European Prediction and Measurement Campaigns of Wake Vortices and Meteorological Parameters: Datasets, Quality Assessment and Achievements

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In this talk I intend to present the major outcomes of recent wake vortex campaigns in terms of forecasted and observed meteorological conditions and their impact on predicted and measured wake vortex transport and decay. The necessity of probabilistic approaches will be pronounced. The potential to reduce aircraft separations with the given quality of prediction and observation data and methods will be discussed.

Probabilistic Wake Vortex Decay Model Predictions Compared with Observations of Four Field Measurement Campaigns

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Predictions of the parametric aircraft wake vortex transport and decay model P2P are compared with field observations. The two-phase decay model predicts probabilistic wake vortex behavior as a function of aircraft and environmental parameters in real time. Observation data from field deployments accomplished at the International Airports Memphis and Dallas Fort Worth, from the WakeOP campaign performed at the airfield in Oberpfaffenhofen, Germany and from the WakeToul campaign at Tarbes airport, France are employed.

The quality of wake vortex and coincident meteorological data and the conclusions that can be drawn from the data strongly depend on many factors including the measurement strategy, the type of sensors used, their locations, and the temporal and spatial resolution of the measurements, as well as the aircraft mix and the prevailing meteorological conditions. Peculiarities of the campaigns and related intrinsic problems are discussed with respect to real-time wake vortex forecasts.

Based on 211 Memphis cases, it is shown that the probabilistic model predicts conservative confidence intervals for vortex decay with the exception of four cases in which constant background wind shear increases vortex lifetime. Nonetheless, the aircraft spacing reduction potential based on vortex decay appears small. In contrast, consideration of advection outside the lateral limits of a safety corridor results in a large potential spacing reduction. Vortex drift is investigated based on input from different wind measurement devices with a focus on the spatial and temporal variability of the crosswind. Safety corridor clearances based on short term weather forecasts yield promising results. Further, it is found that shear layers may modify vortex transport such that predicted uncertainty allowances are exceeded. Measurements of the 2 micron pulsed lidar system at the WakeTOUL campaign allow to observe circulation evolution until a progressed state of vortex decay. The measurement results clearly supply evidence of the two-phase vortex evolution anticipated by P2P.
NASA Langley Research Center (LaRC) has collected large amounts of field data to support wake vortex research. These data include wake vortex position and strength information from a variety of research sensors, and corresponding meteorological parameters relevant to wake vortex behavior. The data was collected during field deployments from 1994 to 2000. The content and availability of the LaRC wake data will be summarized in this presentation, as well as the usefulness of the various types of data for wake modeling activities. Recent analysis of the data for wake modeling and wake mitigation concept development will also be discussed.

**STL Data Collection Campaign – Status and Analysis Plans**

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The Federal Aviation Administration (FAA) and National Aeronautics and Space Administration (NASA) are jointly investigating wake turbulence avoidance strategies for eventual implementation into the National Airspace System (NAS). They have jointly developed a phased approach to increase airport capacity through safe reduction of existing wake turbulence constraints. The objective of the first phase of the program is the development of procedural wake avoidance solutions for CSPR airports and is led by the FAA. The objective of the second phase of the program is the development of wind-dependent procedures for wake avoidance that include wind prediction algorithms and simple controller tools to support decision making. This phase also targets CSPR airports and is led jointly by the FAA and NASA. The objective of the third phase of the program is the development of active wake avoidance solutions including technologies for wake prediction and monitoring and is led by NASA.

In the first phase of the program, the FAA is seeking to make a near-term change to the 2500 foot rule for CSPR arrivals to define a lesser runways centerline separation minimum for avoidance of wakes generated by Small and Large aircraft. The objective is to permit today’s dependent (1.5 NM diagonal separation) CSPR approach procedures between Large and Small aircraft and for any type aircraft trailing a Large or Small leading aircraft on the parallel runway. The first data collection and analysis campaign for this effort is being conducted at STL. This campaign is designed to support the safety assessments to be conducted by the FAA’s Flight Standards (AFS) organization in support of the procedure change. The short presentation will describe the goals of the joint FAA/NASA wake turbulence program with an emphasis on the near-term goal. A description of the current data collection plans will be provided in the context of the needs of AFS to conduct the safety assessment. Other analysis activities being conducted in support of this procedure change will also be briefly discussed.

It should be noted that the 2-day workshop agenda includes presentations from NASA, FAA and other contributing organizations to program and should provide the audience with a fairly broad perspective the scope of the joint FAA/NASA Wake Turbulence Program.
Near ground lateral transport/decay of vortices as observed from windline data at Frankfurt and its implications

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The Frankfurt windline is used to track vortices under routine operations at Frankfurt/Main Airport. Ten state-of-the-art ultrasonic anemometers are installed between the closely spaced parallel approach paths to runways 25L and 25R approximately 0.5 NM before the thresholds. The device is part of the Wake Vortex Warning System and is operating on a 24 hours a day, 365 days a year basis. Although the system has not been designed for this purpose and therefore has some limitations, it allows for wake vortex behaviour analyses to an extent that can not be achieved with data dedicated short-term measurement campaigns. Major advantages of the Frankfurt Windline Data are:

♦ a high statistical significance, even if the data is sorted by aircraft types
♦ a large fraction of heavy aircraft
♦ measurement under all weather conditions

In the presentation the influence of the ambient meteorological conditions on wake transport and decay is examined: The vortex transport distances are well correlated with the ambient crosswind, but a clear relationship between the lifetime of wake vortices and any of the available atmospheric variables could not be determined. Nevertheless the data suggests that wake vortex lifetimes increase with aircraft size in such a way that is not in agreement with the widely used scaling with $t^*$. 

The NASA/DoT Volpe Transportation Center
Wake Acoustic Data Collection Campaign at Denver International Airport
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Analytical and experimental evidence suggests that a variety of atmospheric phenomena generate acoustic signals that might be exploited to provide some warning of the hazard’s presence. Aircraft wake vortices created as a by-product of lift are among these phenomena. Existing knowledge suggests that wakes emit acoustic signals, but at very low frequencies and at low intensities. Preliminary acoustic signal findings from work conducted under the SOCRATES Program and independently by the German Aerospace Center (DLR-Berlin) suggested that an additional data collection experiment was justified to establish a better scientific understanding of the potential of this phenomena.

An experiment was designed to acquire the most pristine acoustic data ever collected to more fully understand the wake acoustic phenomena. A number of sensors and equipment were deployed at the Denver International Airport to experimentally investigate the acoustic properties of wake vortices and to increase the scientific understanding of these acoustic signals. The hypothesis upon which this effort was done is that wake vortices generate unique, consistent acoustic signatures that may be exploited to mitigate the adverse effect of wake turbulence on airport operations. The Denver test was conducted during August/September 2003.

The wake acoustic sensor for the Denver International Airport test was a 252-element phased microphone array and meteorological instruments to acquire data permitting a more thorough
fundamental investigation of the wake acoustics phenomenon. Both pulsed lidar and CW lidars were used to provide an estimate of actual wake behavior. Additionally, a 4-beam SOCRATES wake acoustics research sensor was deployed to assess modifications made the SOCRATES hardware and signal processing software in the past two years.

This presentation describes the motivation and purpose of the test, the sensors used and their configuration with respect to the DEN airport, a summary of the data files collected and plans for three independent teams to conduct analyses of these data to answer fundamental questions on the relationship between wake acoustic signals and the hazard characteristics of the wake vortex.

Analysis of Wake Vortex Measurement databases
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Full-scale flight investigations of vortex wakes have been conducted for many years starting with RAE Farnborough and NACA Langley in 1954. These tests involved one aircraft penetrating the wake of another aircraft. With the introduction of the B-747 in 1969, wake turbulence separation standards were introduced.

Many wake vortex databases have been collected and analyzed over the past three decades. Most of these tests were conducted at airports. The early tests examined the safety of the separation standards. As a result, in 1976 the separations were increased for Small or Light following aircraft. Then, the tests examined potential means to increase airport capacity or throughput. Examples include the Vortex Advisory System (VAS), the German Wake Vortex Warning System (WVWS), the French Système Anticipatif de Gestion des Espacements (SYAGE), and the NASA Aircraft Vortex Spacing System (AVOSS). Now, the tests are oriented toward studies of potential operational solutions, such as closer-spaced independent parallel runways, LDA approaches, and the Simultaneous Offset Instrument Approach (SOIA).

The presentation will document what measurements were made in the many test programs and summarize the status of the raw and processed data. These datasets may be useful in new studies or as initial datasets for the development of new processing and analysis methods that will be used in future tests.
In the mid nineties the National Aeronautics and Space Administration (NASA) began developing the Aircraft Vortex Spacing System (AVOSS) with the goal of improving airport capacity through improved aircraft arrival spacing. The system involved a set of ground-based sensors used to forecast, detect and monitor vortices on the approach path. An initial requirement of this system was to establish a vortex decay threshold or boundary that defined how weak a vortex on the approach path must be for the in-trail aircraft to safely continue the approach.

Developing a decay threshold required extensive use of wake vortex encounter simulations of a variety of aircraft. It was quickly noted that although a number of wake encounter simulation studies had been conducted since the mid seventies the wake encounter models used in the simulations were either not validated or validated purely on subjective pilot evaluation. This was primarily due to the lack of flight test data sufficient to validate the wake encounter simulation models.

In an effort to fill this void in test data NASA conducted a series of flight test from 1995 through 1997 using a Lockheed C-130 as the wake generator and a Boeing B737-100 as the wake encounter aircraft. A modified North American Rockwell OV-10 Bronco was used to measure the wake, the atmospheric state and stereo video of the wake encounters. The goal of these tests was to provide a data set for validation of wake encounter simulation models and develop an improved understanding of wake vortex physics and atmospheric interaction. The test data has been compiled into an integrated database available to the wake vortex research community. This paper describes the wake vortex flight tests, the data processing, the database development and access, and results obtained from preliminary wake-characterization analysis using the data sets.
Within the 5th European framework technology project S-WAKE, full-scale wake vortex encounter flight tests were performed. In two campaigns (August 2001, March 2002) more than 100 encounter were flown with the aircraft Do128 and Cessna Citation, while the leading aircraft VfW-614 ATTAS visualized its wake using a smoke generator installed on the outer left wing. Under favorable conditions, the smoke trace was visible up to 3 nm. Both follower aircraft were fully instrumented with inertial sensors and flow probes in order to measure the flow field characteristics of the wake vortex as well as the aircraft response during each encounter.

The gathered flight test data are of excellent quality and were used successfully for flow field determination as well as encounter model validation.

1. **Determination of flow field characteristics**
   The flight test data of the follower aircraft were evaluated to determine the flow field characteristics during each of its individual encounter. The flight path was reconstructed in high quality with system identification and flight path reconstruction methods. Using the flow sensor measurements, two different analytical velocity distributions (Burnham-Hallock, Lamb-Oseen) were investigated in order to match the measured flow field characteristics determining the model parameters with parameter identification techniques. The model parameters (circulation strength, core radius, separation, and vortex location) could be determined trustworthy for each encounter. The method seems to be a promising alternative to vortex parameter measurements by lidar.

2. **Validation of the aerodynamic encounter models**
   Two types of encounter models were successfully validated with the encounter flight test data: the Strip Method (SM) and the Lifting Surface Method (LSM). The encounter models were added to the basic flight mechanic models of the encountering aircraft (Do128, Cessna Citation) providing incremental aerodynamic coefficients. Measured control surface deflections as well as the determined vortex characteristics were taken into account. Comparing the model outputs to the measured flight test data, model benefits as well as model deficiencies could be demonstrated, the quality of both methods were compared.

Altogether, it was shown within the S-WAKE work that the gathered encounter flight tests are a valuable data base of excellent quality. The data are unique in Europe and it can be highly recommended to use them for future work.
This presentation describes the NATS Database of voluntarily reported wake vortex incidents. This will include outlining the process by which reports are captured for pilots and ATC, and also the information gained from other sources (met/radar data).

Examples will be given of how this data is analysed and presented for an annual UK Wake Vortex performance report (although due to commercial sensitivity it is not possible to report numbers).

The presentation will also suggest a potential methodology for calculating wake vortex separations for new spacing categories from historical data (i.e. for categories for which no current data exists).

This presentation will include a summary of the work undertaken by NATS in the S-Wake Project. This includes

- Validation of the NLR-Vortex Algorithm.
- Analysis of Preliminary Wake Vortex Encounters detected from Flight Data Recorder (FDR) data by algorithm
- Analysis of Pilot reported Wake Vortex Encounters
From the year 1999 NLR began the development of an algorithm that allows wake vortex encounters to be detected from processing Flight Data Recorder (FDR) data, recorded on-board the aircraft. Initially, in cooperation with the National Air Traffic Services Ltd (NATS), from 1999 to 2000 the first part of the algorithm, the so-called WINDGRAD algorithm, was developed, which computes wind gradients from available inertial and aerodynamic data. Sophisticated data processing takes place to derive these quantities from basic FDR data. Among these are angle of attack calibrations performed on the data, computation of the sideslip angle from lateral accelerations, the application of Kalman filtering and smoothing to determine the inertial path (in 3D), and computation of a pseudo-vorticity, i.e. the rotation in the airflow through which the aircraft flew. For this process to be possible, estimates of the aircraft’s stability derivatives were obtained from the same data set. Although the estimation process worked well, some values of derivatives are questionable.

In the S-wake project NLR developed the second part of the algorithm, the so-called VDC algorithm, which stands for Vortex Detection and Classification. From the available wind gradients and other parameters (as a pre-cursor to the vorticity data) an initial detection logic was devised, assuming the data has a normal distribution. In this case signal-to-noise ratios were computed for a number of variables that were assumed to play a role in detecting the true occurrence of an encounter. Later NLR developed in-house an alternative algorithm based on the use of the vorticity data. The NLR-VORTEX algorithm was applied to the Heathrow database built up in the S-Wake project.

Since the occurrence of a valid WV encounter is assumed to be probable only under certain circumstances (e.g. low winds, little or no turbulence, etc.), also other measures were derived from the FDR data, viz. the eddy dissipation rate, turbulent kinetic energy, the Richardson’s number, as well as a measure of windshear (through the windshear hazard factor F). In order to assess the severity of an encounter, the roll-control ratio was computed, but also new parameters were introduced, viz. the uncontrolled angular rates and the uncontrolled attitudes. These are measures of the severity of an encounter in terms of angular rates and attitudes that can develop, given the pilot takes no action for 3 seconds.

The final algorithm as it stands per 2002 works well and gave a wake vortex encounter alert for all those cases where, by visual inspection and through pilot reports, a valid encounter occurred in the Heathrow database. However, the NLR-VORTEX algorithm was sensitive to false alarms, in that it indicated more events to have occurred than really was the case. This relatively high false alarm rate was primarily due to lower-than-desired data quality, in terms of data dropouts, sampling rate, etc., and due to the use of non-validated values for aircraft’s stability derivatives. This is evidenced by the fact that for the experimental test aircraft good results were obtained; from this aircraft all required data were known well.

Different standardization of the data will be shown to have an effect on the (peak) detection of a Wake Vortex Encounter (WVE). Compared to the version used in S-wake it looks like a 60 seconds central-moving averaging, with pre-filtering of the data, provides less ambiguous results and may be less sensitive to noise and other outliers.

Future efforts will therefore focus on reducing the false alarm rate by introducing more filtering at the proper points in the algorithm as well as different kinds of standardization, and by replacing estimates of stability derivatives by values given by the airplane manufacturer, if and when available (preferably per configuration, i.e. a function of flap setting, Mach, etc.).
The current separation minima stem from the early 70’s. Although they have ‘proven to be sufficiently safe’, the current safety level is unclear and there is a deficiency of tools to support new developments in operational usage at busy airports. The S-Wake project has proposed a probabilistic model to assess safety, and to evaluate the relation between wake vortex induced risk and aircraft separation distances. This probabilistic approach supports two commonly accepted rationales for acceptance of a newly proposed ATM concept (or procedure) by involved interest groups: by showing that the number of wake vortex induced risk events:
- does not exceed some pre-defined, and agreed upon, safety requirement;
- does not increase with the introduction of a new ATM procedure.

The WAVIR methodology and tool-set has been extended and applied, following modeling improvements (within S-Wake) of all of its major three sub-models: flight path evolution model, wake vortex evolution model, and wake encounter model. A safety assessment of single runway approaches under different weather, wind and operational conditions was carried out. The results show that the impact of the investigated procedural aspects – as compared to the impact of weather and wind conditions – is relatively small. Reduction of separation distances requires a reduction of the risk near the runway threshold, by measures that reduce the probability and/or consequences of such encounters. The risk assessment results also show that – for single runway approaches – the largest runway capacity improvement might be achieved through exploiting weather conditions favourable for a rapid decay or destruction of the vortices, in particular when located close to the runway threshold. This conclusion is supported by wake encounter data analysis from different sources (including ETWIRL data and NTSB data).

Other applications of WAVIR are foreseen within the ATC-Wake, I-Wake and Awiator projects, and support the evaluation of wake vortex safety aspects and required separation distances for:
- Air Traffic Management warning and avoidance procedures;
- On-board wake detection, warning and avoidance instrumentation;
- Advanced aircraft wing technology operations;
- Newly designed high capacity aircraft.

Following S-Wake recommendations, specific topics under investigation are:
- Extension of WAVIR with a causal structure based on conflict scenarios, enabling to model the performance of humans working with wake alleviation systems and procedures;
- Further validation of WAVIR (e.g. relation between encounter severity and incident/accident risk), using wake encounter incident data and pilot/controller wake report forms;
- Compliance of risk metrics with existing regulatory requirements (including Eurocontrol ESARRs (for Air Traffic Management), the ICAO Annex 13 (for incident/accident investigations), and the JAA JAR 25.1309 hazard categorization (for aircraft systems));
- Applications of WAVIR to cover the airport environment (departures, CSPR approaches).

Besides showing the results of the S-Wake incident/accident risk assessment with WAVIR for single runway approaches, this presentation will provide a short overview of the other WAVIR applications, and will introduce a proposed approach to deal with the above recommendations.
Wake turbulence is a major cause of terminal delays. This is particularly true during Instrument Meteorological Conditions (IMC). NASA and the FAA have recently proposed a research plan to improve airport capacity related to these standards. The plan includes near-term solutions (e.g., modification of the 2,500 foot separation standard for independent operations on closely spaced parallel runways during IMC), mid-term solutions (e.g., use of weather sensitive procedures to account for cross-winds), and far-term solutions (e.g., a dynamic wake-avoidance tool to optimize in-trail spacing based on weather conditions).

This talk discusses plans by NASA and George Mason University to apply the TOPAZ (Traffic Organizer and Perturbation AnalyZer) safety modeling methodology to analyze proposed USA concepts of operations for reduced wake vortex separation. To motivate the methodology, we first present an application of statistical techniques used by the methodology in the analysis of simultaneous runway occupancy and runway collision probabilities at Atlanta Hartsfield Airport. We then discuss ways to extend the methodology to predict the probabilities of severe wake vortex encounters under the proposed reduced separations.
Operational concept and system requirements for an ATC system allowing dynamic wake vortex separations

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Under Instrument Flight Rules (IFR), currently applied wake vortex separations between aircraft are based on worst-case scenario. The spacing is determined by considering the leader/follower aircraft weight categories and wake persistence observed during atmospheric conditions favourable to long vortex life. These separations are often over conservative although they do not completely avoid the effect of wake vortices, but long experience in applying them demonstrates they are sufficient to be safe in most meteorological conditions.

Several technologies to detect and predict wake-vortex have been developed during the last years. These technologies are now quite mature and weather conditions in which wake vortices decay quickly can be identified and used reliably by "wake vortex predictors". There is potential for making the separation distances dependent on these predictors as well as aircraft weight. This could increase the capacity of airports in certain weather conditions. Nevertheless, none of these systems are connected to ATC providers (en-route, approach, tower and arrival/departure managers and remain at the R&D stage.

The ATC-WAKE project intends to develop and build an operational platform. For this purpose, the first step is:

• To define operational requirements;
• To define operational concepts and procedures,
• To update and refine the selected operational concepts and procedures;
• To define users requirements;
• To define the system requirements based on operational concepts and users requirements.

The following issues have been addressed:

• Operational issues: need and use of WV information in the context of ATC operations, constraints and required supporting systems
• Technical issues: high level interface to existing (legacy) ATC systems of WV targeted system.

As a first step towards implementation of ATC-WAKE Facility, the system requirements have drawn the preliminary operational concept and the requirements for using separation minima based on WV detection and prediction information. Next steps in the project aim at validating such requirements through system design and safety assessment and then operational feasibility evaluation.

During the development of ATC-WAKE requirements, a number of key issues have been identified and still need to be carefully assessed:

• Transitions between ATC-WAKE and ICAO separation modes
• Aircraft separation and sector loading
• Evaluation of safety requirements
• Evaluation of capacity benefits

During the next phase, the operational feasibility of the new integrated ATC system, including an analysis of the interoperability with existing ATC systems and the usability and acceptability by its foreseen end-users (air traffic controllers) will be evaluated. Following the definition of operational concepts and procedures, this will be realised through fast-time simulations with a total airspace and airport modeller.
Evaluation of Two Hazard Identification Techniques in the Context of Time Based Aircraft Separations

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Up to now, no research project at the Eurocontrol Experimental Centre (EEC) impacting Air Traffic Management (ATM) has been accompanied by a formal safety assessment. This is to change as in future all such projects must be ESARR4 compliant. The need arises therefore to find one or more suitable methodologies that can be used to demonstrate that a project is ESARR4 compliant. In essence, this requires that risks be identified and assessed and corresponding mitigating actions be defined.

The EATM Safety Assessment Methodology (SAM) is one possible means to demonstrate that a project complies with ESARR4. It aims at recommending one or more suitable techniques depending on the nature and status of the project in question.

A survey of over 600 safety methodologies has recently been carried out and a number of suitable candidate methodologies have been identified. Two of these methodologies were selected for an in-depth evaluation focusing on human factors (people and procedures) elements: HAZOP (HAZard and Operability study) and TRACEr (Technique for the Retrospective and predictive Analysis of Cognitive Errors in ATM). These were applied to three current projects at the EEC. One of these projects was the Time Based Separations project.

Today, in conditions of strong headwinds on final approach, the runway arrival capacity diminishes as the ground speed decreases if no compensating increase in airspeed is made by the pilot. This is directly due to the application of standard distance separations which take longer to run with the diminished groundspeeds. If instead, suitable time separations were applied this loss could, at least partially, be recovered.

The objectives of the evaluation were to identify the benefits and limitations of the methodologies when applied to EEC projects and to see what they could offer to the design process. In addition, an analysis was carried out to determine what can go wrong with the proposed system and to identify suitable remedial actions.

The results indicated that the HAZOP approach offered a high level view of the complete system. It was felt that the experiment was a successful, positive experience for the group who had had little, if any, exposure to safety assessment methods and provided useful help in defining the system concept. TRACEr was seen to provide a detailed analysis of the human/system interaction.

Both methodologies were found to have their applications: HAZOP could be recommended to be used at an early stage of a project in order to refine the concept whereas TRACEr could be used to analyse core tasks and to identify critical, high level errors as well as to contribute towards refining operational procedures.
New and advanced Air Traffic Management (ATM) systems and procedures are being developed for busy airports to cope with the increase in air traffic. The ATC-Wake project for the European Commission proposes an operation, in which airport capacity is improved by the use of dynamic weather-based aircraft separation standards, using an advanced ATC-Wake system.

The current study lays a foundation for the safety and capacity analysis of the ATC-Wake operation by providing a qualitative safety assessment of potential risks associated with the proposed operations. Potential safety bottlenecks identified in this study give early-stage feedback to operation designers and provide focusing points for subsequent safety modelling and quantitative safety assessment in the ATC-Wake project.

The risks associated with the ATC-Wake operation were assessed using NLR’s qualitative safety assessment methodology. This methodology is largely based on structured use of operational experts’ judgement. The applied risk criteria are based on ESARR 4 requirements, using the ESARR 4 severity classification scheme and the ESARR 4 maximum tolerable probability of an accident, plus some additional assumptions that had to be made for this qualitative risk assessment.

The risks of the proposed ATC-Wake operations were assessed for single runway arrivals, single runway departures and closely spaced parallel runway arrivals. In various brainstorming sessions with operational experts, 228 hazards were identified that might occur in the considered operations. These hazards were structured into 11 conflict scenarios, which aim to cover all imaginable ways in which the hazards can lead to or worsen a conflict situation. Using operational experts’ judgement and knowledge from other studies, for each of these conflict scenarios the severity and the frequency of occurrence were assessed. Based on these severity and frequency assessments, and the risk criteria, an evaluation of the acceptability of the risk of each conflict scenario was given.

For each of the three arrival and departure operations several conflict scenarios were assessed to potentially have unacceptable risks associated with them. It could, however, not be ruled out that these risks are tolerable or negligible, due to uncertainty in the assessment results. These conflict scenarios include consideration of, e.g., wake vortex encounters, collisions on the runway and an increase in the number of landings in crosswind. For each conflict scenario with a potential unacceptable risk, conditions and hazards leading to this risk (safety bottlenecks) were identified. The uncertainty in the risk assessment results is related to

- uncertainty in the judgement of operational experts, who had to extrapolate their experiences with current operations to future operations with several new aspects,
- a lack of detailed specification of some aspects in the operational concept, and
- uncertainty in the evaluation of the dynamics of human operators handling, technical systems and aircraft evolution in the operations considered, and of wake vortex evolution and encounters via expert-based reasoning only.

Means to reduce the uncertainty in the assessment results include more detailed specification of aspects of the operations and evaluation of the safety using mathematical models. These issues will be handled in subsequent steps of the ATC-Wake project.

The presentation will give a broad overview of the steps of the qualitative safety assessment, the safety criteria adopted and the main risk assessment results of the conflict scenarios identified.
Wake Vortex Encounter Avoidance
Computation of Safe Aircraft Separations Using the SHAPe Concept
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The presentation will introduce a concept of wake vortex encounter avoidance using the Simplified Hazard Area Prediction (SHAPe) concept. This approach is based on the definition of a hazard zone around a wake vortex derived from quasi-steady considerations. SHAPe is an element in the Wake Vortex Prediction and Observation System which is under development in the frame of the DLR “Wake Vortex II” project to reduce aircraft approach separation and to improve flight safety.

In any case the separation distance of approaching aircraft has to be established in such a way that no dangerous wake vortex flow will be encountered. This results in the demand that the approach corridor is free of hazardous flow conditions for an approaching aircraft. The question to be answered is what is the meaning of “hazard free”? Therefore, many investigations and simulator studies have been set up and executed with the aim to find a universal criterion for the definition of wake vortex encounter constraints being hazardous to an aircraft. Although impressive progress has been made it could not be expected that an exact prediction will be possible if an encounter will definitely be hazardous or not. Accepting this fact that a clear criterion of what is hazardous (in terms of encounter boundaries and constraints leading unquestionably into an unsafe situation) is difficult to set up (especially if a pilot is in the loop) an “inverse” approach of hazard definition is proposed.

The presented approach for solving the fundamental hazard assessment problem follows the idea that it is easy to define an area around a wake vortex outside which the vortex flow is definitely not hazardous to an aircraft. This methodology is more a non-hazard concept than a real safety assessment method. But it seems to be very promising in terms of operational application.

The worst case situation can be assumed to be a wake vortex parallel to the glide path with permanent demand for roll moment compensation. In that quasi-steady case the threat can easily be calculated from the required control power expressed in terms of normalized aileron deflections $\xi^* = \xi_{req}/\xi_{max}$. A certain fraction of this expression is identified to present a safe limit in terms of wake vortex encounter depth. The resulting boundaries of the hazardous area to be avoided are investigated by numerous offline simulations.

The SHAPe model is an important element in DLR’s Wake Vortex Prediction and Observation System. Its application is based on the following concept: Starting from the nominal flight path of an ILS approach the vortex generating aircraft shows some deviations forming an elliptical approach corridor where the generation of wake vortices has to be assumed. The resulting iso-probability ellipse of maximum aircraft deviation can be simplified by a rectangle around this approach corridor. DLR’s Probabilistic Two Phase Wake Vortex Development and Decay model (P2P) predicts an area of probable vortex locations after a period $N\Delta t$, the so called Potential Wake Vortex Area. At the boundaries of this area the hazard zones computed by SHAPe are superimposed. The envelope covering all the individual hazard zones is the overall hazard zone which is not allowed to be encountered by an approaching aircraft. For the determination of safe separation distances for an individual aircraft pairing the period $N\Delta t$ has to be chosen in such a way that no overlapping of approach corridor and over all hazard zone exists.
NASA Conops Team and the Identification of Required Data to Establish Safety of Proposed Active Prediction Wake Vortex Solutions

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The outline of my presentation on the NASA Conops Evaluation Team will cover the following points:

- Wake Conops Team Goals and Objectives, Scope
- Team Membership & Expertise
- Candidate Operational Enhancements to be Analyzed by the Evaluation Team
- Order of Analysis
- Baseline Report Contents
- Conops Evaluation Report Contents
- Description of Conops for Closely Spaced Parallel Runway Arrivals, dynamic separation based on active wind sensing and prediction
- Comparison of Conops with Related FAA Operational Enhancements
- Results to Date:
  - Conops Definition and Analysis
  - Safety Analysis Methodology Selection
  - Research Issues Identified
  - Issues Identified to Decision Makers
NEW PRINCIPLES IN THE AREA OF WAKE VORTEX SAFETY FOR AIR TRAFFIC CONTROL

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Serious efforts being made recently in the area of wake vortex safety all over the world require, in our opinion, thorough investigation of the ways of design, construction and implementation of air traffic control systems intended to alleviate wake vortex risks, increase airport capacity, and lighten the work of pilots. The main problem is the increase in the airport capacity (using the reduced separations between aircraft) results in the inevitable decrease of the wake vortex safety.

The only way to overcome this trouble is to provide the pilots with visual information on possible locations of dangerous wake vortices invisible to the eye. In view of the fact that instrumental methods of wake vortex detection are not valid, we suggest to use the numerical methods adapted to this aim.

The airborne system to prevent the aircraft entering into wake vortices of a vortex generator (typically, another aircraft – the leader) consists of: the unit tracking parameters of the generator and the aircraft provided with the system (below – the aircraft); the unit calculating the wake vortices of the generator; the unit simulating the control plane situated at some distance ahead of the aircraft perpendicular to the aircraft velocity vector; the unit indicating a dangerous situation when the wake vortices lie within the prescribed zone (the zone of the aircraft possible positions at the time of the flight through the control plane) in the control plane, and some other auxiliary units.

The system functions as follows. When the generator wake vortices are away from the prescribed zone, the vortices are not visible on the indicator screen. As soon as they are close enough to the zone, they become visible and the sound alarm notifies the pilot about the situation. Then the pilot decides which actions could prevent the vortex entering into the zone.

All errors in the wake vortex calculations could be included in the sizes of the wake vortices or of the prescribed zone. When the instrumental methods for detection of the wake vortices will be elaborated, they could be included in this system replacing or amplifying the numerical methods. In the future the airborne system should be integrated with the ground based systems giving rise to the integrated vortex forecasting systems (the IVFS). In the IVFS the information on the generator wake vortices could be obtained on the ground (in computer centers or by lidars) and sent to the aircraft. Moreover, each of the aircraft in flight could obtain information on its own wake vortices and send it to the other aircraft and to the ground based equipment. Of course, the standard protocols for the information traffic should be used in that case.

We believe that the airborne systems of the type like that described above will be necessary for all certified aircraft and therefore the structure of the ground based systems should be designed taking into consideration the future availability of the airborne systems and their integration with the ground based systems.

The presentation is accompanied by demonstration of computer demo versions of the airborne system.
The Airbus A380 will be larger and heavier than existing commercial air transport aircraft. In order to maintain the operational safety of other aircraft, air traffic service providers/national aviation safety regulators need assurance of the adequacy of the separation standards to be applied to the A380. Due to the increase in mass/size of the A380 compared to current aircraft types, a special study was deemed necessary to investigate the A380’s wake vortex characteristics and to compare them with other existing types of aircraft.

To accomplish this study and ensure that the results would be applied internationally, a Steering Group was established with members from CJAA, Eurocontrol, FAA, ICAO Secretariat, and Airbus. This Steering Group forms appropriate Working Groups as required, consisting of experts and specialists in appropriate areas. At the initial meeting, a Technical Working Group was formed to accomplish the more scientific aspects of this effort.

This talk will provide an overview of the composition and responsibilities of the Steering Group and Technical Working Group. It will introduce two additional talks, which address the approaches to be taken in assessing the A-380 wake turbulence risk.

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Implementation of AVOSS Wake Turbulence Model into the FAA’s Airspace Simulation and Analysis for TERPS (ASAT) Monte-Carlo Simulation System.

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Dr. David N. Lankford (FAA/AFS-440, Flight Systems Laboratory)

The presentation discusses three major points namely:
1. The philosophy behind the development of the FAA’s Airspace Simulation and Analysis for TERPS, also known as ASAT.
2. The Monte-Carlo style implementation of the wake turbulence model developed for AVOSS.
3. The manner the combined system has been utilized in a critical wake turbulence study regarding simultaneous parallel approaches to closely spaced parallel runways at San Francisco International Airport, California, USA.
Airbus has prepared a methodology to assess the severity of a wake vortex encounter, WVE. This methodology is called Vortex Encounter Severity Assessment (VESA). VESA makes it possible to compare a/c reactions and the effects of vortex encounters behind various a/c. (for example behind all a/c in the HEAVY class).

VESA is proposed as a tool to support air traffic service providers and national aviation safety regulators, which need assurance of the adequacy of the separation standards, if modifications of the current system are proposed. A potential application is to assess if the operational safety of other aeroplanes is maintained after introduction of the A380.

The presentation will describe the methodology.

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