<ATC-Wake>

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<D1_5: System Requirements>

ATC-Wake System Requirements

(ATC Wake D1_5)

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This document constitutes the final report from ATC-WAKE WP 1000 dedicated to the specification of Operational Requirements, Operational Concept and Procedures, User Requirements and System Requirements for an ATC system integrating wake vortex prediction and detection capabilities.

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ATC-WAKE WP1000 System Requirements

Deliverable D1_5

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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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ATC-Wake WP1000 Manager

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ATC Wake Project Manager

Acronyms

ACC	Area 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
DEP	Departure
DGPS	Differential Global Positioning System
DMAN	Departure Manager
DME	Distance Measuring Equipment
EAT	Expected Approach Time
ETA	Estimated Time of Arrival
FAF	Final Approach Fix
FAP	Final Approach Point
FDPS	Flight Data Processing System
FIR	Flight Information Region
FL	Flight Level
GND	Ground Controller
HALS / DTOP	High Altitude Landing System (HALS) / Dual Threshold Operations (DTOP)
HMI	Human Man Interface
IAF	Initial Approach Fix
IAS	Indicated Air Speed
IF	Intermediate Fix
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INI	Initial Approach Controller
ITM	Intermediate Approach Controller
LDA	Localizer Directional Aid
LVP	Low Visibility Procedure
MAP or MAPT	Missed Approach Point
MAS	Missed Approach Segment
MET	Meteorological
MLS	Micro Wave Landing System
NDB	Non Directionnal Beacon
NTZ	Non Transgression Zone
P2P	Probabilistic Two-Phase wake vortex decay model
PRM	Precision Radar Monitor
ROT	Runway Occupancy Time
RWY	Runway
RVR	Runway Visual Range
SMP	Separation Mode Planner
SMR	Surface Movement Radar
SOIA	Simultaneous Offset Instrument Approaches
STAR	Standard Arrival Route
THR	Runway Threshold
TKE	Turbulent Kinetic Energy
TMA	Terminal Manoeuvring Area
TWR	Tower Controller
UAC	Upper Airspace Centre
VFS	Vortex Forecast System
VHF	Very High Frequency
VMC	Visual Meteorological Conditions

WP	Work Package
WSWS	Wirbelschleppen-Warnsystem
WV PMS	Wake Vortex Prediction and Monitoring System
WV	wake vortex

Executive Summary

This document constitutes the final report from ATC-WAKE WP 1000 that addresses Operational Requirements, Operational Concept and Procedures, User Requirements and System Requirements for an ATC system integrating wake vortex prediction and detection capabilities. At present, in instrument meteorological conditions (IMC), the currently applied wake vortex constraints are not weather dependent and the separation between aircraft is therefore based on a worst-case scenario. The spacing is determined by considering the leader/follower aircraft weight categories and wake persistence observed during atmospheric conditions favourable to long vortex life. These separations are conservative; they do not completely avoid the effect of wake vortices, 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. 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. This could increase the capacity of airports in certain weather conditions. 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). Hence, the objectives of the WP 1000 are:

- To define operational requirements (WP 1100);
- To define operational concepts and procedures, to update and refine the selected operational concepts and procedures (WP 1200);
- To define users requirements (WP 1300);
- To define the system requirement based on operational concepts and users requirements (WP 1400).

Therefore, in the context of WP1000, the following issues have been addressed:

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

As a first step towards ATC-WAKE System, the WP1000 on system requirements has drawn the preliminary operational concept and requirements for the application of aircraft separation minima based on WV detection and prediction information. Next steps in the project are aimed to validate such requirements through system design and safety assessment and then operational feasibility evaluation.

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

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

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1 Introduction

As traffic grows steadily, airport congestion becomes an increasing problem and already a limiting factor at several European airports. Many of the international hubs and major airports are operating at their maximum throughput for longer and longer periods of the day, and some have already reached their operating limits as prescribed by safety regulations or environmental constraints.

This situation is expected to become more widespread all over the ECAC area and future traffic distribution patterns are likely to generate congestion at airports that currently do not experience any capacity problems.

An important hazard limiting today's airport capacity is the phenomena of wake vortices generated by aircraft with the potential of dangerous encounter for a following aircraft, especially in the case of small aircraft encountering the wake vortex of a large preceding aircraft.

Amongst potential solutions for enhancing airport capacity while improving safety, new methods for determining and monitoring the safe aircraft separation during arrival and departure phases based on wake vortex detection and prediction are being developed in Europe and North America.

This document constitutes the final report from ATC-WAKE WP 1000 that addresses Operational Requirements, Operational Concept and Procedures, User Requirements and System Requirements for an ATC system integrating wake vortex prediction and detection capabilities.

The structure of the document is intended to be consistent with the Operational Concept Document (OCD) of the MIL-498-STD Software Development and Documentation standard.

- Section 1 : Introduction
- Section 2 : Background and Objective of ATC-WAKE project
- Section 3 : Current System and Situation in Airport or Approach ATC Centres
- Section 4 : Justification for and Nature of Changes
- Section 5 : Concept for a New or Modified ATC System
- Section 6 : ATC-WAKE WP1000 Conclusions
- Annex A : Traceability to WP1000 Reports
- Annex B : Matrix of Operational, User and System Requirements

1.1 Identification

The document is identified as D1_5 ATC-WAKE deliverable.

1.2 System Overview

The system considered, for the introduction of ATC-WAKE operations, is the operational ATC System currently implemented in Approach (APP) and in Aerodrome ATC Units, it includes in particular a communication system between air and ground (voice and data), a surveillance system (radar data), a flight data processing system and an ATCO workstation for the visualisation of aircraft data (position, level, speed) and flight information.

Such ATC Units are in charge of arrival and departure traffic and respectively responsible for Approach and Aerodrome control.

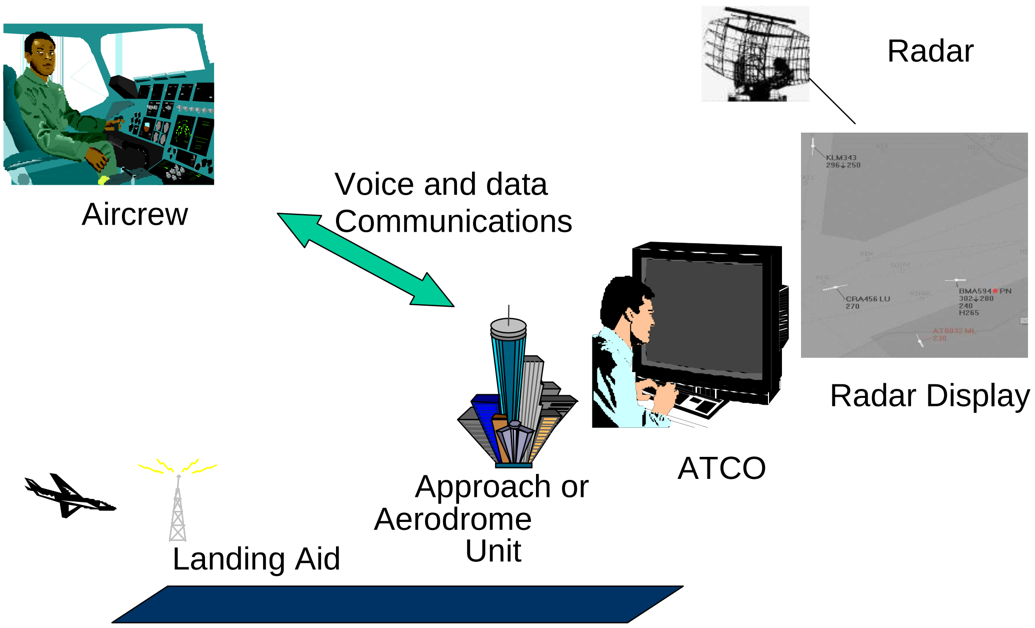

Figure 1 – ATC Systems Overview

1.3 Reference documents

The main reference documents for the WP1000 Final Report are the following four deliverables, which have been issued respectively from WP1100, WP1200, WP1300, WP1400

- ICAO Procedures for Air Navigation Services – Air Traffic Management (PANS-ATM), Doc 4444, Edition 14, 2001

- ICAO Procedures for Air Navigation Services - Rules of Operations (PANS - OPS), Doc. 8168, 1998
- L.J.P Speijker (Editor), ATC-WAKE Description of Work (Annex I), ATC-WAKE Consortium, 21 January 2002
- L.J.P Speijker (Editor), ATC-WAKE Project Plan : Integrated Air Traffic Control wake vortex Safety and Capacity System, NLR-CR-2003-250, Version 1.0, February 2003
- [D1_1] ATC-WAKE Operational Requirements, Edition 1.0, 2003
- [D1_2] ATC-WAKE Operational Concept and Procedures, Edition 1.0, 2003
- [D1_3] ATC-WAKE User Requirements, Edition 1.0, 2003
- [D1_4] ATC-WAKE System Requirements, Edition 1.0, 2003
- EUROCONTROL EEC / SAF, wake vortex Activities Report, June 2002
- S-WAKE Final Report, A.C. de Bruin, L.J.P. Speijker, H. Moet, B. Krag, R. Luckner and S. Mason, S-WAKE Assessment of wake vortex Safety, Publishable Summary Report, NLR-TP-2003-243, May 2003-07-07
- I-WAKE Synthesis Report of System Operational Requirements, September 2002
- Flight Safety Foundation, US Wake Turbulence Accidents, April 2002

2 Background and objective

2.1 The ATC-Wake project

Since new high capacity aircraft (such as the Airbus A380) will be heavier and larger, and air traffic has grown continuously with an average rate of 5 % per year, today's aircraft separation rules are considered increasingly inefficient, and may result in unnecessary delays. 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. Such system aims to enhance ATC decision support at airports, enabling Air Traffic Controllers to apply new weather based aircraft separation methods.

The main objective of ATC-Wake is to develop and build an integrated platform that contains – and integrates – all the necessary subsystems for building this system. These subsystems will be integrated such that the platform can (and will) be used within a test bed environment role:

- To evaluate the interoperability of the integrated system with existing ATC systems currently used at various European airports;
- To assess the safety and capacity improvements that can be obtained by local installation of the integrated system at various European airports;
- To evaluate the operational usability and acceptability of the integrated system;
- To draft a Technological Implementation Plan (TIP) and to assess cost elements for further development, implementation and exploitation of this platform (e.g. into the system that can be installed at European airports).

This integrated platform will support the evaluation of the safety and capacity implications of different operational concepts at selected European airports, with various runway configurations and multiple infrastructure systems.

An aim will be to analyse both tactical and strategic benefits of using this integrated system at various European airports. Tactical benefits in terms of temporary capacity increases, to improve the management of arrival flows while reducing holding. Strategic benefits in terms of long-term runway capacity for airline schedule planning. The proposed time frame for local installation of the integrated system at European airports is 2005-2010, which implies that the baseline – with the exception of the wake vortex systems evolving from this project – is today's airport environment with current infrastructure systems.

2.2 Objectives of WP1000 "System Requirements"

The main objective of ATC-Wake WP1000 is to define the requirements for the integrated ATC system. This includes the definition of operational concepts and procedures in support of the development and actual use of the integrated system. At present, in low visibility conditions, the currently applied wake vortex constraints are not weather dependent and the separation between aircraft is therefore based on a worst-case scenario. The spacing is determined by considering the leader/follower aircraft weight categories and wake persistence observed during atmospheric conditions favourable to long vortex life. These separations are conservative; they do not completely avoid the effect of wake vortices, 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. 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. This could increase the capacity of airports in certain weather conditions. 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) Hence, the objectives of the WP 1000 are:

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The interactions between the work packages are given in the figure below:

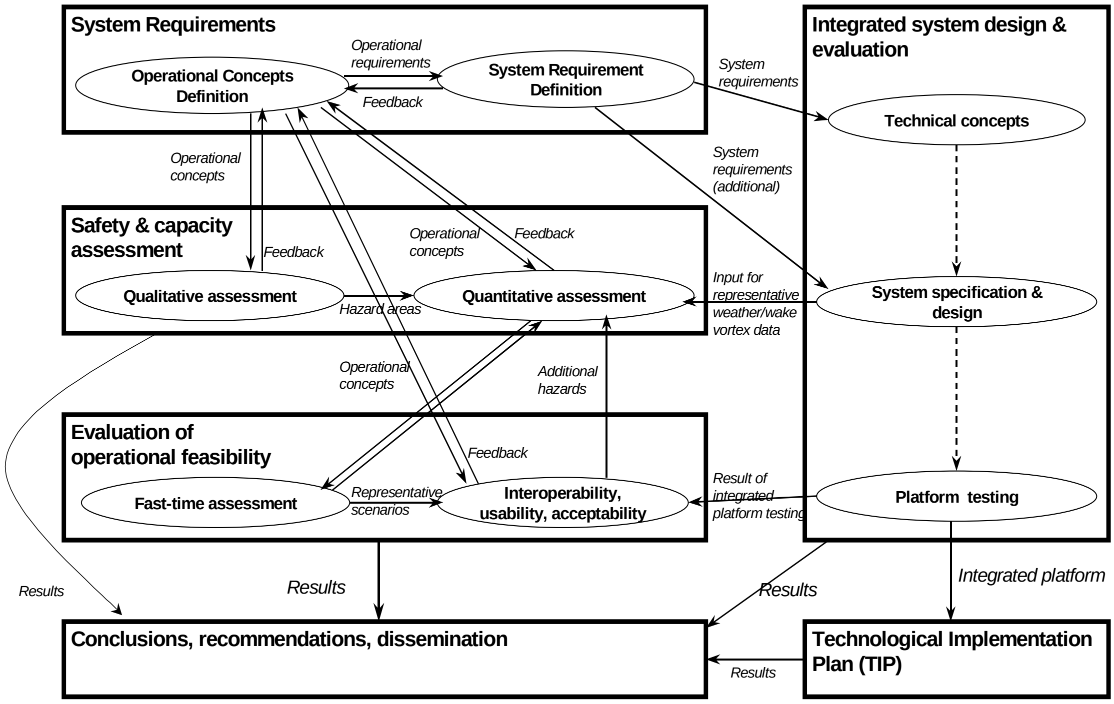

Figure 2 – Interactions between work packages of ATC C-Wake

3 Current System and Situation

3.1 Operational Policies and constraints

Current operational policies and constraints are built upon the ICAO recommendations for the provision of Air Traffic Services (see PANS-ATM) and national regulation.

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.

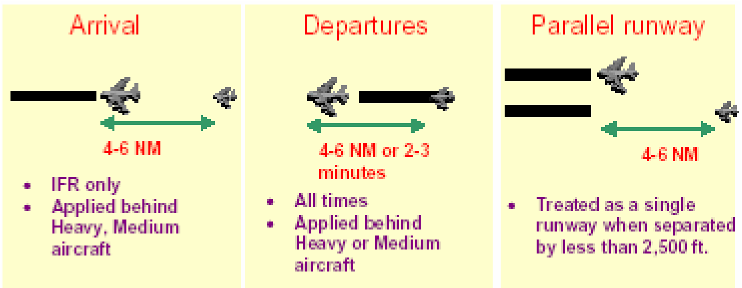

Figure 3 – ICAO Standard Separation for Approach and Departures

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.

3.2 Description of current system and situation

Current ATC systems supporting operations in APP or Aerodrome units have to be considered in ATC-WAKE context.

Current control practices are based on ICAO recommendations (PANS-ATM) or national regulation. Aircraft are classified into different categories according to the Maximum Take-Off Weight (MTPOW). ICAO defined standard categories and separation between aircraft is based on the preceding aircraft category (fixed distance or time). USA and UK have brought some changes in the weight and the categories definitions.

In current operations, no information concerning wake vortex behaviour is provided to ATC Controllers or Flight Crews.

3.3 Operational environment

The expedition of arrival and departure traffic on an airport and corresponding performance key indicators (capacity, efficiency) are strongly related to the operational environment in which ATC operations are conducted. The operational environment for airport operations may be presented by considering a number of key elements that have direct and mutual influence on the arrivals and departures.

Table 1 - Meteorological Conditions

Op. Environment Element	Impact / Role on Airport Operations
Wind speed and direction	Selection of runway in use
Visibility : RVR, cloud ceiling	Selection of flight rules : VMC / IMC
Runway Brake Efficiency	Runway Occupancy Time

Airport Layout and Infrastructure

Airport layout is a key element for establishing landing or departure procedures. In the context of wake vortex influence, runways are treated individually (single runway) or by pairs (parallel or intersecting runways).

Table 2 - Airport Layout and Infrastructure

Op. Environment Element	Impact / Role on Airport Operations
Runway Layout : single runways / parallel runways / intersecting runways	Balance between arrivals / departures
Taxiway Layout	Runway Occupancy Time decreased in case of rapid exit taxiways

Table 3 - Ground and aircraft equipment

Op. Environment Element	Impact / Role on Airport Operations
Navigation Aids: VOR DME, GNSS	Guidance to pilot (or FMS) for approach and departure
Landing aids : ILS / MLS	Guidance to pilot for final approach and landing phase Depending on flight rules, impose minimum aircraft separation (protection area)
Approach Radar	Surveillance of arrival, departure traffic, monitoring of aircraft trajectory and separation with preceding or following aircraft Minimum radar separation to be applied depends on surveillance method and equipment
A-SMGCS Equipment : Surface Movement Radar, Mode S Multilateration systems	Surveillance of ground movements and prevention of runway incursions (risk of collision)

Table 4 - ATC Organisation

Op. Environment Element	Impact / Role on Airport Operations
Sectorisation	Grouping or splitting of TMA sectors is planned in advance in order to balance airport capacity with traffic demand

3.4 System components

In the context of ATC-WAKE several existing components of ATC systems require particular attention, for the presentation of traffic information to controllers and to provide automated support for the planning of operations. Such components are presented in section 5.6.2.

3.5 Procedures involved

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.

In order to monitor the application of such procedures, “working methods” have been developed for controllers as well as for pilots. These may be associated to automated tools (e.g. ATCO tools for arrival management) or rely on information sources (e.g. traffic situation display, weather forecast) and taught through training.

3.5.1 Arrival Operations

Inbound traffic to an airport flies through Upper and Lower Airspace before entering the TMA at points as defined in the STARs (standard arrival routes) procedures.

An Approach Control Centre generally controls any holding stacks located at the boundary of the radar vectoring area.
The Approach Centre is divided into 3 sectors to manage arrivals:

- Initial approach: management of the holding stacks near to the airport (entries, exits, FLs)
- Intermediate approach: ILS sequencing and interception
- Tower sector : final approach and RWY utilisation

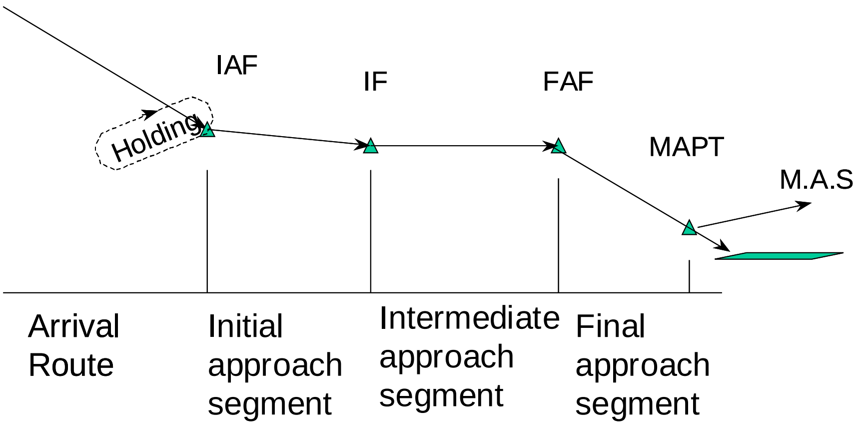

Figure 4 – Aircraft Approach Segments

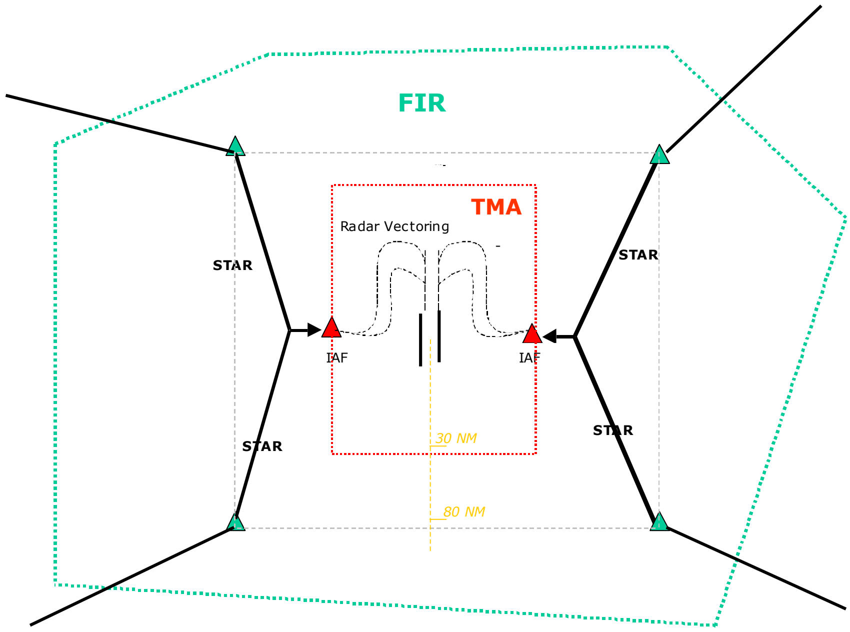

Figure 5 – Schematic view of Terminal Airspace and Arrival Procedure

RWY landing rate is defined according to local meteorological conditions, configuration and use of the RWYs etc….

The landing rate is defined as an average value. It does not take into account the weight categories of the traffic.

This rate is transmitted to the initial ATCO co-ordinator in charge of managing the flow of traffic entering the approach area.

During the co-ordination phase between ACC and APP, the ATCO:

- selects the first available landing slot (i.e. the landing time of the last aircraft that entered the approach area + RWY rate)
- calculates the Expected Approach Time (EAT) at which the aircraft should leave the arrival stack and assesses the delay

EAT information is passed to the ACC Terminal sector during the hand over co-ordination and transmitted to the crew at the first radio contact with the APP ATCO. The EAT is updated regularly based on radar data.

All this is carried out in order to respect the declared capacity and to avoid traffic overload or underload in the approach area.

Information on delay is transmitted, only, by the approach centre to the ACC terminal sectors. No absorption of delay is performed up stream in other ACC sectors.

Nevertheless radar separations according to weight categories must be applied.

This task is allocated to the Intermediate APP ATCO who will radar vector aircraft to intercept the ILS at a specified altitude.

3.5.2 Departure Operations

On runways dedicated to take-offs, the basic rules for separation are based on time if air traffic control is provided in a non-radar environment.

If the first aircraft taking-off is a “heavy”, then take-off clearance for the following aircraft is issued after a delay of 2 minutes irrespective of its weight category. The same time separation is applied in the case of a “light” aircraft taking-off behind a “medium” aircraft.

If an intermediate taxiway take-off is used, the time separation between a “heavy” aircraft and other categories and between “medium” aircraft and “light” aircraft is increased up to 3 minutes.

Pilots are well aware of the danger of wake turbulence effects and are reluctant to shorten this time separation even if there is a crosswind above 15 Kt.

3.5.3 Application of Reduced wake vortex Separation

Reduction of separation minima is authorised in certain cases to cope with the increasing traffic and to enable airports to make the best use of possible capacity while maintaining the same level of safety.

Examples of reduced separation working methods are “land-after” and “anticipated-landing”. They are applied under specific conditions. The authorisation is given to an aircraft to land while the preceding aircraft has still not vacated the runway. As specified by ICAO PANS-ATM, such working methods are only applied when visual contact between aircraft is established and dependent on flight crew agreement.

3.6 Capabilities of individual systems

Capabilities of individual systems have been investigated for the introduction of ATC-WAKE operations. Main constraints associated to such operations have been identified in section 5.5.

3.7 Users or involved actors

This section briefly introduces the actors of ATC-Wake target system, i.e. its users, either human actor (ATC Controller, Pilot) or automated systems, and their respective roles in current operations are explained.

Different roles of ATCO exist depending on responsibilities and assigned airspace :

- ATC Supervisor
- Planning Operations ATCOs : Arrival Sequence Manager
- Tactical Operations ATCOs
    - Approach Controller : Initial / Intermediate / Final
    - Tower Controller
    - Ground Controller

Responsibilities and evolution of actors' role in the context of ATC-WAKE is explained in section 5.2.

4 Justification for and Nature of Changes

4.1 Justification for Changes

Before 1970, aircraft of similar weights and low traffic density mitigated the risk of wake vortex encounters. In 1970 and during the following years some wake vortex related incidents occurred due to the introduction of the Boeing 747 and the constant traffic growth. Between 1969 and 1976, extensive collection of data led to the definition of the ICAO separation standards based on aircraft maximum takeoff weight classes.

As recognised by Aviation Stakeholders and investigated during intensive flight trials (AVOSS trials performed by NASA), the main issues affecting ICAO WV standard separations are:

- Over-conservative standard separation is applied in a majority of cases
- Insufficient standard separation is applied in a minority of cases
- Inappropriate regulation for closely spaced parallel runways : which results in inefficient use of some runway configurations

In current ATC operations, no exchange of information concerning wake vortex is provided between ATC and Aircrews, specific procedures exist only for the heaviest freight aircraft (Beluga, AN-22).

As a consequence there is no system integrating all the sources of WV related information together at a single source, accessible by all ATC service providers (en-route, approach, tower and arrival/departure managers).

Since new high capacity aircraft (such as the Airbus A380) will be heavier and larger, and air traffic grows continuously at a rate of 5 % per year, today's aircraft separation rules are considered to be increasingly inefficient, and may result in unnecessary delays. New weather based rules used in combination with a suitable ATC decision support system are expected to provide the means to significantly enhance airport capacity.

Since 1993, several European Union research and development programmes have been launched to get better knowledge of the physical and safety aspects of the wake vortex phenomena and to develop technologies for wake vortex detection and prediction. Taking benefit of such technologies, an objective of ATC-WAKE is to develop and validate operational concepts for approach and departure phases of aircraft, while maintaining and ensuring an appropriate and required level of safety.

4.2 Priority Among Changes

As shown by recent surveys of WV accidents, a majority of wake vortex encounters happen during the final approach or the initial climb and flight crews agree that during these flight phases near the ground, WV encounter is the most hazardous.

WV behaviour is characterised by transport and decay, both are highly dependent on atmospheric conditions. In the context of ATC-WAKE both effects have been considered but the preferred situation is when WV is transported out of the concerned airspace area.

The main changes introduced by ATC-WAKE operations are:

- In planning operations: determination of safe aircraft separation minima using wake vortex prediction information (enhanced with present detection information)
- In tactical operations: application of and transition between pre-determined separation minima.

4.3 Changes Considered but not Included

Alternatives for approach operations using WV information have been identified, in particular in the case of closely spaced parallel runways (CSPR) :

- simultaneous parallel approaches : SOIA concept developed by FAA
- displacement of threshold : HALS – DTOP developed by DFS

In addition, the application of dynamic or individual aircraft separations according to aircraft type and Meteorological conditions has not been retained. In ATC-WAKE operations, a pre-determined aircraft separation is to be applied to the whole traffic during a specified timeframe.

4.4 Assumptions and Constraints

The prediction of wake vortex behaviour in ATC-WAKE will be performed by combining met forecast and now-cast and real-time wake vortex measurements on airport arrivals and departures. The quality of WV prediction is directly related to the quality of input data (met, radar). A safety buffer has to be applied to satisfy accuracy and stability requirements of ATC users.

- **Accuracy :** covers the properties of the predicted WV behaviour especially within the critical arrival / departure areas
- **Stability :** covers the associated timeframe to prediction, i.e. sudden changes to start / end time(s) for application of reduced separations shall be avoided in order not to create hazardous situations (e.g. re-organisation of arrival sequence) or constraints (flight holding)

Quantified values for accuracy and stability attributes will be evaluated during ATC-WAKE operational feasibility evaluation.

The main principles followed for the calculation of the wake vortex behaviour in the context of ATC-WAKE are the following :

- The aircraft weight and speed define the strength of the produced vortices (expressed as the circulation m^2/s).
- The turbulence (measured as the TKE or EDR level of the atmosphere at the vortex location) and temperature stratification control vortex decay. Constant background shear may prolong vortex lifetimes slightly.
- The aircraft span defines the initial vortex spacing.
- The vortex circulation and the spacing determine the self-induced velocity and thus the sink rate.
- The atmosphere stratification (function of the temperature profile) can obstruct or slow down the sinking of wake.
- The (cross and head) wind profile induce the vortex transport.
- The wind shear can induce a vortex tilting. One of the two vortices may stall or rebound and the other continues to descend.
- The ground proximity can induce a rebound of both vortices or an increasing of their spacing (or both effects simultaneously).

5 Concept for the ATC-WAKE System

5.1 Background & Objective

The definition of ATC-WAKE operational concepts has been made using ATC expert judgement for safety and capacity issues, as well as using experimental data to assess wake vortex transport and decay in particular weather conditions.

From the current situation where ICAO standard minimum separations are applied, the objective is to integrate WV detection and prediction information in order to :

- Determine and implement safe separation between aircraft during approach or take-off phases.
- Sequence approach and runway operations in a seamless way.

ATC-WAKE operations are associated to the following flight phases: en-route (descent / end of cruise), initial / intermediate / final approach and departure.

5.2 Users or Involved Actors

Table 5 - ATC-Wake Users or Involved Actors

Actor	Current Responsibility	Specific/additional Role in ATC - WAKE
Airport ATC Supervisor	Monitors ATC tower and ground operations	Decides on arrival and departure separation mode and in case of ATC-Wake separation decides on the rate to be applied
Arrival Sequence Manager	In charge of arrival planning management for one or several runways, in co-ordination with adjacent ATC Units (sequencing and spacing of aircraft can be assisted by an arrival manager tool (AMAN)	Uses WV prediction information for determination of aircraft sequencing and spacing in the final approach corridor (according to the separation mode decided by the ATC Supervisor) Co-ordinates forecast sequence upstream to en-route and / or approach ATSUs
Initial Approach Controller (INI)	In charge of inbound traffic from initial approach fix (IAF). Responsible for holding stacks management.	Establishes arrival sequence based on WV.
Intermediate Approach Controller (ITM)	In charge of intermediate approach, ILS interception Establishes sequence for final approach and landing	Establishes final approach sequence based on WV prediction and informs about deviations

Actor	Current Responsibility	Specific/additional Role in ATC - WAKE
Tower Controller (TWR)	In charge of final approach, landing, and take-off phases	Monitors safe and optimal separations using WV detection and short term forecasting of the WV displacement. Instructs aircrew on any necessary evasive action.
Ground Controller (GND)	Organises and monitors aircraft and vehicles ground movements Sequences departures according to landings	Uses WV detection and short term forecasting of the WV displacement to optimise departure sequencing
Aircrew	Navigates aircraft safely	Complies with Controller's instructions to meet arrival sequence constraints based on WV prediction information Takes necessary evasive actions to avoid WV encounter if instructed by ATC or alerted by on-board equipment (I-WAKE).

In addition to human actors, **an automated system** for arrival management has been considered as an actor of ATC-WAKE, i.e. a user of WV prediction information for arrival sequencing and spacing.

Table 6 - Automated systems for ATC-Wake operations

Tool	Current Functionality	Specific/additional Function in ATC - WAKE
AMAN	Assists Arrival Sequence Manager in arrival sequencing and spacing for one or several runways	Uses WV prediction information for determination of aircraft sequencing and spacing in the final approach corridor Communicates forecasted sequence upstream to en-route and / or approach ATSUs

5.3 Operational Policies and Constraints

For the definition of the ATC-WAKE operational concept and procedures, the principle of **"evolution not revolution"** has been retained. As far as possible, existing concepts and procedures for arrivals and departures have been considered, use of WV information analysed in order to allow a smooth transition from current ICAO aircraft separation rules to ATC-WAKE aircraft separation rules.

In this context, the proposed evolution of policies in ATC-WAKE impact mainly on working methods, in order to allow:

- Safe and efficient use of wake vortex detection and prediction information;
- Determination of appropriate separation between aircraft based on wake vortex information.

During the definition of ATC-WAKE operations, three notions and critical issues have been identified:

- Wake vortex critical areas, i.e. parts of the airspace where the risk of a WV encounter is clearly identified and where detection and prediction of WV will contribute to ATC operations;
- Application and transition between different aircraft separation modes (and minima) : potentially inferior aircraft separation distance to ICAO standard;
- Representation of wake vortex information for ATC Controllers.

5.3.1 Wake Vortex Critical Areas

Amongst the different phases of flight, the final approach and the departure path are the most critical with respect to the risk and consequences of wake vortex encounter.

The final approach path starts indeed at the geographical point reached by all aircraft (FAF) and from it they will follow almost identical trajectories (bounded by the ILS tolerances) until the touchdown zone. The wake vortex develops behind the aircraft in approach aircraft (leader) and may potentially hit the follower aircraft.

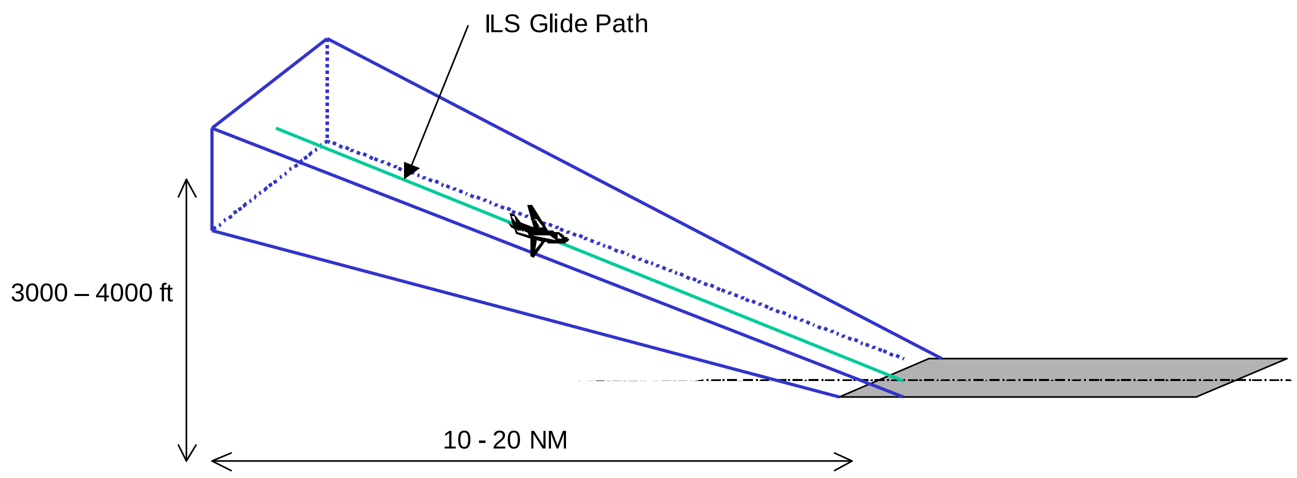

Figure 6 – WV Critical Area for Arrivals

The departure path and in particular the initial climb is also a geographical area where separation between aircraft is low and where WV encounter risk exists. Contrarily to arrivals, strong variations between departure paths are observed, aircraft rotation point and initial climb rate depending highly on aircraft type and weight. This complicates the definition and the forecasting of a safe take-off rate.

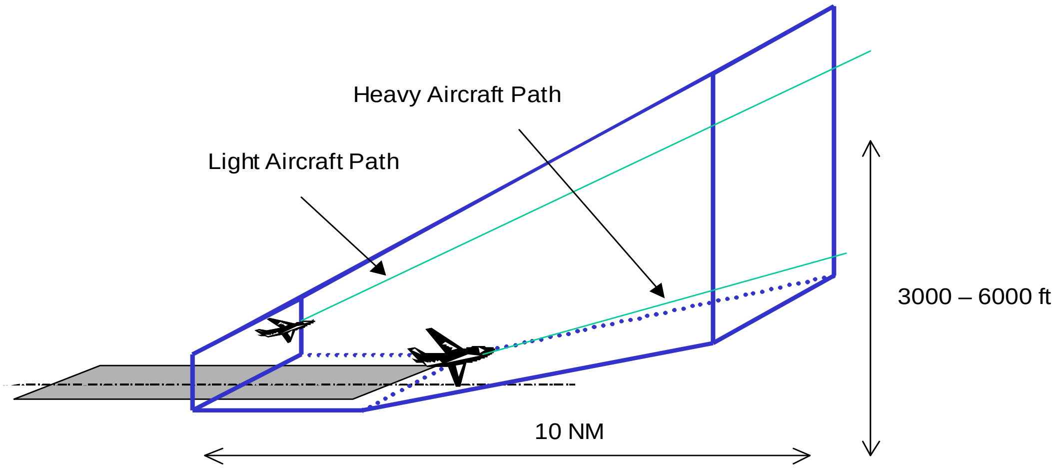

Figure 7 – WV Critical Areas for Departures

5.3.2 Application of Reduced Wake Vortex Separation

The minimum applicable aircraft separation for landing traffic is related to the runway acceptance rate and to the performance of surveillance equipment. Under favourable wake vortex situations (transport out of arrival path), **a separation of 2.5 NM for aircraft flying on the same final approach path (in particular at runway threshold) is targeted**.

In case of closely spaced parallel runways, a separation of 2.5 NM between aircraft on parallel approach path is targeted (staggered approaches).

For departures a separation of 90 s between aircraft on the same runway is targeted, provided that WV transport out of runway area is confirmed by detection.

These minima are applicable only if it complies with the safety requirements associated to the equipment used for IMC approach (e.g. radar, ILS).

As an example, an average runway occupancy time is 50 s to reach the exit taxiway, plus a 10 s buffer as a safety margin gives a minimum of 60s between two consecutive landing aircraft. With a landing speed of about 120 Kt, this gives a separation of 2 NM at RWY THR.

Airport local working methods exist to authorise landing that is conditional to the runway exit of the preceding aircraft (also called “land after” procedure). The application of such procedures is allowed by ICAO provided that visual contact of aircraft on the runway is made by aircrew in approach.

5.3.3 Representation of Wake Vortex Information for ATC Controllers

The wake vortex information provided to ATC Controllers in charge of tactical operations is aimed at confirming that safe separation is applied (pre-determined during planning of operations) and is not intended to be used as a mean to visualise minimum separation.

The concept of the Vortex Vector has been defined : a straight line behind an aircraft corresponding to the predicted maximum length of the wake vortex contained into the critical area (arrival or departure) and that takes into account transport and decay effects is displayed on a radar display.

The vortex vector will be kept up-to-date all along the flight path, an initial value is calculated before aircraft entry in the critical area and updated with WV measurements or recalculations. When deviation between prediction and actual measurement may lead to a hazardous situation, notification is distributed to the ATC Controller.

- For arrivals : starting at the alignment with ILS axis
  In case of Closely Spaced Parallel Runways (CSPR), the vortex vector length shall take into account the parallel corridor.

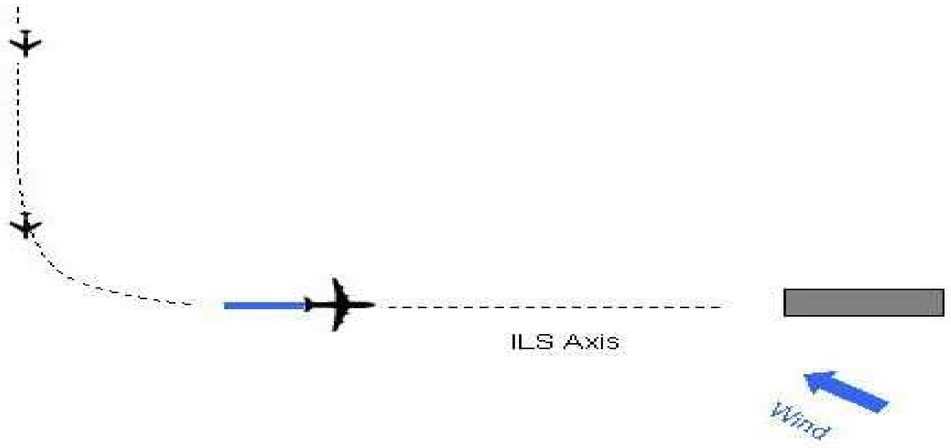

Figure 8 – Vortex Vector for Arrivals

- For departures : from the rotation point and along the initial climb (before first turn)

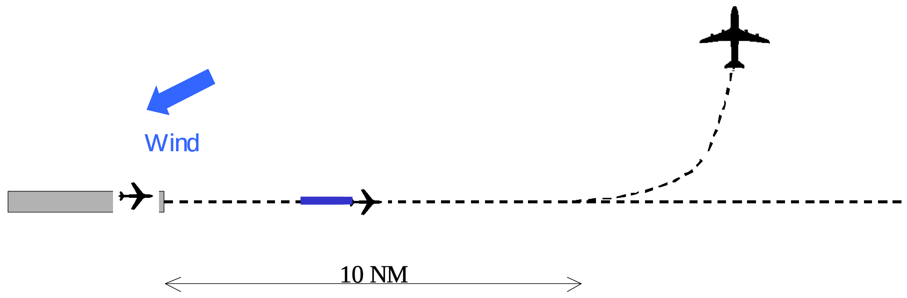

Figure 9 – Vortex Vector for Departures

5.4 Description of new Concept, System and Situation

The ATC-WAKE operational concept introduces in today practices the following activities :

- **Determination of separation mode:** use of WV behaviour prediction in approach or departure paths with a look ahead time of 20 - 40 min to determine the distance / time separation to be applied between aircraft in WV critical areas.
- **Approach tactical operations following the pre-determined separation mode:** use of WV short term prediction and detection information by ATCO in order to monitor the safe separation between aircraft along the final approach path
- **Departure operations following the pre-determined separation mode:** use of WV short term prediction and detection information by ATCO in order to monitor the safe separation between aircraft along the rotation and initial climb phase

In the context of ATC-WAKE the following table introduces the runway configurations and the modes of operations that have been considered (Table 7).

Table 7 - Runway configurations and modes of operations

Modes of Operations \ Runway Configuration	Arrivals only	Departures only	Mixed Mode
Single Runway	Specialised[1] for arrivals	Specialised for departures	Same concept as for arrival or departures only
Closely Spaced Parallel Runways (separated by less than 2500ft)	Staggered approaches	No	Departures inserted between 2 arrivals

[1] The term « Specialised Runway » is used to define a single runway configuration used for landings only or departures only during a significant period of time (minimum of 10 successive movements).

Modes of Operations \ Runway Configuration	Arrivals only	Departures only	Mixed Mode
Non-Closely Spaced Parallel Runways	Simultaneous approaches	No	Equivalent to 2 single runways
Crossing Runways	No	No	No

5.4.1 Determination of Separation Mode

Depending on weather conditions influencing WV transport out of the arrival or departure WV critical areas, two modes of aircraft separation for arrivals and departures have been defined:

- **ICAO standard separation**
- **ATC-WAKE separation**

Based on meteorological conditions, ATC-WAKE will advise the ATC Supervisor about applicable separation mode and associated validity period (start / end).
The ATC Supervisor has the responsibility to decide the minimum separation to be applied for approach or departure phases as well as the landing rate to be used for arrival sequencing (using AMAN or not).

The time horizon to be considered for arrival sequencing is 40 min if an AMAN is used, 20 min otherwise. Based on planned traffic and meteorological conditions (wind profile), an assessment of WV transport and decay is performed in order to advise the ATC Supervisor about the applicable minimum separation for a fixed period of time (start / end of ATC-WAKE operations).

ATC Supervisor decision is based on the proposal made by the ATC-WAKE system but also depends on multiple factors related to the airport situation (visibility conditions, runway(s) in use, ATC sectorisation).

The ATCO in charge of tactical operations needs to be informed about which separation mode is to be applied at least 40 minutes in advance if an AMAN is used.

This time is necessary to anticipate the necessary traffic increase in case ATC-WAKE separation is to be applied. The update of inbound traffic planning is almost immediate but one has to consider a delay to implement the new planning during en-route phase (time to lose / gain).

If sequencing and spacing is made manually by the Arrival Sequence Manager, then different working methods have to be considered, in particular if the arrival planning horizon is narrower (entries / exits from holding stacks), a 20 min notice is needed for changing the separation mode criteria.

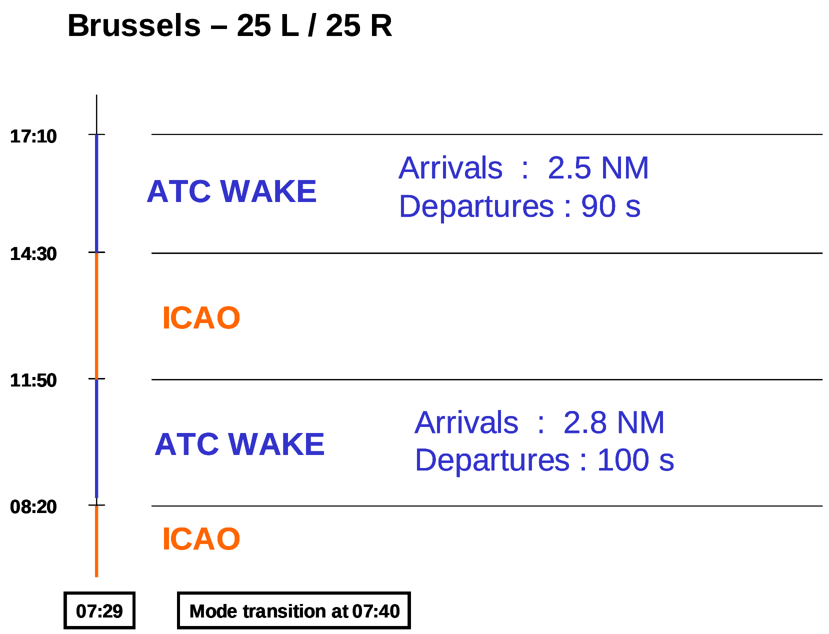

Figure 10 – Example of a Planning of Separation Modes

Not only the prediction of the VW situation shall be known in advance (20 to 40 min), but also the stability of prediction shall be high in order to avoid sudden changes of separation mode.
It is assumed that the WV situation will be monitored by comparing results of prediction and detection. From ATC supervisor or operator viewpoint a typical refresh rate of such information is 30 minutes.

5.4.2 ATC-WAKE Concept for Arrival Operations

The section presents the general ATC-WAKE operational concept for arrivals to be applied for a single runway configuration.

Specific operations for closely spaced parallel runways have been considered and an example of procedure for such an operation is presented in section 5.7.

5.4.2.1 Planning of arrivals

Based on landing rate, AMAN and / or the Arrival Sequence Manager establishes the aircraft arrival sequence and backward propagation is used to define entry times at IAFs.

In order to realise such a sequence at the IAF, the amount of time to lose or to gain for each flight is determined by AMAN and displayed to the en-route Controllers for them to apply.

The determination of the time to lose is currently implemented in a number of arrival manager tools, e.g. COMPAS (Frankfurt), OSYRIS (Zurich), MAESTRO (PARIS), CTAS (US). However, none of them integrates WV prediction as yet.

In the absence of an Arrival Manager, the sequence is established on a First In- First Out (FIFO) method on entering the holding stack. More accurate spacing is then achieved by the Initial Approach Controller by adjusting the holding time.

5.4.2.2 Initial Approach Controller

At first contact, the initial approach controller (INI) informs the pilot about the separation mode in force (ATC-Wake or ICAO standard). The INI organises the holding stack exit times according to the separation to be applied. He is also responsible for allocating the flight levels.

I-WAKE equipment might be installed on-board aircraft to further enhance WV safety. Such instrumentation for on-board detection, warning and avoidance of atmospheric hazards (including WV) will be used as a "safety net" and not to monitor separation.

It is anticipated that it will be difficult to require all airlines to install I-WAKE equipment in all of their aircraft. A safety study of ATC-WAKE operations shall therefore take into account a "mixed fleet of aircraft".

5.4.2.3 Intermediate Approach Controller

The intermediate approach controller vectors aircraft up to the ILS interception point.

When aircraft N°1 has intercepted the ILS, the controller informs the pilot of aircraft N°2 about the type of aircraft N°1. In the case where ATC-WAKE separation mode is in operation, the pilot of aircraft N°2 must confirm that he has visual contact with aircraft N°1.

It is anticipated that an ATC-WAKE system will also be beneficial in all visibility conditions. However the current ICAO working methods require visual contact for reduced wake vortex separation (PANS-ATM, PANS-OPS). Therefore the application of ATC-WAKE separations in all visibility conditions require an alternative way to inform or to transfer data about the position of aircraft no1 to the pilot of aircraft no2. The pilot could then confirm sufficient awareness about the preceding aircraft before he/she is allowed to land in ATC-WAKE separation mode.

The controller receives a visual confirmation via the Vortex Vector of the suitability of the current applied separation (see in 5.3.3) in the final approach corridor behind the aircraft plots (see schematic view below), starting at alignment with ILS and ending at RWY THR).

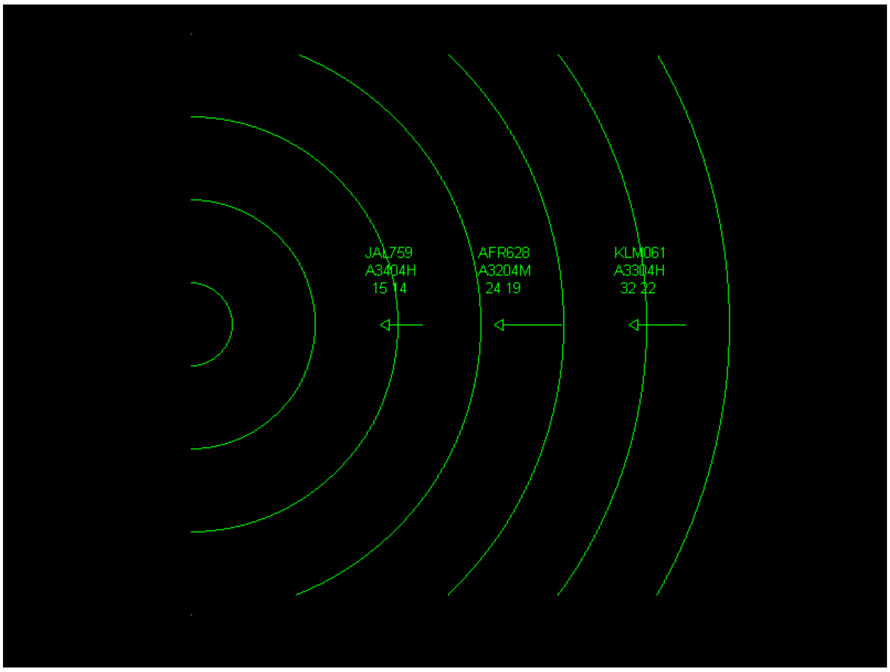

Figure 11 – Proposed ATCO HMI with WV information

5.4.2.4 Tower Controller

The Tower Controller monitors the final approach and landing of the aircraft by ensuring safe separation between the preceding aircraft (vacating the runway) and the following aircraft.

The controller HMI displays the vortex vector behind the aircraft plots in the final approach corridor and enables the detection and correction of any deviation from safe separation.
The detection of WV is performed in the final approach corridor. If WV encounter is predicted by the ground equipment, an alarm is raised to the controllers who then inform the pilot.

If the on-board equipment detects an immediate risk of a WV encounter, the pilot is informed immediately and decides about adequate evasive action (most probably a go around).

Note: A deviation from the established arrival sequence (go around) is fed back to AMAN or other controllers in order to re-compute the sequence.

5.4.3 ATC-WAKE Concept for Departure Operations

WV prediction information is used by the Ground Controller to determine the WV position, transport and decay. Planning of departures is done on a relatively short term and taking into account ATFM slots.

The Tower Controller uses WV detection information (now cast) to confirm safe separations between aircraft in the departure phase (up to the first turn) using a vortex vector (see in 5.3.3).

The detection is performed along the extension of runway axis and approximately up to a distance of 10 NM from runway and using a reference corridor of +- 5 deg.

WV detection information will serve to decrease further waiting time between consecutive departures if wake vortex situation is more favourable at operation time than at planning time.

5.5 Operational environment

Referring to section 3.3, this section summarises the prerequisites and requirements on ATC operational environment that are associated to ATC-WAKE operations.

Table 8 - Meteorological Conditions for ATC-Wake operations

Requirement	Need (essential / option)
Dry runway (max. braking efficiency)	essential to reduce ROT
Cloud ceiling : min 4500 ft	essential for visual contact between pilots
Visibility : min 5 km (RWY length or 2.5 NM)	essential for visual contact between pilots

In addition to visibility and braking efficiency prerequisites, an initial analysis of favourable meteorological conditions for the application of ATC-WAKE separation mode has been performed using airfield trials data (FAA AVOSS experiment).

The following table provides indications for envisaged separation mode depending on atmospheric conditions.

Table 9 - Atmospheric conditions and Separation Modes

Atmospheric Conditions	Separation Mode
Cross Wind	ATC-WAKE Cross wind potentially ensures a quick transport of the WV out of the approach corridor (minimum speed to be determined) and therefore enables a reduced wake separation to be applied. Remark : the transport of the WV needs to be carefully assessed in case of CSPR
Head Wind (strong)	ICAO standard or ATC-WAKE Head winds (combined or not with cross wind) can increase or decrease the apparent descent speed of the wake
Calm Atmosphere	ICAO standard or ATC-WAKE
Wind Shear	ICAO standard
Turbulence	ATC-WAKE As flying aircraft in such conditions is more difficult, pilots usually increase the aircraft approach speed. This will be reflected in the aircraft separation to be applied.
Stratification	ICAO standard or ATC-WAKE

NB: The boundaries for atmospheric conditions (threshold values) described in the table are defined in WP2000 – System design.

Table 10 - Airport Layout and Infrastructure

Requirement	Need (essential / option)
High speed runway exits	essential to ensure expeditious flows of landings

Table 11 - Ground and aircraft equipment

Requirement	Need (essential / option)
Precision Approach Radar	essential to support 2.5 NM separation
Landing Aid : ILS / MLS / GNSS	essential
A-SMGCS (monitoring runway occupancy)	option
I – Wake	option
B-RNAV	essential
ATIS : Publish applicability and planning of ATC-WAKE separation	essential

In addition adaptations of approach procedures as explained in 5.7 will also imply to amend information provided in aeronautical information provider (AIP).

5.6 System Components

The ATC-WAKE system will include four main specific (functional) components and will also interface with several existing ATC system components.

5.6.1 ATC-WAKE Specific Components

Table 12 - ATC-WAKE Separation Mode Planner

Function	Determines the applicable separation mode (ICAO mode or ATC-WAKE mode)and advises about minimum aircraft separation distance Advisory includes expected time for future mode transitions, indication of aircraft separation minimum applicable
Comment	Determination of separation mode is based on met and “general” wake vortex forecast (e.g. wind profile picture and expected “worst case” pairing), it also uses the currently observed WV situation. Changes of separation mode have to be decided with a minimum look ahead time of 40 min if AMAN is used, 20 if not, plus/minus a buffer determined at local implementation. Minimum aircraft separation distance is based on a worst-case scenario (e.g. Heavy aircraft followed by a Light one) simulation taking into account traffic distribution.

Table 13 - ATC-WAKE Predictor

Function	Predicts for individual aircraft the WV behaviour (“vortex vector”) in the pre-defined arrival or departure area(s) “ vortex Vector” = Part of the critical area (e.g. ILS Glide Slope) potentially affected by the wake vortex
Comment	Prediction is performed using real-time available met data from the time the aircraft reaches the critical arrival area entry UNTIL it lands and from the take-off UNTIL it leaves the critical departure area. The quality of WV prediction is directly related to the quality of input data (met, radar). A safety buffer has to be applied to satisfy accuracy requirements of ATC users. These data consist of the most recent met now-cast data as well as ground or down-linked airborne measurements (wind/temperature profiler, wind/temperature aloft). The prediction is updated in short intervals (e.g., 1 min) and is vaulted/assessed by measurements of WV behaviour of preceding aircraft.

Table 14 - ATC-WAKE Detector

Function	Detects for individual aircraft the WV position, extent ("vortex vector") and –if possible – also its strength in the pre-defined arrival or departure area(s)
Comment	Detection is performed using ground-based equipment (e.g. pulsed LIDAR) which scan pre-defined parts of the considered critical area (e.g. ILS glide path) in pre-defined windows (size is to be defined, see MFLAME and I-Wake) No connection to airborne equipment is assumed but detection may be complemented using airborne equipment (see I-WAKE project)

Table 15 - ATC-WAKE Monitoring and Alerting

Function	Alerts ATCO in case of : significant deviation between WV detection and WV prediction information which raises the risk of WV encounter failure of one or several WV components
Comment	This component plays the role of a "safety net" for ATC-WAKE operations, its design must be kept simple : • No connection to airborne equipment is assumed • No use of aircraft behaviour model for WV encounter is assumed

5.6.2 Re-use of Existing ATC Components

Table 16 - ATCO Human Machine Interfaces

Function	Provides the traffic situation picture and automated support for various ATCO tactical roles (Approach, Tower).
Comment	A generic component is used in the context of ATC-WAKE but specialisation exists depending on ATCO role. It is foreseen to integrate WV related information together with flight information (position, altitude, ground speed, aircraft type)

Table 17 - Arrival Manager (AMAN)

Function	Determines automatically optimum arrival sequence and provides advises for realising this sequence. Communicates forecast sequence upstream to en-route and / or approach ATSUs
Comment	It assists in scheduling traffic from TMA entry (Initial Approach Fix) to runway. Sequencing is based on the landing rate decided by ATC Supervisor (ICAO or ATC-WAKE separation mode).

Table 18 - Flight Data Processing System

Function	Keeps track of every flight information and updates, in particular the flight plan, the trajectory prediction, ETA and ETD, aircraft type and equipment

Table 19 - Surveillance System

Function	Provides and maintains the air traffic situation picture using all available detection means (radars, air-ground data links)

5.7 Procedures involved

The introduction of ATC-WAKE operations does not require an important re-development of arrival or departure procedures but rather the application of new ATC working methods. The main adaptation to be performed on existing arrival procedures is :

- Missed approach procedure in case of ATC-WAKE separation

Specific new procedures have been identified and analysed during WP1000 :

- Transition between ICAO separation and ATC-WAKE separation modes
- Staggered approaches to Closely Spaced Parallel Runways (CSPR)

5.7.1 Closely Spaced Parallel Runways

The term "closely spaced" designates parallel runways separated by less than 2500 ft, ICAO considers such pair of runways as one unique with regard to wake vortex turbulence.

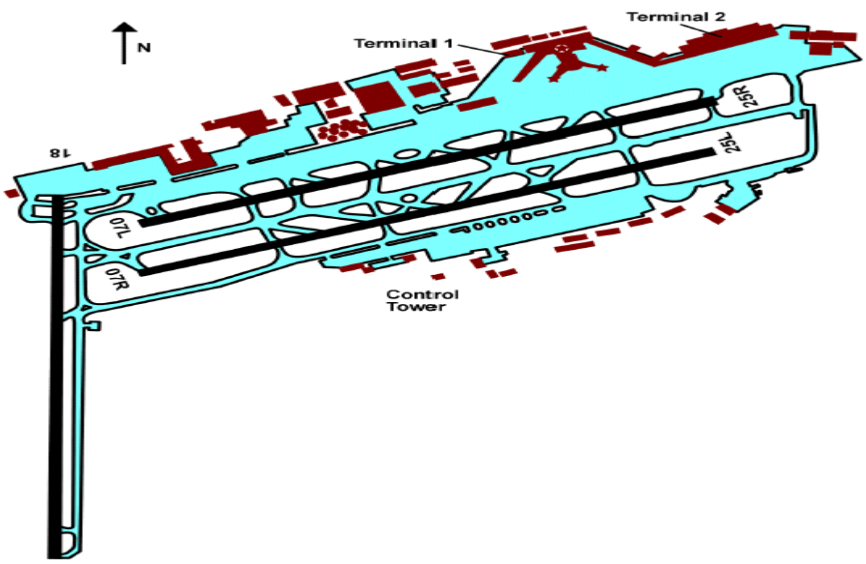

Figure 12 – Frankfurt Airport Layout

In the context of ATC-WAKE both runways will be used for arrivals at traffic peak hours, typically to handle a sequence of at least 20 arrivals.

The proposed concept of operations for CSPR involves the use of both runways for staggered approaches based on the segregation of traffic according to aircraft type (Heavy / Medium / Light). One runway is dedicated to Heavy landings whereas the other one will be used for Medium or Light landings only and landings of Heavy and Medium occur alternatively.

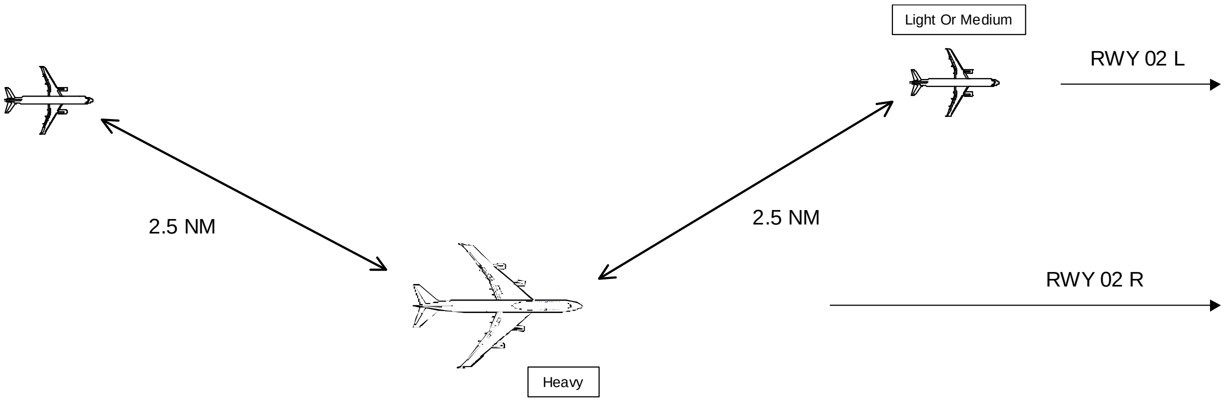

Figure 13 – Staggered Approaches

Depending on weather conditions and in particular wind speed and direction, air traffic will be segregated between Heavy on the downwind runway and Medium and Light on the upwind runway.
Heavy aircraft will be assigned to the downwind runway and perform initial – intermediate approach 1000 ft below Light and Medium aircraft so that WV generated by Heavy aircraft will be transported out of Light or Medium approach corridor.

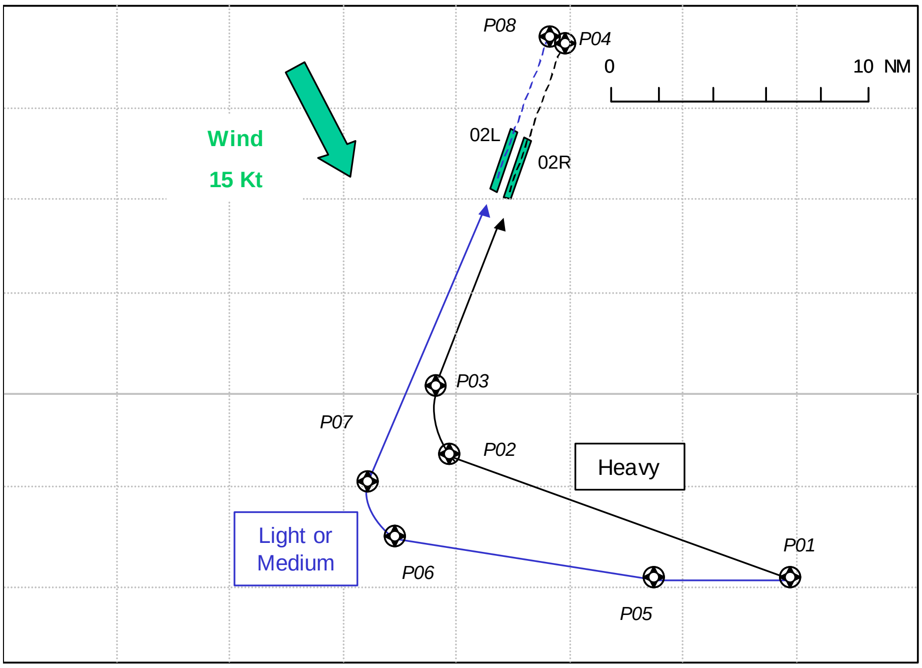

Figure 14 – Example of a Staggered Approach Procedure – Horizontal Profile

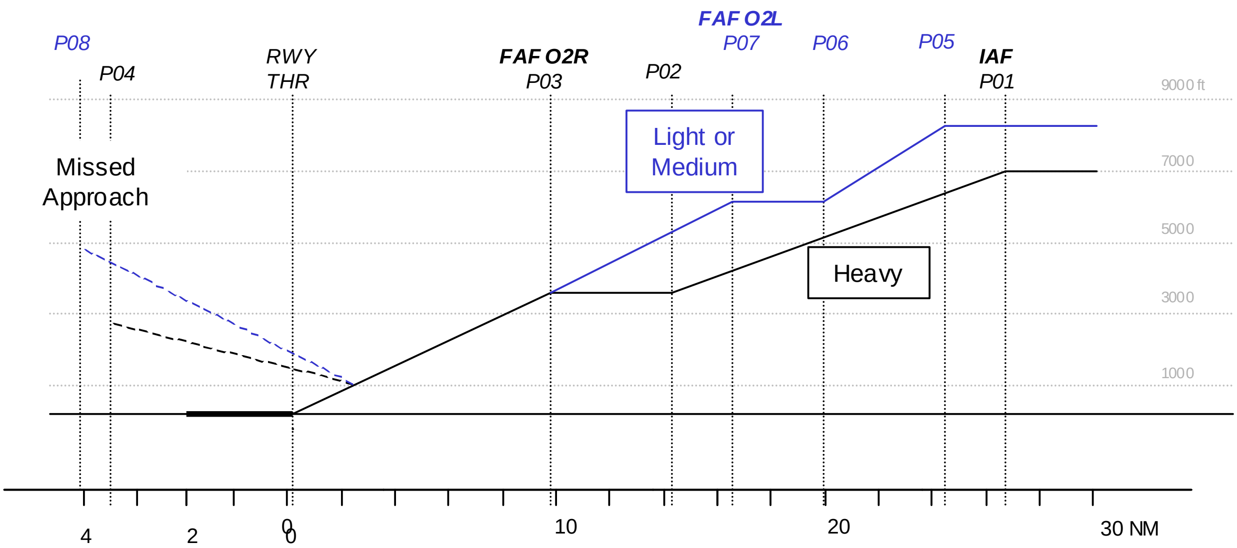

Figure 15 – Example of a Staggered Approach Procedure – Vertical Profile

5.7.2 Missed Approach Procedures

One of the main changes introduced by ATC-WAKE operations concerns the missed approach procedure. When reduced wake vortex separations are applied (compared to ICAO), a missed approach may be decided on right up to the touchdown zone (e.g. ATC-WAKE or I-WAKE alarm) even if the preceding aircraft has vacated the runway.

As a consequence, new elements of phraseology have to be introduced. In addition, the awareness of meteorological events that affects WV transport and decay needs to be developed.

5.7.3 Transition between ICAO and ATC-WAKE separation modes

The ATC Supervisor is the decision-maker for the separation mode and minimum separation distance to be applied during tactical operations. Such decision is based on the proposal made by the ATC-WAKE Separation Mode Planner but also depends on multiple factors related to airport situation (visibility conditions, runway(s) in use, ATC sectorisation).

In order to avoid holdings at the TMA entry point, such transitions shall be planned as early as possible. A time horizon of 20-40 min has been proposed but the availability of accurate weather prediction data at this timeframe needs to be evaluated.

The transition from ICAO to ATC-WAKE separation mode will begin by considering the incoming aircraft that have a planned arrival time included in the start / end time period for ATC-WAKE operations. Such aircraft have not reached the TMA.

The re-planning of arrivals (if necessary) will be performed by the Arrival Sequence Manager or by AMAN and transition information (start / end of separation mode to be applied) will be distributed to concerned ATCOs. The time adjustments will be implemented by En-Route controllers through speed modifications, radar monitoring or/and holding pattern.

For departures, transition will not imply immediate actions but transition information will be distributed to concerned ATCOs.

In case of an unexpected change of meteorological conditions, the application of larger separation on short term (less than 10 min) or in case of ATC-WAKE equipment failure is required, a procedure to reverse back to ICAO separation has to be defined.

5.8 Capabilities of individual systems

The capabilities of ATC-WAKE specific components identified in section 5.6.1, will be analysed during the design phase and validated against ATC-WAKE requirements.

6 Conclusions

As a first step towards ATC-WAKE System, the WP1000 on system requirements has drawn the preliminary operational concept and requirements for the application of aircraft separation minima based on WV detection and prediction information. Next steps in the project are aimed to validate such requirements through system design and safety assessment and then operational feasibility evaluation.

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

Transitions between ATC-WAKE and ICAO separation modes
Frequent transitions between ICAO and ATC-WAKE separation modes may have negative effect on capacity as such event potentially requires significant ATC resource for the re-planning of arrivals.

Aircraft separation and sector loading
The definition of the reduced aircraft separation (2.5 NM) has been evaluated based on typical figures for individual runway occupancy time. In the case of large airports with three to four active runways, the effect of increased throughput on TMA traffic load needs to be examined. Adequate strategy for the application reduced wake vortex separation together with TMA sectorisation plan is to be evaluated.

Evaluation of safety requirements
The safety assessment of ATC-WAKE system and corresponding operational concept shall demonstrate that, when implemented, tolerable safety levels are met. In this respect, both the S-WAKE risk management framework and Eurocontrol Safety Regulatory Requirements (ESARRs) provide a regulatory framework that will be used for the setting of safety targets.
The safety study might also lead to further improvements of the operational concept developed in WP1000 System Requirements through identification (and subsequent implementation of risk mitigation measures).

Evaluation of capacity benefits
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.
However, the determination of actual capacity gain is complex as ATC-WAKE operations do not require only a technical framework but the combination of favourable meteorological conditions and efficient co-operation between ATC Controllers and Flight Crews to operate in dense traffic conditions.

VERSION FRANÇAISE DU SOMMAIRE

Ce document constitue le rapport final de la tâche WP1000 du projet ATC-WAKE. Il traite des besoins opérationnels, du concept opérationnel, des procédures, des besoins utilisateurs et des exigences système pour la mise en place d'un système ATC intégrant les fonctionnalités de prédiction et de détection de la turbulence de sillage.

Une des contraintes majeures à l'augmentation de la capacité des pistes est due au phénomène de turbulence de sillage. Il existe un risque majeur d'accident lorsque la turbulence générée par un avion rencontre celui qui le suit, particulièrement si un avion léger rencontre la turbulence d'un gros porteur.

Aujourd'hui la présence de la turbulence de sillage n'étant pas estimée par rapport aux conditions atmosphériques en vigueur, il en résulte un espacement entre deux avions basé uniquement sur le cas théorique le plus défavorable. L'espacement à appliquer est déterminé en considérant la catégorie de masse de l'avion leader et de l'avion suiveur et en prenant pour référence le comportement de la turbulence de sillage dans des conditions atmosphériques favorisant sa persistance. En conséquence les distances d'espacement réglementaire prévues par l'OACI peuvent apparaître dans certains cas comme trop conservatrices. Elles sont néanmoins suffisantes pour assurer la sécurité des avions dans la majorité des conditions atmosphériques mais peuvent cependant se révéler insuffisantes pour des conditions atmosphériques très particulières.

Plusieurs solutions technologiques ont été développées pour détecter et prédire le comportement de la turbulence de sillage. Ces solutions sont aujourd'hui matures et peuvent être utilisées de façon opérationnelle lorsqu'une disparition rapide de la turbulence de sillage est observée (transport au-delà de la zone concernée).

L'opportunité de déterminer l'espacement à appliquer par les contrôleurs aériens en fonction des résultats de prédiction, de détection, de la trajectoire et du poids de l'avion générant la turbulence est aujourd'hui envisagée. A ce jour il n'existe néanmoins aucun système intégrant toutes les sources d'information ATC et météorologiques nécessaires pour fournir un tel service au contrôleur (en-route, approche, aérodrome, gestion des départs et arrivées).

Dans cette perspective, les objectifs du WP1000 du projet ATC-WAKE ont été définis comme suit :

- Définir les besoins opérationnels de haut niveau (WP1100)
- Identifier les concepts opérationnels et les procédures associées possibles Développer le concept et les procédures sélectionnés pour le projet (WP1200)
- Définir les besoins utilisateurs (WP1300)

- Définir les exigences système en se basant sur le concept opérationnel et les besoins utilisateurs (WP1400)

En tant que première étape vers le système ATC-WAKE, la tâche WP1000 a permis de déterminer le concept opérationnel et les exigences associés à l'application d'un minimum d'espacement entre avions basé sur la détection et la prédiction de la turbulence de sillage. Les étapes suivantes du projet concernent la validation du cahier des charges notamment par le développement d'un démonstrateur, l'étude approfondie de la sécurité des opérations et l'évaluation de la faisabilité opérationnelle au travers de simulations.

Dans le cadre du WP1000, les difficultés pour la réalisation du système ATC-WAKE ont été identifiés comme suit :

Contraintes opérationnelles: définition et utilisation d'information relative à la turbulence de sillage par les contrôleurs aériens (approche et aérodrome), contraintes de l'environnement ATC opérationnel existant.

Contraintes techniques: définition d'interfaçage du système cible avec les systèmes ATC existants.

Au cours du développement du cahier des charges du système ATC-WAKE, un certain nombre de points clé ont été identifiés et devront être analysés minutieusement dans la suite du projet :
- Transitions entre deux modes de séparation avion: séparation ATC-WAKE vers séparation OACI (et vice versa)
- Impact de la séparation avion sur la charge de trafic des secteurs d'approche
- Evaluation des exigences de sécurité
- Evaluation des bénéfices en terme de capacité

La structure du rapport final ATC-WAKE WP1000 est basée sur le standard MIL-498-STD (Développement de systèmes informatiques) :
- Partie 1 : Introduction
- Partie 2 : Contexte et objectifs du projet ATC-WAKE
- Partie 3 : Situation actuelle et systèmes en opérations dans les centres ATC approche et aérodrome
- Partie 4 : Justification et nature des changements
- Partie 5 : Concept pour un système nouveau ou modifié
- Partie 6 : Conclusions de la tâche WP1000
- Annexe A : Correspondance entre le rapport final et les rapports intermédiaires
- Annexe B : Matrices des exigences opérationnelles, utilisateurs et système

Annex A – Traceability to WP1000 Reports

In order to identify further documentation on ATC-WAKE operational concept and requirements, the following table depicts the correspondences between WP1000 Final Report and intermediate deliverables, which are listed below :

- [D1_1] ATC-WAKE Operational Requirements, Edition 1.0, 2003
- [D1_2] ATC-WAKE Operational Concept and Procedures, Edition 1.0, 2003
- [D1_3] ATC-WAKE User Requirements, Edition 1.0, 2003
- [D1_4] ATC-WAKE System Requirements, Edition 1.0, 2003

The table below presents as well the consistency between WP1000 results with the Operational Concept Description (OCD), as recommended by MIL-498-STD Software Development and Documentation standard, and which is used as a reference for the structure of the WP1000 Final Report.

Table 20 - Traceability of ATC-Wake System Requirements documentation

Final Report		**WP1000 Reports**
Section	Title	Deliverable Id – Section - Title
1.2	System Overview	[D1_1] Sections 1, 2, 3
2	Background and Objectives	[D1_1] Section 2 Analysis of the Problem
3.2	Description of current system and situation	[D1_1] Section 5.1.2 Current ATC practices [D1_1] Section 5.1.3 Current ATC Systems
3.4	System components	[D1_1] Section 5.1.3 Current ATC Systems
3.5.3	Application of Reduced Aircraft Separation	[D1_1] Section 5.1.3 Current ATC Systems
4.1	Justification for changes	[D1_1] Section 2 Analysis of the Problem
4.4	Assumptions and constraints	[D1_1] Section 5.4 Use of WV Prediction Information [D1_1] Section 5.5 Use of WV Detection Information (Alerts)
5.3.1	Wake Vortex Critical Areas	[D1_1] Section 4.2 Prediction - Detection Areas
5.1	Background & Objective	[D1_2] Section 2.1 Scope of Operations
5.4	Description of new Concept, System and situation	[D1_2] Section 2.1 Scope of Operations [D1_3] Section 3 Planning Phase User Requirements [D1_3] Section 4 Tactical Phase User Requirements [D1_4] Section 3.4.1 Planning Operations [D1_2] Section 3.4.2 Tactical Operations
5.6	System components	[D1_4] Section 3.2 Components
5.7	Procedures involved	[D1_2] Section 3 Arrival Procedures [D1_2] Section 4 Departure Procedures
5.8	Capabilities of individual systems	[D1_1] Section 4.4, 5.1

Annex B – ATC-WAKE Requirement Matrix

This section contains the ATC-WAKE operational user and systems requirements that have been devised during WP1000 and will be kept on configuration management all through the project.

The following attributes have been assigned to the requirements:

- ID: Unique identification X – nn, X denoting the specific category (OR for operational requirement, UR for user requirement, SR for system requirement) and nn the reference number
- Description: title of the requirement, followed by the requirement text
- Status:
  - P - Proposed: requirement has been requested by a source;
  - A - Approved: requirement has been analysed and has been allocated;
  - IA - In analysis: proposed requirement is analysed for possible approval or rejection;
  - D - Designed: requirement has been incorporated in design;
  - IM - Implemented: requirement has been implemented;
  - V - Verified: requirement has been verified;
  - E- dEleted: requirement has been deleted (including an explanation);
  - R- Rejected: proposed requirement has been rejected;
  - Stalled: in case of unforeseen problems during the implementation,
- Priority: a classification of the requirement: essential (Ess), desirable (Des) or nice-to-have (Nth)

Supplementary information are provided as notes:

- Source : a reference to the source of the requirement in WP1000 deliverables
- Traced to : dependency between requirements (especially system requirements)
- Verification method: the method for verifying that the requirement has been met: inspection, analysis, feasibility test (operational or technical)

Operational Requirements

ID	Description	Status	Priority

OP - 01	**Hazard Prediction Capability**	**IA**	**Ess**
The ATC-WAKE system shall predict wake vortex behaviour : for planned arrival and departure traffic in pre-defined (critical) areas			
Note : Prediction – Detection Areas see D1_1 § 5.2 : in these areas, follower aircraft may be potentially hit by WV from leader (arriving or departure) aircraft. *Verification method : feasibility test*			

ID	Description	Status	Priority

<table>
<tr><th>OP - 02</th><th>Hazard Detection Capability</th><th>IA</th><th>Ess</th></tr>
<tr><td colspan="4">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)</td></tr>
<tr><td colspan="4">Note : Prediction – Detection Areas see D1_1 § 5.2 : in these areas, follower aircraft may be potentially hit by WV from leader (arriving or departure) aircraft
Verification method : feasibility test</td></tr>
<tr><th>OP - 03</th><th>Quality of Prediction Information</th><th>IA</th><th>Ess</th></tr>
<tr><td colspan="4">The prediction information shall have a high level of quality in order to :
guarantee safety of operations based on such information
support the application of reduced aircraft separation and reversion to standard separations</td></tr>
<tr><td colspan="4">Note : Performances of Prediction see D1_1 § 5.4 : Performances attached to prediction information concern :
the accuracy of the prediction,
the stability of the prediction
the time horizon for such prediction (look-ahead time) and
the refreshment rate
Quantification of detection quality requirements will be performed through WP1000 - WP2000 collaboration
Verification method : analysis</td></tr>
</table>

<table>
<tr><th>OP - 04</th><th>Quality of Detection Information</th><th>IA</th><th>Ess</th></tr>
<tr><td colspan="4">The detection information shall have a high level of accuracy in order to avoid false alarms.</td></tr>
<tr><td colspan="4">Quantification of detection quality requirements will be performed through WP1000 - WP2000 collaboration
Note : typical delay at Paris Charles de Gaulle airport induced following a go around procedure is 35 min
Verification method : analysis</td></tr>
</table>

<table>
<tr><th>OP - 05</th><th>Wake Vortex Information to ATC Controllers</th><th>IA</th><th>Ess</th></tr>
<tr><td colspan="4">ATC-WAKE shall support ATC Controller decision making process related to wake vortex hazard prevention.</td></tr>
<tr><td colspan="4">Note : Operational use see D1_1 §6.2 to § 6.6
Verification method : feasibility test</td></tr>
<tr><th>OP - 06</th><th>Integration to ATC Environment</th><th>IA</th><th>Ess</th></tr>
</table>

ID	Description	Status	Priority

ATC-WAKE prediction and detection system shall : adapt to ATC environment, in particular to arrival / departure procedures, to runway configuration and to ATC decision support tools use relevant information from existing ATC systems provide relevant VW information to ATC Controllers and automated systems involved in arrival and departure management in order to achieve the minimum safe spacing between aircraft according to vortices transport and decay not add workload to ATC Controllers
Note : Operational use see D1_1 § 6.2 to § 6.6 *Verification method : analysis*

User Requirements

ID	Description	Status	Priority

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).			
Verification method : feasibility test			

UR - 02	WV Separation Mode Transitions	IA	Ess
The ATC Supervisor and ATCOs shall receive information about transition between separation modes at least 40 min in advance with AMAN, 20 min otherwise.			
Verification method : feasibility test			

UR – 03	WV Prediction	IA	Ess
On request, the ATCO shall be provided with a visualisation of WV (named vortex vector) on the radar display for each individual landing aircraft from start to end of arrival / departure critical area. The vortex vector shall be updated using actual met information (e.g. wind profile).			
Note : arrival critical area is relatively well-defined (from localiser interception till touch-down, ILS axis) whereas for departure the dimensioning of departure area shall be investigated further (during WP2000 and WP4000). *Verification method : feasibility test*			
UR – 04	**WV Alerting**	**IA**	**Ess**
The ATCO shall receive an appropriate alarm when detected WV differs significantly from WV prediction (vortex vector).			
Note : ATC-WAKE alarm are transmitted to pilot using voice communication *Verification method : feasibility test*			

System Requirements

ID	Description	Status	Priority
SR - 1	**Separation Mode Planner**	**IA**	**Ess**
The ATC-WAKE system shall determine the applicable separation mode (ICAO mode or ATC-WAKE mode) and its validity, support the planning and implementation of mode transitions and advise ATCO about minimum aircraft separation distance			
Traced to : *Operational Requirements : OP-1, OP-3, OP-5, OP-6* *User Requirements : UR-3* *ATC – WAKE Component : see D1_4 § 3.2.1* *ATC-WAKE Use Cases : see D1_4 § 3.5* *Verification method : feasibility test*			

SR - 2	**WV Predictor**	**IA**	**Ess**
The ATC-WAKE system shall predict for individual aircraft the WV behaviour ("vortex vector") in the pre-defined arrival or departure area(s) and within a pre-defined timeframe.			
Traced to : *Operational Requirements : OP-1, OP-3, OP-5, OP-6* *User Requirements : UR-1, UR-2* *ATC – WAKE Component : see D1_4 § 3.2.1* *ATC-WAKE Use Cases : see D1_4 § 3.6* *Verification method : feasibility test*			
SR - 3	**WV Detector**	**IA**	**Ess**
The ATC-WAKE system shall detect in real-time for individual aircraft the WV behaviour ("vortex vector") in the pre-defined arrival or departure area(s).			
Traced to : *Operational Requirements : OP-2, OP-4, OP-5, OP-6* *User Requirements : no direct link to user requirements* *ATC – WAKE Component : see D1_4 § 3.2.1* *ATC-WAKE Use Cases : see D1_4 § 3.6* *Verification method : analysis*			

SR - 4	**WV Monitoring and Alerting**	**IA**	**Ess**
The ATC-WAKE system shall monitor the WV situation with respect to critical areas and raise appropriate alarms to ATCOs in case of : significant deviation between WV detection and WV prediction information with a risk of WV encounter failure of one WV component			

ID	Description	Status	Priority
Traced to : *Operational Requirements : OP-2, OP-5, OP-6* *User Requirements : UR-04* *ATC – WAKE Component : see D1_4 § 3.2.1* *ATC-WAKE Use Cases : see D1_4 § 3.6* *Verification method : analysis*			