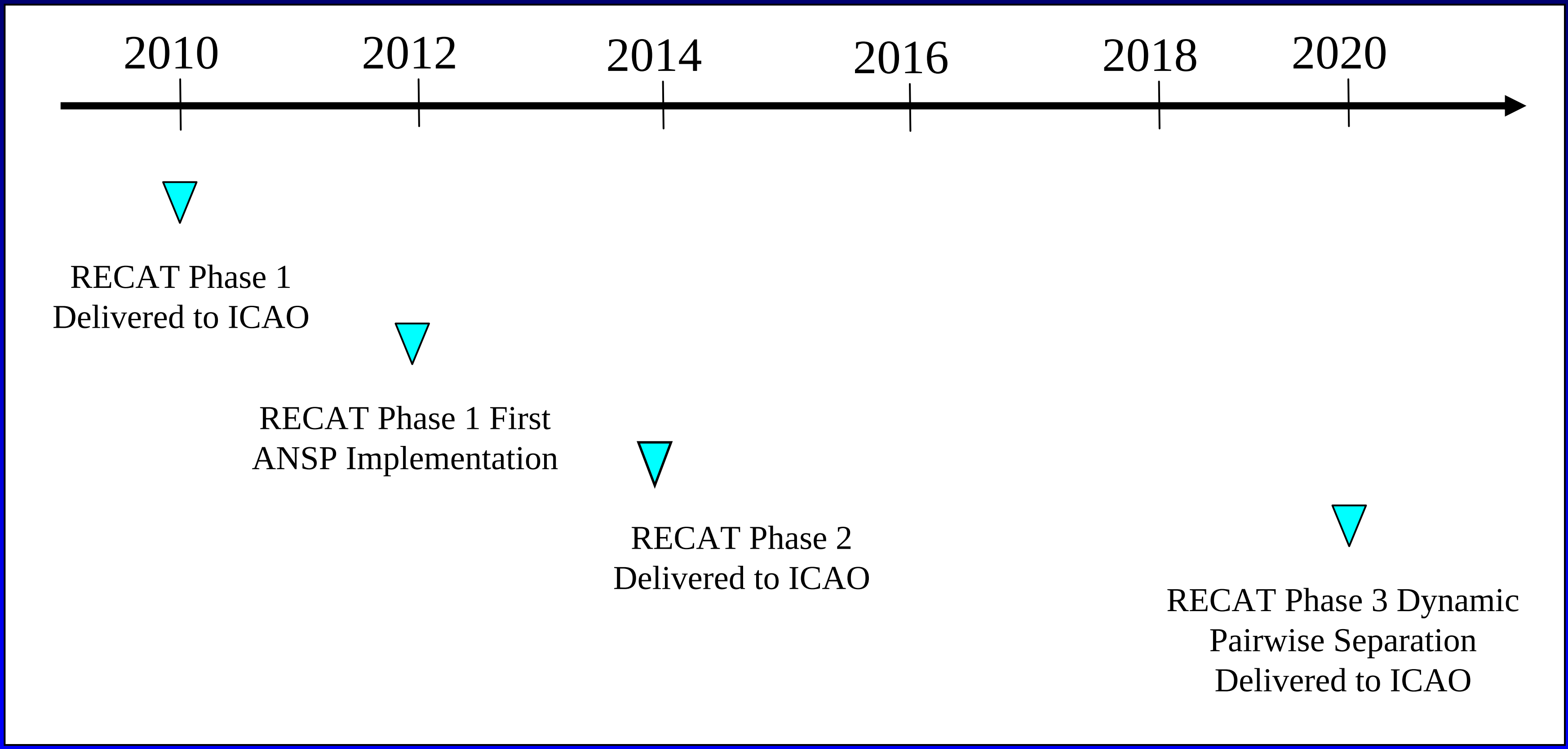


- Intense 4+ year effort
- Significant Resources Sustained on a Monthly Basis
  - R&D Funding
  - World preeminent wake scientists
  - Operations expertise
  - Regulatory expertise
  - Safety expertise

Requirements and Scope of the Effort

- Safety: As safe or safer than today
- Transparency: Openly available tools and data
- Optimization:
  - Provides new categories and separations optimized to current fleet mixes and evaluated for potential future fleet mixes
  - Focuses on 61 representative aircraft types
- Applies to Arrival and Departure
  - Distance and time based separation provided for approach and departure
- Increase capacity

Next Phases



2010
2012
2014
2016
2018
2020
RECAT Phase 1 Delivered to ICAO
RECAT Phase 1 First ANSP Implementation
RECAT Phase 2 Delivered to ICAO
RECAT Phase 3 Dynamic Pairwise Separation Delivered to ICAO

Current ICAO Matrix

		Follower			
		A380	Heavy	Medium	Light
Leader	A380		6NM	7NM	8NM
	Heavy		4NM	5NM	6NM
	Medium				5NM
	Light				

RECAT Separation Table

		Follower					
		A	B	C	D	E	F
Leader	A		5.0NM	6.0NM	7.0NM	7.0NM	8.0NM
	B		3.0NM	4.0NM	5.0NM	5.0NM	7.0NM
	C				3.5NM	3.5NM	6.0NM
	D						5.0NM
	E						4.0NM
	F						

RECAT Separation Matrix

RECAT Separation Matrix

		Follower					
		A	**B**	**C**	**D**	**E**	**F**
Leader	**A**	MRS	5.0	6.0	7.0	7.0	8.0
	B	MRS	3.0	4.0	5.0	5.0	7.0
	C	MRS	MRS	MRS	3.5	3.5	6.0
	D	MRS	MRS	MRS	MRS	MRS	5.0
	E	MRS	MRS	MRS	MRS	MRS	4.0
	F	MRS	MRS	MRS	MRS	MRS	MRS

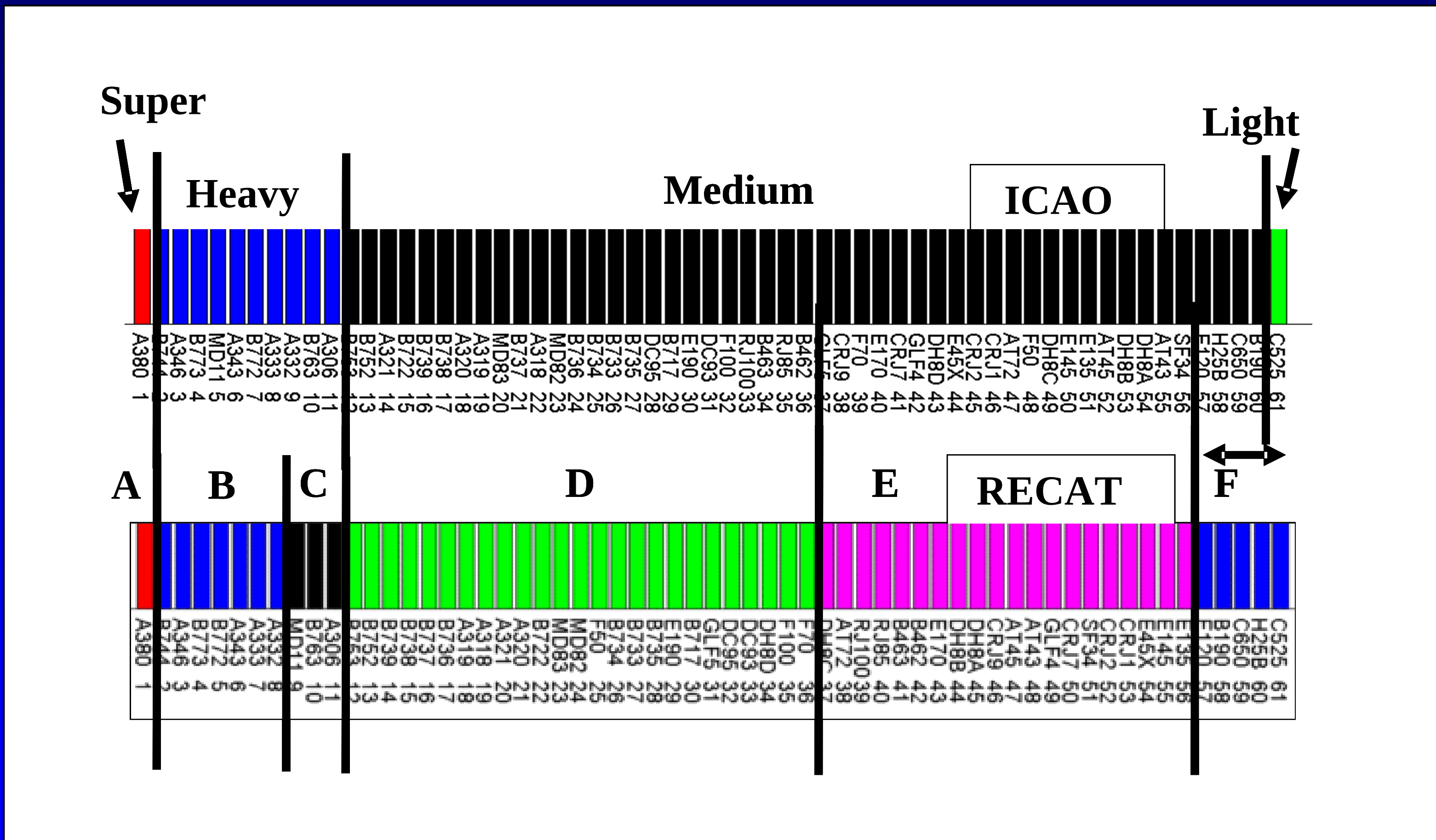
Separation was increased for some or all aircraft pairs

Separation was decreased for some or all aircraft pairs

Separation remained the same for some or all aircraft pairs

MRS Minimum Radar Separation (3NM, or 2.5 NM when existing requirements are met)

Categories: ICAO vs. RECAT (61 aircraft types)



61 Aircraft Types Used in RECAT

Manufacturer	Model	Equip	Manufacturer	Model	Equip
Aerospatiale	ATR 42-300	AT43			
Aerospatiale	ATR 42-500	AT45	Boeing	DC-9-30	DC93
Aerospatiale	ATR 72	AT72	Boeing	DC-9-50	DC95
Airbus	A306	A306	Boeing	MD-11	MD11
Airbus	A318	A318	Boeing	MD-82	MD82
Airbus	A319	A319	Boeing	MD-83/MD-88	MD83/88
Airbus	A320	A320	Bombardier	CRJ-100	CRJ1
Airbus	A321	A321	Bombardier	CRJ-200	CRJ2
Airbus	A330-200	A332	Bombardier	CRJ-700	CRJ7
Airbus	A330-300	A333	Bombardier	CRJ-900	CRJ9
Airbus	A340-300	A343	Bombardier	DHC8-100	DH8A
Airbus	A340-600	A346	Bombardier	DHC8-200	DH8B
Airbus	A380	A380	Bombardier	DHC8-300	DH8C
Avro	RJ-85	RJ85	Bombardier	DHC8-Q400	DH8D
Avro	RJ-100	RJ1H	British Aerospace	Bae 146-200	B462
Beechcraft	1900D	B190	British Aerospace	Bae 146-300	B463
Boeing	B717-200	B712	Cessna	Citation CJ1	C525
Boeing	B727-200	B722	Cessna	650 C-III/VI/VII	C650
Boeing	B737-300	B733	Embraer	EMB-120	E120
Boeing	B737-400	B734	Embraer	EMB-135	E135
Boeing	B737-500	B735	Embraer	EMB-145	E145
Boeing	B737-600	B736	Embraer	EMB-170	E170
Boeing	B737-700	B737	Embraer	EMB-190	E190
Boeing	B737-800	B738	Embraer	EMB-145XR	E45X
Boeing	B737-900	B739	Fokker	F-50	F50
Boeing	B747-400	B744	Fokker	F-70	F70
Boeing	B757-200	B752	Fokker	F-100	F100
Boeing	B757-300	B753	Gulfstream	G-4	GLF4
Boeing	B767-300	B763	Gulfstream	G-5	GLF5
Boeing	B777-200	B772	Saab	340	SF34
Boeing	B777-300	B773	Raytheon	125-700	H25B

Selected Aircraft by Category

A	B	C	D	E	F
A380	B744	MD11	B753	DH8C	E120
AN-225	A346	B763	B752	AT72	B190
	B773	A306	B739	RJ100	C650
	B772		B738	RJ85	H25B
	A343		B737	B463	C525
	A333		B736	B462	
	A332		A319	E170	
			A318	DH8B	
			A321	DH8A	
			A320	CRJ9	
			B722	AT45	
			MD83	AT43	
			MD82	GLF4	
			F50	CRJ7	
			B734	SF34	
			B733	CRJ2	
			B735	CRJ1	
			E190	E45X	
			B717	E145	
			GLF5	E135	
			DC95		
			DC93		
			DH8D		
			F100		

- Selected aircraft listed here, plus all 9000+ ICAO registered aircraft were successfully assigned to these 6 categories

Project Assumptions (1/2)

- All Current ICAO Separations are Acceptably Safe
- Results to be Applicable for Approach and Departure and under all weather conditions
- No required changes on the flight deck
- Minimum modifications on the ground (if any)
- Minimum changes in procedures
- Multiple aircraft parameters considered, in addition to weight (wingspan, speed, lift force distribution)

Project Assumptions (2/2)

- Methodology developed to categorize future aircraft types
- Reasonable worst case wake strength from airport operational data
  - Analysis performed at threshold, where wake encounters are most critical
- Optimization based on traffic mixes from 4 European and 5 US congested airports
- Capacity gain will
  - Provide benefit at constrained airports as well as other airports world wide
  - More than justify minimum changes to procedures and on the ground
- Used airport operational measurements and presently available knowledge

Traffic Samples

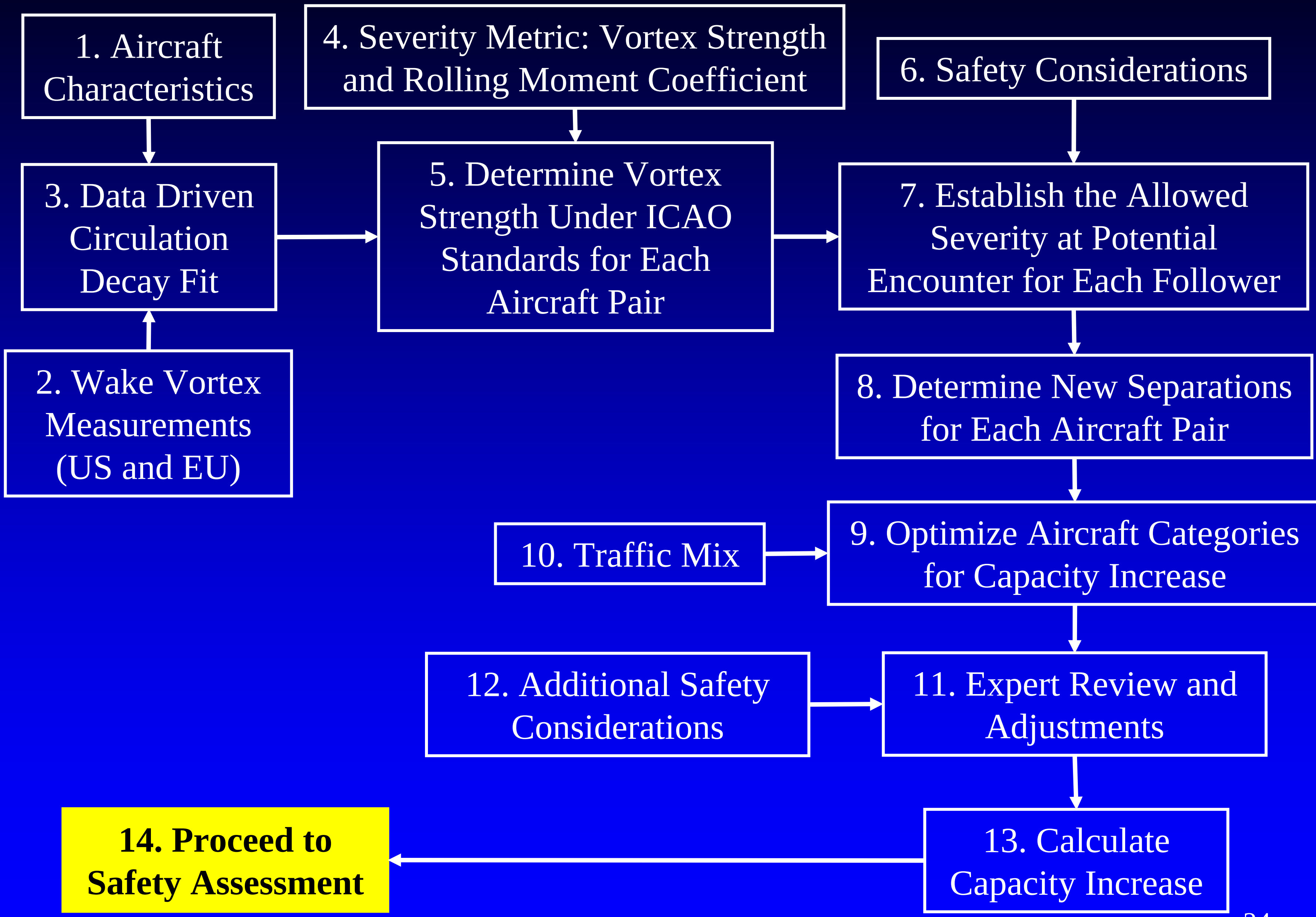
- 4 European airports:
  - Heathrow (EGLL)
  - Amsterdam (EHAM)
  - Frankfurt (EDDF)
  - Paris “Charles de Gaulle”(LFPG)
- 5 U.S. airports:
  - Atlanta (KATL)
  - Newark (KEWR)
  - John F. Kennedy (KJFK)
  - Chicago O’Hare (KORD)
  - San Francisco (KSFO)
- Representative traffic mix of 61 aircraft types (85% of the traffic)

Operational Percentage in US and Europe

US Avg Peak		European Peak		US Avg Peak		European Peak	
A306	0.69%	A306	2.53%	CRJ9	1.51%	CRJ9	0.17%
A318	0.06%	A318	0.79%	DC93	0.14%	DC93	0.00%
A319	2.87%	A319	6.18%	DC95	0.26%	DC95	0.00%
A320	7.17%	A320	9.86%	DH8A	0.00%	DH8A	0.00%
A321	0.25%	A321	5.96%	DH8B	0.06%	DH8B	0.00%
A332	0.39%	A332	0.21%	DH8C	0.00%	DH8C	1.10%
A333	0.18%	A333	1.55%	DH8D	0.97%	DH8D	0.87%
A343	0.31%	A343	0.80%	E120	1.46%	E120	0.00%
A346	0.43%	A346	0.28%	E135	2.14%	E135	0.29%
AT43	0.00%	AT43	0.11%	E145	8.48%	E145	0.65%
AT72	0.80%	AT72	0.06%	E170	2.37%	E170	1.26%
B190	0.00%	B190	0.04%	E190	1.33%	E190	0.00%
B712	4.28%	B712	0.00%	E45X	0.88%	E45X	0.00%
B722	0.18%	B722	0.00%	GLF4	0.08%	GLF4	0.06%
B733	3.00%	B733	11.76%	GLF5	0.05%	GLF5	0.04%
B734	0.38%	B734	4.52%	MD11	0.38%	MD11	1.30%
B735	2.36%	B735	5.21%	MD82	3.29%	MD82	0.58%
B736	0.00%	B736	0.77%	MD83/88	8.07%	MD83	0.02%
B737	2.85%	B737	1.71%	SF34	0.00%	SF34	0.01%
B738	4.53%	B738	7.12%				
B739	0.23%	B739	1.58%	**US Only Aircraft**			
B744	2.74%	B744	2.84%	H25B	0.12%		
B752	10.30%	B752	0.46%			**European Only**	
B753	0.39%	B753	0.14%			AT45	0.05%
B763	3.25%	B763	1.60%			A380	0.00%
B772	1.81%	B772	0.90%			RJ85	1.13%
B773	0.15%	B773	0.17%			RJ1H	0.08%
C525	0.02%	C525	0.11%			B462	0.58%
C650	0.02%	C650	0.04%			B463	2.75%
CRJ1	0.82%	CRJ1	0.00%			F50	2.91%
CRJ2	11.21%	CRJ2	1.58%			F70	7.81%
CRJ7	6.74%	CRJ7	0.89%			F100	6.38%

Methodology

- Focused on representative aircraft for process efficiency
- Wake strength used as the primary hazard metric
  - Data driven wake decay used to derive the hazard metric
  - Wake decay data from both US and Europe used joint FAA and EUROCONTROL measurements from both continents
  - Historically, 5-15m circulation gives good agreement with flight test encounter data
- Also used rolling moment coefficient as a metric
- Categories optimized for capacity increase
- Simple Relative Safety argument: Same or better than today


1. Aircraft Characteristics
4. Severity Metric: Vortex Strength and Rolling Moment Coefficient
6. Safety Considerations
3. Data Driven Circulation Decay Fit
5. Determine Vortex Strength Under ICAO Standards for Each Aircraft Pair
7. Establish the Allowed Severity at Potential Encounter for Each Follower
2. Wake Vortex Measurements (US and EU)
8. Determine New Separations for Each Aircraft Pair
10. Traffic Mix
9. Optimize Aircraft Categories for Capacity Increase
12. Additional Safety Considerations
11. Expert Review and Adjustments
14. Proceed to Safety Assessment
13. Calculate Capacity Increase

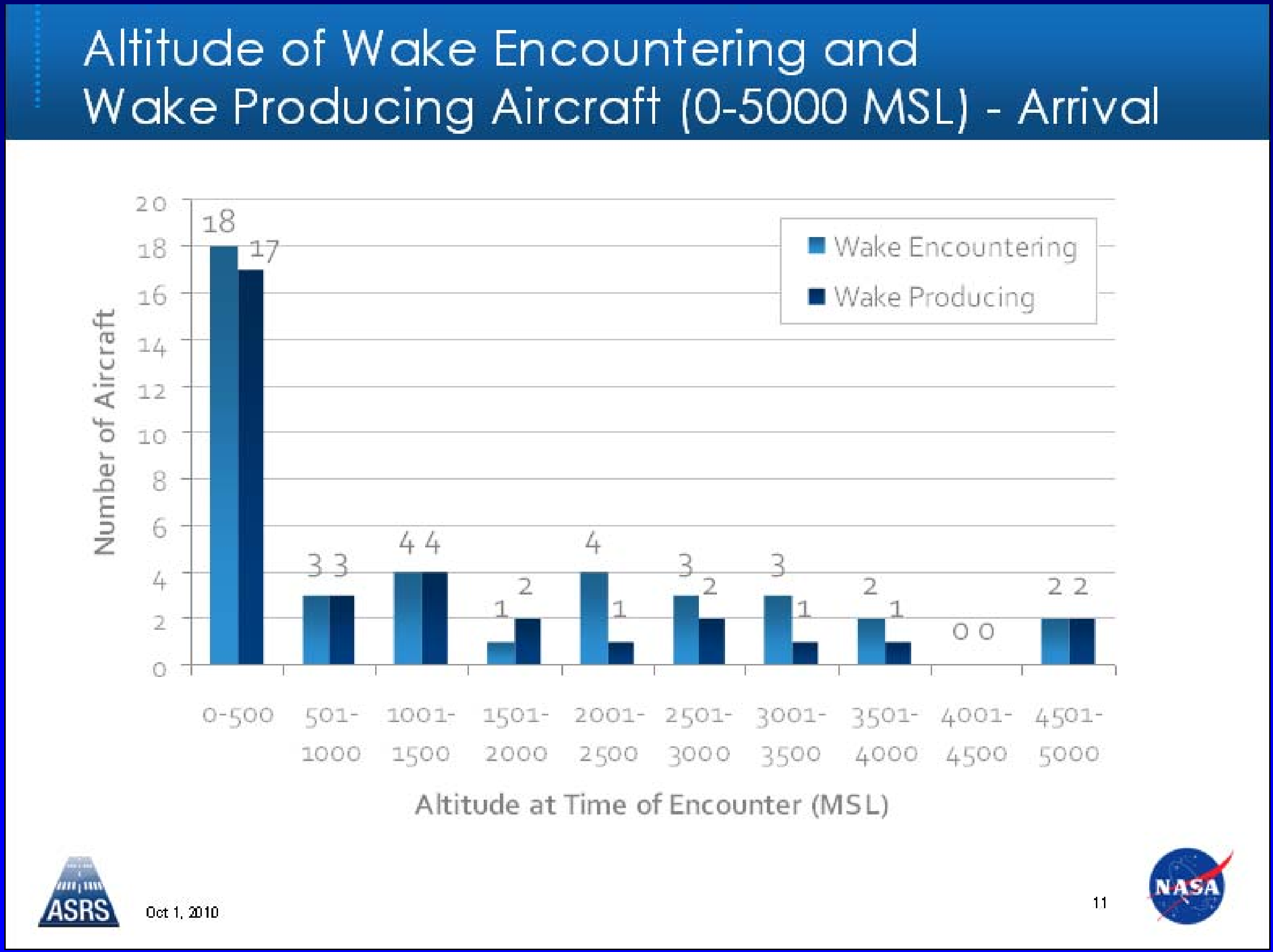
#1 Aircraft Characteristics

- Focused on 61 aircraft types comprising 85% of traffic at busiest European and US airports
- Extended to include 9000+ aircraft types globally
- Publicly available data

#2 Wake Vortex Measurements

- Wake data collected in low wind conditions at both US and European sites (16,112 tracks from 15 different aircraft types obtained at 2 European and 3 US airports)
  - Used data from three different sensors: continuous-wave Lidar, pulsed Lidar and a line of propeller anemometers (windline)
  - Reasonable worst case: Nearly all data collected with winds of 5 kt or less
- Data collected near threshold, since this is considered to be the most dangerous phase of flight

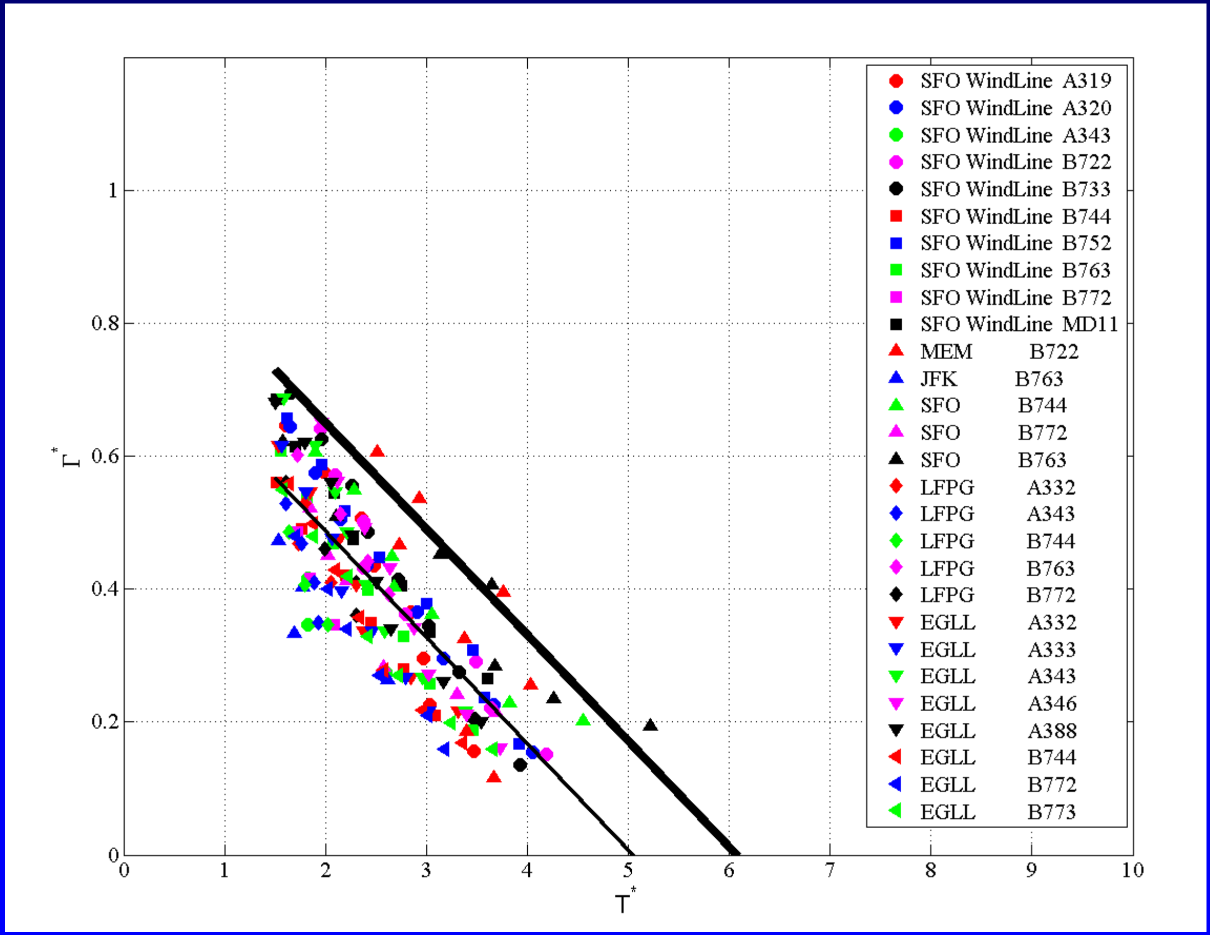
Results From the Aviation Safety Reporting System (ASRS)



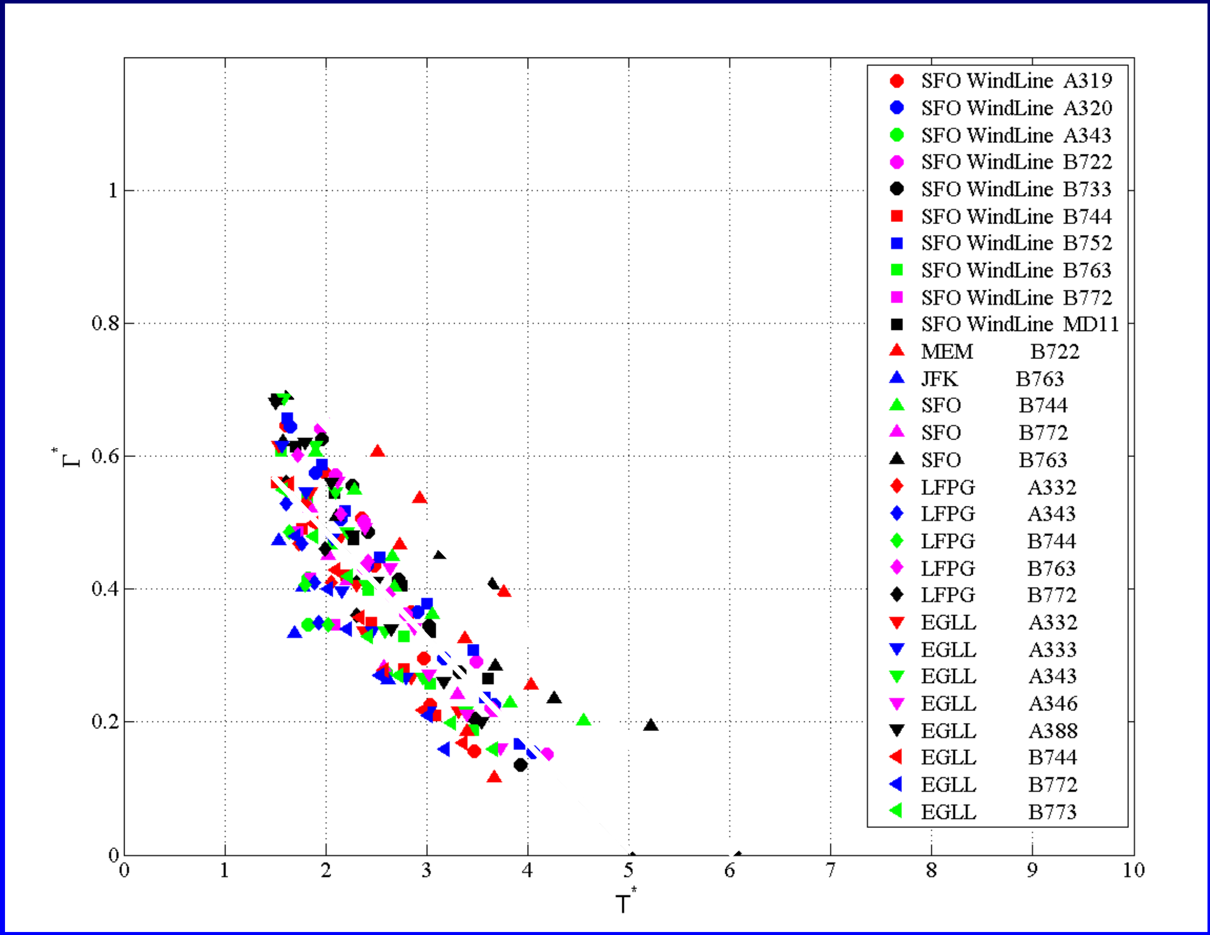
#3 Data Driven Circulation Decay Fit

- Long lasting wakes used in wake strength (circulation) decay fit
  - For Safety, reasonable worst case used
- Decay fit derived through European and US collaboration
  - 16,112 aircraft tracks
  - 15 aircraft types
  - 5 different airports
  - 3 different wake sensors

Median Data, Fit (Thin Line), and 95% Confidence Interval (Thick Line)



Median Data



SFO WindLine A319
SFO WindLine A320
SFO WindLine A343
SFO WindLine B722
SFO WindLine B733
SFO WindLine B744
SFO WindLine B752
SFO WindLine B763
SFO WindLine B772
SFO WindLine MD11
MEM B722
JFK B763
SFO B744
SFO B772
SFO B763
LFPG A332
LFPG A343
LFPG B744
LFPG B763
LFPG B772
EGLL A332
EGLL A333
EGLL A343
EGLL A346
EGLL A388
EGLL B744
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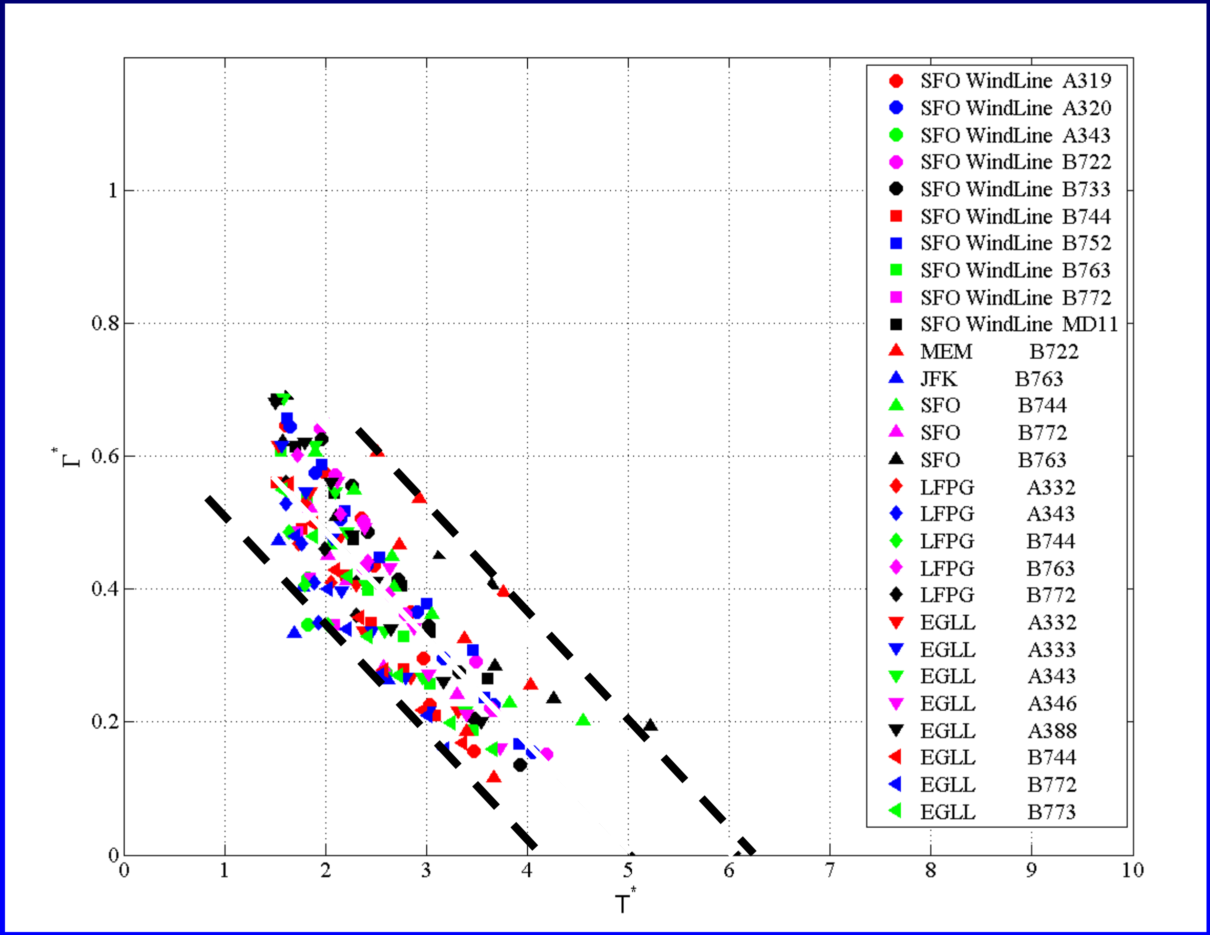
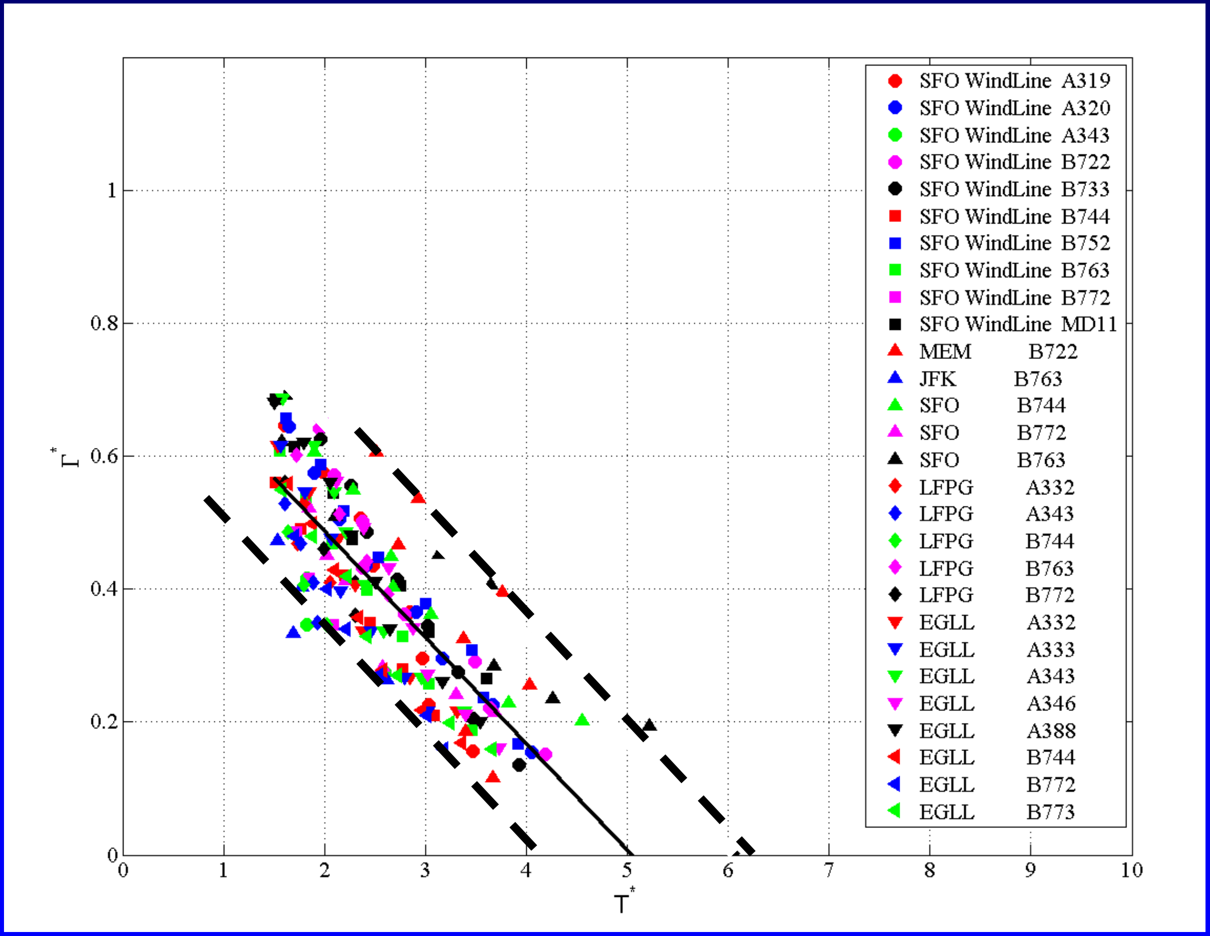
0 1 2 3 4 5 6 7 8 9 10

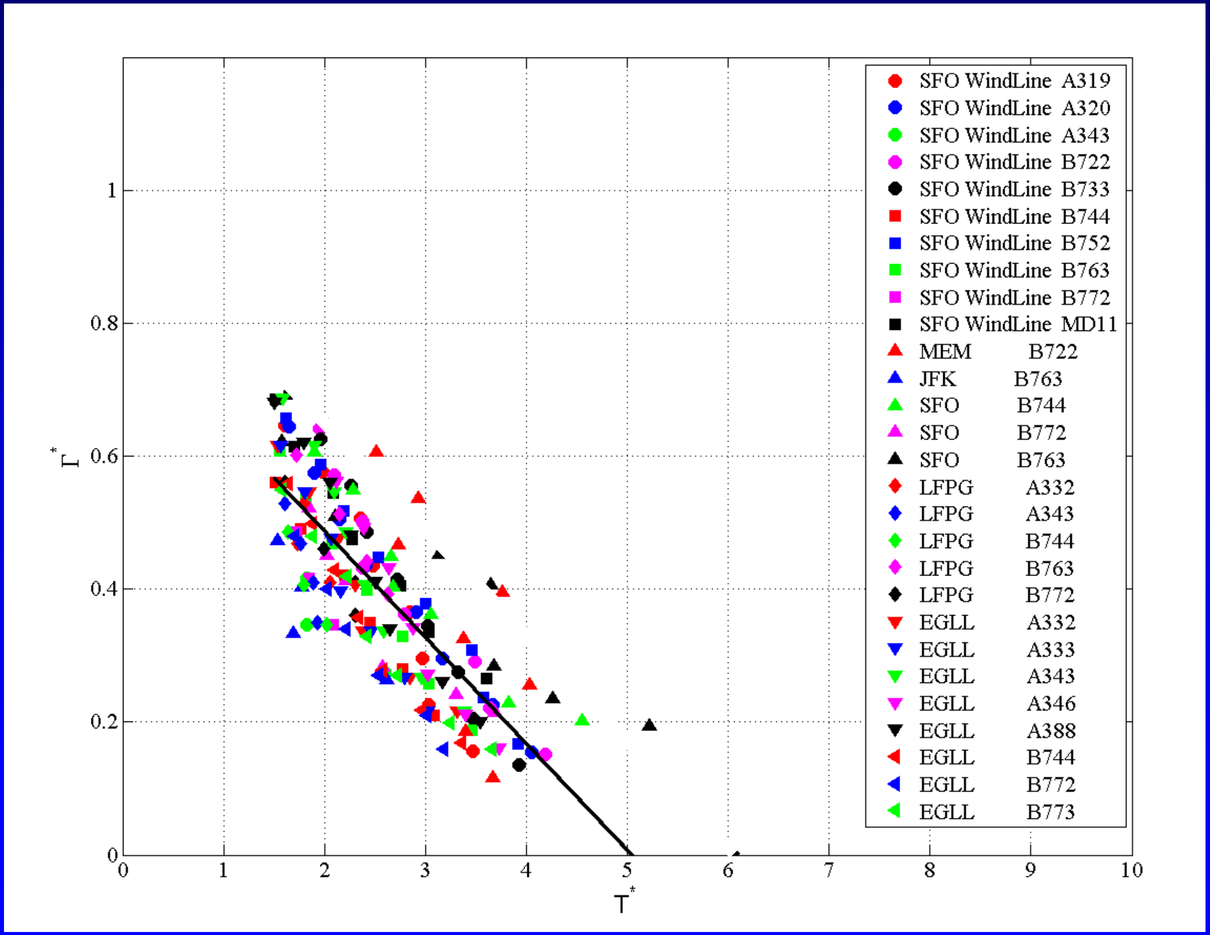
Median Data with Bounds



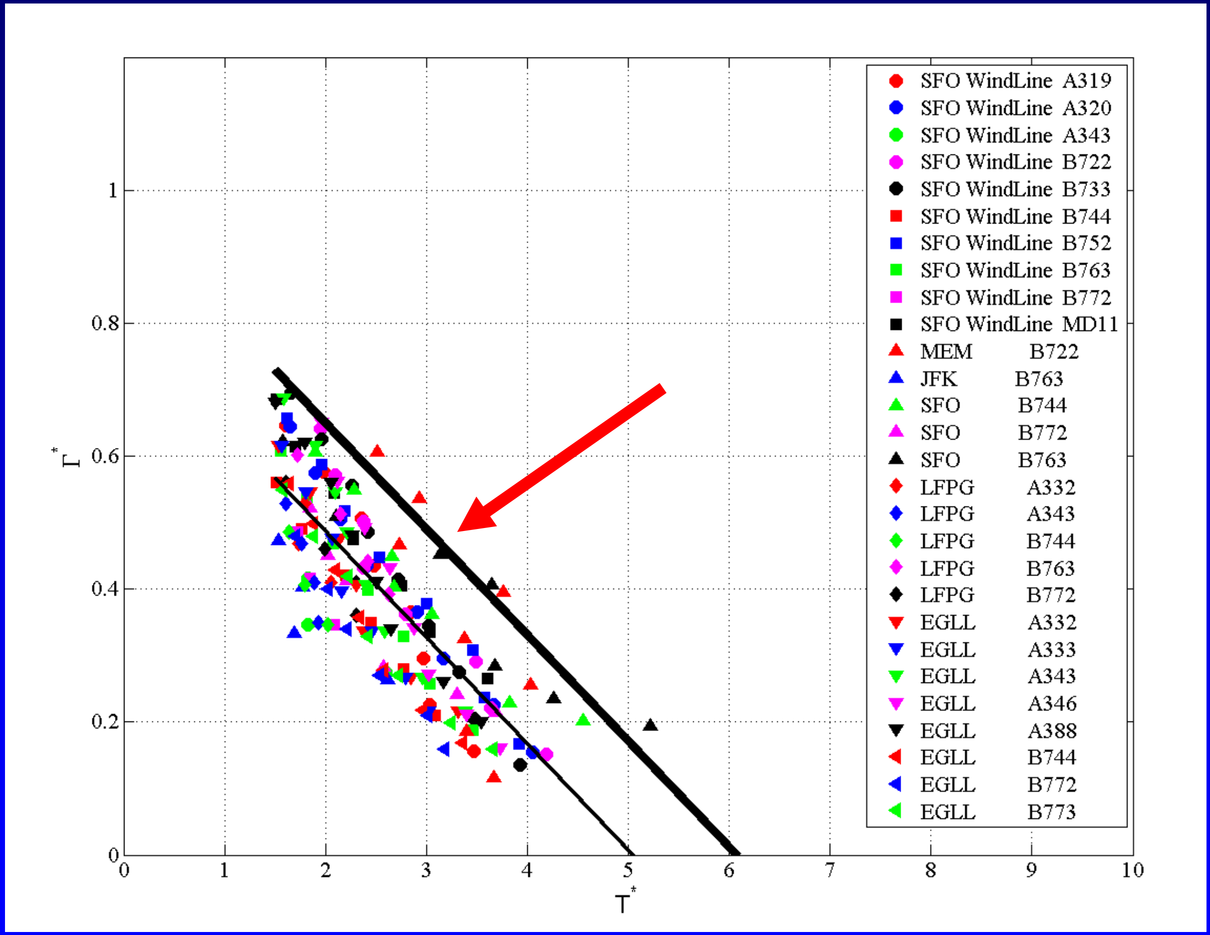
Median Data with Bounds and Fit



Median Data with Fit



Median Data, Fit (Thin Line), and 95% Confidence Interval (Thick Line)



#4 Severity Metrics

- Wake strength used as the primary hazard metric
- Rolling Moment Coefficient was also used as a hazard metric
  - Aircraft size and resistance to vortex encounter considered for aircraft in the top end of the ICAO Heavy category
- Other considerations in support of safety assessment used to add additional conservativeness and confidence
  - Roll Control Authority
  - Bank Angle

#5 Determine Vortex Strength Under ICAO Standards For Each Aircraft Pair

For each aircraft pair:

- Used generator aircraft characteristics to determine initial wake strength
- Used follower speed to determine time interval between wake generated and potentially encountered by follower at ICAO separation
- Used wake strength decay fit to operational data to determine wake strength at current ICAO separation standard

Initial Wake Strength From a Generator

$$\Gamma_o = g\,W / (\rho\,U\,b_o)$$

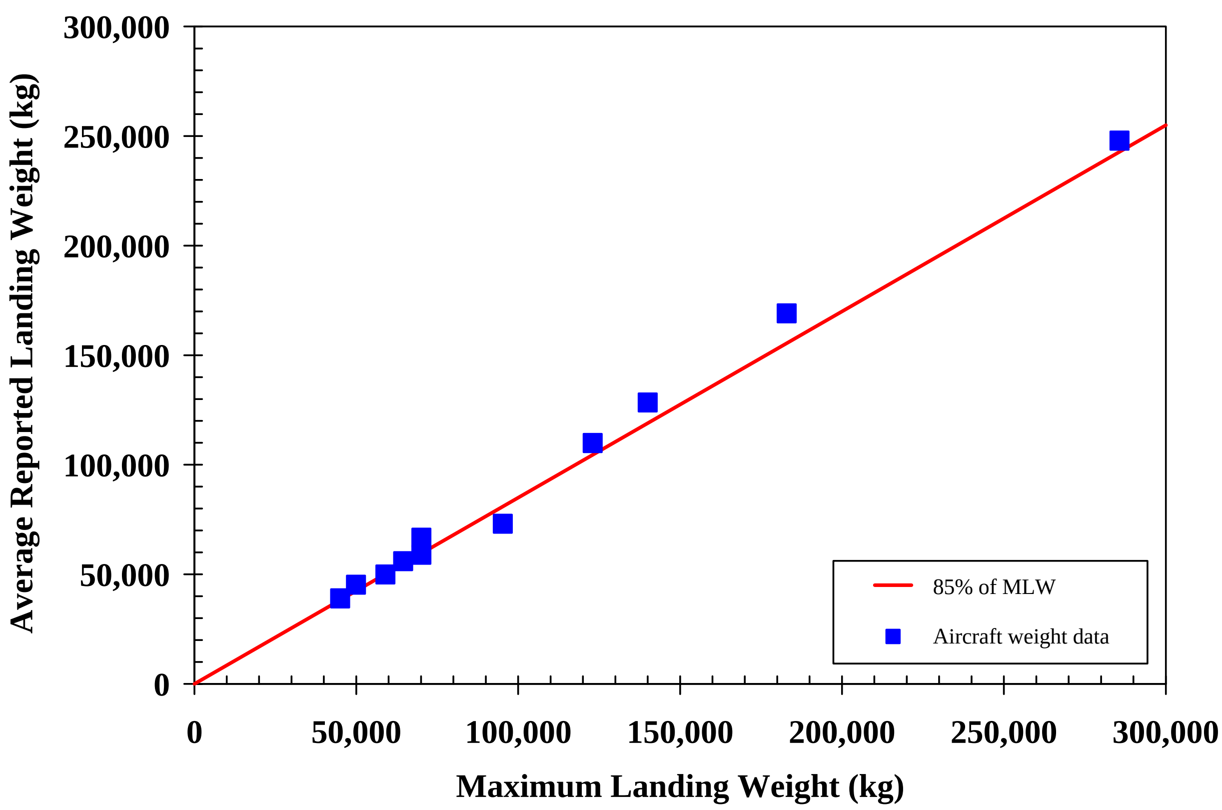
where bo = (π/4) $\times$ wing span,

g is the acceleration due to gravity,

ρ is the air density, and

W and U are the weight and speed of the aircraft. (In this analysis, 85% of the maximum landing weight and the final approach speed for each aircraft are used to calculate circulation)

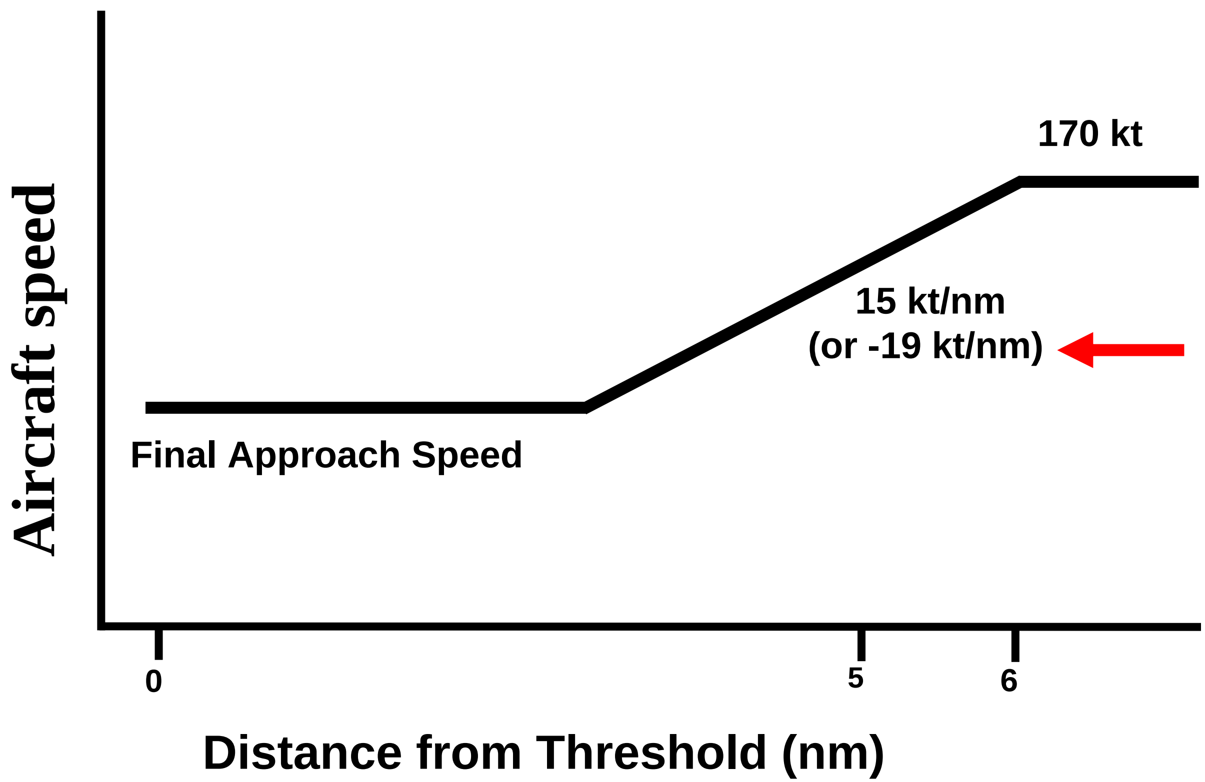
Validity of the Assumption of 85% of MLW (from NASA)



Time Interval Between Wake Generator and Follower Aircraft Under ICAO Separations

- All aircraft are assumed to follow a certain speed profile (next slide)
- Time interval found using ICAO distance separations
- Circulation decay fit used to determine median circulations (or longest lasting wakes) under current ICAO separations

Speed Profile for All Aircraft



Needed for DHC8-100, DHC8-200, DHC8-300, and ATR-42-300 only, to achieve final approach speeds above 500 feet glide slope altitude

#6 Safety Considerations

- Current ICAO separation standards are acceptably safe
- Safety of smaller aircraft enhanced by increasing separations
  - Wake strength exposure under RECAT limited to 75% of that allowed under ICAO today

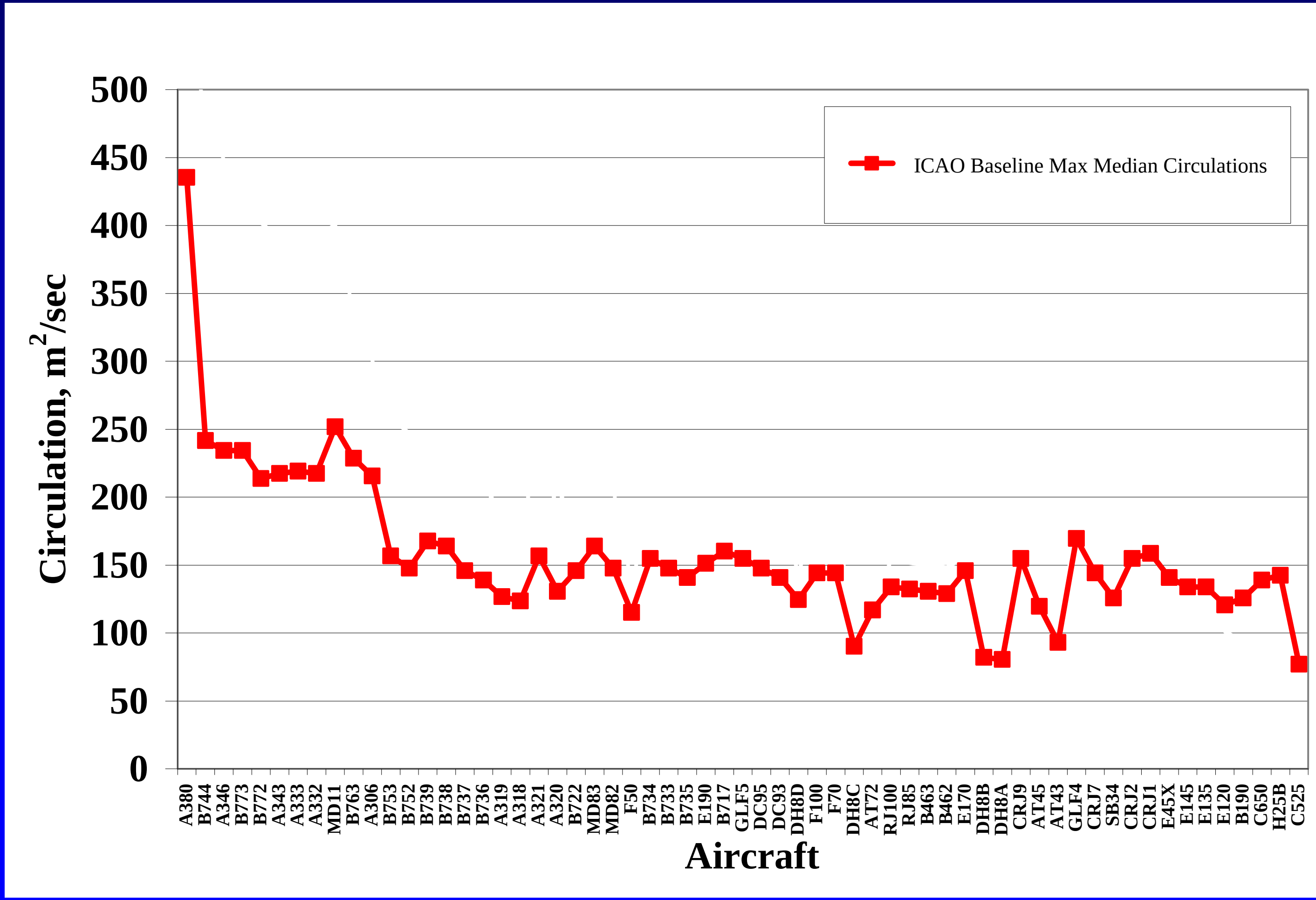
#7 Establish the Allowed Wake Strength at Potential Encounter for Each Follower

- Not to exceed wake strength values potentially encountered today under ICAO standards
  - Except for category B, where rolling moment coefficient was used
- Additional conservativeness added for lightest, most vulnerable aircraft

Found Maximum Median Allowed Circulations Under ICAO Today

- Approach speed profile and circulation decay fit used for each 61 by 61 aircraft pairs
- Found the maximum median circulation allowed today for any follower following all 61 generators
  - Used this circulation
  - Allowable since all ICAO separation standards are acceptably safe today

Maximum Median Allowable Circulations Under ICAO Today



#8 Determine New Separations for Each Aircraft Pair

- Computed RECAT separation matrix for each 61 by 61 aircraft pair using the allowed wake strength values on last slide

#9 Optimize Aircraft Categories for Capacity Increase

- Aircraft grouped into categories and total separation distance computed
  - Separation for each aircraft pair changed to maximum within a category
- All possible groupings computed
  - Initial sorted list maintained for groupings
- Optimized set of categories found for maximum capacity

Example With 5 Aircraft and 3 Categories

- Label the 5 aircraft 1 through 5
- There are 6 possible groupings, maintaining the initial list and having at least 1 aircraft in each category

1	2	3	4	5
1	2	3	4	5
1	2	3	4	5
1	2	3	4	5
1	2	3	4	5
1	2	3	4	5

Look at this grouping

Example Separations From 1 Grouping

Separations for the first category leading the first category

Follower=>	1	2	3	4	5
Leader 1:	4.0	5.0	5.0	6.0	6.5
Leader 2:	4.0	4.5	4.5	5.0	5.5
Leader 3:	3.5	4.0	4.0	4.5	5.0
Leader 4:	3.0	3.5	3.5	4.0	4.5
Leader 5:	2.5	2.5	3.0	3.0	3.5

Example Separations From 1 Grouping

Separations for the second category leading the first category

Follower=>	1	2	3	4	5
Leader 1:	4.0	5.0	5.0	6.0	6.5
Leader 2:	4.0	4.5	4.5	5.0	5.5
Leader 3:	3.5	4.0	4.0	4.5	5.0
Leader 4:	3.0	3.5	3.5	4.0	4.5
Leader 5:	2.5	2.5	3.0	3.0	3.5

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Leader 2:	4.0	4.5	4.5	5.0	5.5
Leader 3:	3.5	4.0	4.0	4.5	5.0
Leader 4:	3.0	3.5	3.5	4.0	4.5
Leader 5:	2.5	2.5	3.0	3.0	3.5

For safety, all these separations need to be changed to the largest in the grouping

Example Separations From 1 Grouping

Follower=>	1	2	3	4	5
Leader 1:	4.0	5.0	5.0	6.0	6.5
Leader 2:	4.0	4.5	4.5	5.0	5.5
Leader 3:	3.5	4.0	4.0	4.5	5.0
Leader 4:	3.0	3.5	3.5	4.0	4.5
Leader 5:	2.5	2.5	3.0	3.0	3.5

Follower=>	1	2	3	4	5
Leader 1:	5.0	5.0	5.0	6.5	6.5
Leader 2:	5.0	5.0	5.0	6.5	6.5
Leader 3:	4.0	4.0	4.0	5.0	5.0
Leader 4:	3.5	3.5	3.5	4.5	4.5
Leader 5:	3.5	3.5	3.5	4.5	4.5

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Leader 2:	4.0	4.5	4.5	5.0	5.5
Leader 3:	3.5	4.0	4.0	4.5	5.0
Leader 4:	3.0	3.5	3.5	4.0	4.5
Leader 5:	2.5	2.5	3.0	3.0	3.5

Example Separations From 1 Grouping

Follower=>	1	2	3	4	5
Leader 1:	4.0	5.0	5.0	6.0	6.5
Leader 2:	4.0	4.5	4.5	5.0	5.5
Leader 3:	3.5	4.0	4.0	4.5	5.0
Leader 4:	3.0	3.5	3.5	4.0	4.5
Leader 5:	2.5	2.5	3.0	3.0	3.5

Follower=>	1	2	3	4	5
Leader 1:	5.0	5.0	5.0	6.5	6.5
Leader 2:	5.0	5.0	5.0	6.5	6.5
Leader 3:	4.0	4.0	4.0	5.0	5.0
Leader 4:	3.5	3.5	3.5	4.5	4.5
Leader 5:	3.5	3.5	3.5	4.5	4.5

Example Separations From 1 Grouping

Initial Separation Matrix

Follower=>	1	2	3	4	5
Leader 1:	4.0	5.0	5.0	6.0	6.5
Leader 2:	4.0	4.5	4.5	5.0	5.5
Leader 3:	3.5	4.0	4.0	4.5	5.0
Leader 4:	3.0	3.5	3.5	4.0	4.5
Leader 5:	2.5	2.5	3.0	3.0	3.5

Final Separation Matrix

Follower=>	1	2	3	4	5
Leader 1:	5.0	5.0	5.0	6.5	6.5
Leader 2:	5.0	5.0	5.0	6.5	6.5
Leader 3:	4.0	4.0	4.0	5.0	5.0
Leader 4:	3.5	3.5	3.5	4.5	4.5
Leader 5:	3.5	3.5	3.5	4.5	4.5

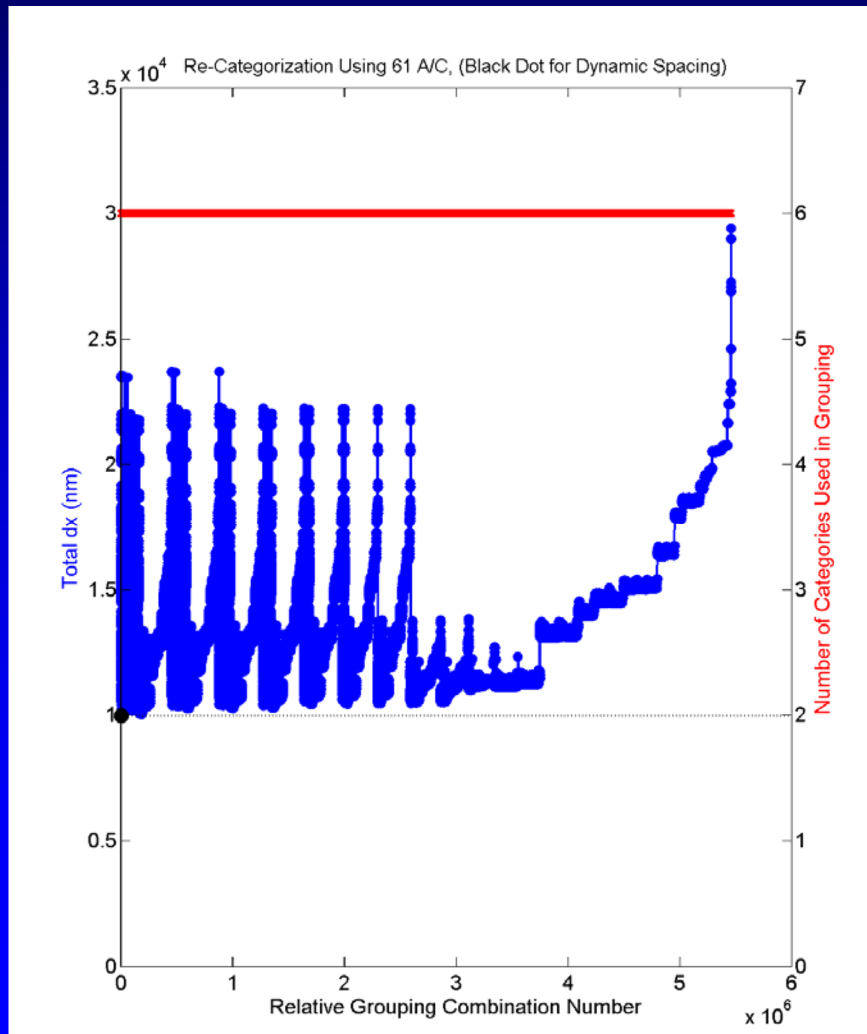
Sum of all the separations is the capacity metric for each grouping (117 nm here)

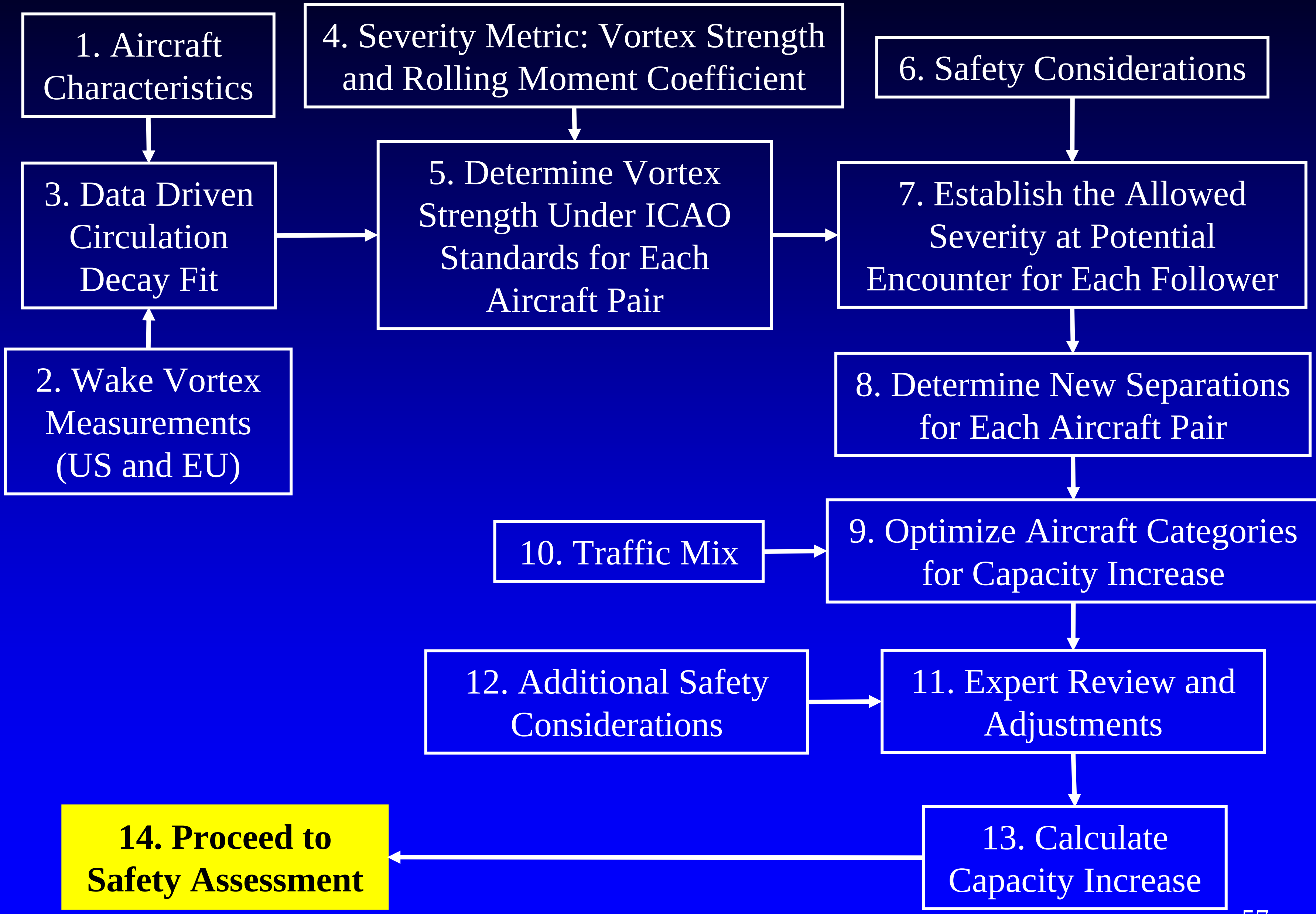
Extension to 61 Aircraft

- Example above is for one possible grouping of 5 aircraft into 3 categories
- RECAT problem is to optimize 61 aircraft into 6 categories
  - Above example had 6 possible groupings
  - RECAT problem has 5,461,512 possible groupings

Total Separations For All Groupings of 61 Aircraft Into 6 Categories

Minimum is the grouping with the best capacity

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10. Traffic Mix
9. Optimize Aircraft Categories for Capacity Increase
12. Additional Safety Considerations
11. Expert Review and Adjustments
14. Proceed to Safety Assessment
13. Calculate Capacity Increase

#10 Traffic Mix

- Traffic mix was used in the optimization
- Traffic mixes for the U.S. determined from five U.S. airports and for Europe determined from four European airports
  - US: Atlanta (ATL), Chicago (ORD), Newark (EWR), New York JFK (JFK), and San Francisco (SFO)
  - Europe: Amsterdam (AMS), Frankfurt (FRA), London Heathrow (LHR), and Paris Charles de Gaulle (CDG)
- These traffic mixes are assumed to be representative of the larger fleet mix
  - Confirmed analyzing traffic mixes at world wide capacity constrained airports
- Pair-wise statistics derived by assuming probability of occurrence of each aircraft is independent

Aircraft Traffic Mix

- If the probabilities of occurrence of each aircraft and each aircraft pair are uniformly distributed, there is no need to modify the separation matrix
- If there is a non-uniform traffic mix, the separation between the i-jth pair is modified by

$$\Delta t_{ij} = N^2 \Delta t_{ij} P_{ij}$$

  - where N is the number of aircraft and P_{ij} is the probability of occurrence of the i-jth aircraft pair

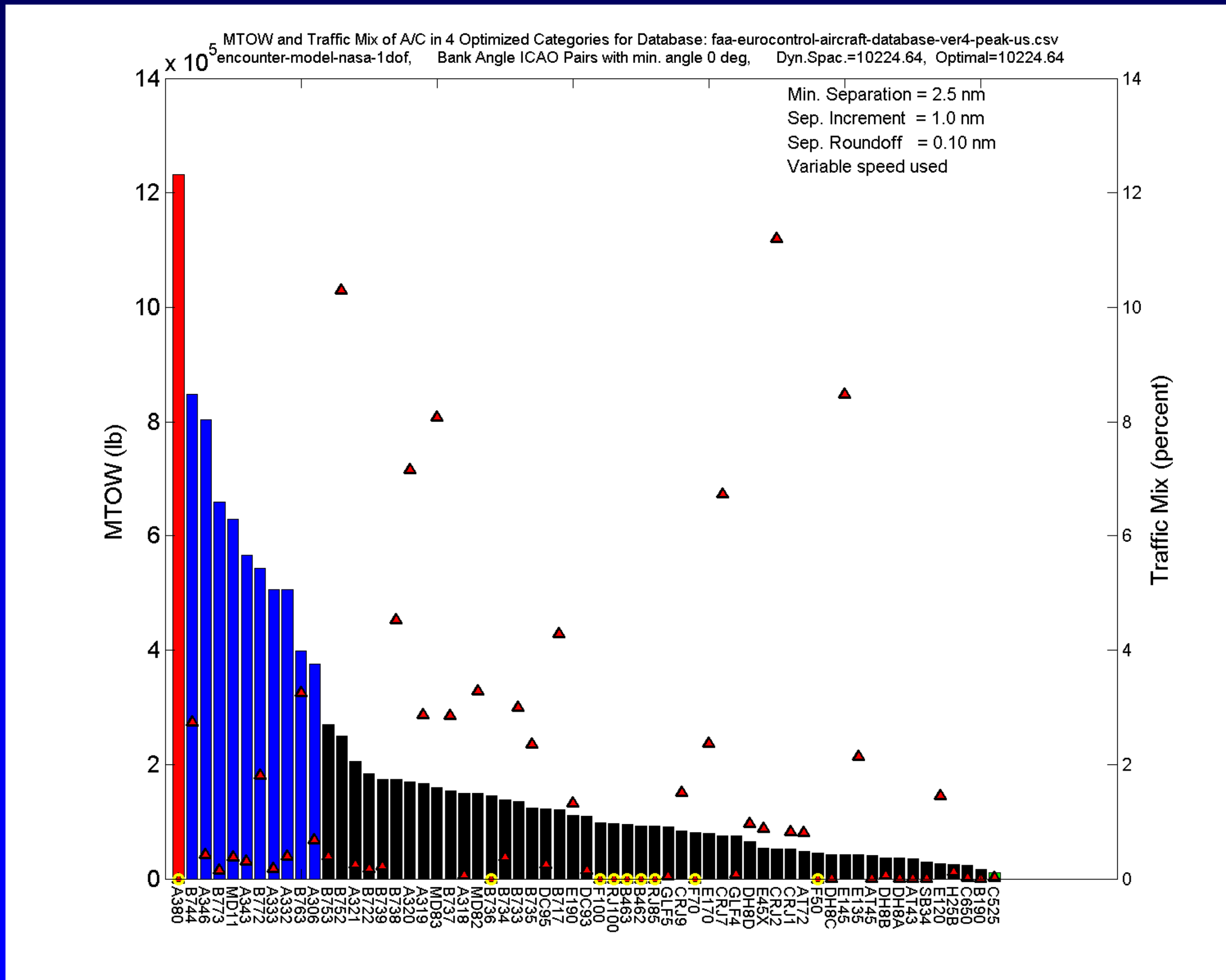
Aircraft Traffic Mix (cont.)

- If the probabilities of occurrence of aircraft pairs are not available:
  - Can assume probabilities of occurrence for each aircraft are independent
  - Modify the separation matrix by

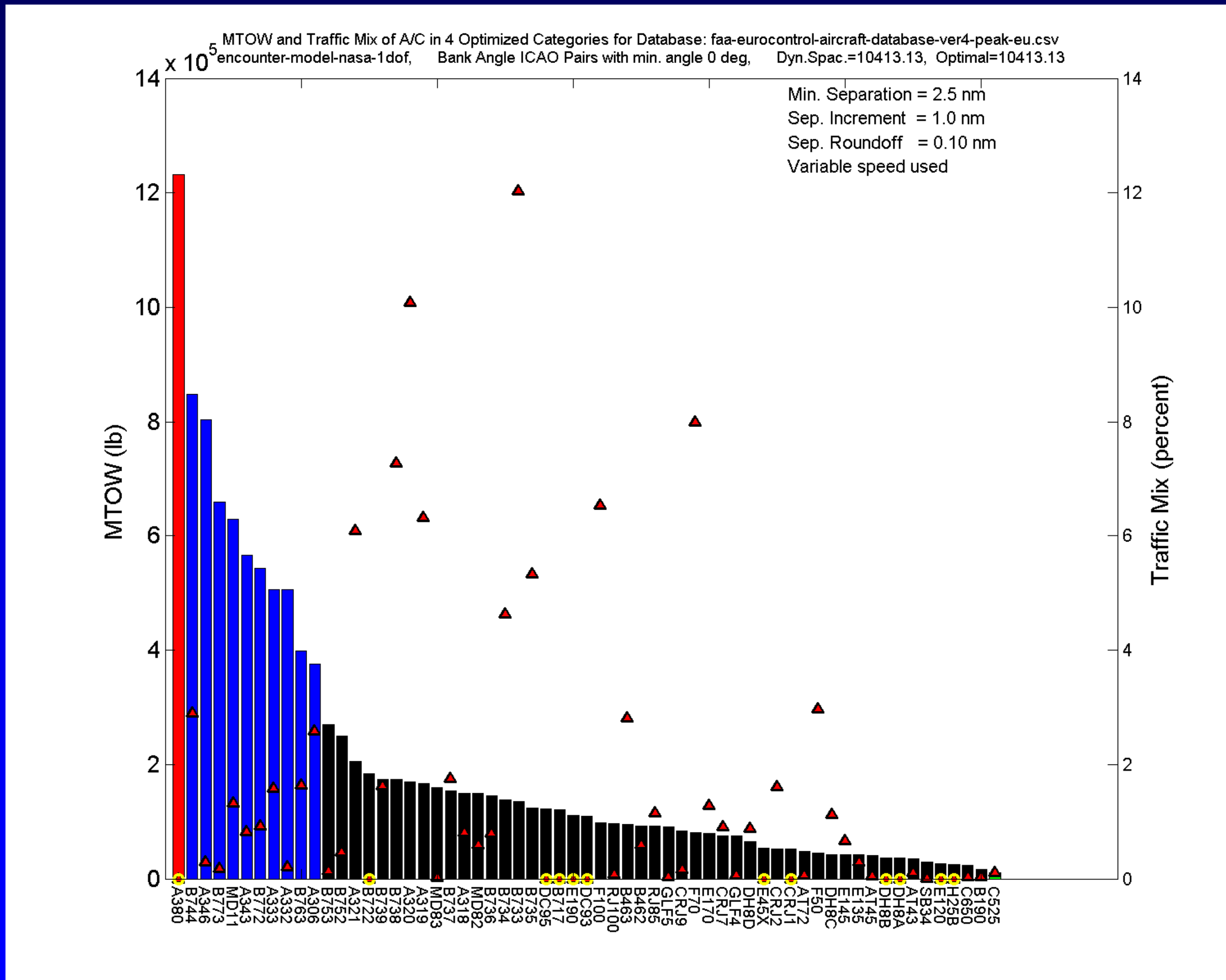
$$\Delta t_{ij} = N^2 \, \Delta t_{ij} \, P_i \, P_j$$

  - where P_i and P_j are the probability of occurrence of the i^{th} and j^{th} aircraft, respectively

Average US Peak Traffic Mix



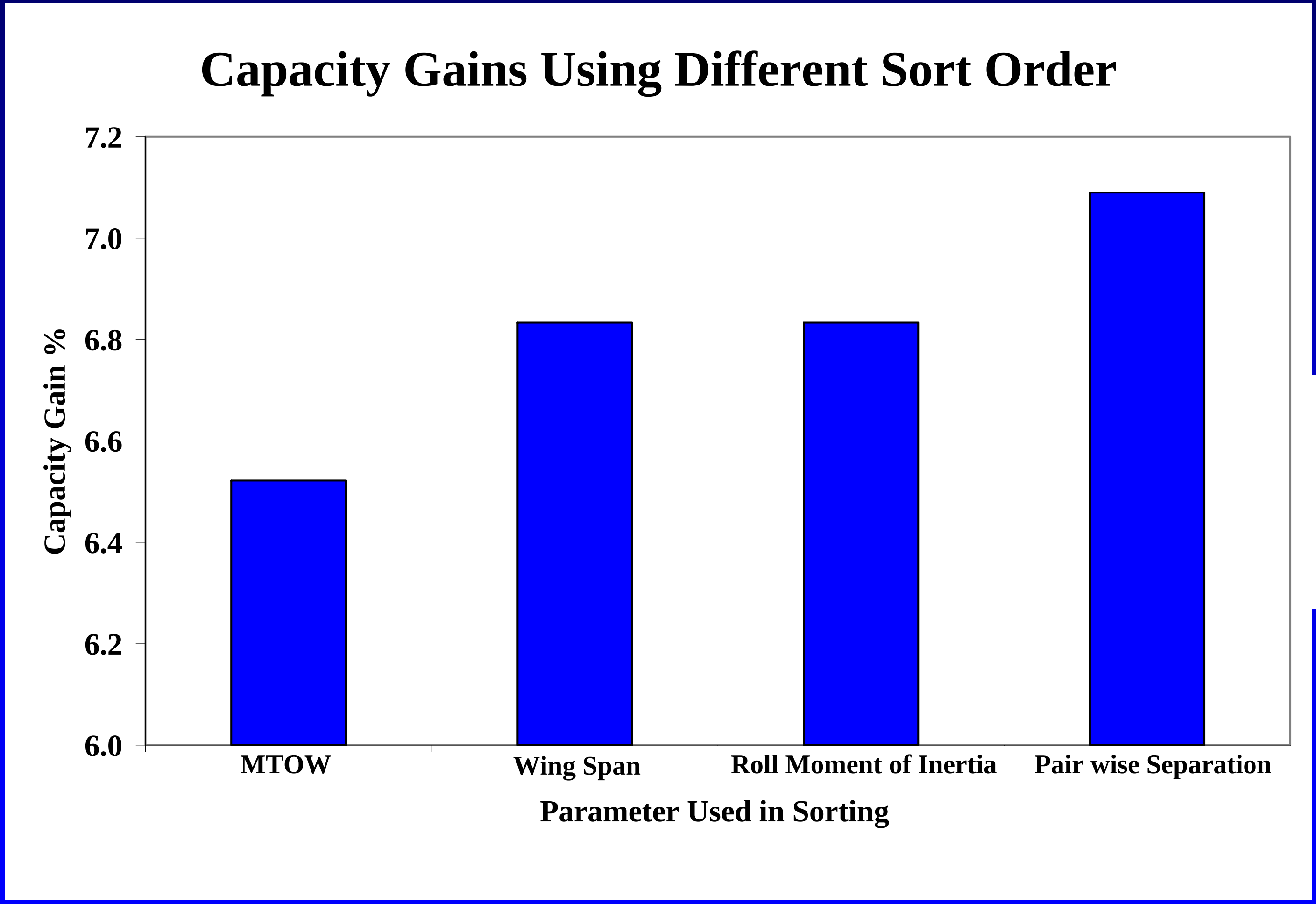
Average EU Peak Traffic Mix



Optimizations

- Optimization performed for average US peak traffic and average EU peak traffic
- Blending of US optimization and EU optimization performed
- Looked at optimizing based on maximum take off weight, wingspan, rolling moment of inertia, and pair-wise separation

Capacity Gains for Different Sorting

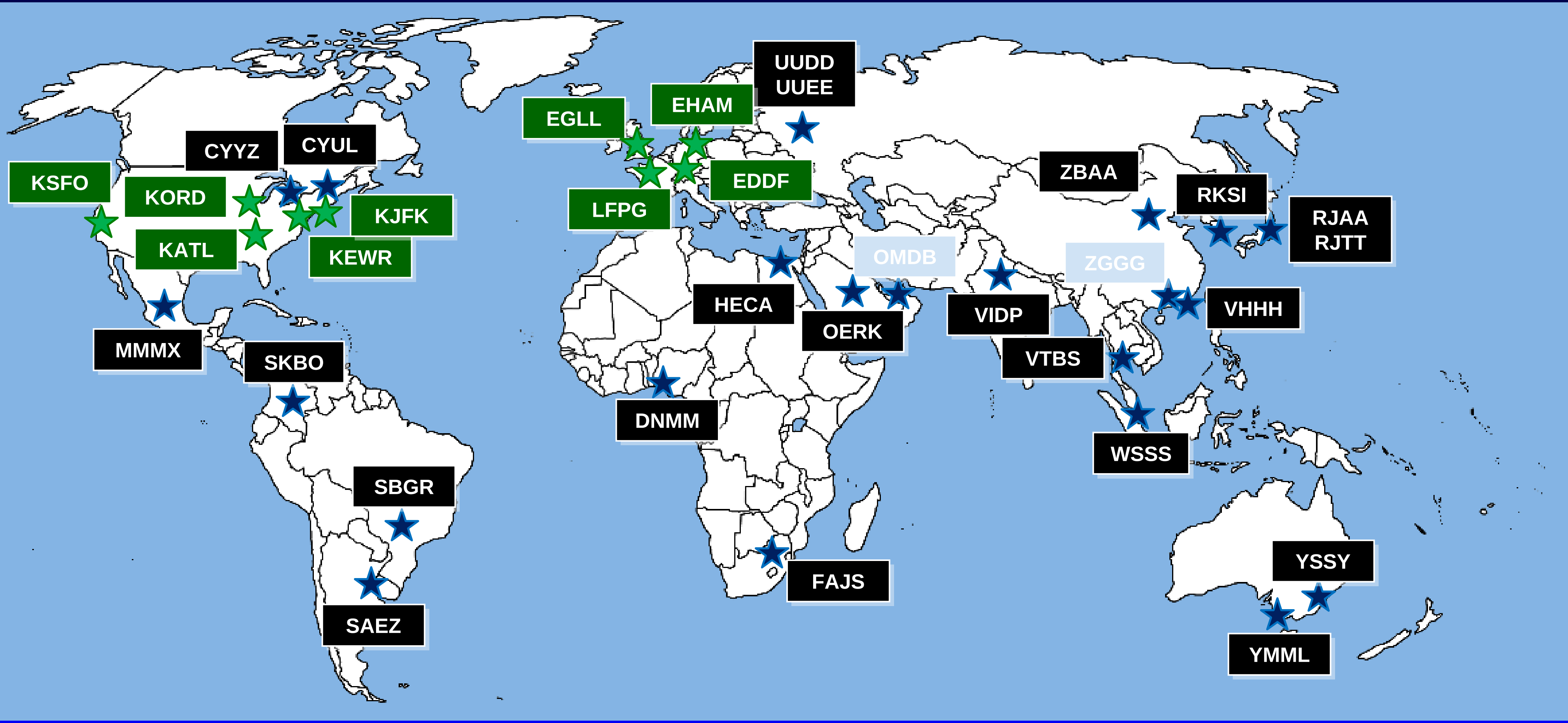


For ease, we used wing span sorting

Additional Airports Checked

- Additional airports were checked world-wide to ensure that the blended optimization worked beyond Europe and the US

Airport Traffic Analyzed in RECAT To Provide Worldwide Coverage



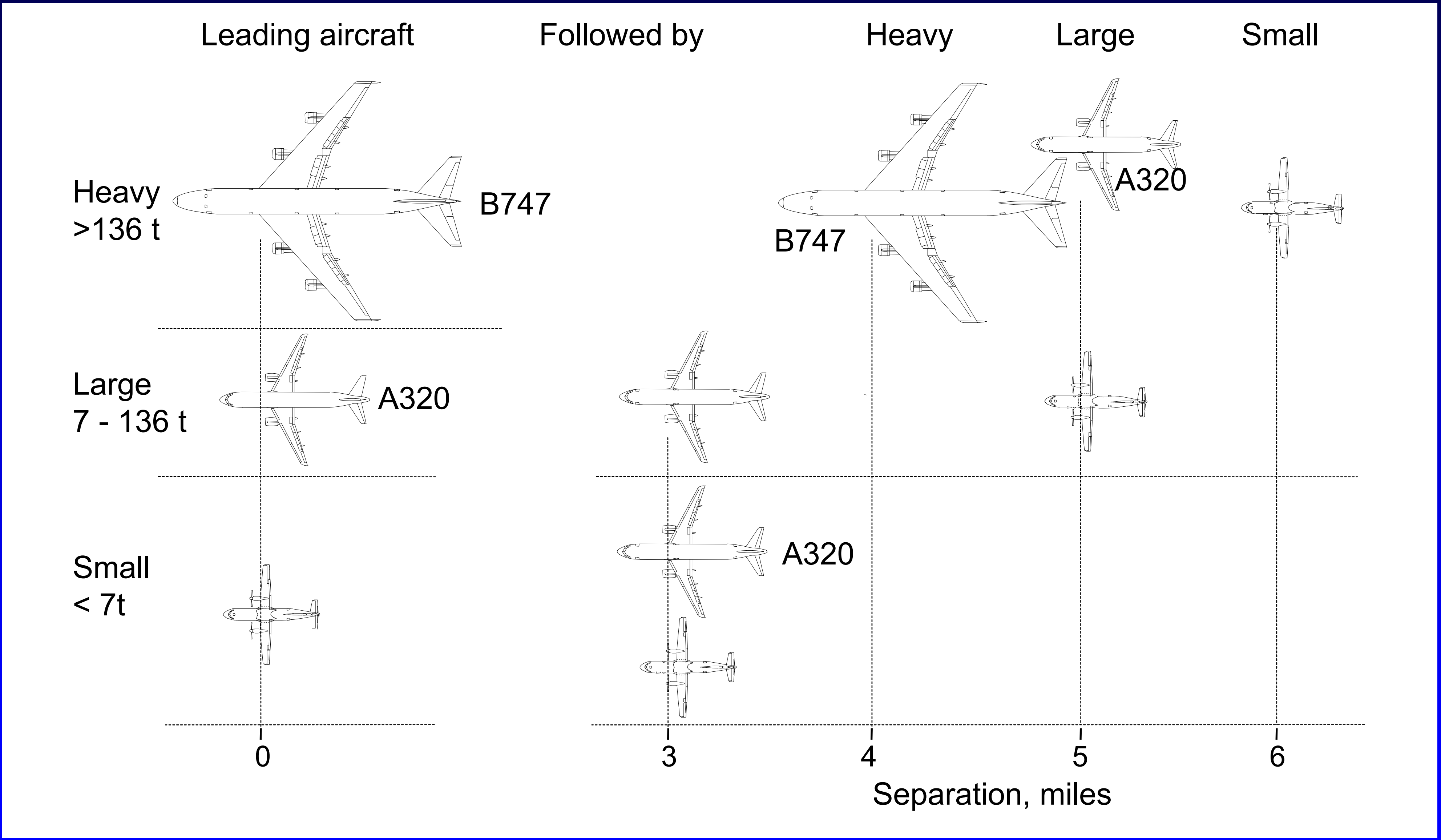
- Airports selected for detailed analysis (Green)
- Additional airports analyzed to confirm benefits (Black)

66

#11 Expert Review and Adjustments

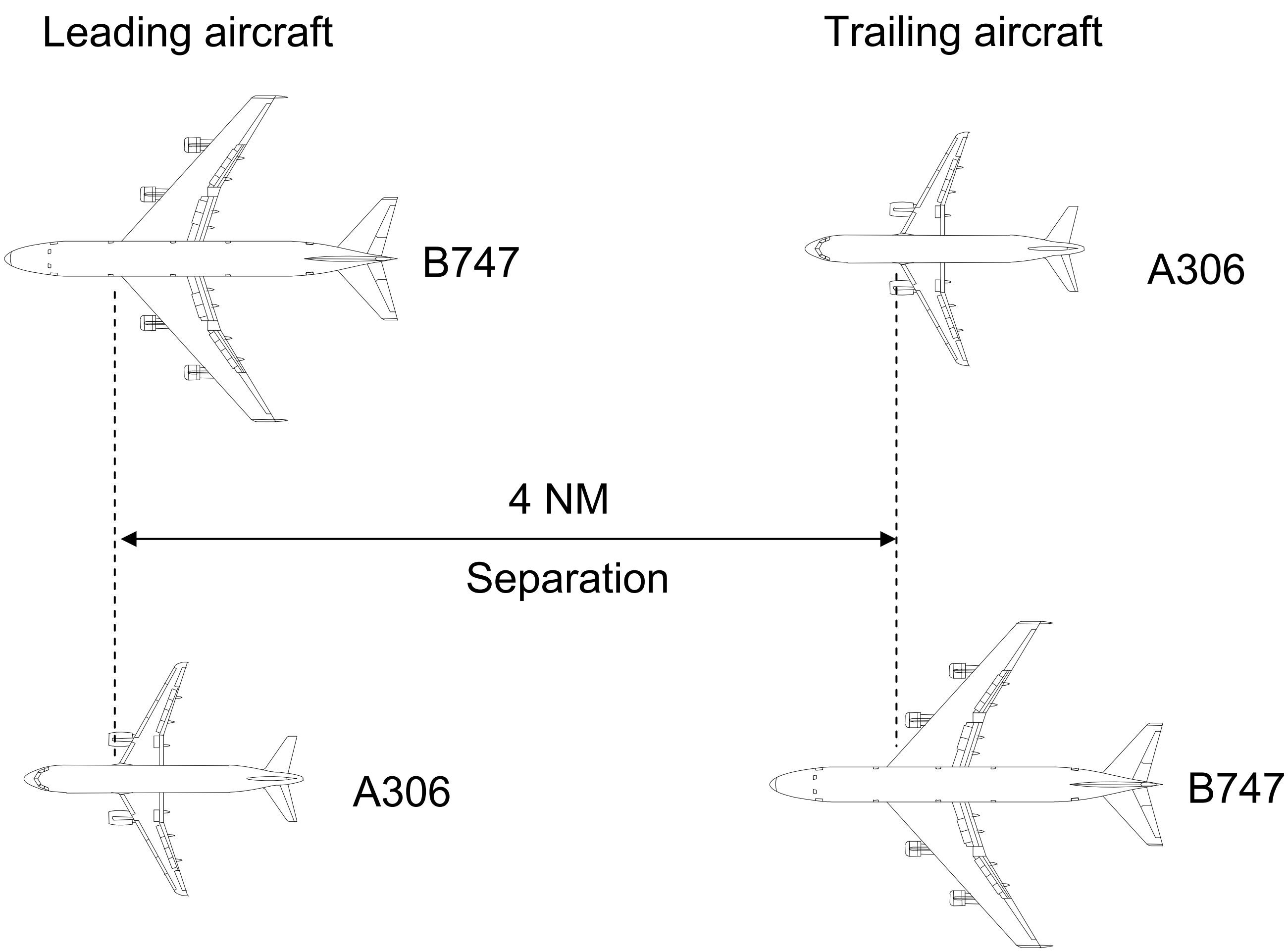
- Adjusted the categories by blending the US and EU optimized categories
- Added further conservatism by
  - Manually moved one selected aircraft
- Reduced separations for Heaviest aircraft behind Heaviest aircraft

Current ICAO Wake Turbulence Separations



Current ICAO Wake Turbulence Separations

Heavy to Heavy

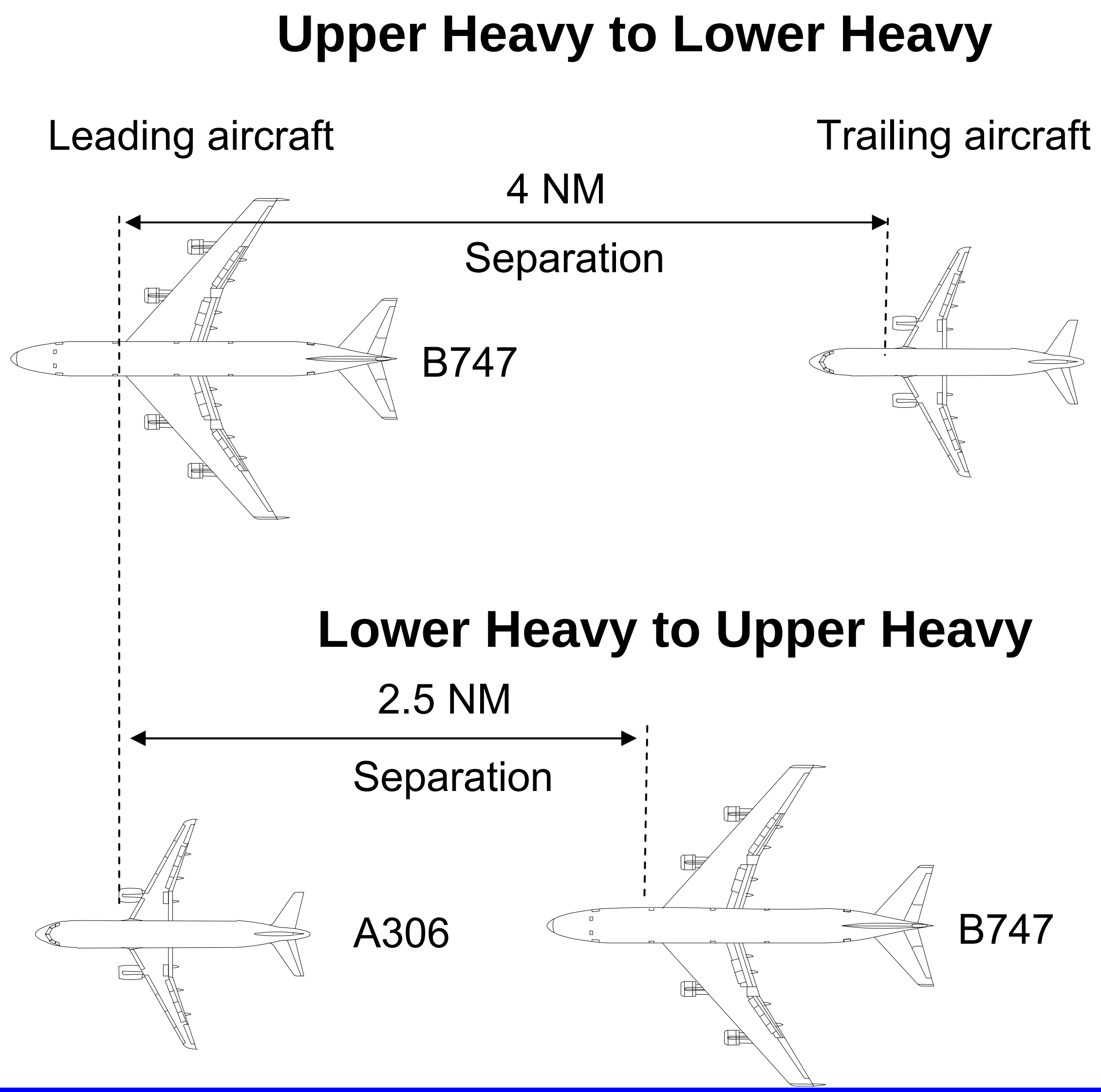


This is Safe

This is Overly Conservative.

A result of the Breadth of the Heavy Category

Safety Example Wake Turbulence Separations



This Is Safe (Current ICAO)

This Is Also Safe (RECAT)

Used Rolling Moment Coefficient

- We used rolling moment coefficient to reduce the separation of Category B (the Heaviest of the Heavy category) behind Category B
  - Rolling moment coefficient is a way to effectively compare the roll vulnerability characteristics of different aircraft

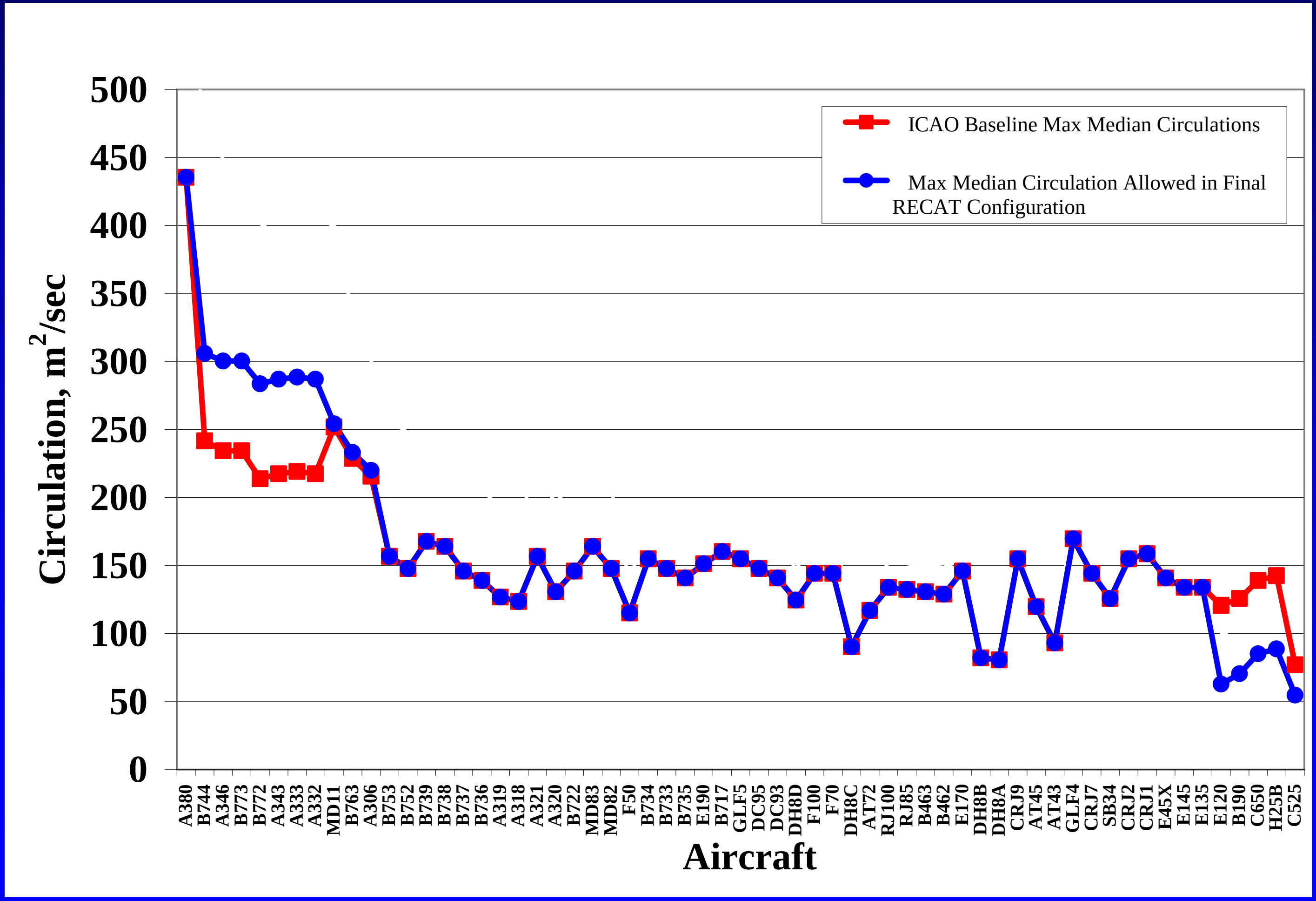
Rolling Moment Coefficient

- Proportional to $\Gamma / U b$
- Γ is the circulation of the vortex from the leading aircraft
- U and b are the aircraft speed and wingspan of the follower aircraft

#12 Additional Safety Considerations

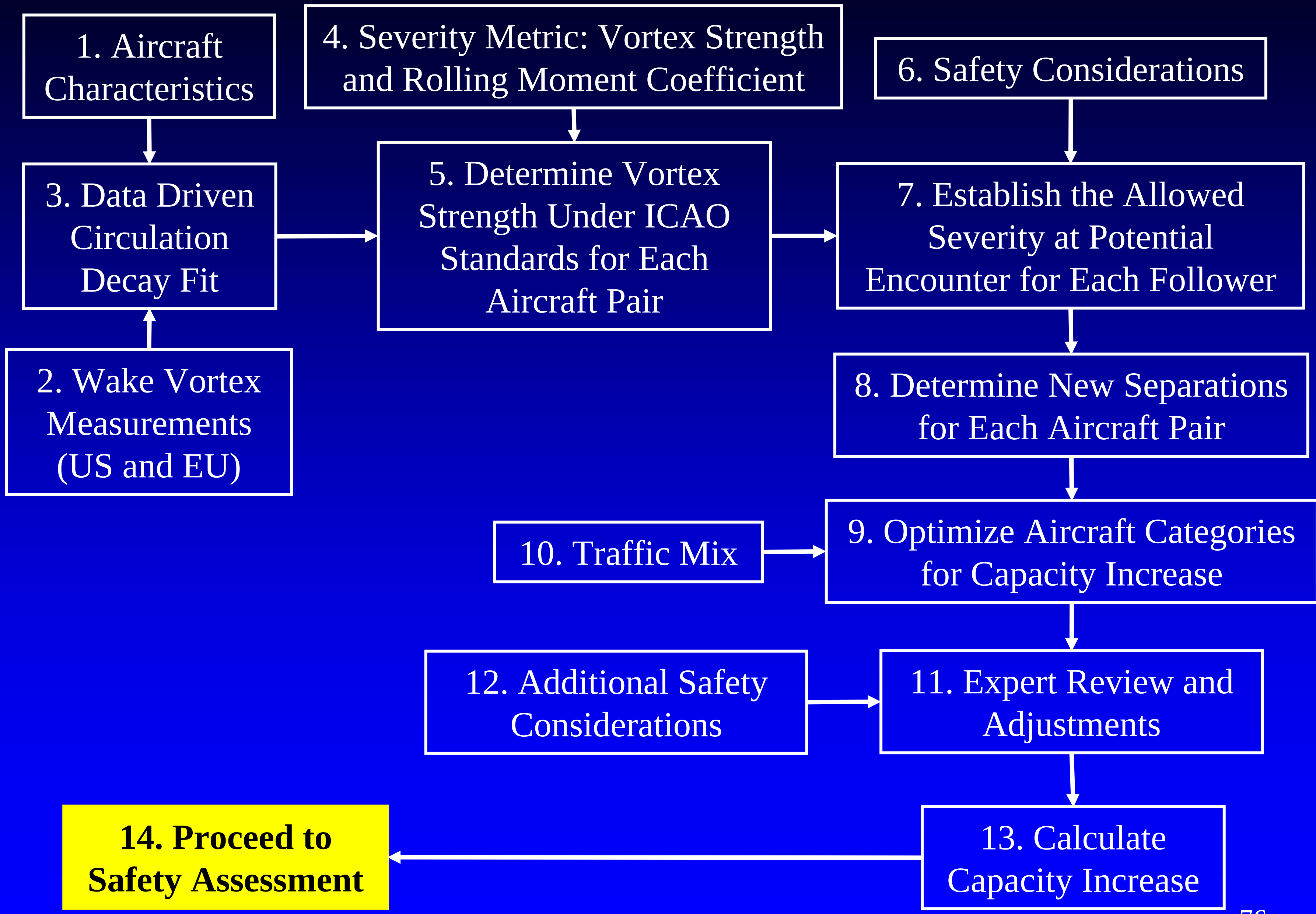
- Added additional separation for smallest category of aircraft in trail for additional conservatism

Max Median Circulations



#13 Calculate Capacity Increase

- Percentage of capacity increase computed relative to baseline
  - Baseline computed using current separations
  - Capacity increase computed using RECAT categories and separations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8. Determine New Separations for Each Aircraft Pair
9. Optimize Aircraft Categories for Capacity Increase
10. Traffic Mix
11. Expert Review and Adjustments
12. Additional Safety Considerations
13. Calculate Capacity Increase
14. Proceed to Safety Assessment

#14 Proceed to Safety Assessment

- Develop Safety Case and Safety Analysis Report for the recommendation to ICAO

Risk Due to Wake Turbulence

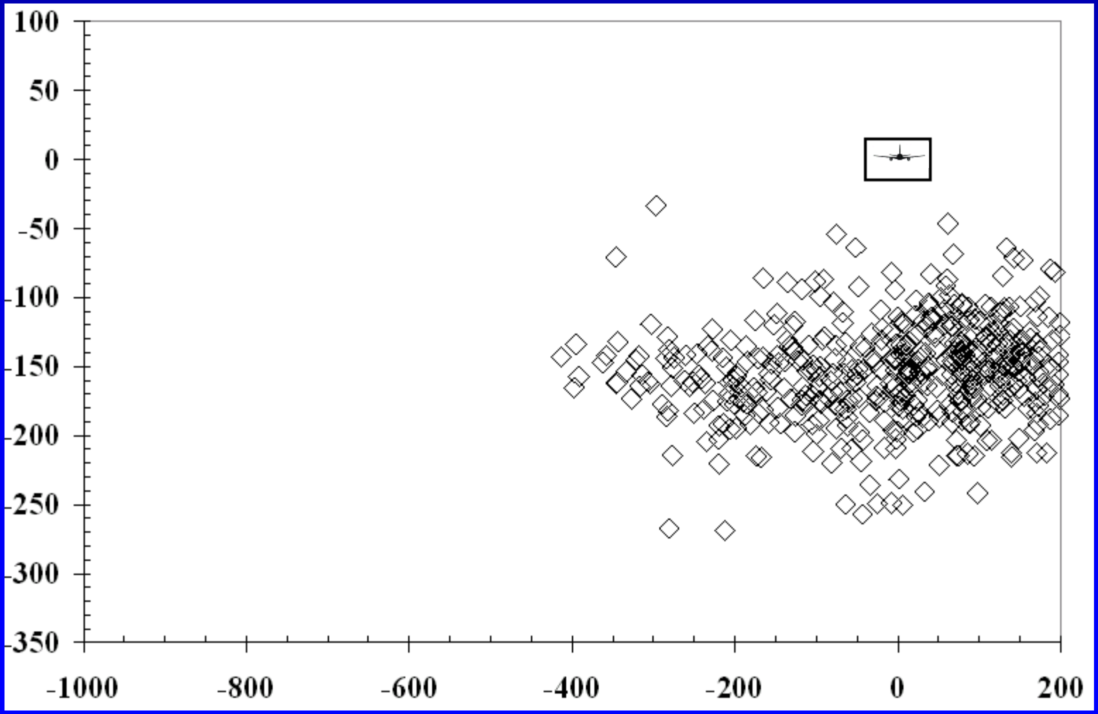
We define Wake Turbulence (WT) risk for an aircraft pair as:

Probability of encounter x Severity of WT encounter

(Severity can be wake strength or rolling moment coefficient)

Probability of Encounter

- We would like the Probability of Encounter to be in a box around the aircraft, centered on the extended runway



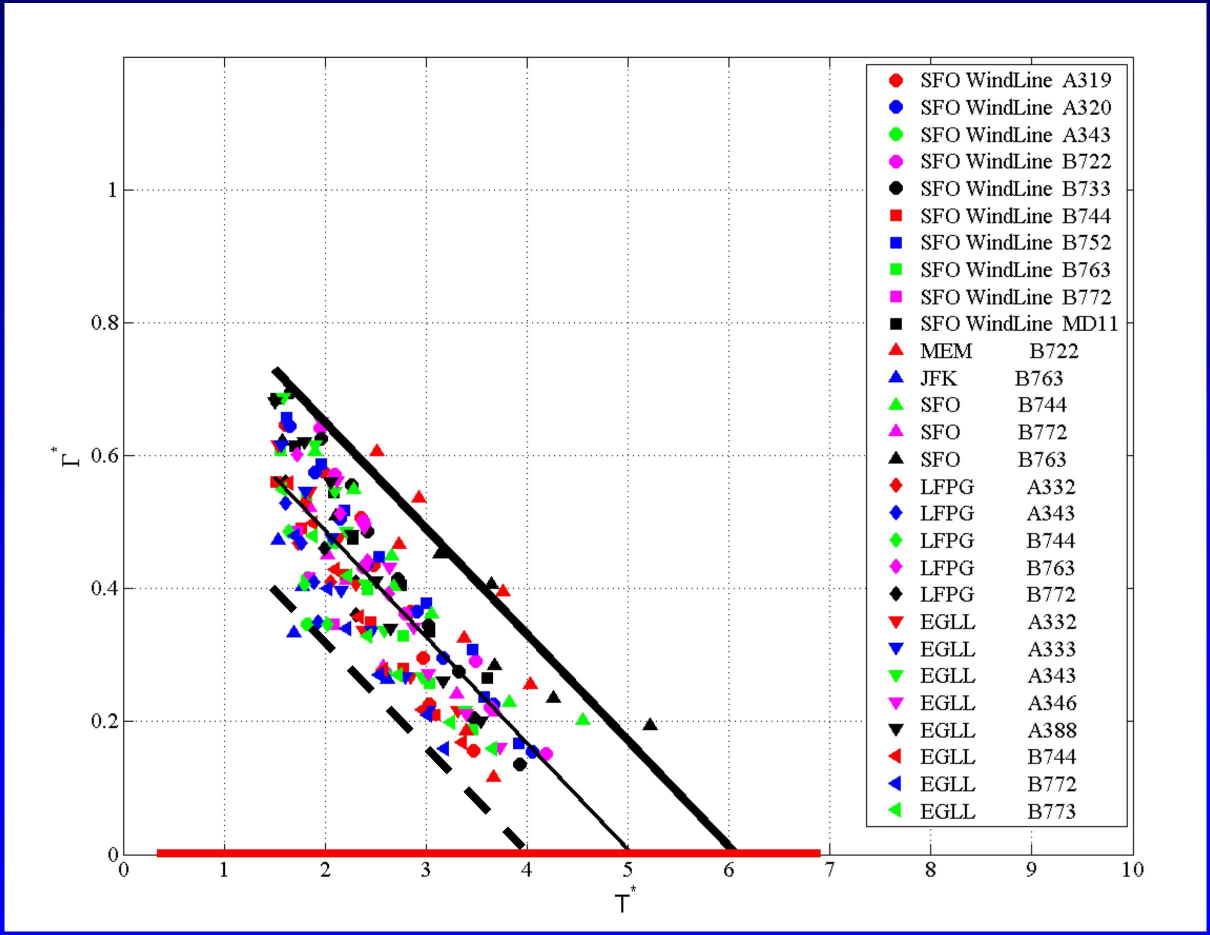
Probability of Encounter

- We do not have this kind of data for all 61 aircraft, so we use a more general approach, where we use an infinite volume

Probability of Encounter

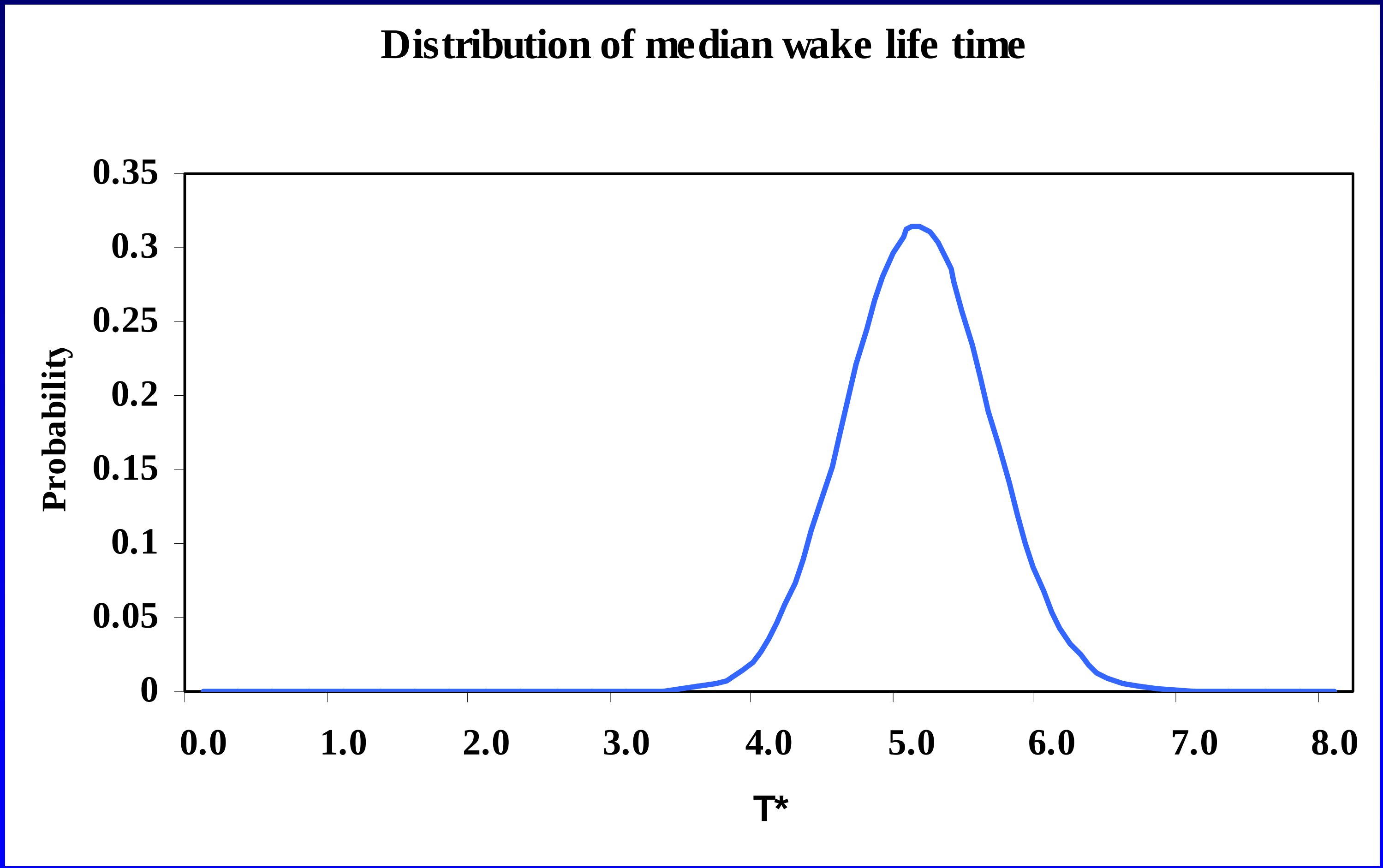
- We will show an example of how to assess the Wake Survival Probability at a non-dimensional circulation, Γ^*, of zero
  - Probability of Encounter is Wake Survival Probability

Circulation Decay Fit with Threshold of $\Gamma^* = 0$ (red line)

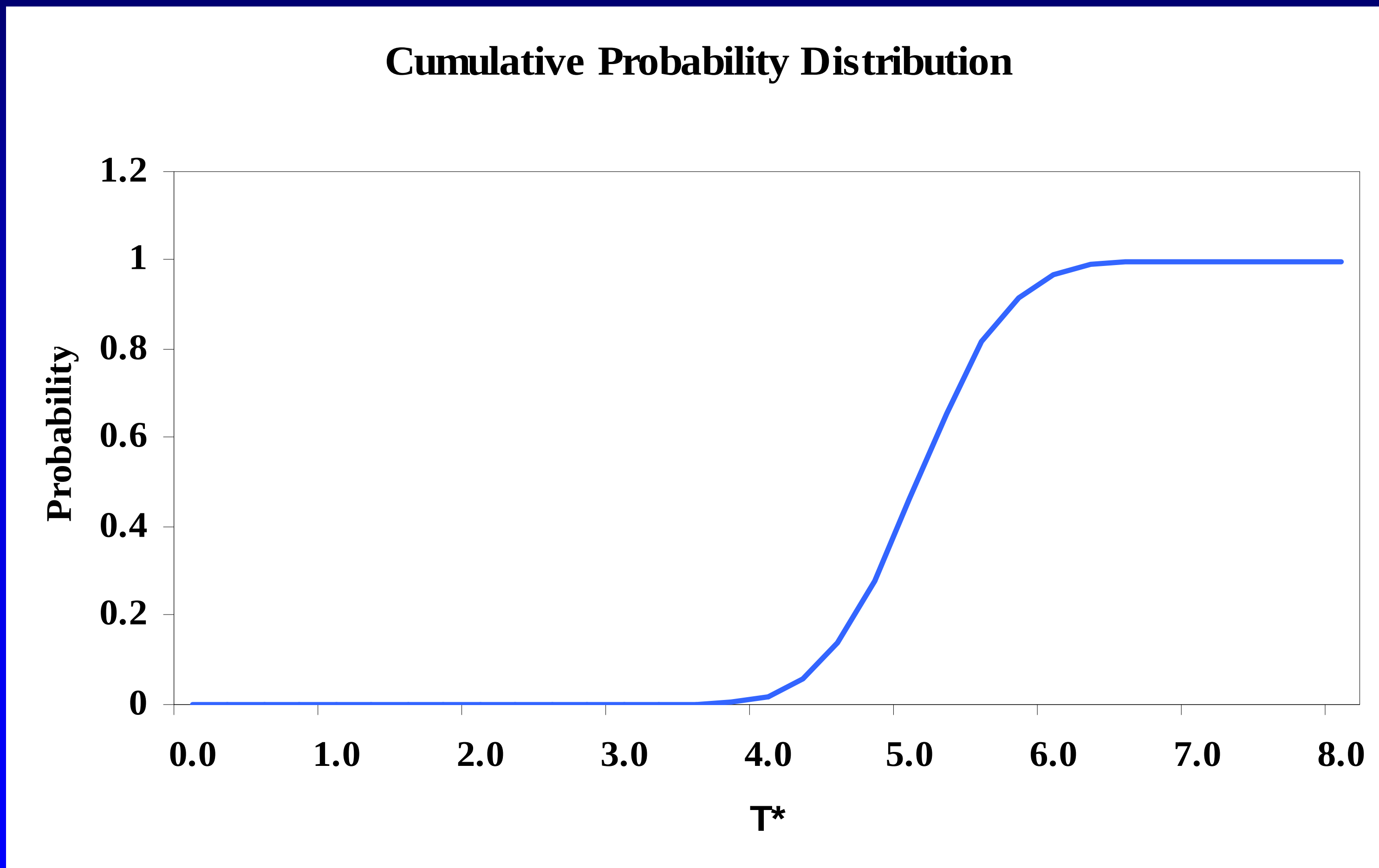


Distribution is nearly Gaussian

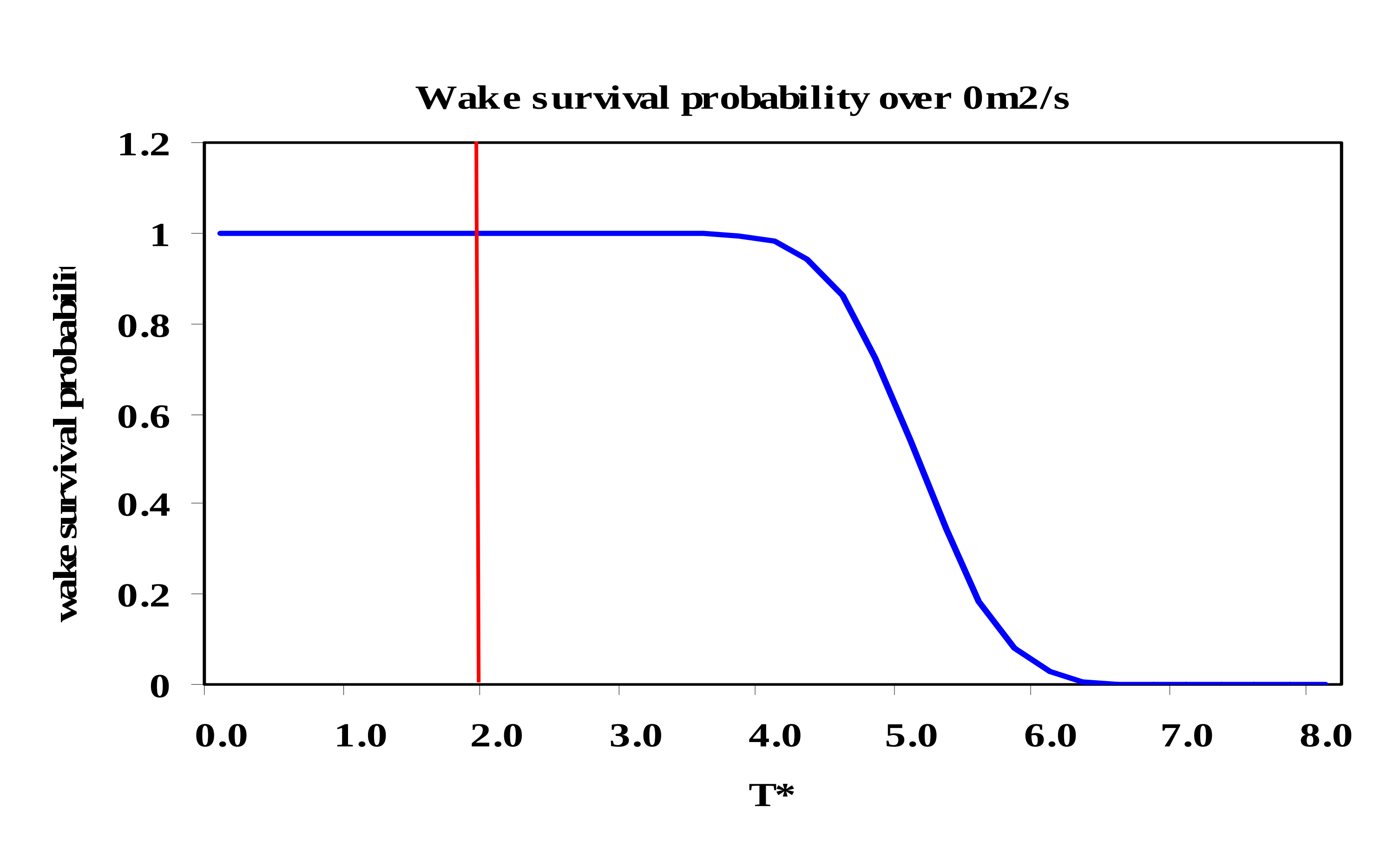
Gaussian Distribution of the Non-Dimensional Life Times of the Median Wakes



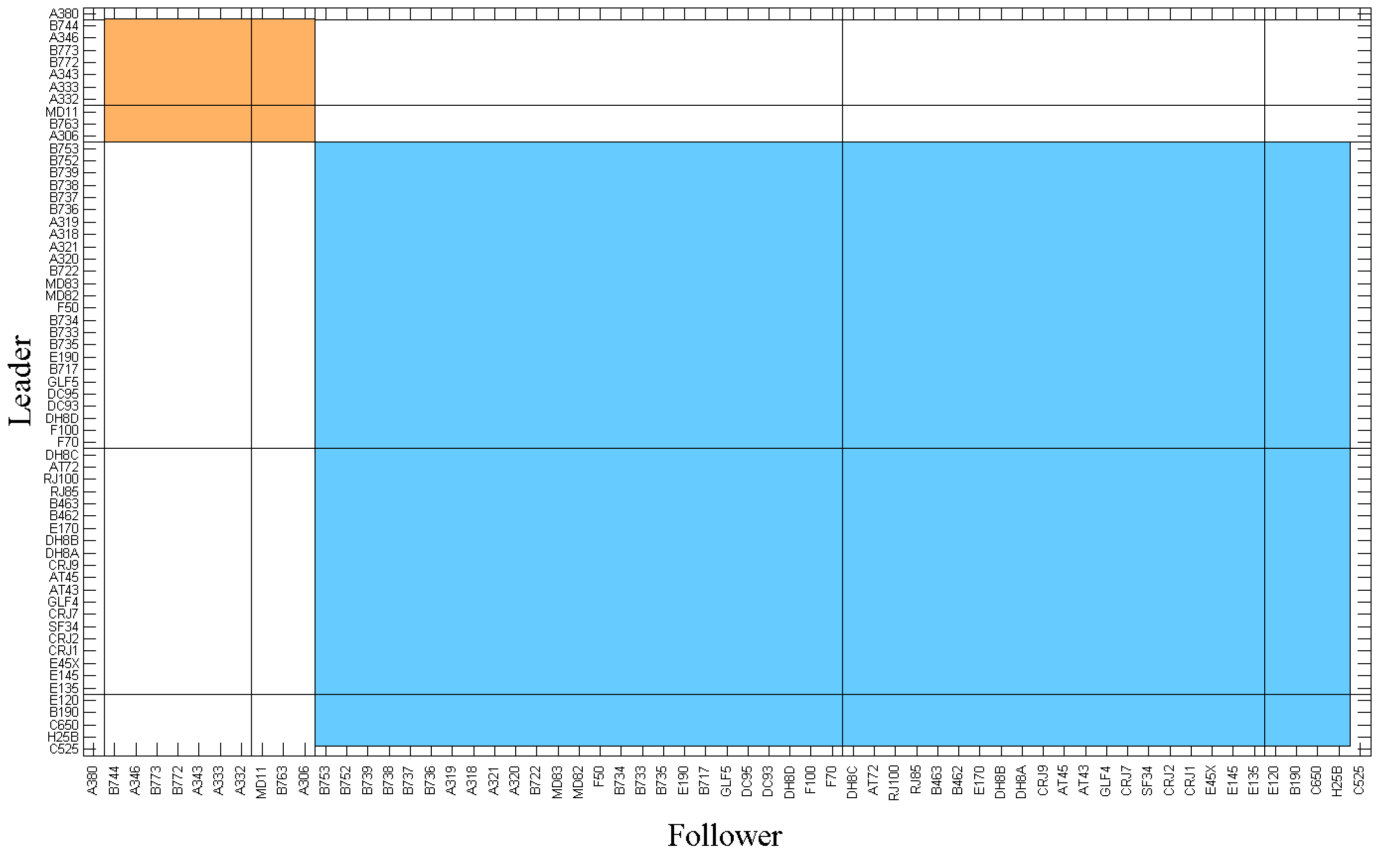
Integration of the Gaussian Distribution Along the Red Line



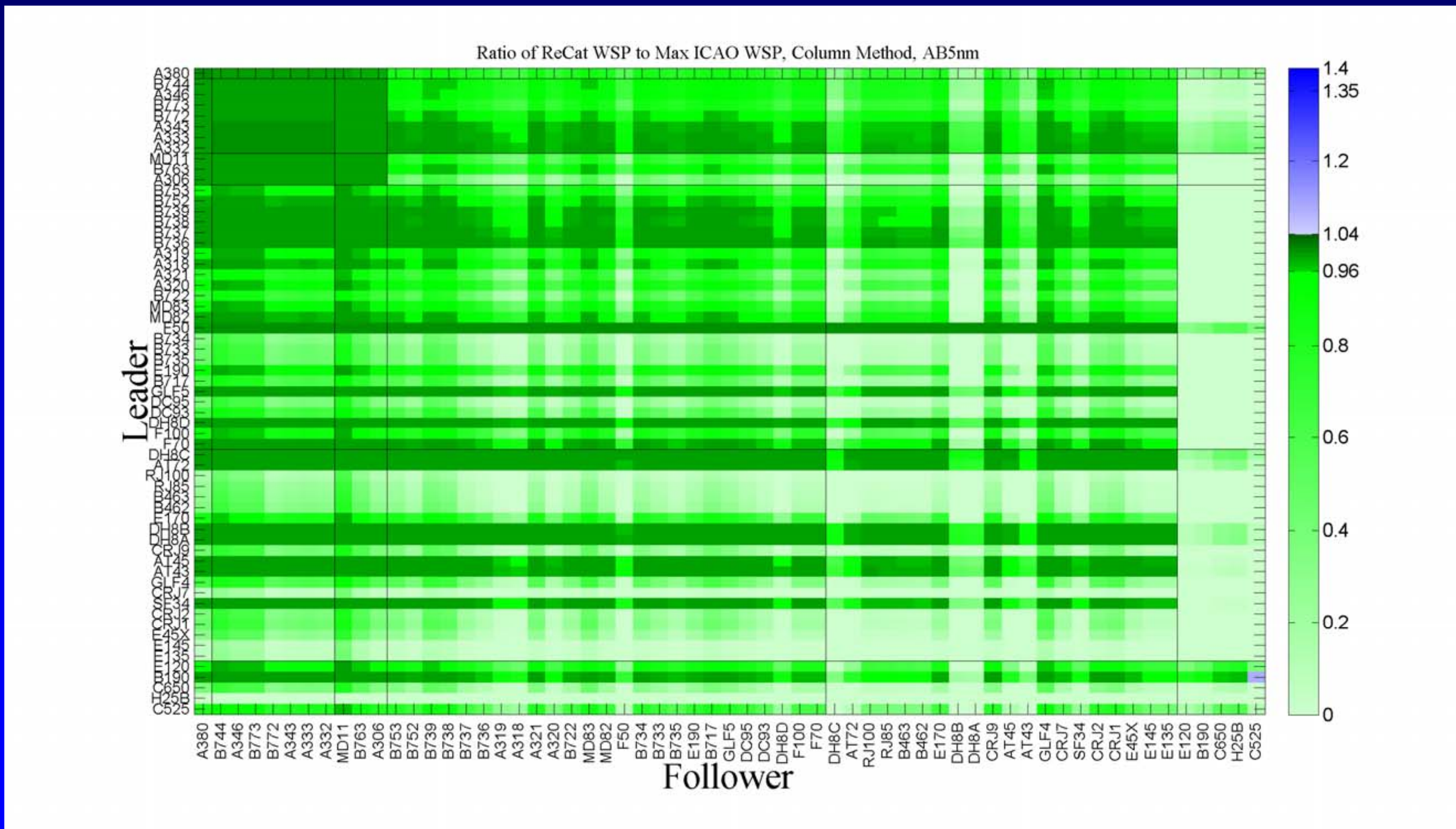
One Minus the Distribution Shown in Last Slide



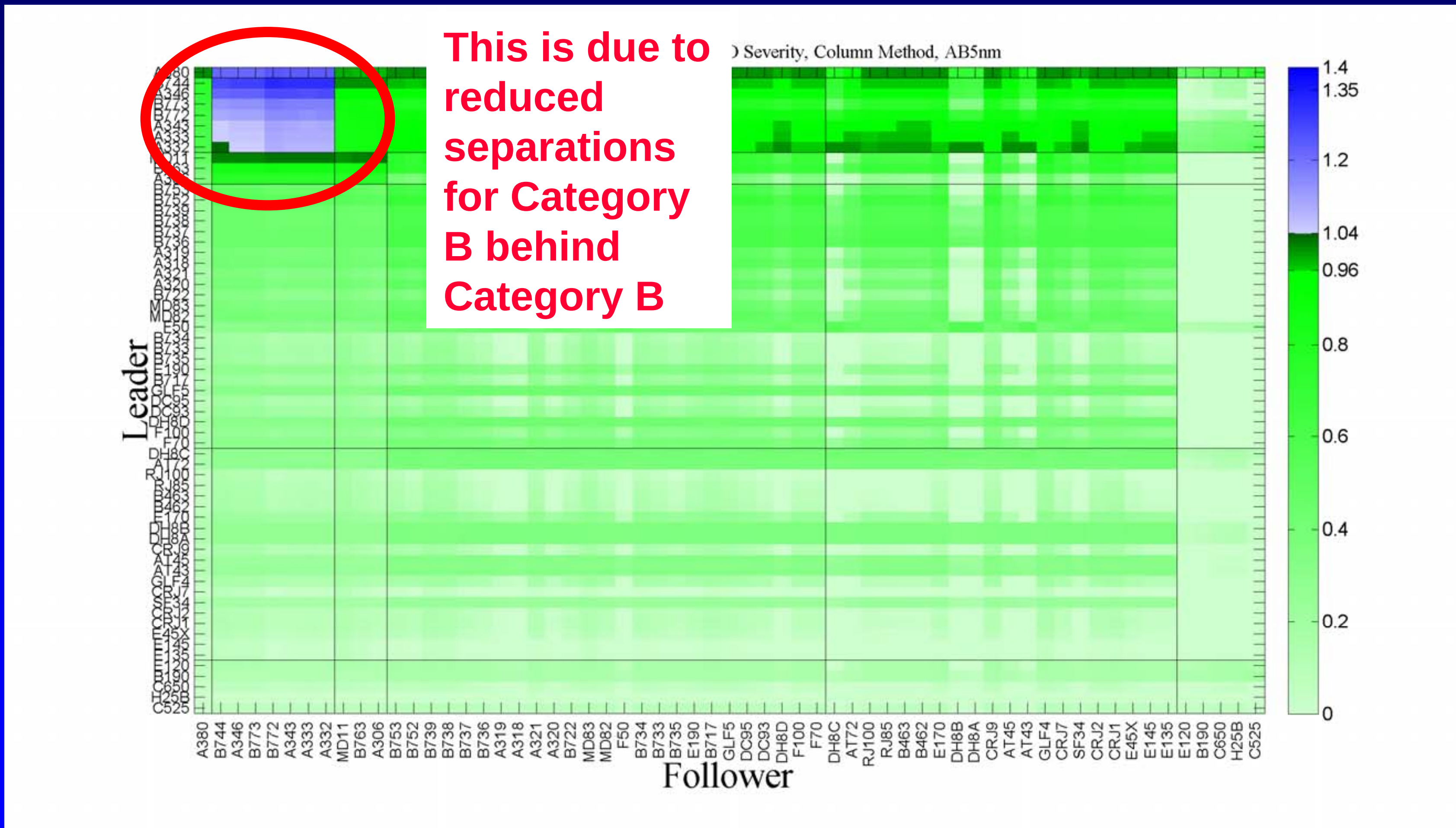
Sample Heat Map (ICAO Shown)



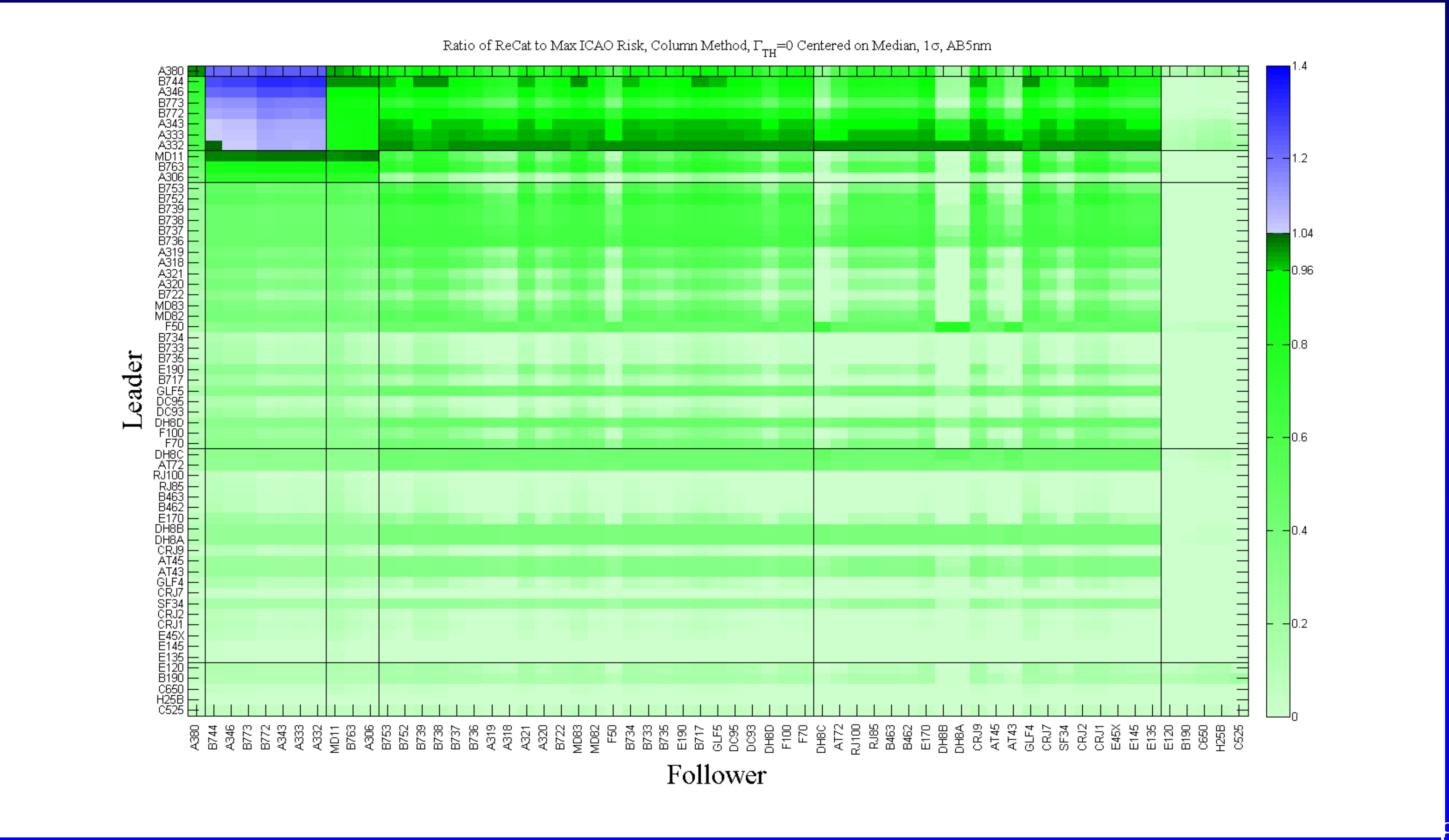
Median Wake Survival Probability Ratio (RECAT divided by Maximum ICAO)



Wake Strength Ratio (RECAT divided by Maximum ICAO)



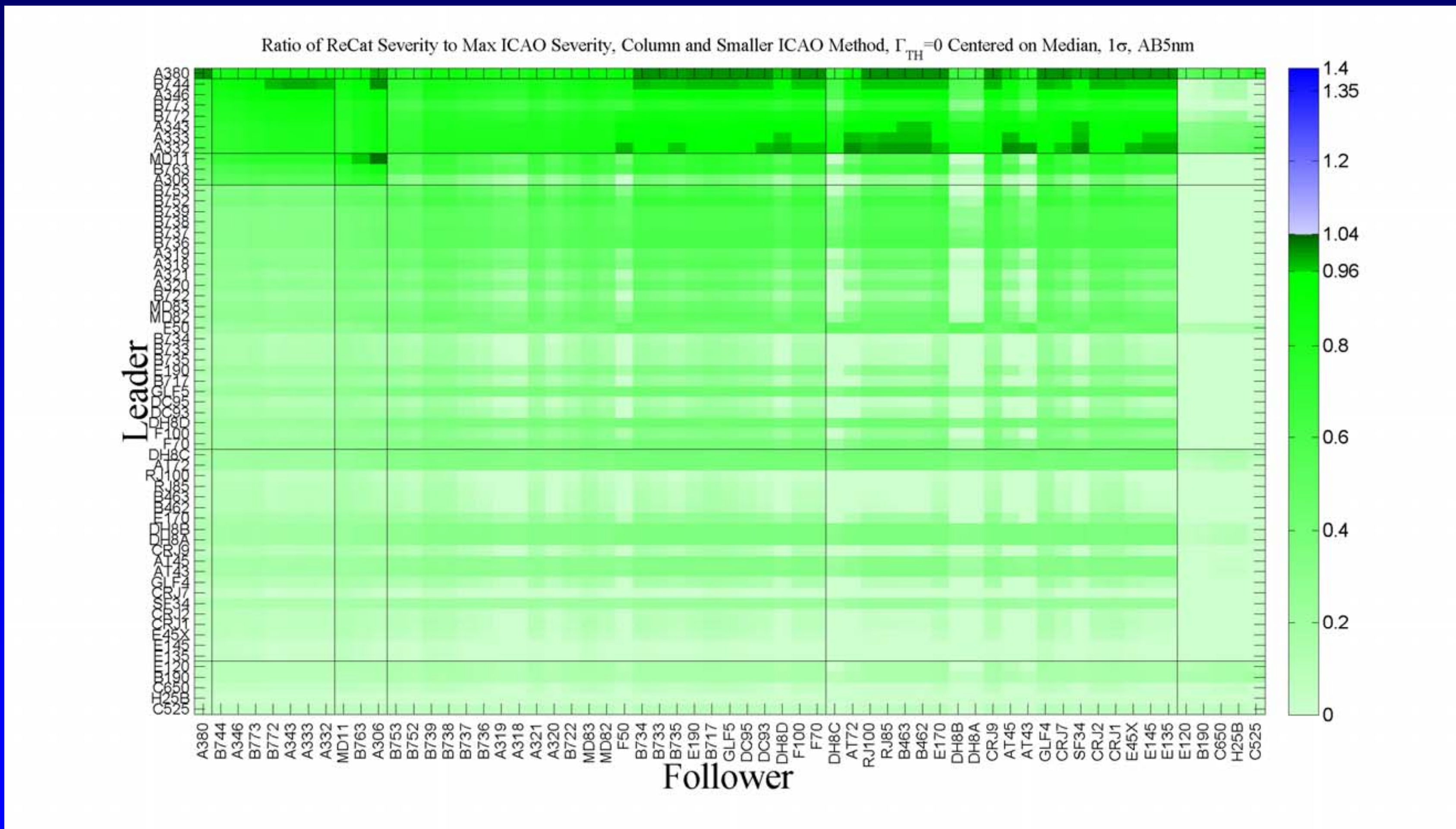
Risk Index Ratio
(RECAT divided by ICAO Maximum)



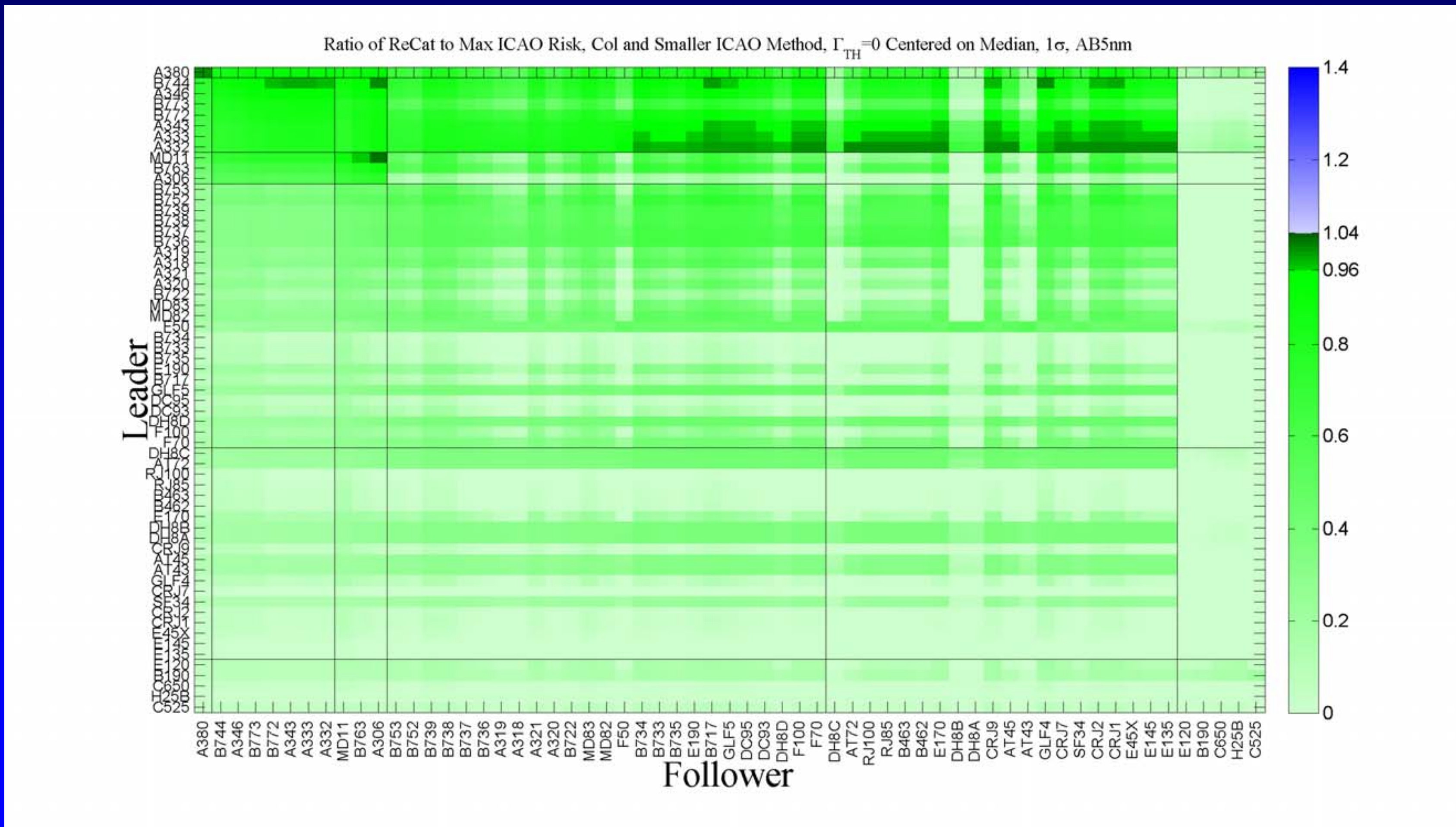
Justification for Reduced Separations for B Behind B

- Used rolling moment coefficient
  - Proportional to $\Gamma / U b$

Severity Ratio Using Rolling Moment Coefficient (RECAT divided by Maximum ICAO)



Risk Ratio Using Rolling Moment Coefficient (RECAT divided by Maximum ICAO)



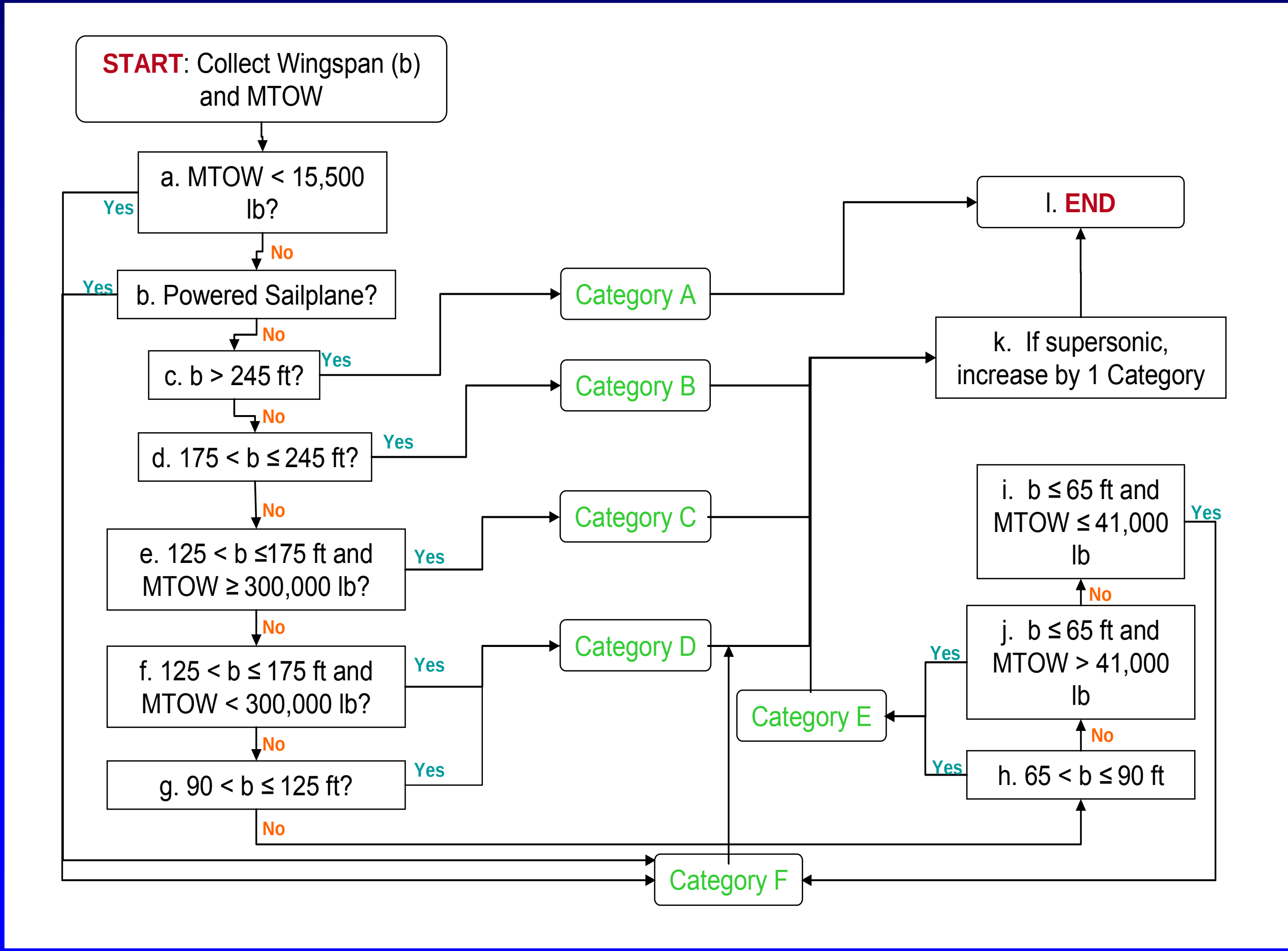
Other Analyses

- Performed sensitivity analyses using aircraft speed uncertainty
- Calculated departure times using a departure circulation decay fit to field data
- Calculated bank angles for worst case encounters

Application of Methodology to All ICAO Aircraft Types

- 61 representative aircraft types were used in developing the categories and separations
- Methodology was then applied to all 9000+ ICAO aircraft types
  - Methodology flow chart shown in next slide

Flow Diagram To Determine the Wake Turbulence Category for New Aircraft



Estimated Benefits

- Capacity gain
- Traffic mix and local procedures influence the benefits
- Estimated capacity gain for Europe (constrained airports) is on average 4%
- Estimated capacity gain for U.S (constrained airports) is on average 7%
- Similar estimated capacity gains for other world wide (capacity constrained) airports

Safety Case Breadth

- Safety Assessment Report
  - ICAO Compliant safety methodology
  - Hazard Identification
    - Exhaustive list of hazards assessed
    - Only wake turbulence risk evaluated as relevant and potentially affected by RECAT
  - Wake Turbulence Risk Assessment (Likelihood and Severity)
  - Review of Publicly available, World Wide Safety Reporting Systems
- Methodology Report
- Report on Classification of 9000+ Aircraft Types

Safety Case Depth

- Data driven from US and European Multiple Data Campaigns
- Critiqued by multiple safety oversight organizations in US and EUROCONTROL
- Independent Experts Contracted to Develop and Provide Industry Best Practices
- Wake Strength and Rolling Moment Coefficient were used in a relative sense
- Additional Supporting Analysis that Guided Assessment used Multiple Models for additional confidence

RECAT Phases 2 and 3 Effort

- Phase 1 is Static 6 Category Separation
- Phase 2 is static pair-wise separation
- Phase 3 is dynamic pair-wise separation

Summary

- Joint Effort by FAA/EUROCONTROL as requested by ICAO
- Harmonization
- Capacity benefit local and network wide (Congested airports have impact worldwide)
- Maintain or Improve Today's Safety
- Methodology developed for categorizing current and future aircraft types
- Approach and Departure separations, Distance and Time Based
- Used Present and future traffic mix
- Openly available tools, methods and aircraft data
- Solution supported by ICAO compliant safety case
- Path to SESAR and NextGen goals require Phase I and Phase II elements of RECAT to achieve maximum benefits