



WakeNet3-Europe
Grant Agreement No.: ACS7-GA-2008-213462

Deliverable D-2.03

Coordination Area Safety Report 3

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Work Package:2
Dissemination level:PU
Version:v1
Issued by:NLR
Reference:D-2.03
Date:3 September 2012
Number of pages:44

Project acronym: WakeNet3-Europe
Project full title: European Coordination Action for Aircraft Wake Turbulence
Project coordinator: Airbus Operations S.A.S
Beneficiaries:

A-F	Airbus Operations S.A.S
TR6	Thales Air Systems
THAv	Thales Aerospace
DLR	Deutsches Zentrum für Luft- und Raumfahrt
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
DFS	DFS Deutsche Flugsicherung GmbH
ONERA	Office National d'Etudes et Recherches Aéronautiques
NERL	NATS En-Route Plc.
UCL	Université catholique de Louvain
TUB	Technische Universität Berlin
ECA	European Cockpit Association
TU-BS	Technische Universität Braunschweig
A-D	Airbus Operations GmbH

Document Revisions

Version	Date	Modified page(s)	Modified section(s)	Comments
1.0	03-09-2012			Version 1.0

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Executive Summary

The Coordination Action WakeNet3-Europe promotes multidisciplinary exchange between scientific and operational specialists in the field of wake vortex turbulence. The WakeNet Coordination Area Safety is a Working Group of WakeNet3-Europe, established by three partners of WakeNet3-Europe: NLR, Airbus, and DFS. The main objective is to close the gap between end-users and equipment manufacturers and the regulatory authorities in defining a consistent set of safety requirements and safety assessment procedures that are acceptable for the authorities to serve as a baseline for the operational approval of actual new systems or procedures. To reach this main objective, three separate tasks are ongoing:

- 1) Creation of a common understanding on the applicable rules, regulations, and associated safety requirements, for *operators, service providers, manufacturers, end-users (e.g. pilots and air traffic controllers)*. This task deals with the fundamental issue of what is acceptable for *regulatory authorities* to serve as baseline for the operational approval of new wake vortex advisory systems or procedures.
- 2) Promotion of information exchange and communication between partners, participants and stakeholders on requirements, development, definition, validation of:
 - 1) *wake vortex encounter severity criteria* and 2) *safety assessment methods*
- 3) Promotion of European WV incident monitoring and analysis by 1) establishing and maintaining a link to existing wake turbulence incident reporting activities, 2) implementing Wake Vortex reporting and analysis at Frankfurt airport, and 3) trigger WV incident monitoring and analysis at other airports.

This document provides a state-of-the-art in Wake Vortex Safety in the following areas:

1. *Applicable wake vortex regulations and safety requirements.* ICAO Annex 14, by referring to the ICAO PANS-ATM, mentions wake vortex standards. The PANS-ATM provides guidance on the standards for wake vortex separation minima, but it should be noted that these minima are not a binding requirement. The operational procedures and AIP defining separations applied by ANSP at national level and approved by the CAA (Regulatory Authority) are based on ICAO PANS-ATM [3]. In principle these procedures and separations are then also binding for operations in that national state. ICAO Doc 9426 gives a very high-level set of (prescriptive) requirements for the introduction of wake vortex advisory systems, whereas ESARR4 provides the basic ATM safety requirements for an (analytical) approach to derive - using guidance material and safety assessment methods - specific safety requirements for the humans, procedures, and subsystems involved. However, in view of the recent transfer of responsibility for the certification and approval of ATM systems to EASA and the ongoing development of the Implementing Rules to be completed by 2013 [6], it is likely that detailed Acceptable Means of Compliance (AMC) for new ATM concepts and systems for wake vortex avoidance (as are being developed in SESAR) will not be available in the next few years. In addition to the ESARR 4 Risk Assessment and Mitigation [9], applicable to the EUROCONTROL Member States and for which AMC are existing and used, the EU Members States must comply with a set of EC safety regulations, including EC 2096/2005 with respect to which the ANSPs have been certified.
2. *Wake vortex safety assessment.* Several simulation models that support the assessment of the actual wake vortex risk level of flight procedures have been identified. The simulation models that support wake vortex safety assessment have some generic resemblance, but at the same time they differ essentially at the level of sub-models employed and the calculation processes used. A comparison and validation of sub-models used within different methods is likely to reveal several differences at sub-model level. Therefore, it is recommended to direct efforts into a comparison of the available models and validation of the employed sub-models. This would provide an indication which simplifications would be allowable, and where the models would be sensitive to the modelling structure and parameters. This will give an indication of the level of differences between models and will help to identify required accuracies of sub-models to equalize differences to an acceptable level.
3. *Wake vortex incident and accident monitoring and analysis.* Within Europe, so far only in the U.K. a well structured incident reporting and analysis scheme has been applied to adapt wake turbulence separations according to objective local safety needs. As part of WakeNet, it is foreseen to use these well-known current best practices as a starting point for a wake incident reporting for Frankfurt airport. CREDOS provides recommendations for a Wake Vortex Safety Management System for Air Navigation Service Providers with respect to safety policy; safety achievement; safety assurance; and safety promotion. This includes details for wake vortex safety data collection, data processing and statistical treatment of data to be processed and used as part of a WV safety management system.

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1. Introduction

1.1. Background

The Coordination Action WakeNet3-Europe promotes multidisciplinary exchange between scientific and operational specialists in the field of wake vortex turbulence. It enables the development of a shared view on how to address capacity-related issues caused by wake turbulence. It was established to continue the Thematic Networks WakeNet and WakeNet2-Europe. The main access to information is provided via the WakeNet3 website (<http://wakenet.eu>), which provides information about the various activities undertaken by the different partners and through WakeNet3 workshops, which allow WakeNet3 partners to present their work, meet other experts and promote discussion. These workshops also invite partners from other networks working on wake vortex turbulence, including outside Europe, or also to communicate to ATM experts with an operational or regulatory concern. The WakeNet Coordination Area Safety is a Working Group of WakeNet3-Europe, established by three partners of WakeNet3-Europe: NLR, Airbus, and DFS.

1.2. Objectives

The main objective of the WakeNet3-Europe Coordination Area Safety is:

To close the gap between end-users and equipment manufacturers and the regulatory authorities in defining a consistent set safety requirements and safety assessment procedures that are acceptable for the authorities to serve as a baseline for the operational approval of actual new systems or procedures.

1.3. Approach

To reach the main objective, three separate tasks have been defined

1. Creation of a common understanding on the applicable rules, regulations, and associated safety requirements, for *operators, service providers, manufacturers, end-users*. This task deals with the fundamental issue of what is acceptable for *regulatory authorities* to serve as baseline for the operational approval of new wake vortex advisory systems or procedures.
2. Promotion of information exchange and communication between partners, participants and stakeholders on requirements, development, definition, validation of:
 - 1) *wake vortex encounter severity criteria* and 2) *safety assessment methods*
3. Promotion of European WV incident monitoring and analysis by 1) establishing and maintaining a link to existing wake turbulence incident reporting activities, 2) implementing WV reporting and analysis at Frankfurt airport, and 3) trigger WV incident monitoring and analysis at other airports.

1.4. Structure of the report

This report addresses the work that was done between April, 1st 2008 and December, 31st 2010. As the initial focus is the establishment of the state-of-the-art in Wake Vortex Safety, it is structured as follows:

- Section 2 presents the current status of wake vortex regulation and safety requirements;
- Section 3 presents the current status of wake vortex safety assessment;
- Section 4 presents the current status of incident and accident monitoring and analysis
- Section 5 provides intermediate conclusions and recommendations for the next period;
- Section 6 provides the references.

The Appendix A provides a summary of the specific workshop on “Wake vortex regulation and safety requirements”, organized by NLR at NLR-Amsterdam on 17 November 2010. The Appendix B provides a summary of the specific workshop on “Incident monitoring and accident analysis”, organized by DFS in NLR-Amsterdam on 18 November 2010. A specific workshop on “Wake Vortex Encounter Severity Criteria” has been organized by DLR and Airbus at DLR Braunschweig, on 7 February 2012.

2. Regulation and safety requirements

2.1. Introduction

It is important to close the gap between end-users and equipment manufacturers and the regulatory authorities in defining a consistent set of safety requirements and safety assessment procedures that are acceptable for the authorities to serve as a baseline for the approval of new wake vortex systems and/or procedures. This deals with the fundamental issue of what is acceptable for regulatory authorities to serve as baseline for their operational approval. This chapter therefore discusses a number of issues related to the regulatory framework pertaining to wake vortex separation minima, and in particular the steps required to introduce new systems and procedures that would allow reductions of separation minima. In this context it has to be first established what is actually meant with the term “regulatory framework”. A short description is given of the main organisations involved in regulation and their responsibilities. Subsequently the actual regulatory framework (standards and recommended practices) relevant to wake vortex separation minima and related safety requirements are described. Further the mechanisms of approval or certification of new systems or procedures, particular in the wake vortex area, are elucidated.

2.2. Overview of the current status

General definitions

In general a regulatory framework in the area of aviation has the following functions:

- To set the minimum admission standards for entry into the aviation system;
- To define the responsibilities of all the participants within the civil aviation system;
- To provide effective sanctions for non-compliance with safety rules;

The main functions of a civil aviation regulator are:

- Rulemaking; i.e. to provide standards for the different sectors of the civil aviation system;
- Certification, approval and licensing; i.e. to perform entry control by means of licensing, approving or certificating new entrants into the system;
- Oversight and enforcement; i.e. to perform functional supervision by means of surveillance, support and corrective actions;

Based on these definitions it is shortly addressed how the regulatory framework and the responsible authorities are organised, globally, and on a European and national scale as well, with particular emphasis on Air Navigation Service provision.

On a global scale, the regulatory framework has been established by ICAO. Within Europe EUROCONTROL (comprising today 38 states) previously assumed responsibility with respect to safety related rulemaking and publications of standards on European Level for the domains of ANS and ATM (ground part and some airborne elements). This responsibility has been shifted by the EC by end of 2012 to EASA [6]. The aviation regulatory framework therefore clearly has its roots in international rulemaking. However, the main regulatory functions so far are still the responsibility of the *national authorities*. For this reason the introduction of any new system or procedure in a certain country needs approval at national level. This means that any country can decide which interpretation of the international standards and practices are acceptable. Also the acceptable means to show compliance are agreed on a national level. This is specifically true in the area of ANS and ATM. In other areas of the aviation system, such as airworthiness, operations and maintenance, international harmonisation of rules and standardisation of approval processes has largely been accomplished within (first) JAA and (now formally) within EASA.

ICAO

ICAO was established in 1944 with the signing of the Convention on International Civil Aviation in Chicago. Today ICAO has 185 contracting States, including all European states. Usually it is the civil aviation authority that represents the State in ICAO. The Convention and its 18 technical Annexes are comparable to international law. The Convention and the Annexes can be considered multi-lateral agreements between States, essential for the regulation of international aviation. It is a contract between

States, and that is why the 185 member States are called contracting States in the ICAO vocabulary. The Annexes contain international Standards and Recommended Practices (SARPs). States implement the Standards, and endeavor to implement the Recommended Practices in their national legislation and regulations. In practice there are instances in which states may deviate from the Standards for particular reasons. In such cases the state has to inform ICAO of such deviations by means of a formal Notification of Difference. There is no requirement to inform ICAO concerning deviations from Recommended Practices. In general, the ICAO regulatory framework is considered as a set of minimum requirements to be implemented in each State. However, there are areas, where developed States may be expected to go above the minimum ICAO requirements. Despite the fact that the global regulatory framework is established by ICAO, ICAO can not be regarded as a global civil aviation authority. This is because ICAO is functioning primarily at the rulemaking level. It is not responsible for either certification/approval or for supervision/enforcements. These functions are strictly the competence of national aviation authorities. The consequence of this is that it may lead different interpretations of the regulations, and to varying methods and processes for approval and certification at national level.

EUROCONTROL

In 1998 EUROCONTROL established a Safety Regulation Commission (SRC), which main objective is to harmonise ATM safety regulation and safety initiatives within the EUROCONTROL Member States. The formal rulemaking function, i.e. the taking of decisions that bind EUROCONTROL's Member States is the preserve of EUROCONTROL's Permanent Commission. The harmonised framework for ATM safety regulation is currently embodied in the EUROCONTROL Safety Regulatory Requirements (ESARR). According to the "Single European Sky" regulations, these ESARRs are to be progressively translated into the European Commission (EC) legislation. The concern with EUROCONTROL's function is that it suffers to a certain extent from a similar drawback as ICAO. EUROCONTROL is not a regulator which is directly able to transfer rules into binding legislation. It needs the adoption of rules into national or Community legislation to make them binding. Also it does not have the authority within Europe to certify or approve systems and to supervise and -if required- enforce the implementation of the regulations. It is still the national authority that has this competence. As a result differences exist in the implementation of ESARRs among the Member States of EUROCONTROL.

Wake turbulence separation minima

Annex 14 – Aerodromes – [2] is the only regulatory standard document that mentions the issue of wake turbulence separation minima, as part of a recommendation concerning the minimum distance between two parallel runways, by referring to the so-called PANS-ATM (Doc 4444) [3], see text below.

ICAO Annex 14, Aerodromes, par. 3.1.10

Note.— Procedures for wake turbulence categorization of aircraft and wake turbulence separation minima are contained in the Procedures for Air Navigation Services — Air Traffic Management (PANS-ATM), Doc 4444, Part V, Section 16.

Inspection of the PANS-ATM shows that in fact in the following sections the guidelines for wake turbulence separation minima are laid down:

- chapter 4.9: Wake turbulence categories
- chapter 5.8: Non-radar wake turbulence longitudinal separation minima
- chapter 8.7.4: Radar separation minima

For details on these well-known criteria it is referred to the PANS-ATM itself. The PANS-ATM is however not an ICAO standard. This means that states in general will endeavor to comply with the requirements of the PANS-ATM, but it is no binding requirement. To avoid misunderstandings, most states do follow the requirements scrupulously and will not deviate without good reason and motivation.

However, in the present context it is interesting to note that there are various states that use deviant radar separation minima. For instance within the US, a different definition of the weight categories is used, and

in addition the Boeing B757 is categorized as a “heavy” aircraft, whereas based on its actual max. take-off weight it would be categorized as “medium” weight aircraft. It is expected that the FAA will increase the upper limit of their 'Large' category, so that the Boeing 757 is no longer in the Heavy category. Within the UK (CAP 943) a set of criteria is used, that is based on another definition of the weight categories. CAP 943 specifies 4 categories, i.e. heavy (> 162000 kg), medium (between 162000 and 40000 kg), small (between 40000 kg and 17000 kg) and light (< 17000 kg). Further, in addition to the Boeing 757, which is in the UK Medium category for departures and in the UK Upper Medium category for arrivals, a number of other aircraft (DC8, B707, IL62 or VC10) are also categorized as “heavy” aircraft in so far these aircraft are leading aircraft in the separation of aircraft pairs.

The reasons for these deviations from the ICAO criteria are known to be based on national experience and reported incidents. Therefore, they are –safety-wise– most probably a sound initiative of mentioned states. This is a clear illustration that the regulatory framework inherently incorporates substantial freedom for the various states to tailor criteria and requirements to local circumstances.

Requirements for Wake Vortex Advisory Systems (WVAS)

Similar to the wake vortex separation minima there is also substantial freedom for any state to introduce new systems that might enable a relaxation of the wake vortex separation minima. As indicated the approval of such systems is currently a national responsibility and the set of applicable requirements and associated procedures (in the absence of applicable ICAO standards) needs to be defined at a national level. This current practice invokes however a certain dilemma. Despite their formal responsibilities as the local authority in charge, many states lack the resources and the expert knowledge to define the set of requirements and the acceptable means of compliance for new and complex systems, such as for instance a wake vortex advisory system. For that reason there is a strong urge to pool resources at an international level, and to come to common sets of requirements and implementation rules. Usually, this occurs on a voluntary basis. However, all these initiatives have as yet not materialized either into a common agreed set of wake turbulence separation minima or a uniform set of requirements for wake vortex advisory systems. This is a serious bottleneck for the introduction of such systems, because without a clear definition of requirements, and the associated acceptable means of compliance to show that the system will meet these requirements, it is not possible to design any system that would be accepted for practical application. For this reason it is of essential importance to define such standards, and acceptable means of compliance, if we want such systems ever to become reality. This would require direct consultation with approving authorities (national and international) and user communities.

Prescriptive and analytic requirements

When reflecting on how requirements and the associated means of compliance could look like, there basically are two approaches. One option is that the authorities prescribe exactly the performance and safety requirements (reliability, integrity, availability), and propose the means of compliance at system and sub-system level. To put it simplistically, the manufacturers in that case basically would have to build the system in conformance with the requirements specification, and tick-off the means of compliance checklist to obtain approval. This could be called a **prescriptive** approach to system certification. Many aircraft systems are more or less build and certified in this way, by submitting the design to extensive and rigorous certification specifications, including guidance material, means of compliance and Technical Standard Orders (TSO). The notion “acceptably” safe is then inherent to compliance with the certification specifications. Another option is that the authority would leave the design and the associated design requirements largely to the applicant (manufacturer or service provider) and would approve the system on the basis that it can be proven that the system or procedure would meet a certain pre-defined and agreed target level of safety. This could be called an **analytic** approach towards obtaining certification approval.

The main advantage of this approach is that the authority does not have to prepare a detailed set of requirements and that the applicant is not limited in his design freedom. The consequence is that the authority must have the expert knowledge to comprehend and analyse the system design and to rightfully judge the safety documentation required for approval. In this case the notion “acceptably” safe is now directly determined by comparing the established safety level with the target level of safety.

Both approaches (and mixes thereof) are in general acceptable to authorities.

Practical approach towards approval of wake vortex advisory systems

If we would now focus on the introduction of wake vortex advisory systems, the question is how such a system could be approved or certified for a practical application. It appears that there are currently very few prescriptive requirements for such a system and its components, embedded within the current regulatory framework. Some requirements can be found in ICAO Doc 9426 [4], which provides 1) guidance material for States in the development of their national services, 2) a basis for harmonization of planning activities on a regional scale (as included in regional air navigation plans) (see box below).

ICAO Doc 9426, Part II, Chapter 3, Appendix A:

[..] a wake vortex avoidance system should meet the following requirements:

- a) replace fixed wake vortex separation minima with separations adapted to individual cases, thus optimizing traffic flow;
- b) detect the presence of a vortex hazard and generate information necessary to avoid it;
- c) make the system ground-based. No additional avionics should be required to obtain the use of the system;
- d) use a modular system design, tailoring the system capabilities and cost to specific requirements;
- e) use a complement of ground instrumentation to ensure uniform system performance independent of site constraints;
- f) design the system for maximum independence from other ATS systems to ensure maximum system reliability
- g) use of the system shall not place any additional burden on air traffic controllers or pilots.

It is evident that such a set of requirements would fall short as a sufficient basis for approval. Moreover they would unnecessarily limit the design freedom of the applicant, for instance by specifying that the system should not require airborne components (see c). Clearly a large effort would be required to develop and verify the required certification specifications to a similar level as for instance is currently in place for wind-shear detection and guidance systems (see e.g. TSO-C117 [7] and AC25-12 [8]). Therefore, it seems most practical to use an analytical approach towards achieving system approval. The basic requirements for such an analytic approach are laid down in ESARR4 [9]. Moreover guidance material for the application of ESARR4 is available and safety assessment methods (e.g. SAM [10]) have been defined to conduct the safety analysis. Nevertheless application of ESARR4 is not without difficulty.

The problems arising from the non-harmonised regulatory framework, and non-uniform implementing rules, in the area of ATM, ANS and airports have been recognised at the European level by the European Commission. For this reason, on 21 October 2009, the European Parliament and the European Council adopted two regulations to improve the performance and safety of the European aviation system – the first strengthens the Single European Sky legislation, while the second extends the tasks of EASA to the safety of aerodromes, air traffic management and air navigation services (Regulation (EC) 1108/2009 [6]). Both regulations were adopted following a first-reading agreement with the European Parliament in March 2009. The Regulation (EC) 1108/2009 has transferred the regulatory competences in the mentioned domains to EASA. This implies that an approval or certification of wake vortex advisory systems within Europe will fall under the authority of EASA, against the safety requirements that are (to be) adopted by EASA. It is as yet not clear how such framework will look like. It is likely that it will be based to some extent on the current ESARRs, but at the same time it may be expected that EASA will adopt a total aviation system approach, and will apply experiences and processes from other domains (airworthiness, operations) in the approval of ATM systems and procedures. In the context of wake turbulence regulations it is furthermore important to mention that there are several ongoing and future technological and operational developments, in which regulatory authorities (including EC, ICAO, EASA, FAA) are either participating or providing guidance as member of a steering group. Noteworthy are the SESAR Programme, EC project CREDOS, EUROCONTROL activities on Time Based Separation, Airbus A380 Wake Vortex Steering Group (which prepares new separation criteria for take-off and landing behind the Airbus A380 with representatives from EASA, FAA, EUROCONTROL, and Airbus), the FAA/EUROCONTROL Re-categorization effort, the Boeing B747-8 Wake Vortex Steering Group (which prepares guidance for separations behind the new Boeing B747-8), and the ICAO Wake Vortex Study Group. It is therefore reasonable to assume that emerging results will be embedded in future wake turbulence regulations.

2.3. Future developments

A new structure for operational and implementing rules has been developed as part of the work on the 1st extension of the EASA remit. It is planned to accommodate into this structure the future implementing rules for ATM and aerodromes as part of the 2nd EASA remit extension to be completed by 2013. Three ATM working groups have been set up by EASA in support of this 2nd extension:

- ATM.001 for development of rules on Requirements for Air Navigation Service Providers
- ATM.003 for development of rules on Air Traffic Controller licensing.
- ATM.004 for development of rules on competent authorities

These working groups will e.g. deal with the transposition of and cross reference to the Single European Sky (SES) regulations (including the ESARRs) and the ICAO SARPS. As the objective is to develop Implementing Rules (IRs) and, as appropriate, the necessary Acceptable Means of Compliance (AMC), Certification Specifications (CS) and Guidance Material (GM), the resulting regulatory material will encompass the safety regulatory requirements and related implementation material for ATM concept and systems, including the wake vortex advisory systems such as are being developed as part of SESAR.

As mentioned before, the ICAO A380 Wake Vortex Steering Group which - with representatives of EASA, FAA, Airbus and EUROCONTROL - has prepared new separation criteria for take off and landing behind the Airbus A380. This aircraft, with a maximum take-off mass in the order of 560 000 kg, is the largest passenger aircraft that has ever entered into revenue service. According to ICAO standards, the aircraft is in the HEAVY wake turbulence category and the Procedures for Air Navigation Services — Air Traffic Management (PANS-ATM, Doc 4444) apply. However, as vortices generated by the A380-800 are stronger than for other aircraft in the HEAVY wake turbulence category, the Steering Group has developed guidance recommending States to implement an increase in relation to the wake turbulence separation minima published in the PANS-ATM. Further research efforts to revise this ICAO guidance further are still ongoing, and this is expected to eventually result in an update of the ICAO PANS-ATM.

Following a request from ICAO, an update of the existing wake turbulence categories has been initiated. It is colloquially called “reategorisation”. The existing categories are felt to be out of date and do not take the latest aircraft types into account. This project is driven by EUROCONTROL and FAA. Other stakeholders like aircraft manufacturers (e.g. Airbus, Boeing) or airspace users are not directly involved. The project aims to look into:

- Characteristics other than weight which could be used to determine wake vortex separations;
- Sub-divisions of the current Medium and Heavy categories will be investigated;
- Dynamic pair-wise spacing based on actual aircraft weight is a long term objective of this project.

This effort is expected to lead to amendments of all ICAO reports that use wake turbulence categories.

It is noted that the Quality Assurance Manual for Flight Procedure Design (ICAO Doc 9906-AN/472), Volume 1, contains specific guidance regarding the safety assessment of the Time Based Separation concept as is currently being developed by EUROCONTROL [5]. This guidance is based on the EUROCONTROL preliminary safety case approach, in which five safety (sub)arguments are distinguished for which safety evidence will need to be gathered: intrinsic safety, design completeness, design correctness, design robustness, and mitigation of internal failures. The latter is usually supported by a Functional Hazard Assessment (FHA) and a Preliminary System Safety Assessment (PSSA).

The recently started SESAR Development Phase contains four projects that specifically deal with wake turbulence related activities:

- WP6.8.1 (Flexible and dynamic use of wake vortex separations)
- WP9.11 (Aircraft Systems for Wake Encounter Alleviation)
- WP9.30 (Weather Hazards / Wake Vortex Sensor)
- WP12.2.2 (Runway Wake Vortex Detection, Prediction and decision support tools).

It is expected that these projects will deliver (proposed) safety requirements using a similar approach as recommended for Time Based Separation (and contained in the new document ICAO Doc 9906-AN/472), Volume 1). However, the ultimate responsibility for approval and certification in Europe will be with EASA.

2.4 Research needs

Emphasis is now being placed on establishing wake vortex encounter safety arguments that will satisfy the concerns of all stakeholders, with particular emphasis on the concerns of pilots and pilot associations given that they are in the 'front line' of WVEs and their consequences, and also airline operators, controllers, controller associations, ANSPs, airport operators, and safety regulators. Additional research might be needed to investigate how such WVE safety arguments can be used in certification processes.

Even though requirement c) from ICAO Doc 9426 (see page 9) states that a wake vortex advisory system should be ground based, with no additional avionics required, efforts are underway (e.g. in the SESAR projects 9.11 and 9.30) to develop airborne wake vortex systems. Industry will remain cautious towards progressing from R&D towards actual implementation of new ground and aircraft wake vortex advisory systems as long as it is unclear if and how such system's new capabilities will be taken into account in future separation standards and how such advisory systems will have to be certified. Additional research might be needed to investigate how the certification process for such systems in detail should look like, and how the safety benefits of such systems could be incorporated in the related regulatory framework.

A big hurdle towards the development of ground and airborne systems aiming at reducing wake turbulence separation requirements while assuring today's safety level is the unavailability of detailed Acceptable Means of Compliance (AMC) and detailed requirements from regulators regarding the development of the associated safety case. While there have been recent example wake turbulence safety assessments (e.g. A380, WIDAO), which for the first time since the introduction of ICAO wake turbulence separations allowed defining new separation requirements, so far these initiatives mainly take into account the characteristics of the wake vortex but not specifically the capabilities of the follower aircraft. The EASA WATUS (Safety Case for Wake Turbulence Separation of Large Aircraft) project, which is being performed by NLR, provides an attempt to take the capabilities of the follower aircraft into account. However, WATUS is still ongoing and the first results are currently not expected to be made available to the public before the end of 2011. Additional research might be needed to investigate how to progress from the individual safety case examples towards harmonized requirements for the safety case.

3. Safety assessment

3.1. Introduction

All efforts addressing the safety of flight operations with regard to wake vortex encounter (e.g. wake warning systems) or aiming at increasing the capacity of the air transport system by adjusting wake turbulence separations (e.g. new separation schemes) ultimately aim at reducing the risk of severe wake encounters or must assure that the level of risk is not increased. It is the task of dedicated safety assessments to validate that this risk is either reduced or kept at current levels. Those risk-based safety assessments that consider the possibility of unintentional wake encounter must determine the probability (i.e. frequency) of wake vortex encounters and their associated severity level. Severity assessments concern the determination of the severity of a specified wake vortex encounter. Within such assessments severity criteria correlate objective, measurable quantities with severity descriptions of more general nature and stakeholder-wide understanding. Safety assessments may differ in depth. The most detailed assessments include models of air traffic, weather, wake vortex transport and decay as well as dynamic wake encounter simulations to determine frequency and severity of wake encounters on a statistical basis. Experience shows that a common definition of applicable severity criteria is especially difficult to achieve. This difficulty is due to the fact that many different stakeholders are directly concerned (basically answering the question: “which wake encounter is acceptable?”) but that they have different perspectives, experiences and requirements. While an airline might already be concerned about the number of encounters affecting passenger comfort, a regulator is more likely to be concerned only about encounters leading to incidents.

Absolute safety assessments

Application of ESARR4 is often based on specification of the required safety target of the system in an absolute sense. Such safety target can (but not necessarily has to) be derived from the risk classification scheme as presented in ESARR4. This scheme presents the maximum tolerable probability of the overall ATM contribution to accidents as $1.55 \cdot 10^{-8}$ per flight hour. A fraction of this number has to be apportioned to the system in question, representing the overall safety design requirement for the system. Research would be needed to determine a reasonable value for this design requirement. It would comprise an analysis of the contribution of the currently applied separation minima to the overall ATM related accident rate in order to establish a baseline safety requirement. Some of this research has already been conducted in the past, but results have to be verified and agreed to be a valid base for the system design. Further, it is necessary that models are constructed that enable a sufficiently accurate estimate of the actual risk involved in the application of the system. It is of essential importance to the approval process that it can be satisfactorily proven that these models provide trustworthy and valid results, because the results of model simulations factually determine the acceptability of the system in question.

This means that the applicable models will have to be subjected to a rigorous validation process, before they can be accepted as an acceptable means of compliance.

We know the elaborate scale of such validation efforts from -amongst others- aircraft autoland system certification processes. As an illustration it is shown here what is required to be delivered for certification approval of such system (JAR-AWO):

- A specification of the airborne equipment;
- Evidence that the equipment and its installation comply with the applicable standards;
- A failure analysis and an assessment of system safety
- A performance analysis demonstrating compliance with the applicable performance criteria;
- Flight test results including validation of any simulation;
- Limitations on the use of the system and description of crew procedures;
- Evidence that the crew work-load is acceptable;
- Inspection and maintenance procedures shown to be necessary by the system safety assessment

It should be added to this that the performance and safety analysis of a wake vortex advisory system would require a much more complex model than required for auto-land certification. This stems from the fact that simulation of the wake vortex advisory system would have to include the properties of various aircraft types, ground equipment, meteorological conditions and prediction thereof, wake-vortex prediction, and human performance. Development and validation of all these model elements will require a tremendous effort, depending on the required accuracy.

It may even be expected that a complete simulation model of WVAS operation to a similar fidelity as autoland certification simulations might prove to be beyond current technological feasibility. One should think of Monte Carlo type of simulations with a representative number of real (qualified, non-linear, 6 degrees-of-freedom) aircraft models, 3D encounter models, wake vortex measurement and prediction, wind and weather prediction, and human interaction.

Therefore it is clear that simulation models require substantial simplifications. The effects of such simplifications on the accuracy need to be carefully analysed, and it has to be established whether the resulting accuracy will be sufficient for the analysis at hand. Therefore, further research will be needed to establish and validate which model approximations would be acceptable.

Relative safety assessments

A possible outcome of mentioned research might be that an absolute estimation of the actual risk can not be performed with sufficient accuracy, to support approval decisions based on a comparison with a specified (absolute) risk level.

Therefore, alternative methods should be investigated that reduce the effects of model simplifications.

It is known that relative estimates have smaller ranges of uncertainty, and thus are less susceptible to model simplifications. In this respect it should be noted that currently there is not any requirement or standard that would preclude system approval on a relative basis. The basic reasoning is that current ATM procedures and/or systems are each contributing to the currently accepted level of safety (or rather unsafety), as f.i. specified in ESARR4, although the actual quantitative contribution might not be exactly known. If it can be proven that new systems or procedures are at least equally safe as the ones they replace, the overall safety level would not be affected and therefore would satisfy the required target level of safety. The acceptability of such an approach should be further investigated. In particular, agreement should be reached concerning baseline scenarios that would represent current standard practices, and concerning the judgment that these scenarios are considered acceptably safe. Also it would have to be established which model simplifications are allowable in a relative comparison.

Introducing new systems

It should be realized that the outcome of any safety assessment (relative or absolute, qualitative or quantitative) will inherently encompass certain levels of uncertainty, due modeling inaccuracies, assumptions and simplifications. Therefore methods should be found that reduce these uncertainties to acceptable levels before the new systems or procedures are fully applied in practical operation. A common procedure is to define a specific introduction phase for the system at hand. A good example of such approach is the autoland system. After the initial approval, based on the safety assessment results, the system is first required to demonstrate a certain number of actual autolands in service before weather limits, under which the system can be operated, are gradually lowered. Clearly such a phased introduction builds confidence in the system and the associated safety assessments. This enables a gradual and controlled transition from the standard operation to the full operational application of the system. In the context of wake vortex advisory systems it is therefore prudent to conduct further research to specify a suitable introduction phase for such systems.

Simulation models and validation

Evidently, there is wide array of safety methodologies that can be used for safety assessments, both qualitative and quantitative. It is beyond the scope of the present chapter to address all of these (qualitative and quantitative) methods. However, in light of the anticipated application of ESARR4 requirements for performing risk assessments, simulation models that are able to estimate the risk level in a quantitative (probabilistic) way are of particular interest here.

These models are further addressed in the following.

3.2. Overview of the current status

At present, twelve simulation models that support the assessment of the actual (wake vortex) risk level of flight procedures have been identified:

- WAVIR, developed by NLR-ATSI.
- WakeScene, developed by DLR
- VESA, developed by Airbus
- A380 wake vortex safety assessment package, developed by Airbus
- Wake Encounter Pilot Model, developed by the TU Berlin.
- Vortex Encounter Risk Assessment for curved Vortices (VERA-C), developed by TU Berlin
- RECAT safety assessment method, developed by FAA - EUROCONTROL
- Wake Vortex Encounter Risk model, developed by DNV
- Wake Vortex Scenario Screening Tool, developed by EUROCONTROL
- Wake Encounter Risk Indicator Simulation package, developed by M3S and UCL
- ASAT, developed by the FAA Flight Procedure Standards Branch
- Probabilistic wake vortex hazard model, developed by the George Mason University
- Recat Step I method, developed by Airbus
- Equivalent roll rate approach, developed by NLR

These models differ in scope and complexity. Some of the models are actually sub models of others or sub models of a common, larger process.

WAVIR (Wake Vortex Induced Risk) is a stand-alone risk assessment method, based on a modular approach. Risk assessment process employed by WAVIR is depicted in the figure below [24, 32].

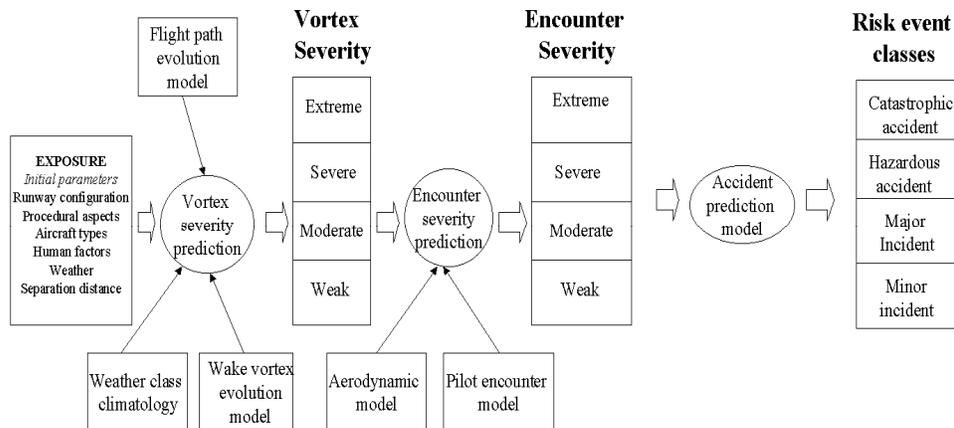


Figure 1 Wake vortex induced risk assessment (WAVIR)

Basically it is a three step approach. First evolution of the wake vortex generated by a leading aircraft is calculated at a given number of gates along the approach or departure path. The flight path of leader and follower aircraft is specified based on aircraft speed profiles and the nominal trajectory, taking into account uncertainty in speed and position. From this the relative position and strength of the wake vortex can be determined at the time that a following aircraft passes the defined gates. Secondly, the effect of the wake on the passing (i.e. follower) aircraft is determined. Depending on the encounter model used this can be expressed in one or more disturbance parameter (induced roll angle, roll control ratio, loss of height, induced load factor, equivalent roll rate). Finally these disturbances are translated to a certain risk event.

The set-up of the model allows Monte Carlo simulations, using probability distributions for meteorological conditions (stratification, turbulence, wind), aircraft position and speed and other stochastic input parameters. Simulation of a specific scenario, defined in terms of involved aircraft types, flight paths (departure, approach, missed approach, or en-route; interception angle), and the applied separation (horizontal or vertical, distance or time) provides frequency estimates of the risk events in that scenario. This can then be compared with a certain target level of safety in order to establish the anticipated acceptability of the operation.

WAVIR has been used in EC projects (S-Wake, ATC-Wake, I-wake, and Awiator) and supports evaluation of wake vortex safety and required separation distances for:

- Air Traffic Management warning and avoidance procedures [53];
- On-board wake detection, warning and avoidance instrumentation [54];
- Advanced aircraft wing technology operations [55];
- Optimised use of airspace [56]; and
- New designed high capacity aircraft [57].

The **WakeScene** (Wake Vortex Scenarios Simulation) Package allows assessing the encounter probabilities and the related vortex strengths behind different wake vortex generating aircraft for different air traffic scenarios [45, 46]. For arrivals the simulation domain extends from the final approach fix to the threshold, for departures it ranges from the runway along different departures routes up to heights of about 3000 ft. Currently, WakeScene is extended to other phases of flight and, in particular, to approaches to closely-spaced parallel runways. In the DLR project 'Weather & Flying' it is planned to apply WakeScene for a risk assessment of the WSVBS (WirbelSchleppen-Vorhersage- und - Beobachtungs System) and for the elaboration of suggestions for a new aircraft separation matrix.

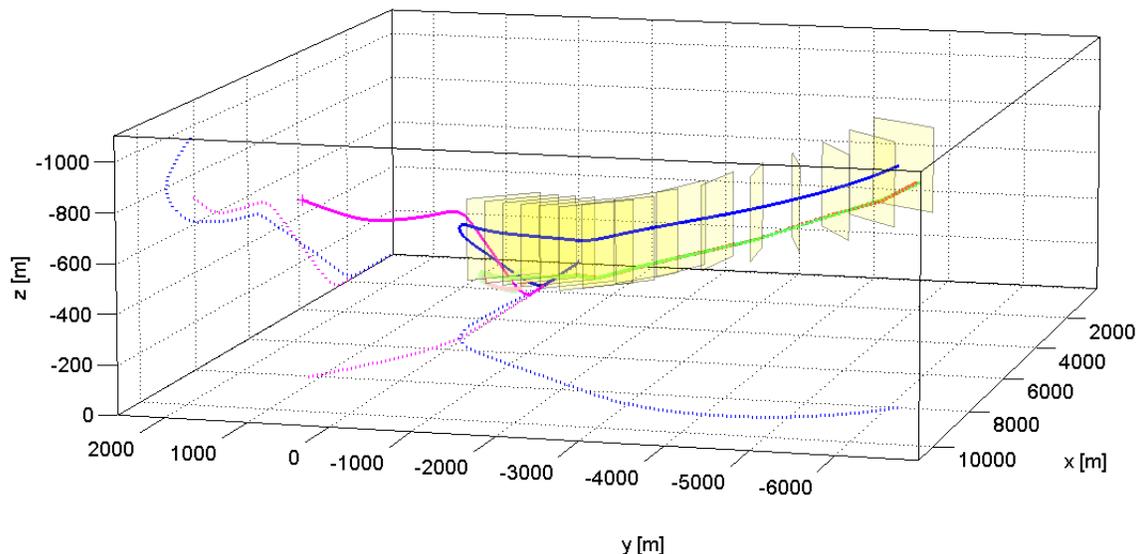


Figure 2 WakeScene simulation of departing aircraft in EU project CREDOS

The modelling environment supports Monte-Carlo Simulation as well as prescribed parameter variations and generates statistical evaluations. The package consists of elements that model traffic mix, aircraft trajectories, meteorological conditions, wake vortex evolution, and potential hazard area. The Aircraft-Trajectory Model provides time, speed, altitude, mass, and lift of generator and follower aircraft at different gate positions (simulation planes), using point-mass aircraft models or the Advanced Flight Management System (AFMS) based on the BADA database. A large number of environmental- and aircraft specific parameters influence an aircraft trajectory and its deviations from a nominal flight path.

The Meteorological Data Base comprises a one-year statistics of realistic meteorological conditions (more than $1.3 \cdot 10^6$ vertical profiles) for the Frankfurt terminal area which were produced with the weather forecast model system NOWVIV. Based on vertical profiles of environmental conditions and aircraft parameters, the Probabilistic Two-Phase Wake Vortex Decay and Transport Model (P2P) simulates the development of wake vortex trajectories, circulation, vortex core radius, and attitude of wake vortex axes. The hazard area module defines an area of interest around the wake vortex. When this area of interest is penetrated by the follower aircraft, this is considered to be a “potential wake vortex encounter”. Different options exist for the area of interest definition. A simple circle with 50 m radius around each vortex, or the more differentiated approach of “simplified hazard areas” (SHA) [47], which are dynamically adjusted according to vortex strength and aircraft pairing and designed to ensure operationally safe flight outside of the SHA. In cases with potential wake encounters all relevant parameters can be provided to VESA, which may subsequently perform detailed investigations of the encounter severity.

Validation activities have been conducted for the employed sub-models of WakeScene [46]. For example, the one-year meteorological data base has been validated against a 30-year wind climatology and a 40-days subset has been compared to field measurement data collected at Frankfurt airport [48]. Validation activities of the P2P wake vortex model have been conducted using data of over 10,000 cases gathered in two US and six European measurement campaigns. Assessments of the wake prediction skill of P2P based on predictions of meteorological conditions with NOWVIV can be found in [49, 50].

Monte-Carlo Simulations using WakeScene have been used to investigate the wake vortex encounter probabilities for crosswind departure scenarios within the EU-project CREDOS. Sensitivity analyses have been conducted regarding the effects of various crosswind scenarios, departure route combinations, flight path adherence, wake vortex modelling, the development of aircraft separations during the departures, the sample size of the Monte Carlo simulations, aircraft type combinations, aircraft take-off weights, meteorological conditions, airport operation times, and a comparison to approach and landing [51, 52].

VESA (Vortex Encounter Severity Assessment)

The research work performed by Airbus in the last years regarding wake encounter safety assessment built upon different earlier projects that investigated wake encounter hazards. In the EC-funded S-WAKE project (2000-2003) modeling tools were developed that ultimately lead to the wake vortex encounter simulation platform VESA (Vortex Encounter Severity Assessment) [21, 42]. VESA is able to simulate the effect of wake vortex encounters on an encountering aircraft by adding vortex models to high-fidelity, six degrees-of-freedom flight simulations using dedicated aerodynamic interaction models to couple the wake vortices with the basic aircraft's aerodynamics and flight dynamics. Additional elements included were a model for pilot behavior during wake encounters in approach and hazard criteria to assess the severity of the wake encounter, based on single parameters like bank angle or Roll Control Ratio.

The work in the S-WAKE project focused on the approach phase of flight, and the VESA platform had only limited capabilities to be applied to other flight phases. After S-WAKE the capabilities were continuously extended. Most recently within the CREDOS project (2006-2009) for example the platform was extended to the departure flight phase and existing sub models have been further refined. In particular an advanced severity model was integrated that was developed by TU Berlin using data from extensive piloted simulator tests of wake encounters during departure in the A320 THOR development simulator at Airbus in Hamburg [22, 25]. Pilots taking part in this simulator study also provided subjective hazard ratings for each individual encounter through a dedicated questionnaire. The severity model is based on a multi-parameter envelope approach [43, 44] that takes into account the main hazards of a wake encounter on an aircraft, including dynamic aircraft reactions and parameters like load factors, flow angles or aircraft attitude. Advantages of such criteria are that they take into account the actual resistance of the encountering aircraft to the disturbance, and that they can in general be applied to all flight phases and encounter conditions, as all possible hazards caused by the wake are considered. Furthermore a new pilot model was developed by TU Berlin capable of conducting take-off and departure as well as recovery from wake encounters in a way representative of real pilots [26]. It is based on a neural net, which has been trained to the recorded pilot reactions from the A320 simulator sessions in CREDOS, simulating wake encounters of varying strengths and types.

The new VESA platform was used within the CREDOS project for an assessment of wake encounter risk during the departure phase, using the Frankfurt/Main International Airport environment as an example. For this assessment the VESA platform was connected to the WakeScene tool developed by DLR [12, 13], which focuses primarily on the frequency of encounters in the airspace environment. WakeScene identifies potentially significant encounters out of a number of departures, but does not consider any influence of the vortices on the encountering aircraft and thus cannot finally assess the severity of the hazard they pose. The identified potential encounters are instead investigated in detail by VESA. In VESA the encounter conditions in terms of wake intercept angles, vortex characteristics and flight state of the encountering aircraft identified in WakeScene are reconstructed. VESA then allows an estimation of the severity of each identified encounter, using the severity model mentioned above applied to the dynamic response of the aircraft. Both results, the frequency of encounters and their respective severity, allow characterizing the wake encounter risk for the considered scenario. In CREDOS different wake turbulence separation times for Heavy-Medium departures with varying crosswind levels have been compared in a relative way with the goal to find a possible crosswind threshold above which a safe reduction or suspension of wake turbulence specific departure separations is possible.

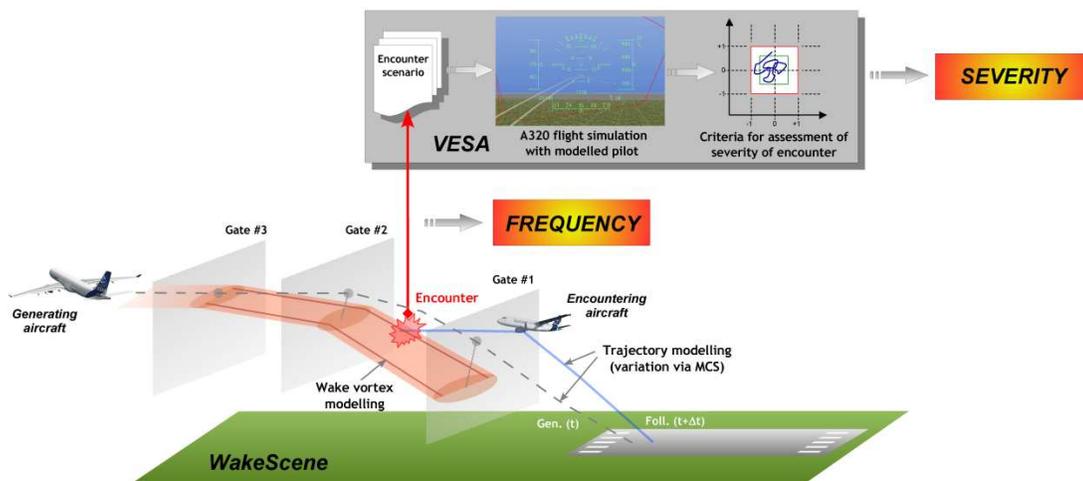


Figure 3 Coupled WakeScene/VESA encounter simulation for departures

The validation activities undertaken so far for the different sub-models generally show a good quality. The pilot model based on a neural net shows a behaviour representative of real pilots and seems to be a promising approach for this kind of application. It could also be shown that multi-parameter hazard criteria are feasible that correspond reasonably well with pilot judgement of the severity of an encounter [25]. Further refinement and validation of the criteria's definition will be necessary however, including expert judgement on which limits are acceptable for the different considered dynamic parameters. Further development in this area will be conducted for example in the frame of SESAR, in which Airbus is involved in several projects concerned with wake vortex topics. WakeNet will be used as a further means to move towards a wider discussion and acceptance of this approach e.g. via dedicated workshops.

Airbus A380 wake vortex safety assessment package

In preparation of the Airbus A380 entry into service, Airbus engaged in extensive wake vortex research, measurements, evaluations and analyses. Live trials included ground-based and airborne measurements by LiDAR as well as dedicated wake encounter flight tests involving several different generator and follower aircraft types. Results from these activities are reviewed and evaluated by an international A380 Wake Vortex Steering Group (SG) composed of Airbus, EASA, EUROCONTROL and the FAA as well as ICAO as observer. The A380 Wake Vortex Steering Group has issued its findings from dedicated Safety Assessments to ICAO which in turn has issued several ICAO State Letters to its member states, providing recommendations on safe wake turbulence separations for A380 operations.

The last related ICAO State Letter was issued in July 2008 [39]. In this the A380 radar wake turbulence separation minima for approach have been recommended as follows: no separation requirement for an A380 as follower aircraft, 6 NM for a Heavy following an A380, 7 NM for a Medium and 8 NM for a Light. These recommendations are primarily based on the relative assessment of the A380 wakes' circulations compared to that of other Heavy aircraft already in service. For this, circulation has been measured by ground-based LiDAR. The State Letter does not recommend any special separations for A380 operations in cruise flight – a finding that has been established by direct comparison with existing Heavy aircraft, based on wake encounter flight tests and in-flight LiDAR measurements.

Wake encounter simulations using VESA indicated that the recommendations from the LiDAR-based Safety Assessment for the approach flight phase may still be overly conservative. VESA has shown that vortex circulation is not the only parameter influencing the impact of a wake on an encountering aircraft, but that further characteristics of the wake such as the vortex spacing and core radii play an important role as well. Still, VESA could not be used directly to identify safe A380 separations due to a perceived lack of validation. Given the successful wake encounter tests performed at altitude, Airbus hence engaged in a most extensive wake encounter flight test campaign with the aim to further refine safe separation standards for approach flight conditions. This refinement shall be achieved through evaluation of encounter flight test results that include tests useable for a relative comparison of the wakes behind the A380 and other, reference Heavy aircraft.

Straight-forward comparisons of encounter flight test results already show marginal differences in aircraft responses. To support A380 Wake Vortex SG activities Airbus has developed methods and tools specifically aimed at evaluating wake encounter flight tests by comparing the direct impact of two different wakes on an encountering aircraft. This direct impact is expressed by wake-induced forces and moments acting on the aircraft and can be established from flight testing by comparing the recorded aircraft response with the known aircraft characteristics in calm air. Compared to circulation, direct wake impact established from encounter testing is closer related to relevant operational hazard since wake-aircraft interaction is included. Because the specifics of the encountering aircraft's flight control system are inherently excluded from the evaluated direct wake impact the results obtained can be generalised and the outcome of a relative assessment can be generally applied.

Aiming at objectively documenting flight test conditions as well as showing coherence with ground-based LiDAR measurements, flight test results are furthermore evaluated with regard to the encountered wakes' circulation and the relative flight path. This is achieved by evaluation of air data recordings in an optimisation process called wake identification.

Despite the promising results, progress towards refined recommendations by the A380 Wake Vortex SG is slower than expected given the scrutiny with which flight test results are analysed and the novelty of the flight test evaluation methods. In the future the Airbus flight test results may be used to further validate VESA as well as other methods and metrics to set safe separation distances, for example in the context of recategorisation.

Wake Encounter Pilot Model

TU Berlin operates a suite of software programmes in support of wake vortex safety assessment. This suite, which has been developed - as part of the CREDOS project - specifically for departures, includes a trajectory model, a pilot model, and severity metrics and criteria to judge the hazard of wake encounters.

The pilot model is developed for fast-time Monte Carlo Simulations with varying wake vortex encounter conditions for safety analyses. The model consists of different submodules to perform the take-off run, rotate, follow a standard instrument departure route and recover and stabilize the aircraft during and after a wake vortex encounter. The pilot model generates sidestick pitch, sidestick roll, pedal, throttle lever, flap lever, and landing gear lever commands and manipulates those control elements as a pilot would do. For design and validation of the pilot model, data was generated in a certified A330 Full Flight Simulator and using an A320 development simulator with licensed commercial airline pilots. For final validation, the pilot model was implemented into the flight simulation to compare it with recorded pilot reactions.

Severity metrics and criteria have been developed to judge the hazard of a wake vortex encounter under certain conditions. The criteria take into account several objectively measurable aircraft parameters (like e.g. load factors, air flow incidence angles or aircraft attitude), validated by the subjective judgment of the pilots, who had to rate each flown encounter with regard to the perceived safety hazard. Those criteria, which are also implemented in VESA, allow analysis of the influence of certain parameters on the severity of the wake hazard, as well as a statement on which fraction of the simulated encounters are actually hazardous.

The trajectory model has been developed, implemented, and verified with results from a certified A330 full flight simulator and validated on the basis of measured aircraft trajectories. The trajectory model allows simulating aircraft departures beginning with the aircraft's start position on the runway. The trajectory model takes into account wind conditions, standard departure routes, aircraft weights, start point positions, and pilot behaviour. These input dependencies have been implemented as Monte Carlo Simulation parameters for variation of aircraft departure trajectories. The departure trajectory model is also used in WakeScene. Further improvements are needed in the following areas:

- Quality of performance and aerodynamic parameters for simulated aircraft, data for additional aircraft.
- Development of more sophisticated performance calculation including an improved takeoff thrust calculation,
- Implementation of additional and different climb schemes.

Vortex Encounter Risk Assessment for curved Vortices (VERA-C)

VERA-C is a research project of the Technical University of Berlin that investigates vortex encounters with curved vortices. It is funded by the German Research Foundation. The objective of VERA-C is to analyze the impact of vortex distortion on vortex encounter severity by means of risk analysis. The strength of a vortex encounter, specifically vortex induced upsets of aircraft attitude and flight path, is mainly influenced by vortex circulation and encounter geometry. Initial studies show that vortex deformation also has some affect on the induced disturbance. Depending on the level of distortion, the encountering aircraft upset may degrade compared to an encounter with straight vortices.

As part of VERA-C, analytical models of curved vortices will be set up and implemented in the research flight simulator SEPHIR (Simulation for Educational Projects and Highly Innovative Research). Simulator test with airline pilots will provide a data base for the development of vortex encounter pilot control models and for models that describe the pilots severity assessment. These models will then be integrated in a fast-time simulation environment to perform risk analysis based on large numbers (~100.000) of simulated encounters. Sensitivity studies and worst-case analysis will be used to assess the impact of vortex distortion on encounter severity.

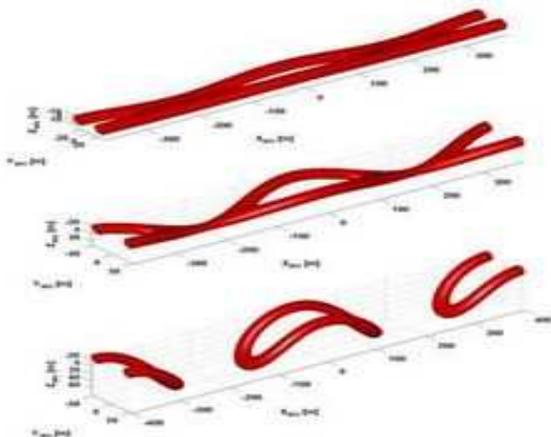


Figure 4 Different stadiums of curved vortices

RECAT approach

RECAT is a EUROCONTROL-FAA initiative whose objective is to review existing ICAO wake turbulence categories and associated pair-wise separation minima for both departure and arrival operations. RECAT uses up-to-date knowledge about the wake vortex phenomenon to propose new categories that are more adapted to today's aircraft and allow gains in runway capacity. It focuses on re-categorization of airspace in three steps. By 2012, it should provide static changes using the six current aircraft weight categories and adjust wake separation distances to account for fleet mix changes. By 2014, it should develop an alternate set of flexible airspace classifications for use under specific conditions to increase the capability to place more aircraft in the same volume of airspace. By 2020, it should support dynamic, pair-wise separation.

The objective of the methodology used in RECAT is to identify new categories that optimise capacity gains while adapting pair-wise separations such that operations will be at least as safe as they are today. These new separations will be assessed using wake behaviour models for transport and decay, as well as models that estimate wake impact on a following aircraft. RECAT may necessitate establishment of a severity criterion for wake encounters, a definition of what an 'acceptable' encounter is, and adapted criteria for allocating wake turbulence categories to aircraft. However, with respect to safety it is at present not clear from public RECAT material how RECAT intends to define the severity criterion for wake encounters.

The RECAT methodology to determine separation minima involves eleven stages, among which:

- 1) Identify the most frequent aircraft types operating both in the ECAC area and in the USA.
- 2) For each pair of identified aircraft types, estimate the minimum safe separation based on the wake characteristics of the generator and the worst possible impact of its wake encounter on the Follower.
- 3) Identify boundaries of the new categories and associated pair-wise separations that optimise capacity gains. The associated minimum separations correspond to the largest minimum for pairs of aircraft.

The RECAT documentation currently consists of the following (non-public) documents:

- RECAT Preliminary Safety Case;
- RECAT Methodology report;
- RECAT Safety Assessment report;
- RECAT report extending RECAT to all ICAO aircraft types; and
- RECAT report on WT incidents.

The RECAT team aims to present the RECAT documentation to the ICAO Wake Turbulence Study Group in November 2011, after which the introduction of RECAT Phase I is planned to be implemented.

Recat Step I method by Airbus

At the first major workshop of WakeNet3-Europe, held in January 2009, Airbus presented a study of technical methodology for recategorisation step I ("Recat Step I"), which is defined as a new, static MTOW-based aircraft wake turbulence classification with more than three classes. The goal of the study was to identify if simple recategorisation may deliver safety and capacity gains and to identify potential technical challenges and research requirements. The goal was not to propose a new classification. The methodology presented is depicted in the figure below and can be characterised as follows:

- Representation of all aircraft pairs by the evaluation of a 50x50 matrix of generator / follower aircraft pairs at 10 distinct separation distances ranging from 2.5 to 10 NM.
- Use of generic, probabilistic aircraft models for the generator and the follower aircraft to account for current and future aircraft characteristics and with generalisation achieved through statistical evaluation of up to 161 existing aircraft types.
- Modelling of an operational approach scenario evaluated at a single "gate" along the approach path
- Statistical evaluation of encounter risk through Monte Carlo Simulation of wake generation, wake decay, wake transport and wake encounter as a function of aircraft pairs and separation distance.
- Encounter consequence or severity expressed by wake-induced rolling moment as a function of relative position (distance) between wake vortex and follower aircraft, vortex circulation, spacing and core radius as well as follower aircraft characteristics like speed, span and rolling moment of inertia.

- Modelling of traffic mixes by statistical distributions of aircraft weights representing different airport scenarios.
- Target Level of Safety estimated for current ICAO separations for “Largest individual aircraft risks” as well as for “Average aircraft risks”.
- Derivation of minimum pair-wise separation distances based on Target Level of Safety.
- Computation of three different, non-segregated, single runway capacity metrics (average separation between aircraft, number of aircraft operations per hour, payload throughput per hour).
- Establishing of wake turbulence classes or categories based on minimum pair-wise separations with capacity as optimisation goal.

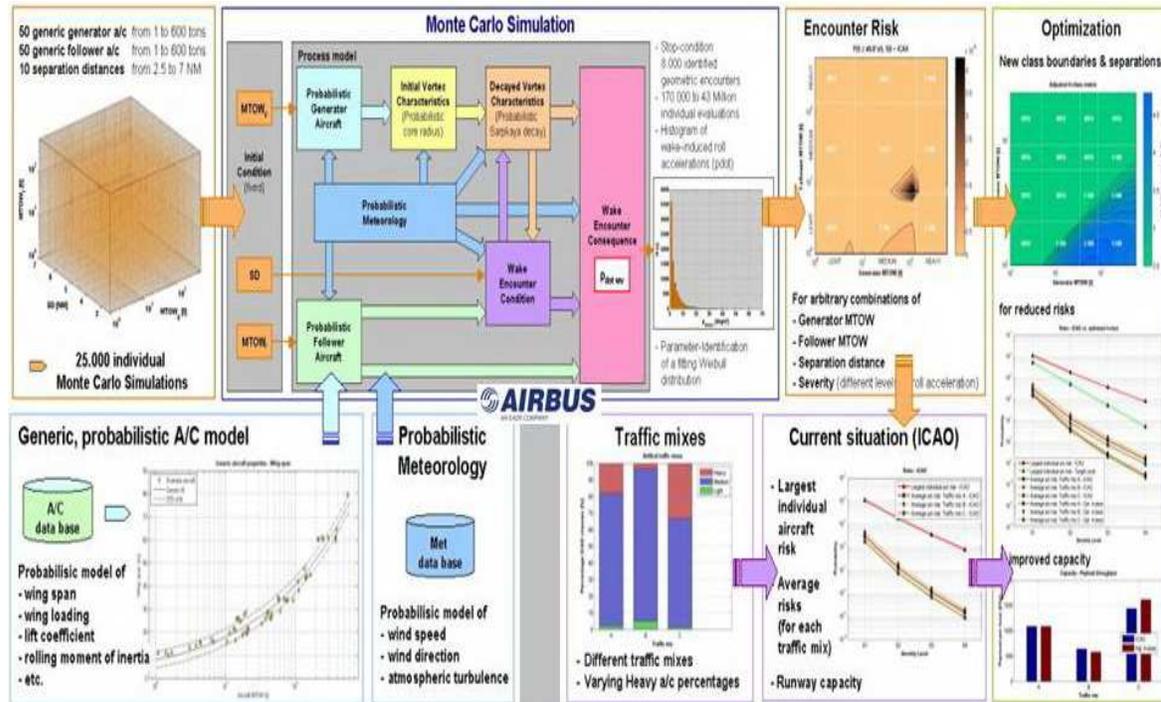


Figure 5 Overview: Recat Step I method by Airbus

Wake Vortex Scenario Screening Tool

The WV Scenario Screening Tool, available at EUROCONTROL, provides a means of examining and comparing very simple Time-Based Separation and Distance-Based separation scenarios. The WV Scenario Screening tool provides a graphical representation of the positions of the leading and following aircraft in a pair on approach and shows the positions of Wake Vortices generated by the leading aircraft according to a very simple Wake Vortex transport model. The tool also shows the minimum distance from the wake vortices and provides a risk estimate based on an assumed hazard radius for the Wake Vortices, distributions of the vertical and lateral position keeping accuracy of aircraft on an ILS approach.

Wake Encounter Risk Indicator Simulation package

M3S has developed a Wake Vortex Encounter Risk Indicator Simulation package allowing to support the preliminary risk assessment of new concept of operations (as done for the preliminary safety case of the Time Based Separation concept). This package could also be used to support the development of new concepts of operation or to assess the Wake Vortex Encounter (WVE) risk associated with current real operational situations. The tool is constituted of three separated modules that could be removed and replaced by other ones (provided that the interface with the two other modules is compliant): a) The scenarios definition module, b) The Wake Vortex Simulation module (not developed by M3S, but consisting of the WAKE4D platform developed by UCL), c) The Risk Indicator computation module.

The Scenarios Definition module is used to determine all relevant parameters of the investigated scenario. On the one hand, it allows setting:

- the aircraft characteristics such as the aircraft type, dimensions, weight and lift distribution;
- the aircraft trajectory, i.e. the time evolution of aircraft position (including aircraft navigation errors);
- and the atmospheric conditions such as the wind profile (both head and cross- wind), the atmospheric turbulence and the temperature profile.

On the other hand it allows describing the application of the new concept of operation by ATCO such as aircraft spacing applied along the flight track or aircraft speed constraints applied.

For prediction of Wake Vortex (WV) behaviour, the WAKE4D platform developed by UCL has been selected and plugged in the risk assessment process. In the WAKE4D the modelling of the aircraft WV behaviour is made using the Deterministic Vortex Model, DVM, or the Probabilistic Vortex Model, PVM). The predictions are conducted in several computational gates along the flight path that move in space with the wind. From the 3-D “gate by gate” DVM (resp. PVM) computations, one obtains the 3-D envelope of the wake. The trajectory can be straight or curved. The computational effort depends on the density of time steps within each gate and the number of gates.

The WAKE4D platform contains also some post-processing routines. The results can be interpolated in a fixed control gate (similar to a LIDAR scanning plane). In PVM mode, one can also count the vortex in a given box as a function of time (useful for potential encounter analyses). For reconstruction of the induced velocity field a first routine uses a vortex tube segment approach to compute the velocity induced both by the primary and secondary vortices. This approach enables the evaluation of the velocity for complex aircraft trajectory scenarios (e.g., take-off, landing, turns ...). A second routine uses the simplified Crow instability model of the WAKE4D, in a vortex filament approach, to compute the 3-D velocity induced by deformed vortices. This evaluation is only applicable to straight aircraft trajectories far from the ground. Both routines evaluate the induced velocity at a hundred of points in real time and can thus be integrated in a flight simulator (as was done in the CREDOS project). The choice of the vortex circulation distribution model is of great importance for encounter analysis.

The WAKE4D, and its subcomponents DVM and PVM, have been used in fast-time and real-time simulations of WVEs as well as a vortex forecast function in experimental detection, warning and avoidance systems in aircraft and on ground. The complete description of the WAKE4D platform is available in [41], which also contains WV prediction results validation against WV measurements performed in the framework of FAR-Wake and CREDOS.

Based on the Scenario Definition and based on extensive Wake Vortex numerical simulations, the Risk Indicator Computation module allows Wake Vortex Encounter risk assessment through the computation of risk indicator. The risk indicator selected for the study covers the 2 dimensions of wake vortex encounter risk as follows:

- the WV Area Encounter probability: the probability for a follower aircraft to penetrate within a wake vortex area defined by geometric considerations and related to the wingspan of leader and follower aircraft;
- the severity: the severity of a potential encounter is measured through the WV circulation.

Considering the number of factors affecting both aircraft profiles and wake vortex behaviour, including the actual mass of the aircraft, its position with respect to the ground as well as the atmospheric conditions (wind and temperature), the method proposes to follow a relative approach for the risk calculation of potential wake vortex encounter. Relative estimates are felt to have a smaller range of uncertainty and are less susceptible to model simplifications.

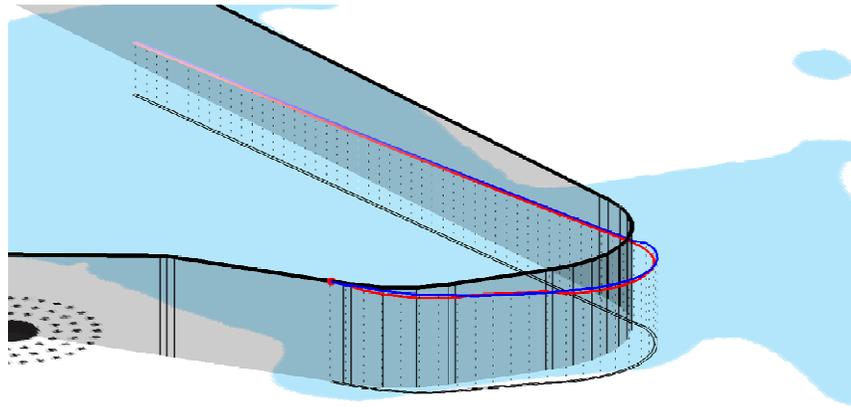


Figure 6 Example of trajectory and wake vortices computed by the WAKE4D pre-processor

ASAT (Airspace Simulation and Analysis for TERPS) is a collection of models and simulations that can be used to analyze safety and risk factors for a large range of aviation scenarios. ASAT is a Monte Carlo Simulation tool that uses statistical input for Aircraft (flight dynamics, propulsion/performance, wake turbulence, on board avionics), Geographical/Geodetic (digital terrain elevation data, obstacles), Environmental (standards atmosphere, non-standards atmosphere, measured wind and temperature gradients data), Navigation ground systems, Surveillance (PRM, ASR-9, ARSR, TCAS, ADS-B), Human factors (pilot, ATC). ASAT can provide answers either in a deterministic or a probabilistic way.

As opposed to WAVIR and WAKESCENE/VESA it has not been specifically designed as a wake vortex risk assessment model. In fact it is a generic simulation package that can be used for many applications, of which wake vortex safety assessment is one.

The heart of the system consists of the high fidelity engineering flight dynamics models of three Boeing aircraft (737, 767, and 747) against which the lesser models normally used in the high speed simulations are frequently checked. Model performance is also driven by empirical data collected in flight simulators and flight tests. In addition to these aircraft simulation models ASAT comprises models of aircraft avionics (FMS, autopilot, etc.) based on real equipment, models of ground navigation aids, etc. In this respect the simulation models resemble the models as for instance used in auto-land certification.

The system also can generate and track wake vortices and identify encounters between wakes and aircraft in the scenario. As such ASAT is regarded as a candidate for wake vortex risk assessments.

Probabilistic wake vortex hazard model

To calculate the Wake Vortex hazard and 'Simultaneous Runway Occupancy' (SRO) risks for a given target wake vortex separation, the George Mason University (GMU) defines a method based on probability distribution functions of:

- Aircraft spacing in the common landing path when infinitely many aircraft are in the line to land
- Landing Time Intervals (*LTI*) to the runway threshold
- Inter-Arrival Times (*IAT*) at the final approach fix (*FAF*)
- Aircraft Runway Occupancy Times (*ROT*)

These probability distributions are to be calculated from samples extracted from aircraft time-position track data collected by the multi-lateration surveillance systems in the vicinity of an airport. Imposed separation, corresponding to the first distribution, is not directly observable from aircraft track data and is obtained using distributions of the other variables. Probability distributions for the locations and strengths of wake vortices are using existing wake vortex models such as the Probabilistic Two Phase (P2P) model, the AVOSS Prediction Algorithm (APA), and the TASS-Driven Algorithm for Wake Prediction (TDAWP). A safe wake vortex separation threshold is assessed with a hybrid simulation methodology

using separation probability distributions. The approach is hybrid as part of the simulation is conducted using a data feed of flight-track data, while the other part is obtained by simulation of wake-evolution models. The approach uses a sample of flight tracks to predict the frequency of potential wake alerts, which is defined as event where the trailing aircraft is in a *region* of space where the wake is likely to be.

The Equivalent Roll Rate Approach is based on an interesting new severity metric that could be considered as candidate to enhance the acceptability of Safety Cases and safety evidences [59, 60]. The basic idea behind the definition of the new metric is that it should be representative for the disturbance acting on the follower aircraft and that it should meet the following requirements:

- Static
- Meaningful
- Strong relation with the encounter severity, as experienced by the follower aircraft;
- Aircraft independent;
- Easy to be determined for a large range of aircraft, without need for access to proprietary data;
- Applicable in an absolute sense.

The equivalent roll rate metric [59] is called equivalent roll rate, because it represents the roll rate that provides an equivalent (opposite) rolling moment as the induced wake vortex induced rolling moment.

During a presentation at the 4th major & final WN3E workshop, Langen, Feb 28 2012, some results were shown of application of the equivalent roll rate criterion to current ICAO separations [60]. It was based on the approach used in RECAT work, using the decay line as proposed. For all 61 representative aircraft the maximum equivalent roll rate was calculated at the prescribed ICAO separation. It was shown that very good correlation existed for the calculated equivalent roll rate as function of the wing span.

The equivalent roll rate metric is a new development, and has never been subject to the scrutiny of extensive validation. Although results seem promising, in particular when considering the simplicity of the method and intuitively correct results, more work would be required to formally validate the metric. Also a sensitivity analysis would be required with respect to key parameters such as the effective chord and for instance the WV model to be used, including associated parameters such as the core-size. Another limitation of the metric is that it addresses only the lateral disturbance of the aircraft in response to WV encounters. If it is assumed that aircraft may traverse the wake vortex at some interception angle, it is clear that vertical disturbances may occur due to entering the downwash area between the vortex cores. Equivalent roll rate will not address the safety of this aspect of the encounter. Other than above mentioned limitations and considerations the equivalent roll rate criterion seems to be universally applicable, and a good candidate for application in follow-up RECAT activities. It will also be further developed by NLR in the EU Project UFO (Ultra Fast wind sensors for wake vortex hazards mitigation), which is being coordinated by Thales Air Systems S.A. (and which is planned to start in December 2012).

3.3. Research needs

The simulation models that support wake vortex safety assessment have some generic resemblance, but at the same time they differ essentially at the level of sub-models employed and the calculation processes used. A comparison and validation of sub-models used within different methods is likely to reveal several differences at sub-model level. For instance wake vortex evolution in ground-effect show significant discrepancies. Also the flight path evolution and wake vortex encounter models in the various risk assessment methods are often modelled differently. It is presently unknown how the various model assumptions and model simplifications in the mentioned models affect the final risk assessment results. However, in light of the anticipated application of the models in future approval processes, it is undesirable if the outcome (in terms of risk estimates) of the various models would differ significantly from each other. Therefore, as part of a future research outlook it is recommended to direct efforts into a comparison of the available models and validation of the employed sub-models. This would provide an indication which simplifications would be allowable, and where the models would be sensitive to the modelling structure and parameters. The outcome of this research could provide a baseline for modelling requirements that would be acceptable as a means of compliance in future approval (or certification)

processes. How this research should be mechanized is an issue that still needs to be agreed upon. An effective proposal could be to define a benchmark scenario and apply the various models to conduct a risk assessment for this scenario. This will give an indication of the level of differences between models and will help to identify required accuracies of sub-models to equalize differences to an acceptable level.

The WV behaviour analysis and WVE safety analysis activities are very time consuming and labour intensive and so it takes a long elapsed time before analysis results become available. There is a need for a much more automated and systematic process founded on standard data formats for the wake turbulence measurement data, the correlated aircraft data, and the correlated meteorological data. Automated methods need to be developed for data cleaning which automatically generate an auditable file to support the safety arguments and safety evidence requirements. Automatic methods need to be developed to carry out the safety analysis and generate the safety analysis results. Safety metrics need to be developed against which to assess the safety analysis results. The role of WV behaviour models towards providing safety evidence in support of safety arguments remains an important issue. The challenges associated with the validation of models such that the analysis results can be considered reliable enough to be used as safety evidence remains a research needs challenge. WV behaviour models have the potential to considerably reduce the need for WV behaviour data collection campaigns.

With the deployment of new operational concepts envisaged by SESAR and NextGen, the possibility of encountering wake vortices might increase. Especially 4D-Reference Business Trajectories (RBT) might lead to an increase of crossing, climb and descent through of other aircraft trajectories compared to today. To characterize the impact of these concepts and also the impact of different performance levels of ASAS applications on the Air Traffic System, the following research is recommended:

- Simulation of future air traffic containing estimated traffic mix and 4D-RBT to assess the probability and frequency of wake vortex encounters;
- Assessing the benefit of reduced ASAS Self Separation applications based on airborne Wake Vortex mitigation and alleviation systems;
- In combination with ASAS Self-Separation functions, the need arises to investigate and develop methodologies to mitigate wake vortex encounters en-route.

An innovative method to incorporate the safety benefits of (ground and airborne) wake vortex advisory system in the safety assessment has been developed and applied to two example concepts of operations [53, 54]. Additional research might be directed to further development, verification and validation of such methods, in order to improve the understanding of how the capabilities of these airborne and ground wake vortex systems can properly be taken into account in WV safety assessment and WV safety cases.

4. Incident and accident monitoring and analysis

4.1. Introduction

Incident Monitoring is a most important means to support operational changes. So far only in the U.K. a well structured incident reporting and analysis scheme has been applied to adapt wake turbulence separations according to objective local safety needs. As part of WakeNet, it is foreseen to use these well-known current best practices as a starting point for a wake incident reporting for Frankfurt airport. Experiences from the process to implement an incident reporting and analysis at Frankfurt will be collected and shared with the WakeNet3-Europe Partners. If successful, it might trigger similar attempts at other German and other European airports with wake turbulence related capacity or safety problems.

4.2. Overview of the current status

NATS and the CAA-UK are still running the voluntary wake vortex encounter reporting scheme in the UK, which was first established in 1972. NATS now has over 5000 wake vortex encounter reports in the UK Wake Vortex Encounter Database. The wake vortex reporting scheme became a national scheme in January 2008, so NATS now also requests wake vortex reports from non-NATS airports in the UK.

NATS assesses all wake vortex encounter reports as soon as they are received for severity and then all severe reports are sent onto the appropriate ATC unit for investigation. In order to monitor the safety of current operations, NATS analyses the wake encounter reports on a quarterly basis in order to identify any changes in the wake vortex encounter rate for specific aircraft pairs. This process identifies any aircraft pairs which have a statistically significant increase in the encounter rate compared with previous years. Observed increases in the wake encounter rate for particular aircraft pairs has been used historically to file for differences from the ICAO wake turbulence separation categories (e.g. the splitting of the Medium category). Analysis of wake vortex encounter reports also identifies any particular locations or altitudes where encounters are more likely to occur. In addition to standard monitoring and analysis activities, the wake vortex database has been used for the following safety activities:

- Wake vortex encounters have been correlated with LIDAR data collected at Heathrow airport as part of the Time Based Separation safety validation activities. This has provided a unique opportunity to determine the wake vortex behaviour that directly results in a wake vortex encounter. Wake vortex encounter analysis has also been conducted on the wake vortex database in support of the Feasibility and Options stage of the NATS Procedural Time-Based Separation project.
- Since May 2010, NATS have continued to monitor the wake vortex encounter rate as part of the safety case for the Reduced Time Based Longitudinal Separation (RLongSM) trial.
- NATS provided wake vortex encounter analysis to support the validation of the EUROCONTROL/ FAA RECAT project.
- The wake vortex database is being used to monitor the number of reports behind an A380 in UK airspace. This will be used as evidence to support whether the ICAO recommended separations for the A380 can be adopted in the UK.

The majority of publications related to the wake vortex database are confidential to NATS; however, a presentation given at the EUROCONTROL First Global Wake Vortex conference provides insight [19].

The CREDOS project provides recommendations for a Wake Vortex Safety Management System for Air Navigation Service Providers with respect to safety policy; safety achievement; safety assurance; and safety promotion. This includes the specification of details for wake vortex safety data collection, data processing and statistical treatment of data to be processed and used as part of the wake vortex safety management system [18]. Such data can be used for wake vortex reporting systems, safety occurrence investigation, safety monitoring. ANSPs may collect and analyze: flight identification data, actual aircraft separation data, meteorological data, wake vortex encounter engineering data, wake vortex evolution data, traffic statistics data, operational practices and procedural data, aircraft configuration data, wake turbulence report forms, as well as data from hazard/risk identification brainstorming. Guidance for the

design and set up of an ANSP wake vortex safety survey is also given. In this context, it is recommended to design a checklist and a questionnaire and to perform some statistical analysis on relevant causal factors and on actual aircraft separation data collected with a flight track registration system.

In case a new ATM operation with reduced aircraft separation (preferably supported by new wake vortex advisory systems) has actually been approved, a gradual transition phase from the current operation towards the new operation is proposed. During such transition phase, ANSPs are recommended to [18]:

- Perform *quarterly wake vortex safety surveys* to assess wake vortex safety of normal operations, using (wake vortex safety related) data available from:
 - Air traffic controller logs;
 - ANSP wake vortex safety survey checklists and questionnaires;
 - ANSP wake encounter reporting forms;
 - Flight track registration system data.
- Perform a *yearly analysis of wake vortex safety*. In addition to the above ANSP internal data sources, this could require (wake encounter) data from:
 - ICAO ADREP data;
 - JRC ECCAIRS data;
 - NLR ASR database information;
 - Pilot wake encounter reporting forms;
 - Quick Access Recorder (QAR) data;
 - Meteorological data sources;
 - WAVENDA analysis [40].

After the introduction of reduced aircraft separation (at least until it can be concluded that the actual implementation has actually been safe for a couple of years), the following wake vortex safety information will need to be provided on a regular basis [18]:

- Wake vortex safety survey results as part of quarterly safety bulletins;
- Wake vortex safety alerts to the air traffic controllers in case of safety findings and/or safety recommendations resulting from the wake vortex safety surveys;
- Wake vortex safety performance results as part of a yearly performance report.

4.3. Future developments

In recent years, Safety Management Systems (SMS) have become widely used in aviation. After introduction in other domains, it is now also promoted by ICAO, FAA, IATA, FSF and national authorities to support/manage safety improvements. For wake vortex safety monitoring, methods should be put in place to detect changes in systems or operations which may require corrective actions to be taken. The maintenance of (wake vortex) safety records throughout the entire life cycle of a system should provide evidence and argumentation demonstrating that a system is safe for operational use. A complete WV Safety Management System, as proposed by CREDOS, would also require the following [18]:

1. An ANSP is already required to have an operational SMS. Normal Operations Safety Surveys (NOSS) are being carried out on a regular basis, the resulting data are fed into the SMS database, and the Safety Manager is required to *add the WV component* to the NOSS.
2. The ANSP maintains a database with incidents and accidents, which is accessible for the air traffic controllers, who are required to report on WV encounters and WV separation infringements using reporting forms. Safety performance indicators and targets are maintained and updated regularly.
3. Willingness of airlines to provide Flight Data Analysis (FDA) or Flight Operations Quality Assurance (FOQA) data on wake vortex encounters for safety research investigation purposes and for inclusion into the ANSPs Wake Vortex Safety Management System database.

One should be aware that some of these assumptions are more realistic than others. As all the ANSPs in the ECAC region are formally required to implement the ESARRs, it seems reasonable to assume that most ANSPs are using an operational SMS and are also maintaining a database with incident and accidents. However, the willingness of airlines to make Flight Data Analysis (FDA) on wake vortex encounters available is, at present, relatively low due to confidentiality issues. In addition, it is noted that the use of supporting software and data(bases) may depend on commercial arrangements with the owners. Nevertheless, as wake vortex safety awareness within the aviation community increases, it is reasonable to hope that the above requirements for a complete WV SMS are satisfied in the near future.

One should note that pilot reports have an added value compared to ATC reports, as they tend to include more details about the effect of the encounter on the aircraft. However, ATC reports are usually more accurate in the description of the actual separation. Pilots should be encouraged to fill in their Airline Safety Reports as wake turbulence report forms or use the ICAO report form, which is currently available.

4.4. Research needs

It will be of particular importance to in-service monitoring that new WV separation procedures continue to show to be safe through quarterly and annual safety trend monitoring. It is still not clear for pilots how they can recognize a wake vortex encounter and distinguish such event from e.g. clear air turbulence. In support of WVE safety monitoring there is therefore a need to supplement the current subjective WVE reporting of pilots with a more systematic approach for monitoring WVEs. There is a need to develop on-board automatic recording of WVE events in such a way that they can be systematically processed after every flight and collected into a global WVE database to support future global WVE safety monitoring and WVE safety analysis activities. As parts of an Automatic WVE Reporting System it is suggested to include 3 elements: a) WVE Identification (including generator identification, b) WVE Severity Assessment, and c) data transmission, storage, and a link with safety management systems. A key enabler would be the current and future air-to-air data link standards. Further human factors research should be aimed at investigating how the reporting rate could be increased and how valid feedback should be provided to pilots and air traffic controllers reporting wake vortex encounters, e.g. using the ICAO WT reporting forms.

5. Conclusions and recommendations

The Coordination Action WakeNet3-Europe promotes multidisciplinary exchange between scientific and operational specialists in the field of wake vortex turbulence. The WakeNet Coordination Area Safety is a Working Group of WakeNet3-Europe, established by three partners of WakeNet3-Europe: NLR, Airbus, and DFS. The main objective is to close the gap between end-users and equipment manufacturers and the regulatory authorities in defining a consistent set of safety requirements and safety assessment procedures that are acceptable for the authorities to serve as a baseline for the operational approval of actual new systems or procedures. To reach this main objective, three separate tasks are ongoing:

- 1) Creation of a common understanding on the applicable rules, regulations, and associated safety requirements, for *operators, service providers, manufacturers, end-users*. This task deals with the fundamental issue of what is acceptable for *regulatory authorities* to serve as baseline for the operational approval of new wake vortex advisory systems or procedures.
- 2) Promotion of information exchange and communication between partners, participants and stakeholders on requirements, development, definition, validation of:
 - 1) *wake vortex encounter severity criteria* and 2) *safety assessment methods*
- 3) Promotion of European WV incident monitoring and analysis by 1) establishing and maintaining a link to existing wake turbulence incident reporting activities, 2) implementing Wake Vortex reporting and analysis at Frankfurt airport, and 3) trigger WV incident monitoring and analysis at other airports.

In support of the main objective, this document provides a state-of-the-art in Wake Vortex Safety:

4. *Applicable wake vortex regulations and safety requirements*. ICAO Annex 14, by referring to the ICAO PANS-ATM, mentions wake vortex standards. The PANS-ATM provides guidance on the standards for wake vortex separation minima, but it should be noted that these minima are not a binding requirement. ICAO Doc 9426 gives a very high-level set of (prescriptive) requirements for the introduction of wake vortex advisory systems, whereas ESARR4 provides the basic ATM safety requirements for an (analytical) approach to derive - using guidance material and safety assessment methods - specific safety requirements for the humans, procedures, and subsystems involved. However, in view of the recent transfer of responsibility for the certification and approval of ATM systems to EASA and the ongoing development of the Implementing Rules to be completed by 2013, it is likely that detailed Acceptable Means of Compliance for new ATM concepts and systems for wake vortex avoidance (as are being developed in SESAR) will not be available in the next few years. It is recommended that WakeNet 3 Europe identifies the Research Needs in support of this change.
5. *Wake vortex safety assessment*. Several simulation models that support the assessment of the actual wake vortex risk level of flight procedures have been identified. The simulation models that support wake vortex safety assessment have some generic resemblance, but at the same time they differ essentially at the level of sub-models employed and the calculation processes used. A comparison and validation of sub-models used within different methods is likely to reveal several differences at sub-model level. Therefore, it is recommended to direct efforts into a comparison of the available models and validation of the employed sub-models. This would provide an indication which simplifications would be allowable, and where the models would be sensitive to the modelling structure and parameters. This will give an indication of the level of differences between models and will help to identify required accuracies of sub-models to equalize differences to an acceptable level.
6. *Wake vortex incident and accident monitoring and analysis*. Within Europe, so far only in the U.K. a well structured incident reporting and analysis scheme has been applied to adapt wake turbulence separations according to objective local safety needs. As part of WakeNet, it is foreseen to use these well-known current best practices as a starting point for a wake incident reporting for Frankfurt airport. CREDOS provides recommendations for a Wake Vortex Safety Management System for Air Navigation Service Providers with respect to safety policy; safety achievement; safety assurance; and safety promotion. This includes details for wake vortex safety data collection, data processing and statistical treatment of data to be processed and used as part of a WV safety management system.

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7. List of Acronyms

ADREP	Accident/incident Data Reporting System
ADS-B	Automatic Dependent Surveillance Broadcast
ANS	Air Navigation Service
ANSP	Air Navigation Service Provider
APA	AVOSS Prediction Algorithm
ARSR	Air Route Surveillance Radar
ASAT	Airspace Simulation and Analysis for TERPS
ASR	Air Safety Report
ASR-9	Airfield Surveillance Radar 9
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Service
AVOSS	Aircraft Vortex Spacing System
AWO	All Weather Operations
BADA	Base of Aircraft Data
CAA	Civil Aviation authority
CAP	CAA Publication
CREDOS	Crosswind Reduced Separation for Departure Operations
CS	Certification Specifications
DFS	DFS Deutsche Flugsicherung GmbH
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EASA	European Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference
ECCAIRS	European Co-Ordination Centre for Aviation Incident Reporting Systems
ESARR	EUROCONTROL Safety Regulatory Requirements
EU	European Union
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FANOMOS	Flight Track and Noise Monitoring System
FDA	Flight Data Analysis
FHA	Functional Hazard Assessment
FOQA	Flight Operations Quality Assurance
FSF	Flight Safety Foundation
GMU	George Mason University
ICAO	International Civil Aviation Organisation
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements
IAT	Inter Arrival Times
IATA	International Air Transport Association

ILS	Instrument Landing System
IR	Implementing Rules
LIDAR	Light Detection And Ranging
LOSA	Line Operations Safety Audit
LTi	Landing Time Interval
NERL	NATS En-route Plc.
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
NOSS	Normal Operations Safety Surveys
NOWVIV	Nowcasting Wake Vortex Impact Variables
P2P	Probabilistic Two Phase
PANS	Procedures for Air Navigation Services
PRM	Precision Runway Monitor
PSSA	Preliminary System Safety Assessment
PU	Public
QAR	Quick Access Recorder
RECAT	Revision of the Wake turbulence categories
RLongSM	Reduced Time Based Longitudinal Separation
ROT	Runway Occupancy Times
SAM	EUROCONTROL Safety Assessment Methodology
SARPS	Standards and Recommended Practices
SES	Single European Sky
SESAR	Single European Sky ATM Research
SMS	Safety Management System
SRC	Safety Regulation Committee
SRO	Simultaneous Runway Occupancy
TASS	Terminal Area Simulation System
TBS	Time-Based Separations
TCAS	Traffic Collision Avoidance System
TDAWP	TASS Driven Algorithm for Wake Prediction
TERPS	Terminal En-Route Radar Procedures
TSO	Technical Standard Order
UCL	Université Catholique de Louvain
UK	United Kingdom
US	United States
USA	United States of America
VESA	Vortex Encounter Severity Assessment
WAVENDA	Wake Vortex Encounter Detection Algorithm
WAVIR	Wake Vortex Induced Risk assessment
WVAS	Wake Vortex Advisory System
WN3E	WakeNet 3 Europe
WV	Wake Vortex
WVE	Wake Vortex Encounter

Appendix A Workshop Regulation and safety requirements

09:30	Registration and coffee/tea
10:00	Opening session: Welcome & Introduction Michel Piers, Director NLR Air Transport Safety Institute Lennaert Speijker, Senior R&D Manager, NLR-ATSI
10:10	Topic 1: Applicable ICAO standards and potential changes
10:15	<i>Amendment of ICAO wake turbulence provisions</i>
10:25	Re-categorization of the wake turbulence separation minima Vincent Treve / EUROCONTROL
10:45	Discussions
11:00	Coffee/tea break
11:10	Topic 2: Initiating the Safety Regulatory Process
11:30	The European certification process Frederic Copigneaux / EASA
11:50	Safety scanning for introduction of changes to the aviation system Jos Nollet / EUROCONTROL Safety Regulation Commission (SRC) member
12:10	Discussions
12:30	Lunch
13:30	Topic 3: Existing rules and guidance for certification and approval of changes
13:35	Implementation of SES RAM regulations and their migration to EASA IRs John Penny / CAA UK
13:55	Wake turbulence from light rotorcraft and separation criteria Panagiota Pantazopoulou / CAA UK
14:15	Discussions
14:45	Coffee Break
15:15	Topic 4: The Safety Case – Practical example
15:20	Introduction of Wake Independent Operations (WIDAO) in France Vincent Treve (EUROCONTROL) & Laurent Chapeau (DGAC)
15:40	Introduction of the Airbus A380 Vincent Treve (EUROCONTROL)
16:00	Discussions
16:30	Closing session : Synthesis Lennaert Speijker, WakeNet Task Leader "Wake vortex regulation and safety requirements"
16:45	End of Workshop on wake vortex regulation and safety requirements

WELCOME, BY Piers

Mr. Piers opened the Workshop and welcomed all the participants, noting the wide variety of experts, carefully selected, so as to cover all relevant issues in the field of wake vortex safety and regulations.

INTRODUCTION & AMENDMENT OF ICAO WAKE TURBULENCE PROVISIONS, BY Speijker

Mr. Speijker explained the main purpose of the Coordination Area Safety, aiming to close the gap between end-users and equipment manufacturers and the regulatory authorities in defining a consistent set safety requirements and safety assessment procedures that are acceptable for the authorities to serve as a baseline for the operational approval of actual new systems or procedures. It was highlighted that the ICAO Annex 14 Aerodromes is the only regulatory standard document that mentions the issue of wake turbulence separation minima, by referring to the PANS-ATM (Doc 4444). Wake turbulence separation minima guidelines are laid down in three sub-sections:

- 4.9: Wake turbulence categories
- 5.8: Non-radar wake turbulence longitudinal separation minima
- 8.7.4: Radar separation minima

ICAO wake vortex advisory system guidance is provided in ICAO Doc 9426, Part II, Chapter 3, Appendix A, which states high-level requirements that a wake vortex avoidance system should meet.

RE-CATEGORIZATION OF THE WAKE TURBULENCE SEPARATION MINIMA, BY TREVE

Mr. Tréve explained the rationale behind the RECAT project, a joint EUROCONTROL – FAA effort. Its aim is to design new wake turbulence categories and associated separation standards. Specifically, the idea is to design a 6 category wake turbulence scheme, based on a methodology that can also handle future new aircraft types. The aim is no changes on the flight deck, minimum modifications on the ground (if any), and minimum changes in procedures. Instead of the current maximum take off weight based scheme, the methodology is expected to also take into account speed and wingspan. Next steps will be to define the procedures, evaluate human factors aspects, and initiate a proposal for amendment of the ICAO Doc 4444 wake turbulence separation minima provisions. Such proposal would be based on the assumption that states will decide on the implementation time schedule based on their local needs, allowing for the use of the current ICAO wake turbulence scheme and the future RECAT scheme. It is noted that the supporting Safety Case for RECAT still needs to be established.

THE EUROPEAN CERTIFICATION PROCESS, BY COPIGNEAUX

Mr. Copigneaux introduced EASA (its structure, remits, rules and their levels), the process for Product Certification, the concept for Design Organization Approval, the Type Design Certification process, Safety Oversight, Flight Standards certification. Initially, EASA became responsible for airworthiness and environmental design approvals. The first remit extended the responsibility to Operations and Flight Crew Licensing. The second remit extends the responsibility to also cover ATM and Airports.

SAFETY SCANNING – WHERE DOES IT FIT, BY NOLLET

Mr. Nollet introduced Safety Scanning, a new pro-active method – developed by the Safety Regulation Commission - to be used by a National Supervisory Authority (NSA) for a) effective safety and risk management planning, and b) review of (major) changes. Safety scanning is designed on the basis of so-called Safety Fundamentals (areas of safety interest) and is to be used in a multi-actor stakeholder setting. It will be offered to the SRC for formal endorsement by the end of 2010, and is planned to be formally launched in a joined workshop with the EASA Safety Assurance Task Force by March 2011. Further work (e.g. development of additional guidance) is still foreseen, and it is aimed to get the associated Safety Scanning Tool accepted by EASA as Acceptable Means of Compliance material.

IMPLEMENTATION OF SES RAM REGULATIONS INTO EASA REGULATIONS, BY PENNY

Mr. Penny explained the process of changing from the existing situation with Single European Sky (SES) Risk Assessment and Mitigation (RAM) regulations to a future situation where – as a consequence of EASA having taken responsibility in the safety regulation of ATM - safety elements of the SES regulations are moved into EASA Implementing Rules (IR). This process is facilitated by the EASA Safety Assurance Task Force (SATF), which – besides Implementing Rules (IR) – also handles AMC and Guidance Material associated with management, assurance and supervision of a change. It was explained how and why the use of a safety case grants Air Navigation Service Providers (ANSPs) the freedom to choose whether to use a standard or not. Even if they choose to use a standard they would still have to demonstrate safe use of the standard. WakeNet Europe will be beneficial when it provides re-usable evidence on causes and effects of wake turbulence. An ANSP can use this evidence to decide what separations are appropriate for his operation (and its interaction with neighbouring operations) and include it in his safety case. The ANSP would also establish the safety requirements for the change. Mr. Penny feels that these cannot be determined in advance and so working groups such as WakeNet should be cautious when using the term ‘safety requirements’.

WAKE TURBULENCE FROM LIGHT ROTORCRAFT & SEPARATION CRITERIA, BY Pantazopoulou

Mrs. Pantazopoulou explained that currently there are no separation criteria for light aircraft following the same weight group helicopters (weight < 7,000 kg) in hover or forward flight, in or out of ground effect. The need to address and investigate emerged as a result of an accident, in which on approach to land a Piper PA-28 flew through the wake vortex generated by a Sikorsky S76 and the aircraft rolled uncontrollably to the right and struck the ground. The AAIB accident report concluded that “*hazards associated with rotor wash generated by helicopters in hover or in air taxi operations should be investigated. In absence of encounter measurements for the case of hover flight, it is recommended that small airplanes, at the same altitude and downwind of a hovering helicopter, maintain at least 500 feet of separation*”. Activities are in progress and it is planned to inform the ICAO WTSG about this.

INTRODUCTION OF WIDAO IN FRANCE, BY CHAPEAU & TREVE

Mr. Chapeau highlighted the objectives of the French National Supervisory Authority (NSA), as being:

- To review the safety case to assess the conformity to DSNA procedures and to Regulations;
- To provide formal acceptance before implementation of the change;
- To ensure that all stakeholders are involved throughout the process.

Key issues from the point of view of the French NSA are e.g. to have a Safety Plan, updated over the project duration, and in which it is demonstrated that the measures are sufficient. Important is to establish a Wake Vortex-Safety occurrences analysis, so as to ensure and show that the change did not – as planned - have a negative impact on safety. The specific case of the Airbus A380 requires special attention. Important is also the evaluation of the impact on ATCOs procedures, provision of sufficient ATCOs information and training, and oversight of the implementation of mitigation means. Mr. Tréve described the principles and methodology used for the WIDAO wake vortex encounter risk assessment and mitigation. He also provided an overview of the data collection, analysis and modelling techniques used to support the wake turbulence risk assessment in the WIDAO project.

INTRODUCTION OF THE AIRBUS A380, BY TREVE

Mr. Tréve explained the process used for design of the A380 Wake Turbulence Separations, which included back to back test of the Boeing 747-400 and Airbus A-380. New separation for this “Super” Heavy aircraft was designed based on relative comparison of LIDAR wake turbulence measurements. A first set of separations based on a first LIDAR measurement campaign was delivered to ICAO in 2006. Reduction of the separations based on a second LIDAR measurement campaign was delivered to ICAO in 2008. Potential further reduction of current wake separations based on advanced metrics for Wake Vortex Encounter characterization is ongoing. Results from this activity is expected in 2011.

Appendix B Workshop Incident monitoring & accident analysis

09:00	Registration and coffee/tea
09:20	Opening session: Introduction Jens Konopka, DFS
09:30	Topic 1: Wake Vortex Reporting Requirements
09:35	Wake vortex reporting as means for monitoring safety impact of new procedures versus being a wake vortex encounter data source for additional research and development
09:55	Wake encounter severity metrics as input to monitoring requirements Andreas Reinke / Airbus
10:15	Discussions
10:45	Coffee Break
11:15	Topic 2: Wake Vortex Incident/Accident Data Repositories
11:20	Use of existing incident/accident data repositories Peter van der Geest / NLR
11:40	Wake Vortex Incident/Accident Analysis in the UK Matt Ross / NATS, UK
12:00	Discussions
12:30	Lunch
13:30	Topic 3: Analysis of Wake Vortex Encounters – ATM view
13:35	Implementation of wake incident reporting for Frankfurt – approach, status, lessons learned Jörg Buxbaum / DFS
13:55	Discussions
14:25	Coffee break
14:55	Topic 4: Analysis of Wake Vortex Encounters – aircraft operators view
15:00	Wake vortex reporting requirements – a pilot’s view Markus Wahl / ECA
15:20	Analysis of wake vortex encounter flight data Michael Wendt / Lufthansa
15:40	Discussions
16:30	Closing session : Synthesis Jens Konopka, WakeNet Task Leader “Incident/accident monitoring and analysis”
16:45	End of Workshop on incident and accident monitoring and analysis

WELCOME, BY KONOPKA

Mr. Konopka opened the Workshop and welcomed all the participants, while mentioning that accident analysis is not a pressing issue, since there is a very small number of accidents where wake turbulence was the prime cause and wake turbulence is not among the large aviation hazards. Data about wake turbulence encounters are rare not because of rare occurrence of wake encounters. He explained that there might be a difficulty related to gathering wake vortex encounter data due to the following:

- Data about wake turbulence encounters are rare not because of rare occurrence of wake encounters.
- Wake encounters are considered part of a pilot's regular business.
- Many encounters are not recognized as such.
- The majority of encounters are felt to be a passenger discomfort issue rather than a safety threat.
- Pilots/air traffic controllers have only little possibility to take notes shortly after the incident.
- Benefits of reporting wake turbulence encounters are not known to aircrews and air traffic controllers.

He explained the current ICAO recommendations for collection of wake vortex encounter information as indicated in ICAO State Letter AN 13/4-07/67 from 26 October 2007, implying that all ICAO States should commence a wake vortex reporting scheme 'as soon as practicable'. Mr. Konopka highlighted the aims of the workshop, including acquiring insight into the perception of the participants on the following topics:

- Can the frequency of wake encounters (per flight phase) be deduced from currently available data?
- Have the available wake incident/encounter data already been fully exploited?
- Does the current level of reporting yields a representative picture about the occurrence of WVEs?
- Is the information provided sufficient and accurate enough?
- Which means could ease reporting by pilots and air traffic controllers?

WVE SEVERITY METRICS AS INPUT FOR MONITORING REQUIREMENTS, BY REINKE

Mr. Reinke highlighted as main needs and objectives for Wake Encounter Incident Reporting:

- To identify critical and/or relevant operational conditions
- To establish baseline safety levels
- To monitor safety trends after implementation of new procedures or aircraft
- To identify encounter events for advanced analysis of encounter effect on the aircraft

Two options for WVE incident reporting were discussed: pilot reporting and automatic WVE reporting. With respect to the former, as main limitations are noted a) a full operational picture is not available (e.g. generator aircraft info) or not remembered or not asked, b) reporting level is not known, c) severity level is not standardized (or not asked). Therefore, he feels that Pilot Reporting cannot be used to establish baseline safety level, would provide low level of confidence in monitoring safety trends. Nevertheless, it can help to identify critical and/or relevant operational conditions. With respect to the latter, as main limitations are noted a) currently no system is available, b) severity level is not standardized, and c) aircraft equipage is required (although initially a low equipage level could suffice). Therefore, he feels that automatic WVE reporting could be used to establish baseline safety level and would provide an objective monitoring of safety trends, while it can also help to identify critical and/or relevant operational conditions.

As parts of an Automatic WVE Reporting System he foresees a) WVE Identification (including generator identification, b) WVE Severity Assessment, and c) data transmission, storage, and a link with safety management systems. A key enabler would be the current and future air-to-air data link standards.

USE OF EXISTING INCIDENT/ACCIDENT DATA REPOSITORIES, BY VAN DER GEEST

Mr. Van der Geest presented a study performed in the context of the CREDOS project. It concerns an assessment of WV incidents using existing incident/accident data repositories to provide an estimate of current WV related incident rate per flight phase and for each flight phase the aircraft combinations involved (leader/follower). The results were presented for the following flight phases: departure, climb, cruise, descent, and arrival. It is striking that during arrival still 27.6% of the incidents occur between aircraft combinations for which wake turbulence separation minima apply. Flight crew actions to recover the aircraft include aileron/rudder input, flying off track and/or auto-pilot disengagement (manual action).

WAKE VORTEX INCIDENT/ACCIDENT ANALYSIS IN THE UK, BY ROSS

Mr. Ross provided the background to the successful UK wake encounter reporting scheme and explained what happens when they receive an encounter report. He provided examples of analysis, explained the regular monitoring activity and the steps that are being taken to improve the reporting. According to Mr. Ross, a voluntary wake turbulence reporting scheme can be used to:

1. Monitor the effectiveness of current separation minima and file for changes against the current ICAO wake vortex categories, e.g. splitting of the Medium category.
2. Highlight specific areas of concern, e.g. turn onto glide-slope.
3. Highlight potential wake turbulence risk areas in new procedures or airspace changes.

An effective wake turbulence reporting scheme requires feedback to the pilots and airlines to encourage them to continue reporting, while it is aimed to increase the ATC awareness and effective WT reporting.

IMPLEMENTATION OF WAKE INCIDENT REPORTING FOR FRANKFURT, BY BUXBAUM

Mr. Buxbaum described the effort to introduce a DFS-wide, voluntary WVE reporting. The reports form is designed to consist of basic elements: time or exact place of incident, aircraft in question (Callsign), replay of incident is based upon radar data / track data and flight plan information. If needed, acquisition of meteorological circumstances. Behavior of aircraft is only assessable, if further information (e.g. roll movement) is provided by pilots and/or airline. Unfortunately until now, only a minor amount of reported incidents, possibly due to the fact that pilots and ATCOs only have partial wke vortex knowledge. In conjunction with fragmentary data of actual WVEs this could lead to wrong interpretation, false deductions and bad lessons learned. Only an open exchange between the scientists and operational experts can help. Reporting of non-ATC-relevant 'minor' events with a lucky outcome might be difficult for ATCOs because they are used to look ahead, rather than backwards. Alternative ways to document wake vortex incidents should be considered. This could e.g. include a voice recorder with speech recognition, voice based incident data logger with exporting function to logbook and/or other automatic processing means.

WAKE VORTEX REPORTING REQUIREMENTS – A PILOT'S VIEW, BY WAHL

Mr. Wahl stresses that pilots usually not read ICAO manuals, but will focus on their Operation Manuals. Therefore, it could be that the Wake Turbulence provisions, which are described in detail in the ICAO documentation, are not well known to pilots. Furthermore, in most Operation Manuals, Wake Vortex Encounters are not a mandatory reporting item. Even if there is mandatory reporting, it is not clear how a pilot can recognize a wake vortex encounter and distinguish such event from e.g. clear air turbulence. Reporting could be hindered because of high workload during the various phases of flight, and after the flight it may be difficult to remember exactly all the circumstances. Nevertheless, there are reports and pilots would of course like to receive feedback and recommendations to keep motivated to file reports. Feedback should include a detailed analysis of the situation and recommendations on how to avoid the situation with the information that is available in the cockpit. Three basic questions remain:

1. How to distinguish between a WVE and "regular" turbulence?
2. How to improve the reporting rate?
3. How to provide a valid feedback to the pilots?

Appendix C Workshop Wake Vortex Encounter Severity Criteria

09:20	Workshop Opening, Welcome and Logistics
09:35	Presentation Session
09:35	Wake Vortex Encounter Severity Criteria Carsten Schwarz, Dennis Vechtel / DLR
10:20	Airbus View Andreas Reinke / Airbus
10:50	Coffee Break
11:10	Assessment of Wake Vortex Encounter Severity Criteria Robert Luckner / TU Berlin
11:40	Wake vortex severity criteria – the search for a single metric: the potential of equivalent roll rate Peter van der Geest / NLR
12:10	Discussion Session
12:10	No Encounter – Policy 2012 – Thoughts and ideas from an email brainstorming Nikolaus Braun (ECA) and ALL
12:35	Lunch
13:50	Discussion on next steps towards commonly accepted severity criteria: the WHAT is needed? (requirements, applications, levels of severity) Carsten Schwarz (DLR) and ALL
14:30	Coffee break
14:50	Discussion on next steps towards commonly accepted severity criteria: the HOW to get there? (evaluation parameters, criteria design, threshold identification, validation) Carsten Schwarz (DLR) and ALL
15:30	Closing Session
15:30	Summary and wrap-up Carsten Schwarz (DLR), Andreas Reinke (Airbus) and ALL
16:00	End of Workshop on Wake Vortex Encounter Severity Criteria

Motivation/ focus/ goals of workshop

This international workshop on wake encounter severity criteria is organized because there are (still) no commonly accepted severity criteria available (e.g. for differentiation between “acceptable” and “unacceptable” WVEs). Furthermore, severity criteria are an important element of any WVE safety assessment. There is therefore a need for agreement on international level. The focus of workshop was on severity criteria, not on complete safety assessments. Topics to be considered include:

- requirements & target applications
- classes of severity criteria (a priori vs. a posteriori criteria)
- associated severity levels
- flight dynamic evaluation of wake encounters and fundamental parameters
- criteria design and identification of thresholds
- validation requirements and means

The goals of the workshop are:

- agreed next steps towards commonly accepted severity criteria, requirements, definitions
- overview on available data, tools/ methods
- create short synopsis document (no minutes) with few consolidated agreed statements

Wake Vortex Encounter Severity Criteria (Carsten Schwarz, Dennis Vechtel - DLR)

General considerations for severity assessment/criteria are presented. Possible steps include:

- Survey of quantitative limits applicable for passenger air transport
- Selection of limit values relevant for wake vortex encounters
- Development of severity criteria
- Setting of severity boundaries/limits: acceptability vs. unacceptability

Severity Assessment is usually based pilot evaluation rating scales and severity analysis/ assessment activities: analytical studies, offline simulations, pilot-in-the-loop simulations, wind tunnel studies, flight tests. FAA severity criteria activities aim to characterizing wake vortex encounters for hazard analysis for Safety Management System (SMS) purposes and developing models/ analysis tools to determine today's wake vortex encounter frequency/ intensity. Applications and tools include airspace simulation, encounter assessment, ATM advisory systems. Available data includes evaluated piloted wake vortex encounter data, and wake vortex aircraft data. At present, there are no commonly accepted severity criteria available. There is therefore a need to agree on the next steps towards commonly accepted severity criteria, requirements, definitions to consider (as well as the available data, tools/ methods, applications).

Wake vortex severity criteria - The search for a single metric: The potential of equivalent roll rate (Peter van der Geest - NLR)

WV severity metrics used today include circulation, rolling moment, rolling moment coefficient, roll control ratio, and roll response. A new metric is proposed: Equivalent roll rate. Is a measure for induced rolling moment, but presented in a (physically and easily) understandable quantity. It can be computed with a minimum of information concerning aircraft properties, but yet provides a metric with which aircraft mutually can be compared. Initial research indicates that a single, absolute, criterion discriminates well between acceptable and non-acceptable encounters. An example application of equivalent roll rate to RECAT scenario is presented. It is concluded that the equivalent roll rate appears to have very good potential. Therefore, it should be further considered, analysed and validated.

Assessment of Wake Vortex Encounter Severity (Robert Luckner - TU Berlin)

Methods and criteria to assess WVE severity have been extensively investigated. They exist and have been demonstrated in research projects. Limits that distinguish acceptable and unacceptable encounters have been proposed. However, an agreed definition of what is acceptable does not exist. Methods and criteria have not yet been applied in rule making; instead indirect measures are used. FAA has proposed a way ahead on the methodology to develop severity criteria that are accepted by all stakeholders [58]

Airbus View (Andreas Reinke - Airbus)

Andreas Reinke revisited an Airbus presentation from a WakeNet Europe Berlin 2006 workshop. Some additional thoughts on severity criteria were mentioned:

- Categories could include acceptable (“green”)/ reportable (“amber”)/ unacceptable (“red”)
- For evaluation of design changes a posteriori multi-parameter criteria appear essential
- Candidate a priori indices:
 1. allow variations of all primary wake vortex parameters (circulation, core radius, vortex separation)
 2. allow variations of only a few key follower parameters
 3. roll inertia radius to measure follower vulnerability (inversely proportional) is surprisingly constant

„No Encounter“ - Policy 2012 – Thoughts and Ideas from an Email-Brainstorming (Nikolaus Braun - ECA)

IFALPA Policy Statement of 2004: "Wake turbulence separation standards should ensure that aircraft are not exposed to known wake turbulence caused by preceding aircraft (= "No Encounter" Policy)". Some personal pilot statements (no official IFALPA view) were made. Pilots thoughts on encounters include:

- “The clearest dividing line is between no encounter and an encounter.”
- “... not intentionally put our crews and passengers at risk by trying to assign an exact separation number to an inexact natural hazard without better understanding it.”
- “... suggestion for a way forward would be to go along with the existing definitions for turbulence effects (PANS-ATM Appendix 1) ... MODERATE (and more) should continue to be avoided.”

Pilots thoughts on systems include:

- There is a need for predictive equipment, Flight Data Recordings analysis, Wake Vortex reporting
- Reporting is “inadequate”, Flight Data Recordings screening “may provide a more accurate baseline”
- Visualisation on “HUD might be a nice option to have”,
- First step could be to get rid of Preventive Windshear Detection (PWS) inhibition at higher altitudes.

Workshop conclusions - Next steps towards commonly accepted severity criteria

Next steps towards commonly accepted severity criteria: The WHAT (“What is needed?”)

The following applications are targeted for utilising wake encounter severity assessment:

- System/procedure development (e.g. ATM advisory, onboard warning, avoidance, flight control)
- Separation minima adaptations based on new systems/procedures
- Safety cases
- Monitoring of operations

The following requirements apply for severity criteria:

- Authorities may only accept safety cases for specific applications, but not issue general statements on wake encounter severity assessment
- Existing safety regulatory guidelines (e.g. ESARR) do not include wake encounter specifics
- Evaluation could be relative, but absolute evaluation is important and is desirable
- Several safety cases have been accepted by authorities (using some kind of criteria)
- For short term applications short term solutions (i.e. less complex) are required, however long term solutions may still be developed

Properties/characteristics of severity criteria:

Different definition/properties of the term “criteria” exist. Severity criteria simplify a complex event. Severity criteria are not necessarily considered to be a model. A model is a representation of a process or object. By contrast criteria allow evaluation or categorisation and comparison on an abstract level. The Definition of “criterion” according to <http://www.merriam-webster.com>: “a standard on which a judgment or decision may be based”

The following requirements were stated:

- severity criteria should be reasonably conservative
- severity criteria should be designed in a reasonably simple way/reasonably transparent
- severity criteria should be discriminative (strong relationship between severity and metric)
- severity criteria should be aircraft independent/ possible to determine for numerous aircraft types
- severity criteria should be for absolute assessment (opposed to relative)
- severity criteria should be meaningful, i.e. directly relating to relevant parameters/effects
- validation of thresholds must be possible

A priori severity assessment could include:

- Severity „prediction“
- Severity assessment before an encounter takes place
- Assessment based on limited data, e.g. estimated vortex strength and position

A posteriori severity assessment could include:

- Severity „analysis“
- Severity assessment after a (simulated) encounter takes place
- Assessment based on detailed data including time histories of aircraft parameters

Next steps towards commonly accepted severity criteria: The HOW (“How to get there?”)

The IFALPA policy on “reduced wake turbulence separation minima” states “Wake turbulence separation standards should ensure that aircraft are not exposed to known wake turbulence caused by preceding aircraft (= “No Encounter” Policy).” (2004). IFALPA supports the 1997 US FAA Flight Standards position that no planned penetration of wake vortices of any intensity is permitted.” (1998). Pilot views/policies should be considered for future activities and possible new definitions of severity, analysis of operational limits by operators or airframers, and analysis of actual aircraft movement in other conditions (turbulence) as a comparison for WVE scenarios. It was noted that it may be necessary to evaluate wake encounters in combination with other failures (e.g. engine out, control system failures). Numerous wake encounter pilot rating scales exist and should be considered for further piloted tests before developing new ones.

Fundamental wake encounter evaluation criteria/ parameters (subjective/ quantitative) include: roll control ratio RCR, equivalent roll rate, wake induced rolling moment coefficient, static/equivalent roll acceleration, and roll response (i.e. bank attitude).

Criteria design and identification of thresholds could be based on today’s situation, which is considered to be safe for the existing traffic mix, proven by decades of operations. For bank angle limits one has to distinguish between coordinated turns and turbulence encounters. According to DLR, possible steps include: 1) a survey of quantitative limits applicable for passenger air transport (flight phase dependent), 2) selection of parameters and limit values relevant for wake vortex encounters, and 3) development of severity criteria containing the relevant limits from step 2, i.e. not violating the severity criteria ensures not to violate any of the relevant limits from step 2. According to TU Berlin, possible steps include 1) combined evaluation of piloted WVE data, manual/ procedure information, literature references, 2) selection of metrics and envelope limits, 3) criteria validation, and 4) derive severity criteria model.

Final conclusions (from this workshop)

Future research activities towards commonly accepted wake vortex encounter severity criteria are encouraged. Revisiting what has been done and is already available is recommended. For the application of wake vortex encounter severity criteria the following is required: involvement of all stakeholders, a road map that describes the procedure for criteria development and validation, possibly based on considerations from this workshop as well as the required data for validation. Experience shows that research results may not be applied in rule making and certification otherwise. Therefore, the commitment of all stakeholders, especially the regulators, is essential for this approach. The objective to develop commonly accepted wake vortex encounter severity criteria should be part of the future EC framework programmes in order to advance European know-how.