<ATC-Wake>

<IST-2001-34729>

<D4_7: ATC-Wake Operational Feasibility>

ATC-Wake Operational Feasibility

(ATC Wake D4_7)

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Report Version:	Final Version
Report Preparation date:	31/12/2005
Classification:	Public
Contract Start Date:	01.07.2002
Duration:	31.12.2005
Project Co-ordinator:	National Aerospace Laboratory NLR
Partners:	Deutsches Zentrum für Luft- & Raumfahrt DLR
	EUROCONTROL Experimental Centre EEC
	Thales Air Defence TAD
	Thales Avionics TAV
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Project funded by the European Community under the “Information Society Technology” Programme (1998-2003)

DELIVERABLES SUMMARY SHEET

Project Number:	IST-2001-34729
Project Acronym:	ATC-WAKE
Title:	ATC-Wake Operational Feasibility
Deliverable N^{o}:	D4_7
Due Date:	31/12/2005
Deliverable Date:	31/12/2005

Short Description:

Following the definition of ATC-WAKE operational concepts, procedures and requirement (WP1000), the assessment of operational feasibility (WP4000) has been performed through a series of simulations (fast-time) of air traffic, airspace and airport environment, the analysis of usability and acceptability issues, the review of issues on the operational concept raised during ATC-WAKE meetings and the analysis of interoperability needs with existing ATC systems.

As a main conclusion the ATC-WAKE operational feasibility analysis has allowed to build confidence in the proposed operational concept for the application of reduced separations to represent a sound evolution from existing ATC procedures and working practices, to deliver significant benefits for runway throughput and average delay per flight without major rework to the current ATC systems.

The study provides an overview of the different activities performed in the ATC-Wake WP4000 on Operational Feasibility and recalls the main conclusions drawn.

Partners owning:	ATC-WAKE Consortium
Partners contributed:	ATC-WAKE Consortium
Made available to:	EC, IST Programme

Contract No. **IST-2001-34729**

ATC WAKE WP4000

Task Title ATC-Wake Operational Feasibility

Deliverable D4_7

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Document control sheet		**NLR-TP-2006-253**	
Work Package:	**WP4000**	**Released by:** L.J.P. Speijker (NLR)	
Version:	**Final**	**Approved by:** A. Vidal (EEC)	
Issued by:	**EEC**	**Reviewed by:** ATC-Wake consortium	
Date of issue	**31/12/2005**		

This report is Public, and has been produced by the ATC-Wake consortium:

National Aerospace Laboratory NLR

Deutsches Zentrum für Luft- & Raumfahrt DLR

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Acronyms

ACC	Air traffic Control Centre (en route)
AGL	Altitude above Ground Level
AMAN	Arrival Manager
APP	Approach ATC Unit
ARS	Airport Radar System
ATCO	Air Traffic Control Officer
ATIS	Air Traffic Information Service
ATSU	Air Traffic Service Unit
AVOL	Aerodrome Visibility Operational Level
CSPR	Closely Spaced Parallel Runways
DMAN	Departure MANAGER
DME	Distance Measuring Equipment
EAT	Expected Approach Time
ETA	Estimated Time of Arrival
FAP	Final Approach Point
FDPS	Flight Data Processing System
FIR	Flight Information Region
GND	Ground Controller
HMI	Human Man Interface
IAF	Initial Approach Fix
IAS	Indicated Air Speed
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INI	Initial Approach Controller
ITM	Intermediate Approach Controller
LDA	Localizer Directional Aid
ILS	Instrument Landing System
LVP	Low Visibility Procedure
MAP	Missed Approach Point
MLS	Micro Wave Landing System
MTOW	Maximum Take-Off Weight
NDB	Non-Directional Beacon
NM	Nautical Mile
NTZ	Non Transgression Zone
PRM	Precision Radar Monitor
ROT	Runway Occupancy Time
RWY	Runway
SART	Situation Awareness Rating Technique
SMR	Surface Movement Radar
SOIA	Simultaneous Offset Instrument Approaches
STAR	Standard Arrival Route
SUS	System Usability Scale
THR	Runway Threshold
TLX	Task Load Index
TMA	Terminal Manoeuvring Area
TWR	Tower Controller
UAC	Upper Airspace Centre
VFS	Vortex Forecast System
VHF	Very High Frequency
WP	Work Package
WV	Wake Vortex

Foreword

An important factor limiting today's airport capacity is the phenomenon of wake vortices generated by aircraft in flight. To avoid aircraft entering the zone of turbulence of another aircraft during the approach phase, minimum separation criteria between aircraft were published in the 1970's. These separations are expressed in terms of longitudinal distances and have since served to provide acceptable safe separations between aircraft at all major airports through the use of radar. An integrated Air Traffic Control (ATC) wake vortex safety and capacity system (including a controller Human Machine Interface (HMI)) used in combination with new modified wake vortex safety regulation is expected to provide the means to significantly enhance airport capacity.

The main objective of the ATC-wake project is to develop and build an innovative platform integrated into the Air Traffic Control (ATC) systems with the aim of optimising safety and capacity. This platform will have a test bed environment role:

- To assess the interoperability of this integrated system with existing ATC systems currently used at various European airports;
- To assess the safety and capacity improvements that can be obtained by applying this integrated system in airport environments;
- To evaluate its operational usability and acceptability by pilots and controllers.

The local installation of an integrated system at European airports will require new safety regulation, since the present wake vortex safety recommendations and best practices do not take new modified ATC systems into account. Specific attention will be given to the issue of development and harmonisation of new wake vortex safety regulation.

The main expected exploitable project outputs is the integrated ATC Wake Vortex safety and capacity platform, which contains as further exploitable elements:

- Wake Vortex Prediction and Monitoring Systems;
- Wake Vortex Safety and Separation Predictor;
- Weather forecasting, now-casting and monitoring systems;
- Wake Vortex Predictors and monitors;
- Fast-Time ATC Simulator (upgraded with 'wake vortex modules');
- Controller Human Machine Interface (HMI).

In addition to these exploitable project outputs, new modified wake vortex safety regulation will be proposed. This will strongly enhance the introduction of new systems and procedures to alleviate the wake vortex problem.

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Executive Summary

With the steady increase in air traffic, civil aviation authorities are under continuous pressure to increase aircraft handling capacity. One potential approach is to reduce the separation distance between aircraft at take-off and landing without compromising safety. One limiting factor is that aircraft always give each other a wide berth to avoid each another's wake turbulence. 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 as "wake vortex predictors"; there is potential for making the separation distances dependent on these predictors as well as aircraft weight. Nevertheless, today, there is no link to ATC and subsequently no system integrating all the sources of information together at a single source, accessible by all ATC providers (en-route, approach, tower, and arrival/departure managers). The IST project ATC-Wake aims to develop and build an integrated platform for ATC (Air Traffic Control) that would allow variable (reduced) aircraft separation distances.

Following the definition of ATC-WAKE operational concepts, procedures and requirement, ATC-Wake WP4000 evaluates the operational feasibility of the proposed ATC-Wake system for ATC operations, including the analysis of the interoperability with existing ATC systems and the usability and acceptability by ATC Controllers. The operational feasibility assessment of the operational concept and procedures includes a qualitatively and quantitatively analysis of expected benefits and anticipated constraints from the application in the current European airports operations environment and systems. The following steps are performed:

- Review of the operational concept and procedures, analysis of the issues raised by a group of ATC Controllers' involved in the real-time simulations and other issues raised by the participants of the ATC-Wake project. Such assessment has covered the correctness, usability and acceptability from ATC Controllers' perspective of the ATC-Wake concept.
- Airport and airspace simulations: a series of fast-time simulations aiming at measuring the size of the operational benefits for ATC-WAKE has been performed, the simulations have been prepared considering existing airport operations, a generic airport layout and existing traffic samples.
- Evaluation of the necessary interoperability with existing ATC systems: the proposed user and system requirements for ATC-WAKE have been evaluated against existing airport systems and the size of the required changes assessed.

The ATC controllers involved in the validation exercises recognize that the ATC-Wake concept is a valuable evolution from the current concept applied in Europe. The integration of the information on wake vortex detection and prediction both for planning and tactical operations is positively received. The transition between ICAO standard separation and reduced separation is compared by the ATC Controllers involved in the trials to the current meteorological transitions (wind direction or visibility) that influence airport operations

(change in runway directions, application of low visibility procedures). The ATC-WAKE operational feasibility analysis builds confidence in the proposed operational concept for the application of reduced separations to represent a sound evolution from existing ATC procedures and working practices, to deliver significant benefits for runway throughput and average delay per flight without major rework to the current ATC systems. Nevertheless such positive conclusions on operational feasibility will need to be traded-off against the actual weather 'windows' to perform such operations and the costs for the acquisition and implementation of the new equipments or infrastructure required (wake vortex sensors, new atmospheric sensing systems, enhanced weather forecast capabilities).

This study provides an overview of the different activities performed in ATC-Wake WP4000 Evaluation of Operational Feasibility, and recalls the main conclusions drawn.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Scope

Currently the ICAO separations are conservative, not dependent on the weather conditions: they do not completely eliminate the risk of wake vortex encounter but 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 and ATC-WAKE has developed an operational concept to apply reduced wake vortex separation minima in the context of European airport operations.

Therefore, important issues for ATC-WAKE are to assess the operational feasibility, benefits and limits of the use of reduced separations as well as to identify the evolutions induced or changes required with respect to today's ATC operations or systems.

1.2 Objectives

The main objective of WP4000 is to evaluate the operational feasibility of the proposed ATC-WAKE integrated system for ATC operations, including the analysis of the interoperability with existing ATC systems and the usability and acceptability by ATC Controllers. Following the definition of operational concepts and procedures (see ATC-Wake D1_5), the operational feasibility assessment will be realised through:

- Review of the operational concepts and proposed ATC working methods with ATC operations experts or against current operations in European airports;
- Assessment of the potential operational benefits from ATC-WAKE through the performance of a series of fast-time simulations with a airspace and airport modeller;
- Analysis of existing airport environment and ATC systems and the impact of ATC-Wake.

1.3 Approach

The operational feasibility assessment of ATC-WAKE operational concept and procedures consisted in analysing qualitatively and quantitatively the expected benefits and anticipated constraints from the application of such concept in the current European airports operations environment and systems. The operational feasibility assessment has been decomposed in several steps as following:

- Review of the operational concept and procedures, analysis of the issues raised by a group of ATC Controllers' involved in the real-time simulations (WP2700) and other issues raised by the participants of the ATC-WAKE project. Such assessment has covered the correctness, usability and acceptability from ATC Controllers' perspective of the ATC-WAKE concept.

- Airport and airspace simulations: a series of fast-time simulations aiming at measuring the size of the operational benefits for ATC-WAKE has been performed, the simulations have been prepared considering existing airport operations, a generic airport layout and existing traffic samples.
- Evaluation of the necessary interoperability with existing ATC systems: the proposed user and system requirements for ATC-WAKE have been evaluated against existing airport systems and the size of the required changes assessed.

1.4 Structure of the Document

This document is structured as follows:

- Section 1: Introduction
- Section 2: Overview / State of the art
- Section 3: Analysis of ATC-Wake concept and procedures
- Section 4: Usability and acceptability from ATC Controllers' perspective
- Section 5: Airport and airspace simulations
- Section 6: Interoperability with existing systems
- Section 7: Conclusions and recommendations

2 Overview / State-of-the-art

2.1 Reduction of Wake Vortex Separation

Wake vortices are a natural by-product of lift generated by aircraft and can be considered (or viewed) as two horizontal tornados trailing after the aircraft. A trailing aircraft exposed to the wake vortex turbulence of a lead aircraft can experience an induced roll moment that is not easily corrected by the pilot or the autopilot.

ICAO safety provision for aircraft separation criteria has been defined in the early 70's and has, since then, served to maintain acceptable standards of wake vortex safety. Such standard is based on fixed distance or time separation between aircraft according to their respective category.

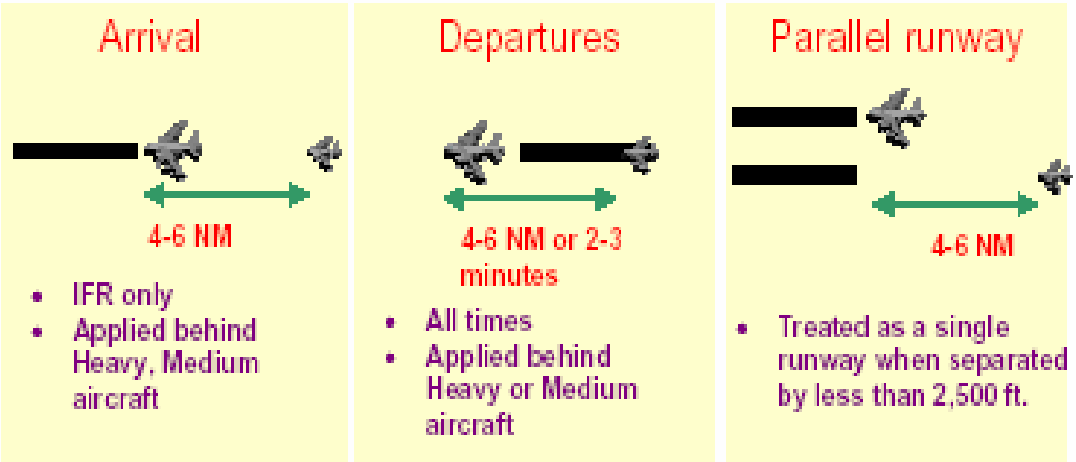


Figure 1 – ICAO Standard Separation for Approach and Departures

Current safe wake vortex separations are achieved with a set of rules for air traffic control and procedures for the pilots. At major European airports most traffic perform instrument approach arrival and departures (IFR flights), where ATC Controllers are responsible for applying wake vortex standard separation.

ATC separation standards, designed for the worst-case scenario, have been introduced to ensure operation without a wake vortex hazard. Wake vortex separation standards have a significant impact on airport departure and arrival capacity especially at the busiest hub airports. For this reason both the USA WakeNet Conops Team and the European Wake Vortex Conops Team (EWVCT) are developing technologies and procedures for increased arrival and departure rates at airports through reduced separation *without* an impact on safety.

In Europe, currently three new concepts of operation are under consideration by the European Commission and Eurocontrol. The near term procedure involves modification of the separation method used during arrivals: here the focus is on introducing *Time Based Separation* at airports with a large frequency of strong headwind conditions. Mid- to long term procedures focus on new ground and airborne systems as covered in the ATC-WAKE and I-WAKE projects based on real-time detection / prediction and monitoring of wake vortices.

In the USA, currently three concepts of operation are under consideration by NASA and the FAA to improve runway flow capacity by reducing separation distances under certain conditions. The near-term procedure involves modification of the rules associated with closely spaced parallel runways. Here the aim is to enable dependent parallel runway arrival operations with parallel runways separated by less than current standards under favourable weather conditions. Mid-term procedures involve modification of separation times for departures. Long-term systems and procedures (including *WakeVAS*) aim to execute dynamic separation distances based on measurements of weather conditions.

2.2 ATM Operational Concept Validation

Validation is the process by which the fitness-for purpose of a new system or operational concept being developed is established. The process of validation is essential if a development project is to deliver the improvement in performance intended when the customer originally initiated the work programme involved.

To "guide" the ATM concept through the development process, a validation strategy is developed. Such a validation strategy (or “route map”) defines, for each stage in the ATM life cycle, when a decision needs to be taken and what type of validation should be used for the next phase. For each life cycle stage there may be a preferable validation technique that delivers the most useful results at that development stage.

The figure below presents an example route that may be taken over a pre-defined validation route map. The “nodes” on the route map indicate the validation techniques that may be employed. It must be noted that, in general practice, the route taken will not be as straightforward as shown in Figure 3 and will frequently involve “looping” back up the route map – e.g. fast-time simulations conducted to broaden the scenario scope of results obtained in real-time simulations.

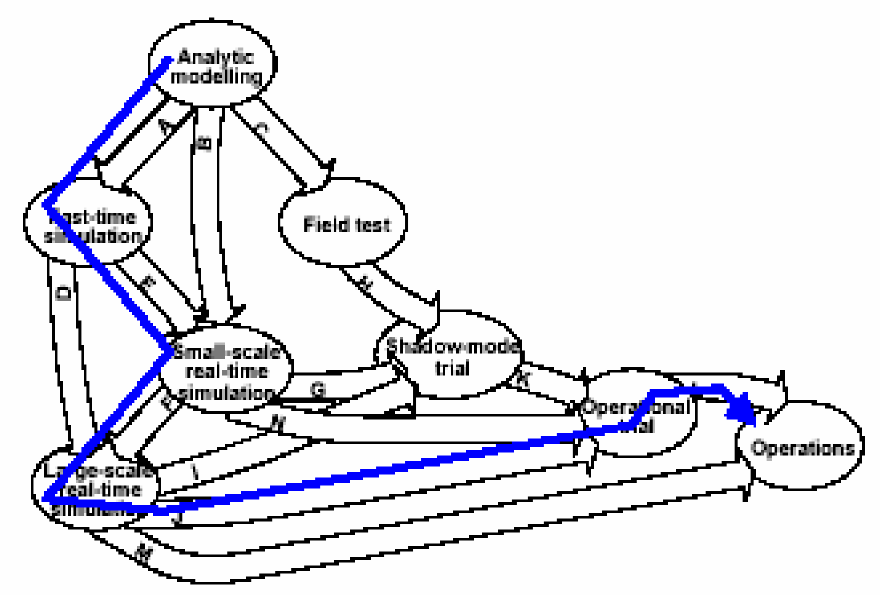


Figure 2 – Example of a Validation Route (MAEVA)

Developed by the European Commission DG TREN, MAEVA methodology proposes to establish a uniform framework for the validation of ATM projects. The MAEVA methodology consists of a five-step process for conducting validation exercises. These steps are as follows:

- Step 1: Define validation aims, objectives and hypotheses.
- Step 2: Prepare the validation plan and exercise runs.
- Step 3: Execute the exercise runs and take measurements.
- Step 4: Analyse results.
- Step 5: Develop and disseminate conclusions.

Each of these steps is described in detail in the MAEVA handbook available at the following website: http://www.maeva.isdefe.es.

2.3 Fast-Time Simulation

2.3.1 General

Building decisions for changes to airport operations require a thorough analysis of the various options and their outcomes at the planning stage. Demand-capacity analysis, therefore, plays a key role in defining the operational procedures and the physical requirements of airport facilities to meet future traffic demand. Fast-time simulations represent a mean to investigates different runway configurations to evaluate each of the airport layout in terms of runway system capacity utilisation.

Fast-time simulations do not require the direct involvement of ATC controllers since their working methods are modelled; moreover these simulations operate many times faster than real-time simulations. This enables a statistically significant number of runs to be performed for a particular set of input parameters representing all the various possible operational scenarios, and a comprehensive test of the sensitivity of the system to the variation of particular parameters.

The runway throughput is primarily dependent on the runway occupancy times of, and separation standards applied to successive aircraft in the traffic mix.

Other key items affecting runway throughput include: mode of operations (arrivals only, departures only or mixed mode) availability of exit taxiways, especially that of high speed exits that help minimising runway occupancy times of arriving aircraft, aircraft type/performance, traffic mix, weather conditions, spacing between parallel runways, procedures for runway crossing.

2.3.2 TAAM

TAAM, the Total Airspace and Airport Modeller tool is a gate-to-gate simulator, i.e. able to simulate ground, terminal area and en-route operations and was selected for the ATC-Wake project.

Developed by The Preston Group (now Boeing) in cooperation with the Australian Civil Aviation Authority, TAAM (Total Airspace & Airport Modeller) is a large scale detailed fast-time simulation package for modelling entire air traffic systems. The model is a four dimensional flight path simulator.

A number of factors may be randomised in the simulation to reflect day-to-day fluctuations. A versatile simulation model, TAAM has been used in a wide variety of applications including airport capacity estimation (gate, taxiway, runway capacity), planning airport improvements, extensions, de-icing, noise impact, effect of severe weather, design of terminal area procedures (SIDs/STARs) and terminal area ATC sectors, controller workload assessment, impact of new ATC rules, system wide delays and cost/benefit studies.

The version of TAAM used for ATC-WAKE contained a number of limitations:

- The staggered approach separation was available within the model, but not working
- The wind option was theoretically available, but not working.

3 Analysis of ATC-Wake Concept and Procedures

Following the definition of the ATC-WAKE Operational Concept, User and System Requirements in WP1000, a number of potential issues, ambiguities, refinements and alternatives to the requirement specification have been identified and further investigated.
Examples of such issues are:

- **Transitions between ATC-WAKE and ICAO separation modes**
  Frequent transitions between ICAO and ATC-WAKE separation modes may have negative effect as they potentially requires significant ATC resource for the re-planning of arrivals.
- **Missed Approaches when ATC-WAKE is applied**
  When an aircraft is caused to abort a landing after it has already started its landing approach, the aircraft has to follow a pre-defined path to leave the airspace surrounding the aerodrome.
  The missed approach procedure to be followed in such case is an integral part of the published approach procedure.
  The issue of go-around movements while applying reduced separations has been raised during several presentations of ATC-WAKE concept of operations.
- **Prevention of wake vortex encounter**
  Even as they understand the concept, ATC Controllers interviewed by NLR keep their doubts about the decline of the wake vortex length along the ILS when the aircraft comes closer to the runway

The operational issues have been responded by the ATC operational experts in charge of WP1000 and changes to the ATC-WAKE requirement specification have been introduced.

3.1 Analysis of ATC Controllers' Questionnaires

During the real-time simulation exercises of ATC-WAKE concept at NLR, a questionnaire has been prepared for the ATC Controllers (coming from 5 different countries) involved during the simulations. Such questionnaire is detailed in [D4_6] and the HMI concepts have been analysed in [D2_7]. The following remarks concerning the ATC-Wake concept were supported by all the controllers:

- The concept itself is easy to understand;
- The system is preferred to be operational for 24 hours a day, seven days per week;
- The system is preferred as a safety system;
- The difference between ICAO and ATC-Wake mode could be eliminated in the future;
- The weight category information could be kept available in the ATC-Wake mode ;
- When the suggested separation in ATC-Wake mode is larger than 3 NM, the ATC-Wake mode is not useful anymore;
- A transition between ICAO and ATC-Wake modes and vice versa is no problem.

But also some controllers had their doubts. The most important remarks:

- Some controllers have doubts about the decline of the wake vortex length along the ILS when the aircraft comes closer to the runway.
- Some controllers have doubts about the anticipated actions of the pilots, who will need to follow their instructions when they put a medium aircraft close (but within ATC-Wake separation) behind a heavy aircraft.

Such results confirm that there are no major concerns with respect to the operational and user requirements proposed by ATC-Wake WP1000 (see D1_5).

The ATC Controllers have recognised that the ATC-WAKE concept is an evolution from the current concept applied in Europe. The integration of the information on wake vortex detection and prediction both for planning and tactical operations has been positively received.

The transition between ICAO standard separation and reduced separation has been compared by ATC Controllers to the current meteorological transitions (wind direction or visibility) that influence airport operations (change in runway directions, application of low visibility procedures).

To be used as a safety net, the ATC-WAKE system shall warn ATC Controllers about:

- WV information lack of integrity: provide alarms when there is a difference between the actually observed wake vortex behaviour and its predicted behaviour (position or decay)
- WV encounter prevention: provide the appropriate alarm to the ATC Controller when the risk of encounter is detected for an aircraft, by monitoring the position of aircraft with respect of the “danger area” of the preceding one.

3.2 ATC-WAKE Operational Concept and Missed Approaches

When an aircraft is caused to abort a landing after it has already started its landing approach, the aircraft has to follow a pre-defined path to leave the airspace surrounding the terminal. The missed approach procedure to be followed in such case is an integral part of the published approach procedure. The issue of go-around movements while applying reduced separations has been raised during several presentations of ATC-WAKE concept of operations. Two main concerns have been identified and analysed :

1. **Risk of WV encounter for aircraft following the go-around aircraft**
   The case of an aircraft aborting its final approach is frequently observed (e.g. obstruction on the runway). Such aircraft starts to climb immediately and joins the missed approach point following a straight path, then the aircraft will resume the approach following a pre-

defined path. The follower aircraft will then be under the considered aircraft, which represents a potential risk for WV encounter.

Two sub-cases exist:

- Cross-wind : the WV of the climbing aircraft will be laterally displaced as well
- No cross wind (unpredicted change of wind conditions): the presence or absence of WV in the landing zone will be continuously monitored through appropriate detector. If the WV of the leader aircraft represents still a danger for the follower aircraft, this one will be instructed by the ATC Controller to abort landing.

The application of reduced separation in ATC-WAKE is dependent on the existence and persistence of cross-wind, therefore the risk of WV encounter for aircraft following the g-around aircraft shall be considered for the determination of safe separation but is not increased.

2. Risk of multiple go-arounds for aircraft in trail while reduced separation is applied

In case reduced separations are applied and in case a sudden fall in cross-wind speed is observed (not predicted), the risk of having multiple aircraft going around simultaneously has been raised.

Considering a typical situation where final approach path is 10NM long and 2.5 NM separation is applied, potentially 5 aircraft are in trail along such path.

The role of the ATC Controller will then to take the measures to protect the aircraft from WV encounter by issuing when appropriate go-around(s) and radar vectoring instructions and coordinating with the other approach controllers.

No change to current ATC working methods for missed approaches is required but training sessions covering such situations have to be prepared.

Two main conclusions have been drawn:

1. the determination of the reduced separation distance to be applied (worst case scenario) shall consider as well the missed approach path
2. Adapt the ATCO training for cases where several missed approaches have to be executed for aircraft in trail

3.3 Changes to the Requirement Specification

Following previous remarks, the following operational and user requirements developed in WP1000 (see ATC-Wake D1_5) have been revisited:

	OP - 02	Hazard Detection Capability	IA	Ess
Initial version	The ATC-WAKE system shall detect Wake Vortex occurrence : - for landing and taking-off aircraft - in pre-defined (critical) areas (e.g. ILS glide slope)			
New version	The ATC-WAKE system shall continuously monitor the behaviour of Wake Vortices : - for landing and taking-off aircraft - in pre-defined critical areas (e.g. ILS Glide Slope)			

For the determination of safe minimum separation to be advised by the system, the issue of missed approaches have been raised through a note:

UR - 01	WV Separation Mode	IA	Ess
The ATC Supervisor shall receive information on applicable separation mode (ICAO or ATC WAKE) and separation minimum distance associated to their validity period (predicted).			
Note : the applicable separation minima will take into account: - the applicable approach and departure procedures, including the missed approach procedure(s) - potential worst case scenarios with respect to the traffic distribution and planning, meteorological conditions			

On alerting ATC Controllers about safety hazards, 1 user requirement has been updated and completed by 1 new requirement as follows:

	UR – 04	WV Alerting	IA	Ess
Initial version	The ATCO shall receive an appropriate alarm when detected WV differs significantly from WV prediction (vortex vector).			
New version	The ATCO shall receive an appropriate warning when the actual behaviour the detected WV for individual aircraft differs significantly from its predicted behaviour (slower WV transport)			

	UR – 05	WV Monitoring	IA	Ess
New requirement	The ATCO shall be continuously informed about the presence or absence of WV in pre-defined critical areas for landings or take-off (close to the ground).			

One new user requirement has been added for the notification to flight crews about the application of ATC-WAKE:

	UR – 06	**Information to Flight Crews**	**IA**	**Ess**
New requirement	The application of reduced separations for take-off and landings shall be notified to Flight Crews using ATIS (Air Traffic Information Service).			

3.4 Potential alternatives to ATC-WAKE Concept of Operations

The ATC-WAKE concept of operations covers the integration of Wake Vortex prediction and detection information both during the planning phases (aircraft landing in 40 min horizon) for the definition of the appropriate separation minima and during the tactical operations for the monitoring of the vortices. Several alternatives concepts have been proposed in the context of US and European projects such as:

- Cross-wind departures : reduced separation for consecutive take-off movements in case of persistent cross-wind, potentially without monitoring of the WV behaviour (wake free paths).
- Determination of periods where reduced separations are not applicable, for instance the Wake Avoidance System (WakeVAS) system proposed by FAA aiming at reducing separations for staggered approach or departures on closely spaced parallel runways (CSPR) or for departures on a single runway. "If the wind criteria is met (as determined for each of the 5-minute periods extending about 30 minutes into the future) for a runway and its approach and missed approach paths, the WakeVAS wind prediction subsystem would indicate this to the controller whether one, both, or neither runway is predicted to be wake independent".

Such alternative represent intermediate steps where reduction of separation is decided during tactical operation in order to optimise the runway throughput. ATC-WAKE represents a further step of integrating meteorological forecast system with ATC planning systems in order to increase flight efficiency (no holding pattern).

4 Evaluation of Usability and Acceptability

The impact on current ATC working methods and training has been assessed through 2 questionnaires responded by European Airport Operators and licensed ATC Controllers involved in a real-time simulation of ATC-WAKE at NLR(WP2700).

4.1 Analysis of the Questionnaire to European Airports

4.1.1 Objectives of the Questionnaire

To maximize the effectiveness of the American Wake Program, a CONOPS Evaluation Team (CET) has been set up by FAA/NASA, with, in particular, the following objectives:

- Identify research issues requiring safety assessment and findings,
- Identify appropriate risk analysis methodology
- Establish a plan for data collection and analysis,
- Identify transition and implementation issues.

The EUROCONTROL Experimental Centre is a member of this CET, according to the EUROCONTROL Wake Vortex strategy which the following objectives:

- To bring together European and American experts in wake procedures & systems.
- To inform the US Team on safety and risk assessment methodologies
- To better understand US projects
- To bring European experience to those American operational issues

In this framework, a reference team of operational experts from major European airports such as Paris, Frankfurt, Amsterdam, Madrid and London has been set up. This group was named European Conops Team (ECT).

During the Kick-off meeting of the ECT (held in Brétigny the 5th of July 2004) the Terms of Reference of this group of experts were discussed and it was decided to establish the present state-of-the-art in Europe, in terms of Operational Concepts in operation at different airports and the impact of the Wake Vortex on these operational concepts, using a questionnaire.

This questionnaire is divided in different sections:

- Airport Layout
- ATC systems
- Weight categories
- Procedures and working methods
- ATC actors
- Wake Vortex knowledge

4.1.2 Summary of the Responses

The questionnaire prepared by the European CONOPS Team (led by Eurocontrol EEC) has been responded by a number of airport in ECAC area.
The following table summarises the responses obtained with a focus on reduced separations and wake vortex.

Table 1 – Responses to European CONOPS questionnaire to airports

	London Stansted	London Heathrow	Manchester	Birmingham	Gatwick	Madrid	Paris Orly	Palma de Majorca
Runway Configuration	Single	2 independent	2 closely spaced	2 crossing runways	single	2 independent runways	3 closely spaced + 1 crossing	2 closely spaced
Taxiway configuration	2 high-speed per runway	About 6 to 8 exits per runway, only 1 high speed exit per runway	standard	standard	standard	4 high-speed per runway	1-2 high-speed per runway	
Number of Aircraft Weight Categories	5	5	5	4	5	ICAO (3)	ICAO (3)	
ATC Team resource	2 Tower + 1 Ground + 1 Ground Planner	2 Tower + 2 Ground + 1 Arrival Planner	2 Tower + 1 Ground	2 Tower + 1 Ground	1 Tower + 1 Ground + 1 Arrival Planner	2 Tower + 1 Ground	2 Tower + 1 Ground + AMAN	1 Tower + 1 Ground
Aircraft Separation Minimum	ICAO	ICAO 7 NM for Light	ICAO 7 NM for Light	ICAO 7 NM for Light	ICAO + local	ICAO	ICAO	
Reduced separation applied	in good visibility	No	In good visibility (departures only)	In specific conditions	no	no	in good visibility	In good visibility (arrivals only)
Wake vortex encounter	20 incidents per year	100 reported per year	10 per year	Less than 20 per year	Less than 20 per year	none	Between 20 and 100 per year	Less than 20 per year

The observations made by ATC-WAKE while considering the responses are the following:

1) The reduction of standard separation in good visibility is acceptable. This implies the explicit acknowledgement of the Pilot of a reduced separation from the leader aircraft (landing or take-off).
2) ICAO Aircraft Weight Categories are not the only reference for separation minimum: special cases not only in UK are already part of today operational concepts in Europe.
3) The number of Wake vortex encounter incidents increase with the percentage of heavy aircraft of the airport traffic.
4) High-speed taxiways are commonly implemented in Europe
5) ATC Team is generally divided in 3 roles: supervisor or planner, tower and ground controllers that share a significant knowledge about wake vortex phenomenon.

4.1.3 Acceptability of ATC-WAKE

A high-level analysis of the acceptability issue both for Airport Operator and ATC Controllers has been made by considering the main aspects for the application of ATC-WAKE:

1. **Responsibility for reduced separation**: ATC WAKE assigns the responsibility of reduced separations to the ATCO with acknowledgement of the Pilot. No change compared to current operations
2. **Separation Minimum**: ATC-WAKE proposes a fixed minimum separation distance or time covering all aircraft categories. This may imply that for air traffic rarely observed at the considered airport (light aircraft or super heavy) exceptions are foreseen. Currently for busy airports, homogeneous distributions of traffic are observed by periods (e.g. a peak of arrivals of heavy aircraft (long haul) early in the morning followed by a peak of medium aircraft (intra Europe). These traffic patterns facilitate the application of a common separation minimum (ATC-WAKE mode of separation).
3. **Closely Spaced Parallel Runways**: currently one single Tower Controller is responsible for both runways, therefore the application of reduced separations and the introduction of staggered approach increase significantly the Tower Controller workload (especially for the control of runway crossing and vacation). On each RWY the separation between two consecutive flights is roughly 5 NM, this gives enough time to allow the aircraft on the other runway to cross the other runway and start taxiing. The workload is increased for the Tower Controller in charge of the runway where the landings and crossings occur. So two Tower Controllers should be established, no change being done to the rest of the control chain: 1 INI ATCo, 1 Intermediate ATCo, 1 Ground ATCo. Hand over between Tower Controllers (runway crossing) should be a silent procedure.
4. **Airport Infrastructure**: high-speed exit taxiways are needed in order to enable the increased runway throughput. In addition for parallel runways, the influence between arrival and departure traffic (e.g. arrival flights having to cross the departure runway) and between consecutive arrivals is a major concern and appropriate solutions such as central taxiways are also needed. The central TWY linking the high speed TWYs must be

built out of protected area of both RWYs to allow the landings to hold without interfering with the protected area of the other RWY. The crossing TWYs should be built with an angle of 90 ° with the axis of the RWY to shorten a s much as possible the time needed to cross and give the best possible visibility of the traffic to the crossing flights.

4.2 Analysis of Real-time simulations

- In May 2004 and March 2005 two real-time simulations took place at NLR. The simulations took place at the NARSIM Tower facility and were using the Schiphol environment. The first simulation was to determine the preferred HMI by the Approach and Tower controller (see D2_7), the second to verify this result by other controllers and showing them the ATC-Wake concept.
- All controllers were asked to fill in NASA TLX (annex 1) and SART Scale (annex 2) questionnaires at the end of each scenario and a System Usability Scale (annex 3) questionnaire at the end of their participation. Furthermore there was a debriefing at the end of each day, discussing all kind of ATC-Wake topics.
- Totally 9 controllers from 5 different countries took part in the simulations. Because the purpose of the simulations was to propose a first HMI version and showing the ATC-Wake concept no objective measurements of the performance of the controllers were taken, but the answers on the questionnaires and debriefing give a good indication of the usability and acceptability of the ATC-Wake HMI and ATC-Wake concept.

4.2.1 The ATC-Wake HMI.

The so-called "variable wake vortex vector" was selected by all the controllers as the best HMI candidate for the Approach and Tower position. The HMI was intuitive and unambiguous. It added no additional workload and was not used by the controllers for separating the aircraft. For more details see D2_7.

The HMI was easy to use and accepted by all the controllers. A short introduction was enough to understand the HMI, so no special training is needed to use the HMI.

4.2.2 The ATC-Wake concept.

For testing the HMI in real-time a simplified but representative simulation of the whole ATC-Wake concept was defined. All existing, enhanced en new systems were simulated and controllers were instructed how to use the system. Also background information about the ATC-Wake concept was given. Three different sources of information are available to get an idea how the controllers thought about the ATC-Wake concept. First the information given by the controllers during the debriefing, secondly the analyses of the questionnaires and at last the observations of the controllers during the simulation.

Hereafter a summary is given of the information received per source followed by the conclusions.

4.2.2.1 Debriefing

As mentioned above at the end of each day a debriefing took place. The following remarks concerning the ATC-Wake concept were supported by all the controllers:

- The concept itself is easy to understand;
- The system is preferred to be operational for 24 hours a day, seven days per week;
- The system is preferred as a safety system;
- The difference between ICAO and ATC-Wake mode could be eliminated in the future;
- The weight category information could be kept available in the ATC-Wake mode ;
- When the suggested separation in ATC-Wake mode is larger than 3 NM, the ATC-Wake mode is not useful anymore;
- A transition between ICAO and ATC-Wake modes and vice versa is no problem.

But also some controllers had their doubts. The most important remarks:

- Some controllers have doubts about the decline of the wake vortex length along the ILS when the aircraft comes closer to the runway.
- Some controllers have doubts about the anticipated actions of the pilots, who will need to follow their instructions when they put a medium aircraft close (but within ATC-Wake separation) behind a heavy aircraft.

4.2.2.2 Questionnaires

The NASA TLX and SART Scale questionnaires, filled in after each scenario, says something about the perceived workload of the controller to accomplish his/her task. This is a subjective measurement and because no objective measurements were taken no correlation between perceived and real workload can be determined. The following conclusions about the perceived workload can be drawn from the questionnaires:

- The workload for the Tower Controller is lower than for the Approach Controller;
- The workload for a Schiphol ontroller is lower than for controllers from other airports;
- The workload of non Schiphol controllers decreases when they get acquainted with Schiphol environment;
- The workload increases when the separation is smaller and the demand (number of aircraft) is higher (this is especially applicable to the Approach controller);
- The frustration level is low and the understanding of the situation is high.

The System Usability Scale questionnaire is of interest because it says something about the usability of the system. It has a scale from 1 (strongly disagree) to 5 (strongly agree). Table 1 contains the average of all 9 controllers.

Table 2 – Result SUS questionnaire to ATC Controllers

	1 (strongly disagree) to 5 (strongly agree)				
Statement	**1**	**2**	**3**	**4**	**5**
I think I would like to use this system frequently				4,0	
I found the system unnecessarily complex		1,6			
I thought the system was easy to use				4,4	
I think that I would need the support of a technical person to be able to use this system	1				
I found the various functions in this system were well integrated			3,6		
I thought there was too much inconsistency in this system		1,7			
I would imagine that most people would learn to use the system very quickly					4,7
I found the system very difficult to use		1,6			
I felt very confident using the system				4,0	
I needed to learn a lot of things before I could get going with the system		1,6			

4.2.2.3 Observations

During both simulations the controllers were observed. The following observations were made:

- The style of controlling the aircraft is different per airport (in particular for approach). This implies that training and daily operations have a great influence on controlling.
- The style of controlling the aircraft has an influence on the performance during high demand and small separation (some approach controllers have difficulties with separating the aircraft on 2,5 NM on the ILS).
- The Approach Controllers automatically apply a larger separation between heavy and medium category aircraft than the 2,5 NM instructed by ATC-Wake, because they know that heavy aircraft need more time to vacate the runway.
- When the Approach Controllers are instructed to apply 2,5NM at the ILS intercept, the number of goarounds increases;
- The workload of the Approach Controller is higher than the workload for the Tower Controller
- One or two training scenarios is enough to familiarise the non-Schiphol controllers with the Schiphol environment.

4.2.3 Conclusions of Real Time Simulations

The conclusions of the simulation are very promising. There is no contradiction between the results from the debriefing, the questionnaires and the observations.

The ATC-Wake concept and system is easy to understand and to work with. Controllers really like the concept of a wake vortex vector behind an aircraft, because this was the first time that what they already "knew" about the behaviour of wake vortices is visualised.

According to the controllers, a transition between ICAO-mode and ATC-Wake mode is not really an issue, because they are already used to such changes. A system displaying the wake vortex 24 hours a day would be very helpful and would eliminate the transition between ICAO and ATC-Wake mode. The controller should be instructed at the beginning of its shift to look what the separation criteria are and when these will change.

Separation of the aircraft at 2,5 NM on ILS is a difficult task, it looks like that the "style" of the controller, especially the Approach controller, has influence on the performance. The "style" is a combination of how the controller has learned to control (this differs between airports) and the capacity demand he/she is used to handle. Some Approach controllers were not able to "deliver" the aircraft at 2,5 NM.

Another interesting phenomena appeared: when the controllers were informed about the wind condition and 2,5 NM separation, the Approach controller automatically made the distance between a heavy and medium weight category aircraft somewhat larger, because they anticipate that the heavy aircraft needs more time to leave the runway. When the Approach controller was instructed to apply 2,5NM separation for all aircraft, the workload of the controllers and the number of go-arounds increased noticeable. The increase of go-arounds was expected, because the time between the heavy clearing the runway and the other waiting for landing clearance becomes smaller. Also the place of the exits of the runway has an influence on this. The significant increase in workload was less expected, because the traffic load was identical. Apparently, the controllers use the specified separation criteria as a minimum, and do not aim to deliver the aircraft with this separation.

In general the ATC-Wake concept is useable and easily accepted by the controllers.

To make optimal use of the ATC-Wake concept (2,5 NM separation for arrivals) controllers should be trained to handle the shorter separation and the higher traffic load (this applies especially to the Approach controller).

Furthermore, during the introduction of the ATC-Wake concept, controllers and pilots shall be taught/convinced that the smaller separations for arrivals and departures are safe to use.

5 Airport and airspace simulations

In Fast-time simulations the tasks performed by the controller are included in the model, and therefore do not require the direct involvement of controllers and operate many times faster than real-time simulations. This enables a statistically significant number of runs to be performed for a particular set of input parameters representing all the various possible operational and weather scenarios, and a comprehensive test of the sensitivity of the system to the variation of particular parameters. The total airspace and airport modeller TAAM developed by Boeing Preston is a gate-to-gate simulator, i.e., able to simulate ground, terminal area and en-route operations, including weather conditions.

5.1 Objectives for Fast-Time Simulations

The aim of ATC-WAKE fast-time simulations has been to assess the potential benefits relating to capacity-efficiency of the considered airport as well as the potential cost-savings for airlines that have been identified during the project set-up and to provide indicators to size such benefits:

- **Capacity – Efficiency**: the application of reduced wake vortex separation has the potential to significantly increase the efficiency of arrival or departure movements by the reduction of (intermediate) delays as well as to increase the maximum number of movements per runway.
- **Cost savings for Airlines:** savings resulting from aircraft delay absorption or the increase of airport movements per hour impact significantly on airline costs.

5.1.1 Indicators for ATC-WAKE validation

From the validation objectives devised with airport operations experts, a set of indicators have been identified. Such indicators express a significant quality of the simulated aircraft traffic and will be calculated automatically through one or several measurements.

Table 3 – Metrics for ATC-WAKE Simulations

Indicator	**Description**	**Measurement**
Flight Indicator		
Intermediate delay	time spent in holding manoeuvres during approach (initial, intermediate) or during departure (runway holding position)	Comparison between flight times
Aircraft separation	separation distance or time with the preceding aircraft during approach or departure	Measured at the runway threshold for arrival, time between start of rolling for departure

Runway Occupancy Time (ROT)	time elapsed between the entry event (eg THR crossing) and exit event (e.g. runway vacation)	Entry / exit event recorded
Traffic Indicator		
Runway Throughput	Number of runway movements (departures or arrivals)	Traffic counter (average and peak)
Sector loading	Number of aircraft crossing a particular ATC sector	Traffic counter (average and peak)

5.1.2 Hypotheses for ATC-WAKE Simulations

Following MAEVA guideline, an hypothesis is a proposition made about the operational concept to be validated derived from the validation objectives and described in statistical terms. Three main hypotheses have been formulated for ATC-WAKE simulations and are explained in the following table.

Table 4 – ATC-WAKE Hypotheses

Hypothesis	**Description**	**Comment**
Reduction of Intermediate Delays	The application of ATC-WAKE separation mode with reduced aircraft separation enables the absorption of intermediate delays for arrivals. Such reduction impacts directly on the fuel consumption of delayed aircraft.	The gain is related to the minimum separation distance applied.
Increase of runway throughput	The application of ATC-WAKE separation mode enables the insertion of supplementary flights in arrival or departure sequences in comparison with the current situation	The throughput increase is complex to guarantee in all conditions. It is related to favourable meteorological conditions, pilot-controller cooperation for runway occupancy issues and airport and ATC organisation.
Usability of ATC-WAKE separation mode	The application of ATC-WAKE separation mode and the transition to ICAO separation mode is applicable in current operational environment	Controller supplementary workload to cope with transition phases ATC-WAKE – ICAO separation is acceptable

5.1.3 Assumptions for ATC-WAKE Simulations

- The main assumptions made for the initial survey of potential simulations are :
- the correct (pre-determined) separation minimum determined during the planning of operations is applicable for tactical operations (final approach or take-off)
- the requirements associated to ATC-WAKE operations in particular for visibility conditions and supporting systems are met, no technical failure is introduced during simulations
- pilots will always comply with the reduction of separation minimum for arrival or departure phases
- no operational error (human)
- the aircraft actual performances are compatible with corresponding TAAM model

5.2 Scenarios for Fast-Time Simulations

The scenarios for fast-time simulations have been built using traffic samples from Paris – Charles de Gaulle for arrival and departure movements.

Such traffic sample have been then modified to introduce the reduced separations between aircraft (distance or time) following the application of the ATC-WAKE operational concept.

For arrivals, reduced separation between aircraft was simulated with 3 different values:
- 2.5 NM for all traffic in a sequence
- 3 NM for all traffic in a sequence
- 4 NM only between:
  - Heavy followed by Medium/Light
  - Medium followed by Light.
  - ICAO standard separation otherwise

For departures, reduced separation between aircraft, for all traffic in a sequence, was simulated with 3 different values:
- 60 sec
- 90 sec
- 120 sec

In addition 2 scenarios combining arrival and departure traffic have been identified, taking into account runway crossing, ground movements and a transition in ATC-WAKE separation mode (from reduced separations to ICAO standard separation and vice versa)

The switch between these two modes of aircraft separation was enabled by a transition plan.

5.2.1 Airport Layout

The Charles de Gaulle (CDG) airport detailed model was created by EEC within the GAM (Generic Airport Model) project and has been validated by the CDG operational staff. GAM is the airport layout used within the simulation. The Airport layout GAM is described below.

There are two independent pairs of parallel RWYs: one in the north (27L, 27R) and one in the south (26L, 26R). Normally external runways are dedicated to arrivals and internal runways to departures [See Figure 3].

For the purpose of the project only the westerly configuration was considered.

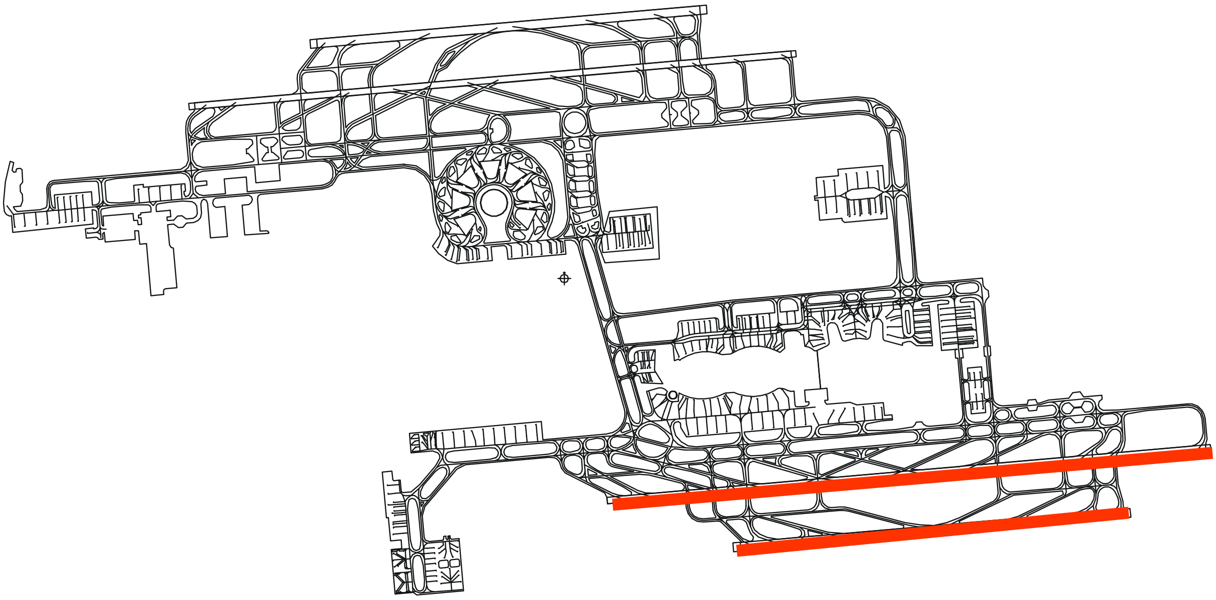


Figure 3 – GAM layout

5.2.2 Traffic Sample

5.2.2.1 Initial Traffic Sample

The traffic sample used in fast-time simulation was collected from CFMU data. The reference day was an average annual day (without special events).

The selected day was the 26th of June 2003 (based on 24h) for Paris CDG (LFPG) inbound and outbound traffic, it included 1486 movements.

For each flight, the following data are available:

- Callsign
- Airport Departure

- Departure time
- Requested flight level
- Aircraft type
- Airport Destination.

5.2.2.2 Adaptations to the Traffic Sample

Some adjustments were performed on the CFMU traffic sample. These adjustments, listed below, have been done to facilitate the use of the TAAM simulator and the collection of outputs.

Arrival and Departure Procedures[1]

A majority of wake vortex encounters happen during the final approach or the initial climb, WV encounter is the most hazardous and this is why the portion of airspace area simulated was concentrated around the TMA.

- Arrivals: for each entry point of the TMA, four waypoints for each STAR were added to become the new starting point. Aircraft were distributed amongst the different existing approach procedures depending on their real actual STAR route. For arrivals all waypoints from the departing airport to the TMA entrance were eliminated.
- Departures: it was decided to introduce one additional waypoint after the last point of each real SID, at about 50 NM from the mentioned last point. For departures all the waypoints situated outside the TMA to the destination airport were deleted. The same criteria for departure procedures were applied to be input in the simulator, fixing altitude restrictions at each SID and for each aircraft type.

Arrival and Departure Times

In TAAM for the correct use of the simulator at least one time reference, either ETD or ETA is needed. The complete traffic sample was initially introduced, with the entire route, from the departing airport to the destination airport. Given the ETD in TAAM timetable, the arrival time was calculated automatically.

Once both departing and arrival time were known, trajectories were cut, as explained before. Again the new timetable was introduced in the simulator which calculated the new departing time for arrivals and the new arrival time for departures.

[1] In the context of ATC, the term “Procedure” designates the set of recommendations or instructions issued for the navigation through a defined airspace or airport area, i.e. terminal or en-route airspace structure, airport runways and taxiways.

Traffic Increase

The traffic provided by CFMU was loaded but, in order to ensure a significant number of flights to evaluate the different scenarios, especially those with a reduced separation (2.5 NM), the traffic sample has been manually increased by 30%. This figure was chosen because considered suitable to obtain the same results achieved with some previous traffic analysis.

As at first the number of Heavy aircraft in the period simulated was not sufficient, it was adjusted to represent around 20% of the traffic that is representative of traffic arriving at Charles de Gaulle airport at morning time.

Traffic distribution on the runways

Theoretically traffic coming from the North should be conducted to the northern runways, as well as traffic coming from the South to the southern runways.

The simulated traffic sample of the selected day was modified so that, despite their trajectories, the inbound traffic landed on runway 26L and the outbound traffic took off from 26R.

The traffic sample, spread on two pairs of runways, was considered not loaded enough to evaluate the impact of reducing the separation minima.

Gate allocation

The CFMU traffic sample did not include the gates so, to simulate actual airport ground movements, the sample has been adjusted: for each aircraft in the timetable a gate was manually allocated according to the GAM layout.

Period simulated

The interval between 5am and 8am UTC was chosen because it was one of the most loaded, compared to other hours of the day. It has to be noticed that TAAM uses a building-up period to contain all possible flights, so the actual interval simulated started at 4 am and ended at 9 am UTC.

5.3 Results of Fast-Time Simulations

The fast time simulations allowed measuring the impact of reduced separations applied for both departures and arrivals, in particular to measure the potential increase of number of movements per hour and the reduction of the average delay per aircraft for the approach phase or the taxi phase.

The simulation results showed different results for arrivals or departures:

5.3.1 Arrivals-only Scenarios

The application of the ATC-WAKE fast time simulations to arrival traffic only (e.g. one runway dedicated to arrivals) showed significant improvements in runway throughput and flight time. The reduction of aircraft minimum separation distance leaded indeed to an increase of the number of landings per hour comprised between 1 and 16 extra landings. This potentially represented a maximum of 34% runway throughput increase.

Table 5 – Arrival Runway Throughput ICAO Separation / ATC WAKE: 2.5 NM, 3 NM, 4NM

NUMBER OF FLIGHTS PER HOUR				
# Time	**ARR_ICAO**	**ARR_2.5**	**ARR_3**	**ARR_4**
5am-6am	**37**	**50**	**42**	**40**
6am-7am	**43**	**53**	**47**	**43**
7am-8am	**39**	**57**	**47**	**43**
Total	**119**	**160**	**136**	**126**

The application of the transition separation also implied the reduction of arrival delay by a maximum of 13 minutes (reduction of the time of the approach phase). This highlights the potential benefits deriving from the utilization of separation modes based on weather conditions, i.e. cost savings for airlines in terms of fuel consumption.

Table 6 – Arrival flight delay: ICAO separation / ATC-WAKE : 2.5 NM, 3 NM, 4 NM

AVERAGE DELAY PER FLIGHT				
#Time	**ARR_ICAO**	**ARR_25**	**ARR_3**	**ARR_4**
5am-6am	**14’04”**	**5’53”**	**11’07”**	**11’57”**
6am-7am	**19’45”**	**7’43”**	**14’12”**	**18’26”**
7am-8am	**16’35”**	**6’28”**	**10’07”**	**12’46”**

5.3.2 Departures-only Scenarios

The application of reduced separation modes between consecutive take-off showed significant benefits in terms of runway throughput and delays.

Table 7 – Departure runway throughput, ICAO separation / ATC-WAKE : 60s, 90s, 120s

NUMBER OF FLIGHTS PER HOUR				
# Time	DEP_ICAO	DEP_60	DEP_90	DEP_120
5am-6am	28	54	39	30
6am-7am	27	55	40	30
7am-8am	28	45	40	30
Total	83	154	119	90

Table 8 – Average departure delay ICAO separation / ATC-WAKE : 60s, 90s, 120s

AVERAGE DELAY PER FLIGHT				
#Time	DEP_ICAO	DEP_60	DEP_90	DEP_120
5am-6am	37'01"	2'07"	15'51"	29'44"
6am-7am	32'11"	1'37"	13'55"	26'18"
7am-8am	35'06"	1'51"	16'35"	28'24"

120 seconds separation mode (equivalent to current ICAO separation for 2 medium aircraft) could be considered valuable, either in terms of number of movements per hour with an increase of 8%, or in terms of delays with a decrease of the average delay of 18%. This is directly related to the distribution of traffic (20% of Heavies in the traffic sample).

From the delay point of view the application of the same separation time between aircraft, independently of the aircraft category, may result in negative cumulative effects on delays, i.e. an increase of 30s of the separation time resulted in an increase of 13 minutes of the average delay per aircraft.

5.3.3 Combined Arrivals and Departures Scenarios

Several simulation exercises combining the reduction of separation minima for arrivals and for departures for the pair of parallel runways of the generic airport have been performed.

The reduced separations applied were the following :

- 2.5NM for arrivals
- 60s for departures

One of the exercises (Suffix TR) has been dedicated to the transition between ICAO and ATC-WAKE separation modes:

- reduced separation 5am - 6am,
- ICAO separation 6am - 7am,
- reduced separation 7am – 8am.

Table 9 – Table for arrivals and departures runway throughput

NUMBER OF FLIGHTS PER HOUR						
# Time	Arr ICAO	Dep ICAO	Arr WV	Dep WV	Arr TR	Dep TR
5am-6am	37	26	50	33	49	35
6am-7am	43	25	53	29	42	28
7am-8am	39	26	57	33	52	34
Total	196		255		240	

ICAO : standard separation
WV : reduced separation (permanent)
TR : transitions between reduced separation / ICAO standard separation

Table 10 – Table for arrivals and departures flight delays

AVERAGE DELAY PER HOUR			
# Time	AD_ICAO	AD_WV	AD_TR
5am-6am	23’10”	11’02”	11’00”
6am-7am	19’52”	8’53”	18’11”
7am-8am	18’56”	6’33”	9’05”

The transition scenario was the most relevant within the scope of the ATC-Wake project: the application of reduced wake vortex separation, compared to the application of ICAO standard separation minima, significantly increases the efficiency of arrival or departure movements by the reduction of (intermediate) delays, namely 40%, as well as to increase the number of movements per runway, passing from a total of 196 movements for the ICAO scenario to a total of 240 movements (+22%).

However a number of issues for the performance of the combined arrival and departure simulation scenarios have been raised:

- Potential benefits of the application of reduced separations were highly dependent on the traffic distribution.
- The general behaviour of departing and landing aircraft is highly related to the selected airport layout (e.g. existence of a central taxiway avoiding arrivals to cross the departure runway).

The number of departing aircraft per hour within all the transition scenarios was logically reduced in comparison with the departures-only scenarios because of the queuing/waiting method and runway crossing procedure.

For this fast-time simulation, where one of the objectives was to determine the potential gain in runway throughput brought by reduced wake vortex separations, it was of primary importance that the level of traffic was sufficiently high to maintain pressure at the runway.

A more precise assessment of such improvement is essential for the analysis of cost / benefits associated to ATC-WAKE platform since the determination of actual gains for a particular airport do not require to consider the airport or a technical framework but the combination of favourable meteorological conditions and efficient cooperation between ATCOs and Flight Crews to operate in dense traffic conditions.

6 Evaluation of interoperability with ATC systems

The main objective is to determine the efforts needed in terms of improvements of the ATC-Wake system(s) or other ATC systems, installation activities, and topics to be studied in follow-up research, before the ATC-Wake system(s) can be installed and used at European airports. More specifically, the detailed objectives are:

- To identify the existing ATC systems affected by the changes proposed by ATC-Wake;
- To assess the impact of ATC-Wake on the current operational procedures;
- To assess the expected benefits of the ATC-Wake mode of operation when using an arrival manager (AMAN) and/or a departure manager (DMAN)
- To evaluate the interoperability of the four new ATC-Wake components (Separation Mode Planner, Predictor, Detector, Monitoring and Alert) with existing ATC systems;
- To assess the implementation efforts and costs for introduction of ATC-Wake at airports;
- To provide recommendations for follow-up research, when necessary.

6.1 Systems affected

The ATC-Wake system requirements specify four new ATC-Wake components, to be integrated in the airport environment. It concerns the ATC-Wake Separation Mode Planner, Predictor, Monitoring and Alert, and the Detector. Existing ATC systems to be adapted are described below.

Meteorological Forecast
Adequate meteorological forecast data has been identified as a major enabler for the introduction of ATC-Wake. Existing meteorological systems for the aerodrome environment offer a limited set of information concerning current wind, temperature, and visibility conditions as well as tendencies. ATC-Wake operations require a number of supplementary atmospheric sensing systems, such as wind profilers or temperature profilers, which provide more accurate meteorological information (possibly even complemented by a specific forecasting system).

Flight Planning and Flight Information
The application of reduced separation in aerodrome operations requires changes to existing systems used for the planning of arrivals. When a change of the Separation Mode (ICAO or ATC-Wake) is decided, this shall be communicated to an Arrival Manager (AMAN), which updates accordingly the timing of the approach phase (time over initial approach fix, landing time) for each individual flight.

Human Machine Interface (HMI)

The HMI of ATC Controllers needs to be updated for the introduction of wake vortex separation mode, and wake vortex prediction and detection information (displayed as wake vortex vector and alerts).

From a survey conducted by the Eurocontrol Experimental Center (EEC), it can be concluded that currently only one of the participating airports has an operational arrival manager and no airport has an automated tool for sequencing the take-off movements. The same survey also addressed the (current) organisation of ATC services for approach and aerodrome operations. The results show that the actor/responsibility decomposition proposed in ATC-Wake:

- Matches with existing job descriptions for the following actors: ATC/Tower Supervisor, the Initial/Intermediate Approach Controller, the Tower Controller and the Ground Controller.
- Matches with the Arrival Sequence Manager (ASM) function at airports London - Heathrow, London – Gatwick, and Paris – Orly (at the other 7 investigated airports there is no ASM).

6.2 Impact on current CONOPS

The main change implied by ATC-Wake (as compared with the current operational procedures) is the transition from the fixed wake vortex separation minima defined by ICAO to the ATC-Wake separation minima, which is updated regularly (with at least a 40 minutes pre-notice). From the ATC controller perspective such transition can be compared with a runway configuration change (e.g. from west to east configuration) and therefore does not represent a revolution for aerodrome operations.

Another significant change is the issue of wake vortex related alerts (indicating the potential risk of a wake vortex encounter) by the ATC-Wake system. Such alerts do not exist in the today operational procedures. Nevertheless, during the final approach operations, the main actions required for ATC controllers will be limited to informing the pilot and supporting his/her decision (i.e. to continue the approach or initiate a missed approach) by providing guidance and/or separation with other traffic.

6.3 Impact of ATC-Wake on arrival and departure management

To improve efficiency, airports are introducing arrival manager and departure manager tools, called AMAN and DMAN. These tools use the ICAO separation criteria as basis to determine the optimal arrival and departure sequence. During ATC-Wake mode other separation criteria are applied and by means of an analytical study an indication about the impact of ATC-Wake mode on both tools will be given.

For the analysis of ATC-Wake mode a model for capacity estimation has been used. Furthermore, a queuing model for arrival delay estimation has been used, and for estimating the effects of the Departure and Arrival Managers two sequencing approximation models have been used.

The following has shown when the ATC-Wake mode is compared with the standard ICAO mode:

- The arrival capacity increases significantly when changing from standard ICAO wake vortex separations to ATC-Wake mode separations.
- The departure capacity increases significantly when changing from standard ICAO wake vortex separations to ATC-Wake mode separations.
- The average arrival delay decreases significantly when changing from standard ICAO operations to ATC-Wake mode for the same demand level.

The parameters for the models are based on estimations. Applying small changes to these parameters gives an indication of the sensitivity of the output. The sensitivity analysis for arrivals showed that:

- ATC-Wake mode is less sensitive for the traffic mix than the standard ICAO operations;
- ATC-Wake mode is more sensitive for the runway occupancy time than the standard ICAO operations.

The arrival and departure manager approximation analysis (FCFS versus optimised sequence) shows the following:

- The current generation of arrival managers has almost no effect on capacity when using ATC-Wake mode, compared to the effect on standard ICAO operations, due to the fact that the separation is based on the weight categories of the aircraft;
- A departure manager shows a small increase in capacity when comparing ATC wake mode with standard ICAO departure operations.

6.4 Interoperability issues of the ATC-Wake system components

As described in Work Package 1000 [D1_4], the ATC-Wake Operational System includes four new functional components which are interfaced with several existing and/or enhanced ATC systems.

The new components are:

- ATC-Wake Separation Mode Planner
- ATC-Wake Predictor

- ATC-Wake Monitoring and Alerting
- ATC-Wake Detector

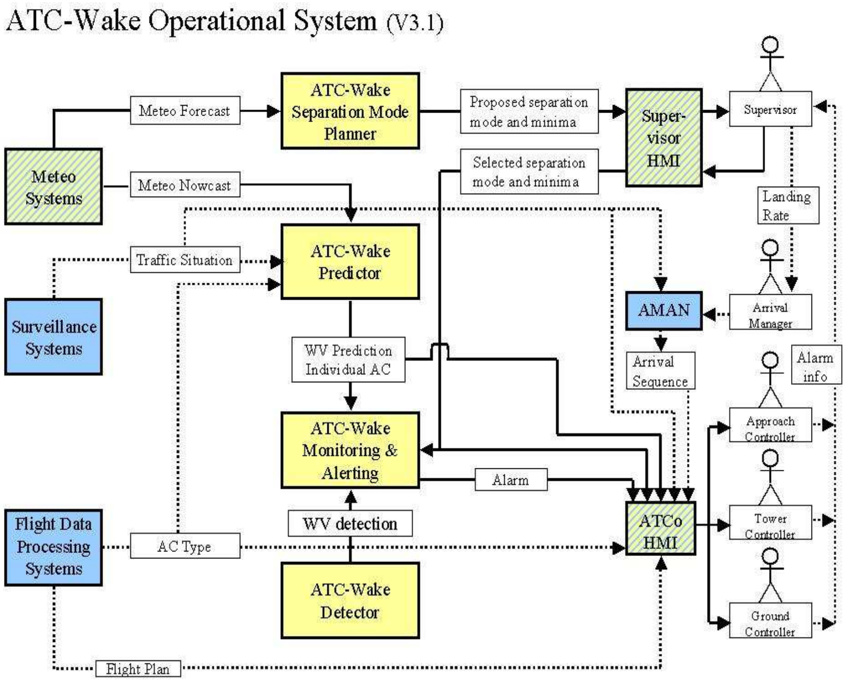
Existing ATC systems are:

- AMAN
- Flight Data Processing System
- Surveillance System

Enhanced ATC systems are:

- Meteorological Systems
- Supervisor HMI
- ATCo HMIs

Figure 4 – represents the functional overview of the ATC-Wake Operational system.



With the following legend:

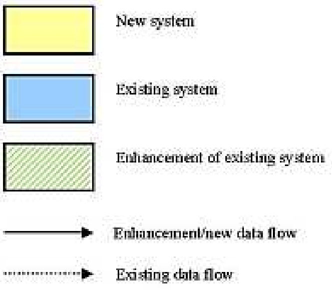


Figure 4 – Functional flow of ATC-Wake Operational System

This figure shows the functional flow of ATC-Wake at high level. This means that the functions of existing systems shall be used as is, so no change in hardware and software is foreseen; only a "connection" is made with these systems to extract the necessary data. For enhanced and new systems it is somewhat different. Enhanced systems mentioned in this figure deliver functionality that is already available but not "good" enough for ATC-Wake. It makes sense to use the current systems as basis and add the new functionality on top of these systems. For the new systems it is the opposite, sometimes the new functionality can be build on top of a current system and the development of a complete new system is not necessary

6.4.1 Existing systems

From the ATC-Wake point of view the following systems deliver a functionality that is necessary for the ATC-Wake concept, but the mentioned systems shall be used as is and no changes are foreseen.

6.4.1.1 Flight Data Processing systems

The Flight Data Processing System (FDPS) consists of different systems. From ATC-Wake point of view this is handled as one system. Purpose of the FDPS is to keep an actual overview of all aircraft information within the ATC system. The active flight plan of an aircraft is enhanced and modified if necessary.

Integration of the interface between the ATC-Wake Predictor and FDPS is simple. Only the interface between FDPS and ATC-Wake Predictor is new. The ATC-Wake Predictor shall be hooked on the already available airport interface infrastructure and shall extract the Aircraft data from this network.

6.4.1.2 Surveillance systems

The Surveillance systems contain different systems such as primary and secondary radar. From ATC-Wake point of view this is handled as one system and described as surveillance system. The purpose of the surveillance system is to visualise on a screen of the controller the actual position of aircraft's flying en-route, in the vicinity of an airport or on taxiing on the airport (depending on the range/type of radar and task of controller).

Integrating the interfaces between the surveillance system and the ATC-Wake Predictor, AMAN and ATCo HMI is simple. Only the interface between the surveillance system and ATC-Wake Predictor is new. The ATC-Wake Predictor shall be hooked on the already available airport interface infrastructure and shall extract the necessary data from this network.

6.4.1.3 AMAN

On more and more airports an AMAN-like system is introduce to use the airport runways more efficient. It is foreseen that if AMAN is available there should be a minimum lead of 40 minutes before changing separation mode in stead of 20 minutes when no AMAN is available. Be aware that AMAN is a system and Arrival Manager a person. Purpose of AMAN is to sequence the arriving aircraft following certain constraints in such a way that the runway(s) is used most efficient.

From at Figure 4, it is clear that there is no direct link between AMAN and one of the new components or that new data flows originate from AMAN, so AMAN shall be used as is.

From the ATC-Wake perspective no additional implementation efforts are needed.

6.4.2 Enhancement of existing system

From the ATC-Wake point of view the following systems deliver a functionality that is necessary for a realisation of the ATC-Wake concept. These systems exist today but need to be improved, adapted, and certified to account for that purpose.

6.4.2.1 Meteo systems

The Meteo systems can be divided into meteorological forecasting and nowcasting systems.

For the ATC-Wake project, the weather-nowcasting system NOWVIV (Nowcasting of Wake Vortex Impact Variables) has been developed. The new feature consists of a combination of different-scale forecast models. NOWVIV uses a high resolution mesoscale weather forecast model (MM5) designed to provide real-time 3-D-weather information in the terminal area with a lead time of 3-12 hours and a planned update rate of 1 hour. NOWVIV has a horizontal resolution of 2.1 km, 12-50 m in the vertical, and considers topography and detailed land use maps to predict realistic boundary layer features. At grid points along the glide slope (roughly every nautical mile) time series of vertical profiles of wind, virtual potential temperature, turbulence kinetic energy, and eddy dissipation rate are computed.

Weather sensors are a SODAR/RASS, a LIDAR and a weather RADAR. A SODAR emits an acoustic pulse into the atmosphere and receives a back-scattered signal caused by natural atmospheric turbulence. The RASS technique uses artificially generated sound waves (e.g. by a SODAR) to infer the virtual temperature from changes in the propagation speed of sound waves. The variance of the vertical velocity component serves as a measure for turbulence.

A Doppler LIDAR emits light into the atmosphere and receives the signals reflected by aerosols and small dust particles. The Doppler shift between the transmitted and received signals is a measure of the velocity of the air volume which contains the reflecting material along the line-of-sight (LOS) of the laser beam. The RADAR is a polarimetric Doppler C-band weather radar, which can transmit and receive waves at any polarisation base (not only linear). The polarimetric radar products can be used for improved estimation of rainfall rate and hydrometeor classification. The Doppler velocity can measure the motion of the scattering particles. The Doppler velocity gives the radial motion with respect to the radar. Turbulence within the radar measurement volume can be observed by the spectral width of the Doppler velocity

RADAR, SODAR/RASS and other wind and temperature profilers are ready for use. LIDAR needs improvement in terms of higher power per emitted pulse in order to cover the entire glide path of about 25 km length; further its evaluation process needs to be automated. A weather data analyser and synthesiser needs to be built: It will provide the ATC-Wake Predictor with optimised wind and temperature profiles by combining data from all sources

The Meteo Systems as needed by ATC-Wake do not exist today on an airport in Europe. RADAR, SODAR/RASS and other wind and temperature profilers, which exist today, can be used as is for the ATC-Wake purposes. Installation of at least one Wind & Temperature profiler (WTR) and a LIDAR is necessary. Current available LIDARs, which provides wake vortex positions with some accuracy but the vortex strength in term of circulation values, are not reliable today. In the future 2 LIDAR systems (with larger energy per emitted pulse) may monitor WV and measure cross-wind/turbulence for an airport.

6.4.2.2 Supervisor HMI

The ATC-Wake system will present the proposed separation mode (ICAO or ATC-Wake) and separation criteria on the Supervisor HMI. With this information and information from other sources the supervisor will determine the declared capacity and landing rate, and will enter his/her decision into the ATC system and inform the controllers.

The Supervisor HMI is the interface of the supervisor with the ATC-Wake system. The HMI displays the proposed separation mode (ICAO or ATC-Wake) and the separation criteria for the ATC-Wake mode, see figure II for an example.

Figure 5 – Example Supervisor HMI with data of SMP

Currently the equipment of the supervisor consists of several systems. Each system (in general) consists of display (monitor or panel) which gives an overview of the current situation and an input device (keyboard or switches) to take control or to enter the selection. More and more the systems are (from the supervisor point of view) integrated into one system. Some kind of "windowing" mechanism to display the information is used, where each "old" system is represented by one "page". A keyboard is used for input.

The HMI itself is a very straightforward representation of the data coming from the SMP. The HMI shall use the same format as the other systems used by the supervisor. A standalone console (screen and keyboard) is not necessary because the update rate of the data is low, but can be used. In the newer system(s) the HMI can be displayed as a "page".

6.4.2.3 ATCo HMI

The Human Machine Interface (HMI) of the controllers is very important. Information from the ATC-Wake Predictor and the ATC-Wake Monitoring & Alerting shall be displayed on the position of the ATCo's in such a way that he/she can use this information to make decisions.

Each controller shall be informed about the separation mode (ICAO or ATC-Wake), separation criteria and when the different separation modes are active. On each airport there is some kind of an Information System available that informs controllers for example about the expected weather, operational runways etc. Anticipated is that this system will also be used to inform controllers about the above-mentioned ATC-Wake information.

The most important task of an ATCo HMI is to inform the controller about the current situation, the changes in the near future and draw his/hers attention when something (seems to) go wrong. Very important is that the HMI will not add extra workload, is unambiguous and only used for which it is developed. In the case of the ATC-Wake project this means that the HMI shall not be used as separation tool.

Each controller shall be informed about the separation mode (ICAO or ATC-Wake), separation criteria and when the different separation modes are active. On each airport there is some kind of an Information System available that informed controllers for example about the expected weather, operational runways etc. Anticipated is that this system will also be used to inform controller about the above-mentioned ATC-Wake information. The ATC-Wake data is coming from the Supervisor HMI.

The ATC-Wake Predictor will determine for each aircraft in the so-called critical area the length of the vortex behind the aircraft, projected on the ILS. This information can be used to be displayed to the controller. Looking at the responsibilities of the controllers this information will be of interest of the (final) Approach controller and the Tower controller. For the Ground controller this information may be interesting but is not seen as necessary or useful. The information is displayed on a so-called PVD. This display shows information from the surveillance system and FDPS. Figure III is an example PVD display for the Tower controller.

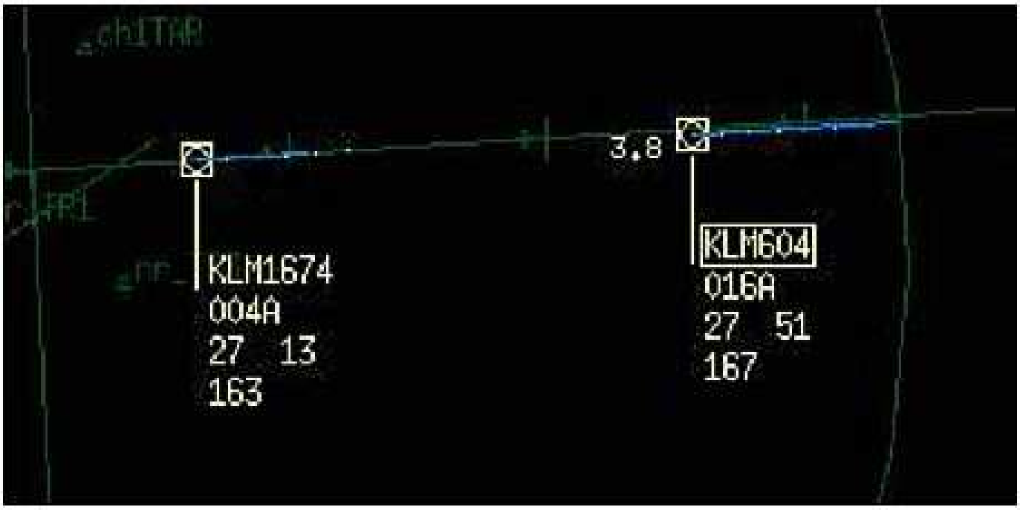


Figure 6 – Example PVD display Tower controller with wake vortex info

The ATC-Wake Monitoring & Alerting system will monitor the wake vortex progress behind each aircraft and generate an alarm when something is not correct or not safe.

Currently the following four types of alarm are discriminated:

A. there is a system failure;
B. the predicted wake vortex (from ATC-Wake Predictor) is larger than the separation applied (SMP), consequence ATC-Wake mode is not valid anymore;
C. the detected wake vortex length of an aircraft is larger than predicted (from ATC-Wake Predictor) and larger than the applied separation.
D. when preceding aircraft is entering the wake vortex of the leading aircraft.

To maximise interoperability with existing systems all enhancements shall be an update of an already existing system. The proposed separation mode, separation criteria and time shall be presented as an extension on the Information System already available to the ATCo for weather information and operational runways.

For the Approach and Tower controller the Wake Vortex Vector and distance to preceding aircraft shall be displayed on their PVD according to the format in use. The Approach and Tower controller shall have the option to turn the WV vector on or off.

The surveillance system delivers a track-id for each track. The ATC-Wake Predictor shall add the variable wake vortex vector length to this track-id when it is in the critical area. The software that drives the PVD will use this information to draw the vector behind the aircraft. The same software shall calculate the slant range to the leading aircraft and present this information in the micro-label.

Also the ATC-Wake Monitoring & Alerting system shall use the track-id to identify the aircraft involved and the corresponding alarm, and send this information to the PVD software.

The system failure (alarm A) shall be handled according the common procedures at an airport in case of a system failure. Currently it is not clear how to handle alarm type B. The HMI shall use the same format as the other systems used by the ATCo. Only changes of the Approach and Tower controller are foreseen.

6.4.3 New systems

The systems described in this section have been developed for the ATC-Wake concept. They don't exist today at an airport.

6.4.3.1 ATC-Wake Separation Mode Planner

The Separation Mode Planner is a new subsystem in the ATC-Wake system that advises the ATC Supervisor on the possibilities to apply reduced separation in the next – say – three hours. This concerns separation for single runway departures, single runway arrivals and closely spaced parallel runway arrivals. The main input to the SMP is meteo forecast data from Meteo Systems. Besides, the SMP requires configuration to account for local conditions such as runway layout and operation modes. The SMP analyses the meteo forecast data to determine these time periods that enable a safe reduction of separation. The criteria on meteo conditions in relation to safe separation are established off-line in dedicated safety assessments. The most important function of the SMP is to propose a separation mode, separation criteria and time frames when the mode can be applied to the supervisor.

The following functional steps are needed to make every half-hour the proposal for the supervisor:

1. Obtain meteorological forecast data for the next 3 hours from the Meteorological Systems that include wind speeds and wind direction along the nominal flight path with a time spacing of 10 minutes.
2. Determine the “bounding box” of the wind that includes the variability of the wind during the considered time frame and along the flight path, as well as the uncertainty in the forecasts.
3. Apply the wind criteria (derived from the WAVIR safety database) that allow a safe reduction of separation, to the bounding box and determine time periods where the bounding box satisfies the criteria: i.e. these time periods that allow a safe reduction of separation.
4. Provide the ATC Supervisor HMI with the time periods in the next three hours that allow reduced separation.

Before the SMP can be used, the following local data shall be available within the SMP:

- Configuration data to configure the SMP to the local airport conditions, such as
  - Runway co-ordinates
  - Runway operation mode
  - Nominal flight path information
- Results of wake vortex safety assessments, to determine the wind criteria that allow a safe reduction of separation. This will require a safety assessment of local conditions at the airport and result in a WAVIR safety database for that specific airport.

To monitor the actual safety situation, the actual track data and meteo conditions shall be compared automatically with the WAVIR safety database. (Such a “Safety Monitoring system” being an interface between actual track data, meteo conditions and WAVIR safety data base has also been designed and demonstrated within ATC-Wake as an extension to the ATC-Wake operational system). This information can also be used to further improve and update the WAVIR safety database.

Implementation of a Separation Mode Planner is rather straightforward. The following issues have to be considered:

- An interface will have to be developed in order to let the local weather forecast systems provide the meteo forecast data in the format as described above.
- To further complete the database with safety assessment results, a safety assessment that focuses on local conditions needs to be performed.
- In addition to the previous bullet, a safety monitoring system needs to be installed that assesses the actual situation and provides feed back on the advice of the SMP. This feed back is furthermore used to extend and improve the contents of the WAVIR safety database.
- The SMP is a relatively simple tool that runs on a desktop computer.

6.4.3.2 ATC-Wake Predictor

The ATC-Wake Predictor is a new sub-system of the ATC-Wake system, which assesses the suitability of the separations, suggested by the SMP. It determines the part of the glide slope potentially affected by wake vortices. This information is provided to the Monitoring & Alerting sub-system and the ATCo HMI through a Wake Vortex Vector (WVV).

The two main inputs of the ATC-Wake Predictor are the Meteo Nowcast data provided by the Meteo Systems and the Traffic Situation provided by the Surveillance Systems. Furthermore the ATC-Wake Predictor requires databases describing the aircraft characteristics, radars accuracy, and runway layout.

In ATC-Wake, the ATC-Wake Predictor is not just a “wake vortex prediction” (using P-VFS and P2P); it is the sub-system used to assess, during the tactical phase, the suitability of the separations previously suggested by the SMP during the planning phase.

Every 6 seconds, the ATC-Wake Predictor takes a snapshot of the entire traffic situation around the airport. For each aircraft, it computes, using the weather data at the aircraft position, the time evolution of the danger volume which contains the wake vortices generated by this aircraft.

Combining these information with the glide slope tolerance mode used the ATC-Wake Predictor computes the part of the glide slope potentially affected by wake vortices resulting in the WVV of each aircraft.

Before the ATC-Wake Predictor can be used though, the following local data need to be available to:

- Runway co-ordinates
- Meteo measurement point co-ordinates
- Radar accuracy

Integration of a Predictor module is rather straightforward but the following issues still have to be considered:

- An interface will have to be developed in order to let the local Meteo Systems provide the Meteo Nowcast data in the format as described above.
- An interface will have to be developed in order to let the local Surveillance Systems provide the Traffic Situation data in the format as described above.
- An interface will have to be developed in order to let the local Flight Data Processing Systems provide the AC Type in the format as described above.
- An interface will have to be developed with the local Monitoring & Alerting module
- An interface will have to be developed in order to let the local ATC-Wake Predictor provide the WV Prediction Individual AC at the ATCo HMI

One may note that the ATC-Wake Predictor itself is a relatively simple tool that runs on a desktop computer.

6.4.3.3 ATC-Wake Monitoring & Alerting

The ATCo's, in charge of approach, landing, and take-off phases, are responsible for safe and optimal separations. When an unsafe WV situation is detected, he/she instructs aircrew on any necessary evasive action.

The Monitoring & Alerting module will monitor every aircraft in the critical area and raise appropriate alarms to ATCo's in case of significant deviation between WV detection and WV prediction information with a risk of WV encounter.

The purpose of the Monitoring & Alerting module is to raise alarms. The controller HMI displays this alarm in combination with the vortex vector behind the aircraft plots in the final approach or departure corridor to enable the detection and correction of any deviation from safe separations.

Integration of a Monitoring & Alerting module is rather straightforward but the following issues still have to be considered:

- An interface will have to be developed in order to let the local ATC-Wake Predictor provide the WV Prediction Individual AC data in the format as described above.
- An interface will have to be developed in order to let the local Detector provide the WV detection data in the format as described above.
- An interface will have to be developed in order to let the Monitoring & Alerting module provide to the ATCo HMI the Alarm in the format as described above.
- The Monitoring & Alerting module is a relatively simple tool that runs on a desktop computer (even the same as for the ATC-Wake Predictor).

6.4.3.4 ATC-Wake Detector

The ATC-Wake Detector is a new system. Purpose is to detect the WV behind an aircraft and gives this information to the ATC-Wake Monitoring & Alerting system.

The Wake-Vortex Detector in ATC-Wake monitors the relevant airspace (cross-sections of the glide path) for the presence of wake vortices and, if so, gives a warning to the Monitoring & Alerting system. The Detector serves as a safety net and, thus is a stand-alone technique, which only reports its monitoring result

The *Detector* in the ATC-Wake Operational System is necessary at least for an initial period of time after installation of the ATC-Wake at an airport. Once the prediction and monitoring system has proven to be safe, which may happen after some years of operational application, a LIDAR for detection could be obsolete.

6.5 Evaluation of implementation efforts and costs

Table 11 contains an overview of the operability issues of the ATC-Wake system with the existing ATC systems.

Table 11 – Overview implementation effort per system

System	Effort	Risk	Training	Validation
Surveillance system	*Low*	*None*	*None*	*Low*
FDPS	*Low*	*None*	*None*	*Low*
AMAN	*None*	*None*	*None*	*None*
Meteo	*High*	*Medium/High*	*Low*	*High*
Supervisor HMI	*Low*	*Low*	*Low*	*Low*
ATCo HMI	*Low*	*Low*	*Low*	*Low/Medium*
ATC-Wake SMP	*Low*	*Low*	*Low*	*Medium/High*
ATC-Wake Predictor	*Low*	*Low*	*Low*	*Medium/High*
ATC-Wake Monitoring & Alerting	*Low*	*Low*	*Low*	*Medium*
ATC-Wake Detector	*High*	*Medium/High*	*Low*	*High*

From this table it is clear that the main implementation efforts of ATC-Wake are concentrating around the Meteorological enhancement and the ATC-Wake detector. For ATC-Wake the Meteorological system shall deliver more accurate data with a higher update rate than the current Meteorological information used by ATC. These risks are lower for the ATC-Wake Detector. The current laser technology used by the LIDAR, one of the possible ATC-Wake Detector systems, has its limitations in range and detection capabilities. Also the radar technology used for detecting wake vortices is still under development and it is currently not known how well it will perform.

The validation effort needed for validation of the ATC-Wake system is high. Before being able to use the full potential of the ATC-Wake system a lot of data shall be collected. The more data is collected the better the prediction of the ATC-Wake system components (SMP, Predictor) will be. The installation can be compared in this way with an ILS system. At the beginning the system can not be used on the highest level, but after some time of measurements the confidence in prediction will improve.

The costs involved (see Table 12) shows the same pattern.

Table 12 – Overview costs per system

System	Investment	Recurring	Non-Recurring
Surveillance system	*Nil*	*Nil*	*Nil*
FDPS	*Nil*	*Nil*	*Nil*
AMAN	*Nil*	*Nil*	*Nil*
Meteo	*High*	*Low*	*Medium*
Supervisor HMI	*Low*	*Low*	*Low*
ATCo HMI	*Low*	*Low*	*Medium*
ATC-Wake SMP	*Low*	*Low*	*Medium/High*
ATC-Wake Predictor	*Low*	*Low*	*Medium*
ATC-Wake Monitoring & Alerting	*Low*	*Low*	*Medium*
ATC-Wake Detector	*High*	*High*	*High*

The largest investments concern the Meteorological system and the ATC-Wake Detector system. Especially the ATC-Wake Detector is expensive because at least two systems shall be needed if a runway is operated in both directions.

Looking at the recurring costs it is clear that operating the ATC-Wake system is not so expensive.

The recurring costs of the ATC-Wake Detector system are high because it is still under development. But the expectation is that these recurring costs will decrease and will be on the same level as for other airport systems, as soon as more experience is gained.

The non-recurring costs are mainly the costs necessary to validate the system and for collecting data for the ATC-Wake system components (necessary for the Separation Mode Planner and the Predictor). After the ATC-Wake system is validated the non-recurring cost will be low.

6.6 Installation of ATC-Wake at an airport

Looking at the installation of the ATC-Wake system at an airport the following recommendations can be made:

- Existing or otherwise planned systems shall be used as much as possible. European wise standardisation of interfaces shall make installation of an ATC-Wake system easier and cheaper.
- Also European wise standardisation of tools for controllers will make implementation easier and cheaper
- The benefit of an ATC-Wake system integrated in the ATM/ATC environment of an airport should significantly increase when combined with new flight control features as, e.g., a microwave landing system.
- It is recommended and possible to install the ATC-Wake SMP, Predictor and Monitoring & Alerting components on a single computer platform, this will decrease investment and recurring costs.

The installation of the meteorological observation and forecasting tools for ATC-Wake purposes requires a significant investment. However, a business case study (at the WakeNet2-Europe Workshop in Langen 2004) guessed a benefit-to-cost ratio of more than 100 on average for an ATC-Wake-like system. Even when this number may drop by a factor of 10 due to ambiguities and uncertainties, the benefit still remains very large.

Furthermore, installation (or operating) costs of a Meteo System may be shared by the national weather services since they profit from a high density of data in the terminal area of airports.

Currently it is not known if this is also applicable for the ATC-Wake Detector.

From the results of the analytical study the following recommendations for installing AMAN/DMAN in combination with ATC-Wake system can be made.

An AMAN used in conjunction with ATC-Wake system, should not be used for making optimal sequences but for having fluent mode changes from ICAO separations to ATC-Wake mode and back, because the ATC-Wake mode makes arrival separations, currently based on weight categories, insensitive for traffic sequence.

A DMAN in conjunction with ATC-Wake mode should aim only at sequencing for SIDs and not for weight categories, because ATC-Wake mode is only sensitive to SID sequencing.

6.7 Necessary system improvements

Looking at the separate systems the following improvements are needed/foreseen to operate the ATC-Wake system.

- No improvements at existing systems are needed to be able to use the ATC-Wake concept. European wise standardisation of interfacing will reduce installation/developing costs.
- Looking at the enhanced systems it can be stated that all functionality is available and no major improvements are needed to start field trails
- Looking at the new systems the ATC-Wake SMP and Predictor systems are mature enough and delivers the functionalities needed for the ATC-Wake system. The ATC-Wake Monitoring & Alerting system can be used as is, but needs follow-up research to fine-tune the alarms. This can be done during shadow-mode field trails or real-time simulations.
- The ATC-Wake detector system needs improvement. Currently the LIDAR system is too limited looking at its performance and price. The Radar is promising but not mature enough. The ATC-Wake detector system shall be able in all weather conditions to determine the strength of the wake vortex behind an aircraft
- The quality of weather forecasting and nowcasting can be enhanced by more frequent updates of the initial and boundary conditions provided by, e.g., the DWD. An update every 3 hours (instead of 12 hours today) is foreseen in 2006. The assimilation of measured data into the NOWVIV algorithm will also improve the prediction quality.

6.8 Follow-up research

Parts of the ATC-Wake project were more concentrated around arrivals in stead of departures, so research in this area is needed, but on a smaller scale than the ATC-Wake project.

The following topics can be identified:

- The ATCo HMI development has been concentrating on arrivals, follow-up research is needed for departures.
- The handling of alarms needs also additional research. More insight is needed how some alarms shall be handled by the ATCo's.
- In the first design of the Separation Mode Planner, relatively simple wind criteria have been proposed. Depending on the benefits that can be achieved with such criteria and the requirements of airports, further study may focus on elaborating these criteria. E.g. taking into account height dependent wind criteria or including criteria on wind shear and other meteorological parameters.
- The WAVIR safety database is to be completed with data from safety assessments for local conditions.

- The ATC-Wake Predictor shall be adjusted for departures.
- The performance of the ATC-Wake Detector shall be improved or other alternatives shall be developed.
- A weather and wake vortex forecasting and monitoring campaign is planned for 2006 at Frankfurt airport where elements of the ATC-Wake Integrated Platform will be employed

7 Conclusions and recommendations

7.1 Conclusions

The assessment of operational feasibility for the implementation of ATC-WAKE operational concept within Europe has been performed along several axis:

- **Correctness,** usability **and acceptability of the operational concept** by ATC Controllers: the operational concept is not a 'revolution' for ATC, it represents a sound evolution from existing procedures (runway configuration and transition). The real-time simulations performed by NLR indicates that the ATC-WAKE concept of operations has been easily adopted by a team of ATC Controllers and positive feed-back for its use in operations has been received. In addition the size of the changes from operational perspective (airport infrastructure, training) fits with the existing evolutions observed at European airports to cope with the increasing traffic demand.
- **Operational benefits**: the fast-time simulations have allowed to assess the potential gains for runway throughput and flight times considering a number of potential scenarios for the reduction of minimum separation (distance or time) and the runway usage (arrivals only, departures only, mixed mode). The potential gains following the application of reduced separation are significant, varying between 10% and 30% increase of runway throughput and between 10% and 40% reduction of the average delay per flight. However the actual gains will be dependent on a number of factors:
  - Favourable meteo conditions: the transport of wake vortex out of the arrival or departure corridors is observed when a significant and persistent cross-wind exists and to take benefit out of such situation a minimum 20min reliable wind forecast is necessary to plan traffic. In addition good visibility conditions are required for reduced separation operations;
  - Traffic pressure : the application of reduced separation operations will deliver benefits only when a high level of traffic exists and sufficient notice is made to ATC to plan aircraft movements accordingly;
  - Traffic distribution : potential benefits of the application of reduced separations are highly dependent on the traffic distribution;
  - Airport layout : the general behaviour of departing and landing aircraft is highly related to the selected airport layout (e.g. existence of a central taxiway avoiding arrivals to cross the departure runway)
- **Impact on existing ATC systems**: the analysis of interoperability issues has confirmed that the main changes to systems concern the implementation of specific atmospheric sensing systems (e.g. weather radar or LIDAR), the introduction of ATC-WAKE tools for ATC (separation mode planning, wake vortex prediction, detection and monitoring tools). The impact on existing systems is low, mainly the arrival management tool (AMAN) requires modification to support the fluent transitioning between ATC-WAKE reduced separations and standard ICAO separations (depending on meteo conditions).

As a main conclusion the ATC-WAKE operational feasibility analysis has allowed to build confidence in the proposed operational concept for the application of reduced separations to represent a sound evolution from existing ATC procedures and working practices, to deliver significant benefits for runway throughput and average delay per flight without major rework to the current ATC systems.

Nevertheless such positive conclusions on operational feasibility will need to be traded-off against the actual weather 'windows' to perform such operations and the costs for the acquisition and implementation of the new equipments or infrastructure required (wake vortex sensors, new atmospheric sensing systems, enhanced weather forecast capabilities).

7.2 Recommendations

The positive conclusions on technical and operational feasibility as well as potential safety and capacity improvements will need to be traded-off against the actual weather 'windows' to perform such operations and costs for the acquisition and implementation of the new equipments or infrastructure required (Wake vortex sensors, new atmospheric sensing systems, enhanced weather forecast capabilities).

In this context, a number of recommendations for complete validation of ATC-Wake have been identified. First the **requirements for the validation** of the use of wake vortex detection and monitoring systems **at the targeted airport** have to be specified:

- **Perform a year long measurement campaign** that allows gathering a significant sample of correlated weather (wind and temperature profiles), wake vortex and aircraft data that will serve as a basis for performance and safety assessment.
- **Assess the performance of Wake Vortex sensors** in the critical areas in particular in the landing and take-off areas
    - Are systems requirements and quality of service achievable?
    - Focus on hazardous situations: Are alert cases always detected? What is the rate of false alerts?
    - Confirm the sensor specification from manufacturers.
- **Assess the performance of Wake Vortex predictors** in the critical areas
    - Are systems requirements and quality of service achievable?
    - What is the level of accuracy of the predicted "Danger Areas" position and extent?
    - What is the level of integrity that needed for ATC-Wake operations?
    - What are the best options for the collection of required input to WV Short-Term Prediction?

Second, **for the application of reduced aircraft separations**, based on collected data, the following analysis shall be performed in the context of **a local Safety Case**:

- **Characterise conditions for reduced WV separation (at the targeted airport)**:
    - Are the proposed aircraft separations and decision criteria applicable to the targeted airport? What are the limitations? What are the uncertainties?
    - What is the risk of WV encounters in comparison with current operations?

Third, **the assessment of operational benefits shall be refined** using a repository of information for the main external factors influencing ATC-Wake operations:

- Weather conditions (visibility and wind) and their fluctuations, weather forecast limitations (*at the targeted airport*).
- Traffic demand: what are the limitations of traffic tactical re-planning to best use the non-permanent reduction of separation?

Fourth, **the transition towards the ATC-Wake operational concept shall be assessed**, intermediate steps of the application of reduced separations in well defined conditions, delivering less benefits but available on a shorter time frame and supported by a subset only of ATC-Wake systems, may represent significant incentives for Airport Operators and pave the way for a complete ATC-Wake implementation.

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