



The Development of Wake Turbulence Recategorization in the United States

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This paper describes the background information and provides a status update on a specific aspect of the Federal Aviation Administration (FAA) wake turbulence program known as RECAT (i.e., Recategorization). The fundamental premise of RECAT is that, instead of using the existing FAA Order JO 7110.65 categorical wake turbulence separation minima based on maximum takeoff weight, wake separation can be refined using a more complete set of wake related parameters. This process then leads to a safe reduction of wake turbulence separation minima over those specified in FAA Order JO 7110.65. This paper describes the overall three-phased approach of RECAT, with the ultimate goal of achieving dynamic pairwise separation. Currently, Phase II, or a static pairwise based wake turbulence separation is ready for implementation by the Federal Aviation Administration. The paper describes the analysis approach, including the data sources and severity metrics used in the development of RECAT Phase II.

Nomenclature

b	=	wingspan
b_0	=	initial vortex separation
Γ	=	circulation of vortex generated by leading aircraft
Γ_0	=	initial circulation
Γ^*	=	non-dimensional circulation
T_0	=	normalized wake age
T^*	=	non-dimensional age
U	=	aircraft speed

I. Introduction

THE demand for safely increasing capacity and efficiency at congested airports increases every year. The main constraint on airport throughput is the runway which accommodates only a limited number of flights per unit time. In less than visual conditions, this throughput performance is directly linked with the minimum radar and/or wake turbulence separation between aircraft on arrival. There are two minimum spacing requirements: one driven by collision avoidance and communications/navigation/surveillance (CNS) requirements, and one driven by wake turbulence separation minima. When the wake turbulence separations specified in the FAA Order JO 7110.65¹ are applied, it is the constraining separation of the two. Therefore, it is clear that a reduction in wake turbulence

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separations will aid in achieving capacity enhancement goals, especially for the FAA NextGen initiatives that focus on reducing separation minima from an aircraft collision avoidance standpoint and/or surveillance enhancements.

Prior to the Recategorization effort (RECAT), approach and departure separations, specified in FAA Order JO 7110.65, were set based on weight classes defined using Maximum Certificated Gross Takeoff Weight (MCGTOW). The associated wake turbulence spacing was the result of a mixture of expert judgment and review of operational experience.² These MCGTOW-class based separations have proven to be very safe for wake vortex hazards. No fatalities have occurred when these standards and associated procedures were followed. Furthermore, the risks associated with the less severe outcomes when these standards and associated procedures are followed, have been shown to be acceptable through application of the FAA Safety Management System.³ However, it is also known that due to the use of a single wake separation minimum to each broad weight class, many of the aircraft are overly separated from a wake turbulence point of view. The fundamental premise of RECAT is that, instead of using the existing FAA Order JO 7110.65 weight class-based wake turbulence separation minima, wake separation can be refined using a more complete set of wake-related parameters.

RECAT is designed as a three-phased approach, with the ultimate goal of achieving dynamic pairwise separation. RECAT Phase I,⁴ which defines static categorical wake turbulence separations, is fully implemented at selected locations and Phase II, which defines static pairwise wake turbulence separations, is ready for implementation by the Federal Aviation Administration. RECAT Phase III defines dynamic pairwise separations that takes into account atmospheric and aircraft data to dynamically change separations. RECAT Phase III is still in the early stages of concept development. It is important to note that all three phases directly support FAA NextGen’s goals to safely enhance efficiency and capacity of the National Airspace System (NAS) and fulfill FAA commitment to the International Civil Aviation Organization’s (ICAO) Aviation System Block Upgrades (ASBUs).⁵

RECAT Phase I introduces 6 static wake turbulence categories that replaced the traditional weight classes. MCGTOW and Maximum Landing Weight (MLW) were coupled with approach speed and wing span to more accurately represent the wake severity of a generating aircraft as well as the vulnerability of a trailing aircraft to a potential wake encounter. This process enables the development of a more efficient set of wake turbulence separation minima over those specified in FAA Order JO 7110.65.

RECAT Phase I has been implemented at 10 TRACON (and 17 airport) locations as of April 2016. RECAT Phase I wake turbulence categories,⁴ Category A through F, and associated Aircraft Types are defined in Table 1.

Table 1. RECAT Phase I categories and aircraft types.

RECAT Phase I Categories	Aircraft Types
Category A	Super Aircraft (e.g. A388)
Category B	Upper Heavy (e.g. B744)
Category C	Lower Heavy (e.g. B763)
Category D	Upper Large (e.g. B738)
Category E	Lower Large (e.g. E145)
Category F	Small (e.g. FA50)

RECAT Phase I adds an additional complex category to the traditional weight-based system of 5 categories with the availability of a controller decision support tool (DST) of Automated Terminal Proximity Alert (ATPA)⁶ and the requirement of categories to be displayed on the flight strips and data blocks. ATPA is an automation tool that provides separation information and alerts to the controllers. ATPA monitors aircraft speeds and observes compression trends between aircraft pairs. The DST alerts the controller when the compression is likely to cause a loss of separation.

The methodology employed in RECAT Phase I is described in detail in Ref. 7. A flowchart was presented to represent the high-level overview of that methodology and is presented here in Fig. 1. RECAT Phase I began with a list of 61 aircraft, representing 85% of the traffic mix from 5 US airports and 3 European airports. Aircraft characteristics and wake vortex data collected from a variety of data campaigns in both the US and Europe fed into the development of a linear regression of a median near worst case circulation decay curve, in which the 95% confidence interval was used to represent the wake circulation strength behind an aircraft (Blocks 1 through 3 of Fig. 1). This vortex strength along with Rolling Moment Coefficient (RMC) represent the severity metrics used to determine allowable separation reductions between aircraft pairs (Blocks 4 through 8 of Fig. 1). RMC is a non-dimensional vortex induced torque imposed on the trailing aircraft, essentially the ratio of the vortex induced moment relative to the roll resistance of the follower. Once the pairwise separation matrix is determined (Block 8), the resulting Phase I categorization was based on a general optimization of a fleet mix representative of the sum of

the sites, and averaged benefit from the mix of the 7 sites (Block 9 and 10). The FAA sought and received approval for RECAT Phase I based on the resulting Phase I categorization and the corresponding static 6-category separation matrix.

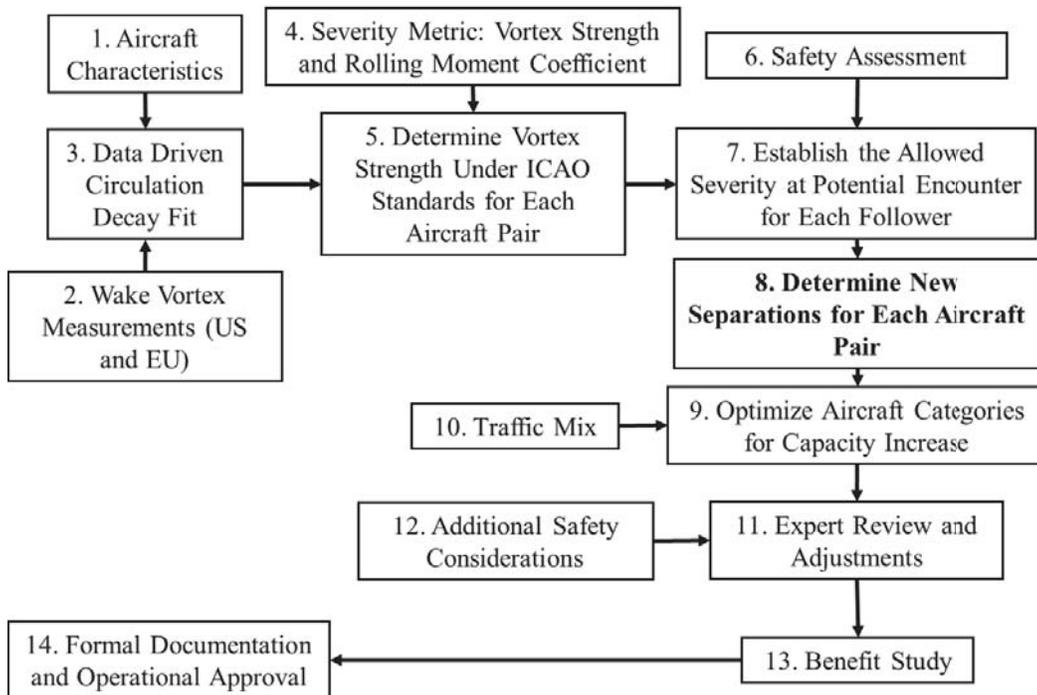


Figure 1. RECAT Phase I methodology flow.⁷

II. Transition from RECAT Phase I to RECAT Phase II

A transition from RECAT Phase I to RECAT Phase II involves a change from an approved set of 6 static categories to an approved pairwise separation matrix. Using the Methodology flow in Fig. 1, the Formal Documentation and Operational Approval (Block 14) occurs immediately after Determine New Separations for Each Aircraft Pair (Block 8) for RECAT Phase II. From a practical standpoint and until the NAS can support true pairwise separation, the implementation philosophy of RECAT Phase II is driven by the fact that better efficiency and benefit can be gained from wake-based separation reduction if categorization is optimized for site-specific traffic mixes. A customization of the categorization for TRACON-specific implementation would allow for the collaboration with the TRACON for consideration of operational constraints and is made possible by having operational approval of the separations at a pairwise level.

The RECAT II pairwise separation matrix defines separations purely based on wake-based parameters and therefore the separation as approved do not take into account today's collision risk separation. In many cases, the pairwise separation matrix has separations smaller than the separations that currently constrained by collision risk. In those cases, implementation of RECAT Phase II will apply the more constraining separations. The advantage of having separations defined that are purely wake-based is in the flexibility of implementation and refinement of implemented RECAT Phase II sites to change separations if the collision risk separations are reduced.

RECAT Phase II follows the same overall high level analysis approach that was used in RECAT Phase I. However, substantial enhancements in databases have been made, thus enhancing the process to be even more data driven. These areas of database enhancements are highlighted below.

A. Traffic and Fleet Mix

RECAT Phase I focused on 61 aircraft that made up 85% of operations from 5 US airports and 3 European airports.

The aircraft list for RECAT Phase II is focused on the aircraft most prevalent in the NAS. 123 ICAO type designator aircraft are used for RECAT II's baseline traffic data needs. These aircraft include both those that comprise more than 99% of the U.S. traffic movements based on 32 U.S. airports and new aircraft that are currently flying that are expected to grow in numbers over time, but are not yet included in the 99% traffic mix. The aircraft characteristics database, containing the aircraft physical characteristics such as MCGTOW and wingspan, used in RECAT Phase I was updated with the addition of more aircraft types. Many ICAO type designators have multiple Make Model Series (MMS) that can have different physical characteristics. With 123 ICAO type designators, there are 230 unique MMS. Each unique MMS has a database entry and for the analysis the methodology ensures that the MMS selected to represent the ICAO type identifier will produce the largest separation. The MMS is selected as a leader aircraft and a follower aircraft separately, choosing the worst case scenario in both positions.

B. LIDAR Circulation Measurements

Phase I analysis used vortex measurements from multiple data collection campaigns executed by the FAA Wake Turbulence Research Team, National Aeronautics and Space Administration (NASA), and EUROCONTROL. This resulted in mixed datasets of different sensors and a diverse set of vortex generation heights. The dataset was sufficient for Phase I category-based separations.

RECAT Phase II uses a larger dataset of wake measurements entirely from the FAA's database. The dataset of wake vortex measurements has grown considerably since the assessment of separations for RECAT Phase I. The FAA Wake Turbulence Research Team's data collection of wake vortex measurements supports various wake initiatives beyond the RECAT effort, and results in a consistent set of assumptions and a more consistent application of wake data to the pairwise separation analysis. Pulsed LIDAR based measurements of wake vortices were made for both arrival and departure aircraft. Arrival data measurement campaigns were deployed at both San Francisco International Airport and John F. Kennedy International Airport at several glide slope altitudes, but the data used for RECAT II development came from those whose generation heights were nominally one wingspan (a subset of the FAA arrival database). The departure data was collected at Frankfurt am Main International Airport as well as at San Francisco International Airport. These LIDAR circulation measurements comprised of 230,000 quality controlled cases from which the near worst cases were identified for both arrival and departure.

The application of the wake vortex circulation data to the pairwise separation analysis is dependent on the definition of near worst case. Near worst cases are operationally-observed longer lasting wakes that occurred a small percent of the time, but not so rare to the point that it is almost never observed. The use of longer lasting wake vortex data is consistent with established international practices/protocol for establishing wake separation minima, used for setting separations of recent aircraft such as the A388, B748, B788, B789, A350 and others. In the arrival scenario, the near worst case is set to be the top five percent of the quality controlled wake tracks and generated close to the ground near the landing threshold. This represents the most safety critical region from a wake turbulence encounter perspective, due to:

- The presence of ground/terrain near the threshold does not allow wakes to descend below the glide slope as they would otherwise do in the nominal situation at a higher altitude. Vortices would eventually interact with the surface and give rise to vortex rebounding to altitudes close to or exceeding the glide slope.
- In the event of a wake induced upset, the aircraft would have less altitude to recover.

For departures, the near worst case scenario would occur in the out-of-ground effect (OGE) region. The near worse case encounter scenario on departure would be a follower aircraft shortly after takeoff at a low altitude encountering the wake of the leader aircraft. Under this situation, the generator's wake is generated higher up in the OGE region and descends to the altitude of the follower. The OGE wake is a worse case than an in-ground effect (IGE) wake because the OGE wake would be stronger as it decays slower due to lack of ground interaction. In the database of vortex measurements, there is a more limited amount of data and therefore the longest lasting wakes are set to be the top ten percent of quality controlled wake tracks.

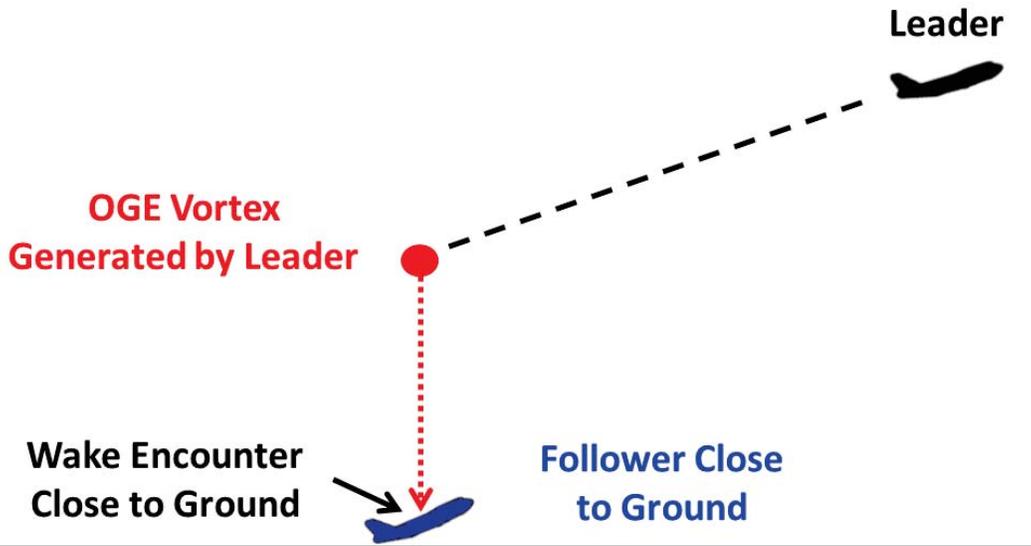


Figure 2. Diagram for the near worst wake encounter scenario for departure.

As with RECAT Phase I, the wake vortex measurements are used to characterize circulation decay. In order to reduce separation, the FAA wake turbulence research team organized the data into three types. Type 1 data represents measured circulations versus wake age, taken straight from the data for specific aircraft types. Type 2 data represents measured initial circulations couple with a non-dimensional decay curve. Type 3 data represents initial circulation numbers computed from aircraft characteristics coupled with the non-dimensional decay curve. The non-dimensional decay curve used for Type 2 and Type 3 data is formed used the long lasting wakes of 6 chosen aircraft (A346, A343, A332, B744, B77W, and B772). The dimensional circulation decay data for each aircraft are normalized by its initial circulation, Γ_o ,

$$\text{Non-Dimensional Circulation} = \Gamma^* = \Gamma(t) / \Gamma_o \quad (1)$$

The wake age is normalized by T_o ,

$$\text{Non-Dimensional age} = T^* = t / T_o \quad (2)$$

where,

$$T_o = 2 \pi b_o^2 / \Gamma_o \quad (3)$$

$$b_o = (\pi/4) b \quad (4)$$

b_o and b are the initial vortex separation and the wingspan, respectively. Elliptical wing loading is assumed in Eq. (4). Note that since the normalization uses a measured Γ_o , no assumptions or measurements for weight and airspeeds are required in this process.

A linear fit was then made through the six median decay curves between non-dimensional times of 1.5 to 4, and the resulting non-dimensional decay curve is shown in Fig. 3, whose form is described as,

$$\Gamma^* = 1.0982 - 0.1679 T^* \quad (6)$$

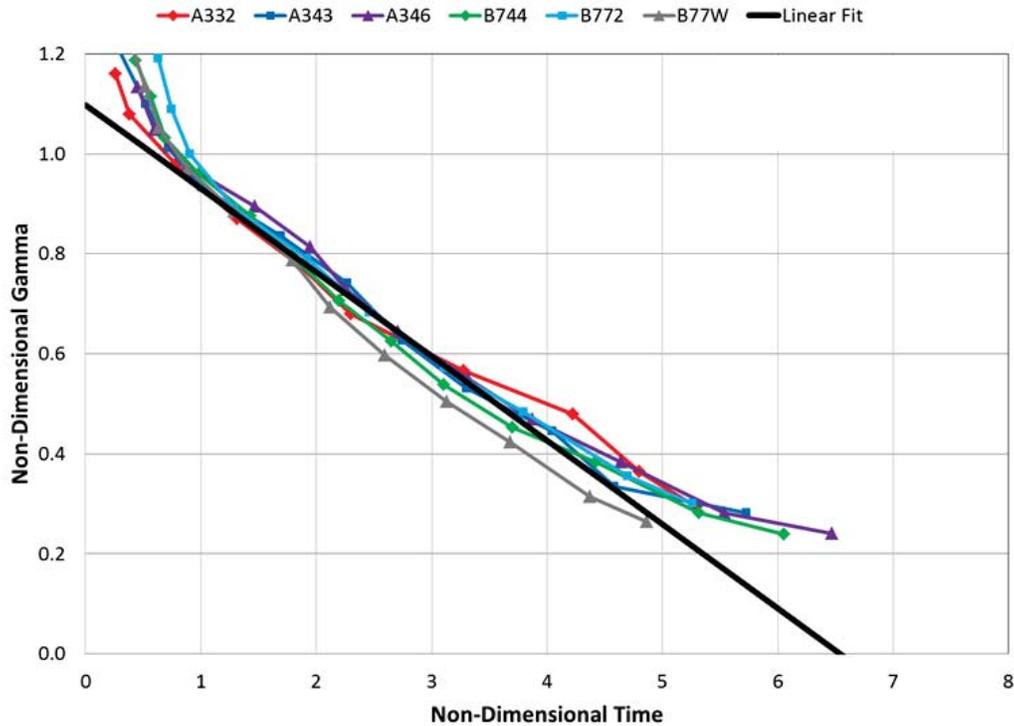


Figure 3. Non-dimensional circulation decay line for arrivals.

The decay curves used for RECAT Phase II, like RECAT Phase I, employed circulation (gamma) binning with the median of the data at each given time bin. As time progresses, there are fewer and fewer data points in each time bin, and the resulting median is essentially weighted by only the surviving vortices, and the vortices that have demised made no contribution to the statistics of the true median circulation in each bin and the associated median age are computed, the resulting decay curve is not biased towards the remaining surviving wakes, leveling off towards the longest-lived vortex observations. The use of circulation binning is not unique to RECAT Phase II and is used in the international wake community,⁸ though the FAA’s research uses the data, rather than curve fits, to define the decay curve to large non-dimensional time units that represent the longer lasting wakes.

C. Aircraft Speed Profiles

Aircraft approach speeds are included in the database of aircraft characteristics. For RECAT Phase I, approach speed profiles were modeled for each aircraft type starting 6 nautical miles (NM) from the threshold. The model assumes that an aircraft 6 NM from the threshold is flying at 170 knots (kts) and will decrease its speed 15 kts per NM (or 19 kts per NM for turboprop aircraft) until it reaches the published Final Approach Speed at 85% MLW as delineated in the database.

Aircraft speed profiles are essential to the development of the severity metrics and significant improvements were made to represent accurate approach speed profiles to replace the modeled speed profiles for RECAT Phase II. Approach and departure speed profiles have been characterized to cover all of the 123 ICAO aircraft type designators used in the RECAT II baseline traffic mix. These were derived from over 5 million flight tracks using fused aircraft surveillance data, including those from Airport Surveillance Radar and high resolution Airport Surface Detection Equipment, Model X (ASDE-X). These flight tracks are then merged with weather and associated air traffic control-related parameters to formulate the speeds and time-to-fly as a function of distance, up to 14 NM, to runway threshold. The resulting ground track-based aircraft speed distributions have been validated through comparison with de-identified aircraft-recorded digital flight data from Flight Operational Quality Assurance (FOQA) data, with approval from the Aviation Safety Information Analysis and Sharing (ASIAS) Issue Analysis Team.⁹

D. Severity Metrics

As with RECAT Phase I, RECAT Phase II uses wake vortex circulation and roll moment coefficient (RMC) as the two primary metrics for characterizing the severity of potential wake encounters between leader-follower aircraft pairs. Circulation quantifies the strength of the wake vortex generated by the leading aircraft, and it is dependent on the parameters of the leading aircraft. RMC is a non-dimensional vortex-induced torque imposed on the following aircraft. Although not explicitly/directly computed, RMC can also be visualized or can be considered as equivalent to the ratio of the vortex-induced moment relative to the roll resistance of the follower. The derivation of the RMC used in the RECAT analysis is described in Ref. 10. RMC is approximated by

$$RMC = \Gamma / U b \quad (7)$$

where Γ is the circulation of the vortex generated by the leading aircraft which could potentially be encountered by the following aircraft, and U and b are the aircraft speed and wing span, respectively, of the follower aircraft.

The RMC formulation fundamentally implies that the dynamics of the encounter is such that the aircraft rolls slowly and does not get ejected out of the vortex quickly. Therefore, it is a severity metric more applicable to larger aircraft because they roll slowly, behave “statically” in a wake encounter, and can stay in the vortex for enough time for roll resistance to be applied and be effective. For such “static” wake encounters, it is then relevant to compare vortex induced roll moment to aircraft roll resistance. Smaller aircraft roll more quickly than larger aircraft and behave statically for shorter amounts of time. For this reason, RMC is used as the primary severity metric for larger aircraft and circulation is used as the primary severity metric for smaller aircraft.

One of the differences of RECAT Phase I and RECAT Phase II lie in which metric was used for which aircraft pairs. Table 2 shows the delineation for groups of aircraft, using the RECAT Phase I categorization of aircraft for reference as easy nomenclature. RECAT Phase I used RMC as the primary metric for Cat A, B, and C (defined in Table 1) followers, and used circulation as the primary metric for Cat D, E, and F followers. RECAT Phase II uses RMC for the “Upper D” Category in addition to Cat A, B, and C. The Upper Cat D group includes the B757s, B737 family, and the A320 family. The extension of the use of RMC as a severity metric to the Upper Cat D aircraft was based on FAA’s six degree-of-freedom flight simulator results of the B738, obtained from the FAA Flight Standard Services’ located at Oklahoma City. The flight simulator results show that the B738 responds to wake encounters in a static sense and therefore RMC is a good metric to apply to this size aircraft and larger.

Table 2. 123 aircraft delineated into reference groups for severity analysis.

Cat A,B,C	Upper Cat D	Lower Cat D	Cat E	Cat F	
				F Medium	F Light
A388	C130	B722	E170	SH36	B350
B748	C30J	B721	DH8C	C750	SW4
B77W	B753	MD90	DC91	E120	BE20
B77L	B752	MD87	AT72	CL30	C25B
B744	A321	MD83	FA7X	F2TH	PC12
A346	B739	MD88	CRJX	C680	C550
A345	A320	MD82	CRJ9	FA50	C208
C5	A319	CVLT	DH8B	GALX	C25A
B773	B738	B734	DH8A	B190	C441
B772	B737	B733	SB20	C56X	C525
A343	B736	B735	AT43	H25B	SW3
A333	A318	E190	GLF4	C560	P180
A332		GLEX	GLF3	ASTR	BE99
B789		GL5T	CRJ7	LJ45	BE10
B788		GLF6	SF34	LJ31	C402

Cat A,B,C	Upper Cat D	Lower Cat D	Cat E	Cat F	
				F Medium	F Light
B742		GLF5	GLF2	LJ60	PAY2
MD11		DC95	CRJ2	LJ55	PA31
C17		B712	CRJ1	BE40	SR22
B764		DC93	E135	LJ35	BE58
DC10		DH8D	E45X		C210
B763		B732	E145		
B762			CL60		
A306			F900		
A30B			F18		
A310			F16		
K35R					

III. Application of Severity Metrics to Determine Pairwise Separation Reduction

Pairwise separation reduction can be achieved by defining reference values of the severity metric from today's separation as bounding values and allowing separation reduction between the applicable aircraft pairs down to those bounding values. The application of circulation behind the largest aircraft in a category calculates the allowable reference circulation experienced by a given follower aircraft today and allows up to this reference circulation for all leaders of the same follower aircraft. Fig. 4 shows schematically this separation reduction methodology for a follower aircraft. The diagonal solid black line represents the baseline circulation decay of a leading aircraft. The diagonal solid blue line represents the circulation decay of a different leading aircraft behind which separation reduction is desired. For a baseline pair of aircraft (the baseline leader and a given aircraft type in trail), the wake age at ICAO separation for that pair is determined, shown by the dashed black line, and defines a bounding circulation value from the black solid line. That circulation value can be safely experienced and can be applied to the reference pair of aircraft on the blue circulation decay line, and the new RECAT in-trail separation time can be determined by the corresponding smaller wake age, shown by the dashed blue line. The separation reduction for a reference trailer behind a given leader will potentially experience a wake encounter of the same wake strength, but no greater than it does today behind the bounding baseline aircraft.

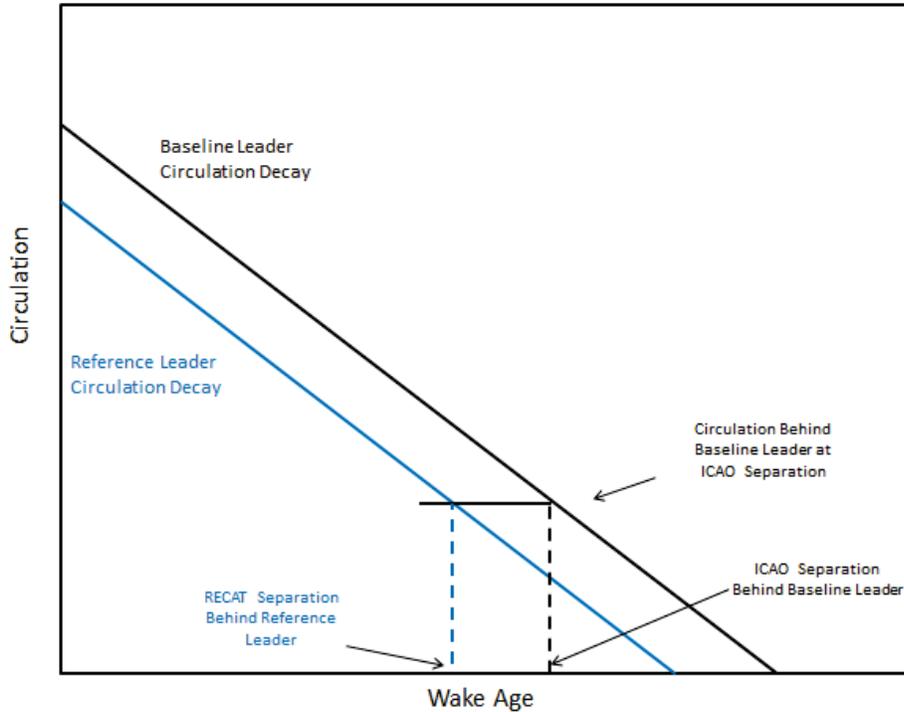


Figure 4. Schematic diagram for separation reduction for a follower aircraft.

The application of RMC calculates the acceptable reference RMC experienced by a follower aircraft from a leader/follower pair and allows all followers in the leader/follower pairs within a defined “block” of aircraft to be exposed up to that reference RMC. The allowable reference RMC used for the block of Cat A, B, and C following aircraft was chosen to be the A306 follower aircraft behind an A346 leader aircraft. The allowable reference RMC used for the block of Upper Cat D followers was chosen to be the B738 behind the A346.

Fig. 5 shows the near maximum RMC (near maximum because the A388 was not used to set the maximum allowable RMC) potentially encountered at today’s baseline separations for the 123 follower aircraft plotted against their wingspan. The figure also shows the categorical boundaries defined from RECAT Phase I. The RMC for Cat A, B, C, and Upper Ds aircraft are indicated with the red circles and are the only ones of interest, since only those aircraft use this metric for determining separations. RMC tends to increase with shorter wingspan. It is important to notice the decrease in RMC between the Cat A aircraft and the largest Cat B aircraft, and between the smallest Cat C aircraft and the largest Cat D aircraft. This is due to the changes in today’s Category boundaries (i.e., Super and Heavy, and Heavy and Large, respectively) and therefore changes in baseline separation.

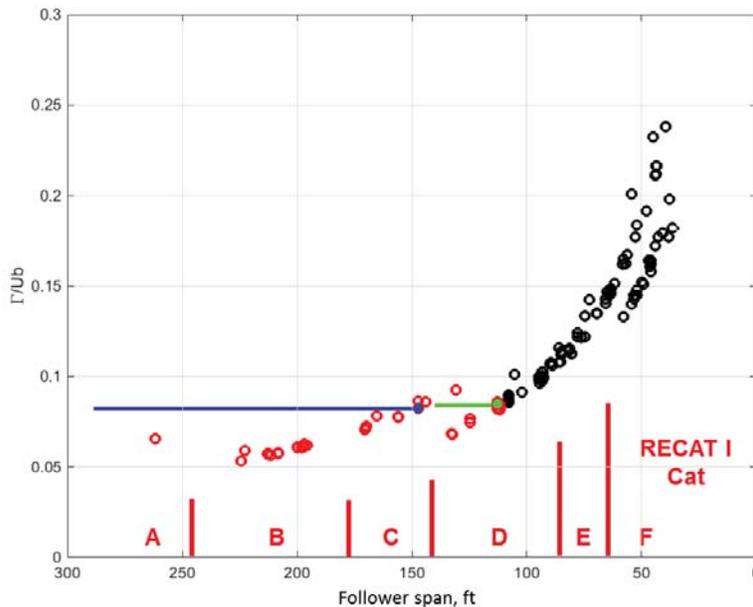


Figure 5. Maximum RMC versus wingspan.

The blue dot on Fig. 5 corresponds to the allowable reference RMC chosen for the block of Cat A, B, and C followers, which is the A306 behind an A346 at today's baseline separation of 4 NM. The blue line on the figure indicates that all the followers within this block are allowed to be exposed to this reference RMC value. The green dot on Fig. 5 corresponds to the allowable reference RMC chosen for the block of upper Cat D followers, which is the B738 behind an A346 at today's baseline separation of 5 NM. The green line on the figure indicates that all followers within this upper Cat D block are allowed to be exposed to this reference RMC value. Transferring RMC values from smaller to larger aircraft is justified because larger aircraft have both larger moments of inertia and larger wingspans, offering passive resistance to wake encounter. Both of these factors slow the dynamics of a potential wake encounter. First, the slow response assures that the aircraft could experience the full wake strength under ICAO separations today and therefore the severity metric is a valid near worst case metric with no pilot or autopilot mitigation. Secondly, the slow response assures that sufficient time exists for pilot (or autopilot) to apply aileron input and for initial aileron motion to begin to work against the wake induced roll moment before the aircraft is thrown out of the wake, thus assuring the RMC value overstates the expected roll severity metric.

IV. Safety Risk Assessment as Part of the FAA Safety Management System

A formal safety risk assessment was performed in accordance to the FAA Safety Management System³ prior to approval of the pairwise separation matrix. The derivation of the proposed pairwise separations for RECAT Phase II is inherently capped by today's overall operations by using today's separation standard as a baseline. While individual aircraft types may be exposed to stronger circulations, those circulations are no stronger than those experienced by other similar aircraft in the NAS today. The RECAT Phase II safety assessment relies on the assumption that the current ICAO, FAA Order JO 7110.65, and RECAT Phase I separations, used as a baseline for Phase II analysis, are acceptably safe for all aircraft. Since there is no absolute criterion for determining acceptable wake strength and likelihood, a relative risk assessment was performed and the risk represented by RECAT Phase II is no worse than the risk that is characterized by today's separations (baseline).

The Aviation Safety Reporting System (ASRS), managed and administered by NASA, has collected wake encounter reports in the US through its history. Since 2004, the FAA Wake Turbulence Research Office has initiated a collaborative effort with NASA to callback every incident report to ASRS that included a wake turbulence encounter. An assessment of ASRS wake encounter reports collected over the past 11 years provides a way to characterize today's risk of wake encounters, under which the risk of the RECAT Phase II separations are capped. With the demonstration that the proposed change has no greater severity or likelihood of wake encounter, today's depiction of a wake encounter can be used to represent the risk of the proposed change.

Each ASRS Wake Turbulence report was assessed for both their severity as well as likelihood by a safety panel of experts that included Air Traffic specialists, pilots, engineers and wake turbulence scientists. While it is unlikely that all wake encounters observed by flight crews are reported, the results of the most severe of those encounters are mandatory reporting events. The wake encounter reports were filtered for those relevant to the RECAT Phase II encounter space. The encounters NOT included are those in en route airspace, helicopter operations, self-induced encounters, aircraft that have accepted a visual separation clearance, non-domestic reports, and reports involving an arriving aircraft encountering the wake of a departing aircraft or vice versa. The likelihood of wake encounter is based on the number of operations during which the wake turbulence encounter reports were recorded and is represented by the formula:

$$\text{Wake Encounters} / (\text{Departure Operations} + (10\% \text{ of Arrival Operations} - \text{GA Arrivals})) \quad (8)$$

This formula is used because wake turbulence separations always apply on departure but only apply on arrival when the pilots are not using visual separation, which is approximately 10% of the time. Also, General Aviation operations make up a small portion of arrival operations that are being provided radar services. For these reasons General Aviation operations on arrival are excluded along with 90% of all other arrival operation counts to remain conservative in the likelihood of a wake encounter. The number of relevant wake encounters organized by severity produces a likelihood with a 10^{-7} magnitude.

V. Implementation of RECAT Phase II

The pairwise separation matrix was approved by the FAA Air Traffic Organization (ATO)'s Safety and Technical Training group (AJI) and FAA Aviation Safety (AVS)'s Air Traffic Safety Oversight Service (AOV) in November 2015. While true pairwise separation offers the maximum benefit of RECAT Phase II, it is impractical to implement without more advanced Decision Support Tools (DSTs). The ATPA tool may allow for an increase over the 6 categories defined for Phase I, however, there is a human factors limitation that caps the complexity of having more categories.

The goal of RECAT Phase II implementation is to offer site-specific capacity benefits while remaining practical and manageable for air traffic controllers. The number of categories, as well as the makeup of those categories, will be determined collaboratively between the air traffic controllers working at the implementation site, the FAA, the National Air Traffic Controllers Association (NATCA), and human factors specialists. The categorical makeup and the resulting separation matrix, where categorical separations are determined by the largest separation in the pairwise separation matrix for the group of aircraft rounded to the nearest 0.5 NM, will be determined on a site-by-site basis, dependent on the fleet mix of the implementation site.

The RECAT Phase II approval of the pairwise separation matrix allows for changes in implemented categorization without the need for a full safety assessment. Changes could be made due to manufacturing and entry into service of new aircraft types or changes in operations or fleet mix at a RECAT Phase II site, as long as the categorization scheme and the updated separation matrix is based on the approved pairwise separation matrix.

The first implementation of RECAT Phase II is expected to be at Southern California TRACON in 2016.

VI. Future Work

As sufficient data become available for more aircraft types, the FAA wake turbulence research team will continue to add aircraft to the RECAT Phase II database and pairwise separation matrix. Further enhancements are being done to RECAT Phase II, often referred to as RECAT 2.5, to assess the ability to apply the RMC severity metric to smaller aircraft. Flight simulator tests, similar to what was done for the B738, are planned for the E190, E170 and E145 aircraft to determine if these can act as reference aircraft for RMC transference. The analysis for RECAT Phase 2.5 is expected to include additional assessment of Intersection departures and Closely Spaced Parallel Runway (CSPR) Operations.

RECAT Phase III envisions dynamic pairwise separations; separations that change with near real-time data (e.g., environmental conditions and aircraft-derived data). RECAT Phase III is still in the early stages of concept development and the timeframe is roughly 2020. The dependency of the availability of near real-time data is the limiting factor to the development of the full RECAT Phase III concept.

Acknowledgments

We would like to thank Frank Wang, Hadi Wassaf, Melanie Soares, Steve Barnes, Wayne Bryant, George Greene, Jim Hallock, Don Delisi, David Lai, Clark Lunsford, Lisa Wynnyk, Tim Fowler, and the ASIAS Issue Analysis Team. The first author is supported by the Federal Aviation Administration's Wake Turbulence Research Office under the funding of DTRT57-12-D-30003 TO# DTRTV-T4016 administered by the USDOT John A. Volpe Transportation Systems Center.

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