Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Executive summary

Increased Arrival Capacity through the Use of the ATC-Wake Separation Mode Planner

Problem area
With the steady increase in air traffic, airports are under continuous pressure to increase aircraft handling capacity. One potential approach is to reduce the wake vortex separation distances between landing aircraft without compromising safety.

Description of work
Within the ATC-Wake project for the European Commission, an integrated Air Traffic Control (ATC) wake vortex safety and capacity system has been designed so as to provide the means to significantly enhance airport capacity. The system will enable Air Traffic Controllers to apply new weather based dynamic aircraft separation. The ATC-Wake Separation Mode Planner (SMP) advices the ATC supervisor about safe separation. The SMP is used in the planning phase where weather and wake vortex forecast information is used together with aircraft separation rules to establish the arrival sequence. Criteria on crosswind and associated safe separation minima are derived from safety assessment results. Analysis of a crosswind climatology provides insight in the potential benefits in terms of runway throughput or delay reduction.

Results and conclusions
The ATC-Wake SMP has been designed and evaluated. It uses Nowcasting Wake Vortex Impact Variables (NOWVIV) wind forecast data and WAke Vortex Induced Risk assessment (WAVIR) results for single runway arrivals to provide an advice on time frames suitable for reduced separation several hours in advance. An accurate prediction of wind is essential as a too low accuracy may lead to an unacceptably large number of missed approaches. Initial WAVIR assessment results show the possibility to safely reduce separation to 2.5 Nm for single runway approaches, provided that crosswind at 10m altitude exceeds 2m/s. It is estimated that this could imply a runway throughput improvement of up to 5% or a delay reduction of 29%.

Applicability
The design of the SMP and the evaluation results support the implementation of the ATC-Wake system at airports. ATC-Wake outcomes and tools can also be used for assessing the wake vortex safety and capacity implications of new wake vortex operational concepts (such as time based separation and crosswind departures).

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Increased Arrival Capacity through the Use of the ATC-Wake Separation Mode Planner

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This report is based on a presentation held at the AIAA Aviation Technology, Integrations, and Operations conference, Wichita (Kansas), U.S.A., September 2006.

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Today's wake vortex separation rules tend to become capacity bottlenecks at busy airports. Within the ATC-Wake project for the European Commission, an integrated Air Traffic Control (ATC) wake vortex safety and capacity system has been designed so as to provide the means to significantly enhance airport capacity. The system will enable Air Traffic Controllers to apply new weather based dynamic aircraft separation. One of the components of the ATC-Wake system is the Separation Mode Planner (SMP) that advices the ATC supervisor about safe and adequate separation. The SMP is used in the planning phase where weather and wake vortex forecast information is used together with aircraft separation rules to establish the arrival and/or departure sequence. Weather nowcasting and wake vortex prediction and detection information is used in the tactical phase to monitor and control safe separation. Wind forecast data along the flight path is used in the proposed methodology of the SMP to determine time frames suitable for reduced separation. Criteria on crosswind and associated safe separation minima are derived from safety assessment results. The methodology is illustrated using Nowcasting Wake Vortex Impact Variables (NOWVIV) wind forecast data and WAke Vortex Induced Risk assessment (WAVIR) results for Single Runway Arrivals. Analysis of a crosswind climatology provides insight in the potential benefits in terms of runway throughput or delay reduction.

Nomenclature

AMDAR	=	Aircraft Meteorological DAta Relay
ATC	=	Air Traffic Control
ATCO	=	Air Traffic Controller
FAR	=	False Alarm Rate
GUI	=	Graphical User Interface
HMI	=	Human Machine Interface
ICAO	=	International Civil Aviation Organization
NOWVIV	=	Nowcasting Wake Vortex Impact Variables
RMS	=	Root Mean Square
SMP	=	Separation Mode Planner
SRA	=	Single Runway Arrival
TKE	=	Turbulent Kinetic Energy
TLS	=	Target Level of Safety
WAVIR	=	WAke Vortex Induced Risk assessment

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I. Introduction

With the steady increase in air traffic, airports are under continuous pressure to increase aircraft handling capacity. One potential approach is to reduce the separation between aircraft at take-off and landing without compromising safety. One major limiting factor is the required separation distance between aircraft during approach and take-off in order to avoid each others wake turbulence. With the aid of smart planning techniques, these distances can be reduced safely, thereby significantly increasing airport capacity.

Within the ATC-Wake project[1] for the European Commission, an integrated system for ATC (Air Traffic Control) has been developed so as to enable variable aircraft separation distances, as opposed to the fixed distances presently applied at airports. This paper describes the ATC-Wake system and operation, with a focus on the Separation Mode Planner (SMP). The SMP is the ATC-Wake subsystem that provides an advice on safe separation minima with a look-ahead time of several hours, based on wind forecast and wake vortex safety assessment results. The proposed SMP methodology is illustrated using detailed crosswind forecast data (provided by NOWVIV[2]) and wake vortex safety assessment data for various crosswind conditions and leader/follower aircraft combinations in a Single Runway Arrival (SRA) operation (provided by WAVIR[3, 4, 5]).

Analysis of a crosswind climatology, constructed from 400,000 measurements at European airports, provides insight in the potential benefits of the system. It is shown that runway throughput may increase up to 5% and/or delay can be reduced by almost 30%, provided that the wind conditions can be forecasted with sufficient reliability.

Section II describes the ATC-Wake system and operation. The concept of Separation Mode Planning, leading to an advice on the aircraft separation to be applied in the coming period, is introduced in Section III. Insight into the potential capacity benefits at European airports are provided in Section IV. The results are discussed in Section V. Finally, Section VI contains the conclusions and recommendations for follow-up research.

II. ATC-Wake System and Operation

The main objective of the ATC-Wake project[1] was to develop and build an innovative platform with the aim of optimizing safety and capacity in the airport environment. The platform serves as a test bed to assess the interoperability of the ATC-Wake system with existing ATC systems currently used at various European airports, to assess the safety and capacity improvements that can be obtained by applying the system in airport environments, and to evaluate its operational usability and acceptability by pilots and controllers.

In the definition of the ATC-Wake operational concept and procedures[6, 7], the principle of “evolution not revolution” has been applied as far as possible. Existing concepts and procedures for arrivals and departures and the use of wake vortex information have been considered to allow a smooth transition from current ICAO aircraft separation rules to ATC-Wake aircraft separation rules. Four key issues have been identified: wake vortex critical areas, different separation modes, wake vortex visualization to Air Traffic Controllers (ATCOs), and alerting of the ATCOs in case of a potentially dangerous situation. Potential solutions for all these issues have been addressed[1].

Wake vortex critical areas have been identified as those parts of the airspace where the risk of a wake vortex encounter cannot be neglected and where detection and prediction of wake vortices will be beneficial to ATC operations. This concerns the final approach path and the initial departure path. Areas around glide path intercept on approach and first turn on departure are also identified as critical[6].

The ATC-Wake operation is based on the application of two different separation modes: ICAO standard separation mode and ATC-Wake separation mode. Depending on weather conditions influencing wake vortex transport out of arrival or departure critical areas, one of these two separation modes is applied. In ICAO standard separation mode, ICAO separation is applied while in ATC-Wake separation mode the targeted separation between two succeeding aircraft is 2.5Nm for approaches or 90s for departures.

To support safe implementation of the concept, the ATC-Wake system[8] is designed with four main components, which will interface with existing ATC systems, including ATCO HMIs, Flight Data Processing Systems, and Surveillance Systems (Fig. 1). The new components are the ATC-Wake Separation Mode Planner, Predictor, Detector, and Monitoring & Alerting. The visualization of predicted and detected wake vortex information is taken care of by the design of an ATC-Wake ATCO Human Machine Interface (HMI)[6].

The Predictor and Detector respectively predict and detect the extent of the wake vortex for individual aircraft within the critical areas. This information supports the ATCOs in tactical operations to apply wake vortex separation and to implement a transition between the two separation modes. The Monitoring & Alerting system provides an alert to the ATCO in case of significant deviation between prediction and detection information or failure of one or more of the system components.

The Separation Mode Planner is used in the planning phase and advices the ATC Supervisor on applicable separation mode and associated validity period. This advice is based on meteorological forecast information in combination with safety assessment results that relate the weather forecast to safe separation minima. A forecast horizon of 3 hours is foreseen where a transition to the other separation mode should be indicated at least 40 minutes in advance when an Arrival Manager is used and 20 minutes otherwise.

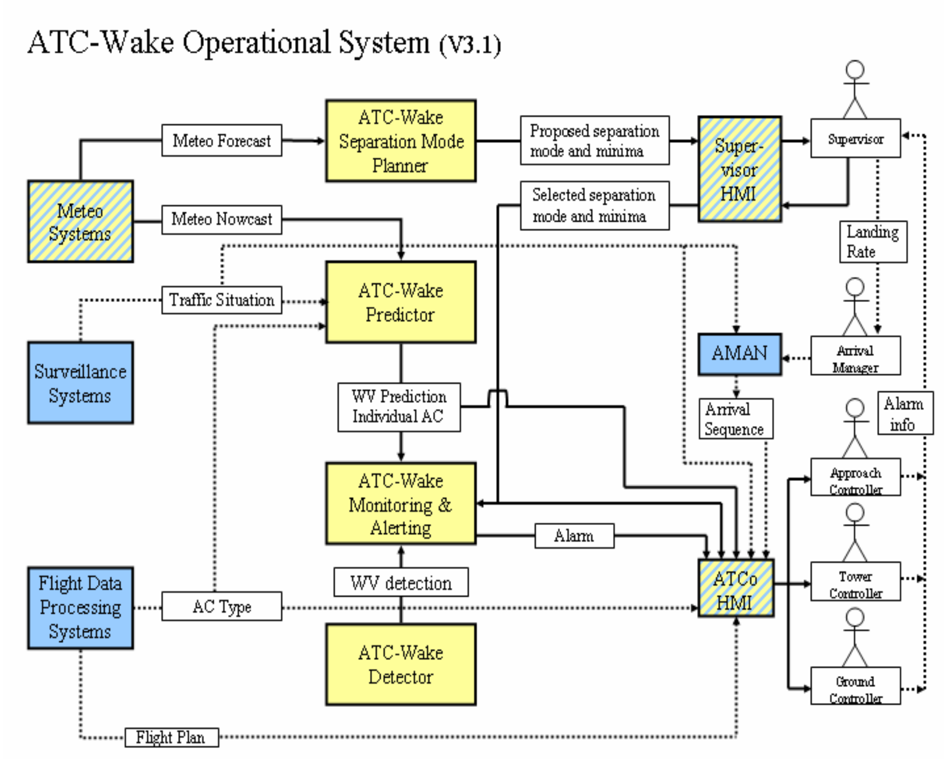

Figure 1. ATC-Wake Operational System and its (functional) elements and involved actors[3].

III. Separation Mode Planning

In the developed methodology for the SMP[9], weather forecast information is analyzed with respect to wind conditions that result in transport of wake vortices out of the critical areas and therefore enable safe reduction of separation. Crosswind conditions that allow safe application of ATC-Wake separation are derived from safety assessment results obtained with the tool-set for Wake Vortex Induced Risk assessment (WAVIR). Both input sources are shortly introduced hereafter.

A. Weather Forecast Data

In order to predict wake vortex behavior, the atmospheric parameters (wind, temperature, and turbulence) influencing wake vortex decay and transport must be known. NOWVIV[2] (Now-casting Wake Vortex Impact Variables) provides forecast of these parameters in the airport environment. NOWVIV consists of a high resolution mesoscale weather forecast model designed to provide real time 3-D weather information in the terminal area with a lead time up to 12 hours and a planned update rate of 1 hour. NOWVIV has a horizontal resolution of 2.1 km, 8-50m in the vertical, and considers orography and detailed land use maps to predict realistic boundary layer features. NOWVIV is driven by standard weather forecast provided by German Weather Service and continuously assimilates data from weather observation systems installed in the airport environment. NOWVIV provides vertical profiles of horizontal and vertical wind, virtual potential temperature, and Turbulent Kinetic Energy (TKE) along the glide path every 2 km and at a temporal resolution of 10 minutes. This nowcasting system has been used in real time during a number of measurement campaigns. For those campaigns Root Mean Square (RMS) errors in wind speed on the order of 2 m/s and in wind direction on the order of 20° were found[10]. The False Alarm Rate (FAR) of the predictions was also investigated. A false alarm refers to a situation where the predicted crosswind is above a certain threshold, whereas the measured crosswind appears to be below the threshold. For thresholds of 2 and 3m/s the computed FAR was 0.2 and 0.32 respectively. This implies that improvements of the crosswind forecast might be needed.

B. WAVIR safety assessment data

WAVIR[3, 4, 5] is a tool-set to assess wake vortex induced risk and follows a probabilistic approach. The WAVIR tool-set includes four submodels for flight path evolution, wake vortex evolution, wake encounter simulation, and risk prediction, see Fig. 2.

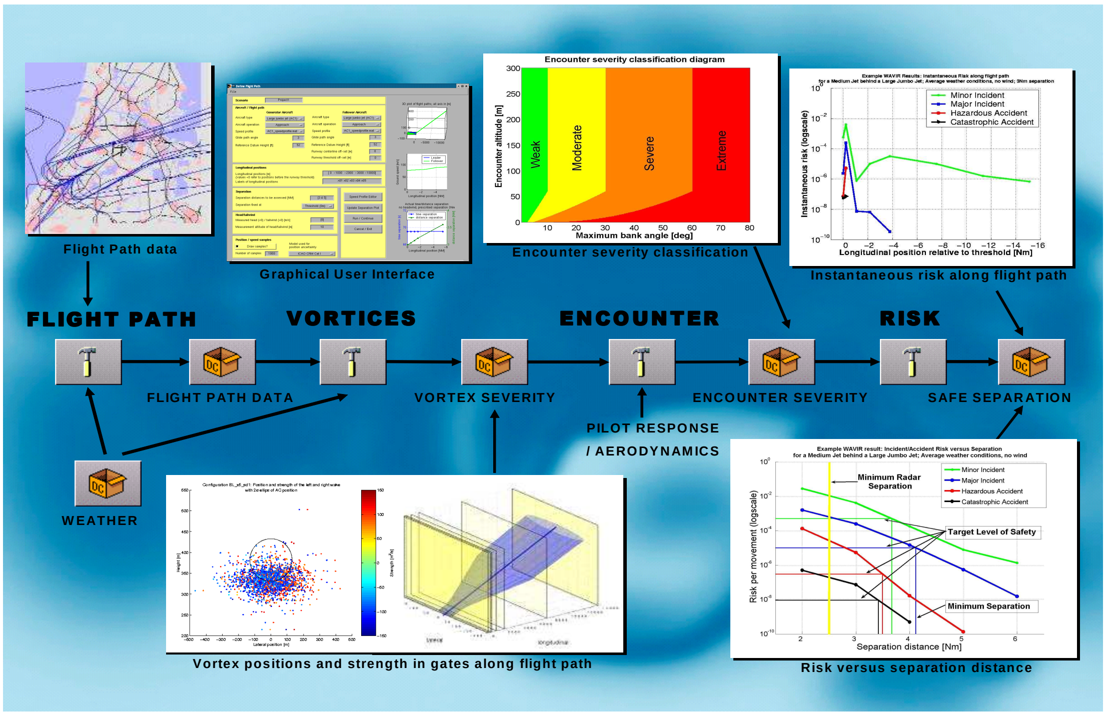

Figure 2. Overview of the WAVIR tool-set.

A WAVIR assessment is carried out in eight steps:

1. To represent the wake induced risk along the aircraft flight path, a set of relevant longitudinal positions ('gates') along the proposed aircraft track is determined, where the instantaneous risk will be evaluated (Fig. 3). Samples of aircraft (lateral and vertical) position and speed in the selected gates are obtained with the flight path evolution model.

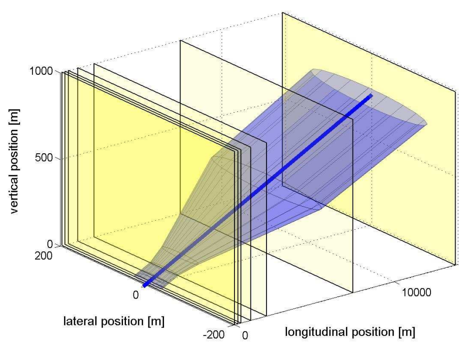

Figure 3. Glide path corridor for Single Runway Arrivals (in blue) with gates (in yellow) at relevant longitudinal positions.

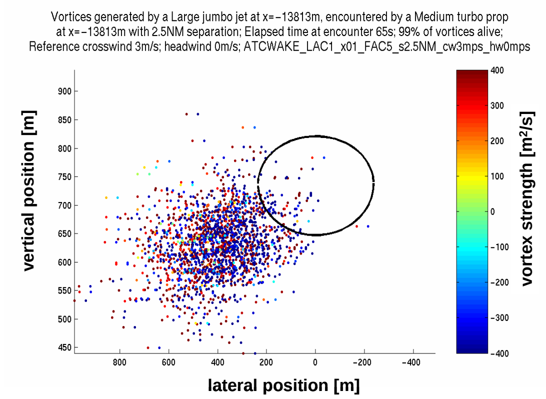

Figure 4. Vortex positions in meters of vortex pairs after Monte Carlo simulation at a certain longitudinal position analyzed at the time that a follower aircraft arrives at that position. The color of the dots indicates the vortex strength. The oval area indicates the flight path corridor.

2. Monte Carlo simulations are performed with the wake vortex evolution model, based on work of Corjon and Poinsot[11] and Sarpkaya[12]. Position, strength, and core radius of the wake vortices are computed as a function of time.

3. The results from step 2 are analyzed at the time instant when the vortices have the same longitudinal co-ordinate x as the follower aircraft (Fig. 4). This time depends on aircraft speed profile, the chosen separation, and longitudinal wind.

4. Using a dedicated probability density fitting procedure that accounts for dependencies between the lateral and vertical position, the strength, and the core radius of the wake vortex pair, the joint distribution of the wake vortices position, strength, and core radius is obtained in each of the gates.

5. Monte Carlo simulations are performed to simulate the wake vortex encounter. In this step the joint distribution from step 4 is used. Samples of the follower aircraft (lateral and vertical) position and speed in the selected gates are obtained with the flight path evolution model. Encounter metrics such as maximum bank angle, altitude of encounter and loss of height are obtained. This step provides the encounter severity probabilities in the different gates (Fig. 5).

6. The instantaneous risk due to a wake vortex is evaluated in each of the gates for four different risk events[4]: Minor incident, Major incident, Hazardous accident and Catastrophic accident.

7. The wake-induced risk is obtained by integrating the risk obtained in step 6 over all gates. By repeating steps 1 to 7 for different separation standards, incident/accident risk curves as function of the separation standard are determined for all four risk events.

8. Application of the risk management procedure provides the required separation minima (Fig. 6). This procedure is based on the requirement that the risk for each of the four risk events should satisfy associated Target Level of Safety (TLS) values[4].

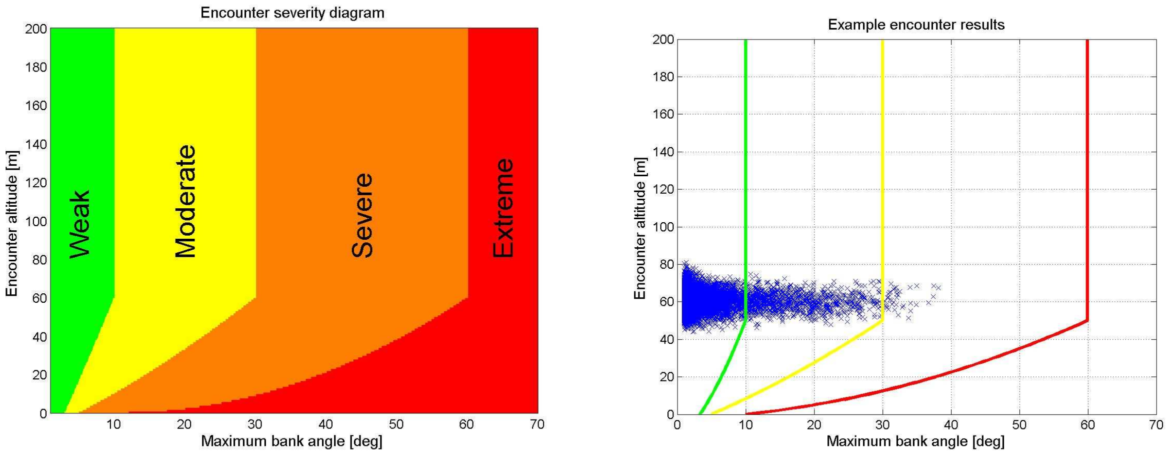

Figure 5. Encounter severity classification scheme (left) and example result (right).

An initial WAVIR safety assessment[4] for the single runway approach operation, in which it was assumed that crosswind can be modeled by a logarithmic profile with altitude, indicates that a crosswind of 2 m/s at 10 m altitude might allow a safe reduction of the aircraft separation to 2.5 Nm (between all aircraft types). The assessment was performed for a Large jumbo jet (like Boeing 747) and Medium jet (like Airbus A320) as leader aircraft in combination with Large jumbo jet, Medium jet, Regional jet (like Fokker 100) and Light turbo prop (like Cessna Citation II) as follower aircraft. Crosswind conditions of 0, 1, 2, and 4m/s were evaluated. The resulting safe separation distances are shown in Fig. 7.

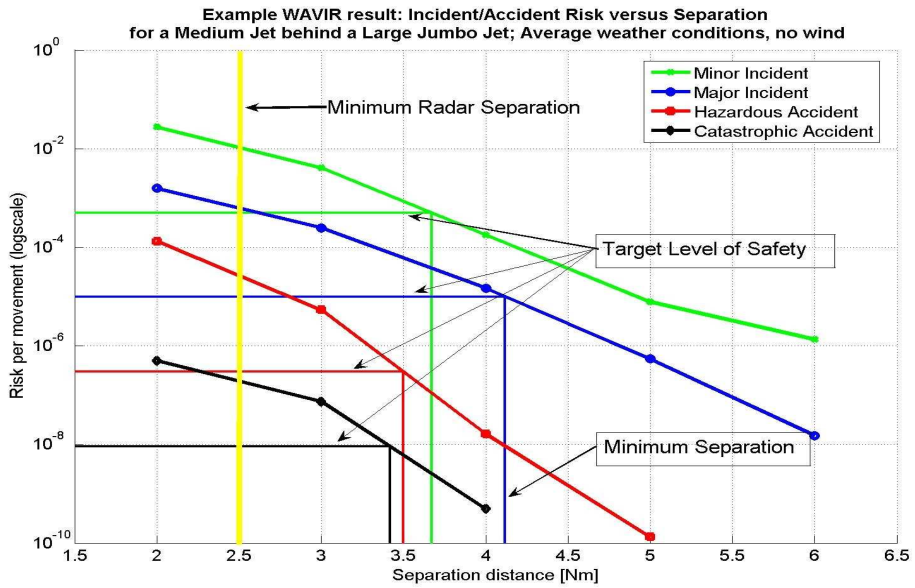

Figure 6. Risk management procedure.

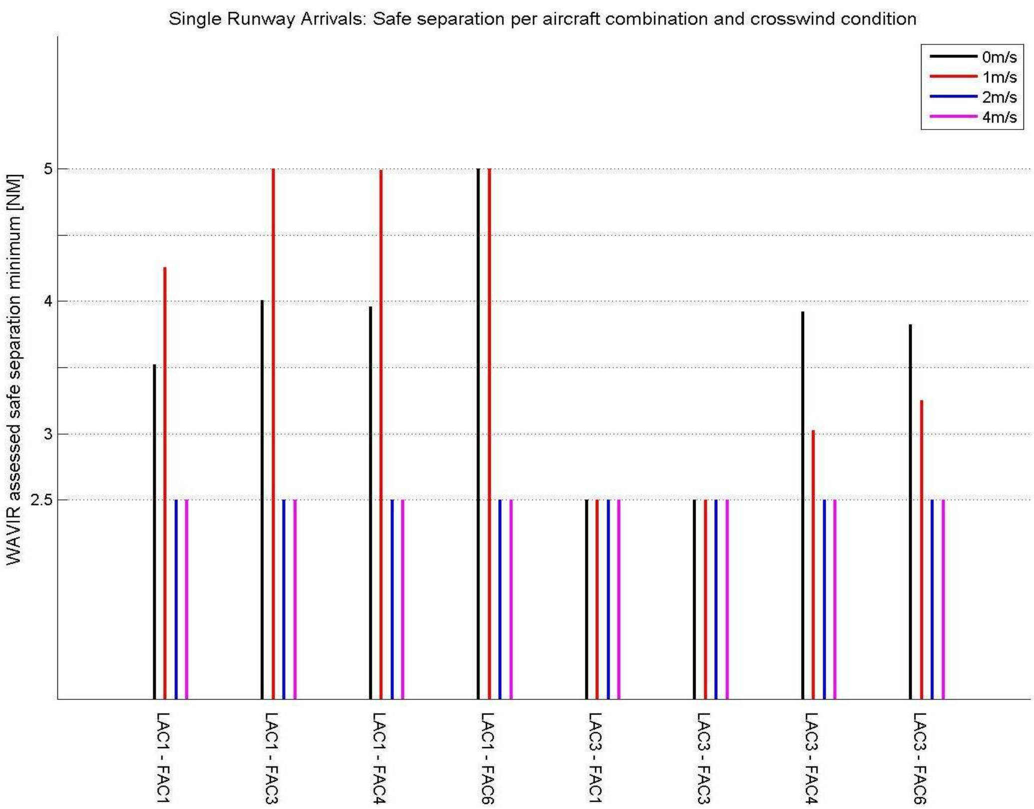

Figure 7. Overview of WAVIR assessed safe separation minima for the SRA operation for various crosswind conditions per leader-follower aircraft combination; (LAC1/FAC1 = Large jumbo jet, LAC3/FAC3 = Medium jet, FAC4 = Regional jet, FAC6 = Light turbo prop).

C. SMP Methodology

The objective of the SMP is to provide advice concerning the separation mode to be applied to the supervisory controller. The functional design of the Separation Mode Planner consists of seven steps in the process to obtain an advice on applicable separation mode. The steps are shown in Fig. 8.

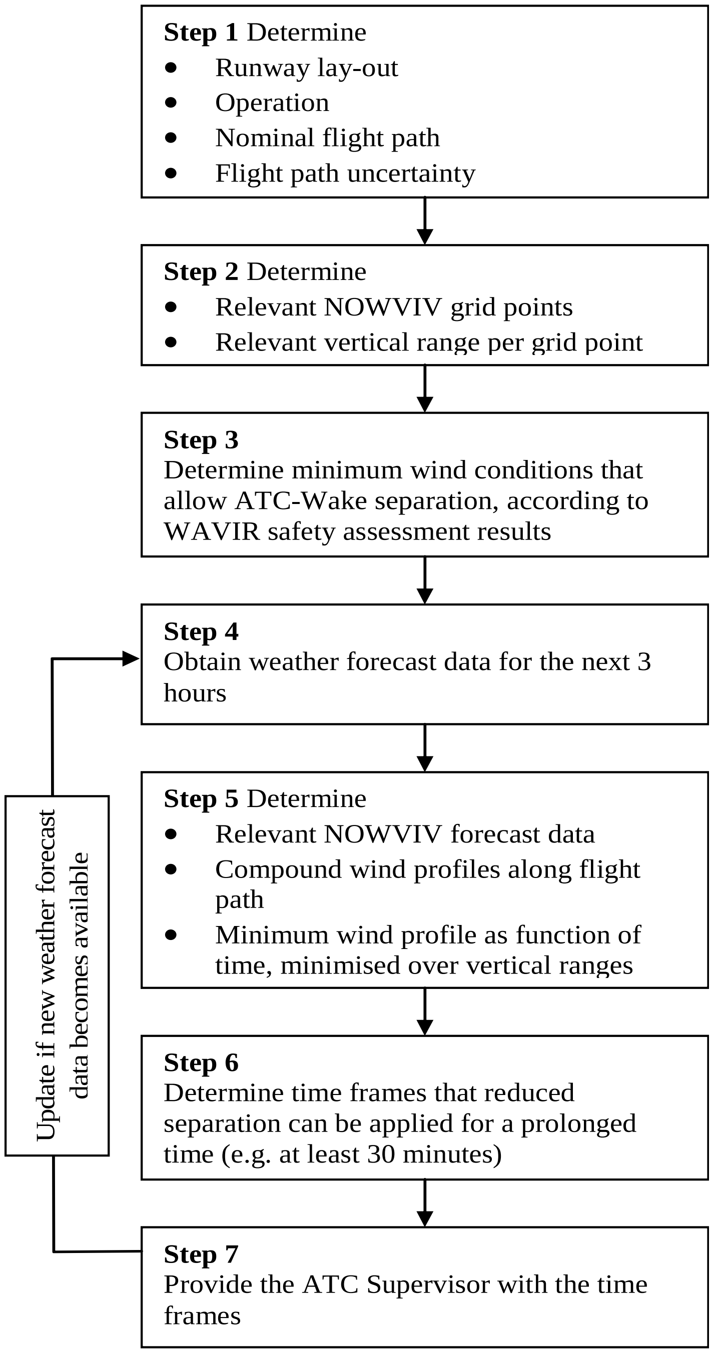

Figure 8. SMP methodology steps.

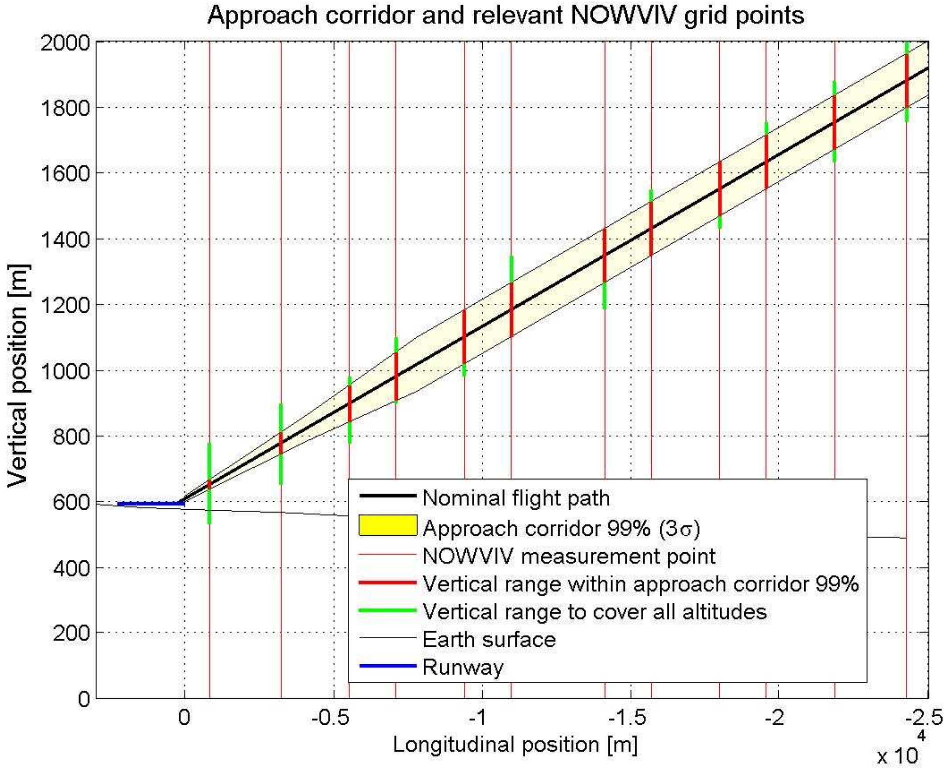

Figure 9. Approach corridor towards runway with NOWVIV grid point locations and relevant vertical ranges.

The weather forecast information needs to be available in an area that encloses the approach and departure corridor, at an accurate distance and time spacing. Given the nominal flight paths of leader and follower aircraft and the crosswind profiles at nearest grid points, the 'compound' profile of crosswind along the flight path can be constructed. Figure 9 illustrates this for an approach operation. Taking into account uncertainty in navigation performance, a flight path corridor is constructed around the nominal flight path. At locations along the flight path close to a grid point, the vertical range covering the vertical positions in the flight path corridor at and around that location is determined.

Figure 10 shows the crosswind profiles at 12 relevant grid points along the approach corridor. The thick red line indicates the nominal vertical position at that location while the red shaded areas indicate the vertical ranges. Each blue curve represents a forecasted crosswind profile at a certain time. The crosswind forecast data within the red shaded areas is used to determine the compound profile as shown in Fig. 11. Next, the crosswind variability along the flight path and during the considered time frame is determined. The blue and pink shaded area in Figure 12 show the crosswind and headwind variability respectively as a function of time of the day, based on an example data set. The minimum crosswind and/or headwind profile is then used to analyze possibilities for reduced separation. From the safety assessment results for various crosswind conditions, a crosswind criteria is derived that safely allows reduced separation for all aircraft combinations. The SMP advice now consists of these time periods within the considered time frame, in which the minimum crosswind profile shows crosswind values that exceed the crosswind criteria for a prolonged time (e.g. at least for 20 or 40 minutes).

Figure 12 shows as an example that if a crosswind of 4m/s or more would safely allow ATC-Wake separation, this would be possible from 09:00 to 09:40 and from 15:30 to 21:50. A Graphical User Interface (GUI) for the SMP has been implemented for analysis purposes. The GUI facilitates the user with buttons and editable fields to select weather forecast data from a data base and specify control parameters like the time frame to be considered and uncertainty in wind forecast to be taken into account. The GUI is shown in Fig. 13.

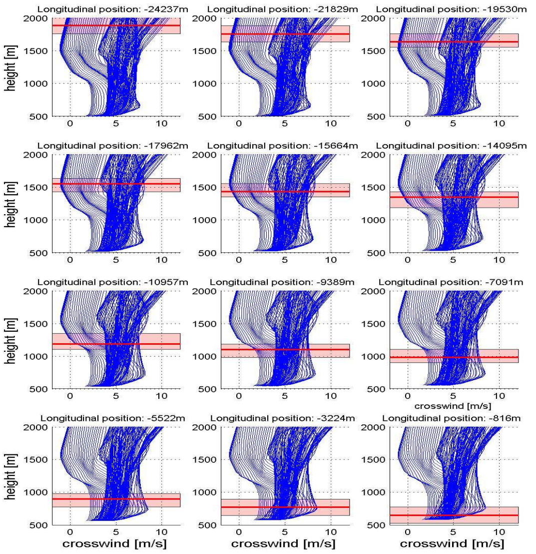

Figure 10. Crosswind profiles at 12 relevant grid points during a particular day. The red shaded areas indicate the vertical ranges that are used to construct the compound profile.

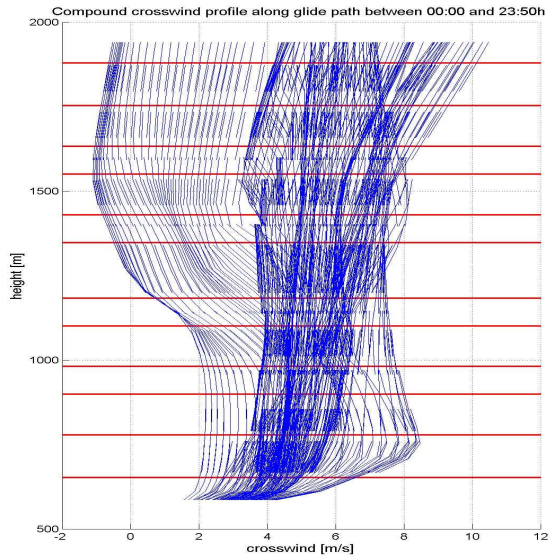

Figure 11. Compound crosswind profiles during a particular day. Each profile represents the crosswind as experienced along the approach path at a particular time. The red lines correspond to the altitudes where the flight path crosses a relevant grid point.

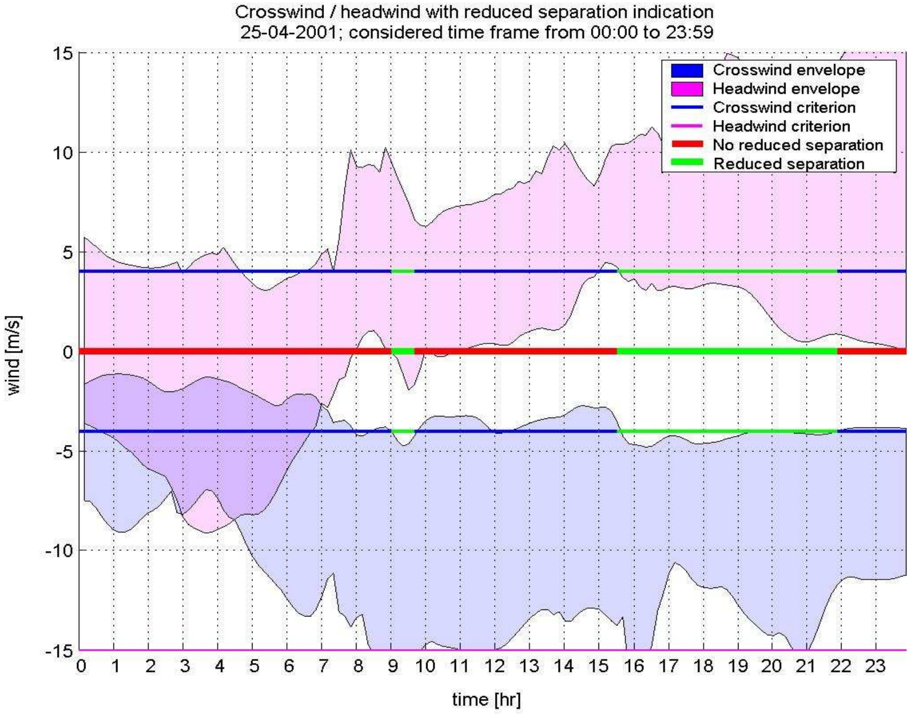

Figure 12. Example result of SMP analysis of NOWVIV data.

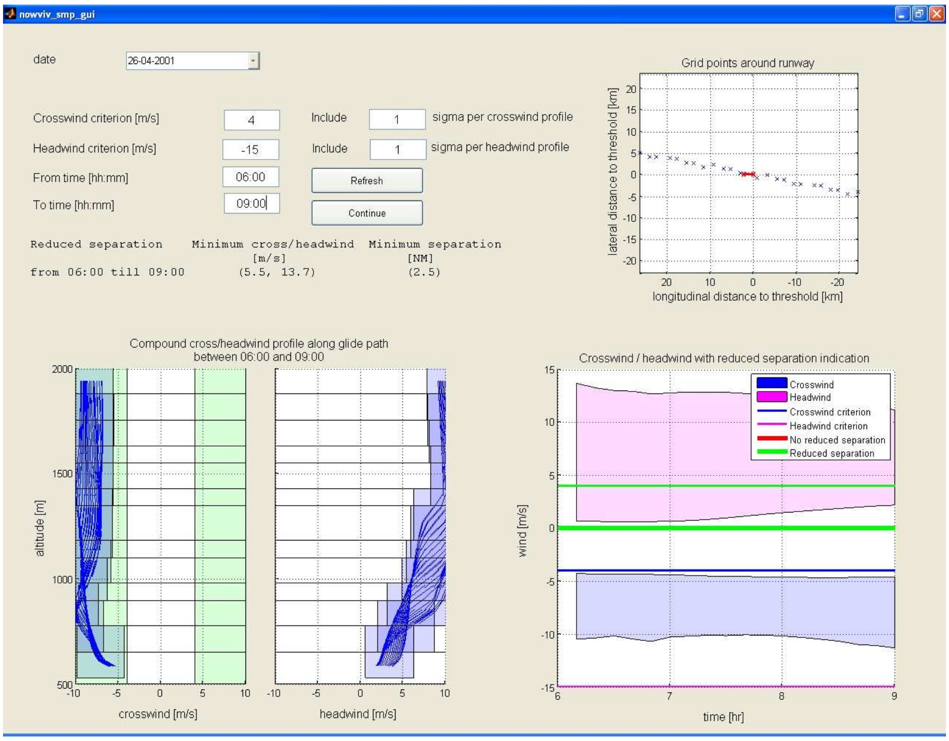

Figure 13. Graphical User Interface for the SMP that shows the control parameters (upper left), grid points (upper right), compound crosswind and headwind profiles (bottom left) and separation mode advice (bottom right).

As an example, day 5 of DLR's WakeOP measurement campaign (April 26th 2001) has been selected for the time frame from 06.00 to 09.00 (AM). On start-up of the SMP GUI, the available weather data is analyzed and the SMP will display the results and associated separation advice for the selected time frame. For a crosswind criterion set to 4 m/s and virtually neglecting the headwind criterion (set to -15 m/s), reduced separation may be applied during the whole time frame. As can be seen from the plots, the crosswind envelope (blue shaded area) is below the crosswind criterion at -4 m/s, i.e. the absolute crosswind is above the criterion of 4 m/s.

IV. Analysis of Capacity Benefits

To provide insight in the capacity benefits that may be expected when the ATC-Wake operation and system are introduced at an airport, a crosswind climatology that is based on about 400,000 observations at about 10m altitude at three large European airports is used[13]. The probability of crosswind exceeding 2m/s is listed in Table 1. Crosswind from left and right appeared to be equally likely.

Table 1. Indicative separation per crosswind interval for the SRA operation and crosswind probability per interval

Crosswind interval	Indicated separation in the SRA operation	Crosswind probability
$0 \le u_c \le 2$m/s	ICAO	0.288
$u_c \ge 2$m/s	2.5NM	0.712

Analytical capacity studies[9] performed within ATC-Wake have provided information regarding runway throughput and delay characteristics.

A sample traffic mix is determined (see Table 2) divided in a number of aircraft weight categories: MT (medium turboprops), MJ (medium jets), MH (medium when aircraft is following another aircraft, heavy when being followed by another aircraft, applicable to the Boeing 757-series only), and H (Heavy). The distinction between MT and MJ is made, because of differences in characteristics (e.g. approach speeds, runway occupancy times).

Table 2. Traffic mix and characteristics

Weight category	**M**			**H**
Sub category	**MT**	**MJ**	**MH**	**H**
Traffic Mix	19%	59%	3%	19%
Approach speed (knots)	130	150	150	150
Arrival runway occupancy time (sec)	45	50	55	60

Table 3 and Table 4 show arrival throughput and arrival delay characteristic numbers in case of ICAO separation and in case of ATC-Wake separation. Although the targeted separation in ATC-Wake mode is 2.5 Nm, 3.0 Nm is also considered. When ATC-Wake mode could be applied at any time, arrival capacity might be increased with up to 6.3% (3.0Nm) or 7.1% (2.5Nm). Delay might then be reduced with up to 33% (3.0Nm) or 40% (2.5Nm).

Weighing the runway throughput and delay characteristics in the different separation modes per crosswind interval with the probability of occurrence of the crosswind interval yields the results as summarized in Table 5. Considering the crosswind climatology for European airports, runway throughput increases up to 4.4% may be expected in case of ATC-Wake separation of 3.0 Nm, while in case of 2.5 Nm separation this further increases up to 5.0%. Delay may be expected to decrease with up to 24 and 29% respectively. Analysis of landing operations in relation to wind conditions at Amsterdam Airport Schiphol has revealed that crosswind exceeding 2 m/s occurs in about 61% of the time[14]. The associated benefits (assuming the same traffic mix and throughput numbers as in Table 2 and 3) are also listed in Table 5: an expected increase in runway throughput of 3.8% (3.0Nm) or 4.3% (2.5Nm) and expected decrease of delay of 20% (3.0Nm) or 24% (2.5Nm). These results are promising as already a 1 or 2% increase in runway throughput may lead to substantial economic benefits.

Table 3. Arrival throughput in case of ICAO or ATC-Wake separation

Configuration	**Arrival Capacity (ac/h)**	**% Change**
ICAO separation	35.2	0 % (reference)
ATC-Wake mode (3.0 Nm)	37.4	6.3 %
ATC-Wake mode (2.5 Nm)	37.7	7.1 %

Table 4. Delay in case of ICAO or ATC-Wake separation

Configuration	**Arrival delay (min)**	**% Change**
ICAO separation	3.0	0 % (reference)
ATC-Wake mode (3.0 Nm)	2.0	-33 %
ATC-Wake mode (2.5 Nm)	1.8	-40 %

Table 5. Runway throughput and delay characteristics for the SRA operation in ICAO and ATC-Wake separation mode when taking into account a crosswind climatology

	Crosswind climatology for European airports		**Crosswind climatology for Schiphol airport**	
	Runway throughput [ac/hr]	Delay [min]	Runway throughput [ac/hr]	Delay [min]
ICAO	35.2	3.0	35.2	3.0
ATC-Wake (3.0Nm)	36.8 (+4.4%)	2.29 (–24%)	36.5 (+3.8%)	2.39 (-20%)
ATC-Wake (2.5Nm)	37.0 (+5.0%)	2.15 (–29%)	36.7 (+4.3%)	2.27 (–24%)

V. Discussion of Results

Within the ATC-Wake project, the SMP methodology has been applied to different scenarios using forecasted weather data for two days of the WakeOP and WakeTOUL measurement campaigns[8]. In some scenarios, the SMP advised to apply reduced separation, while the measured weather information appeared to be below the crosswind threshold value. However, the corresponding wake vortex predictions based on weather nowcast information as well as the wake vortex detection information did not lead to an alarm while reduced separation was applied. The reverse situation, where the SMP advised ICAO separation while the actual conditions would have allowed reduced separation, also occurred.

The abovementioned example scenarios and the calculated False Alarm Rate of the predictions (see Section III.A) obviously illustrate that an accurate prediction of wind is essential for the feasibility of the ATC-Wake operation. Safety analysis of the ATC-Wake operation[9] showed that a too low accuracy may lead to an unacceptably large number of missed approaches that may be initiated when reduced separation is applied erroneously. On the other hand the potential to apply reduced separation may not be used to its optimum. A possible way to further optimize the use of the ATC-Wake Separation Mode Planner is through assimilation of local measurements into the model. Better use of other measured meteorological data from various sources in the terminal area, such as weather radar data and Aircraft Meteorological Data Relay (AMDAR) data, may also contribute to local optimization of the ATC-Wake Separation Mode Planner as part of the ATC-Wake system.

The analysis presented here focused on crosswind only. Headwind is known to be beneficial as well in terms of wake vortex transport, while quartering tailwinds (a wind of about 30 degrees from the rear) are considered hazardous. Reference 14 suggests various aircraft separation strategies to benefit from headwind, such as time-based rather than distance-based separation and adapted true airspeed in order to maintain groundspeed. At Schiphol, headwind landing operations with headwind more than 5m/s occur for almost 40% of the time which leads to an estimated loss of runway capacity of at least 7.2%. An increased glide path angle is also indicated as a way to safely enable reduced separation, though it should be noted that this conflicts with the conclusions from reference 4.

In the WAVIR assessment, crosswind has been assumed to follow a logarithmic profile with altitude, resulting in a somewhat increasing crosswind with altitude, while wind speed and direction can be much more variable in practice. Future work should therefore also focus on a more realistic wind climatology, which can be rather different per airport, so as to evaluate potential benefits and bottlenecks more accurately (see e.g. Ref. 10).

VI. Conclusion

Today’s wake vortex separation rules tend to become capacity bottlenecks at busy airports. Within the ATC-Wake project for the European Commission, an integrated Air Traffic Control (ATC) wake vortex safety and capacity system has been designed so as to provide the means to significantly enhance airport capacity. The system will enable Air Traffic Controllers to apply new weather based dynamic aircraft separation.

This paper has described the design and development of a Separation Mode Planner (SMP), a crucial component of the ATC-Wake system, which can be used in the context of the ATC-Wake operational concept[6, 7]. The SMP is used in the planning phase where weather and wake vortex forecast information is used together with aircraft separation rules to establish the arrival and/or departure sequence. Weather nowcasting and wake vortex prediction and detection information is used in the tactical phase to monitor and control safe separation.

Provided that the forecasted weather, in particular crosswind, satisfies predefined criteria, reduced separation (compared to ICAO standards) appears to be feasible and is expected to increase airport handling capacity at European airports. The weather forecast data should be available at a sufficient accurate time and distance spacing at various locations encompassing the flight path corridor. The SMP methodology takes into account the uncertainty in aircraft navigation performance as well as weather forecast data. The criteria can be derived from safety assessment results obtained with the WAVIR tool-set for a variety of weather and wind conditions and aircraft combinations.

Initial WAVIR assessment results show the possibility to safely reduce separation to 2.5 Nm for single runway approaches, provided that crosswind at 10m altitude exceeds 2m/s. An analytical capacity study showed that runway throughput could increase from 35.2 aircraft per hour in ICAO separation mode to 37.7 in ATC-Wake separation mode and average delay could be reduced from 3.0 to 1.8 minutes per aircraft. Taking into account a crosswind climatology, it was estimated that application of ATC-Wake separation mode when crosswind exceeds 2 m/s could imply a runway throughput improvement of 5% or a delay reduction of 29%. These results are promising as they may lead to substantial economic benefits.

Further study is recommended and should also focus on headwind as an enabler of reduced separation as well as on tailwind which is considered hazardous especially in combination with a crosswind ('quartering tailwinds'). The analysis described in this paper is based on an initial safety assessment of the single runway operation, taking into account simplified aircraft speed profiles and crosswind profiles. Extension of the assessment to more realistic scenarios, preferably representing the local weather climatology at the airport envisaged for installation of the ATC-Wake system will provide more insight in the safety and capacity benefits of the ATC-Wake operation.

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