EUROCONTROL

Principles and guidance for wake vortex encounter risk assessment as used in the Paris CDG Wake Independent Departure and Arrival Operations (WIDAO) Safety Case

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Abstract

This document describes principles for wake vortex encounter risk assessment and mitigation derived from the experience of successful wake turbulence constraint relaxation at Paris Roissy Charles de Gaulle Airport. A methodology is proposed for wake turbulence risk characterisation and quantification, and generalisation of results to all normal conditions within the intended operational environment. An overview of the data collection, analysis and modelling techniques used to support a wake turbulence risk assessment is provided.

Keywords

Wake Turbulence	Safety Assessment
WVE risk	
WIDAO	

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The following table identifies all management authorities who have successively approved the present issue of this document.

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CONTENTS

EXECUTIVE SUMMARY

This document describes principles for wake vortex encounter risk assessment and mitigation derived from the experience of successful wake turbulence constraint relaxation at Paris Roissy Charles de Gaulle Airport. The guidance uses examples from a relative assessment of wake turbulence transport to a closely spaced parallel runway against an in-trail baseline. The tools and techniques are therefore relevant to a wake survey conducted near the airport surface; however the principles for safety assessment may be applicable to other operations, e.g. en-route.

The document is based on the detailed safety case of Wake Independent Departure and Arrival Operations (WIDAO) at Paris CDG.

A methodology is proposed for a wake turbulence risk assessment and generalisation of survey results to other locations. Only the hazard of WT accident is considered, although other hazards may result from modification of wake turbulence constraints in other cases.

An overview of the data collection techniques used to support a wake turbulence risk assessment is provided. Assumptions regarding wake vortex behaviour and possible limitations of the wake survey data are also described.

The following important notes should be remembered when reading this report:

Safety assessments are performed on the basis of a proposed and fixed Concept of Operations (ConOps). This report can only present guidance principles for a specimen operational environment, that may assist the conduct of WVE local safety assessments to be developed based on the ConOps intended for a specific airport;

WVE safety assessments must consider local geometries, conditions and constraints will significantly influence the outcome of the assessment.

1. INTRODUCTION

1.1 Background

Wake turbulence (WVE) risk is a complex subject to assess as the likelihood of a WVE encounter and the consequences on aircraft control depends on many variables. Some wake vortex encounters (WVE) may go almost unnoticed, whereas others can lead to structural damage or loss of control with potentially fatal consequences.

Without the tools and techniques to quantify WVE risk, a conservative approach has been necessary to ensure that there is sufficient margin to achieve the high levels of safety expected of civil aviation. However, advances in technologies such as “light detection and ranging” (LIDAR) system enable cost effective studies of real world operations to be performed. The data gathered can be used to identify the margins of conservatively applied constraints such that operational benefits can be achieved without compromising acceptable levels of safety.

The guidance provided herein has been produced in collaboration with Det Norske Veritas (DNV) based upon the work performed by EUROCONTROL and the DSNA to quantify WVE risk and determine required WVE constraints between departure and arrival aircraft categories in closely spaced parallel runways (CSPR) operations at Paris Roissy Charles de Gaulle airport (CDG). Whilst performing this work some generic principles of WVE safety risk assessment were identified which could be applied to other projects and airports.

1.2 Purpose

This material has been developed to provide the principles on how to perform quantified WVE risk assessments, following the EUROCONTROL Safety Assessment Methodology SAM*E* framework and the experience gained from the “wake independent departure and arrival operations” (WIDAO) project at Paris CDG. It is intended to assist European Air Navigation Service Providers (ANSPs), Airport Operators, Regulators and other Stakeholders, who consider to perform a safety analysis of change to required WT separation provisions at a specific airport.

1.3 Aim and objectives

The aim of this document is to propose a methodology to assess and quantify WVE risk.

The objectives are:

- to describe an approach for WVE safety risk assessment and quantification;
- to overview the possible supporting tools and techniques;

1.4 How to use this guidance

This guidance material has been developed following the successful relaxation of some of the CSPR WT separation constraints at Paris CDG airport. It can be used by Stakeholders in any similar project which involves the assessment of WVE risk for commercial aircraft in take-off or landing phase of flight.

However each safety assessment is likely to be specific and will present different challenges. A ‘one size fits all’ turn-key solution does not exist, however careful consideration of this guidance material combined with reasoned judgement and analysis can enable a structured and complete study of local WVE constraints leading to a better understanding of the WVE risk picture.

Section 1 provides an introduction to the guidance material.

Section 2 describes the principles for WVE risk assessment and quantification.

Section 3 is an overview of the tools used to support the safety risk assessment.

The following important notes should be remembered when reading this report:

- Safety assessments are performed on the basis of a proposed and fixed Concept of Operations (ConOps). This report can only present guidance principles for a specimen operational environment, that may assist the conduct of WVE local safety assessments to be developed based on the ConOps intended for a specific airport;
- WVE safety assessments must consider local geometries, conditions and constraints will significantly influence the outcome of the assessment.

The detailed safety case of Wake Independent Departure and Arrival Operations (WIDAO) at Paris CDG is reported in a dedicated document [ECTL/DSNA-2010]) owned by DSNA and EUROCONTROL.

Note: Use of the tools and techniques described in this guidance material is not a pre-requisite for regulatory approval of changes to WT constraints, nor does its use guarantee regulatory approval.

1.5 Applicable regulations and standards

The following European regulatory requirements are applicable for developing safety risk assessment of ATM changes:

- For European Union (EU) Member States, risk assessment and mitigation of changes to the ATM system must be conducted in accordance with European Commission regulation EC. 2096/2005 “Common Requirements” [EC-2005]
- For EUROCONTROL Member States, risk assessment and mitigation in ATM must be conducted in accordance with EUROCONTROL safety regulatory requirements “ESARR 4” [ECTL-2001]

The following International Standards are applicable:

- ICAO Standards and Recommended Practices for Air Traffic Services “Annex 11” [ICAO-2001], and for Aerodromes Design and Operations “Annex 14” [ICAO-2009]
- ICAO Procedures for Air Navigation Services, Air Traffic Management, Doc 4444 [ICAO-2007]

For local implementation, national regulatory requirements may apply in addition.

1.6 Glossary

Fault-free (or success case)	Where operations are performed as intended; for wake turbulence hazards, fault-free means complete compliance with specified WT separation criteria and with the other specified safety requirements
Faulted (or failure case)	Where operations are not performed as they were intended; for wake turbulence hazards, faulted means non-compliance with specified WT separation criteria or operational constraints
Hazard	Any condition, event, or circumstance which could induce an accident (from ESARR 4)
Heavy (H)	The term heavy has a slightly altered definition in this safety case compared to standard ICAO. When this safety case refers to the heavy aircraft category, the Airbus A380 is not in the scope
Light Detection and Ranging (LIDAR)	LIDAR (light detection and ranging) is a measurement technique that uses a laser to estimate the wake vortex circulation strength in the scanning plane of the laser. Both WVs generated by an aircraft can be measured at the same time. The LIDAR scanning plane at CDG was located 45 m downstream of the 08R THR plane

Relative safety assessment	Compares the risk of a new proposal (e.g. post-WIDAO operations) with the risk from a reference operation that has already been agreed to be tolerably safe (e.g. in-trail WVE risk, or pre-WIDAO WVE risk between the CSPRs at CDG)
Runway Threshold	The location of the start (upstream edge) of the “piano key” markings on the runway. This position on the arrival runway aligned with the runway centre-line is used as the local coordinate origin {0, 0, 0} for all the analyses for the four runway pairs at CDG
Safety Objectives	Qualitative or quantitative statements which define the maximum frequency or probability at which a hazard can be expected to occur
Safety Requirements	Risk mitigation means, defined from a risk mitigation strategy, that achieve a particular safety objective
Wake Turbulence (WT)	ICAO use the term “wake turbulence” to describe the effect of rotating air masses generated behind the wing tips of aircraft. Wake turbulence mainly results from two counter-rotating wake vortices. The WT hazard results from an encounter with either one or both of these wake vortices
WT risk	The combination of the likelihood of a WVE and the severity of the consequence of that encounter on an airborne aircraft, which depends on the resistance and the recovery capabilities of the aircraft; it is measured in terms of effects on aircraft such as accidents or serious incidents, with a corresponding maximum acceptable frequency of occurrence expressed in a unit such as per movement or per flight
Wake Vortex (WV)	The term used to describe the phenomenon of the rotating air mass which is generated when an aircraft wing is producing lift
Wake Vortex (WV) strength	One of the key parameters influencing the effects of a WVE, usually characterised by a metric of WV circulation, measured in m^2/s
Wake Vortex Encounter (WVE)	A hazard occurring when an aircraft flies into the flow field of a wake vortex, or wake vortices, generated by a preceding aircraft, which can have various effects on the aircraft. These effects may range from a mild change in aircraft attitude through to impairment, or loss, of control of the encountering aircraft, and/or structural damage to the encountering aircraft. The consequences of WVE are a complex function of wake vortex strength, structure, encounter geometry, altitude and the properties of the encountering aircraft
WVE risk	The likelihood of an aircraft flying in close proximity to and encountering a WV of a given strength.

1.7 Abbreviations and acronyms

ANSP	Air Navigation Service Provider
ATC	Air traffic control
ATCO	Air traffic controller
CDG	Paris Charles de Gaulle airport
CSPR	Closely spaced parallel runway
DSNA	*Direction des Services de la Navigation Aérienne*
EC	European Commission
ECAC	European Civil Aviation Conference
ECTL	EUROCONTROL (European Organisation for the Safety of Air Navigation)
EPIS-CA	*Etude Préliminaire d'Impact sur la Sécurité – Circulation Aérienne*
ESARR	EUROCONTROL Safety Regulatory Requirements
EU	European Union
FHA	Functional hazard assessment
ICAO	International Civil Aviation Organization
IGE	In-ground effect
LIDAR	Light detection and ranging
LMCT	Lockheed Martin Coherent Technologies inc. (LIDAR supplier)
MET	Meteorological
OPS	Operational
PSSA	Preliminary system safety assessment
RWY	Runway
SNA-RP	*Services de la Navigation Aérienne - Région Parisienne*
THR	Threshold
WIDAO	Wake Independent Departure and Arrival Operations
WT	Wake turbulence
WV	Wake vortex
WVE	Wake vortex encounter

2. WAKE VORTEX ENCOUNTER RISK ASSESSMENT

2.1 Wake turbulence risk background

2.1.1 Wake turbulence encounter hazard for flight safety

Regardless of the phase of flight considered, aircraft wakes rapidly roll up into a pair of counter-rotating vortices, spaced laterally by a fraction of the aircraft wing-span. Owing to their mutual induced velocity, wakes descend in the atmosphere with a sink rate depending on the aircraft configuration, aircraft characteristics, flight conditions, and the detailed structure of the atmosphere (winds, turbulence and temperature). Rebound in free air may occur in a stable stratified atmosphere or vertical wind shear.

In the proximity of the ground, the sink rate decreases and vortices may eventually rebound. In some cases they rebound up to or above the altitude at which the wake was generated. The lateral spacing between the two vortices of the pair increases gradually in ground effect owing to the interaction with the ground. With a combination of ground effect and low cross-wind conditions, the upwind vortex (the one hit first by the wind) may remain laterally near the runway centre-line. The upwind vortex is mainly responsible for wake encounters close to the ground for single-runway operations.

The structure of a vortex is composed of a thin core (the core size is only a few percent of the aircraft wing-span), rotating on itself as a solid body. Outside the core region, the vortex tangential velocity decreases, and is roughly inversely proportional to the distance from the vortex centre/core. Peak vortex velocities may be as high as several tens of metres per second. For an aircraft encountering a vortex, the latter appears as a “coherent gust”.

An aircraft encountering a vortex (or a pair of vortices) may therefore be subject to significant upsets. In encounters where the aircraft’s longitudinal axis is nearly aligned with the vortex axis, the total vortex circulation is closely correlated with the maximum theoretical vortex-induced rolling moment exerted on the aircraft. Vortex circulation (also called vortex strength) thus represents the worst-case vortex-induced rolling moment on the encountering aircraft and is hence a prime measurement for wake-induced aircraft upsets.

Vortex strength decays with time, and the decay is accelerated by the effects of vortex instabilities, ambient turbulence, temperature stratification, or interaction with the ground. In calm conditions, it may take several minutes for a vortex generated by an Heavy aircraft to decay to a non-measurable level. In turbulent conditions, the lifetime of a similar vortex may be reduced by a factor of 5 or more.

In the approach phase of flight, the areas where wake turbulence encounters may occur are:

a) in the glide slope intercept area – especially if the preceding aircraft has intercepted the glide slope above the interception altitude of the following aircraft;

b) on the glide slope – especially if the aircraft flies below the ILS glide slope or if vortex rebound in altitude occurs owing to wind shear or stratification;

c) on final approach, as vortex rebound at the ground and low cross-wind conditions may transport the vortex back into the glide-path area;

d) on approach to a parallel runway system, if the wake of the preceding aircraft flying the parallel track is transported onto the aircraft track under specific cross-wind conditions.

However, the number of occurrences of wake encounters is low:

- The way in which air traffic is managed minimises the number of wake encounters (aircraft are paired as a function of their wake turbulence category whenever practically feasible).
- Type b) encounters occur much less frequently in practice than type a) encounters, since pilots are recommended not to fly below the standard glide slope, and vortex rebound in altitude is also a rare occurrence.
- In the case of type c) and d) encounters, aircraft are protected, in the most frequent atmospheric conditions, by the longitudinal wake turbulence separation distances applied at the runway threshold.

Wake encounters in the approach phase of flight are, in the vast majority of cases, not severe for the encountering aircraft for the following reasons:

- Type a) encounters nominally occur at 2,000 feet AGL or above, providing an altitude margin for recovery from a bank-angle upset.
- The encounter geometry, i.e. the relative position of the aircraft and the vortex, is such that the encounter is much more benign than the worst case mentioned above, because the aircraft fuselage is not aligned with the vortex core. In addition, the vortex may no longer be straight, thereby significantly reducing the exposure time to vortex-induced rolling moments.
- The wake strength may have decayed significantly by the time of the encounter, either through the effect of vortex instabilities or background turbulence, or owing to the interaction with the ground in the in ground effect (IGE).

In the light of these observations, the most severe in-trail wake encounters in the approach phase are likely to occur close to the ground, owing to vortex rebound in ground effect, and in calm conditions with low cross-wind favourable to long-living vortices.

2.1.2 Wake vortex encounter risk definition

The terminology “risk” associated to a certain event is actually the likelihood of this event to happen. Wake turbulence risk is therefore the likelihood for an aircraft to encounter wake turbulence during flight. In order to determine what likelihood is acceptable for wake turbulence encounter, we need first to understand what will be the effects on flight control associated to that encounter, and how often these effects can be accepted.

Depending on various factors (altitude of encounter, geometry of encounter, encounter strength, aircraft static and dynamic recovery capabilities,…), the encounter can lead to a range of effects on flight control, more or less severe, which can vary from minor upset fully recoverable, up to loss of control and accident[1]. Although research, analytical assessment and flight testing were carried out in the domain over the last years to gain knowledge on wake behaviour and encounter effect on flight control, it is still difficult to predict accurately and to determine an acceptable absolute threshold value of WV strength that can be associated to a given effect for an aircraft encounter. But we can consider that the consequences on flight control (effects), that can be observed and collected from historical return of experience, from wake turbulence encounter, also often called wake vortex encounter (WVE) hazard, are generated by a distribution of WVE strength at given location and in given conditions, which can be measured. So, if we want to define the acceptable risk of wake turbulence, one way to proceed is to assess the risk of WVE, being a distribution of frequency of actual WV strength, characterized in a reference flight scenario and conditions, which can be shown to be tolerably safe based on actual safety occurrences and frequency of effects experienced over a significant period of time, and then to compare with the likelihood (probability) distribution of WVE strength in the new situation under assessment. The WT risk assessment will focus therefore on a relative comparison of WVE risk, rather than the likelihood of aircraft recovery in case of WVE, which can be considered not to change for same solicitations.

The risk for a flying aircraft to encounter a wake of a certain strength generated by another aircraft in the vicinity, or WVE risk, will depend on the spatial and timing coincidence between the flight path trajectory and the wake transport and decay. So, we can consider that the likelihood for an aircraft to encounter wake vortex is generated by the combination of events:

a) frequency / likelihood of pairing, subject to WT separation minima;

b) frequency / likelihood for aircraft to be closely spaced or at separation minima, which leaves the least time for preceding generator aircraft wake decay and transport and maximize the WVE risk);

c) frequency / likelihood for a wake to be alive (=survival) in the flight path at the spacing;

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[1] Accident is defined as per regulation EC. 2096/2005 and EU directive 94/56/EC

2.2 WIDAO CDG project background

2.2.1 Background

This guidance document has been produced with the experience taken out of the WIDAO CDG project, formed to consider if, and under what defined circumstances, independent segregated mode operations can be performed with acceptable levels of safety using the two pairs of CSPRs at CDG. The following description of the change is provided in order to clarify the origin of the present guidelines and principles.

Paris Charles de Gaulle (CDG) airport operates four runways organised in two Closely Spaced Parallel Runway (CSPR) pairs. Typically an external runway from each pair is used for landing and an internal runway for take-off. For mainly environmental reasons, the external runways are shorter than the internal runways. The consequence of this is an offset of 600m in West operations between the two runway thresholds and of 900m in East operations (Figure 1).

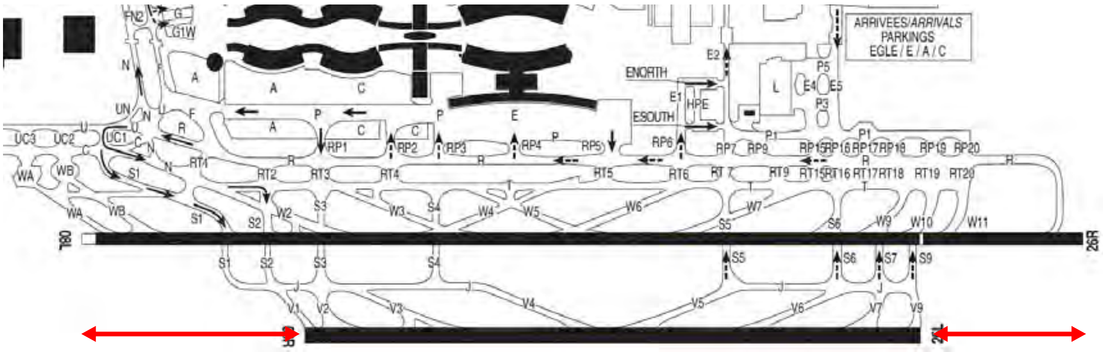

Figure 1 : Example of runway threshold offset at Paris CDG

The landing touch-down points on the external runways are therefore located down-stream of the runway threshold of the internal (departure) runway. Because wake turbulence (WT) is generated by an aircraft until it touches the ground, there is a risk of wake turbulence of a landing aircraft being transported by the wind to the departure runway. If a departing aircraft is lined-up near the runway threshold, its rotation point could be in close proximity to this turbulence (Figure 2.a). The consequence of a wake encounter in these circumstances could be for the departing aircraft to experience a sudden roll, control difficulties or structural damage, depending on the strength of the wake encountered. The associated risk can be particularly severe in such close proximity to the ground. The same kind of wake turbulence risk is also expected for landing aircraft if an aircraft is departing on the CSPR at the same time (Figure 2.b).

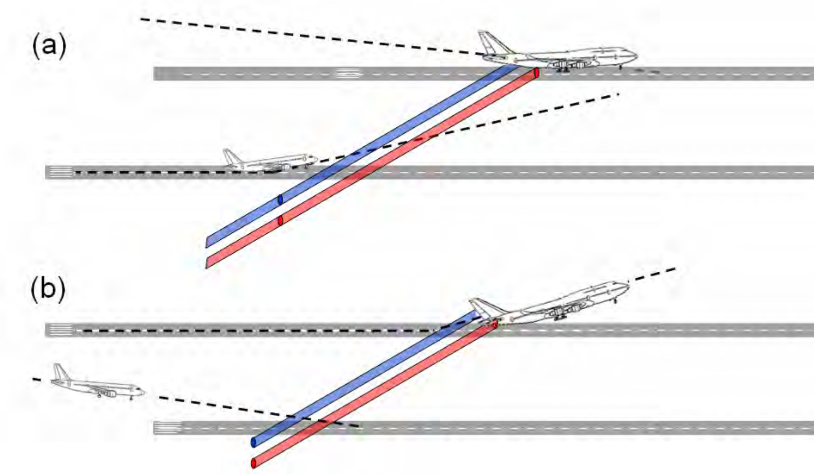

Figure 2 : Wake turbulence hazard on CSPR

The ICAO minimum runway separation recommendation (760m for independent segregated operations for non-staggered runways and even more for staggered CSPR runways like in Paris CDG Airport) is not made with direct reference to WT issues. Nonetheless, many operators (including the French air navigation service provider, DSNA), apply similar wake turbulence separations to CSPR to those that are defined for in-trail aircraft by ICAO.

In order to ensure the proper application of these wake turbulence separations, DSNA has imposed time constraints on departing aircraft lining-up at runway entry points close to the threshold, if an arriving aircraft is landing at the same time on the parallel runway. These constraints had a negative impact on departure capacity by limiting the lining-up strategy and also on taxiway congestion by imposing the use of non-constrained runway entries in close proximity to the CDG terminals.

It was suggested by DSNA that such restrictions placed on CSPR could be overly and unnecessarily conservative and that the relaxation of these constraints could have a positive impact on runway capacity. The relaxation of these constraints was expected to improve departure queue management, reduce taxiway congestion and simplify complex procedures.

In 2007, DSNA requested EUROCONTROL support to prepare a local safety case to investigate whether independent segregated mode operations on CSPR could be performed with acceptable levels of safety. The Wake-Independent Departure and Arrival Operations (WIDAO) project was started in March 2007 and an agenda was defined together with the French regulator for the progressive relaxation of constraints in 3 steps.

In 2007 and 2008, an extensive data collection campaign was conducted in order to gather the evidence required for the safety case. The EUROCONTROL LIDAR (Light Detection and Ranging) system was deployed and used for collecting more than 6,000 tracks of Heavy wake vortex and 25,000 tracks of Medium wake vortex (Figure 3).

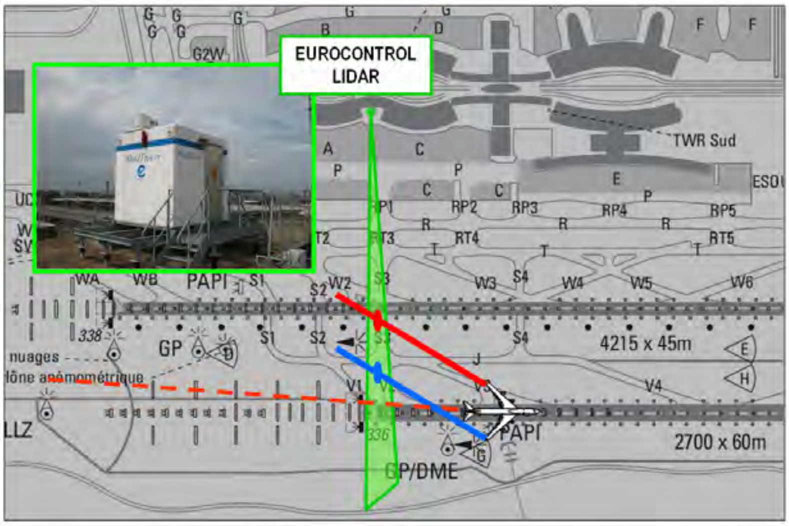

Figure 3 : - EUROCONTROL LIDAR data collection

In parallel, radar track post-processing algorithms were developed and used by DSNA to collect more than 80,000 aircraft rolling distances from ground radar and more than 75,000 landing separation distances in approach from airborne radar.

Based on the EUROCONTROL data analysis, two Preliminary Evaluations of the Impact on Safety ("*Evaluation Préliminaire d'Impact sur la Sécurité d'un Dispositif de Circulation Aérienne*", EPIS-CA) were introduced and were endorsed by the French regulator in November 2008 and April 2009. These preliminary evaluations led to the implementation of the first two steps of constraint relaxation for Medium departures (Phase 1)

Because of the range of airspace to be covered for collecting the required data for supporting the third set of constraint relaxation for Heavy departures (Phase 2), no LIDAR measurement strategy could be found. A decision was made to base the safety assessment of this third step on the use of wake vortex prediction software (WAKE 4D). 8.74 million WAKE 4D runs (Figure 4) were required for covering all Heavy aircraft departure trajectories derived from the radar data and all potential weather conditions observed by Météo France for more than 20 years at CDG. This third step will be followed by a fourth one applying the obtained results to the new runway entry that will be part of the new design of the taxiway network feeding runway 08L.

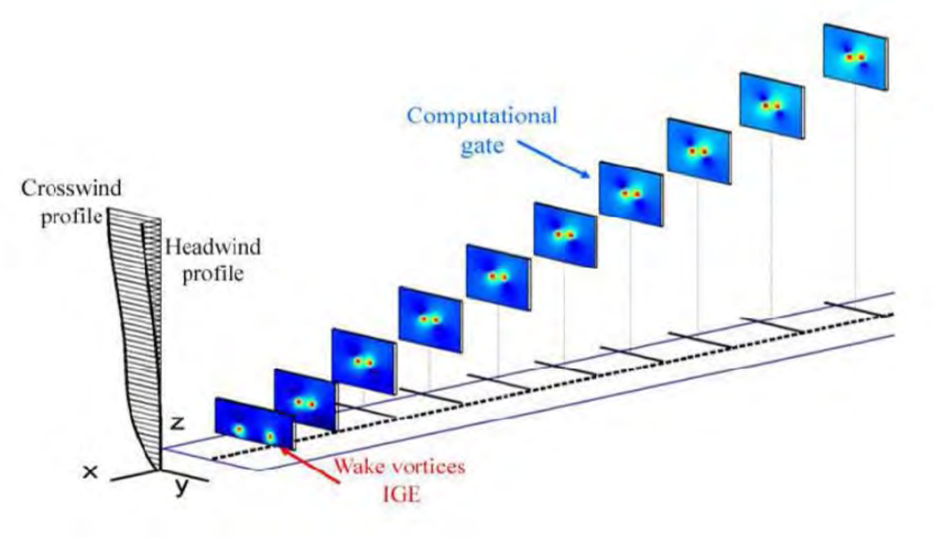

Figure 4 : - Example of a WAKE 4D simulation run

EUROCONTROL and DSNA have now completed the local safety case combining the results of this safety assessment and the details of all previous analysis conducted for the two previous improvement steps. The safety case was delivered to the French regulator in October 2010.

2.2.2 Quantitative benefits resulting from WIDAO step 1 and 2

The implementation of the first phase of the project led to following benefits:

Safety:

1. Increased take off run available (TORAs) without WT constraints
2. Increased runway length available for departures before the crossing taxiways
3. No incident reported, since November 2008, in relation with the release of constraints

Environment:

4. The benefits result from increased departure throughput on the inner runways (less holding before take off- reduced congestion close to threshold…)

Capacity:

5. The number of departure peaks on runway 08L/26R, respectively equal or superior to 42 and 40 D/h, has increased in a very significant proportion
6. Thanks to the above results, the operational departure airport capacity will be increased
7. Maintaining operational departure runway capacity during special events or when works are in progress

2.2.3 Quantitative benefits expected from WIDAO step 3 and 4

Safety:

8. Increased take off run available (TORAs) for H departures, without WT constraints
9. Increased runway length available for H departures before the crossing taxiways

Capacity/ Environment:

10. WIDAO step 4 will allow the building of the new "without WT constraints" taxiway, helping optimizing the design of the new taxiway network feeding runway 08L

2.3 Safety assessment methodology

The principles for WVE risk assessment presented in this document have been extracted from a local safety case developed by application of EUROCONTROL Safety Assessment Methodology SAM, supplemented with SAM*E* guidance [ECTL-2010].

SAM*E* provides an argument based framework for providing safety assurance for changes to the ANS / ATM System (incl. all airborne and ground-based components to allow the safe provision air navigation services) across project lifecycle phases:

- system (change) definition;
- system (change) design and validation;
- system (change) implementation;
- system (change) system transition into operation;
- system (change) system operational service.

The methodology, tools and techniques describe in this guidance material is applicable to the definition, design and validation phase of the project safety assessment lifecycle. The other phases are not covered herein as they are dependent on the local changes to ATM system and will be covered in local safety assessment.

An integral element of the SAM*E* guidance is the success and failure approach to safety assessment. For WVE safety risk assessment, the success approach – which seeks to assess the achieved level of safety in the absence of failure, when the ATM System is operated as intended – is particularly relevant as WVE constraints must be shown to be acceptably safe when they are applied in all range of normal operating conditions. The failure approach will consist in identifying the hazards and required mitigation to prevent faulted operations, i.e. wrong application of changed WT separations.

The main steps to develop a safety risk assessment are the following:

- to describe the operational context, the need for the change to ATM System and scope the assessment
- to define the safety strategy and criteria for the relevant accident types
- to identify the potential hazardous scenarios and define safety objectives and show that they are appropriate
- to show that the safety objectives are satisfied in all normal operating conditions and to identify safety requirements for mitigation of potential failures conditions
- to document the results, to develop an argument supported with direct evidence as well as backing evidence of trustworthiness of the tools, techniques and competency of people involved in the assessment

This guidance is produced to assist EUROCONTROL Stakeholders, who remain in charge of ensuring that specific safety assessment based on the approach proposed in this document will be developed in accordance with the local safety management processes and regulations.

2.4 Safety strategy

2.4.1 Overview

The key accident risk type to be assessed when changing WT separation provision is obviously WT. However, potential impact due to the change on mid-air collision (MAC) or runway collision (RC) should be considered as well but will not be addressed in this document.

Any reduction in the separation between aircraft is likely to increase the risk of wake vortex encounter (WVE). The safety strategy selected for the assessment of WVE constraints must ensure that an acceptable level of safety is maintained despite the expected increase in WVE risk.

Acceptable WVE risk can be determined using one of two criteria:

- Absolute. An absolute risk assessment requires that all wake encounters have strength below an absolute value threshold, with deterministic consequences on flight control for all aircraft and with corresponding maximum acceptable frequency of occurrence. This approach is not yet considered feasible as there is no agreed definition of acceptable severity or frequency of wake turbulence effects on aircraft in flight due to the complexity of factors influencing the outcome;
- Relative. A relative safety assessment is performed by comparing the WVE risk anticipated from implementation of the proposed change to WT separation provision to the WVE risk observed for a chosen baseline operation which is considered tolerably safe today.

2.4.2 Safety criteria

The following safety criteria, considering WVE risk only, are recommended in accordance with the safety strategy:

1. The WVE accident risk due to a modified procedure or operation must be no greater than the WVE accident risk due to an established and tolerably safe procedure or operation;
2. Safety requirements to reduce the overall risk As Far As Reasonably Practicable (AFARP) should be identified in accordance with SES CR 2096/2005 [EC-2005] and ESARR 3 [ECTL-2000].

2.5 Wake vortex encounter scenarios

A hazardous WVE scenario occurs whenever the geometry and timing for a WVE exists between two aircraft. Subsequently, the probability of encountering a wake vortex, given the correct geometry and timing, is dependent on wake vortex decay and transport which are influenced by wind speed and direction (Figure 5).

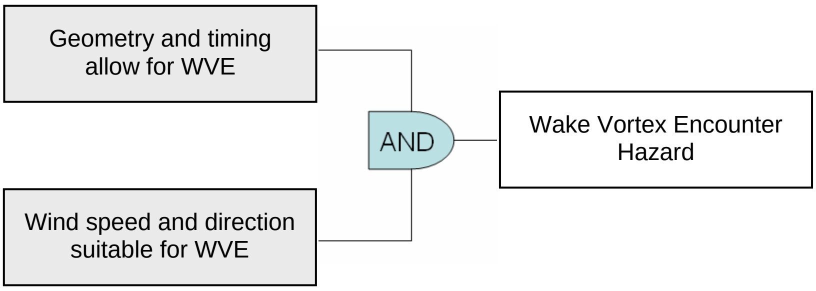

Figure 5: Logic tree leading to a WVE hazard

ICAO in-trail separation minima have been specified to reduce WVE risk to an acceptable level. A straight in approach provides the correct geometry for an encounter, however wake vortices will often be transported away from the approach corridor within the time taken for the following aircraft to cover the separation distance, or will have decayed sufficiently in that time such that any encounter is acceptably safe.

2.6 Safety objectives for WVE

Safety objectives must be defined for each hazard identified within the scope of the assessment, in order to determine the maximum acceptable frequency of occurrence of these hazards and to allow satisfaction of the safety criteria. For the purpose of this guidance material only the WT hazard will be considered: the wake vortex encounter.

If relative safety criteria have been selected, the safety objectives should be defined on a relative basis as well. The safety objectives are established by comparison with a baseline which is appropriate and relevant for the operational environment, and for which the frequency of hazards is acceptable.

Safety objectives for WVE can be defined by the maximum acceptable frequency of a WVE of a given severity as characterised by the baseline scenario.

In WIDAO this was expressed the following respectively for Phase 1 and 2:

- The frequency per movement of WVE (of a given severity) by a Medium on departure following WV generated by Heavy landing and transported from the adjacent CSPR in WIDAO must not be higher than the frequency per movement of WVE (of same severity) by a Medium landing at ICAO in-trail separation minima, as applied for Paris-CDG arrivals.
- The frequency per movement of WVE (of a given severity) by a Medium on normal/missed approach WV generated by Heavy departure and transported from the adjacent CSPR in WIDAO must not be higher than the frequency per movement of WVE (of same severity) by a Medium landing at ICAO in-trail separation minima, as applied for Paris-CDG arrivals on RWY 08R

2.7 Definition of a tolerably safe baseline

A tolerably safe baseline can be selected from on-going ATC operations of WT separation provision and for which evidence of satisfactory level of safety are available.

For example, in the WIDAO CDG safety assessment, the risk of WVE due to lateral transport of wake vortices between Closely Spaced Parallel Runways (CSPRs) was assessed relative to the risk of an in-trail WVE at ICAO WVE separation minima which are widely recognised as being tolerably safe.

To show that the selected baseline is tolerably safe, an evaluation of wake vortex encounter reports and flight data can be performed.

Below are example of questions to be considered when analysing WVE reports and flight data:

Q1: Are the WVE between different aircraft weight categories (i.e. Heavy to Medium, Medium to Medium) distributed proportionally to the traffic mix observed or are there aircraft pairs more exposed than others?

Q2: Is the frequency of WVE reporting in line with the frequency of occurrence of the most encounters derived from LIDAR and RADAR data?

Q3: Where are observed the most frequent WVE reports? This knowledge allows conducting the LIDAR measurements at the right location in order to quantify the current tolerable WT risk.

Q4: Are the WVE rates similar for all operations (e.g., all runways, all orientations,…)? This knowledge allows to generalise LIDAR measurements that can not be carried out, for example in WIDAO, at all runways threshold?

Q5: Do the most frequent WVEs (intermediate severity level) result in a particularly severe effect on the aircraft encountered?

Note that Q5 can be answered by using LIDAR data combined with radar track data to identify WVEs. Where the situation of an aircraft encountering a vortex is identified, and where an agreement with the airline involved, the flight data on the encounter can be analysed to determine the WVE characteristics (actual WT separation, altitude of WVE, weather conditions) the impact on aircraft control and the tolerability of the consequence of the flight: completing the approach or performing a go around.

2.8 WVE risk quantification

2.8.1 Risk components

As presented in Section 2.5, the frequency of WVE is obtained from the combination of the frequency of hazardous scenarios and the probability of a wake vortex of significant severity being transported to, or remaining in, the flight path of another aircraft.

WVE risk can be quantified based on the following parameters and measurements:

WVE risk = f (wake vortex strength at encounter characterised by the wake circulation metric (Γ), likelihood of this encounter with this strength (L))

with:

Γ = f(initial vortex strength (Γ_o), decay time, generation height, atmospheric conditions)

L = f(geometric separation of aircraft, temporal separation of aircraft, WV transport (which is predominantly influenced by atmospheric conditions))

where atmospheric conditions mainly refers to wind speed, wind direction and atmospheric turbulence.

The wake strength (Γ) can be used as an indicator of severity of encounter.

2.8.2 Severity metric

Theoretically, the assessment of the severity of the wake encounter should take into account the aircraft response and consequences. Following a thorough analysis of the state-of-the-art methods and tools available, the project team concluded that a sufficient validation of this sophisticated approach could not be achieved in due time.

Consequently, the criterion chosen as an indicator of wake encounter severity does not take into account the aircraft response to a wake encounter, but rather quantifies the strength of the source itself, i.e. the strength of the vortex as considered for the A380 separation design [ECTL-2008]

The criterion chosen is vortex circulation – also called vortex strength - because it represents an estimate of the maximum theoretical rolling moment experienced by an aircraft whose fuselage is located on the vortex centre and whose longitudinal axis is aligned with the vortex axis. More precisely, the working group chose the standard definition of average circulation integrated between 5 m and 15 m from the vortex core. This definition corresponds to the vortex circulation which may be most accurately estimated from LIDAR measurements or obtained from WAKE4D model simulation.

A relative risk assessment will therefore assess the risk at the point of WVE (as a function of the WV circulation strength) but will not consider the consequences of that WVE in terms of WVE accident risk.

2.9 WVE risk characterisation for the baseline

The characterisation of the safety objective amounts to assessing the WVE risk associated with the selected baseline (considered as tolerably safe). If this requires to make some assumptions (e.g., for the translation of distance based separation in time in order to analysis LIDAR data collected in an unique scanning plane), these assumptions have too ensure an underestimation of the WVE risk. The baseline being used as safety objective, this approach will ensure to be conservative in the assessment of the new concept against this baseline.

In other words, conservative assumptions should be used throughout the baseline definition to achieve risk criteria which are more restrictive than the actual risk experienced in the baseline scenario. Such assumptions will introduce a margin for error and help to mitigate uncertainty in the results of the assessment.

2.9.1 Frequency of the hazardous scenario

To calculate the frequency of the hazardous scenario, the conditions for a WVE must be identified. The frequency of the hazardous scenario is a function of the relative 4D positions of a given pair.

At CDG the WVE risk baseline was characterised from an analysis of in-trail encounters[2]. The conditions for an in-trail WVE scenario are:

a. The wake categories of the lead and following aircraft are such that the WVE poses a hazard to the encountering aircraft (e.g. the wake formed by a Heavy generator poses a hazard to a Medium aircraft).

b. The aircraft are flying at, or close to, the ICAO separation minima for the pair.

The frequency of the hazardous scenario is thus derived from the frequency at which wake category pairs are observed (e.g. a heavy leader and a medium

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[2] Analysis of in-trail WVE risk as a baseline has been provided for example only. Any operation which can be justified as tolerably safe with regard to WVE risk can form a suitable baseline.

follower) – condition (a) – combined with the probability of having each pair sequenced at minimum ICAO separation – condition (b).

This data can be obtained using an airborne radar survey of landing separations at CDG over a representative period of time. Condition (a) is quantified by calculating the number of specific pairs (e.g. Heavy to Medium) as a percentage of total operations.

Condition (b) is quantified by analysing the separation distance between the specific pairs. In the CDG analysis only the lowest 5% of pairs (per WT category pair) at minimum ICAO separation are considered as potentially affected by wake turbulence. This assumption is conservative as it implicitly implies that all other pair separations are not affected by wakes. This leads to an underestimate of the acceptable WVE risk and consequently to a definition of a more constraining safety objective for the subsequent relative safety assessment.

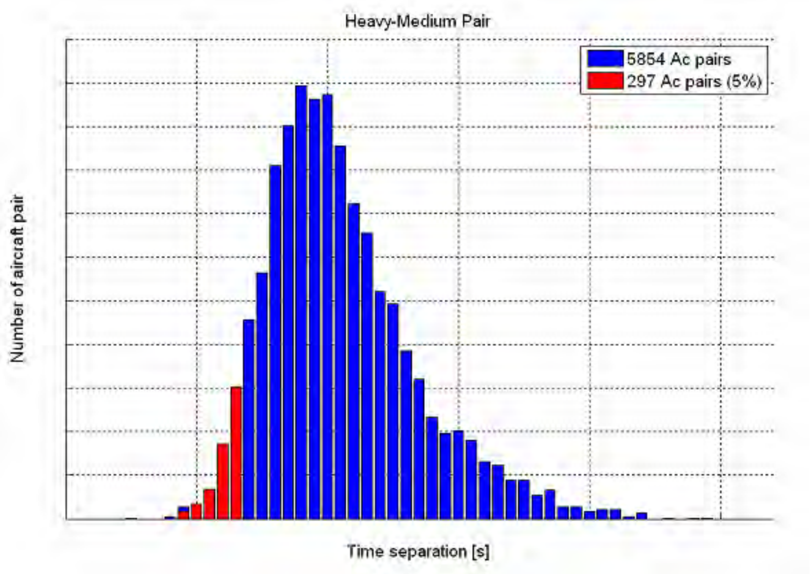


Figure 6: Example of acceptably safe minimum time separation ranges

2.9.2 Likelihood of WV transport / decay

The probability of a wake remaining in the flight path of the following aircraft is a function of the wake decay and transport.

Light Detection and Ranging (LIDAR) equipment can be used to determine the position and strength of vortices. The LIDAR regularly scans the flow field in a fixed plane perpendicular to the direction the generating aircraft. This enables vortices to be tracked over time.

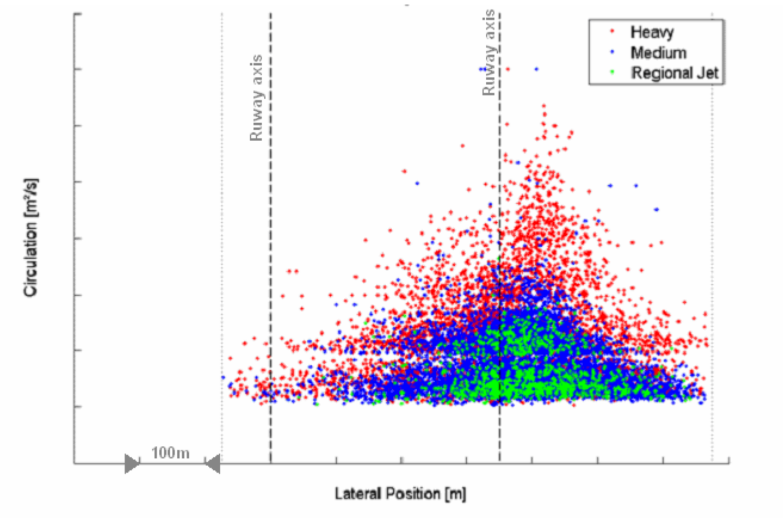


Figure 7: Example LIDAR Dataset

Analysis of LIDAR data can provide the probability of a wake remaining in the runway short final segment corridor (+/- 30 m from axis) at a time which corresponds to the minimum separation spacing distance observed in the airborne radar survey data.

However, the probability of a wake remaining in the corridor does not provide any vortex strength information. A log-linear probability vs. severity plot can be produced from the LIDAR data to indicate the probability of a wake greater than a certain strength remaining in the runway axis over a period of time.

2.9.3 Baseline frequency vs. severity curve

A frequency vs. severity curve characterising the baseline WVE risk per movement can be derived by combining the frequency of the hazardous scenario calculated from operational data with the wake probability vs. severity plot derived from LIDAR data.

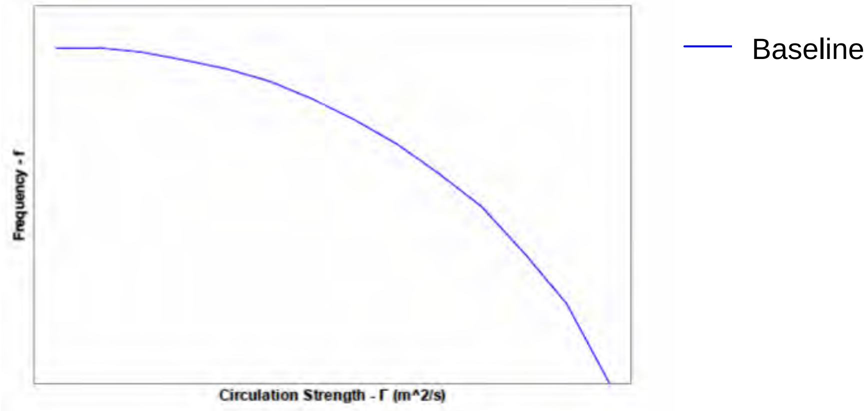


Figure 8: Schematic Example of Log Vortex Frequency (f) vs. Circulation Strength (Γ) Baseline Plot (Log-Linear plot)

The baseline curve represents the cumulative distribution of maximum tolerable frequency of WVEs for each severity. It is a quantification of the safety objective.

2.10 Safety objectives are satisfied for reference scenario in normal conditions

In order to demonstrate that the proposed changed ConOps is acceptably safe in terms of WVE risk, it must be shown that the expected frequency and severity of WVE following implementation can meet the safety criteria.

When quantifying the WVE risk for the proposed ConOps, assumptions should be made which overestimate the expected risk. The purpose of this, as for the restrictive assumptions which underestimate the risk for the baseline, is to increase the margin of error and mitigate uncertainty in the assessment.

2.10.1 Frequency of the hazardous scenario

As for the baseline scenario, the conditions for a WVE hazardous scenario following implementation of the ConOps must be identified.

If we consider the hazardous scenario to be wake transport from a departure runway to a closely spaced parallel arrival runway, the conditions for a hazardous scenario would be:

a. The touchdown point of the departure and the rotation point of the arrival must be located in such a way that the departure wake can perturb the arrival.
b. The timing of the arrival and the departure must be such as to allow the wake to perturb the arrival.

For the CSPR example, a hazardous scenario exists when the departure aircraft rotates before the arrival touch down point on the parallel runway (Figure 2). To calculate the frequency with which condition (a) is fulfilled:

- departure rolling distance and arrival touchdown data are required;
- the product of the total number of departures and the total number of arrivals gives the total number of scenarios;
- the frequency of hazardous scenarios is derived from the ratio of scenarios in which the departure rotates before the arrival touchdown point to the total number of scenarios.

In order to quantify the frequency with which condition (b) is fulfilled:

- aircraft departure time data are required;
- the number of departures and the number of arrivals per hour needs to be determined;
- the maximum duration of the WVE risk on the CSPR can be calculated from analysis of wake turbulence transport to the CSPR. The duration of the WVE risk is dependent on the time taken for the vortices to cross the runway corridor. In order to be conservative it is necessary to

identify the longest time the wake will remain in the corridor. This time will correspond to a ‘worst case’ minimum lateral wake transport velocity sufficient to transport the wake to the CSPR;

- a conservative estimate of the time for which an arrival could potentially be perturbed by a wake generated on the CSPR is needed;
- the temporal probability of hazardous timing is a product of the fraction of an hour for which the WVE risk is present on the arrival runway and the fraction of an hour for which an arrival is exposed to the WVE risk;
- the WVE risk should be over estimated by selecting a high percentile value of all observed probabilities from the operational survey. This should correspond to periods of high simultaneous departure and arrival operations.

- This probability of simultaneous arrival and departure operation can also be computed per movement by comparing all departure and landing times over 8 months of operations. In WIDAO, this approach led to more favourable relative difference to the baseline, and can be used as consistency check.

By combining the frequency of hazardous geometry – (condition (a) – with the probability of hazardous timing (condition (b)) – the frequency of hazardous scenarios can be derived.

2.10.2 Probability of WV transport / decay

The method for determining the probability of wake transport and decay is the same as that described for the in-trail baseline, although for the CSPR example the runway axis of interest is shifted to the CSPR.

At CDG the aim of the assessment was to enable wake independent operations on the CSPR. Therefore, the probability of WVE transport to the CSPR was calculated based upon all wakes which reached the CSPR. There was no filtering of the transported wakes based upon time since generation as an aircraft may fly through the wake at any time if operating independently.

2.10.3 Test frequency vs. severity curve

Similarly to the baseline data, a log-linear frequency vs. severity can be produced for the proposed operation through a combination of operational, LIDAR and meteorological data.

If it can be shown that the frequency and severity of WVE for the proposed ConOps forms a frequency vs. severity curve which does not exceed the baseline curve at any point then the relative criteria will have been met.

However, if the test curve crosses the baseline curve then there exists an encounter scenario which has not been experienced in the tolerably safe operation. This would result in an increase in overall WVE risk per movement and therefore would not satisfy the relative safety criteria. A decision must be made whether to mitigate the risk, to justify the results or to not accept the increase in risk.

2.10.4 Risk ratio

Using the aggregated WVE frequencies determined for the baseline and for pre and post implementation operations the relative WVE risk ratio or risk factor can be found.

- The post implementation to baseline risk factor must be ≤ 1 to meet the safety criteria.
- The post implementation to pre implementation risk ratio will be > 1 if the risk of WVE increases following implementation of the ConOps.

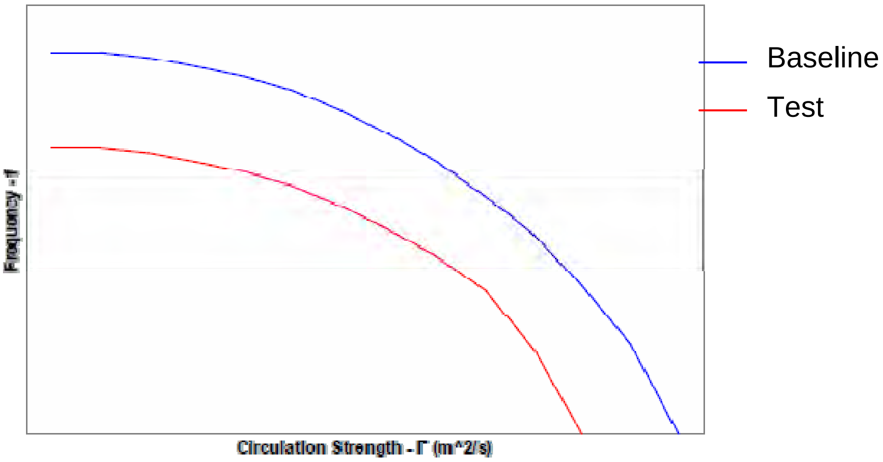


Figure 9: Schematic Example of Comparison of In-Trail Plot with CSPR Transport Plot (Log-Linear plot)

2.11 Generalisation to all scenarios and cases

The aircraft, wake and weather data collection, analysis and assessment results for reference scenario at one specific location and in given conditions must be shown to be valid and representative to assess all scenarios and in all conditions within the scope of assessment.

Given the expense of LIDAR equipment and the difficulty of locating it in the best position to obtain usable data it is may be impractical to use primary LIDAR derived wake data to support quantification of frequency vs. severity for each runway threshold at the subject airport. It may therefore be necessary to generalise the results obtained at one location to other locations, for example for runway operations in the opposite direction.

A qualitative and a quantitative approach can be used to establish whether the results obtained at the wake survey location are transferrable to other locations.

2.11.1 Qualitative

An analysis of crosswind and headwind components from the meteorological data may show that the conditions for wake transport, considering the geometry required for a WVE, occur less frequently than the conditions observed at the survey location.

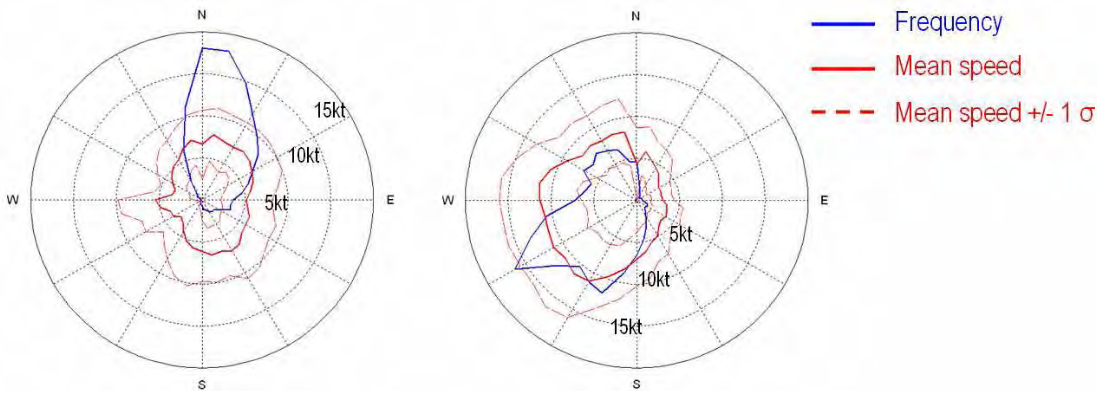
The wind can be characterised in terms of:

- the probability of a crosswind component;
- the probability of a head wind component.

To satisfy the argument, analysis of meteorological data must show that the probability of the wind component required for WVE at the secondary location is lower than that at the survey location.

If we consider a CSPR operation for example, the probability of a cross wind component required for wake transport must be less at the new location than observed at the survey location to satisfy a qualitative argument. Additionally, a headwind could potentially transport the WVE away from the region in which the aircraft on the parallel runway is susceptible to a WVE, thereby demonstrating a further potential reduction in risk.

The wind rose examples from CDG show the difference in the wind components in east and west operations.



East Ops

West Ops

Figure 10: Comparison of wind conditions in east and west operations at CDG

2.11.2 Quantitative

The results obtained from the qualitative approach to generalisation will be a good indicator as to whether the survey results can successfully be used for other locations or runway directions, however such analysis may not be sufficient to satisfy the regulator. If an initial qualitative analysis suggests the survey data can be used then a quantitative analysis should follow.

2.11.2.1 *Using derived statistical model based on locally collected data*

A combination of LIDAR and MET data obtained at one location can be used to derive a model of wake transport and decay for all combinations of head and crosswind speeds. By using this model together with the wind distribution observed for the secondary location it is possible to quantify the probability of WVE transport for an encounter scenario.

The following process can be used to create a statistical generalisation model for the frequency of WVE transport:

- it must first be verified that the wake measurements collected are sufficient to characterise wake transport in a broad range of head and crosswind conditions. A statistically significant number of wake measurements in each of the typically experienced head and cross wind conditions should be demonstrated;
- using LIDAR and MET data, the probability of wake transport over a specified distance (within the LIDAR plane) can be quantified for all observed combinations of head and cross winds;
- anemometer wind data for the secondary location must be collected and assessed to derive:
    - The wind conditions observed;
    - The frequencies with which each combination of head and crosswind are observed (for the runway operating direction being considered);
- by multiplying the frequency with which one head and crosswind combination is observed by the probability of wake transport under these wind conditions the frequency of wake transport at the secondary location can be quantified;
- the frequency of WVE transport should be less at the secondary location than at the original survey location. If the frequency of transport is higher in the generalised scenario then there is insufficient original data to validate the result.

The same modelling approach can be used for the relative assessment of the severity of transported wake turbulence in all head and cross wind conditions. Similarly, the mean strength of the wake turbulence transported must be lower in the generalised case to ensure validity.

2.11.2.2 *Using physical WV modelling using a validated model*

Real-time tools have been developed to predict wake vortex transport and decay. Deterministic wake Vortex Model (DVM) software integrates, in time, various physical models so as to forecast the transport and decay of wake vortices generated by a given aircraft in given meteorological conditions.

Similar to LIDAR, the modelling tool produces results in one computational gate which are equivalent to slices of space along the flight path.

Real aircraft characteristics, RADAR trajectories, touch down point and rotation points were used as inputs to simulation producing data that can be used to derive:

- the wake transport probabilities for all locations, taking into account the respective runway configuration and wind conditions;
- the probability vs. severity curve characterising the transported wake for all locations, taking into account the respective runway configuration and wind conditions.

The use of a wake model must be justified and verified against existing data to determine whether the expected results will be appropriate. However, if results cannot be obtained from LIDAR data then wake modelling offers a possible alternative.

2.12 Safety objectives are satisfied in abnormal conditions (robustness)

2.12.1 Traffic evolution

Airport traffic density may increase following the WVE assessment. In order to be conservative and robust against traffic evolution the WVE risk assessment should consider hazardous scenarios corresponding to the highest density of traffic to demonstrate that the risk is acceptable at a consistently high traffic density under current conditions.

If traffic evolution leads to, for example, a doubling of these densities, the conclusions of the study can be re-assessed and the WVE risk curves obtained recalculated accordingly. If we assume that the increase of traffic pressure would also lead to double the probability of a WVE scenario in the baseline operation, the baseline WVE risk curves could also be recalculated.

Assuming that an increase in the number of pairs at minimum ICAO separation would define a new safety objective, a new comparison of the risk in post-implementation operations can be conducted.

This leads to the conclusion that, as long as baseline operations remain tolerably safe despite a potential increase of traffic density, and as long as the traffic densities for the baseline scenarios and the implemented ConOps are of a similar ratio similar following the traffic increase, the analysis should remain valid.

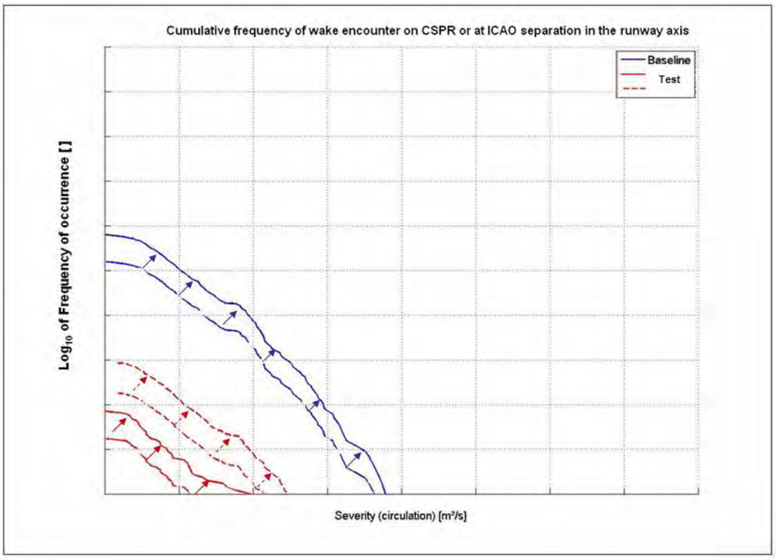


Figure 11: Comparison of the WVE risk in the event of an increased traffic environment

2.12.2 MET conditions

It must be shown that the results of the WVE assessment are robust to changes in MET conditions. Wake measurements should be recorded over a significant period of time, preferably at least one year, to demonstrate that data spanning the typical local operating conditions has been captured.

A comparison of the meteorological conditions for the survey period against historical data should be performed to determine whether the wind speeds and direction experienced, and frequencies thereof, are representative of typical conditions in the longer term.

Note: The meteorological conditions which are suitable for wake transport and longevity are generally not the extremes of wind speed and are frequently observed over a year. Wakes often remain in, or are transported to, the flight path of another aircraft in low to moderate winds.

2.13 Mitigation of failure conditions

After validating that the safety objectives can be satisfied in normal operating conditions and in abnormal environmental conditions (both ‘fault-free’ operations) it must be ensured that the objectives will continue to be met in the failure conditions (‘faulted’ operations).

The main steps of a SAM compliant Preliminary System Safety Assessment (PSSA) process are:

- identification of the causes of each hazard on a logical basis;
- selection of a risk mitigation strategy to apportion the safety objective between the various causes of hazards and to define the maximum acceptable frequency of occurrence for these causes;
- determination of safety requirements according to the risk mitigation strategy applied to ensure that the safety objectives are met.

A possible risk mitigation strategy may consist of controlling the frequency of causal factors to WVE events in fault-free operations to ensure they do not occur more often in time, which would invalidate the results, and that the risk contribution of failure conditions and faulted operations remains at an acceptable level.

Safety requirements must therefore be formulated to ensure that key operational assumptions remain valid in time and to control the frequency of hazard causes. Monitoring of all fault-free and failure events is important to ensure that the safety requirements are met in service.

It can be recommended that systematic checklist is produced and referenced regularly to facilitate identification of the impact of changes to the operational environment and to ensure that the safety requirements are being met.

3. WAKE RELATED TOOLS

3.1 LIDAR

LIDAR is a technique which uses a pulsed laser to determine distance to an object, from the delay time from pulse transmission to detection of back-scattered laser light, and the relative speed of the object, from the Doppler shift of the back-scattered laser light [LMCT-2003, LMCT-2006, LMCT-2009].

LIDAR can be used to determine the position and strength of an aircraft's wake vortex by detecting the scattered laser light from particulate objects (such as soot and water droplets) observed in the wake vortex. The LIDAR beam scans the aircraft's wake about once every five seconds. Analysis software is used to convert the raw signals obtained into wake-vortex transport and decay curves. The spatial resolution of LIDAR is sufficient to track both the port and starboard vortex transport and decay signatures separately.

LIDAR measurements of wake vortices from aircraft in flight are the only practical approach to measurements of wake vortices from real aircraft. LIDAR has been successfully used and provided evidence for safety cases supporting:

- the design of the A380 wake vortex separation – ICAO State Letter TEC/OPS/SEP – 08-0294.SLG;
- the National Rule Change (NRC) 1.5-Nautical Mile Dependent Approaches to Parallel Runways Spaced Less Than 2,500 Feet – FAA ORDER JO 7110.308;
- the Simultaneous Offset Instrument Approach (SOIA) – FAA ORDER 8260.49A;

3.2 Wake vortex simulation

For the CDG assessment wake models developed by Université Catholique de Louvain (UCL) were used. The UCL has developed real-time tools to predict wake vortex transport and decay. The Deterministic wake Vortex Model (DVM) software, based on the Method of Discrete Vortices integrates, in real time, various physical models so as to forecast, also in real time, the transport and decay of the wake vortices in one computational gate generated by a given aircraft in given meteorological conditions.

Because probabilistic modelling and assessment of wake vortices is what is often operationally required, an upper software layer was also developed by UCL: the Probabilistic wake Vortex Model (PVM) software. It is based on a Monte-Carlo approach, using the DVM as a subtool. For each probabilistic run, several deterministic runs are computed, with variations on the impact parameters (i.e., meteorological conditions, aircraft characteristics and physical model coefficients). A statistical analysis (e.g., PDF, mean, variance, confidence envelopes) is then performed on the deterministic result samples.

UCL has also developed a “3-D space + time” (thus 4-D) wake vortex prediction platform software, called WAKE4D, which provides even more operational or modelling capabilities. It uses as its input the whole “situation": the vertical weather profiles as well as the aircraft trajectories (time-varying position and speed), the multiple gates, etc. It can be used either in deterministic mode (thus using deterministic simulations of wake transport and decay in each gate, with the DVM) or in probabilistic mode (thus using Monte-Carlo simulations and probabilistic assessment of wake transport and decay in each gate, with the PVM).

The models used in the UCL tools have been calibrated and validated against various LIDAR databases and are now considered as state-of-the-art for wake vortex modelling [UCL-2010].

Note however that other wake vortex models may be available. It is important that any wake vortex model is validated against measurements before being applied to the safety assessment.

3.3 Operational data collection

Primary input data can be collected using information provided by airborne and ground radar. Data such as rolling distances, approach separation, go-around, climb angles, runway entry used, aircraft types and categories can be identified after post-treatment of raw radar data.

A supporting tool for the visual touchdown point and rolling distance survey was developed by the DSNA-DTI for the CDG analysis. The collected data were used for the validation of the radar data post-treatment algorithm.

3.4 Meteorological data collection

When considering an airport surface MET data should be considered at each of the locations that are being safety assessed. Buildings on the airport surface can create turbulence which can affect the transport and decay of vortices. Anemometers close to each assessment location can provide specific wind speed and direction measurements.

Additional MET data, particularly historic data, may be provided by a national meteorological organisation.

4. ASSUMPTIONS AND LIMITATIONS

4.1 Assumptions

The following assumptions regarding wake vortex behaviour were made for the safety assessment at CDG and may be relevant for other WVE assessments.

- ICAO in-trail heavy aircraft preceding medium aircraft and medium aircraft preceding medium aircraft - ICAO wake turbulence separation minima are tolerably safe.

- Significant vortices are produced only when the generating aircraft is airborne (rotation to touchdown).

- A WVE is not significant if the encountering aircraft is not airborne (i.e. even Light aircraft on the ground will not be significantly affected by wake turbulence).

- WV strength less than that corresponding to “normal” atmospheric (Γ ~ 75 to 100 m^2/s) turbulence is acceptable.

- A WV generated by a lighter ICAO weight category aircraft cannot significantly impact an encountering aircraft in a heavier weight category under fault-free operations (so a WV from a medium aircraft has an insignificant impact on a heavy aircraft in-trail at (current) minimum radar separation).

- For a given WV strength, a WVE due to a vortex pair generated by a heavy aircraft is not more severe than a WVE due to a vortex pair generated by a medium aircraft (i.e. the WVE from a WV of 150 m^2/s generated by a heavy aircraft is not more severe than the WVE from a WV of 150 m^2/s generated by a medium aircraft).

- A given WVE is less significant on departure than on approach. Two reasons have been identified for this: a departing aircraft is correctly configured and powered for climb, whereas an approaching aircraft may be slower and will need to be re-configured to perform a missed approach; moreover, a departing aircraft will be in the correct geometrical relationship to an arrival only for a very short time for a WVE to occur, whereas an arriving aircraft flies “low and slow” for longer.

- If the LIDAR can no longer track a WV it is assumed that this is because its circulation strength is reduced below 100 m^2/s.

4.2 Limitations

The following limitations should be considered when performing a WVE safety assessment.

- Wake data may not be transferred between airports or over significant distances without significant review and analysis because, for example, data on airport geometry, meteorological conditions and traffic mix are unlikely to be similar.

- There may not be sufficient wake data for the analysis of ‘extreme’ types of aircraft such as ‘super-heavy’ aircraft or light aircraft. Great care and consideration should be taken if an attempt is made to justify the modification of wake constraints for these types of aircraft.

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