Modelling of Runway Infrastructure Operations in an Effort to Increase Economic and Environmental Sustainable Development

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Abstract. In the effort to increase economic and environmental sustainability of the airport system; longitudinal spacing of aircraft approaching a runway has been identified as a major obstacle for runway efficiency. As demand approaches capacity at main hub airports, research efforts have focused on safely reducing current aircraft separations, which are considered a bottleneck in the effort to increase the utilization of existing airport facilities. This research uses modelling and computational algorithms to demonstrate the potential for aircraft separation reductions based on discrete scenarios comprising environmental conditions, aircraft-dependent parameters, and aircraft operational capabilities. Results from this research show that separation reductions can be obtained for aircraft such as the A320 and E170, corresponding to groups D and E in RECAT I. This results in single runway airport efficiency increase and gains are further translated into reductions of emission and fossil fuel.

Keywords: Sustainable development · Air transportation
Airport sustainability · Wake separations

1 Introduction

Airports play a vital role in the development of local and national economies; but this development results in a significant environmental impact in terms of noise pollution, emissions and waste water; as well as social impacts such as community development and traffic disruptions and congestions [1].

Airlines continue to merge, and air traffic operations increasingly rely on main hub airports to serve the flight demand. Runway capacity is becoming critical to serving the increasing operational demands and helping airports recover from long queues created by non-favorable weather conditions that result in underutilized economic and environmental resources.

Wake vortex separations have become a major influence for runway throughput because they determine the time that the runway will be unutilized between each pair of sequential arrivals. When the separation between arrivals is large enough, air traffic controllers may allow departures in between, but these departures also rely on wake separation standards for safety [2].

J. Charytonowicz and C. Falcão (Eds.): AHFE 2018, AISC 788, pp. 90–99, 2019.
https://doi.org/10.1007/978-3-319-94199-8_9

In an effort to increase sustainable development of airport operations wake vortex separations become a major parameter to study in order to understand the potential for further safe reductions in aircraft separations. Dynamic wake separations is a concept that proposes the use of dynamic conditions and their impact on wake behavior in order to dynamically adapt such separations according to actual conditions. This would result in reductions from current wake separations distance between aircraft [3].

1.1 Objective

The focus of this research is to develop a computer model of runway operations in order to simulate aircraft wake separation reductions, develop a methodology and present simulation conditions and available operational data that could be used in order to further reduce wake separation and increase airport economic and environmental development.

Parameters for sustainability development in infrastructure utilization such as aircraft emissions and noise are used as variables into the design of the simulation.

The research simulates aircraft operations during final approach utilizing RECAT I.5, the dynamic separations of RECAT III, and real data recorded for fleet mix, runway occupancy time (ROT), operational buffers, and aircraft approach speed. The research calculates and compares the RECAT I.5 and RECAT III gains in runway capacity, according to their proposed reductions in aircraft wake separations.

This research utilizes a methodology to calculate dynamic wake separations dependent on aircraft configuration, such as weight, and environmental conditions, such as turbulence, wind speeds, and temperature. These factors could be considered in airport-specific wake separations under RECAT III [4] (Fig. 1).

Fig. 1. Sustainability development for infrastructure operations.

2 Methodology

The proposed methodology for calculating runway throughput for the airport runways under study is based on Monte Carlo constructive simulation of runway operation procedures. A computer program has been created to simulate real-world conditions of aircraft and airport operations during approach, arrival, and departure conditions. This method accounts for static and dynamic wake vortex separations, ROTs, aircraft approach speeds, aircraft wake circulation capacity, environmental conditions, and operational error buffers.

2.1 RECAT I, RECAT I.5, RECAT III

Wake vortex categorizations are groupings of aircraft with similar wake vortex generation and endurance capabilities. The Federal Aviation Administration created such categorizations in the 1960s, and they remain practical and safe today.

To increase operational efficiency of airports, especially for airports under capacity constraints, the FAA led an effort to revise legacy wake separations. These efforts increased legacy wake separations from a five-by-five matrix to a six-by-six separation matrix called RECAT I. RECAT I was implemented at Memphis International Airport (MEM) at the end of 2012 and has expanded to Louisville International Airport (SDF), Cincinnati/Northern Kentucky International Airport (CVG), Hartsfield-Jackson Atlanta International Airport (ATL), George Bush Intercontinental Airport (IAH), and Charlotte Douglas International Airport (CLT).

RECAT 1.5 was developed as a modification of RECAT I; its results are still being assessed. RECAT 1.5 was implemented at the beginning of 2016 at George Bush Intercontinental Airport (IAH) and continues to expand to airports such as Charlotte Douglas International Airport (CLT), John F. Kennedy International Airport (JFK), Newark Liberty International Airport (EWR), La Guardia Airport (LGA), O'Hare International Airport (ORD), and Denver International Airport (DEN) (Table 1).

Table 1. RECAT I FAA N7100.659A to N7110.659. Wake turbulence separation table for "on approach".

Leader	Follower					
	A	B	C	D	E	F
Old – RECAT I						
A		5NM	6NM	7NM	7NM	8NM
B		3NM	4NM	5NM	5NM	7NM
C				3.5NM	3.5NM	6NM
D						5NM
E						4NM
F						
New – RECAT "1.5" as of april 2015						
A		5NM	6NM	7NM	7NM	8NM
B		3NM	4NM	5NM	5NM	7NM
C				3.5NM	3.5NM	6NM
D						4NM
E						
F						

This research focuses on a proposed methodology development for future wake separations called RECAT III dynamic separations.

ASPM. In order to identify airports that operate under congested conditions, Aviation System performance metrics (ASPM) records from the Bureau of Transportation Statistics (BTS) are used. Late arrival delays, operational delays and National Airspace (NAS) delays and weather delays were studied and an understating of the current delay conditions and causes was obtained.

Late arrival delays were used to understand the delays between the origin-destination for each aircraft pair.

Operational delays include delays due to weather, high volume of traffic and reduced runway capacity; experienced by individual flights. These delays result in the air traffic controller (ATC) detaining an aircraft at the gate before the final approach fixed, short of the runway, on the runway, on a taxiway, and/or in a holding configuration.

National airspace delays are delays that occur after Actual Gate Out. This kind of delay is within the control of the National Airspace System (NAS) may include non-extreme weather conditions, airport operations, heavy traffic volume, air traffic control.

Weather delays are caused by extreme weather conditions that are present or forecasted on the point of departure, en-route, or on point of arrival.

ASDE-X. To provide validity and increase the reality of the simulation results, this research uses detailed data of movement on the final approach, runways, and taxiways, based on Airport Surface Detection Equipment Model X (ASDE-X). This data allows for the calculation of aircraft approach speed, runway occupancy times, and traffic control buffers. ASDE-X data for all runways at the airport under study, for the months January to November of 2016, has been analyzed (Fig. 2).

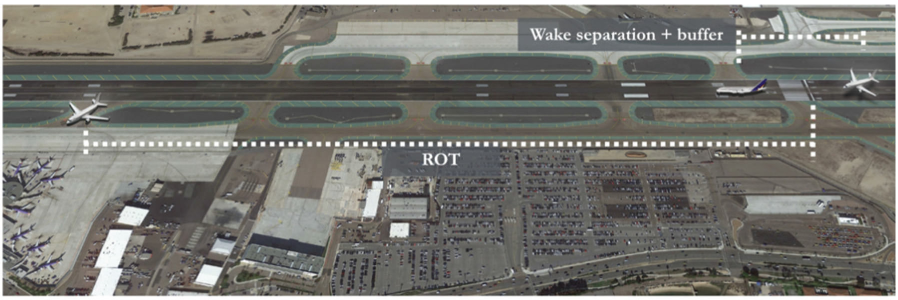

Fig. 2. Wake separation and operational buffer on approach.

Runway Fleet Mix. One of the most important factors influencing runway capacity calculations is fleet mix. The methodology for the aircraft mix selected for simulation is based on ASDE-X recordings of operating aircraft for each runway. Basically, those aircraft that represent between 85% and 90% of operations at the runways under study

Table 2. Approach speed for aircraft ID according to ASDE-X records.

Aircraft ID	A319	A320	B738	CRJ2	CRJ9	E145	E170	MD82	MD83
*Aircraft Mix	4	9	26	8	16	23	8	2	4
**Approach Speed	149	155	158	151	145	154	147	148	150

* Aircraft Mix in Percent.

**Approach Speed Knots.

are selected to represent the runway fleet mix. The simulation consists of launching 1,000 aircraft per runway, which is equivalent to 24 h of peak-hour operation at a typical runway, with 10 operations every 15 min (Table 2).

Runway Fleet Mix. Estimating dynamic wake separation between leader and following aircraft requires consideration of a wake vortex threshold that is known not to adversely affect an aircraft under wake influence flight operation. This threshold considers the maximum wake vortex effect that a follower aircraft can endure at minimum wake separation standards from the wake generator aircraft, referred to as the maximum wake circulation capacity (MCC). The methodology in this research is considering FAA RECAT II wake separations and a 95% confidence interval in the wake behavior CDF curves [5].

Common Approach Path. Final approach fix is a specified point of approach that identifies the commencement of the common approach path or final segment. The common approach path is a specified distance in the FAA terminal procedures charts; this distance is between the final approach point and the runway threshold. The data recordings in ASDE-X show that the length of the common approach path is calculated for each operation; the methodology selected for this simulation applies a fixed common approach path of 8.5 nm (Fig. 3).

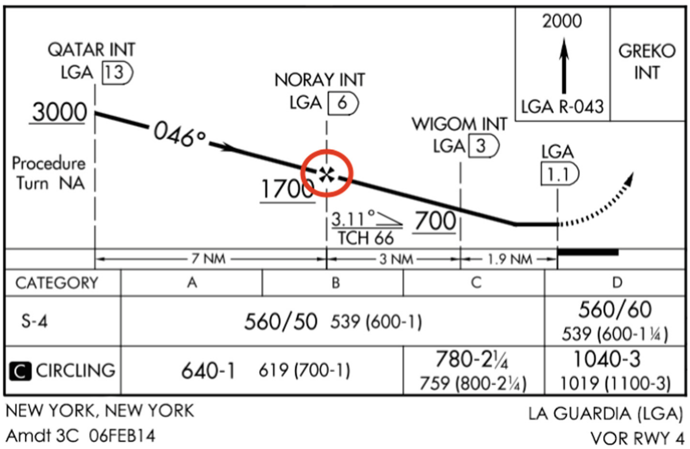

Fig. 3. Common approach path length in VOR chart at La Guardia (LGA).

Operational Buffer Times. Air traffic controllers use operational buffers to modulate aircraft separations at every moment. The purpose of the buffer is to guarantee that controllers do not violate minimum wake separations standards. Operational buffers account for pilot operational errors, delays in communication, and reaction times during pilot-controller interactions.

The proposed methodology calculates operational buffers based on more than ten months of operational data from ORD. The buffers are calculated by measuring inter-arrival time separations and subtracting them from RECAT 1.5 time separation standards. The buffer is calculated in the final, common approach path utilizing a fixed distance of 8.5 nm from the runway threshold. The resulting buffer is the closest point of approach (CPA) between each pair of aircraft during the entire approach path length.

During this analysis, negative buffer values are the result of runway approach operations under Visual Flight Regulations (VFR), where aircraft-to-aircraft separations are below those of Instrument Flight Regulations (IFR) due to pilot self-separation procedures made possible in favorable environmental conditions.

To calculate operational buffer, peak-hour operations were parsed from the ASDE-X data utilizing a baseline of 10 or more operations in 15-min periods. Only peak-hour periods were considered because inter-arrival separation times, and the resulting operational buffers, during non-peak-hours buffers are larger by nature, even though the current wake vortex minimum separation rule is dictated by the RECAT 1.5 separations.

Runway Occupancy Times. When decreasing wake vortex separation during the final approach path, ROT becomes a critical next step in the runway capacity analysis. If a runway must service more aircraft, measured ROTs have to be studied to understand how much of the theoretically calculated capacity increment of RECAT III is operationally feasible on currently available airport infrastructures (Table 3).

Table 3. ROT calculated values for specified aircraft.

Aircraft ID	A319	A320	B738	CRJ2	CRJ9	E145	E170	MD82	MD83
ROT seconds	58	57	57	55	60	53	54	56	57

Environmental and Aircraft Parameters. Environmental and aircraft parameters are key factors in RECAT III dynamic separation calculations. These calculations vary environmental factors such as temperature, crosswind speeds, and environmental turbulence every 15 min. Values for temperature range between 283 and 299 K, values for crosswind speeds range between 0 and 12.86 m/s, and EDR values follow the distribution shown in Fig. 4.

In this research, aircraft operational performance is simulated utilizing the Base of Aircraft Data (BADA), an aircraft performance model developed and maintained by EUROCONTROL in cooperation with aircraft manufacturers and airlines. This database has been designed for simulation and aircraft trajectory prediction The BADA performance model is based on the Total Energy Model, which equates the forces acting on the aircraft with the rate of increase in potential and kinetic energy [7].

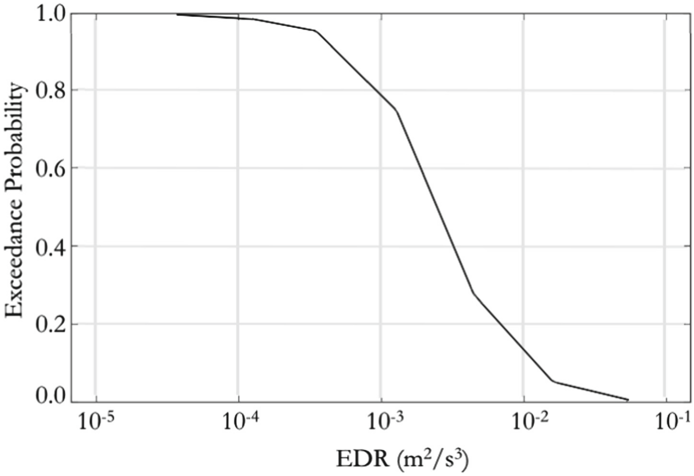

Fig. 4. Distribution of exceedance probabilities at 40 m altitude from DFW 8/97 – 12/98 [6].

Aircraft weight, a critical parameter of wake initial circulation strength, is simulated based on empirical operational data for typical airline operations.

3 Results and Conclusion

Runway capacity improvement is one of the main benefits that make wake separation attractive for sustainable airports.

Results from this research show that separation reductions can be obtained between all aircraft under study but greater gains are obtained for aircraft on different RECAT 1 groups such as the A320 and E170, corresponding to groups D and E in RECAT I. This results in single runway airport efficiency increase. Gains are further translated into reductions of emission and fossil fuel consumption for which the calculation methodology and preliminary results are presented.

Results show that a higher runway utilization; produce fewer aircraft in queue in the airspace surrounding the airport infrastructure and queuing times for aircraft taxing are reduced due to higher runway throughput.

The complexity of implementing pairwise dynamic wake separations, such as in RECAT III, requires advanced decision support tools that can help controllers coordinate and direct arriving and departing flights. There is a need to develop reliable tools that can help the controllers in this task [8].

Dynamic wake separations require more advanced LIDAR capabilities and technologies that allow for wake measurements during flight.

In this simulation, the dynamic wake separation required for a follower aircraft is calculated by using the National Aeronautics and Space Administration (NASA) Aircraft Vortex Spacing System (AVOSS) Prediction Algorithm (APA) model, a semi-empirical wake behavior model developed by NASA that predicts wake decay as a function of atmospheric turbulence and stratification. Wake behavior under each set of dynamic conditions is show in Fig. 5 [9].

The lifetime of the vortex depends on its initial strength, which depends on aircraft weight and wingspan as well as the ambient weather conditions. It is for this reason that the simulation changes environmental conditions every fifteen minutes and aircraft weight in every operation [10, 11].

The number of arrival operations simulated is one thousand. Departures are launched in between successive arrivals if the wake gap for each pair of aircraft is larger than wake minimum separation standards. The simulation assumes 2 nm plus an additional buffer to be the minimum separation between arriving and departing aircraft.

Simulated conditions for ROT and approach speeds are in accordance with the runway under study and follow the distribution according to the ASDE-X data studied. The common approach path length is considered to be 8.5 nm.

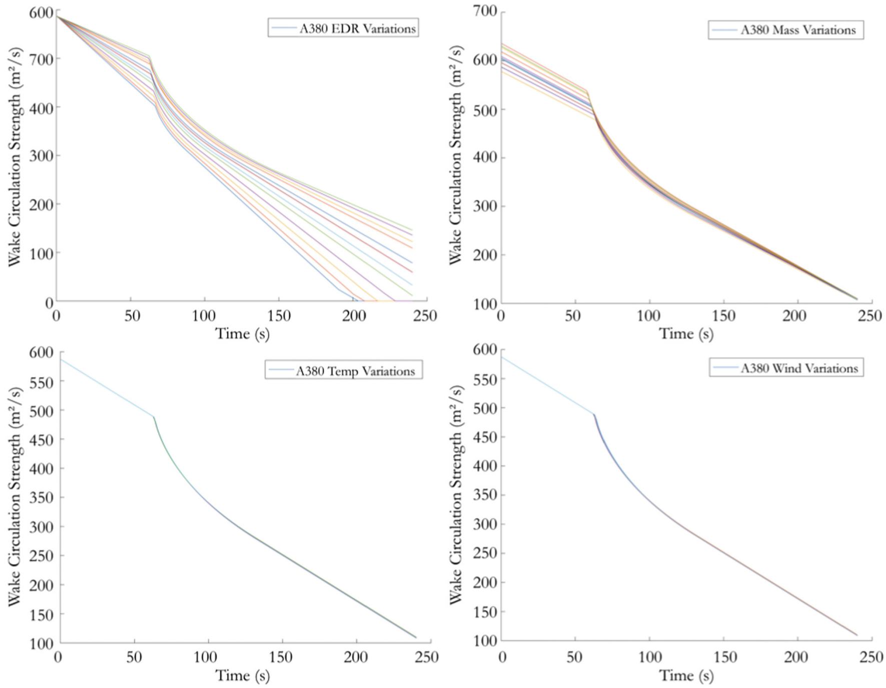

Fig. 5. Wake vortex behavior for dynamic separations.

The approach to calculating the percentage of operations restricted by ROT taking into account the buffer does the following:

If the operational wake separation between leading and following plus operational buffer is less than the ROT for the leading aircraft; then separation is adjusted to ROT plus buffer otherwise use operational wake separation (Fig. 6).

Fig. 6. Aircraft measuring and reporting aircraft parameters and environmental conditions.

The focus of this research is to develop runway operation computer simulation in order to implemented aircraft wake separation reductions and asses the emissions and noise due to less aircraft circling the airspace because of the lack of runway capacity. Dynamic wake separations require airport management tools in order to guarantee proper planning and coordination; as runway throughput increases runway occupancy times and gate utilization become critical factors in the system; it is for this reason that they are the proposed focus of a future study [5].

Acknowledgments. This research has been made possible thanks to the research contributions of the Federal Aviation Administration Wake Program, National Aeronautics and Space Administration (NASA) wake program, EUROCONTROL, Japan Aerospace Exploration Agency, WakeNet meeting members, MIT Lincoln Laboratory, and private industry research labs such as the MITRE Corporation.

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