<ATC-Wake>

<IST–2001-34729>

<D2_12: ATC Wake System Design and Evaluation>

ATC Wake System Design and Evaluation
(ATC Wake D2_12)

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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 fur Luft- & Raumfahrt DLR
	EUROCONTROL Experimental Centre (EEC)
	Thales Air Defence (TAD)
	Thales Avionics (TAV)
	Université Catholique de Louvain (UCL)

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 Integrated System Design and Evaluation
Deliverable N°:	D2_12
Due date:	31/12/2005
Delivery Date:	31/12/2005 (Final Version)

Short Description:

This document describes the work performed in the WP2000 Integrated System Design and Evaluation of the ATC-Wake Project. An integrated wake vortex safety and capacity *platform* has been designed and implemented to serve as test-bed environment for the ATC-Wake Operational System.

The ATC-Wake Integrated Platform comprises a set of tools and data bases which have been prepared by the consortium partners and are running at the different partners' premises. To enable the integrated and distributed use of the ATC-Wake tools and data bases by partners and other users, the ATC-Wake IP *Working Environment* has been created using SPINEware middleware technology.

The technical feasibility of the integrated *system* has been evaluated by experimental simulations with the integrated *platform*. Conclusions and recommendations for installation of an ATC-Wake system at airports are provided.

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

Contract No. **IST–2001-34729**

ATC-Wake WP2000

Task Title ATC-Wake System Design and Evaluation

Deliverable D2_12

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Document control sheet		**NLR-TP-2006-251**	
Work Package:	**WP2000**	**Released by: L.J.P. Speijker (NLR)**	
Version:	**Final**	**Approved by: F. Barbaresco (TAD)**	
Issued by:	**TAD**	**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 fur Luft- & Raumfahrt DLR
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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 with 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 output is the ATC Wake Integrated 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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Acronyms

AAS	Amsterdam Airport Schiphol
AC	Aircraft
AMAN	Arrival Manager
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
HMI	Human Man Interface
IAF	Initial Approach Fix
ILS	Instrument Landing System
NM	Nautical Mile
Kts	Knots
NLR	National Aerospace Laboratory NLR
PVD	Plan View Display
RT	Radio Telegraphy
SART	Situation Awareness Rating Technique
SMP	Separation Mode Planner
SMR	Surface Movement Radar
SUS	System Usability Scale
TAAM	Total Airspace and Airport Modeller
TLX	Task Load Index
UCL	Université Catholique de Louvain
WV	Wake Vortex

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. Nevertheless, today, there is no link of Wake Vortex information 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.

The main objective of WP2000 "Integrated system design and evaluation" is to develop and build the ATC-Wake *Integrated Platform*. A further objective is the evaluation of the technical feasibility of installation of the ATC-Wake system at airports. This system is designed according to requirements imposed by the ATC environment on one side and capabilities of weather and wake forecast and monitoring equipment on the other side. The work includes.

- Development of technical concepts for the integrated platform, including its subsystems;
- Qualitative assessment and selection of the technical concepts;
- Design and specification of weather forecasting and monitoring tools;
- Specification, selection and adaptation of wake vortex predictors;
- Design and specification of Air Traffic Controllers Human Machine Interfaces;
- Development of a SAS (Separation Advisory System);
- Development of the functional integrated system as a virtual platform;
- Testing of the integrated platform and evaluation of technical feasibility of building and (subsequent) installation of an integrated system at European airports.

The ATC-Wake Operational System comprises different subsystems, including weather forecast, now-casting, and monitoring systems, wake monitoring systems, wake prediction systems, separation mode planner, and Human Machine Interfaces (HMI) for the air traffic controllers. Four new functional ATC-Wake components, which interface with several existing and/or enhanced ATC system components, have been designed and implemented.

- *New components: Separation Mode Planner, Wake Vortex Predictor, Wake Vortex Monitoring and Alerting, and Wake Vortex Detector;*
- *Existing ATC systems***:** AMAN, Flight Data Processing System & Surveillance Systems
- *Enhanced ATC systems:* Meteorological Systems, ATC Supervisor HMI and ATCo HMIs. For the Meteo systems enhancements in prediction and update rates are foreseen and the HMI's for supervisor and ATCo are extended with ATC-Wake symbology.

The ATC-Wake IP is an essential first ATC-Wake system development step, in which the ATC-Wake functional components have been integrated. This has been done through the creation and use of the ATC-Wake IP *Working Environment*, using SPINEware middleware technology. The technical feasibility of the integrated *system* has been evaluated by experimental simulations with the integrated *platform*. It has been shown that the functional integration of the components is successful and it will be technically feasible to install the system at an airport and integrate wake vortex information into the existing ATC systems. This however depends on the local circumstances and may require improved quality of in particular weather forecast and now-casting capabilities. Air Traffic Controller Human Machine Interfaces have been designed, specified, and tested successfully through two real-time simulation experiments with nine active controllers from five European countries.

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1 Introduction

1.1 Scope

With the steady increase of air traffic, there is an urgent need for new innovative infrastructure systems enhancing the efficient use of airport facilities, while maintaining safety. An important hazard limiting today's airport capacity is wake vortices generated by aircraft with the potential of a dangerous encounter for follower aircraft, especially in case of small aircraft encountering the wake of large preceding aircraft. This is reflected in the ICAO aircraft separation scheme for single runway approaches defined in the early 70's and, since then, has served to maintain acceptable standards of wake vortex safety. Since new high capacity aircraft will be heavier and larger, and air traffic grows continuously at a rate of 5% per year, today's aircraft separation rules are considered 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 significantly airport capacity increase.

The IST project ATC-Wake aims to develop and build an Integrated Platform (IP) for ATC (Air Traffic Control) that would allow variable aircraft separation distances, as opposed to the fixed distances presently applied at airports. If these fixed distances can be reduced in favourable weather conditions without compromising safety, then airport aircraft-handling capacity increases accordingly. The ATC-Wake IP has a test bed environment role:

- To assess the interoperability of this integrated system with existing ATC systems currently used at various European airports (in WP4000);
- To assess the safety and capacity improvements that can be obtained by applying this integrated system in (simulated) airport environments (in WP3000);
- To evaluate the operational usability and acceptability – by pilots and controllers - of this integrated system in (simulated) airport environments (in WP4000);
- To make a plan and assess the costs for further development, implementation and exploitation of this (prototype) integrated system (in WP5000).

The impact of weather on wake vortex safety is a crucial aspect, and the uncertainty in predicting the behaviour of wake vortices in different weather conditions implies that continuous *monitoring* of both wake vortices and weather is necessary. Continuous verification and update of predictions of safe required aircraft spacing (i.e. separation minima) is then ensured. Therefore, there is a need to address and possibly improve existing and weather forecasting, now-casting and monitoring systems and capabilities.

1.2 Objectives

The main objective of this work package is to develop and build the ATC-Wake *Integrated Platform*. A concept will be designed and built as an integrated *platform* by coupling and integrating existing tools and databases. The platform will integrate subsystems for e.g.:

- weather forecasting and monitoring,
- wake vortex prediction and monitoring,
- aircraft separation planning,
- flight data processing,

A further objective is the evaluation of the technical feasibility of installation of the ATC-Wake at European airports. This system will be designed according to requirements imposed by the ATC environment on one side and the capabilities of weather and wake forecast and monitoring equipment on the other side.

1.3 Approach / description of work

The approach/work plan is based on the following sequential activities:

- Development of technical concepts for the integrated platform, including its subsystems;
- Qualitative assessment and selection of the technical concepts;
- Specification and design of weather forecasting and monitoring tools; specification, selection and adaptation of wake vortex predictors;
- Design and specification of Air Traffic Controllers Human Machine Interfaces;
- Development of a SAS (Separation Advisory System);
- Development of the functional integrated system as an Integrated Platform (IP);
- Testing of the integrating platform and evaluation of technical feasibility of building and (subsequent) installation of an integrated system at European airports.

To enhance acceptability of the integrated system, ATC controllers will be involved in the design and specification of the ATC-Wake Human Machine Interfaces (HMIs). This means that, giving priority to providing optimal decision support to the controllers who will keep the ultimate responsibility for their decisions, the HMIs will have to reflect a synthesis between:

- specific controller needs for information and decision support;
- usability and acceptability of the HMIs;
- airport operational requirements and constraints (e.g. runway availability);
- traffic demands (e.g. amount of inbound/outbound traffic); and
- technical functionalities provided by the integrated system, particularly for wake vortex prediction and monitoring, and aircraft spacing prediction.

For the integration of the subsystems – which have distinct characteristics and are running at different software platforms, an ATC-Wake IP Working Environment will be created, using

SPINEware middleware technology. The interfaces between the integrated tools will be realized in so-called workflows with associated graphical user interfaces. The ATC-Wake IP will be set up as a distributed environment for all the project partners, i.e. all the tools may be operated remotely, from a single place, whereas they run on computers located at the different sites. To enable this secured and distributed access, a Virtual Enterprise concept, based on Project Zones and Virtual Private Network (VPN) connections, will be set up.

1.4 Document structure

The document structure is as follows:

Section 1	Introduction
Section 2	Reference documents
Section 3	Overview / State of the art of Wake Vortex Mitigation Systems
Section 4	ATC-Wake Operational System Description
Section 5	ATC-Wake Components Description
Section 6	HMI Design and Specification
Section 7	ATC-Wake Integrated Platform
Section 8	Technical Feasibility of installation of an ATC-Wake system
Section 9	Conclusions with recommendations and lessons learned.

2 Reference Documents

The following ATC-Wake documents have been used to design, specify, implement, test, and use the ATC-Wake Integrated Platform:

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[D1_2] G. Astégiani (TRANSSIM), D. Casanova, E. Isambert (M3 Systems), J. van Engelen (NLR), V. Treve (UCL); ATC-Wake Operational Concept and Procedures

[D1_3] G. Astégiani (TRANSSIM), D. Casanova, E. Isambert (M3 Systems), J. van Engelen (NLR), V. Treve (UCL); ATC-Wake User Requirements

[D1_4] G. Astégiani (TRANSSIM), D. Casanova, E. Isambert (M3 Systems), J. van Engelen (NLR), V. Treve (UCL); ATC-Wake System Requirements

[D1_5] G. Astégiani (TRANSSIM), D. Casanova, E. Isambert (M3 Systems), J. van Engelen (NLR), V. Treve (UCL); ATC-Wake Final Report for WP1000 System Requirements

[D2_1] M. Frech, T. Gerz, F. Holzäpfel (DLR), F. Barbaresco (Thales AD), V. Treve (UCL), M.J.A. van Eenige (NLR); Architecture Concept and Global Design of the ATC-Wake Integrated Platform

[D2_2] F. Barbaresco (Thales AD), M. Frech (DLR), V. Treve (UCL), M.J.A. van Eenige, G.B. van Baren, T.H. Verhoogt (NLR); ATC-Wake Qualitative Assessment and Selection of Technical Concepts

[D2_3] M. Frech (DLR), F. Barbaresco (Thales AD), V. Treve (UCL), G.B. van Baren (NLR); Interface Requirement Specifications of the ATC-Wake Integrated Platform

[D2_4] M. Frech (DLR), F. Barbaresco (Thales AD), V. Treve (UCL); Software Specification Report of ATC-Wake Integrated Platform

[D2_5] M. Frech, L. Birke (DLR), F. Barbaresco (Thales AD); ATC-Wake weather and wake vortex subsystems and tools

[D2_6] M. Frech, L. Birke (DLR), F. Barbaresco (Thales AD); Specification report of the ATC-Wake IP emulators

[D2_7] T.H. Verhoogt (NLR); Design and Specification of ATC-Wake Controller Human Machine Interfaces

[D2_8] F. Barbaresco (Thales AD), G.B. van Baren, E. Baalbergen, J. van Putten (NLR), M. Frech (DLR), O. Desenfans (UCL); ATC-Wake Integrated Platform Installation and User's Guide

[D2_9] F. Barbaresco (Thales AD), M. Frech (DLR), O. Desenfans (UCL), G.B. van Baren (NLR); Software Test Description of the ATC-Wake Integrated Platform

[D2_10] F. Barbaresco, J.C. Deltour (Thales AD), G.B. van Baren, E. Baalbergen (NLR), M. Frech (DLR), O. Desenfans (UCL); Software Test Report of the Integrated Platform

[D2_11] M. Frech (DLR), G.B. van Baren (NLR), O. Desenfans (UCL), F. Barbaresco (Thales AD); Technical feasibility of building the ATC-Wake Operational System

[D3_1] M. Dalichampt, N. Rafalimanana, A. Vidal (EEC), L.J.P. Speijker (NLR); ATC-Wake Risk requirements and capacity aims

[D3_2] S.H. Stroeve, E.A. Bloem (NLR); Mathematical model for pilot and controller performance models during ATC-Wake single runway arrivals

[D3_3] J.J. Scholte, G.B. van Baren, S.H. Stroeve (NLR); ATC-Wake Qualitative safety assessment of the ATC-Wake operation

[D3_4] A.C. de Bruin, G.B. van Baren (NLR), V. Treve (UCL), F. Holzäpfel (DLR); Validation of the ATC-Wake risk assessment sub-models

[D3_5a] G.B. van Baren, P. Hoogers (NLR), M. Frech (DLR); ATC-Wake Separation Mode Planner

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[D3_6b] L.J.P. Speijker, M.J. Verbeek, M.K.H. Giesberts (NLR), R.M. Cooke (TU Delft); Safety assessment of ATC-Wake single runway departures

[D3_6c] G.B. van Baren, M.J. Verbeek (NLR); Safety assessment of ATC-Wake arrivals on closely spaced parallel runways

[D3_7] P.J. van der Geest, J.A. Post, S.H. Stroeve (NLR); Validation of ATC-Wake aircraft performance models

[D3_8] G.B. van Baren, L.J.P. Speijker (NLR); Evaluation of safe separation distances and capacity

[D3_9] L.J.P. Speijker, G.B. van Baren (NLR), A. Vidal (Eurocontrol), R.M. Cooke (TU Delft), M. Frech (DLR), O. Desenfans (UCL); ATC-Wake safety and capacity analysis.

[D4_1] G. Astégiani (TRANSSIM), D. Casanova, E. Isambert (M3 Systems), V. Treve (UCL); Identification of airport simulation aims

[D4_2] A. Benedettini (Deloitte/Air Service UK), E. Isambert, D. Casanova (M3 Systems), G. Astégiani (TRANSSIM), V. Treve (UCL), L. Sillard, F. Vergne (EEC); Definition of airport and airspace simulation scenarios

[D4_3] A. Bennedettini (Deloitte/Air Service UK), E. Isambert, D. Casanova (M3 Systems), G. Astégianl (TRANSSIM), V. Treve (UCL), L. Sillard (EEC), F. Vergne (EEC); Analysis of airspace and airport simulation scenarios

[D4_4] E. Isambert D. Casanova (M3 Systems), G. Astégiani (TRANSSIM), A. Vidal (EEC); Evaluation of ATC-Wake operational concept, procedures, and requirements

[D4_5] T.H. Verhoogt, R.J.D. Verbeek (NLR), A. Vidal (EEC), T. Gerz (DLR), O. Desenfans (UCL); ATC-Wake Interoperability with existing ATC systems

[D4_6] G. Astégiani (TRANSSIM), D. Casanova, E. Isambert (M3 Systems), T.H. Verhoogt (NLR), A. Vidal (EEC); Evaluation of ATC-Wake Usability and Acceptability

[D4_7] A. Vidal (EEC), A. Benedettini (Deloitte/AS UK), D. Casanova, E. Isambert (M3 Systems), T.H. Verhoogt, L.J.P. Speijker (NLR), G. Astégiani (TRANSSIM), M. Frech (DLR), O. Desenfans (UCL); ATC-Wake Operational Feasibility

[D5_3] K. Pham, F. Barbaresco (Thales A.D.), L.J.P. Speijker (NLR), T. Gerz (DLR), A. Vidal (Eurocontrol), L. Mutuel, H. Barny (Thales Avionics), G. Winckelmans (UCL), ATC-Wake Final Technological Implementation Plan (TIP)

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3 Overview / state of the art

3.1 European Projects for Wake Vortex Mitigation

The following European Projects have taken place during the last ten years:

- **SYAGE developed in France for Toulouse-Blagnac airport**: The “SYsteme Anticipatif de Gestion des Espacements” aims at reduced separations for single runway departures; the system uses ground-based wind measurements and wake vortex model VORTEX.
- **S-Wake**: aims to develop and apply tools for assessing appropriate (safe) wake vortex separation distances. Operational concepts could be used as a baseline for ATC wake operational concepts.
- **I-Wake**: focuses mainly on detection of wake vortices *from the aircraft* to avoid encounters. The systems used have a similar function as TCAS: a last-minute avoidance of a wake turbulence encounter. The system may be used in ATC-Wake operational concepts. I-Wake is the follow-up project of MFLAME where lidar ground-based detection has been successfully tested.
- **Wake Vortex Warning System (WVWS)** developed for DFS at Frankfurt airport: aims at using two closely spaced parallel runways independently. The current WVWS uses data from a wind line, a statistical wind forecast, and a vortex decay and transport model to predict minimum non-hazard times for the two runways at appropriate winds in instrumented meteorological conditions (IMC) for the lowest 80 m above ground level. Work is in progress to extend WVWS to the whole glide path.
- **High Altitude Landing System (HALS) / Dual Threshold Operations (DTOP)** from DFS/Fraport for Frankfurt airport. HALS/DTOP also aims at using two closely spaced parallel runways independently: two aircraft, staggered by radar separation, approach the parallel runways along two glide paths which are separated 80 m vertically and 518 m laterally. The aircraft approaching along the higher path lands at a new runway threshold which is installed 1500 m behind the original threshold. The system is operational as trial phase 2 since 23 June 2001 and works in Cat-1 with IMC conditions.
- **German wake vortex projects “WIRBELSCHLEPPE I & II”**: amongst others develops and tests a wake vortex prediction & monitoring system and studies the possible impact on ATC (DWA cycle).
- **FLYSAFE**: The first objective of FLYSAFE is to design, develop and validate with the most relevant skills in Europe, new solutions able to be integrated on-board aircraft in approx. 2010-2013. It will concentrate on implementing and evaluating an **on-board** system for **all phases of flight**, and more specifically on the **surveillance** aspect of the CNS/ATM concept. It will integrate the solutions against **all weather** phenomena hazards, **traffic** hazards, **terrain** hazards and **loss of control** hazards into innovative **fusion functions** to be validated on an embedded platform (**N**ext **G**eneration **I**ntegrated **S**urveillance **S**ystem) interfaced with the other aircraft systems. FLYSAFE will be the core

European project on **on-board safety systems**, involving all categories of stakeholders through its extensive consortium and the External Expert Advisory Group (EEAG).

- FLYSAFE will also launch research activities on ground based **Weather Information Management System** (WIMS) as it constitutes a major, nevertheless lacking, stakeholder for safety data relative to weather phenomena. Although the solutions proposed by the WIMS will be targeting the on-board safety requirements of the crew, their applicability also extends to the Flight Management System (FMS) and ATM.
- The world-wide acceptance of the solutions designed for both on-board and ground system will require that they be supported by internationally agreed standards. One very important objective of FLYSAFE is consequently to make sure that this standardisation effort is made, as a European initiative.
- FLYSAFE is mainly concentrating on large transport aeroplanes operated in commercial air transport. However, some solutions will have the potential to address the commuter and helicopter market, and possibilities of applications to these sectors will be studied in the Project.

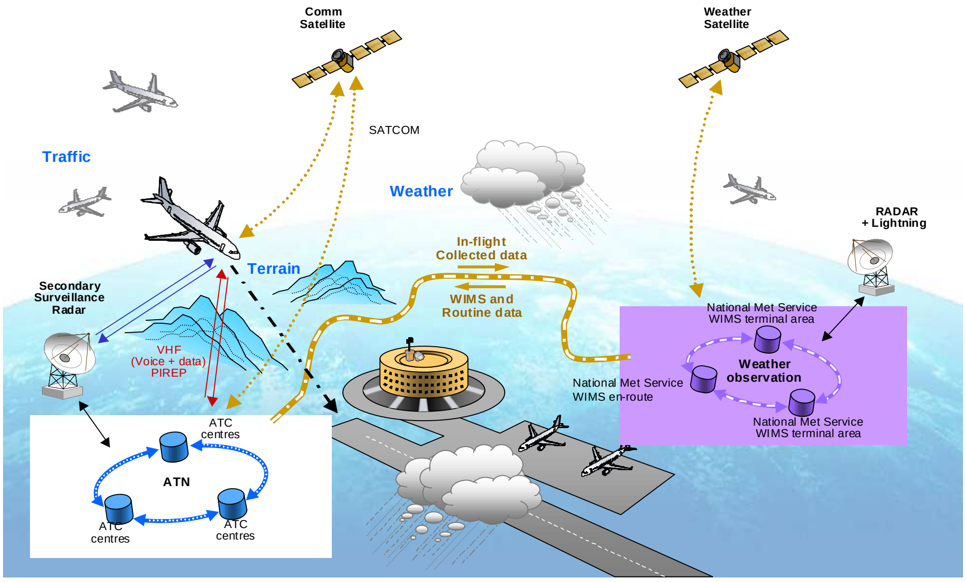


Figure 1 – Global Concept of FLYSAFE

Time Based Separation: developed by EUROCONTROL for investigation of the possibilities of preventing loss of runway capacity against strong headwind conditions while maintaining the required level of safety. Today, distance based separation criteria are generally used at major airports. However, they are used in all weather conditions and do not take into account the impact of the wind on the aircraft speed. Under strong headwind conditions, aircraft need significant more time to fly the same distance. When applying distance based separations, this could result in a loss of capacity. If the standard separation were replaced by time-based interval, this could avoid losing the airport capacity under certain weather conditions.

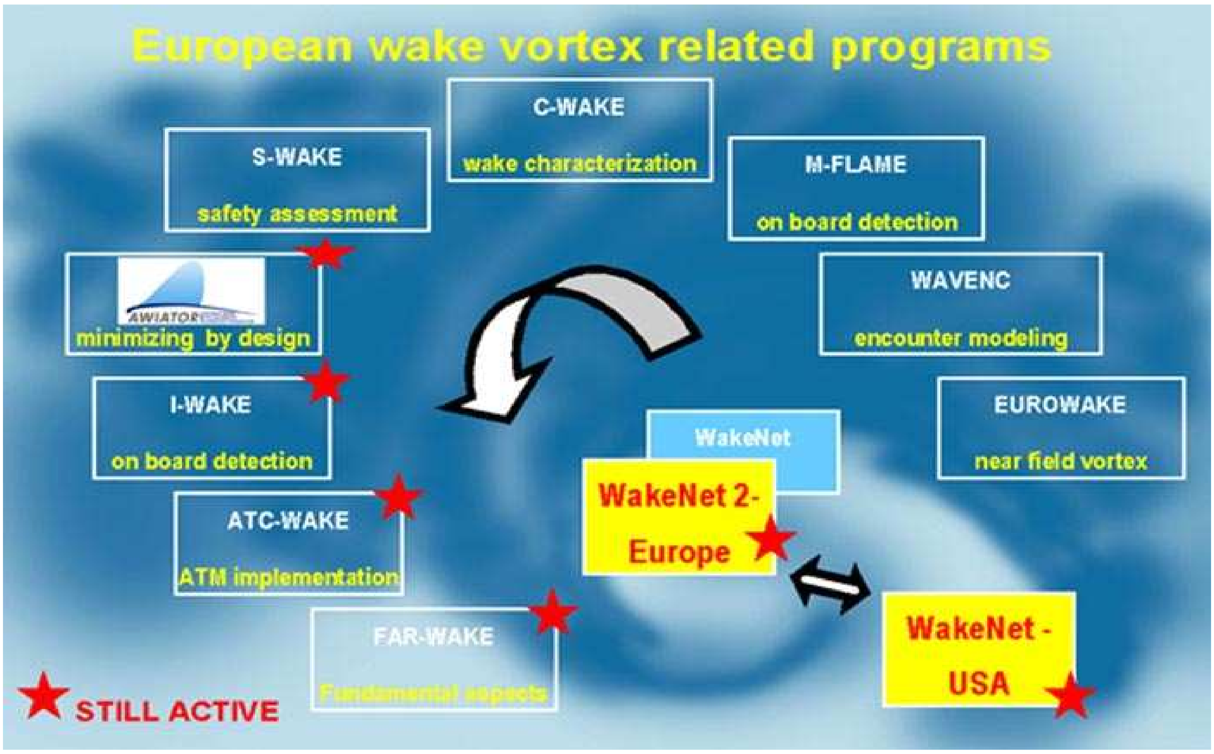


Figure 2 – European Wake Vortex related programs

3.2 Non-European Projects on Wake Vortex Mitigation

Non-European Projects that have taken place during the last ten years are described below:

- **AVOSS (Aircraft Vortex Spacing System)**: has been developed by NASA to produce weather dependent wake vortex spacing criteria in IMC for single runway approach. AVOSS provides current and predicted weather conditions and predicted wake vortex transport and decay. There is however no link to ATC. AVOSS has been deployed at Dallas/Forth Worth International Airport in July 2000. AVOSS includes weather sensors, wake sensors and a wake behaviour prediction algorithm. Real-time wake sensing systems such as pulsed and continuous-wave (CW) Light Detection and Ranging (LIDAR) systems, and wind-lines were used to check the results of the prediction system.
- **Canadian wake vortex project**, in particular the VFS (Vortex Forecast System) provides the predicted wake vortex transport and decay, given the weather and aircraft conditions.
- **SOIA (Simultaneous Offset Instrumented Approach)** by FAA for San Francisco Int'l Airport also aims at simultaneous operations of two closely spaced runways under IMC. When the cloud ceiling is not lower than 1600 feet, two aircraft approach non-staggered but safely separated by 3000 feet laterally until they reach the "missed approach point" at about 1000 feet height and 3.3 nautical miles before the threshold. The final approach is then flown under VMC (S-shape flight pattern).

- **NASA/FAA WakeVAS Program:** Enable the increase of capacity with no decrease in safety for the International Airspace System in the terminal area through new, internationally-agreed upon, standards for wake vortex operations. Development of the Field Test Data and Analysis Required to:
  - Safely Change the ICAO Definitions for WV Separations Standards
  - Provide the Systems Engineering Data Necessary for the FAA to make a Favourable Acquisition Investment Decision for Full Scale Development of an Aircraft Wake Vortex Avoidance System

  WakeVAS key elements are to:
  - Establish the need for change to existing wake vortex standards
  - Define WakeVAS ConOps, Operational Requirements, and Systems Specifications & Analyze Impact to Existing Standards and Regulations
  - Develop, Refine, and Validate Active Wake Vortex Predictor (AVOSS+) to meet selected ConOps Operational Requirements
  - Deploy WakeVAS, Collect Long-term In-Service Data, and Assess Performance (Actual vs Projected)
  - Conduct and Articulate Safety Analysis/Hazard Assessment
  - Manage the project/collaborate with national & international partners

  The interface of a Wake VAS system into the NAS will be accomplished through the implementation of decision support system (DSS) and automation tools. These may include approach spacing tools to provide sequencing, spacing, and runway assignment of aircraft on final approach to congested airports; including refined considerations for wake vortex and specific aircraft characteristic algorithms. Information display techniques will integrate surface, terminal, and wake vortex information into a simplified format to support departing and arriving traffic sequencing. The controller, traffic flow managers, airline operation centers, pilots, and other NAS users will have access to the same DSS and automation tools, which will enable a collaborative decision making capability. Controller-pilot data link communications (CPDLC) service supporting air-ground data exchange used in conjunction with advanced cockpit displays may allow pilots to fly self-separation manoeuvres during IFR conditions in the terminal area.

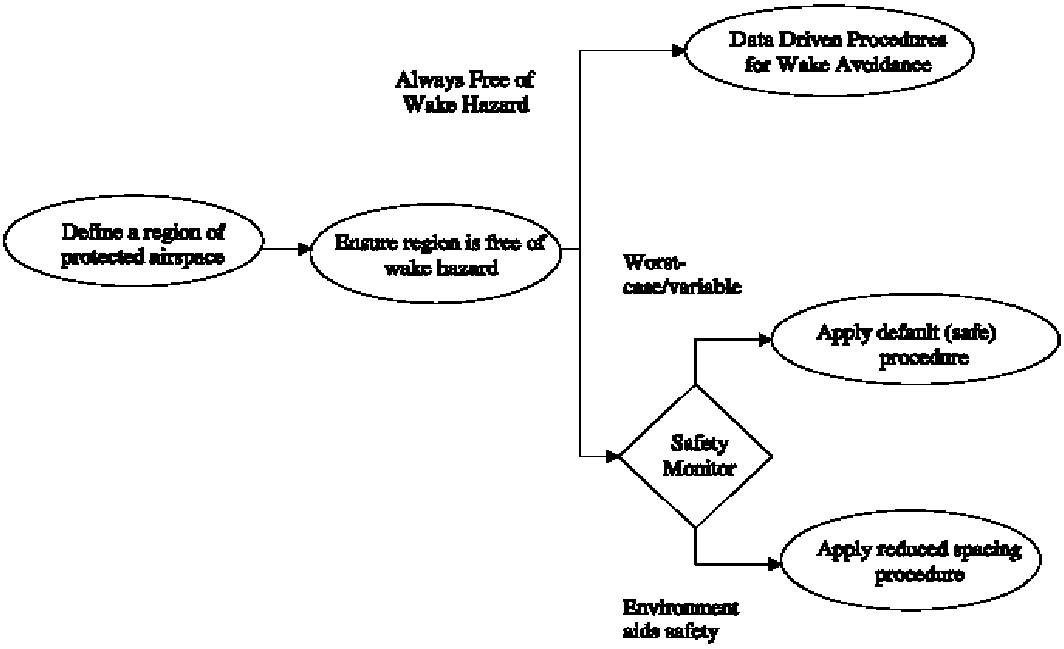


Figure 3 – Wake VAS Functional Block Diagram

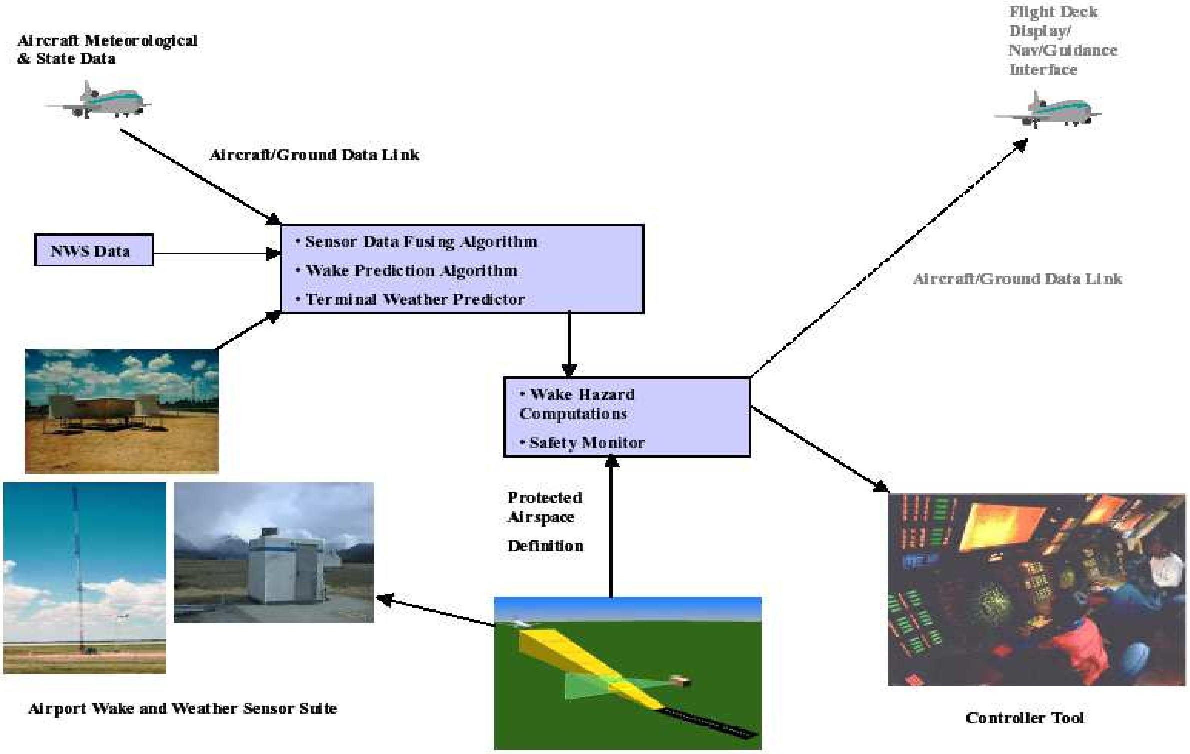
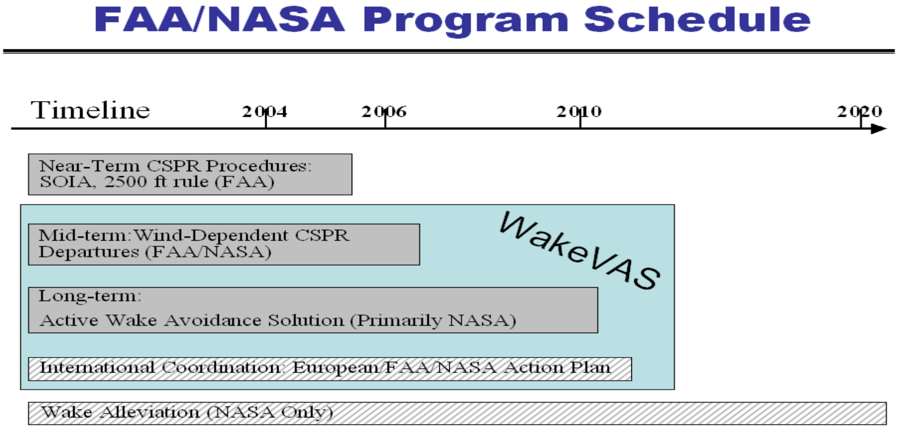


Figure 4 – WAKE VAS System Architecture

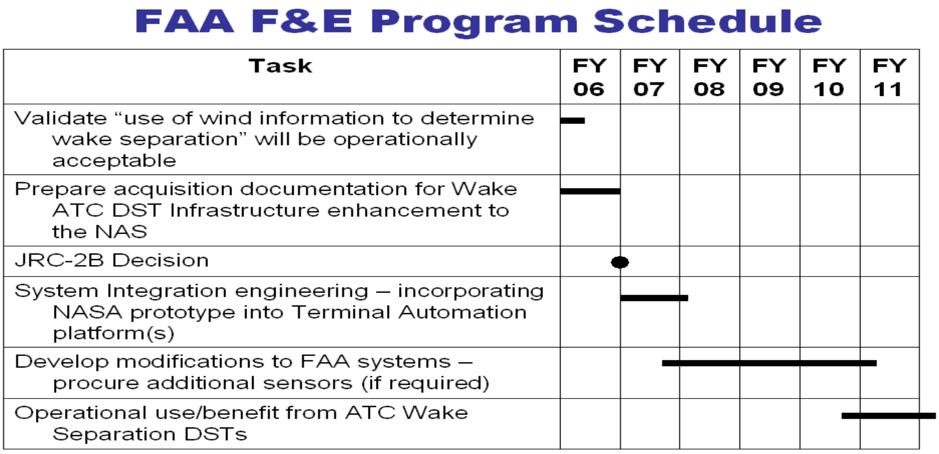
- **NASA Pulsed-Doppler 35 GHz radar** has been designed and assembled for wake vortex detection and tracking in low visibility conditions. The NASA AVOSS project has demonstrated that Lidar systems can be successfully used to detect and track vortices in clear air conditions. *To fill the need for detection capability in low-visibility conditions*, a 35 GHz, pulsed-Doppler radar system is being investigated for use as a complimentary, low-visibility sensor for wake vortices. The radar sensor provides spatial and temporal information similar to that provided by Lidar, but under weather conditions that a Lidar cannot penetrate. Currently, NASA is analyzing the radar design based upon the data and experience gained during the wake vortex Lidar deployment with AVOSS at Dallas/Fort Worth International Airport. Simulations applying pulse compression techniques show that detection is good in heavy fog to greater than 2000 m. Simulation results indicate that excellent wake vortex detection, tracking and classification is possible in drizzle (+15 dBZ) and heavy fog (- 13 dBZ) using short pulse techniques (99ns) at ranges on the order of 900 m, with a modest power of 500 W output. At 1600 m, detection can be expected at reflectivities as low as -13 dBZ (heavy fog). The radar system has the potential to support a wake vortex spacing system in low-visibility conditions ranging from heavy fog to rain, when sited within 2000m of the flight path.

- **Volpe National Transportation Systems Center (Volpe Center) Wake Vortex Program**: A general summary of Volpe Center accomplishments during a long history of effort on the wake vortex problem include the following: developed techniques for detecting and tracking vortices: the Laser Doppler Velocimeter (LDV), the Monostatic Acoustic Vortex Sensing System (MAVSS), and the Ground Wind Vortex Sensing System (GWVSS); extensive test programs at Chicago's O'Hare International Airport, New York's John F, Kennedy International Airport, and other test sites, utilization of a variety of sensors to measure the behaviour of vortices generated by arriving and departing aircraft; measured and classified the vortices generated by rotorcraft. More recent Volpe Center accomplishments are: the set up GWVSS with unattended data collection system at Memphis Airport to support development of the NASA Aircraft Vortex Spacing System (AVOSS); the participation in a cooperative effort with NASA Langley at the FAA/Volpe Center Vortex Test Site at JFK International Airport to evaluate a number of potential wake vortex sensors; development of a cooperative effort with National Oceanic and Atmospheric Administration for the acquisition, review, and analysis of the 1990 Idaho Falls tower fly-by vortex data; validation testing, using the Volpe Center GWVSS at JFK International Airport, to provide ground truth for the testing of a Radar Acoustic Sensing System for the detection of wake vortices; maintenance and operation at the JFK GWVSS to obtain vortex transport data; testing at JFK International Airport to characterize jet blast profiles; testing at LaGuardia International Airport to resolve wake vortex related issues concerning crossing runway operations.



FAA/NASA Program Schedule

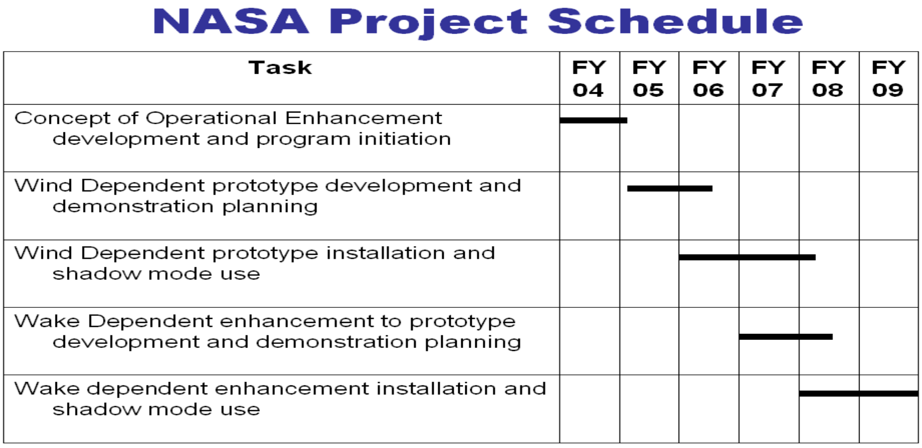
Figure 5 – NASA/FAA Program Schedule related to Wake Vortex



FAA F&E Program Schedule

Task	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11
Validate "use of wind information to determine wake separation" will be operationally acceptable	▬					
Prepare acquisition documentation for Wake ATC DST Infrastructure enhancement to the NAS	▬					
JRC-2B Decision		●				
System Integration engineering – incorporating NASA prototype into Terminal Automation platform(s)		▬				
Develop modifications to FAA systems – procure additional sensors (if required)		▬	▬	▬	▬	
Operational use/benefit from ATC Wake Separation DSTs					▬	▬

Figure 6 – FAA Program Schedule related to Wake Vortex



NASA Project Schedule

Task	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09
Concept of Operational Enhancement development and program initiation	▬					
Wind Dependent prototype development and demonstration planning		▬	▬			
Wind Dependent prototype installation and shadow mode use			▬	▬		
Wake Dependent enhancement to prototype development and demonstration planning				▬	▬	
Wake dependent enhancement installation and shadow mode use					▬	▬

Figure 7 – NASA Project Schedule related to Wake Vortex

4 ATC-Wake Operational System

4.1 ATC-Wake Operational Concept

The ATC-Wake Operational System has been defined to provide the following services:

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

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

- ICAO Standard Separation
- ATC-Wake (reduced) separation

Based on meteorological conditions, ATC-Wake advises the ATC Supervisor on applicable separation mode and associated validity period (start / end). The ATC Supervisor has the responsibility to decide upon 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 Wake Vortex 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. Not only the prediction of the wake vortex 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 wake vortex 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 min. To ensure these functions, the ATC-Wake Operational System has been designed with four new ATC-Wake components: Separation Mode Planner, Predictor, Detector, and Monitoring and Alerting. These new components will interface with several existing and/or enhanced ATC system components, including arrival managers, flight data processing systems, and surveillance systems, meteorological systems, and existing HMIs.

4.2 Functional Description of the ATC-Wake Operational System

The ATC-Wake Operational System includes four new functional components:

- **ATC-Wake Separation Mode Planner**: Determines the applicable separation mode (ICAO mode or ATC-Wake mode) and advises about aircraft separation minima.
    - Determination of separation mode is based on meteorological and “general” wake vortex forecast (e.g. wind profile picture and expected “worst case” pairing. 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.*
- **ATC-Wake Predictor**: Predicts for individual aircraft the Wake Vortex behaviour (“wake vortex vector”) in the pre-defined arrival or departure area(s). Advisory includes expected time for future mode transitions, indication of aircraft separation minimum applicable.
    - Prediction is performed using real-time available meteorological 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 Wake Vortex prediction is directly related to the quality of input data (meteorological data, radar data). A safety buffer has to be applied to satisfy accuracy requirements of ATC users.
    - These data consist of the most recent meteorological *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 Wake Vortex behaviour of preceding aircraft.
- **ATC-Wake Detector**: Detects for individual aircraft the WV position, extent (“wake vortex vector”) and – if possible – also its strength in the pre-defined arrival or departure area(s).
    - Detection is performed using ground-based equipment (e.g. pulsed LIDAR) which scans pre-defined parts of the considered critical area (e.g. ILS glide path) in pre-defined windows.
    - No connection to airborne equipment is assumed but detection may be complemented using airborne equipment (see I-Wake project)
- **ATC-Wake Monitoring and Alerting**: Alerts ATCO in case of significant deviation between WV detection and Wake Vortex prediction information which raises the risk of Wake Vortex encounter, or failure of one or several WV components

  - This component plays the role of a “safety net” for ATC-Wake operations, its design is kept simple (no connection to airborne equipment is assumed, no use of aircraft behaviour model for WV encounter is assumed)

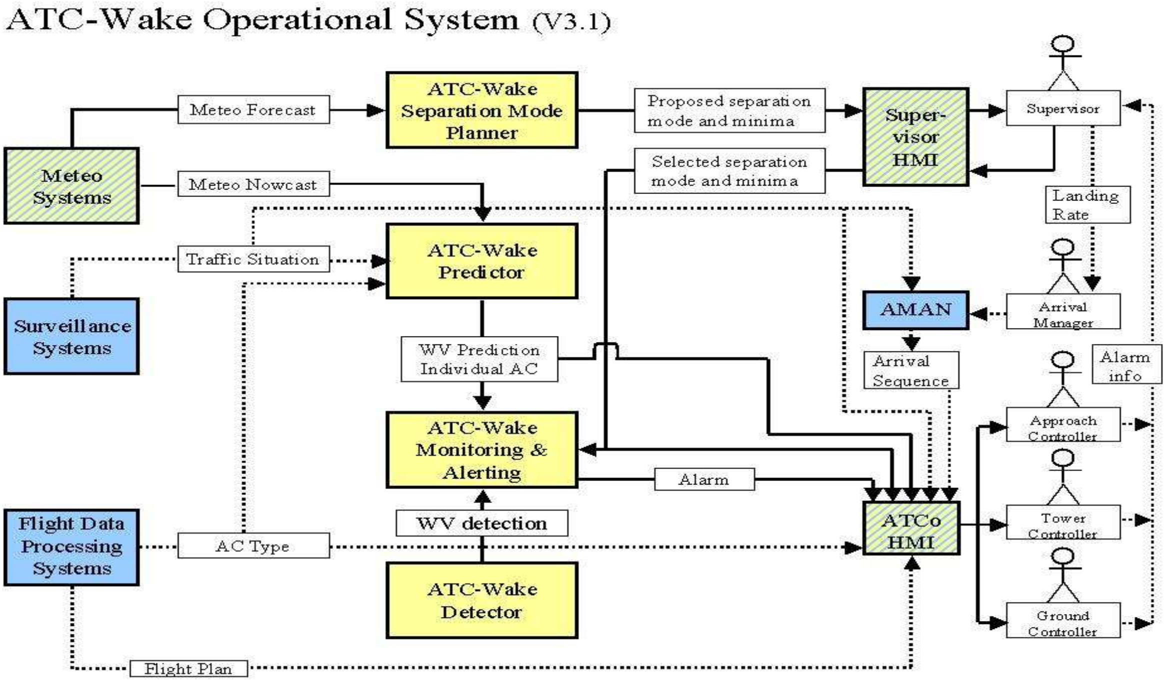
These new components are integrated with existing ATC systems, including:

- **Arrival Manager (AMAN):** Determines automatically optimum arrival sequence and provides advises for realising this sequence. Communicates forecast sequence upstream to en-route and / or approach ATSUs.
  - It assists in scheduling traffic from TMA entry (Initial Approach Fix) to runway.
  - Sequencing is based on the landing rate (which will depend on ICAO or ATC-Wake separation mode) decided by ATC Supervisor.
- **Flight Data Processing System:** Keeps track of every flight and updates flight information, in particular the flight plan, the trajectory prediction, ETA and ETD, aircraft type and equipment.
- **Surveillance Systems (including primary/secondary radar)**: Provides and maintains the air traffic situation picture using all available detection means (radars, air-ground data links).

Enhanced ATC systems linked with new components are the following:

- **Meteo Systems**: Provides Weather Forecast information for the Separation Mode Planner for planning operations, and Weather Nowcast for the Wake Vortex Predictor for tactical operations.
  - This information could come from National Weather providers and from co-localized weather sensors.
  - For the Meteo systems, enhancements in prediction and update rates are foreseen.
- **Supervisor HMI**: Separation mode and minima proposed by the Separation Mode Planner is presented to the Supervisor via the Supervisor HMI. The Supervisor then decides on appropriate landing rate. The landing rate is provided to the Arrival Manager.
- **ATCo HMIs**: Provides the traffic situation picture and automated support for various ATCo tactical roles (Approach, Tower).
  - A generic component is used in the context of ATC-Wake but specialisation exists depending on ATCo role.
  - It is foreseen to integrate Wake Vortex related information together with flight information (position, altitude, ground speed, aircraft type)
  - HMI's for supervisor and ATCo have been extended with the ATC-Wake symbology.

In Figure **8** of the ATC-Wake operational System, the new components are in yellow, the existing ATC systems in blue and the enhanced systems in a combined blue and yellow box. This figure shows all relations between the different components.



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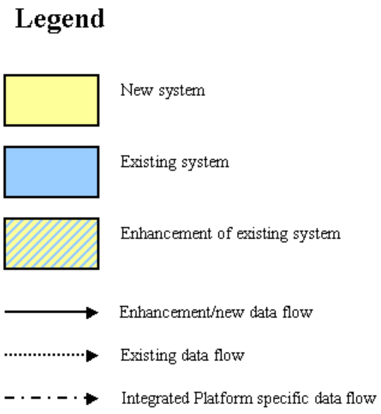


Figure 8 – Functional flow of ATC-Wake Operational System

4.3 Use Cases of ATC-Wake Operational System

The different use cases of the ATC-Wake Operational System are:

- ***Separation Mode Planning Use Case***: The ATC Supervisor is the decision-maker for the separation mode and minima 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).

- ***Separation Mode Transition (between ICAO and ATC-Wake modes) Use Case:*** This event takes place at least 40 min before the actual application of the separation mode to the arrival or departure traffic. Information to be provided by the ATC-Wake Separation Mode Planner includes the separation mode, the separation minima, the time to start application and the (estimated) validity of the selected mode.
- ***Intermediate and Final Approach Use Case:*** The Approach and Tower controllers are provided with WV prediction information when aircraft is in the "critical area". At this point the Approach Controller receives visual confirmation of the correct spacing between the aircraft. The Tower Controller is in charge of the final approach phase, i.e. has to monitor that separation is maintained along the entire glide path. Visual confirmation of the WV “danger area” is kept up to date using meteorological information and short term predictions. Actual WV behaviour is determined by the ATC-Wake Detector and provided to the ATC-Wake Monitoring and Alerting, in order to detect potential discrepancies between detection and short term prediction and raise the appropriate alarm to the concerned Air Traffic Controllers.
- ***Departure Use Case:*** The Ground Controller is in charge of preparing a departure sequence based on the aircraft separation mode information and the departure rate decision made by ATC Supervisor. The Tower Controller is provided with WV prediction information (visualisation of “danger area”) when aircraft start rotating and during the initial climb phase. Actual WV behaviour is determined by the ATC-Wake Detector and is provided to the ATC-Wake Monitoring and Alerting, in order to detect potential discrepancies between detection and short term prediction and to raise the appropriate alarm to Tower Controller.

These four Use Cases are depicted in the following Figures 9 until 12.

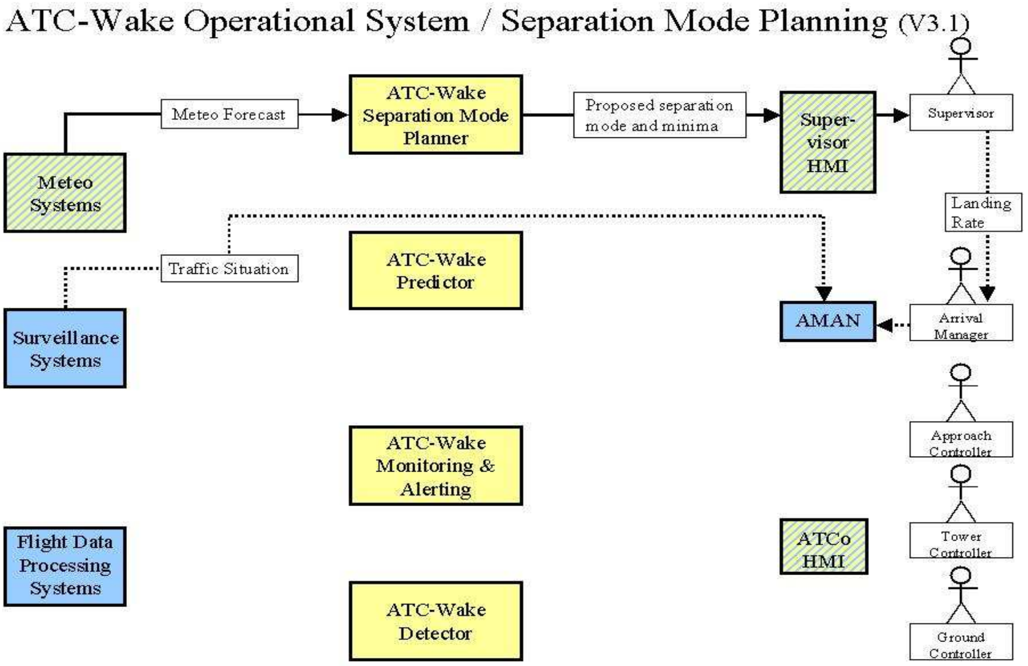


Figure 9 – Functional flow of ATC-Wake Operational System for use case 1, separation mode planning

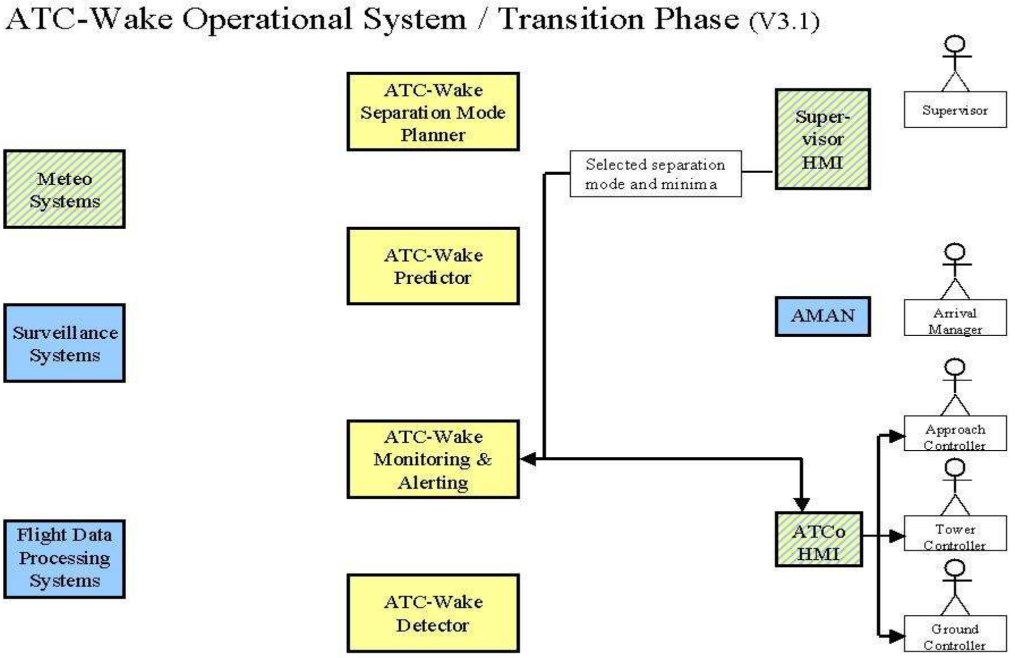


Figure 10 – Functional flow of ATC-Wake Operational System for use case 2, transition phase

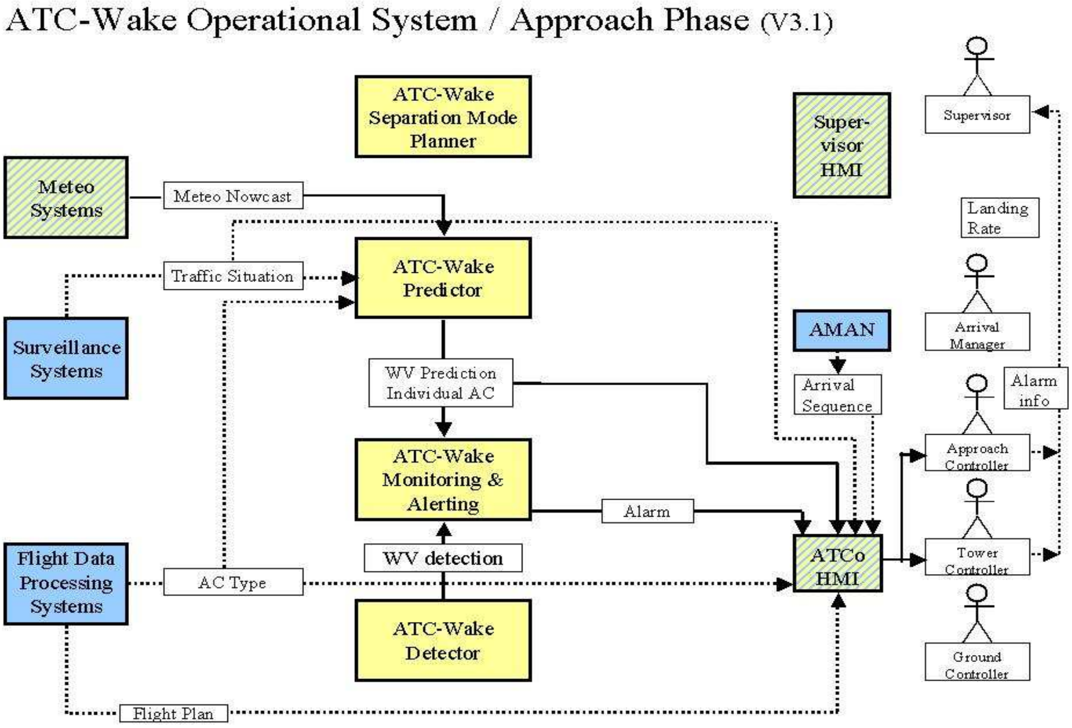


Figure 11 – Functional flow of ATC-Wake Operational System for use case 3, approach phase

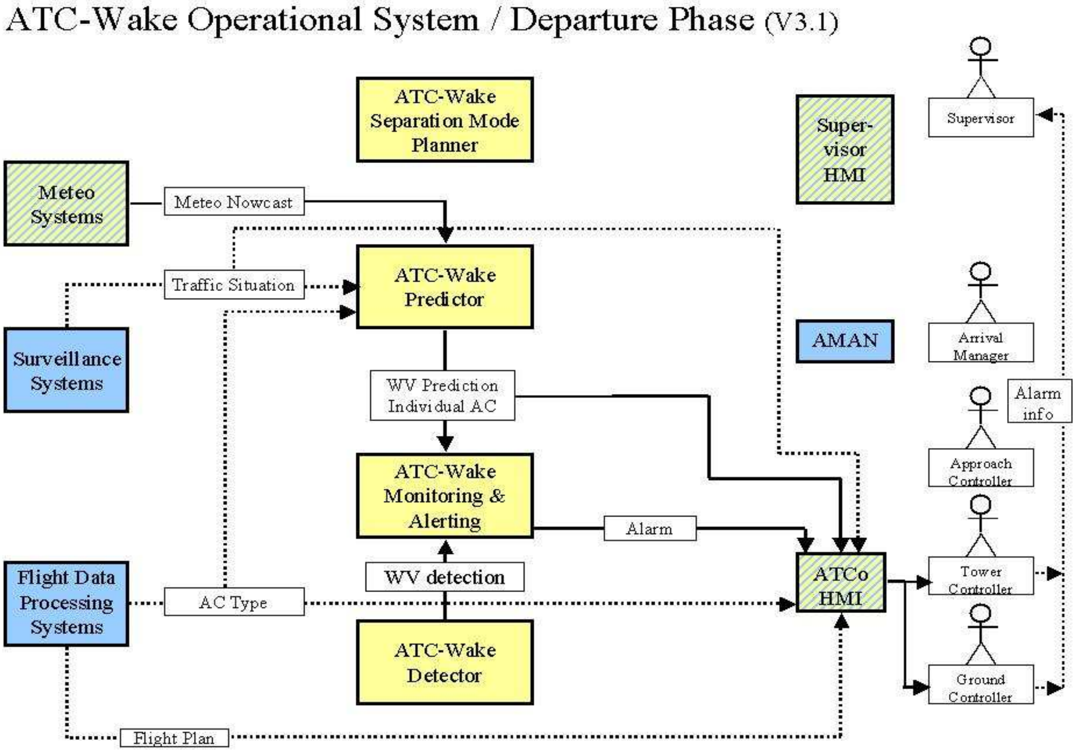


Figure 12 – Functional flow of ATC-Wake Operational System for use case 4, departure phase

5 ATC-Wake Components

5.1 ATC-Wake Separation Mode Planner

The Separation Mode Planner advises the ATC Supervisor on the applicable separation mode (either ICAO or ATC-Wake) and separation minima to be applied in a certain time frame. This concerns separation minima for single runway departures, single runway arrivals and closely spaced parallel runway arrivals. In ICAO separation mode the ICAO wake vortex separation minima are to be followed, while in ATC-Wake separation mode reduced separation may be applied. This advice is used by the ATC Supervisor to decide on the arrival and departure rates to be applied. In making this decision, the traffic demand and the ATC and airport resource availability are also taken into account. The advice is based on meteorological forecast data and runway layout in combination with WAVIR safety assessment results for worst-case combinations of leader / follower aircraft pairs.

The advice includes the expected time for future mode transitions. The time horizon to be considered for adaptations of the separation mode is the time elapsed from holding stacks to runway (minimum 10 min), considering also the time necessary to establish the arrival sequence. Therefore, changes of the separation mode have to be decided with a minimum look ahead time of 40 min if an Arrival Manager (AMAN) is used or 20 minutes if no AMAN is used, plus/minus a buffer *determined at local implementation.* The refreshment rate required for ATC operations is approximately 10 min: if a significant change is observed and the concerned aircraft have not started the final approach (10 min before landing).

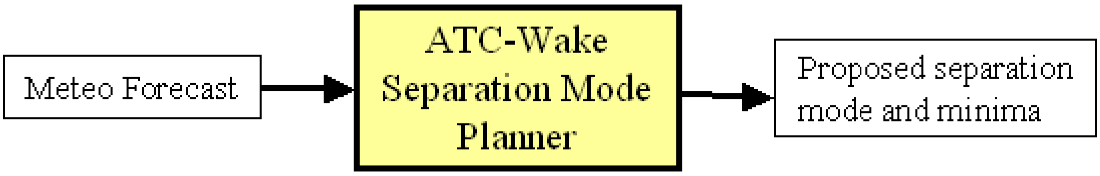
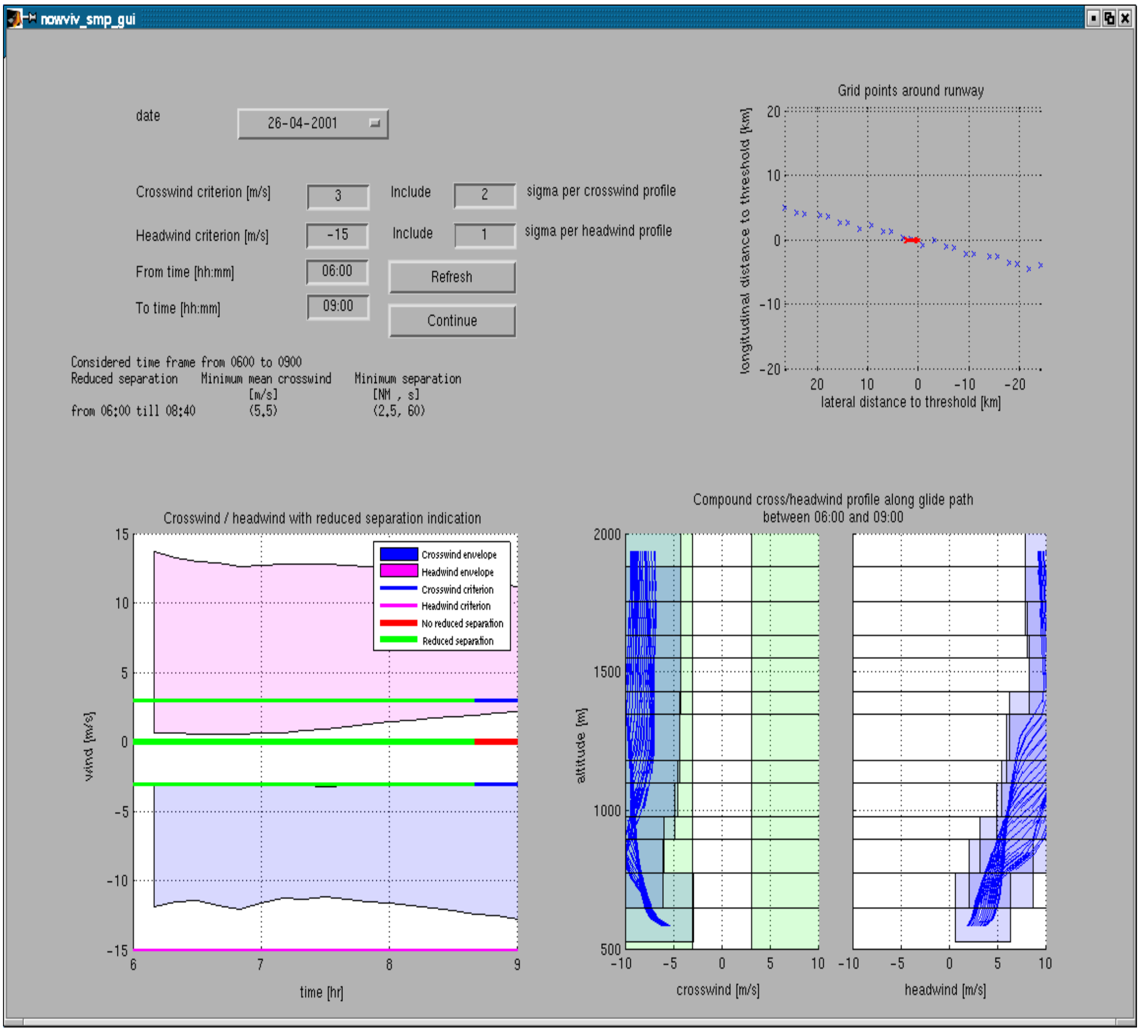


Figure 13 – Separation Mode Planner Component

The Separation Mode Planner uses weather forecast data as input provided by a *Weather forecasting* system (such as NOWVIV), which requires weather forecast information from e.g. the national weather service. For an improvement and correction of the model forecast, locally measured data are assimilated. The SMP further uses results obtained with the Wake Vortex Induced Risk assessment tool-set (WAVIR). The simulation results are used by the SMP to look up separation mode and minima to be recommended to the ATC Supervisor (for the forecasted meteorological conditions). WAVIR simulations are not carried out real-time, but have been carried out (off-line) for a variety of scenarios. The scenarios mainly vary in leader and follower aircraft types, weather and wind conditions and operational aspects.

On start-up of the SMP, the available weather data is checked and the SMP will display the results and associated separation advice for the selected time frame. The SMP provides the Supervisor with an advice on the time window within which reduced separation (i.e. ATC-Wake separation mode) can be applied safely. Outside the proposed time window, it is advised to apply ICAO separation mode with ICAO wake vortex separation standards. The SMP advice is presented on the Supervisor HMI as illustrated in Figure 16.



nowviv_smp_gui

date: 26-04-2001

Crosswind criterion [m/s]: 3 Include 2 sigma per crosswind profile

Headwind criterion [m/s]: -15 Include 1 sigma per headwind profile

From time [hh:mm]: 06:00

To time [hh:mm]: 09:00

```
Considered time frame from 0600 to 0900
Reduced separation    Minimum mean crosswind    Minimum separation
                             [m/s]                   [NM , s]
from 06:00 till 08:40        (5.5)                   (2.5, 60)
```

Figure 14 – SMP advice for selected time frame with crosswind criterion

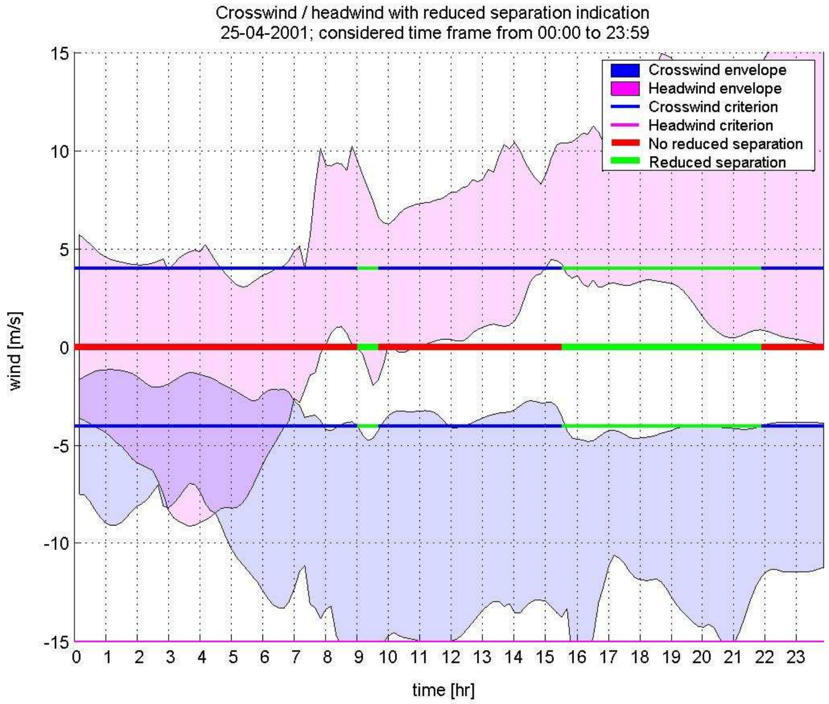


Figure 15 – Example of SMP result (based on NOWVIV wind profiles) : ICAO separation Time Frames (in Red) and ATC-Wake reduced separation Time Frames (in Green)

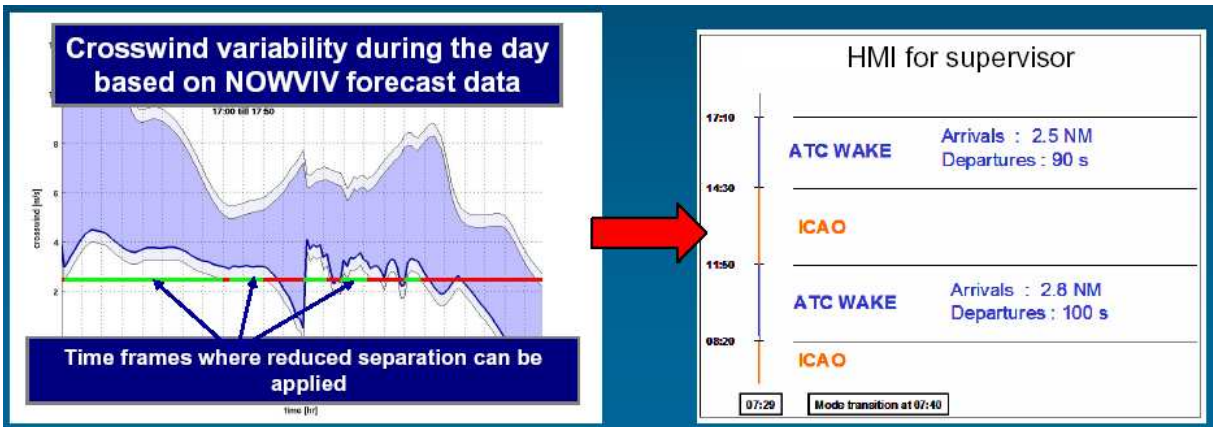


Figure 16 – Example ATC-Wake separation time frames provided by SMP and their display on Supervisor HMI for landing rate decision making for the next 40 minutes

5.2 ATC-Wake Predictor

The Predictor provides information to achieve two objectives:

1. to prevent WV encounters;
2. to allow the optimal use of runway throughput.

Aircraft separation standard refers to ICAO Recommendations, in addition local adaptation have been defined to take benefit of situations where WV develops outside the glide path. The accuracy of information generated by the Predictor covers properties of predicted WV behaviour within the critical arrival / departure areas. The stability covers the associated timeframe to prediction. 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). To the Tower Controller, Wake Vortex Predictor provides WV visualisation information to confirm minimum separation distance.

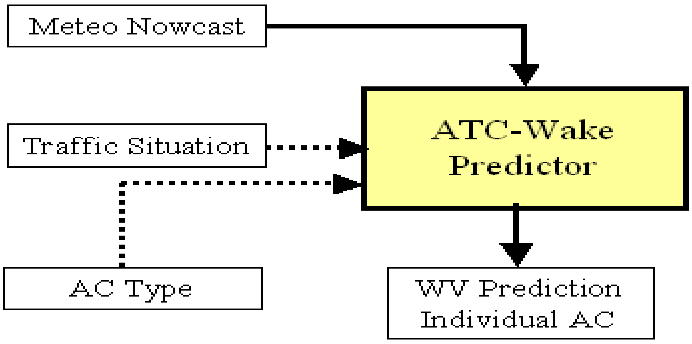


Figure 17 – Wake Vortex Predictor Component

Locally measured meteorological data are used as much as possible by the *Wake Predictor.* The *Weather Data Analyser, from Weather Systems,* provides best-guess meteorological fields combining data from the various measurement sensors (*Weather Data, Radar Data Processing: Wind field estimated by "SKEWIND"*) and *Weather Forecasting.* Weather forecast data will be needed to fill in regions of sparse observational data. The *Wake Predictor* requires as further input *airport data* and actual *aircraft data.*
The Predictor relies on the real-time prediction of wake vortex (WV) behaviour: transport and decay. Wake Vortex prediction models take into account the aircraft types (span, weight), the flight conditions (position, velocity and trajectory), the weather conditions along the glide slope (cross-wind and head wind profiles, thermal stratification profile, turbulence profile). The effects of wind shear (significant vertical variation of the wind profile) on transport and decay are also modelled. The ground proximity conditions are also taken into account: in viscid near ground effects (NGE); viscous in ground effects (IGE) where secondary vorticity is produced at the ground and has significant effects on WV transport and decay.

In ATC-Wake, two main European real-time models are being used (and further developed and validated): ***the "Probabilistic use of the Vortex Forecast System (P-VFS)"*** and ***the "Probabilistic Two-Phase Decay" model (P2P).*** The P2P and the P-VFS are wake vortex predictors based respectively on probabilistic and deterministic approach. Both of them deal with input uncertainties to determine the ranges of possible Wake Vortex lateral, vertical and axial locations as well as the possible ranges of Wake Vortex strength and, if necessary, the range of core radius size. Each range (and their time evolutions) is determined as follows:

Probabilistic approach (P2P):	P2P's model equations are derived from the solution of the spatio-temporal circulation evolution of a decaying potential vortex and are adapted to wake vortex behaviour. P2P provides confidence intervals for vortex position and strength. This is achieved by performing three subsequent runs with variations of the decay parameters and adds uncertainty allowances which depend on ambient turbulence and wind shear.
Probabilistic VFS (P-VFS):	The VFS is a deterministic Wake Vortex Predictor based on the method of discrete vortices (discrete "vortex particles"). Vortex particles are used to model: the aircraft vortices (the "primary" vortices), the "secondary " vortices generated near the ground when IGE. The VFS produces one deterministic Wake Vortex prediction (transport and decay) in each "computational gate" (a vertical 2-D slice of space), taking into account the generator aircraft type (span, weight), speed and altitude. The P-VFS is an upper software layer, for operational "probabilistic use of the VFS". It is based on Monte Carlo type simulations (many VFS runs) using the uncertainties/variations of the aircraft generator parameters, of the input weather profiles, and of the models coefficients.

The crossing of the data provided by those sources can be conducted in two different ways:

- The data are merged. The outputs ranges considered are the unions of the ranges defined by the P2P and the VFS-Module
- The forecasting of one WV predictor is confirmed by the results of the other one. If discrepancies occur, the predictions are considered as not reliable.

The P2P approach is different than the P-VFS. Yet, the purpose (probabilistic assessment of WV transport and decay) is similar: they output confidence intervals for vortex position and strength. In ATC-Wake, both modelling approaches are considered complementary. Their joint use further increases the level of confidence on the Wake Vortex behaviour probabilistic prediction, and thus enhances the quality of the information provided to the ATC controllers.

Both Wake Vortex Predictors P-VFS and P2P take into account:

- ***Transport*** (vortex-induced velocities, cross and head-wind velocity profiles, stratification effects, wind shear effects
- ***Critical demise time and decay*** (based on EDR and/or TKE, “two-phase” decay models, “accumulated damage” models, sensitive to stratification and wind shear effects)
- ***Ground effects*** (models for inviscid Near Ground Effect “NGE”, models for viscous in Ground Effect “IGE”)

The output data of the two predictors can also be considered separately. The risk assessment is conducted for every predictor output as if each set is used independently. This allows an individual evaluation of the integration of every predictor in ATC-Wake.

The ATC-Wake Predictor uses input data from:

- Weather monitoring/now-casting systems (based on NOWVIV and SKEWIND tools that will be described hereafter)
- Airport surveillance systems (more particularly, primary/secondary ATC radar & Baro-Altimeter data)
- Flight data processing systems (for the simulation purpose, traffic on airport has been emulated by TAAM simulator)
- Databases about Airport layout (runways) and Aircraft Characteristics (span, weight). In ATC-Wake, the various data providers are emulated

The Wake Vortex prediction models take into account:

- Aircraft types (span, weight)
- Flight conditions (position, velocity and trajectory)
- Weather conditions along the flight track (cross-wind and head-wind profiles, thermal stratification profile, turbulence profile)
- Wind Shear effects (significant vertical variation of the wind)
- Ground proximity effects: near ground effects (NGE) and in ground effects (IGE, where secondary vorticity produced at the ground affects Wake Vortex transport and decay).

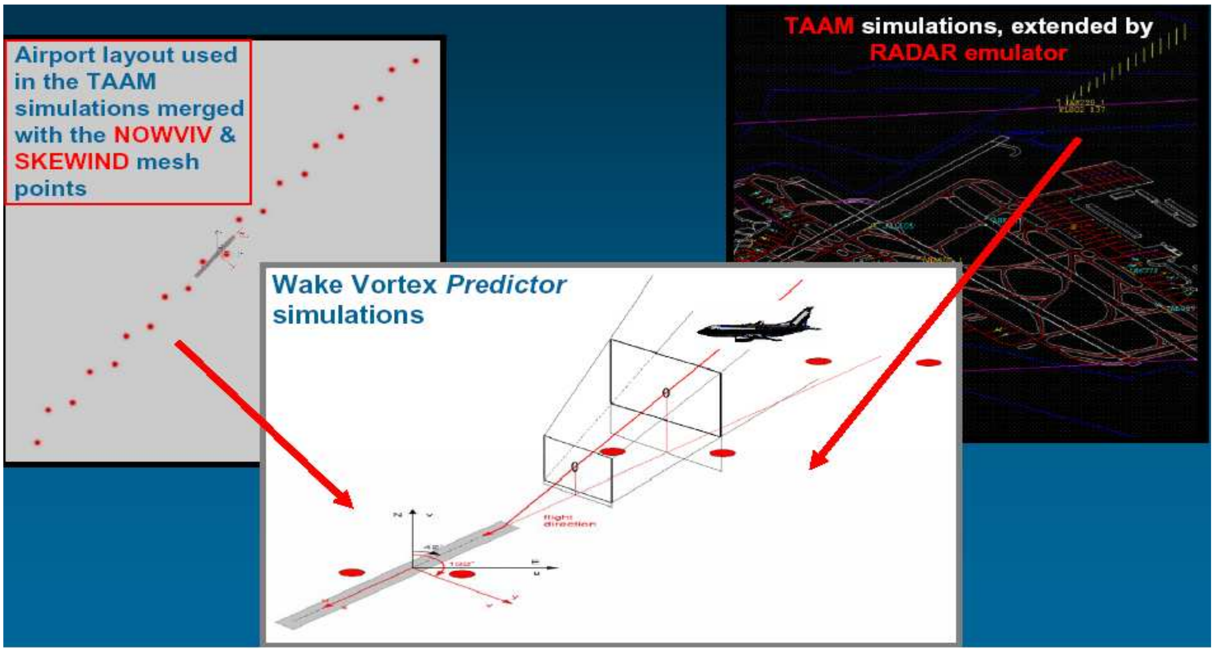


Figure 18 – Wake Vortex Predictor in Airport Geographic Reference system

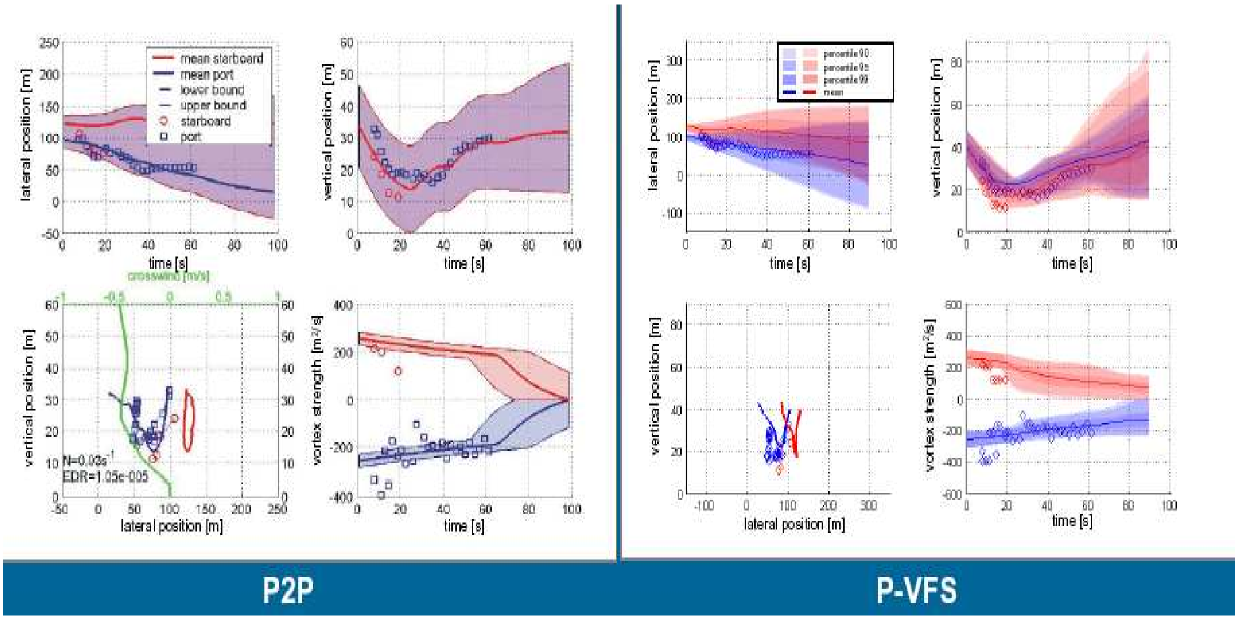


Figure 19 – Comparison between P2P (at left) and P-VFS (at right) Wake Vortex Prediction

The Wake Vortex Predictor handles P2P and P-VFS probabilistic simulations and assessments for all gates corresponding to all aircraft in the airport area (the computation gates being created every 6 seconds). The time evolution of the "3D danger volume" in which the Wake Vortex could be found is provided by a proper reconstruction of the complete Wake Vortex Situation, using all dynamic gates and a 3D space-time reconstruction.

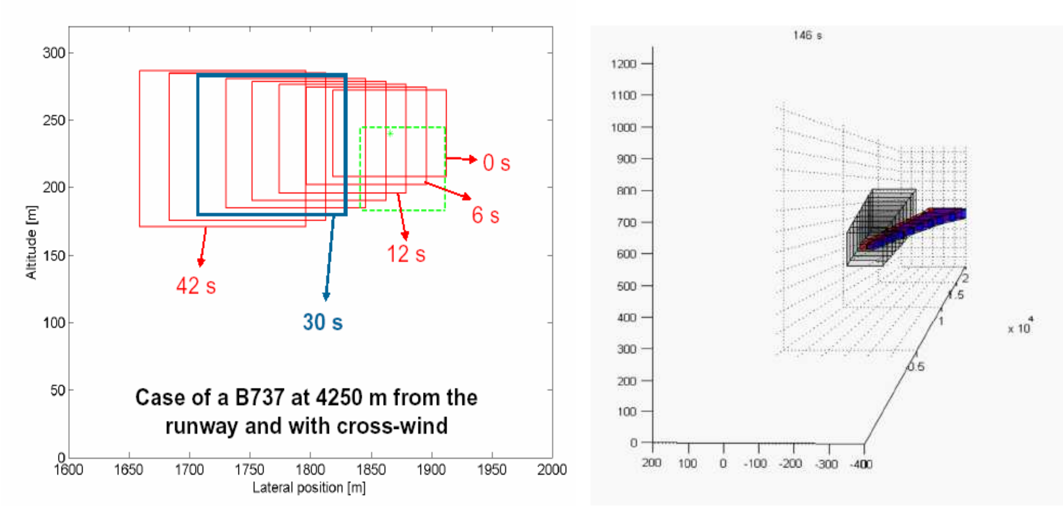


Figure 20 – Example of Danger Volume Evolution by Wake Vortex Predictor

The output of the Wake Vortex Predictor is the “Wake Vortex Vector” (WVV) of an aircraft in the so-called critical area. The length of the Wake Vortex is defined as the distance between the generator aircraft and the first gate considered as “Vortex Free”. This information is presented as an enhancement on the Plan View Display (PVD) showing the information received from the airport radars, combined with flight track data (call sign, aircraft type height, speed, etc.). Because the WVV is only calculated in the critical area, only changes to the PVD of the Final Approach controller and Tower controller are foreseen. The representation of the WVV on the air traffic controllers displays is discussed in Section 6.

5.2.1 P2P Predictor

A detailed description of P2P is given in Holzäpfel (2003). P2P accounts for the effects of wind, turbulence, stable thermal stratification, and ground proximity where the interaction with the ground is modelled following the approach described in Robins et al. (2001). Input data that characterise the wake vortices are time of vortex generation and initial position, circulation, and vortex spacing. Environmental input parameters are vertical profiles of crosswind, vertical wind, rms value of ambient turbulence, eddy dissipation rate (EDR), and potential temperature.

Precise deterministic wake vortex predictions are not feasible operationally. Primarily, it is the nature of turbulence that deforms and transports the vortices in a stochastic way and leads to considerable spatiotemporal variations of vortex position and strength. Moreover, uncertainties of aircraft parameters and the variability of environmental conditions must be taken into account. Therefore, P2P is designed to predict wake vortex behaviour within defined confidence intervals.

The employed uncertainty allowances largely depend on the quality of the measured/ predicted environmental conditions and their variability. The completeness and accuracy of these input parameters determine the width of the predicted confidence intervals. In principle, P2P predictions based on a very limited set of parameters (i.e. aircraft type and crosswind velocity) are feasible. However, in that case the uncertainty allowances of the predictions will be large. With increasing accuracy and completeness of input parameters the uncertainty allowances can be minimised. A final adjustment of the probabilistic components that consider site specific instrumentation and prediction tools will be necessary to find the optimum balance between capacity increase and safety demands.

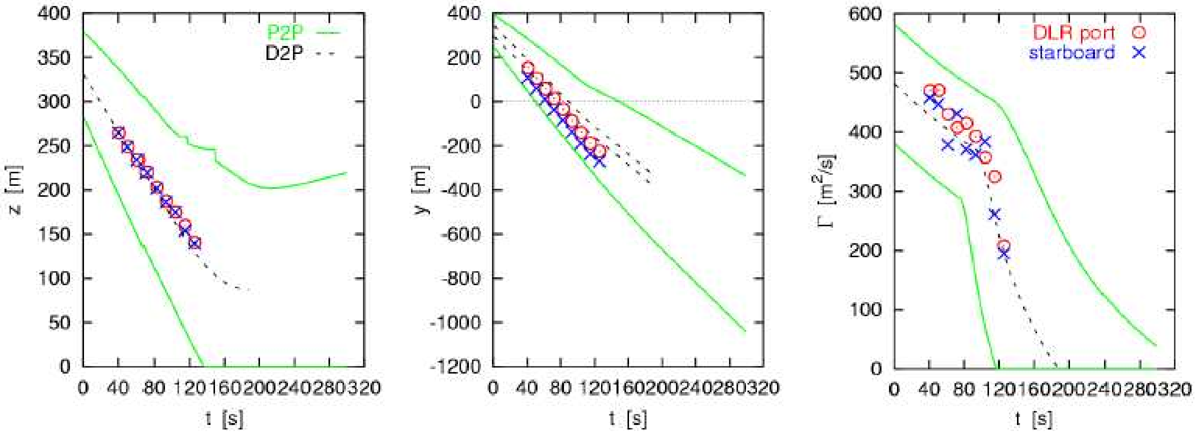


Figure 21 – Example of P2P Wake Vortex Prediction, measured (symbols) and predicted (lines) evolution of vertical and lateral positions, and circulation of wake vortices; deterministic behavior (dash) and probabilistic envelope (solid)

5.2.2 P-VFS Predictor

The VFS uses real-time information about the environment and the aircraft, predicted meteorological conditions, and accurate real-time modeling of vortex transport and decay to predict conditions under which the separation may be safely reduced below the current wake vortex standards. The principal components of the VFS are the Near Wake Database (NWDB), the Far Wake and Danger Area Models. Only the Far Wake Model is available for the ATC-Wake project. The far wake evolution is calculated in real-time. It may start from the NWDB, or alternately from the universal near wake profile (what is used in ATC-Wake). The calculations are based on the 2-D cross-plane method of discrete vortices equations describing the vortex motion in incompressible flow. The model includes:

- near ground and in ground effects;
- non-uniform wind shear effects;
- eddy dissipation rate (EDR) and turbulent kinetic energy (TKE) decay modeling;
- supplemental small effective viscosity coefficient; and
- calculation of time-to-demise (time of abrupt decay in two-phase decay model).

Stratification modeling has been implemented. The different decay parameterizations used in the VFS are described in the “Overview of the Wake Vortex Prediction” (Jackson et al, 2001). Comparisons between the VFS simulations and wake vortex measurements, illustrating the different models, have already been realized and are described in the ATC-Wake deliverable D1_2 (Treve and Winkelmans, 2002). The weather input VFS requires profiles of wind, temperature and turbulence. Those profiles have to be provided for each part of the glide slope (initial climb area). For the wind profile, VFS requires at least a vertical grid of 50 m (less when discretizing sharp wind variations, vertical spacing may be variable). The temperature measurement or forecasting provides two temperature profiles that are characteristic of the extreme situations susceptible to occur. The turbulence measurements or forecasts may be provided as TKE (Turbulence Kinetic Energy) or EDR (Eddy Dissipation Rate) profiles. However, if the profiles are not available, single characteristic value of the atmosphere can also be used. Each meteorological profile is complemented with information about its uncertainty. This uncertainty can result from the measurement tools performance, the forecasting models, the distance from the measurement plane, the mesh and boundary conditions used for the forecasting, etcetera.

The VFS produces one deterministic WV prediction (transport and decay) in each “computational gate” (a vertical 2-D slice of space), taking into account the generator aircraft type (span, weight), speed and altitude. All models are implemented using an “accumulated damage” approach, so as to capture the variations of the input profiles with altitude. The evaluation of the “demise time” uses the formulation based on the atmospheric turbulence (using the “eddy dissipation rate”, EDR) but modified for stratification effects, following. Two decay models are implemented: an EDR-based model and a TKE-based model (“turbulence kinetic energy”). A two-phase decay approach is used in VFS, this is done by increasing the coefficient in the decay model after the demise time has been reached.

It is essential to also recognize the probabilistic/stochastic aspects of WV behaviour. This is especially true for complex aspects such as WV behaviour IGE, behaviour under wind shear conditions, determination of demise time,, and two-phase decay modelling. A probabilistic modelling and assessment is required. An upper software layer was thus developed by UCL, for probabilistic use of the VFS: the “P-VFS”: it is based on Monte Carlo simulations (many VFS runs) using the uncertainties/variations of the aircraft generator parameters (weight, speed, position), of the input weather profiles, and of the coefficients in the physical models. The VFS Module forecasts the displacement and the persistence of the vortices produced by a defined aircraft category all along the glide. *Using the above described input data, VFS computes all possible wake vortex displacements considering the variability of the inputs for both the SMP and WVP operation.*

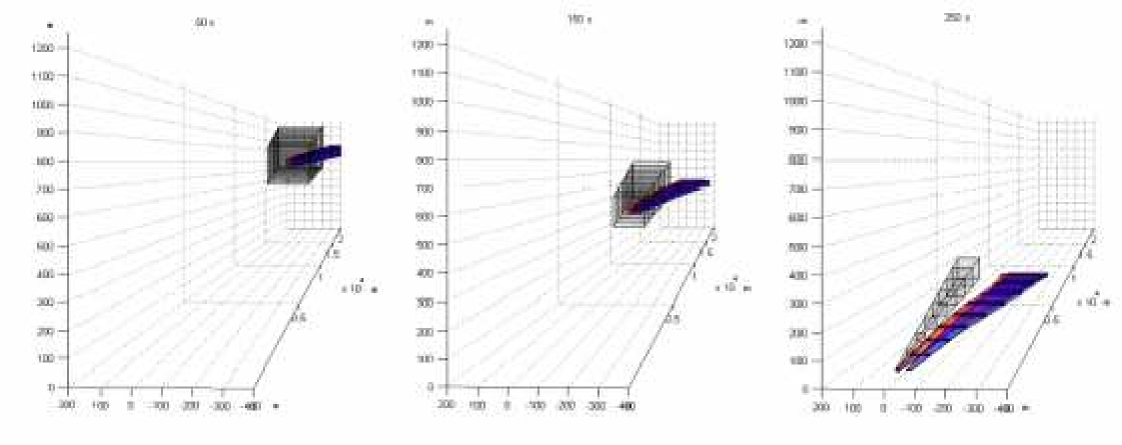


Figure 22 – Real-time computation of the wake vortex displacement using 3D boxes that take into account the input uncertainties

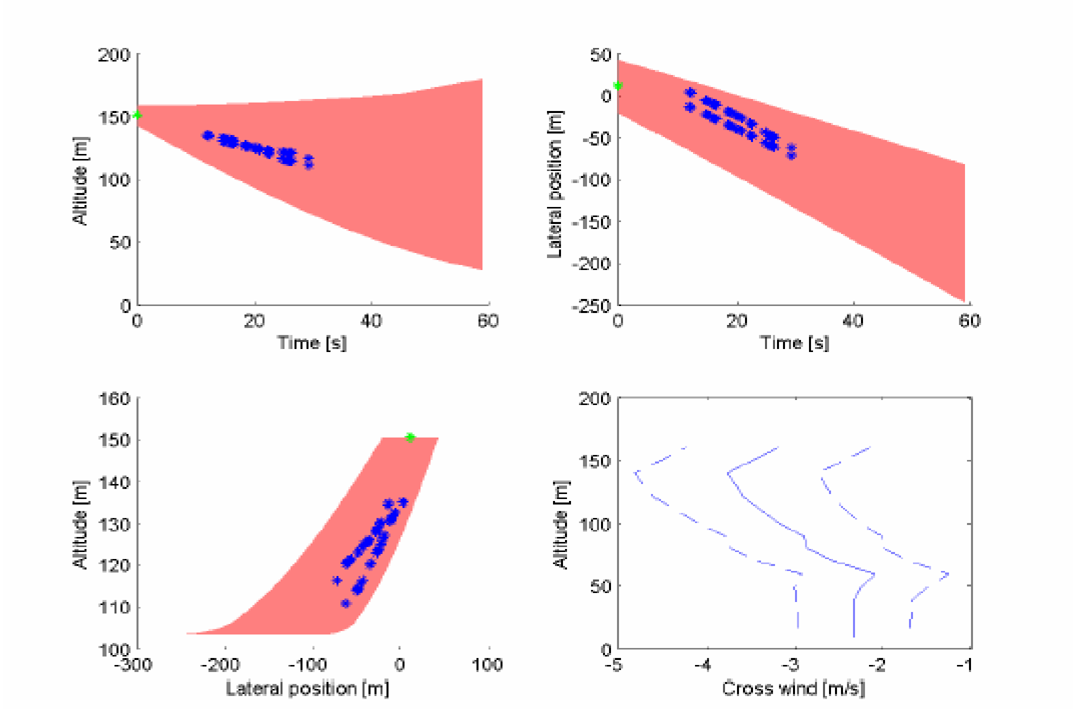


Figure 23 – Example of P-VFS Wake Vortex Prediction; prediction of lateral and vertical wake vortex positions (bounds "shaded area" versus measured data "symbols"); cross wind profiles (measured profile "solid" and envelope "bounds in dash") as obtained using wind uncertainties

5.3 Wake Vortex Detector

The Wake Vortex Detector measures the turbulence in real-time in the critical area with ground-based equipment. These systems are able by means of algorithms (e.g. Doppler) to detect and characterise Wake Vortices. The Monitoring & Alerting module use this data to compare it with the predicted data. The Wake Vortex Detector detects for individual aircraft the WV position, extend (“vortex vector”) and –if possible – also its strength in the pre-defined arrival or departure area(s). Detection is performed using ground-based equipment (pulsed LIDAR, and Doppler Radar processing called “DOPVOR”) which scan along the critical area (ILS glide path) in pre-defined windows. No connection to airborne equipment is assumed but detection may be complemented using airborne equipment.

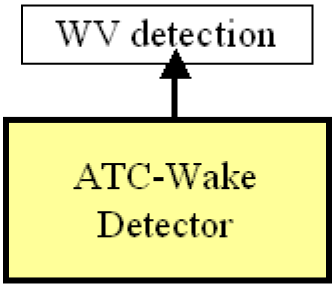


Figure 24 – Wake Vortex Detector Component

The Detector is mainly based on Pulsed-Lidar and Doppler Radar Processing. Lidar for clear air conditions, completed by radar for rainy conditions, is able to detect and monitor Wake Vortex in real time. DOPVOR (Doppler processing on Radar data by rainy weather) provides air turbulence maps inside a specific sector in azimuth for different elevations.

5.3.1 Wake Vortex Detection by Lidar

Lidars are able to detect and monitor Wake Vortices in real time. Since Lidar is a fair weather tool (it require a certain amount of visibility), it may be complemented by Radar techniques to detect Wake Vortices. Ideally the whole glide path should be monitored for Wakes while the focus should be on the Wake Vortex detection close to the surface where a Wake Vortex encounter may be most critical. During the two measurement campaigns WakeOP and WakeToul, Wake Vortices were scanned perpendicular to the flight path in order to characterize the strength and position of the Wake Vortex.

The 2µm pulsed Lidar system also provides detailed information on the wind profile and, as a further product, the turbulent state of the atmosphere. Operationally, such a Lidar system is used at Hongkong airport to detect clear air turbulence along the glide path (however, not the whole glide path can be covered by this system; the range is approximately 8.5 km).

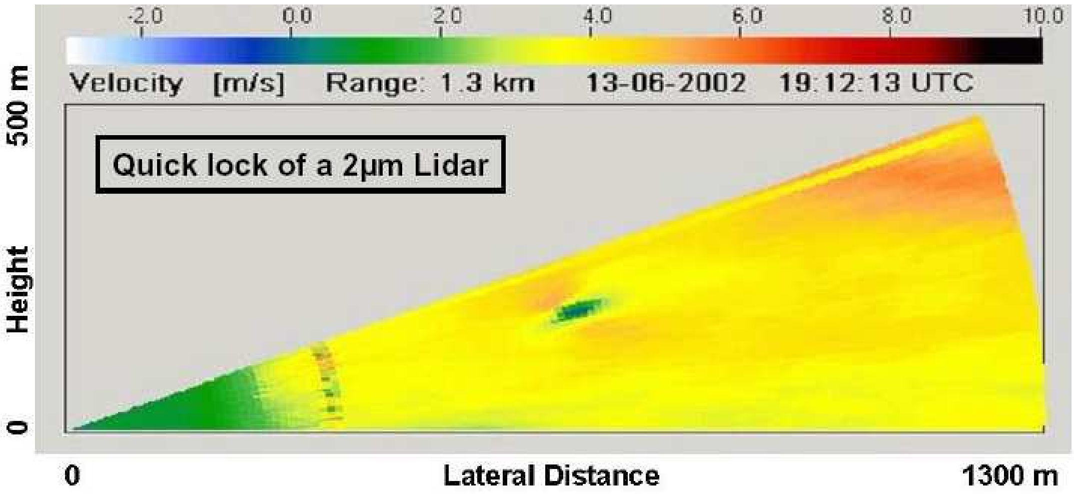


Figure 25 – Example of Lidar scan result for Wake Vortex Monitoring

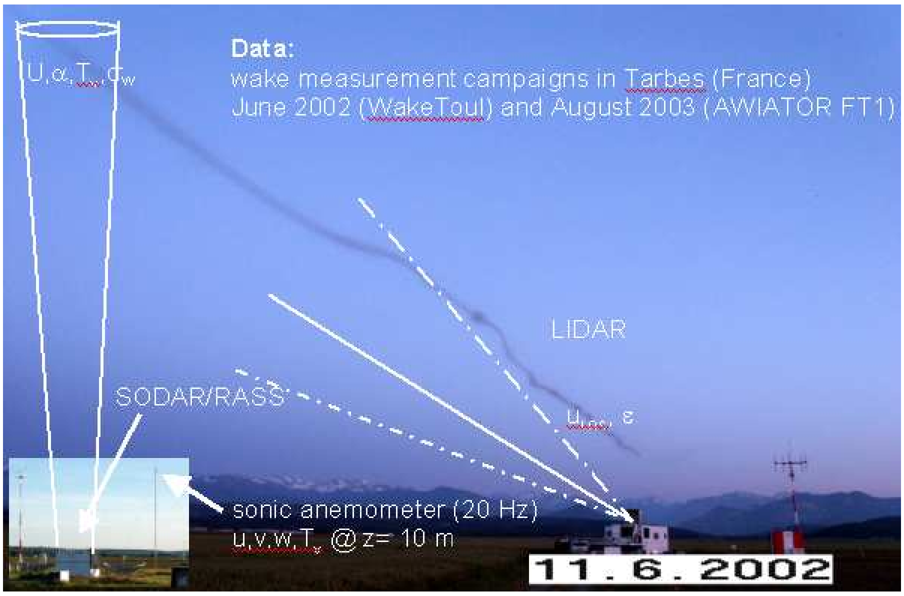


Figure 26 – Instruments deployed during WakeTOUL: SODAR/RASS, vertically pointing upward; LIDAR, scanning perpendicular to the glide path; sonic anemometer, high resolution measurements of wind and temperature at 10 m above ground

5.3.2 DOPVOR Turbulence mapping by Radar

DOPVOR processes Radar Wake Monitoring by Turbulence measurements from Regularized High Resolution Doppler Analysis of Spectrum Width based on Poincaré's metric on reflection coefficients and Cepstrum metric. DOPVOR uses Doppler I&Q (In Phase & Quadrature) Data from DLR's POLDIRAD Radar. In the following figure, we illustrate data from DLR's POLDIRAD radar

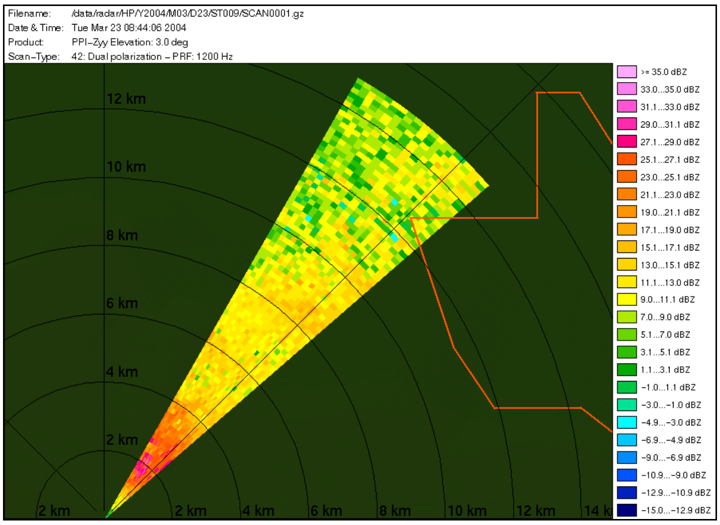


Figure 27 – Illustration of radar records of I&Q data (image of reflectivity in dBz) in one specific azimuth sector (data are record for different successive elevations)

DOPVOR provides air turbulences map inside a specific sector in azimuth for different elevations. These measurements will be put in the airport coordinates system to be correctly matched with the simulated flight corridor. We illustrate in the following figure the map of air turbulence strength as computed by DOPVOR.

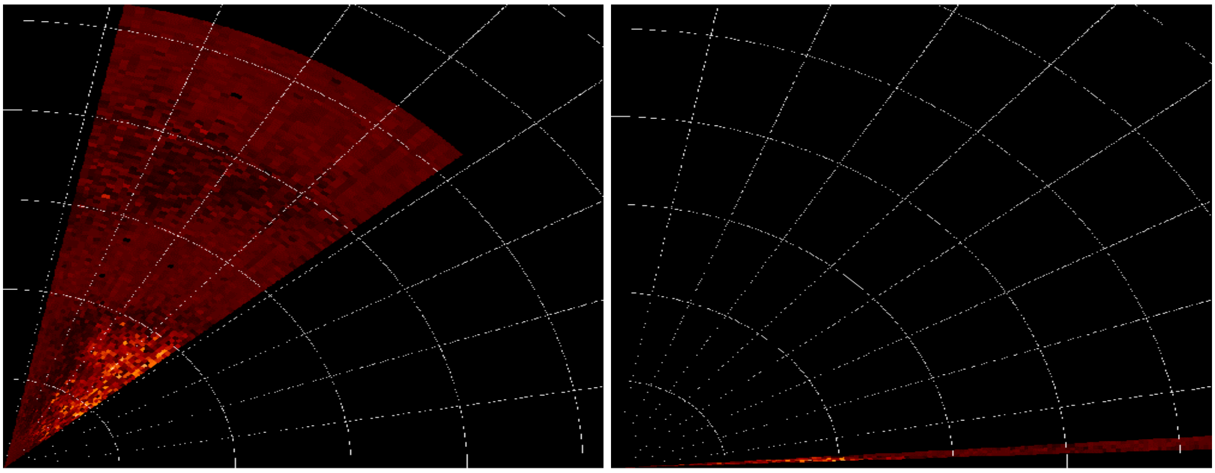


Figure 28 – Illustration of air turbulence strength map (at left: range/azimuth coordinates; at right: range/elevation coordinates)

To provide characterization of air turbulence generated by wake vortex, DOPVOR processes a High Resolution Doppler Regularized Burg algorithm that maintains robustness even with short window of adjacent temporal pulses analysis. Regularization avoids appearance of spurious peaks for each temporal window analysis. DOPVOR measures turbulences by means of a Doppler spectrum width estimation from autoregressive parameters with two kinds of distances:

- ***Cepstrum distance or Group Delay distance*** (differential cepstrum) computed recursively with AR parameters
- ***Siegel Metric*** defined as Modified Poincaré metric in the unitary complex disk, computed with reflexion coefficient parameters to successive orders.

Air Turbulences characterized by a widening of Doppler spectrum are mapped by DOPVOR computing according to previous distance or metric, a spectrum distance from the AR model of order one to the regularized AR model of maximum order. If the flow is laminar, AR spectrum is of order one (mono-modal) but in case of turbulences, the spectrum is widened by dispersion of speed in volume resolution radar cell, and the spectrum corresponds to a spectrum of higher order. Distance from order one and regularized maximum order is equal to zero for laminar flow and increases for higher turbulent flow. DOPVOR uses Regularized AR Doppler spectrum method based on Burg algorithm regularization (lattice structure) to improve temporal resolution. Classical 64 Fast Fourier Transform is replaced by AR analysis on the same 64 pulses or on shorter data window of 8 pulses (resolution of Time/Doppler or Range/Doppler spectrum analysis is increased by a factor 8, compared with 64 FFT).

DOPVOR use parametric spectral distance between signal autoregressive one order model and regularized autoregressive maximum order model. This distance provides spectrum width measure. For parametric spectral distance measures, the L2 norm of the log-spectra difference is efficiently approximated by DOPVOR with a Euclidian distance: the cepstral distance. The cepstral distance is calculated by means of cepstral coefficients that are the coefficients of the Taylor expansion of the logarithm of the filter transfer function. They are also the Fourier coefficients of the log-spectrum. DOPVOR also compute one variant of the cepstral distance based upon the derivative of the phase spectrum, namely the group delay, rather than the logarithm of the spectrum. By extension, DOPVOR computes a new Euclidian distance based on smoothed group delay spectrum. DOPVOR also computes another kind of robust spectrum distance by considering the AR multivariate normal model as a differentiable manifold, equipped with the Fisher Information as Riemannian metric and derives the induced geometry. This metric is invariant under non-singular transformations.

5.4 Wake Vortex Monitoring & Alerting

The ATCOs, 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 by comparing the separation criteria (from the Supervisor), the WV prediction data and the WV detection data. Alarms are raised when the short-term prediction is exceeding the selected separation criteria (from the Supervisor) or the Detector detects a WV stronger than the short-term prediction. 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 separation.

The Tower controller for final approach shall in case of an alarm:

- Advise the pilot (2nd aircraft) about necessary actions to be taken, e.g. go around.
- Provide the AMAN or adjacent ATCO (Intermediate) with information concerning his/her instructions on aircraft go-around;
- Advise pilots to delay departures.

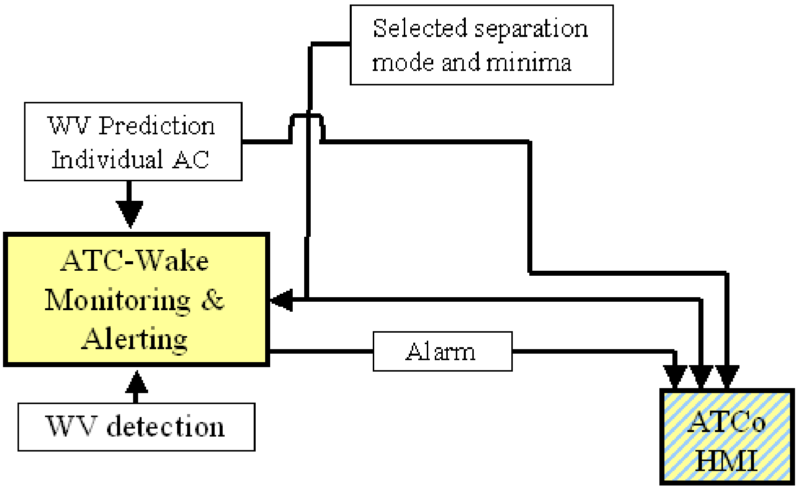


Figure 29 – Wake Vortex Monitoring & Alerting Component

The Monitoring and Alert tool checks the proposed separation mode and issues a warning if the wake observation or the prediction contradicts the ATC separation mode. Inputs are the wake measurements from the Detector and the wake vortex vector from the Predictor. Furthermore the critical arrival area has to be specified for which no Wake Vortex presence is allowed. Following matrix will be evaluated (1=ok, 0=error,"-" = no data available) which summarizes potential scenarios related to the output of the separation model planner, the wake predictors and the wake detector.

Table 1 – ATC-Wake Alerting Principle Overview

Sep. mode	ATC-Wake	ATC-Wake	ATC-Wake	ATC-Wake	ATC-Wake	ATC-Wake	ATC-Wake
Predictors	1	0	0	1	0 or 1	-	-
Detector	1	0	1	0	-	0 or 1	-

An alarm is issued in case of ATC-Wake/1/0 (predictors support separation mode, but Wake Vortex detection issues an alarm because of a Wake Vortex in the safety corridor) and for ATC-Wake/0/0 (predictors and detector find Wake Vortices in the safety corridor).

If the wake detector has no observation available (no wake measurement data in data base available), the combination ATC-Wake/0/- will issue a warning, indicating that the safety-net is missing. A warning is raised if one or both of the tools (predictor/detector) have missing data. Alarms and warnings are sent to the ATCO HMI (CSCI_3_2). In case of an alarm, the colour of the Wake Vortex Vector, displayed on Tower Controller HMI, will change to orange and an audio alarm will be raised (see Section 6 for further details).

5.5 Weather Systems

In order to predict Wake Vortex behaviour, the atmospheric parameters (wind, temperature and turbulence profiles) influencing Wake Vortex decay and transport must be known. Weather now-casting provides forecast of the relevant atmospheric parameters in the airport environment. Here NOWVIV (Now-casting Wake Vortex Impact Variables) is used which consists of a high resolution mesoscale weather forecast model (MM5) designed to provide realtime 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 orography and detailed land use maps to predict realistic boundary layer features. NOWVIV is driven by standard weather forecast provided by German Weather Service (DWD) and continuously assimilates data from weather observation systems installed in the airport environment. The weather monitoring may consist of Radar, Profiler measurements or any other data source around the airport environment. NOWVIV provides meteorological profiles about every nautical mile along the glide path. The output of NOWVIV is used by the Separation Mode Planner to decide on the safe separation mode. The performance of NOWVIV has been analysed with observations which where used by the weather data analyser.

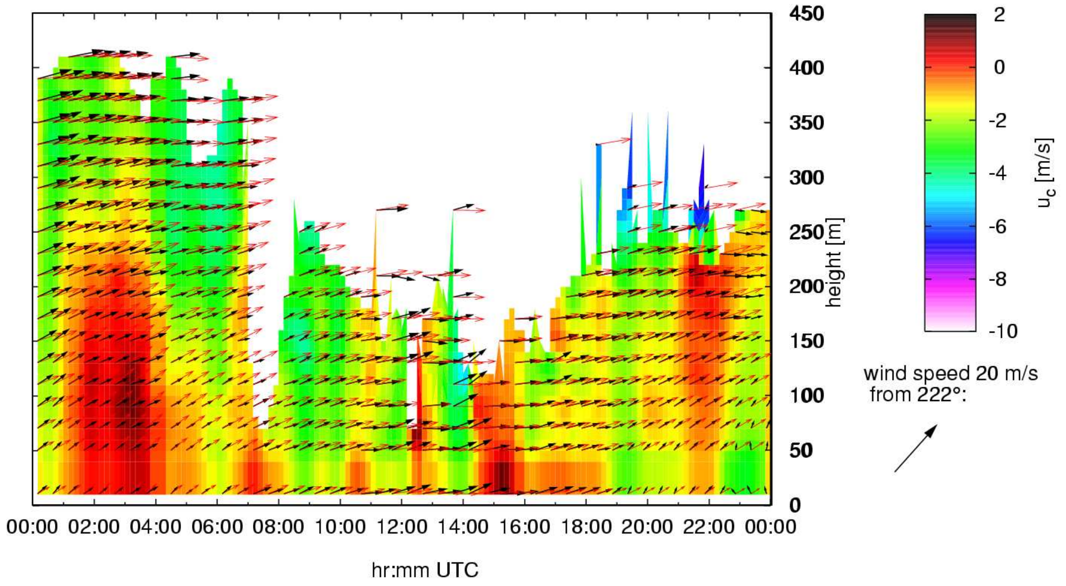


Figure 30 – Difference between observed and predicted cross wind (coloured plot). In addition the observed (in black) and predicted (red) wind vector are plotted upon the cross wind difference

The weather observations in WakeOP and WakeToul have been established through the use of a SODAR/RASS (wind, turbulence, temperature) and a 2 µm Lidar (cross wind, turbulence), which provided the necessary meteorological profiles to describe the Wake Vortex transport and decay measured by Lidar systems.

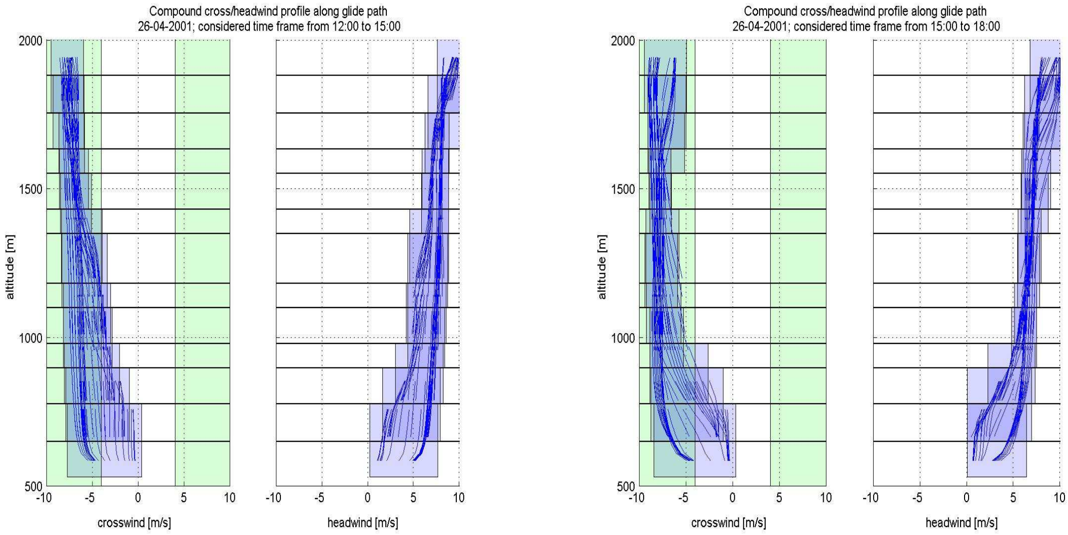


Figure 31 – Compound cross/headwind profiles along the approach path based on NOWVIV data

In rainy conditions, precipitation cloud motion estimation by radar scan can also be useful for now-casting of the wind field. This task is challenging. Indeed, during thirty minutes, the morphology of weather cells (their growth and decay) can change considerably because meteorological phenomena are characterized by distributed systems with motion across a wide spectrum of scales and with complex topological changes. Tracking and forecasting of these evolving dynamic systems can be solved by matching morphological skeletons of previous radar reflectivity images, smoothing and interpolating a dense wind field that deform weather cloud shapes and provides a good estimation of their position for the next thirty minutes. This now-casting of wind field provides reliable wind profile information along the glide slope at different altitudes, in a form accessible to Wake Vortex Predictors. Estimating wind field and weather cells motion by tracking their morphological skeletons is an innovative and disruptive processing entitled SKEWIND.

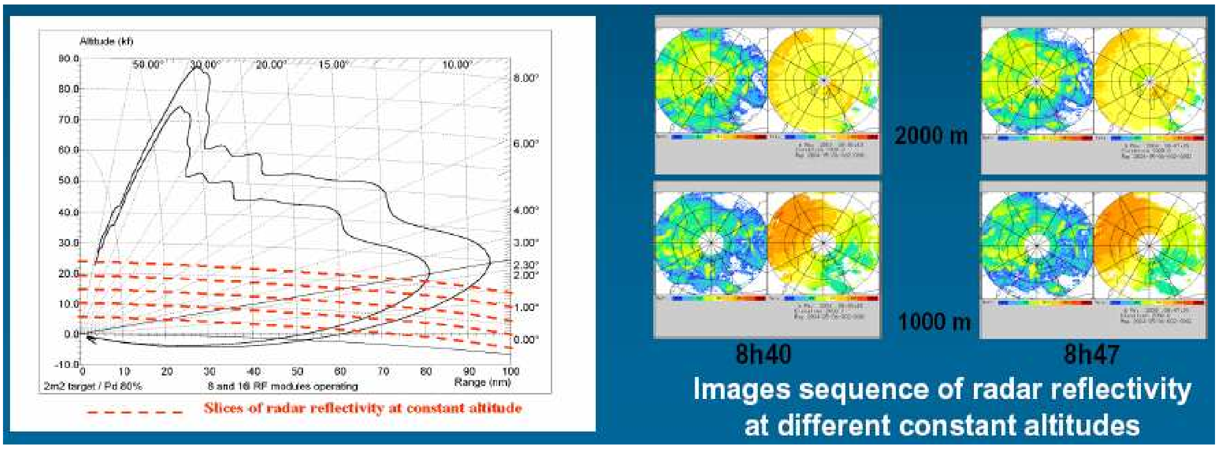


Figure 32 – Radar Reflectivity Images Sequence interpolated at different constant altitude

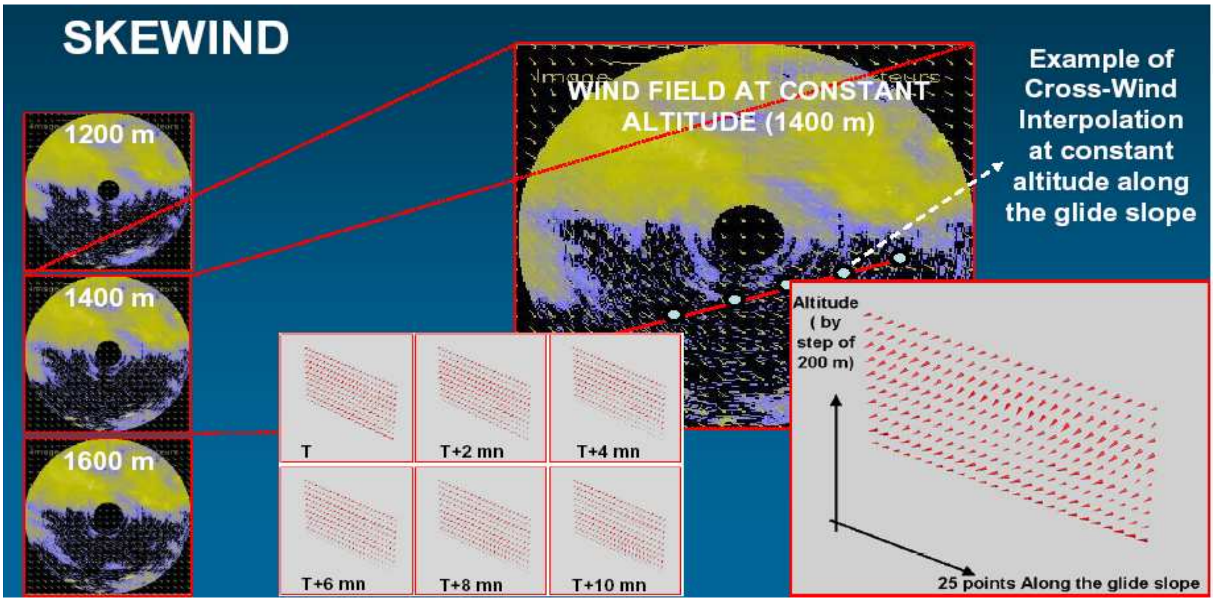


Figure 33 – Cross-wind interpolation along the glide slope by SKEWIND

5.5.1 Weather Data Analyser

The purpose of the Weather data emulator is to provide quality controlled, ‘best-guess’ meteorological profiles representative for the glide path starting with the intercept. The height coverage is between z= 0 and 1500 m above ground. The meteorological profiles are used by the real time WV predictors. The analyser generates those profiles based on input from various sensors and systems which typically have different spatial and temporal resolution. It ingests all meteorological information from the various sensors (in general not synchronized) and NOWVIV output. The Weather Data Analyser is supposed to derive a best-guess profile that checks if at a given time a measurement exists (take nearest neighbour profile).

1. If yes, extract measurement from data base, this measurement is taken as the baseline profile.
2. NOWVIV data are extracted from the data base and interpolated from a 10 min resolution to 2 min resolution.
3. Nearest meteorological measurement time with respect to the required 2 min resolution is identified.
4. Any gaps will be filled by NOWVIV data (up to 1500 m).
5. Is the resulting profile consistent? Jumps, continuity, …..?
6. If the profile is smooth (criteria to be defined), profile is directed to output.
7. Else: smoothing of profiles (criteria to be defined), then directed to output.

The simplest way would be to average everything available for a given height level, without any consideration of instrumental characteristics such as e.g. sensing volumes etc. It is obvious that this merging of data can and should be much more sophisticated compared to simple averaging. The data merging has to be carried out interactively by an expert.

The Weather Data Analyser generates ‘best-guess’ meteorological profiles, provided every 2 min (user requirement); NOWVIV output will be available every 2 minutes.

5.5.2 Wind field Nowcasting/Forecasting by NOWVIV

The purpose of NOWVIV is to provide a weather forecast for at least the next 40 minutes. Based on this forecast, the separation mode is selected. NOWVIV ingests inputs data from:

- Standard forecast from the German Weather Service
- Locally measured meteorological data.

Measured data are individually assimilated into NOWVIV (no weather data analyser involved). NOWVIV forecasts are stored in a database. Based on the selected day, profiles are extracted from the data base and provided to a data container, which is linked to the Separation Mode Planner. NOWVIV generates as output Meteorological profiles, provided every 10 min, along the glide path (i.e. every 2 km) for the next 40 minutes.

A hierarchy of weather forecast models is combined within the model system NOWVIV, NOwcasting Wake Vortex Impact Variables. NOWVIV uses output data from the operational weather forecast model "LM" of the German Weather Service (DWD) which runs at a horizontal resolution of 7 km covering most of Europe. LM on the other hand is driven by the global model "GME" which runs at a resolution of 60 km. The operational GME fields are available to DLR in real time. The core element of NOWVIV is the Penn State/NCAR mesoscale model "MM5" (Grell et. al, 2000) which is used to predict atmospheric state variables within a 2.1 km grid around the airfield with an increasing vertical spacing from 25 to 50m throughout the boundary layer. Detailed terrain and landuse information is provided to NOWVIV. NOWVIV is initialized every 12 hours, 12 UTC and 0 UTC following the issue time of the operational weather forecast. Output variables are vertical profiles of horizontal and vertical wind, u,v,w, virtual potential temperature θ_v and turbulent kinetic energy e. NOWVIV can be run at any location within the LM domain which covers a large part of Europe.

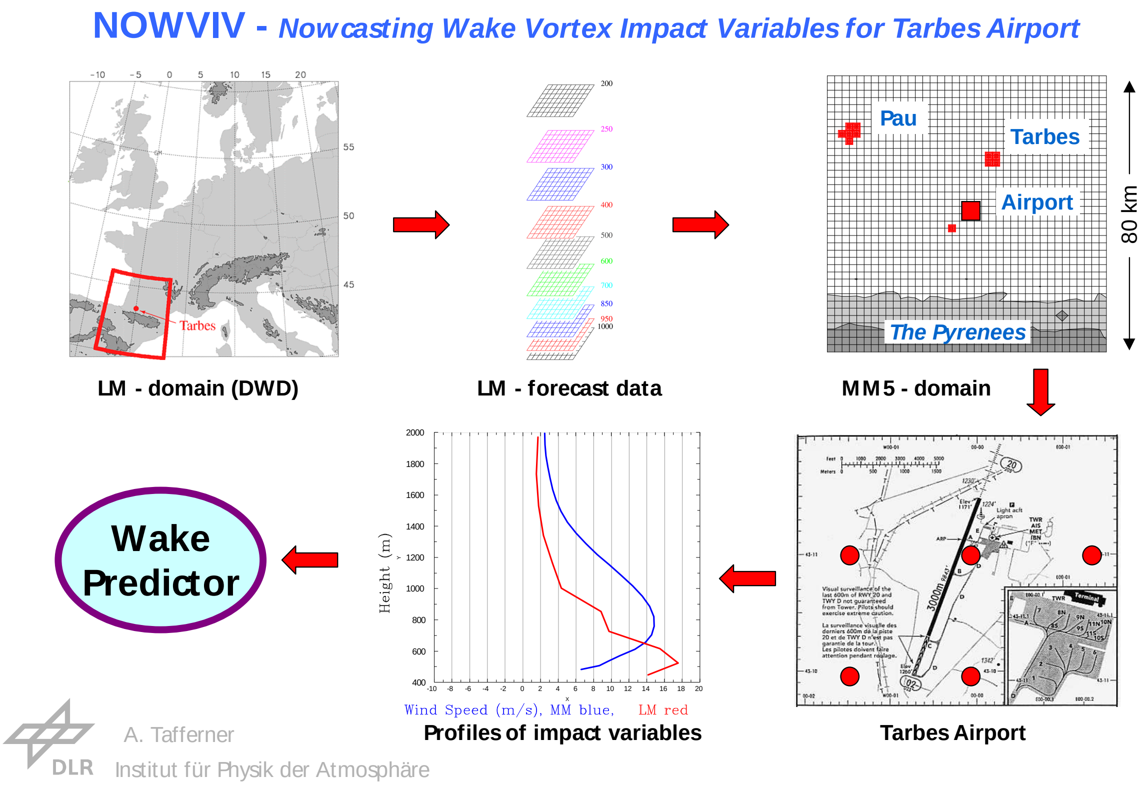


Figure 34 – Schematic flowchart of NOWVIV forecast

5.5.3 Wind field Monitoring by SKEWIND based on Radar Data

Through radar reflectivity, we observe radar clutters, like precipitations, submitted to very complex deformations that cannot be modelled easily. SKEWIND uses a method based on morphological skeleton deformation to forecast the fluid topological evolution and deduce the horizontal wind field. This method allows management of very complex shapes evolution thanks to polygonal approximation of skeleton and matching of their closed couple of elements by relaxation algorithm. Skeleton simplifies shape analysis and deformation but also distinguishes clutter displacement & articulated deformation by skeleton matching from homothetic deformation (inflation and deflation) by medial axis (radius of maximal disks contained in the shape) tracking.

Data from a POLDIRAD Radar has been exploited to validate qualitatively Wind Field estimation by SKEWIND module. The main goal was to prove that the horizontal Wind Field, provided as SKEWIND output could be successfully estimated from a sequence of radar reflectivity images without additional Doppler information as Radial velocity or bi-static measures. Indeed, main big airports have already at their disposal meteorological information of radar reflectivity through meteorological radars (radar integrated in a national network, closed to the airport) or weather channel of primary radar.

For the SKEWIND module evaluation purpose, radar data from a POLDIRAD radar (Doppler & polarimetric C-Band radar) and associated results of Wind field estimation by bistatic radar measurements have been used. Content of the data exploited for evaluation is based on:

- Bistatic Doppler radar measurement.The bistatic Doppler radar network is a system capable to measure several wind components simultaneously which can be combined to a wind vector field. The DLR bistatic Doppler radar network consists of a C-band Doppler radar and three bistatic receiver systems. Wind vector components are measured with a spatial resolution ranging between 600m - 1200m and temporal resolution of 40s for a 360° azimuth scan. The accuracy of the wind field measurement varies between about 2-3 m/s for a dual-Doppler arrangement (one transceiver and one bistatic receiver) depending on the position in space but can be increased if additional receivers monitor the same region. Wind-vector synthesis is achieved in real-time so that also divergence and vorticity fields can be derived in real-time (in fractions of a second). Additional reflectivity and spectral width are measured by each receiver.

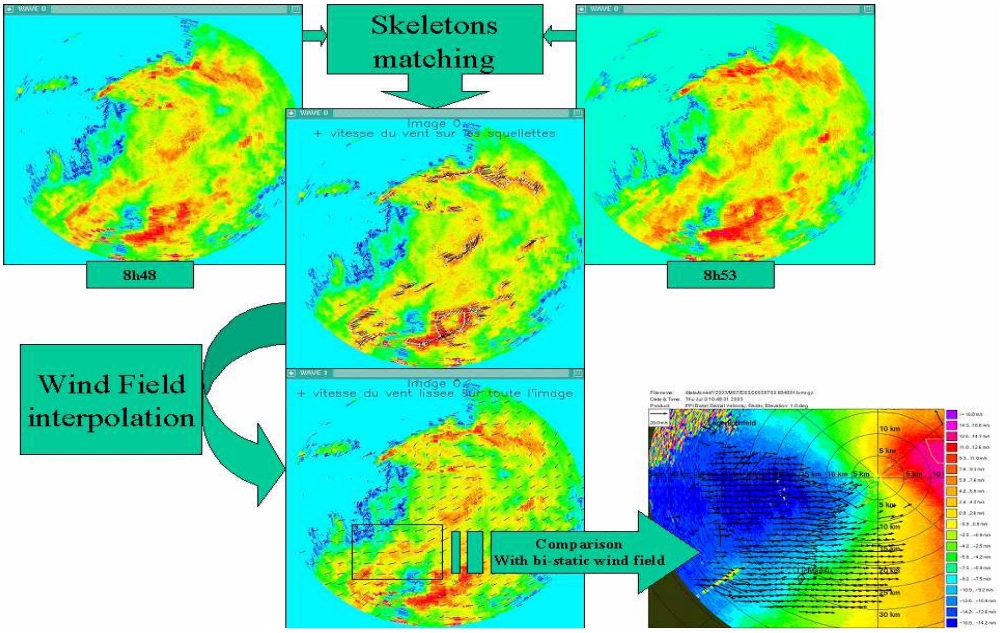


Figure 35 – SKEWIND Wind Field Estimation & Comparison with Bi-static Radar

- Sequences of radar reflectivity, sampled every 2, 3. This radar information are accompanied by radar radial velocity computed by Doppler processing (deduced from the average Doppler frequency given by a classical Fourier Transform or Doppler filter bank as FIR). The sequence of 2 minutes sampling rate corresponds to the date and site of previous bi-static measurement (information are co-localized and simultaneous). So, these sequences will be used to provide SKEWIND wind field and compared with synchronized bi-static measurements. In the same manner. The radial velocity will be correlated with SKEWIND wind field by using classical trigonometric equation or orthogonal projection of the wind field on radar radial axes.

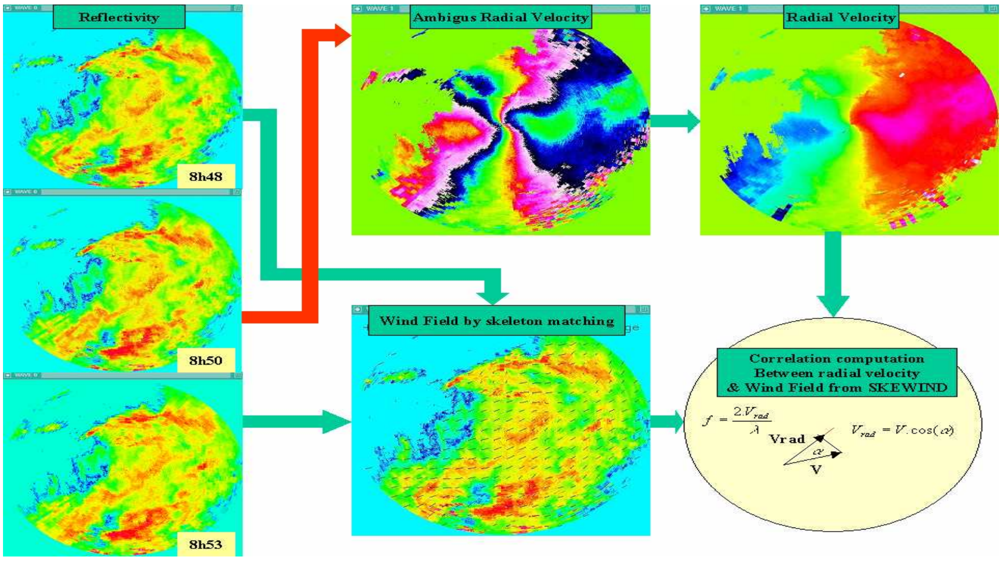


Figure 36 – SKEWIND Wind field estimation & comparison with monostatic Doppler information

Estimation of severe precipitation is essential to improve air traffic control operations and especially to regulate safety distance in a WVPMS system. Precipitation mapping and tracking could be displayed on controller HMI with weather product that warn for potential wake vortex hazards. Precipitation cloud motion estimation will be useful for the forecasting of weather cells thirty minutes in advance. This task is difficult and a challenge, because during thirty minutes, the morphology of weather cells (their growth and decay) can change considerably because meteorological phenomena are characterized by distributed systems that exhibit motion across a wide spectrum of scales with topological changes. Tracking and forecasting of these evolving dynamic systems has been solved by matching morphological skeletons of previous radar reflectivity images, smoothing & interpolating a dense wind field that deform weather cell shapes and provide a good estimation of their position for the next thirty minutes. This forecasting of weather cells contours provides reliable motion information in a form accessible to pilots and controllers. Estimating weather cells motion by tracking their morphological skeletons is an innovative approach for military radar environment assessment. Classical methods for weather cells tracking based on weather-radar data, use two main approaches: centroid method and the correlation method, but these methods suffer of high variability of radar data and weather phenomena and the quality of correlation matching is quite poor. They need to incorporate phenomenological constraints as well as outliers handling, for reliable, robust and autonomous performance (a need for quality-control mechanisms). The SKEWIND module doesn’t suffer of these drawbacks. Skeletons tracking approach of SKEWIND is a high-level approach because the radar data & weather cells shapes are first reduced by morphological analysis to a small number of large-scale features “Skeletons”, which are used as tracers of weather cells movement.

5.6 Surveillance Systems & Flight Data Processing Systems

The various flight data provider systems (i.e. surveillance and flight data processing systems) have been emulated using results of a Total Airport and Airspace Modeller (TAAM) and a newly developed primary radar /baro-altimeter emulator (see Figure 5-27 below).

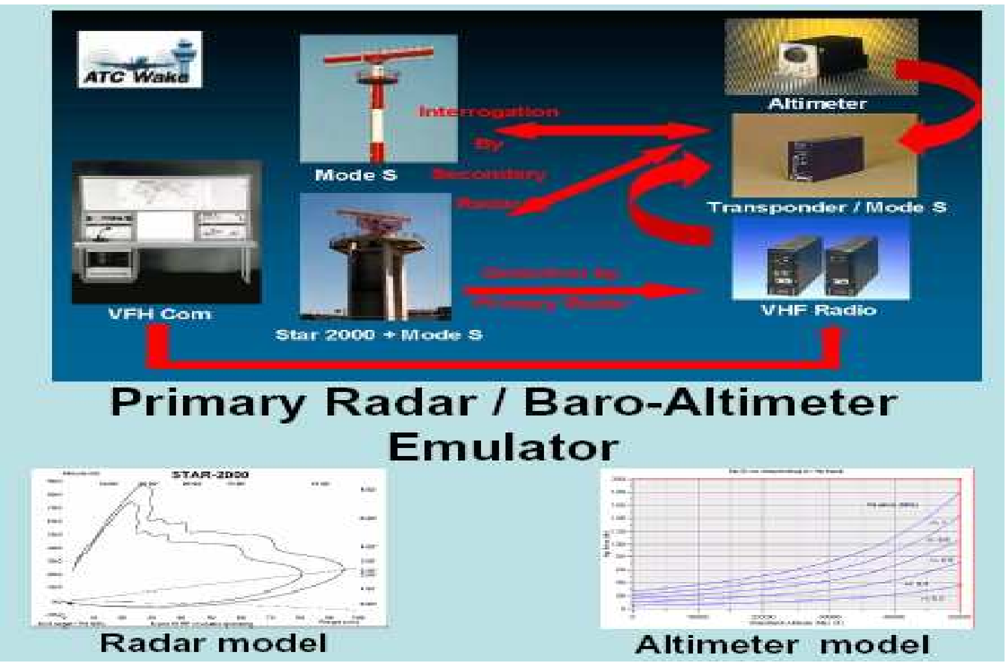


Figure 37 – Surveillance Systems Emulator

5.6.1 Surveillance Systems

Detection and tracks from primary or secondary ATC radar provides 3D coordinates positions of aircraft along the glide path with uncertainties (bias and errors):

- position of flight;
- state vector of flight track (position, speed, acceleration).

Data from the Radar must be previously transformed from its local reference system to a common central tracking coordinate system. The state variables of the central tracks finally presented to the controller will be expressed in a Cartesian coordinate system with origin at the airport reference point (located on the earth surface). Baro-Altimeter provides flight altitude estimation from baro-altimeter measurement according to atmospheric pressure. The secondary radar sends an interrogation, asking for aircraft altitude (Mode C interrogation). This interrogation is detected by all aircraft located in the main antenna lobe. These aircraft then reply to the radar with the requested information about altitude. On board, the altitude is deduced from baro-anemometer that measures atmospheric pressure outside the aircraft. The measure is computed with different repetition rate: 10, 15 and 20 Hz. These measures are filtered and smoothed temporally to provide final information of pressure with a low repetition rate: 2, 3, 4 or 5 Hz. The atmospheric pressure is translated in altitude with classical assumption about pressure gradient variation according to the altitude.

The Baro-Altimeter provides:

- Atmospheric Pressure

- The error on Hp (standard Altitude in feet) doesn’t vary linearly but it depends on the Hp value. The look-up table will be built from the following curves of error on Hp according to Hp for different error on pressure (in Pa).
- Flight altitude (above the earth radius) from TAAM Emulator

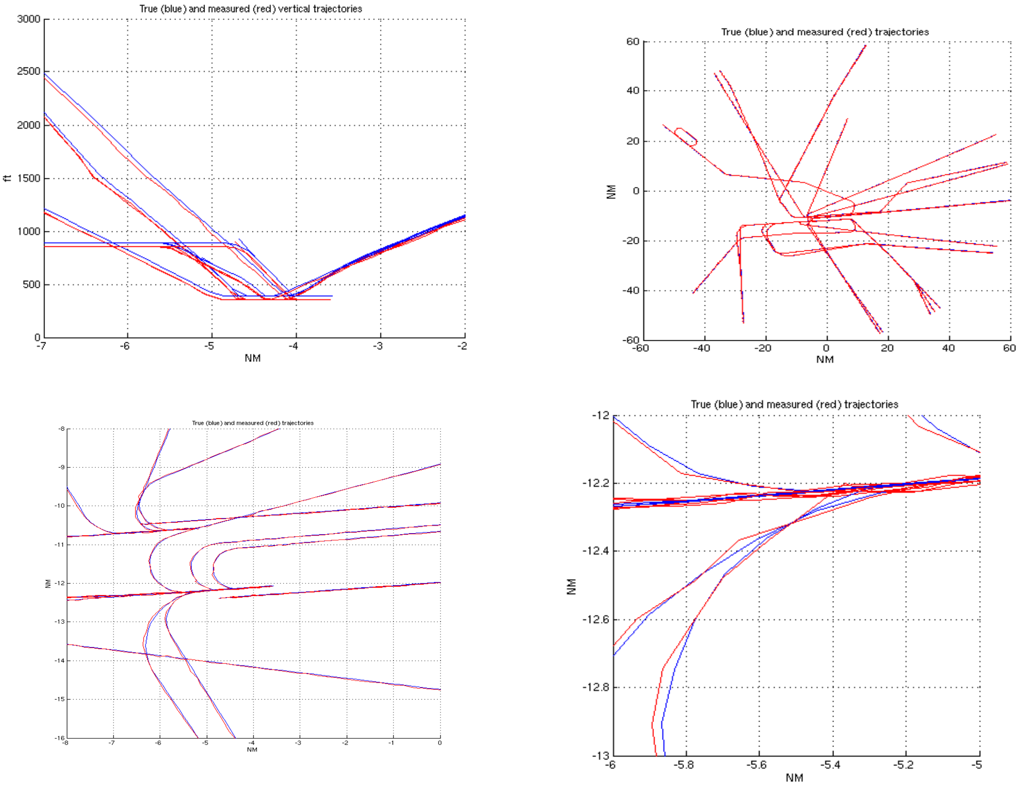


Figure 38 – Illustration of radar plots provided by Primary/Secundary Radar

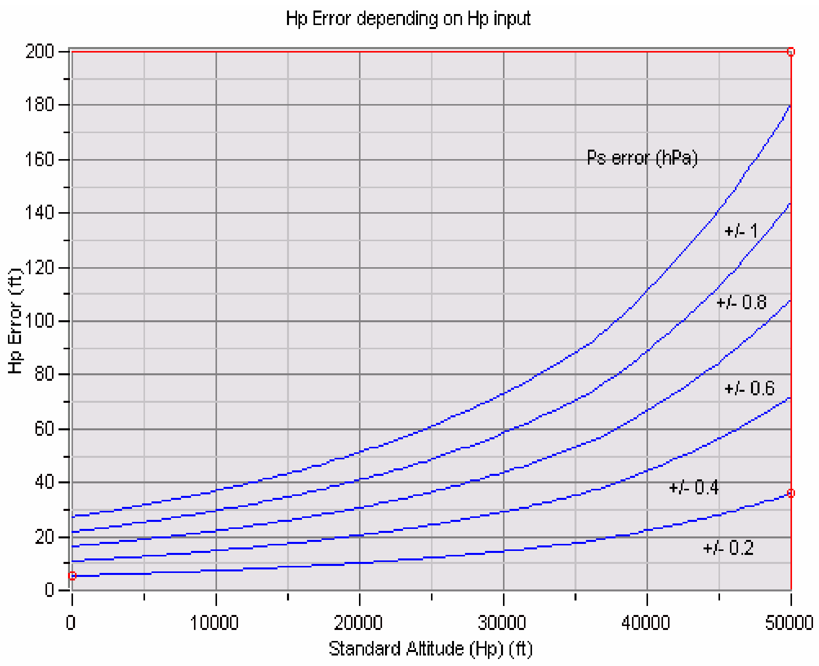


Figure 39 – Baro-Altimeter errors depending on Hp Input

During Taking-off & and Landing Phases, airliners can transmit by data link wind measurement made along their path by anemometric sensor and transmitted by secondary radar to the ATC controller.

5.6.2 Flight Data Processing Systems

The Flight Data Processing System (FDPS) is a subsystem of the ATC-Wake system. From an ATC point of view, the FDPS purpose 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. Information of this system is displayed amongst others on flight strips, PVD and electronic data displays. From an ATC-Wake point of view the FDPS is the tool which provides to the Predictor and to the Detector the Flight Path Accuracy Information (the glide slope tolerance mode: ICAO or FLIP) and the aircraft characteristic data.

5.6.2.1 Total Airport & Airspace Management simulator

The Flight Data Processing Systems has been emulated with TAAM Tool (Total Airport & Airspace Management simulator). Realistic aircraft sequences for two scenarios from TAAM simulation sessions are stored in a data base. One scenario refers to ICAO separated aircraft, the other one to ATC-Wake separation. The TAAM emulator extracts the respective traffic scenario based on decision of the Supervisor.

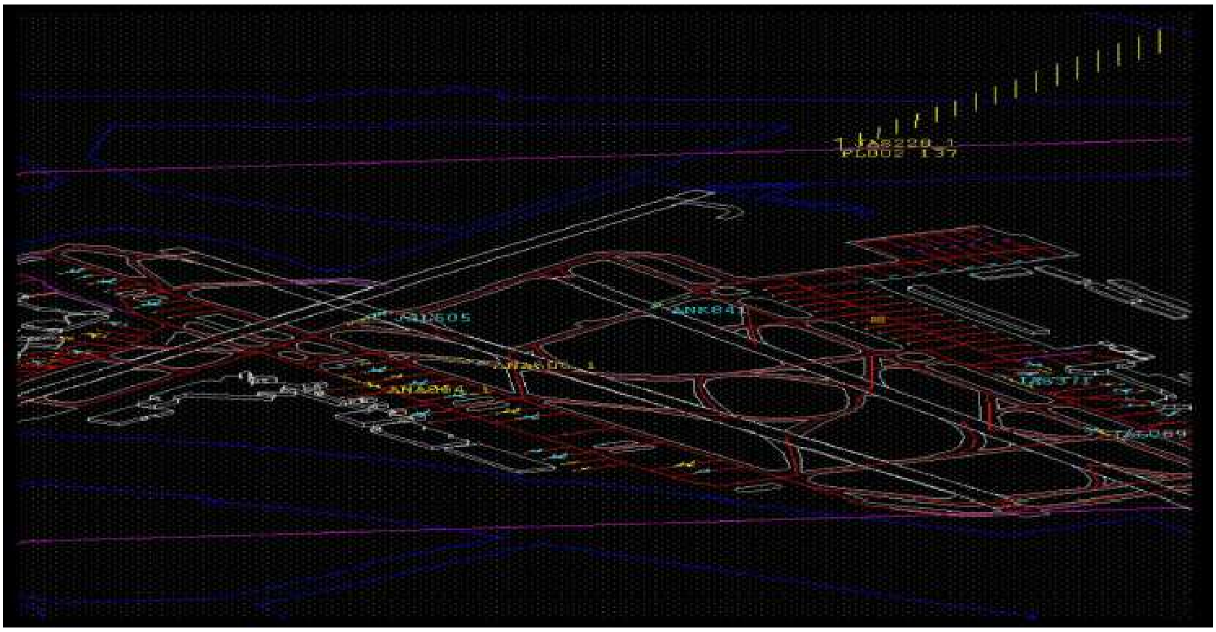


Figure 40 – TAAM Tool (Total Airport & Airspace Modeller)

5.6.2.2 ICAO & FLIP Locations / Glide slope tolerances

Hitting the “SWITCH TO FLIP” button will select the FLIP mode and the plot on the right of the screen will be modified. Hitting the “SWITCH TO ICAO” button allows the user to come back with the ICAO mode selected and illustrated on the graph.

- *ICAO/FLIP tolerance mode on*

  This field shows which glide slope tolerance mode is selected.
- *Switch to ICAO/FLIP* button

  This button allows the user to switch from one glide slope tolerance mode to the other one. Hitting the button changes the selected mode and the graph on the right of the screen.
- *Plot on the right of the screen*

  This plot shows a top view and a side view of the glide path with the limits of the glide slope tolerance corridor selected displayed (blue lines). The red line illustrates the ILS.
- *The lower-right corner button*

  This button is used when the glide slope tolerance mode is chosen. Hitting the “SELECT AND EXIT” button will close the user interface and will generate the output files.

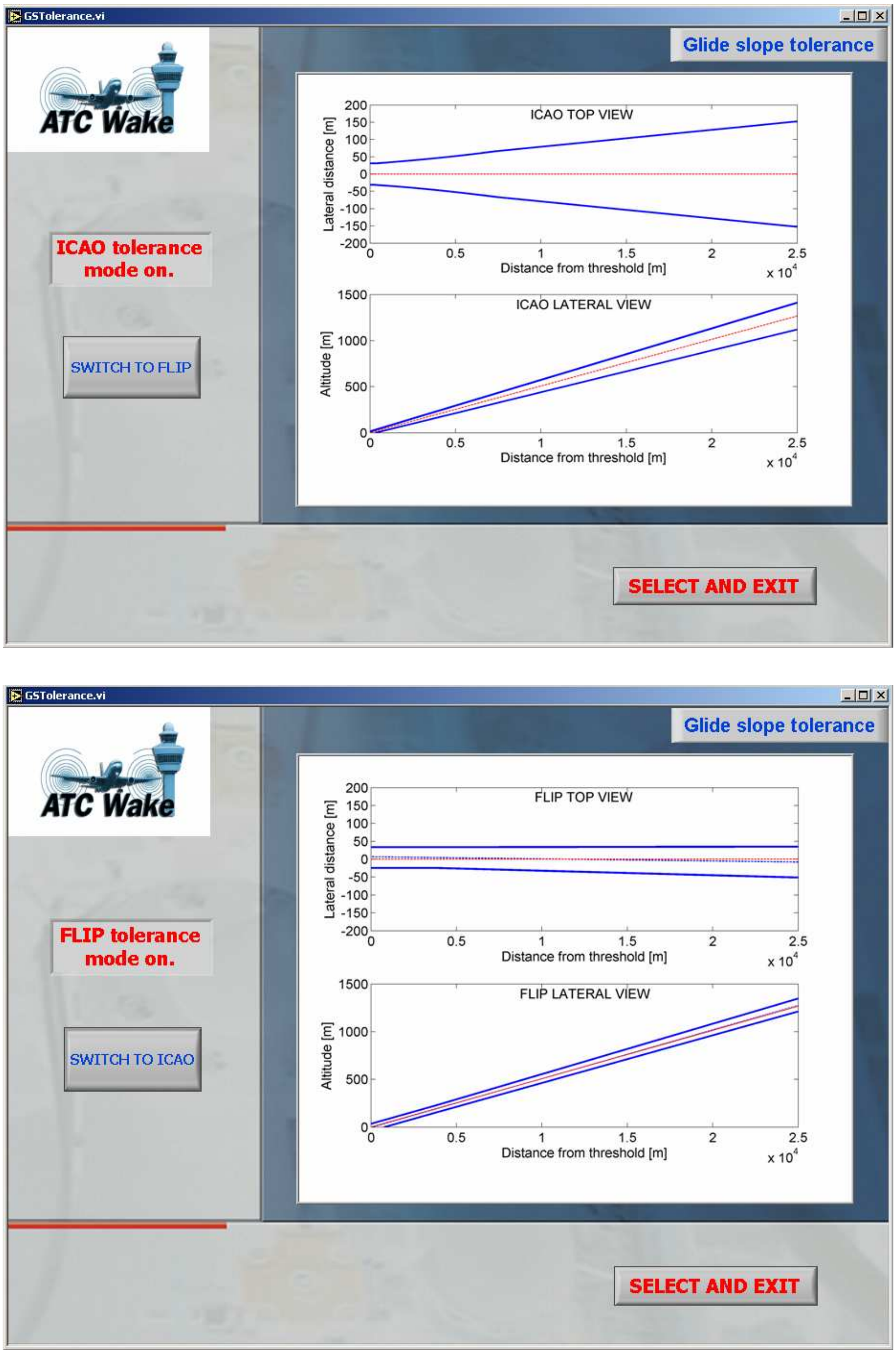


Figure 41 – FDPS graphical user interface start-up screen

6 Design and specification of controller Human Machine Interfaces

6.1 ATC-WAKE HMI Requirements

A difficult aspect of HMI development in the ATC environment is the lack of standardisation in the way data is presented. Almost every airport/country uses different formats, colours and fonts. This implies that the specification of the HMI displays has focused more on the type of information to be presented and its mechanisation than on its appearance. The development of a HMI is an iterative process, which starts with a HMI concept and ends when the HMI is accepted and certified. Each iteration consists of the following four steps:

- Identify changes,
- Determine improvements,
- Apply HMI changes, and;
- Evaluate these HMI changes.

The first iterations during the ATC-Wake project have resulted in an (improved) ATC-Wake HMI that will be used as basis for the ATC-Wake system. A number of different HMIs have evaluated in a simulation experiment. The most important users requirements are [D1_3]:

- The ATC Supervisor shall receive information on applicable separation mode and separation minimum distance.
- The ATC Supervisor and ATCO's shall receive information about transition between separation modes.
- On request, the ATCO shall be provided with a visualisation of Wake Vortex (WV) on the radar display for each individual aircraft in the critical area. The WV shall be updated using actual meteo data.
- The ATCO shall receive an appropriate alarm.
- ATC-Wake system shall not add extra workload to ATCO's.
- The wake vortex information provided to ATCO's is aimed at confirming that safe separation is applied and is not intended to be used to visualise minimum separation.

The HMI concept can be divided into two main functions: strategic and tactical:

- **The Separation Mode Planner (SMP)** is used for the strategic function of the HMI. This system proposes to the Supervisor the separation mode and separation minima and the time of transition between the modes. The Supervisor uses this information to select the separation mode, minima and transition time. This will result in a declared capacity and landing rate for the near future. This information shall be presented on one of the controller's displays and/or verbally by means of a briefing for the tactical phase.
- **The ATC-Wake Predictor, ATC-Wake Detector, and the ATC-Wake Monitoring & Alerting** sub-systems are used for the tactical function of the HMI concept. To enhance the wake vortex awareness of the controllers the WV information of each aircraft in the critical area is presented and alarms are raised in case of a hazardous situation.

6.2 HMI Controller input

An important operational requirement for the ATC-Wake system is the integration in an existing ATC environment. Amsterdam Airport Schiphol (AAS) environment has been selected as baseline for the first HMI evaluation experiments. The NLR Air Traffic Control (ATC) research simulators (NARSIM) have been used to familiarize the controllers with the AAS environment.

A brainstorm session with controllers was organised to get better insight into how controllers currently perceive wake vortices and how they think ATC-Wake information could be presented to them. The concept for the ATC-Wake System described in WP1000 was the basis for this brainstorming. The participants were 3 Dutch controllers, of which two were retired but still active in the ATC world as consultant. All three had experience as Supervisor, Approach, Tower, and Ground controller. The session resulted in the following findings.

In general, the controllers were all very well aware of the wake vortex phenomena. Aside from a lot of operational information, which was very useful in preparation of the simulation experiment, the following remarks related to the HMI's were noted:

- Arrivals are separated in distance, departures in time. The HMI should facilitate this.
- A clear mode (ATC-Wake or ICAO) prediction over a defined time interval should be provided to the Supervisor.
- The HMI of each controller involved in the different modes should indicate the mode and the time interval very clearly.
- A minimum difference in predicted separation distance of 0.5 Nm shall be used.
- Because tolerances will be smaller during close separation, the controllers like to have "distance to preceding aircraft" information
- An auditory warning signal may solve the problem that an ATC-Wake alarm is missed due to the fact that the Tower controllers look outside for most of the time

Because it is impossible to evaluate all the HMI possibilities, the controllers were asked to prioritise between controller's positions, HMI and flight phases (arrival of departure). For this purpose also the HMI examples proposed in D1_5 were shown. The following describes the anticipated changes due to the introduction of an ATC-Wake system:

- Supervisor: the information from the Separation Mode Planner is seen as an extra source for the Supervisor to determine the declared capacity and landing rate. The HMI example for Planning of Separation Modes as described in Section 5.1 looks promising.
- Arrival Manager: No change in operation is foreseen.
- Approach controller: Because the wake vortex information per aircraft is available in the so-called critical area, only the position of the Intermediate Approach Controller is interesting from HMI point-of-view. The proposed HMI is not useful as Plan View Display (PVD) (see Section 6.4).

- Tower controller: The PVD is the display for the visualisation of the WV of each aircraft.
- Ground controller: In ATC-Wake mode the task of the Ground controller will be somewhat easier for departures than arrivals, because the ground controller doesn't have to take the weight category into account for defining the departure sequence. No specific display is foreseen.

The following additional findings resulted from the first experiment:

- The selected separation mode, minima and transition time shall be presented to all the controllers.
- It was not felt appropriate to use the same HMI for all the controllers (e.g. the HMI example for the Supervisor contains too much data for the other controllers).
- During the tactical phase controllers are only interested in the current and next separation mode.
- A change between ATC-Wake and ICAO mode could be seen as a change in the landing rate, which happens currently (airport dependent) several times a day.

6.3 ATC-Wake HMI Experiment preparation

The focus was on the most interesting HMI's and flight phases. The PVD HMI (3 different options) for the Tower Controller and the Approach controller positions during the approach phase were considered. The Supervisor, Arrival Manager and Ground Controller positions were not simulated. The ACT-Wake concept was integrated in the Amsterdam Airport Schiphol (AAS) environment. The procedures and layout of the working positions of the controllers are currently not standardised. This makes it more difficult to define new HMI's and procedures, which are applicable to everyone. For this reason changes were kept to a minimum and only applied when it was necessary to perform the experiment. From the simulation point-of-view, the ATC-Wake system was seen as a black box.

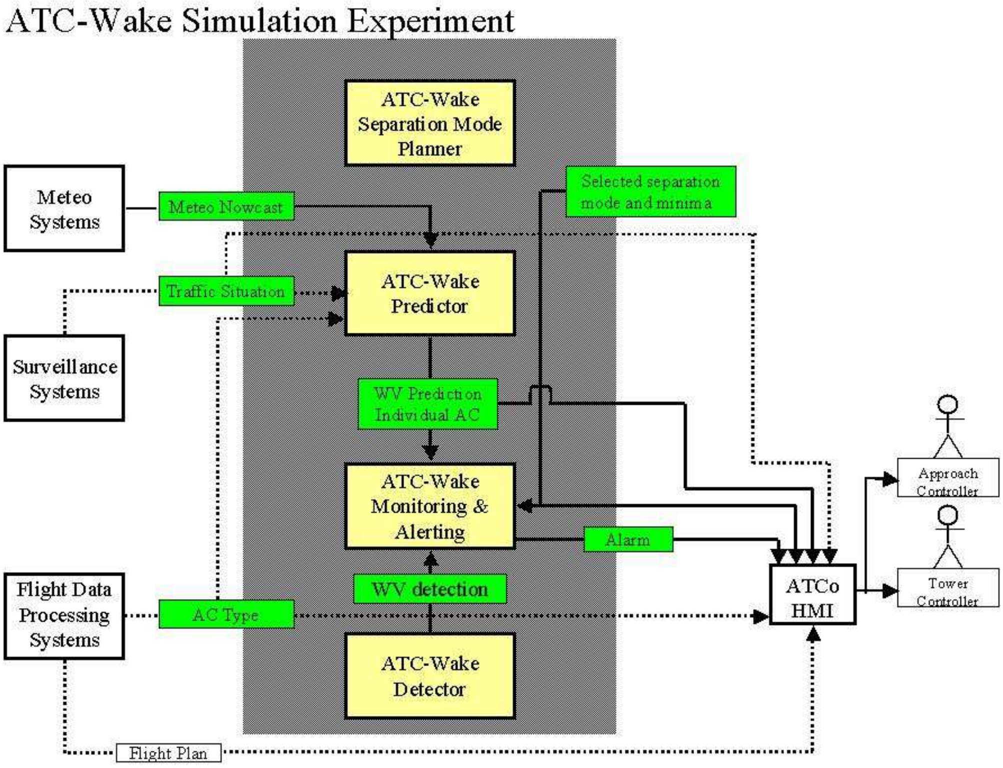


Figure 42 – **Simulation black box**

The following interfaces were realistically simulated:

- "Selected separation mode and minima",
- "WV prediction Individual AC", and
- "Alarm".

The ATCo HMI consists for each controller of more than one display, so not all "new" data appears on the same display. The tower position was configured at the NLR's Tower Research Simulator (TRS) and the approach position at NLR's ATC Research Simulator (NARSIM). These simulators are using the same software and are fully integrated. The whole simulation is controlled from the TRS Control Room, where also the so-called pseudo-pilots, controlling all the aircraft's in the simulation, were positioned. The tower position consisted of 4 monitors, where successively the Surface Movement Radar (SMR), PVD, Electronic Flight Strips and CCIS was presented. The Tower controller was able to us RT for instructing the pilots and the mouse to make changes to the Electronic Flight Strips.

Figure 43 – Tower position

The approach position consisted of a large 2Kx2K screen as PVD and a monitor for CCIS. The Approach controller was able to use RT for instructing the pilots and a so-call Touch Input Device to make changes to the flight plans and for forwarding the flight to the Tower controller.

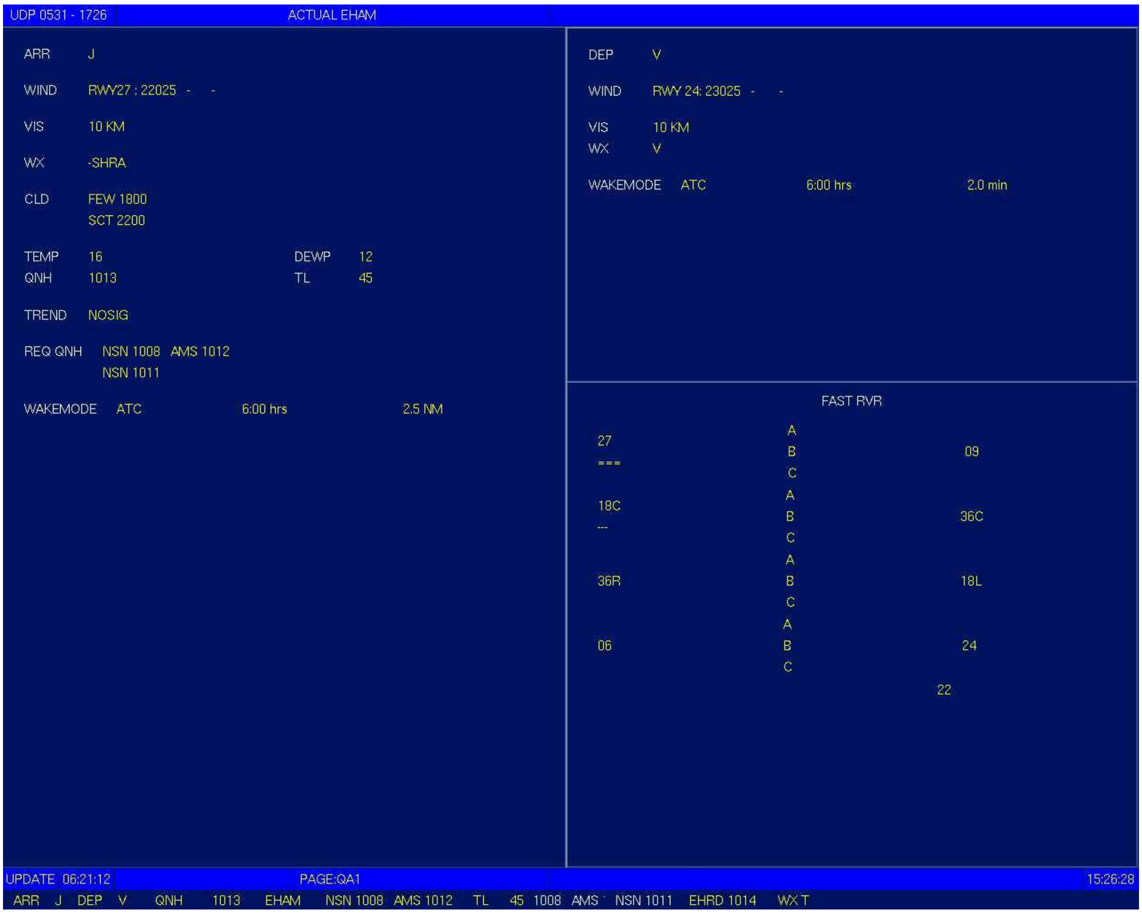
Figure 44 – Approach position

6.4 ATC-Wake HMI Experiment

Two trails with air traffic controllers have been performed in May 2004 and March 2005. In total 9 controllers from five different countries participated and selected unanimous the following HMI's.

6.4.1 Selected Separation Mode & Minima HMI

The "Selected separation mode and minima" was displayed on a page of the so-called Close Circuit Information System (CCIS). This system is used at AAS to give general information to the controllers and presented on a dedicated monitor. The following Figure contains an example of the CCIS page containing the information of which mode is used (in this case ATC-Wake) and which separation should be applied. This page is identical for the Tower and Approach controller.



UDP 0531 - 1726
ACTUAL EHAM

ARR J
WIND RWY27 : 22025 - -
VIS 10 KM
WX -SHRA
CLD FEW 1800
SCT 2200
TEMP 16 DEWP 12
QNH 1013 TL 45
TREND NOSIG
REQ QNH NSN 1008 AMS 1012
NSN 1011
WAKEMODE ATC 6:00 hrs 2.5 NM

DEP V
WIND RWY 24: 23025 - -
VIS 10 KM
WX V
WAKEMODE ATC 6:00 hrs 2.0 min

FAST RVR
A
27
B 09
===
C
A
18C
B 36C

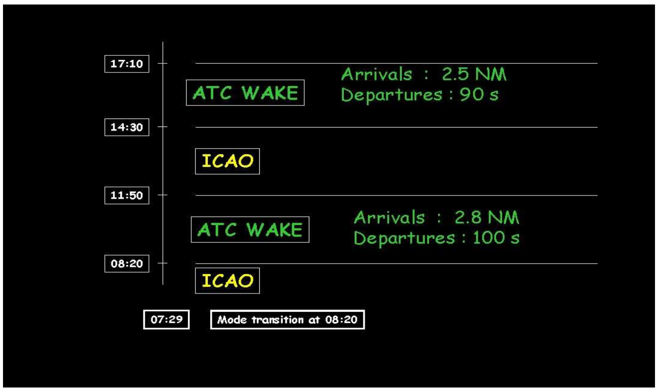
C
A
36R B 18L
C
A
06 B 24
C
22

UPDATE 06:21:12 PAGE:QA1 15:26:28
ARR J DEP V QNH 1013 EHAM NSN 1008 AMS 1012 TL 45 1008 AMS NSN 1011 EHRD 1014 WX T

Figure 45 – CCIS page

6.4.1.1 Supervisor HMI Specification

The Supervisor HMI example as presented in Section 5.1 contains enough information from the Separation Mode Planner to advise the Supervisor. It is advised to show this HMI in a dedicated "window". The font and colours should be in line with the other displays of the Supervisor. The timeline moves from top to bottom and should be updated ones a minute. The SMP data shall be updated at least every 20 minutes. See figure 14 for the Supervisor SMP HMI. Because this HMI is one of the displays the Supervisor will used to decide about the separation mode, distance, time and landing rates, the selected values shall be entered into the ATC-system in the same way as it is done today.



Arrivals : 2.5 NM
Departures : 90 s

Arrivals : 2.8 NM
Departures : 100 s

Mode transition at 08:20

Figure 46 – Supervisor SMP HMI

6.4.2 Selected Wake Vortex prediction individual AC HMI

Simulating the "WV prediction individual AC" realistically was more challenging. A simplified model of the "ATC-Wake predictor" has been integrated. By supplying "Meteo nowcast", "AC type" and "Traffic Situation" this model calculated the wake vortex length of each aircraft in the "critical area". The "critical area" was defined as a 0.7-degree cone around the ILS (see figure 9). In general the length of the wake vortex will decrease linear along the ILS.

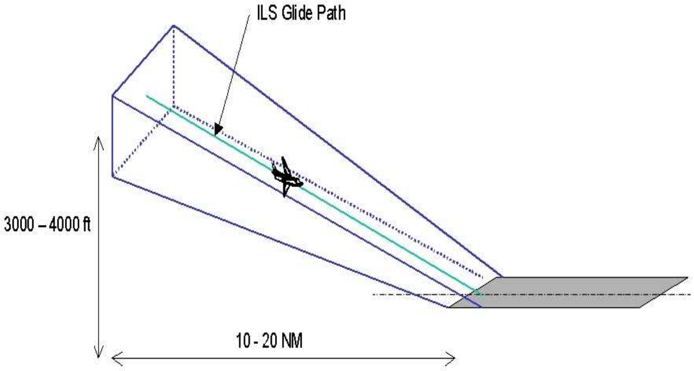


Figure 47 – Critical Area

The wake vortex length is presented on the PVD. Three different options were defined and integrated. The mechanisation and information of the wake vortex symbology was identical for both controllers, but aircraft symbol, presentation of this information in the micro label was different but compliant with the symbology used by AAS. An "ATC-WAKE"- label on the top of the screen gave the controller the possibility to turn the ATC-Wake symbology on or off.

Figure 48 – PVD symbology Approach (left) and Tower

6.4.2.1 *Approach Controller HMI Specification*

All the controllers judged the "Variable Wake Vortex" option as the best HMI (Approach and Tower). The proposed HMI is derived from this HMI by removing the numerical representation of the vortex length beneath the vector.

Figure 49 – (Intermediate) Approach controller HMI

The controller shall have the option to turn on or off the "distance to preceding aircraft" and the "wake vortex vector". In case of an alarm this information shall always be turned on. The blue colour for the wake vortex vector and the orange colour in case of an alarm were well received by the controllers in the AAS environment. The font, colours, symbology and position should be in line with the current PVD of the Approach controller. The wake vortex vector and the "distance to preceding aircraft" shall be drawn when the aircraft is very close to intercepting the ILS until the speed is below 70 kts for approaches. This implies that a change for the intermediate Approach controller only. For departures it is the same only reverse. The wake vortex wake information coming from the ATC-Wake predictor shall be updated every radar sweep (roughly every 4 sec.).

6.4.2.2 Tower Controller HMI Specification

For the Tower controller the same HMI is proposed as for the Approach controller. In the AAS environment this will result in the HMI seen in figure 50.

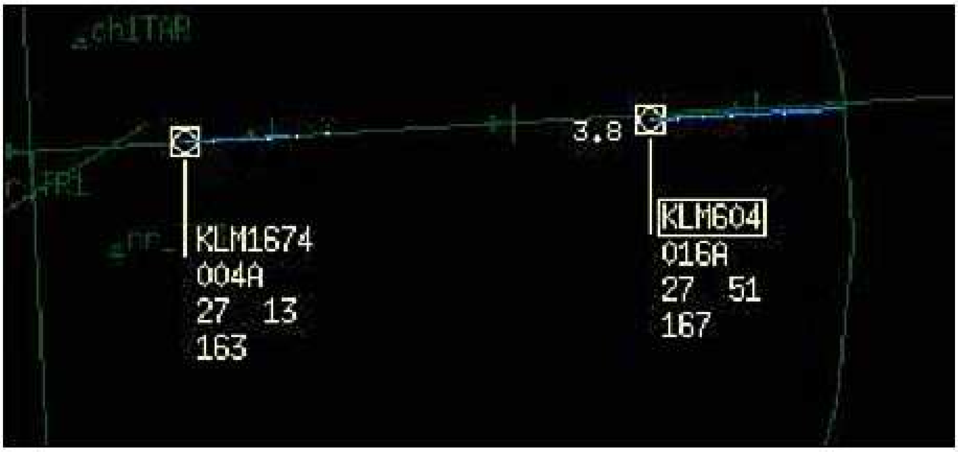


Figure 50 : Tower controller HMI

6.4.2.3 Ground Controller HMI

Except the changes to the CCIS type of display, no specific HMI or HMI enhancement for the Ground controller is foreseen.

6.4.3 Selected Alarm

An alarm is generated in case of one of the following conditions:

- The short-term predicted wake vortex length of aircraft in the critical area is longer than the selected separation distance (long-term prediction);
- The ATC-Wake detector detects a wake vortex longer than the short-term prediction;
- The separation distance to preceding aircraft is shorter than the wake vortex length (an aircraft enters the predicted wake vortex of the preceding aircraft);
- Complete or partial system failure.

Several alarms are recognised. Implementation of these alarms is difficult for a new and advanced concept like ATC-Wake, because also a procedure for the reaction of the controllers shall be defined. Additionally, an alarm can be classified as a "warning" or "alert".

A warning suggests that a dangerous situation is developing, but there is still sufficient time to react. An alert requires immediate action of the controller. For this reason only two alerts were simulated:

- An aircraft enters the predicted wake vortex of the preceding aircraft;
- A system failure.

When an aircraft enters the short-term predicted wake vortex of the preceding aircraft a generic audio alarm was raised and the colour of the wake vortex (including numerical representation) and distance to the preceding aircraft, changed from blue to orange. In this situation the controller should order a go-around to the aircraft entering the wake vortex. This alert was automatically generated when the distance between two aircraft's becomes smaller than the wake vortex length of the preceding aircraft.

A generic audio alarm, flashing of the "ATC-WAKE" -label (on top of the screen) background between black and red and fixation of all-ATC-Wake information simulated the system failure. No specific procedure was defined. The experiment supervisor could introduce this failure during a scenario.

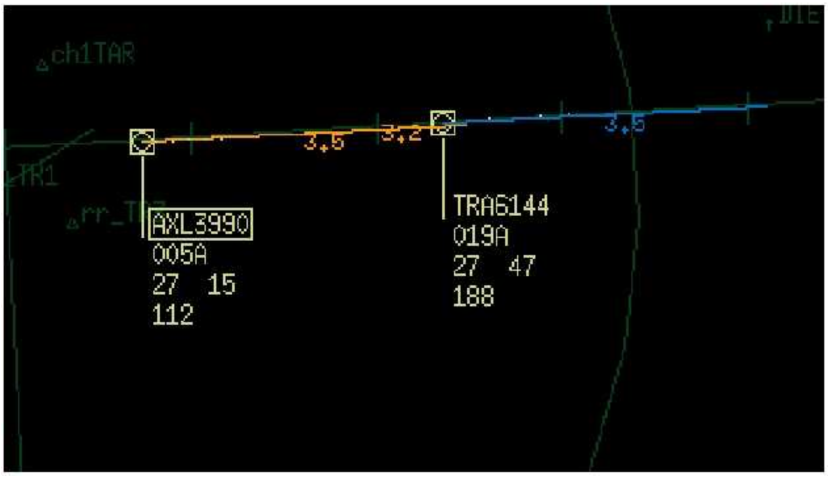


Figure 51 – Alarm

7 ATC-Wake Integrated Platform

7.1 Introduction

Within the ATC-Wake project, an Integrated Platform has been developed to serve as a test-bed environment for a future ATC-Wake Operational System. Each of the system components is represented in the IP by an existing or newly developed tool or data base. The functional overview of the ATC-Wake IP is depicted in Figure 52.

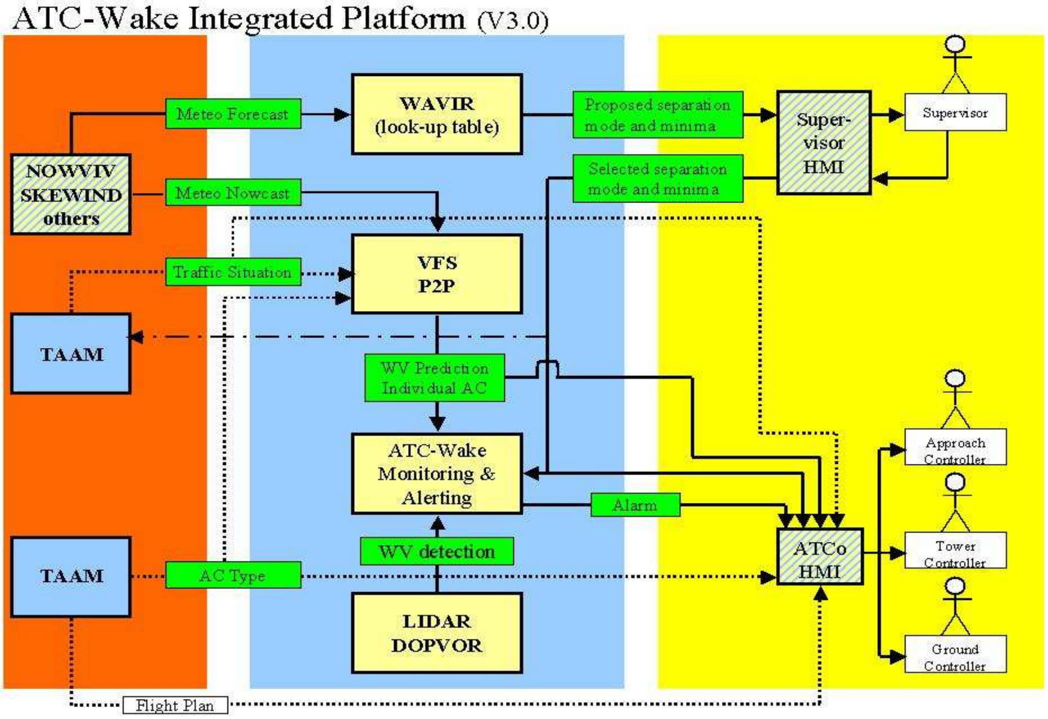


Figure 52 – ATC-WAKE Integrated Platform

The ATC-Wake IP contains the following ATC-Wake tools implementing the corresponding elements in the ATC-Wake Operational System:

- Meteo Systems: The required functionalities are simulated by NOWVIV & SKEWIND.
- Surveillance Systems: The required functionalities are simulated by a Total Airport and Airspace Modeller (TAAM).
- Flight Data Processing Systems: The required functionalities are simulated by TAAM and a Radar Emulator tool.
- ATC-Wake Separation Mode Planner: The required functionalities are represented by a newly designed tool that uses database / look-up tables filled with WAVIR assessment results
- ATC-Wake Predictor: The required functionalities are simulated by mixing results provided by the Wake Vortex Predictors P2P and VFS.

- ATC-Wake Monitoring & Alerting. The required functionalities are simulated by a new tool, which ingesting data from the ATC-Wake Predictor and Detector.
- ATC-Wake Detector: The required functionalities are simulated by using wake vortex and weather radar measurement data from LIDAR measurements, processed by the DOPVOR algorithm.

The relations between the various system components have been taken care of by defining an Interface Requirements Specification diagram (see Figure 53) and developing the required interfaces. The tools have been prepared by the consortium partners and are running at the different partners' premises. The ATC-Wake IP *Working Environment* supports the integrated and distributed use of the ATC-Wake tools by the partners and other users.

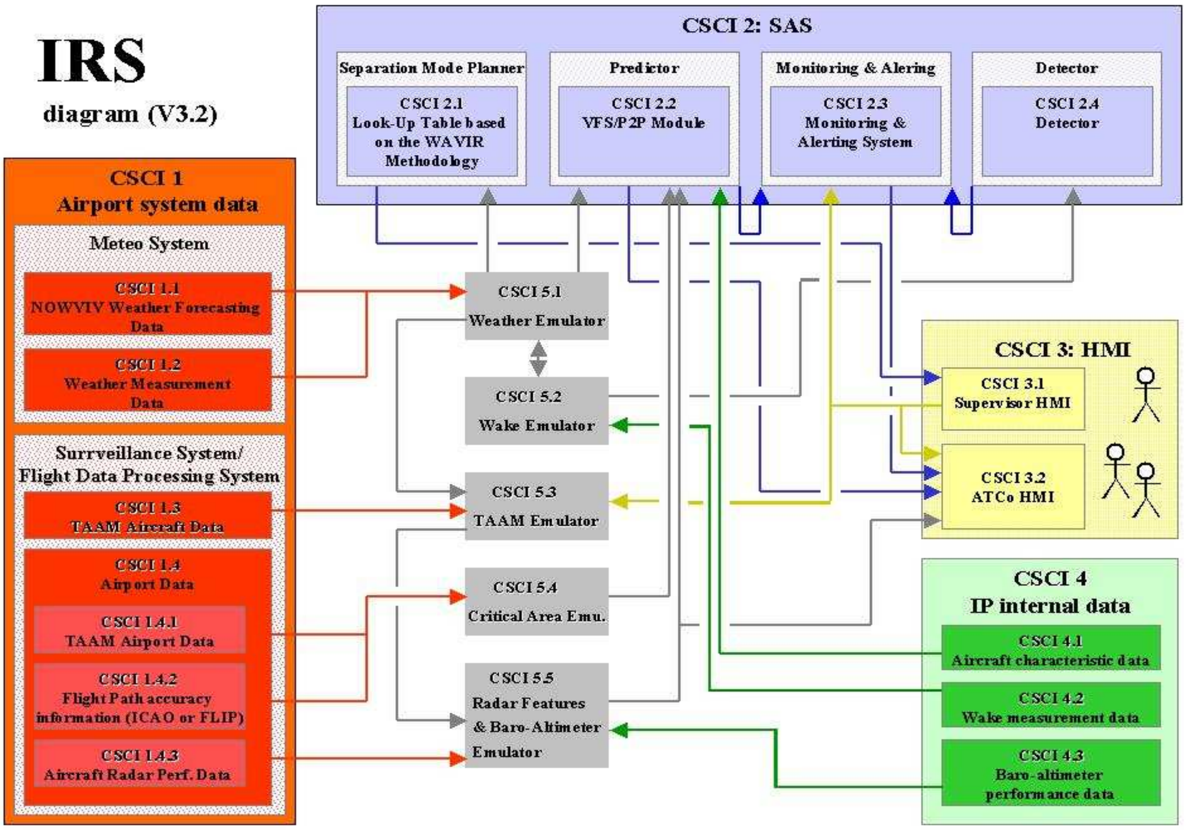
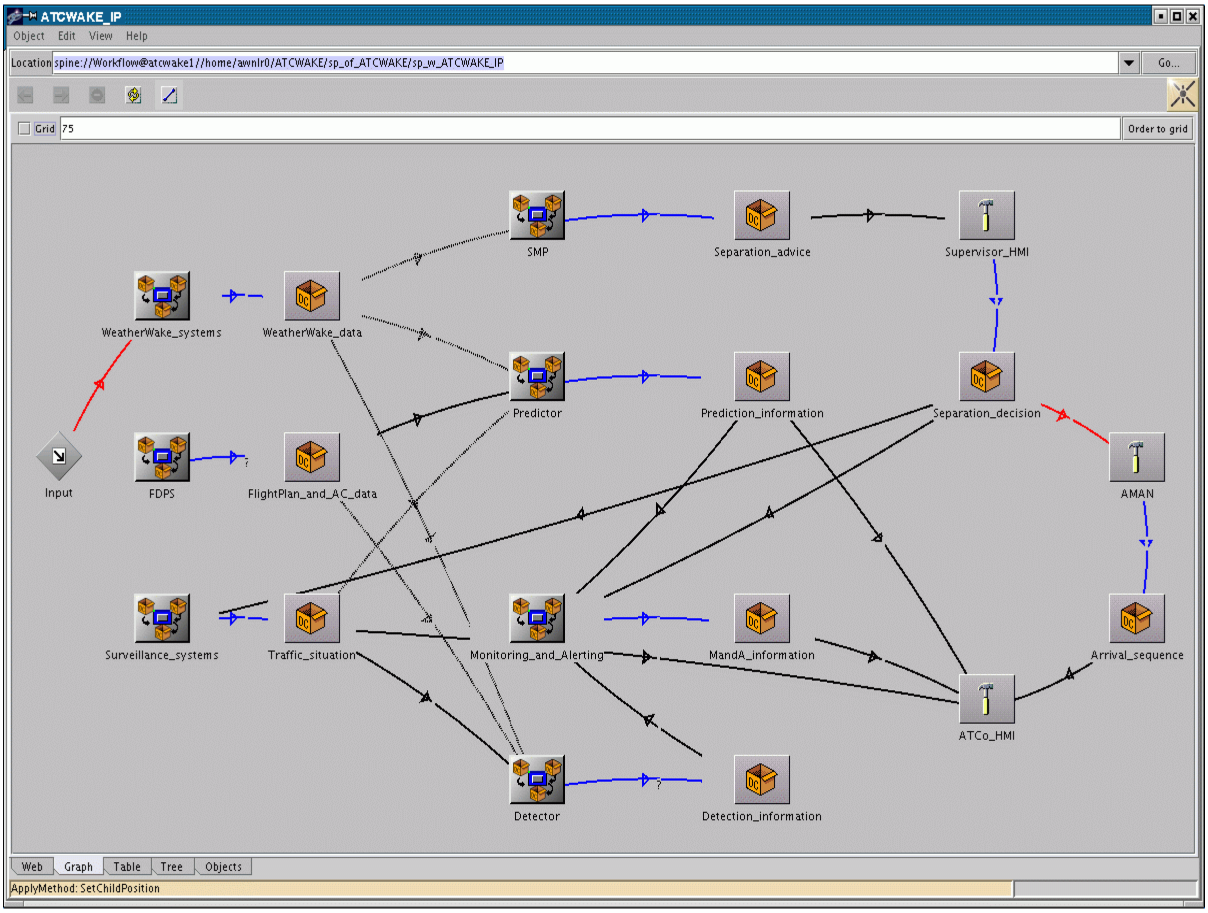


Figure 53 – Interface Requirements Specification diagram for the Integrated Platform

The ATC-Wake IP comprises a set of *ATC-Wake tools* integrated into an ATC-Wake IP *Working Environment*. Key purpose of the ATC-Wake IP is to support integrated and distributed use of the ATC-Wake tools – prepared by the consortium partners and running at the different partners' premises – and data. Integrated use means that the individual ATC-Wake tools proper are wrapped and linked together in order to realise a single, coherent, and user-oriented test-bed of the ATC wake vortex safety and capacity platform. Distributed use means that the tools may be operated remotely, from a single place, whereas they run on computers located with the various consortium partners' premises. The integrated and distributed use of the tools is facilitated through the Working Environment as contained in the ATC-Wake IP. The Working Environment is realised using the SPINEware middleware which provides and combines the notions of *metacomputing* (i.e., means for presenting a distributed set of computing resources as a virtual single computer), *tool wrapping* (i.e., means for integrating existing and legacy tools without modifying the tools proper) and *workflow* (i.e., means for chaining tools) to facilitate the required integrated and distributed use of tools.

From the user's perspective, the key element of, and at the same time main entry point for the ATC-Wake IP is the workflow depicted in Figure 54. This workflow represents the available tools (which may be grouped together and organised into subworkflows) and data sets, as well as the logical flow of data and control among the tools and data. Manipulation of data and activation of tools and subworkflows is done by drag-and-drop and point-and-click mouse operations in the workflow. Whenever an interactive tool is activated, the tool may be operated through the tool's own graphical user interface.



Location spine://Workflow@atcwake1//home/awnlr0/ATCWAKE/sp_of_ATCWAKE/sp_w_ATCWAKE_IP

☐ Grid 75

ApplyMethod: SetChildPosition

Figure 54 – ATC-Wake IP workflow

In the workflow different icons are used for different elements. This includes icons for an Atomic Tool, (sub-)workflow, data container, workflow input, and workflow output :

Figure 55 – Icons for atomic tool, (sub-)workflow, data container, workflow input, and workflow output

The elements can be connected to each other to define the execution order of tools and the transfer of data from one tool or workflow to another one. The colours of the connections indicate the status and special settings of a connection. E.g. connections can be set to start the next tool automatically as soon as preceding tools have provided the required inputs to the tool. Such connection is coloured red.

Each application that is integrated in the ATC-Wake IP is integrated as a SPINEware “atomic tool”. When integrating an application, the integrator takes care of specifying the correct settings of tool and data directories, tool-dependent variable settings, etc. In the ATC-Wake project, a dedicated Virtual Private Network (VPN) solution has been chosen to enable the smooth execution of tools at host computers of each of the partners at their own premises. The user will experience a simulation session with the ATC-Wake IP workflow as if it runs on a single computer. The ATC-Wake tools are either integrated at the top level of the workflow or within one of the subworkflows. A User Guide to the IP workflow and the integrated tools is provided in D2_8. Tools at the top level are the HMI's for Supervisor (Supervisor_HMI) and ATCo (ATCo_HMI), the AMAN. The subworkflows, representing the interfaces between the ATC-Wake components, are described in more detail in ATC-Wake D2_8.

7.2 Design

The concept of the ATC-Wake IP is depicted in Figure 56. The ATC-Wake IP Graphical User Interface (GUI) typically runs on the user’s desktop computer. ATC-Wake tools (such as SMP, Predictor, or Detector) run anywhere in the network of interconnected computers which may be located at the various consortium partners. Data involved is stored in one or several databases. The components communicate via a communication infrastructure. The available tools, data and other resources are integrated in the Working Environment, which is realised using the SPINEware middleware.

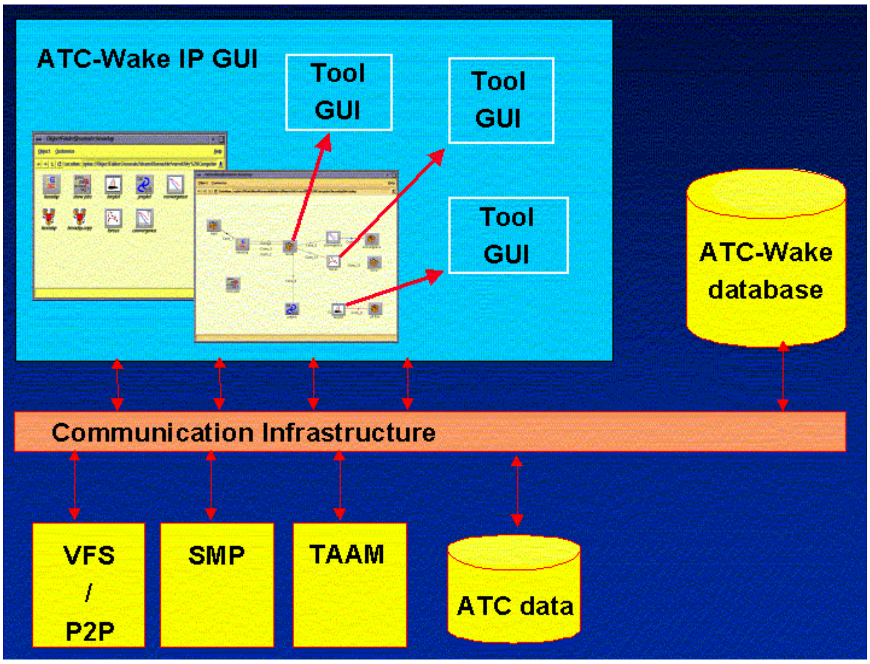


Figure 56 – ATC-Wake IP concept

The top-level architecture of the ATC-Wake IP is depicted in Figure 57. The diagram shows the three key layers:

- The *Virtual Enterprise* comprising the *Project Zones* at the consortium partners interconnected using VPN connections and providing a single secure network of (functionally) closely connected computers, which is a suitable computing base for the Working Environment. A Project Zone is a zone within an enterprise's computer network with its own project-specific security measures. The Project Zone is only accessible for project-trusted entities
- The *Working Environment* providing a single virtual computer that facilitates use of the ATC-Wake tools – stand-alone as well as in workflows – and data involved, located anywhere in the Virtual Enterprise.
- The ATC-Wake IP *Graphical User Interface* (GUI), providing the user with a user-oriented and easy-to-use desktop environment for operating the Working Environment.

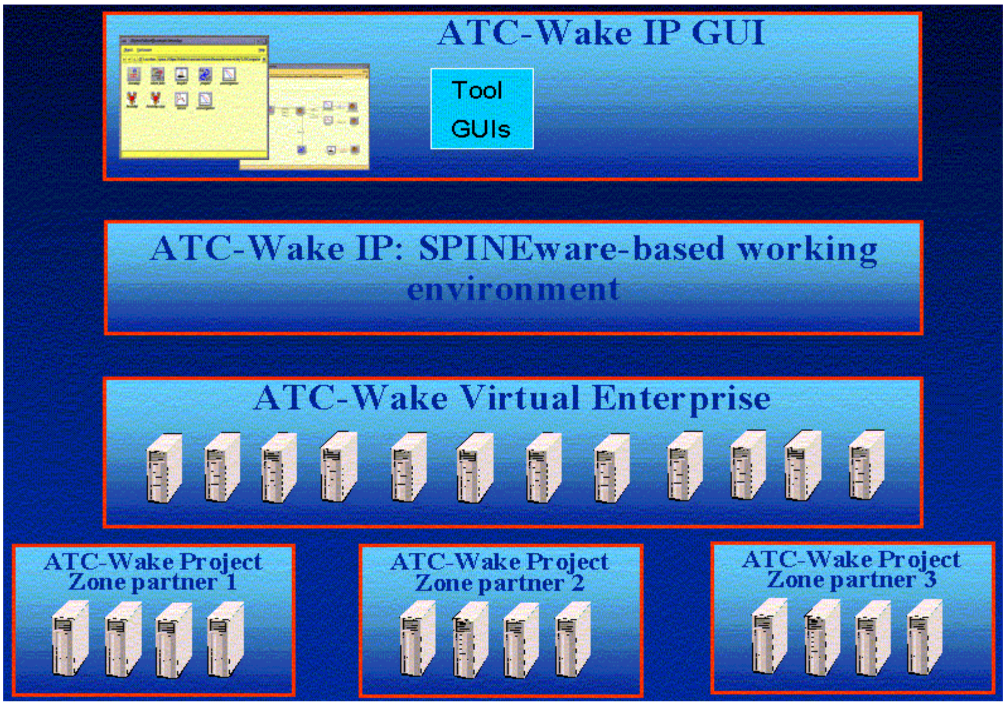


Figure 57 – ATC-Wake IP top-level architecture

The following sections describe, in bottom-up style, the Virtual Enterprise (with the notions of Project Zone and VPN), the Working Environment, and the User Interface.

7.3 ATC-Wake IP Virtual Enterprise

The key goal of the Virtual Enterprise is to provide a secure network of computers with sufficient communication channels among the interconnected computers, to form a suitable basis for the Working Environment. Point of departure is the collection of Project Zones (or isolated computers) located with the consortium partners. A Project Zone is an isolated part of a computer network with its own security policy and measures. It serves to maintain an enterprise's security policy on the one hand, while providing a secure environment that is accessible by external project partners on the other hand. To establish a secure project environment that spans the Project Zones at the different project partners, secure communication channels based on VPN (Virtual Private Networking) technology are established between the Project Zones. The Virtual Enterprise is based on the Common ICT Security Approach as described in section 7.3.1. The design of the Virtual Enterprise is described in section 7.3.2. Aspects of the realisation are presented in section 7.3.3.

7.3.1 Common ICT Security Approach

One of the issues to be considered when interconnecting the ICT infrastructures of enterprises is security. Within the ENHANCE project, the Common ICT Security Approach was introduced, which presents a common methodology for connecting the companies and sharing the information within the Virtual Enterprise in a secure manner.

The Common ICT Security Approach aims at global connectivity, where reliability, flexibility and secure communications are to be guaranteed. Organisations are enabled to share distributed resources. Sharing applications and the use of distributed resources requires from a security viewpoint a number of solutions. The range of resources covered is broad, and varies from product data models to processing power of applications. These objectives are to be realised by interconnecting the ICT infrastructures of organisations participating in a Virtual Enterprise.

7.3.2 Design

Based on the Common ICT Security Approach defined during the ENHANCE project, the ATC-Wake Virtual Enterprise has been defined between five project partners: Thales Air Defence (TAD), Eurocontrol Experimental Centre (EEC), the University of Louvain (UCL), DLR, and NLR; cf. Figure 58.

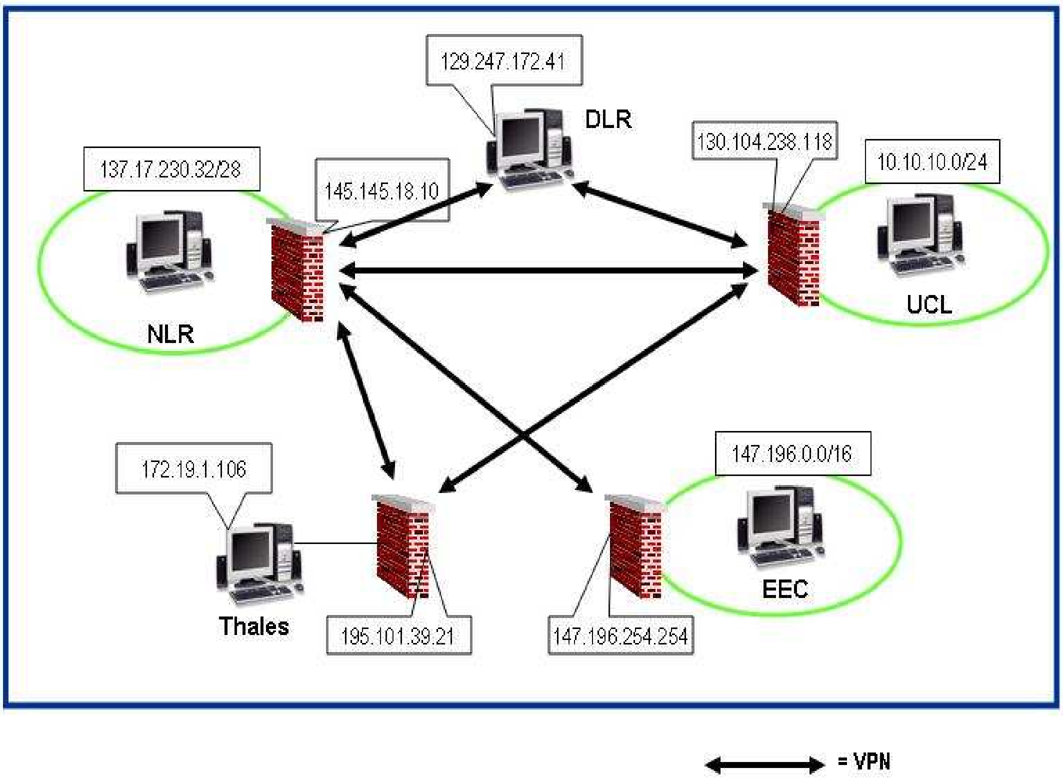


Figure 58 – ATC-Wake Virtual Enterprise

7.3.3 Realisation

A “star” configuration has been established for the Virtual Enterprise, with NLR’s project zone in the middle, and a VPN connection between NLR and each of the four other consortium partners, hence resulting in 4 VPN connections. The “star” configuration supports access between the NLR Project Zone and any of the other partners’ ATC-Wake dedicated computers, which is sufficient to enable operation of the Working Environment from NLR’s Project Zone, with the GUI running at any partner. A more flexible "full-mesh" configuration, supporting direct access between any two arbitrary computers, has also been considered, but appeared to bring along too much technical difficulties. The following steps were defined towards realisation of the ATC-Wake IP Virtual Enterprise:

1. Creation of a project zone at each consortium partner. Each partner places the computer(s) that hosts an ATC-Wake component – and that hence are part of the ATC-Wake IP –in a separate project zone.
2. The project zones of the partners are interconnected using VPN connections, in order to realise a *Virtual Enterprise*, a virtual single computer network that spans the computers located at the partners and dedicated to the ATC-Wake IP.
3. Each system in the Virtual Enterprise is made “ATC-Wake IP prepared”, i.e.:
    - has SPINEware installed;
    - “knows” the names and IP-addresses of all systems in the Virtual Enterprise;
    - provides the same set of user names defined for ATC-Wake IP;
    - has SSH (client + server SSHD) and Java 1.4.2 installed;
    - has Cygwin and VNC server (on Microsoft Windows);
    - provides partners with access via SSH, and via VNC and/or X
    - has operating system (and appropriate type) required for ATC-Wake IP (most likely Red Hat Linux or SuSE, or Microsoft Windows 2000)
4. Testing of the “star” configuration as specified in ATC-Wake D2_9. The detailed test results are reported in ATC-Wake D2_10.

7.4 ATC-Wake IP Working Environment / Infrastructure

The SPINEware middleware was chosen for the realisation of the ATC-Wake Working Environment, because it provides and combines the notions of *metacomputing* (i.e., means for presenting a distributed set of computing resources as a virtual single computer), *tool wrapping* (i.e., means for integrating existing and legacy tools without modifying the tools proper) and *workflow* (i.e., means for chaining tools) to facilitate the required integration and distributed use of tools. SPINEware supports two possible solutions for establishing the required distributed access: a centralised solution and a decentralised solution. In addition, a hybrid solution is possible. For the ATC-Wake IP Working Environment, the decentralised solution was chosen to respect software licenses and property rights (including IPR) of the involved tools and data. In a decentralised setup, each partner has its own SPINEware installation, on each host that is part of the IP. This solution requires a virtual local area network set up to achieve the underlying network model required by SPINEware and secure communication channels among the interconnected hosts. The ATC-Wake IP includes the ATC-Wake computers from the partners. The chosen approach is depicted in Figure 59.

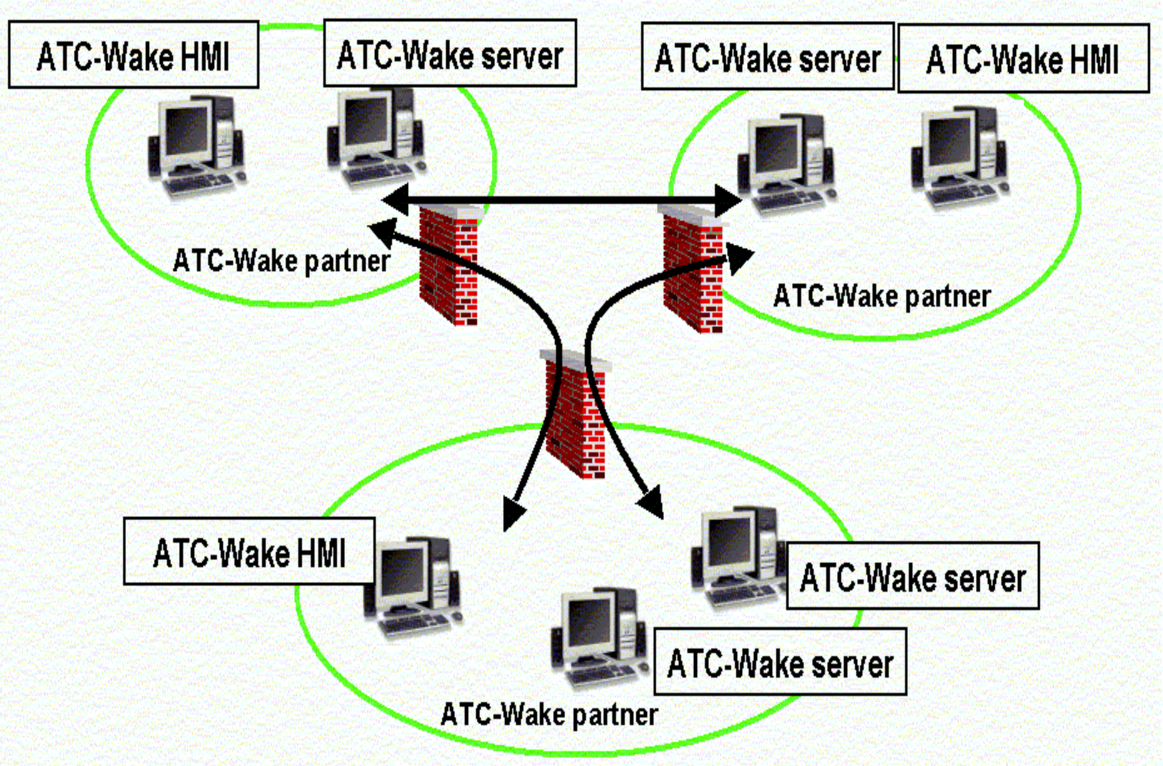


Figure 59 – ATC-Wake IP – decentralised approach

Once all systems in the Virtual Enterprise were made “ATC-Wake IP prepared” (as described in 7.3.3), the ATC-Wake IP was created as a SPINEware-based Working Environment.

More detailed instructions for installation of the ATC-Wake Integrated Platform and getting started with the ATC-Wake IP are included in the User’s Guide in ATC-Wake D2_8.

8 Testing of the ATC-Wake Integrated Platform

8.1 Introduction

The ATC-Wake *Integrated Platform* (IP) is an essential first system development step that will lead to installation of a new ATC decision support system at airports. It serves as a test-bed simulation environment for the future ATC-Wake *Operational System.* As such, the ATC-Wake IP has been used in the remainder of ATC-Wake to (see the other WP Final Reports):

- evaluate the interoperability of the integrated system with existing ATC systems currently used at various European airports (in WP4000);
- assess the safety and capacity improvements that can be obtained by local installation of the integrated system at various European airports (in WP3000);
- evaluate the operational usability and acceptability of the integrated system (in WP4000);
- make a plan and assess costs for further development, implementation and exploitation of this platform into the system that can be installed at European airports) (in WP5000).

The following subsections describe the software test results of the ATC-Wake IP, some highlights from the demonstration trials showing the successful interaction between the ATC-Wake components and (emulated) existing and enhanced ATC systems, as well as further steps needed in order to install the ATC-Wake system at a European airport.

8.2 Software Test results of the ATC-Wake IP

A detailed overview of the qualification test results of the ATC-Wake Integrated Platform is provided in ATC-Wake D2_10, including an overall assessment of the software tested, the impact on test environment and recommended improvements. The detailed qualification test results show that the specified qualification procedures have been followed successfully for all modules, emulators, and interfaces contained in the ATC-Wake Integrated Platform (IP).
The ATC-Wake IP Infrastructure, which comprises the VPN connection and the SPINEware Middleware technology workflows, has also been tested. For each partner, a login session was started on the partner's VE host, using the partner's user name. In each session, the result of the execution was checked, by inspection of the results of executing the commands. For all VE hosts, proper execution, without being prompted for entering a password or confirming something, is required for being able to access the other VE in a SPINEware session. All the tests have been performed and passed successfully.

The following Table 2 provides an overview of the test results for each of the ATC-Wake system requirements (see ATC-Wake D1_5). Appendix A contains a list of requirements with respect to the ATC-Wake IP.

The requirements are numbered as follows:

– SS	ATC-Wake IP Requirements
– OP	Operational Requirements
– SR	Software Requirements
– UR	Users Requirements
– SRS_CSCI	Software Requirement Specification - Configuration Control Item
– INTF	Interface Requirements

Table 2 – Test results synthesis

[SS-01]	IP connection	100%
[SS-02]	IP Interaction with ATC environment	-
[SS-03]	IP operation in heterogeneous distributed computer network	100%
[SS-04]	Communication between partners computer	100%
[SS-05]	Restricted Access to ATC-WAKE IP	100%
[SS-06]	Secure Data Exchange of ATC-WAKE IP	100%
[SS-07]	ATC-WAKE IP Support of components	100%
[SS-08]	Data Conversion from ATC-WAKE IP	100%
[SS-09]	ATC-WAKE IP HMI	-
[SS-10]	ATC-WAKE IP HMI FORMAT FOR USER	100%
[SS-11]	ATC-WAKE IP HMI TAILORIZATION	100%
[SS-12]	ATC-WAKE IP MIDDLEWARE ACCESS	100%
[SS-13]	ATC-WAKE IP MIDDLEWARE INSTALLATION	100%
[SS-14]	ATC-WAKE IP MIDDLEWARE AS SINGLE COMPUTER	100%
[SS-15]	ATC-WAKE IP MIDDLEWARE FOR USER INTERACTION	100%
[SS-16]	ATC-WAKE IP MIDDLEWARE FUNCTIONING	100%
[SS-17]	ATC-WAKE IP MIDDLEWARE CONTROL	100%
[SS-18]	ATC-WAKE IP MIDDLEWARE SECURITY	100%
[SS-19]	ATC-WAKE IP MIDDLEWARE SECURITY	100%
[SS-20]	DATABASE IN ATC-WAKE IP MIDDLEWARE	-
[SS-21]	ATC-WAKE IP DATABASE	-
[SS-22]	ATC-WAKE IP DATABASE FORMATS	-
[OP-01]	Hazard Prediction Capability	100%
[OP-02]	Hazard Detection Capability	100%
[OP-03]	Quality of Prediction Information	100%

[OP-04]	Quality of Detection Information	100%
[OP-05]	Wake Vortex Information to ATC Controllers	100%
[OP-06]	Integration to ATC Environment	100%
[SR-01]	Separation Mode Planner	100%
[SR-02]	WV Predictor	100%
[SR-03]	WV Detector	100%
[UR-01]	WV Separation Mode	100%
[UR-02]	WV Separation Mode Transitions	100%
[UR-03]	WV Prediction	100%
[UR-04]	WV Alerting	100%
[SRS_CSCI_2_1]	Separation Mode Planner requirement	100%
[SRS_CSCI_2_2]	Predictor requirement	100%
[SRS_CSCI_2_3]	Monitoring & Alerting requirement	100%
[SRS_CSCI_2_4]	Detector requirement	100%
[SRS_CSCI_3_1]	Supervisor HMI requirement	100%
[SRS_CSCI_3_2]	ATCo HMI requirement	100%
[SRS_CSCI_5_1]	Weather Emulator requirement	100%
[SRS_CSCI_5_1_1]	NOWVIV requirement	100%
[SRS_CSCI_5_1_2]	Weather Data Emulator requirement	100%
[SRS_CSCI_5_1_3]	SKEWIND requirement	100%
[SRS_CSCI_5_2]	Wake Emulator requirement	100%
[SRS_CSCI_5_2_1]	DOPVOR requirement	100%
[SRS_CSCI_5_3]	TAAM Emulator requirement	100%
[SRS_CSCI_5_4]	Critical Area Emulator requirement	100%
[SRS_CSCI_5_5_1]	Radar Emulator requirement	100%
[SRS_CSCI_5_5_2]	Baro-Altimeter Emulator requirement	100%
[INTF_1_1_to_5_1]	NOWVIV Interface Requirement	100%
[INTF_1_2_to_5_1]	SKEWIND Interface Requirements	100%
[INTF_1_4_2_to_5_4]	ICAO / GLIDE SLOPE Interface Requirement	100%
[INTF_2_1_to_3_1]	SMP Interface Requirement	100%
[INTF_2_2_to_2_3]	P2P Interface Requirement	100%
[INTF_2_2_to_3_2]	P2P Interface Requirement	100%

[INTF_2_3_to_3_2]	Monitoring & Alerting Interface Requirement	100%
[INTF_2_4_to_2_3]	DETECTOR Interface Requirement	100%
[INTF_4_1_to_2_2]	Aircraft characteristic Data Interface Requirement	100%
[INTF_4_2_to_5_2]	Wake Measurement Data Interface Requirement	100%
[INTF_4_2_to_5_2]	DOPVOR Interfaces Requirements	100%
[INTF_5_1_to_2_1]	Weather Emulator Interfaces Requirements	100%
[INTF_5_1_to_2_2]	Weather Emulator Interfaces Requirements	100%
[INTF_5_1_to_2_3]	Weather Emulator Interfaces Requirements	100%
[INTF_5_2_to_2_4]	Wake Emulator Interfaces Requirements	100%
[INTF_5_3_to_2_5]	TAAM Emulator Interfaces Requirements	100%
[INTF_1_4_3_to_5_5]	Radar & Baro-Altimeter Emulator Requirements	100%

8.3 ATC-Wake IP simulations

After the successful integration of the whole ATC-Wake IP, in total eight days of wake vortex and weather measurements campaigns at Oberpffafenhofen (WakeOP) and Toulouse (WakeToul) have been used for testing the IP performance as a whole and to validate the interaction between tools. The full results of the ATC-Wake IP validation tests are documented in ATC-Wake D2_11, which also deals with the technical feasibility of building and installing the ATC-Wake System at European airports. For the WakeOP case, the Separation Mode Planner suggests 2.5 Nm aircraft separation (between all aircraft) and for the WakeToul day ICAO separation is suggested. The main findings are:

- The quality of the weather forecast is in general acceptable and is expected to improve when local measurements are assimilated into the model. The observed forecast quality allows for safe reduced separation proposals (i.e. ATC-Wake Mode) which are verified by the ATC-WAKE Predictor and the Monitoring and Alerting components. The uncertainty allowances for wind that are presently applied by the SMP proved to be sufficient.
- The fusion of measured meteorological data from various sources in the terminal area requires further optimization. In particular, the consideration of RADAR and AMDAR data has to be considered. Both the WakeOP and the WakeToul data bases do not contain these sources of data for testing optimized data fusion algorithms.
- Favourable cross wind conditions all along the glide path might not exist at all airports. This is due to the fact that the wind direction changes in general with height in the boundary layer which eventually leads to cross wind sign changes along the glide path. Wind criteria (and the SMP) might need to be tailored to local airport weather conditions.
- For the two days considered, the ATC-Wake Predictor provides output which is consistent with the Separation Mode Planner proposal. There are some warnings which can be related to limitations of air traffic scenario on the one hand, and to the sequencing

of aircraft onto the glide slope without considering the prevailing wind direction. Latter might not be avoidable due to operational constraints. The result however is consistent with finding at e.g. Heathrow where encounters are frequently reported at the intercept.

- There are no serious warnings raised by the Monitoring and Alerting component tool. This indicates a sufficient level of safety also for the WakeOP 'simulation day' considered, during which 2.5 NM aircraft separation has been applied. However, it has to be noted that this result is based on a very small sample size and therefore should not (yet) be considered as a representative finding. More extensive testing might be needed.
- There is in general a good agreement between the P-VFS and P2P predictions.

To support the evaluation of the usefulness of the ATC-Wake Integrated Platform, some highlights of the Weather Forecasting, Separation Mode Planning, and Monitoring and Alerting process are presented in the following. Note that this information is not present to the Air Traffic Controllers, but is used in the ATC-Wake decision support making process to ensure that safety will be guaranteed. In other words: these highlights provide sub-results on the basis of which the ATC-Wake Operational system derives ATC-Wake HMI information.

Figure 60 shows an example SMP output where the forecasted wind data for the whole day from a WakeOP case is analyzed and periods for reduced separation (green line) is indidcated. The corresponding cross and head wind band widths in the predicted wind profiles along the glide path are shown as well indicating the often large variability of cross wind along the glide path. In this example cross wind can vary by up to 10 m/s, and even larger variation can be found for the head wind.

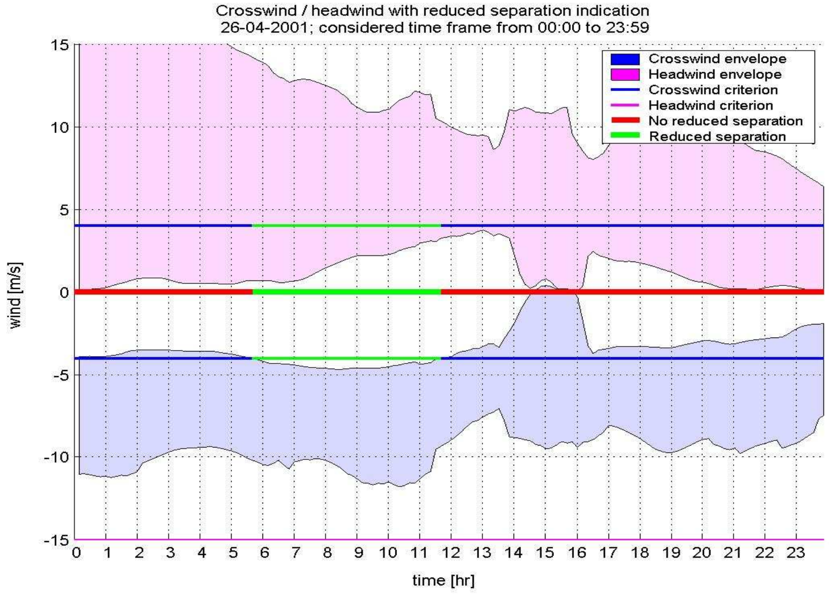


Figure 60 – Analysis of NOWVIV data by SMP (April 26th 2001)

Figure 61 shows how the NOWVIV forecast at an airport agrees with the locally measured wind profile and how errors in wind speed and direction affect the cross wind forecast error. In this example the cross wind bias is typically between -2 and 2 m/s. The RMS error of wind speed is on the order of 2.5 m/s.

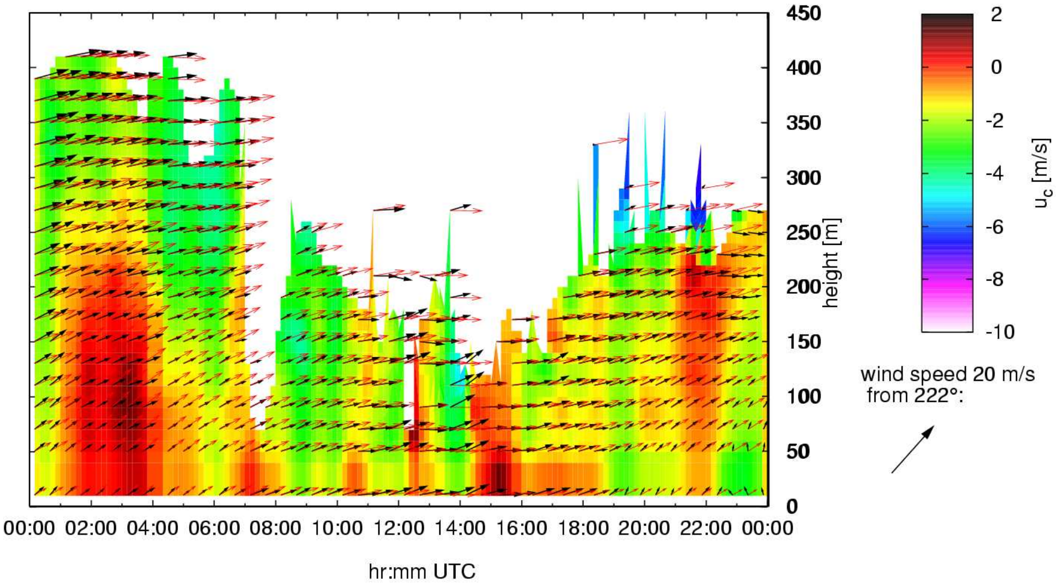


Figure 61 – Difference between observed and predicted cross wind (colored plot). In addition the observed (in black) and predicted (red) wind vector are plotted upon the cross wind difference for the WakeOP day 5, 26.04.2001. The vector scale is given for a wind speed of 20 m/s together with the runway orientation in Oberpfaffenhofen

Figure 62 shows an example where the output of the predictors (which are used to compute the Wake Vortex Vectors for the ATCo HMIs are compared to actual wake measurements (the ATC-Wake detector). In case of a mismatch (e.g. wake is observed in the safety corridor at the proposed separation whereas the predictions indicated no presence of a wake vortex) a warning is issued to ATCO indicating the existence of a possible hazardous situation.

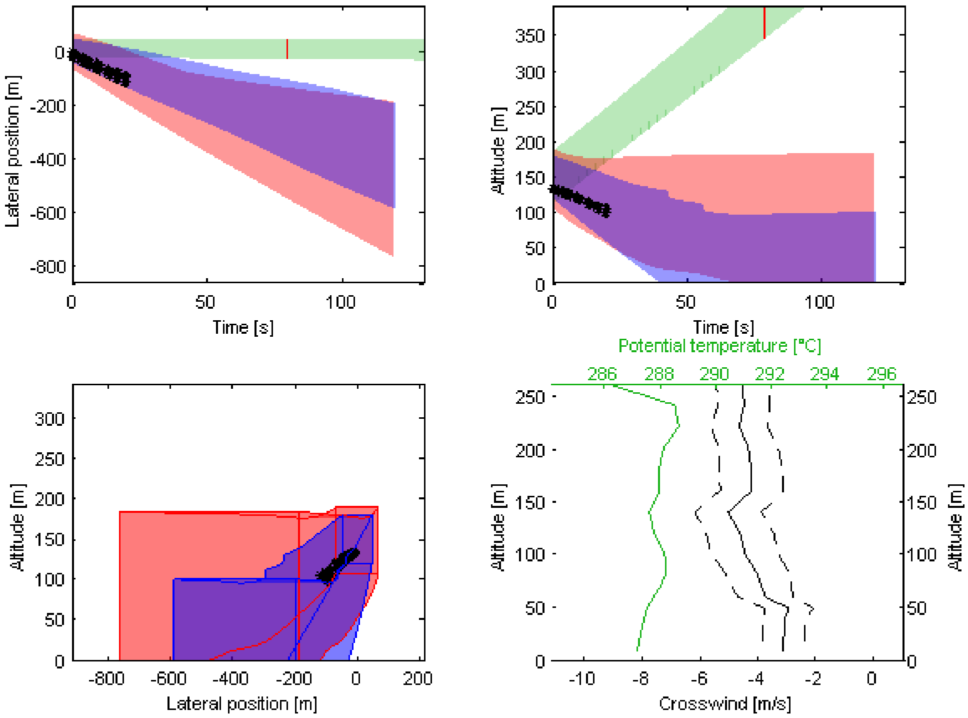


Figure 62 – Monitoring_And_Alerting tool output for the WakeOP day 5 (measurement number 12). Shaded in red the P-VFS prediction and shaded in blue the P2P one. Shaded in green the glide slope corridor selected for the simulation (here the ICAO one). The red vertical line into the green area is the minimum separation suggested by the SMP. On the bottom-right are displayed the temperature (in green) and cross-wind (mean cross-wind in solid and the uncertainties in dash) profiles

A short term solution to deploy ATC-Wake Integrated Platform on Airport is to use existing primary ATC radar capacities or their upgrades. We have proved in the present study that Wind field could be estimated by using SKEWIND tool processed on sequence of radar reflectivity from opportunity rain clouds in wet weather conditions. This radar reflectivity images could be provided by weather channel of primary ATC radar until **80 Nm.** Doppler waveforms of primary ATC radar could be also exploited to extract wind Doppler information to enrich wind field estimation but also for turbulence mapping (turbulence information is one of the information needed by WV predictor : P-VFS). By analysis of key elements of ATC radar Doppler Waveform characteristics, it is felt that ATC radar would be a good candidate to monitor wake vortex in real time in wet weather conditions. However, a dedicated test campaign is recommended to show that this concept will work with sufficient reliability.

9 Conclusions and recommendations

9.1 Conclusions

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. Nevertheless, today, there is no link of Wake Vortex information 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.

The main objective of WP2000 "Integrated system design and evaluation" was to develop and build the ATC-Wake *Integrated Platform*. A further objective was evaluation of technical feasibility of installation of the ATC-Wake at European airports. This system is designed according to requirements imposed by the ATC environment on one side and capabilities of weather and wake forecast and monitoring equipment on the other side. The work included.

- Development of technical concepts for the integrated platform, including its subsystems;
- Qualitative assessment and selection of the technical concepts;
- Design and specification of weather forecasting and monitoring tools;
- Specification, selection and adaptation of wake vortex predictors;
- Design and specification of ATC Human Machine Interfaces;
- Development of a SAS (Separation Advisory System);
- Development of the functional integrated system as a virtual platform;
- Testing of the integrating platform and evaluation of technical feasibility of building and (subsequent) installation of an integrated system at European airports.

The ATC-Wake Operational System comprises different subsystems, including weather forecast, now-casting, and monitoring systems, wake monitoring systems, wake prediction systems, separation mode planner, and Human Machine Interfaces (HMI) for the air traffic controllers. It includes four new functional components which interface with several existing and/or enhanced ATC system components:

- *New components: Separation Mode Planner, Wake Vortex Predictor, Wake Vortex Monitoring and Alerting, and Wake Vortex Detector;*
- *Existing ATC systems***:** AMAN, Flight Data Processing System & Surveillance Systems
- *Enhanced ATC system:* Meteorological Systems, ATC Supervisor HMI and ATCo HMIs. For the Meteo systems enhancements in prediction and update rates are foreseen and the HMI's for supervisor and ATCo are extended with ATC-Wake symbology.

The ATC-Wake IP is an essential first ATC-wake system development step, in which a set of key tools and data bases have been integrated, using SPINEware middleware technology. The technical feasibility of the integrated *system* has been evaluated by experimental simulations with the integrated *platform*. It has been shown that the functional integration of the components is successful and safety and capacity improvements may be realised by using the integrated *system* at an airport. This however depends on local circumstances and may require improved quality of in particular weather forecast and now-casting capabilities.

In the ATC-Wake IP, a distinction can be made between (existing) airport systems, the newly designed Separation Advisory System (SAS), and the Human Machine Interfaces (HMI). The main findings with respect to these system elements are given in the following.

AIRPORT SYSTEMS: ATC-Wake Integrated Platform has emulated existing Surveillance Systems (primary/secondary radar with baro-altimeter) for aircraft localisation on an airport during departure/arrival phases. The system has been coupled with Meteorological Systems.

- **Meteo Systems**: the ***Weather forecasting*** (***NOWVIV*** **:** Now-casting Wake Vortex Impact Variables) requires as input *External Weather forecast*, which denotes forecasts from the operational weather forecast from the national weather service (e.g. DWD in Germany , UK Met Office in UK, Meteo-France in France, or KNMI in the Netherlands). In order to have NOWVIV operational on an airport, it requires an effective interface connection with a high resolution mesoscale weather forecast model (e.g. 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 and which should continuously assimilate data from weather observation systems (the weather monitoring may consist of Radar, Profiler measurements or any other data source around the airport environment.). Current NOWVIV resolution is 2.1 km laterally and 12-50 m vertically and its time update rate is compliant with the resolution needed for Separation Mode Planner and Wake-Vortex Predictor systems. It has been demonstrated that NOWVIV provides meteorological profiles about every nautical mile along the glide path used by the Separation Mode Planner to decide on the safe separation mode. It has also been demonstrated, using real Poldirad data, that the ***SKEWIND*** module could also provide, in rainy weather, wind profiles about every nautical mile along the glide path that could be ingested to the Wake-Vortex Predictor. The performance of NOWVIV could be improved for the model forecast, by locally measured data from lidar, radar and sodar.
- **Surveillance Systems:**: The ATC-Wake IP emulates existing Surveillance Systems (primary/secondary radar with baro-altimeter) for aircraft localisation. We could envisage to improve this system by transmitting weather information measured on board (pressure, wind) by secondary radar or ADS-B system. This kind of information could be useful for the Wake Vortex Predictor to have more accurate head- and crosswind measurements.

SEPARATION ADVISORY SYSTEM (SAS): The SAS integrates ATC-Wake components: a Separation Mode Planner based on a weather forecasting system in combination with a wake vortex safety management system, a Predictor based on the weather now-casting system and on a wake vortex prediction system, a Detector based on weather and wake sensors, and a Monitoring and Alerter which notifies controllers in case of a discrepancy between prediction and detection information. The components are discussed below:

- **Separation Mode Planner (SMP)**: Experiments with the ATC-Wake Integrated Platform have shown that the SMP can determine the applicable separation mode (ICAO mode or ATC-Wake mode) and advise about minimum aircraft separation (advisory includes expected time for future mode transitions and an indication of aircraft separation minimum applicable). The determination of separation mode is dependent on quality of meteorological forecast data. Changes of separation mode could 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. The SMP relies on forecast data provided by weather forecasting systems, such as NOWVIV.
- **Wake-Vortex Predictor**: This tool predicts for individual aircraft the Wake Vortex behaviour ("wake vortex vector") in the pre-defined arrival or departure area(s). It has been shown that prediction could be performed using real-time available meteorological 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. It appears that the quality of wake vortex prediction is directly related to the quality of input data (meteorological data, radar data). A safety buffer has to be applied to satisfy accuracy requirements of ATC users. The input data should consist of the most recent meteorological now-cast data as well as ground or down-linked airborne measurements (wind/temperature profiler, wind/ temperature aloft). The prediction could be updated in short intervals (e.g. 1 min) and be verified with measurements of wake vortex behaviour of preceding aircraft. 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). The Weather Data Analyser, from Weather Systems, provides best-guess meteorological fields combining data from the various measurement sensors (Weather Data, Radar Data Processing: Wind field estimated by "SKEWIND") and Weather Forecasting. Weather forecast data will be needed to fill in regions of sparse observational data. The Wake Predictor requires as further input airport and aircraft data.

  Two main European real-time models have been validated for use in the Predictor: the "Probabilistic use of the Vortex Forecast System (P-VFS)" and the "Probabilistic Two-Phase Decay" model (P2P). The output of the Wake Vortex Predictor is the "Wake Vortex Vector" (WVV) of an aircraft in the so-called critical area, which is presented as an enhancement on the Plan View Display (PVD) showing the information received from the airport radars, combined with flight track data (call sign, aircraft type height, speed, etc.).

- **Wake-Vortex Monitoring & Alerting**: This subsystem alerts ATCO in case of significant discrepancy between WV detection and prediction information which increases the risk of a wake vortex encounter, or in case of a failure of one or several system components. Its design is kept simple (no connection to airborne equipment is assumed, no use of aircraft behaviour model for WV encounter is assumed). An alarm is raised in case of a discrepancy between prediction and detection information. The Tower controller for final approach shall, in case of an alarm, advise the pilot (2nd aircraft) about necessary actions to be taken, e.g. go around; provide the AMAN or adjacent ATCO (Intermediate) with information concerning his/her instructions on aircraft go-around; and/or advise pilots to delay departures. If the wake detector has no observation available (no wake measurement data in data base available), the ATC-Wake system will also issue a warning, indicating that the Monitoring and Alerting component is not working. A warning is raised if one or both of the tools (predictor/detector) are missing data. Alarms and warnings are then sent to the ATCO HMI. In case of an alarm, the colour of the Wake Vortex Vector, displayed on Tower Controller HMI, will change to orange and an audio alarm will also be raised.

- **Wake-Vortex Detector**: It 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). Operationally, this detection should be performed using ground-based equipment (e.g. pulsed LIDAR or Doppler Radar) which scan pre-defined parts of the considered critical area (e.g. ILS glide path) in pre-defined windows. No connection to airborne equipment is assumed but detection could be complemented using airborne equipment (see I-WAKE project). We recommend that complementarities of radar, sodar and lidar should be better understood; the performances claimed for lidar microphones and long-pulse sodars should be independently assessed; and the technical state of the art should be frequently reviewed. Radar campaign should be made to validate monitoring capacity in rainy weather. Lidar, with its fine precision of both spatial and Doppler measurement, is a good tool available to quantify the vortex strength and position, but it has necessary drawbacks: for example, it is not suited to very fast wide-field-of-view scanning, and it dislikes wet or cloudy weather. Lidar and radar (which is usually better in bad weather) are thus complementary tools. Several issues need to be better understood: the complementarities of radar, sodar and lidar: e.g. extending the use of ATC radars in wet conditions, when lidars are handicapped; the performance claims by the manufacturers of LP2C sodar and SOCRATES lidar; passive acoustic techniques and RASS may be important, but we have not enough information to advise.

HUMAN-MACHINE INTERFACES

- The, in terms of usability and acceptability most promising, HMIs for all the ATC controllers (**Supervisor, Approach and Tower controller**) have been specified. Initial HMI concepts have been based on the ATC-Wake user requirements, resulting in three different display formats, which were evaluated in a real-time simulation experiment. One display format, the so-called "Variable Wake Vortex Vector", was preferred by all controllers. The preferred HMI has therefore been specified on basis of this Vector, though the initial HMI concept included all three different display formats, and simulation experiment have also been described. More testing might be needed to find a good balance between timely alerts and an annoying rate of false alerts. Because the specification of the HMI is the first iteration in the development of a (certified) HMI, follow-up iterations have been performed as part of the operational feasibility assessment (WP4000). Such iterations may also include actual field trails at an air traffic control centre, and even a transition plan for the actual implementation of the operation.

9.2 Recommendations

The recommendations call for an implementation of the system at an airport in order to optimize individual components and to find the best sensor combination with respect to the specific airport conditions, and to test the system in a shadow mode for a longer time period to assess safety and capacity gains. A crucial issue to consider before actual implementation will be possible is the provision of sufficient proof that performance requirements will be met.

In this respect, it is noted that, since 2005, the application of the European Operational Concept Validation Methodology (E-OCVM) and the use of the Validation Data Repository (VDR) is required by all new ATM-related projects, in particular within the collaboration between the EC and EUROCONTROL in the ATM Master Plan and also along the ACARE Strategic Research Agenda SRA-2. The E-OCVM aims to provide a common approach to all projects contributing to the validation of operational concepts from early identification to full pre-operational validation as a pre-requisite for industrialisation and operational introduction. *A Safety Case, Human Factors Case, Benefits Case, and a Technology Case will be needed to be produced before the ATC-Wake system can be used at European airports.*

It is recommended to continue with operational testing and validation through shadow mode field as an FP7 Integrated Project (with a follow-up of I-Wake and TALIS). These projects are important in view of potentialities of data-link for on-board/ ground exchange of wake vortex information. Such integration of an on-board system with ATM in support of reduced separation is addressed in more detail in the ATC-Wake Technological Implementation Plan.

Annex A ATC-WAKE IP Requirements

ID	Description	Status	Priority
SS – 01	**IP connection**	**IA**	**Ess**
The ATC-Wake Integrated Platform shall integrate and connect the ATC-Wake System Components (SMP, Predictor, Detector, Monitoring and Alerting) with emulators of existing/enhanced ATC systems.			
Traced to : *System Requirement : SR-01* *Verification method : feasibility test*			
SS - 02	**IP Interaction with the ATC environment**	**IA**	**Ess**
The ATC-Wake platform shall be adapted to and interact with the ATC environment.			
Traced to : *Operational Requirements : OP-4* *Verification method : feasibility test*			
SS - 03	**IP operation in heterogeneous distributed computer Network**	**IA**	**Ess**
The ATC-Wake Integrated Platform shall operate in a (heterogeneous) distributed computer network. (The components mentioned in requirement SS-01 are located at different partner sites. In other words, these components will operate in a distributed computer network. If the components require different types of hardware, this computer network will be heterogeneous as well.)			
Traced to : *Verification method : feasibility test*			
SS – 04	**Communication between partners computer**	**IA**	**Ess**
Physical communications between the computer networks of the companies involved shall be existent or established. (To enable the components to collaborate in a distributed computer network, connections between these networks have to be existent. Such physical communications could be established through, for instance, internet connections or external telephone lines.)			
Traced to : *Verification method : feasibility test*			
SS - 05	**Restricted Access to ATC-WAKE IP**	**IA**	**Ess**
The ATC-Wake platform shall enable access to the platform and to its components (including data) to authorised persons only. (Communication between companies immediately raises the issue of security. This issue concerns both the access to (a part of) the computer network of other companies as well as the transfer of information or data between companies. Typical issues are firewalls and secure data exchange. The issue of firewalls could be resolved by the creation of so-called demilitarised zones and the use of virtual private networks; secure data exchange could be ensured through dedicated telephone lines and/or the ssh communication protocol.)			
Traced to : *Verification method : feasibility test*			

ID	Description	Status	Priority
SS – 06	**Secure Data Exchange of ATC-WAKE IP**	**IA**	**Ess**
The ATC-Wake platform shall ensure a secure data exchange.			
Traced to : *Verification method : feasibility test*			
SS – 07	**ATC-WAKE IP Support of components**	**IA**	**Ess**
The ATC-Wake platform shall support the integration of new and updated ATC-Wake components.			
Traced to : *Verification method : feasibility test*			
SS – 08	**Data conversion for ATC-WAKE IP**	**IA**	**Ess**
The ATC-Wake platform shall enable data conversion between the formats of the data of the ATC-Wake components.			
Traced to : *Verification method : feasibility test*			
SS – 09	**ATC-WAKE IP HMI**	**IA**	**Ess**
The ATC-Wake Integrated Platform HMI shall be tailored for each type of user and be integrated with the ATC controller's HMI, if necessary.			
Traced to : *The ATC-Wake document D1_specifies what type of ATC-Wake information is provided, used and/or needed by what type of user (e.g., airport ATC supervisor and ATC controller)* *User Requirements : UR-01 , UR-04* *Verification method : feasibility test*			
SS – 10	**ATC-WAKE IP HMI FORMAT FOR USER**	**IA**	**Ess**
The HMI shall present relevant information in an appropriate format to the user.			
Traced to : *The main functionality of the HMI is to present relevant information to the ATC controllers and supervisor. The ATC-Wake document D1_4 specifies what type of ATC-Wake information is provided, used and/or needed by what type of user (e.g., airport ATC supervisor and ATC controller). (Additional user requirements for the different foreseen actors have been defined in WP1000 : D1_3).* User Requirements : UR-01 , UR-04 *Verification method : feasibility test*			
SS – 11	**ATC-WAKE IP HMI TAILORIZATION**	**IA**	**Ess**
The HMI shall be tailored for each type of user and be integrated with the ATC controller's HMI, if necessary.			
Traced to : *Verification method : feasibility test*			

<table>
<tr><th>ID</th><th>Description</th><th>Status</th><th>Priority</th></tr>
<tr><td>SS – 12</td><td>ATC-WAKE IP MIDDLEWARE ACCESS</td><td>IA</td><td>Ess</td></tr>
<tr><td colspan="4">The ATC-Wake middleware shall provide selected users access to the ATC-Wake platform.</td></tr>
<tr><td colspan="4"><i>Traced to :</i>
Users of the ATC-Wake platform, in the evaluation phase, should be able to operate this platform from their own desktop computer. This operation includes the control and activation of the various components. To operate the platform in the heterogeneous and distributed computer network, a middleware technology is required. The middleware technology should support the interoperability, inter-working, openness and integration.
<i>Verification method : feasibility test</i></td></tr>
<tr><td>SS – 13</td><td>ATC-WAKE IP MIDDLEWARE INSTALLATION</td><td>IA</td><td>Ess</td></tr>
<tr><td colspan="4">The ATC-Wake middleware shall be installed on the host of each ATC-Wake component in order to integrate this component with the middleware.</td></tr>
<tr><td colspan="4"><i>Traced to :</i>
<i>Verification method : feasibility test</i></td></tr>
<tr><td>SS – 14</td><td>ATC-WAKE IP MIDDLEWARE AS SINGLE VIRTUAL COMPUTER</td><td>IA</td><td>Ess</td></tr>
<tr><td colspan="4">The ATC-Wake middleware shall present the ATC-Wake Integrated Platform as a single virtual computer on the user’s desktop computer.</td></tr>
<tr><td colspan="4"><i>Traced to :</i>
<i>Verification method : feasibility test</i></td></tr>
<tr><td>SS – 15</td><td>ATC-WAKE IP MIDDLEWARE FOR USER INTERACTION</td><td>IA</td><td>Ess</td></tr>
<tr><td colspan="4">The ATC-Wake middleware shall enable the user to interact with the ATC-Wake Integrated Platform.</td></tr>
<tr><td colspan="4"><i>Traced to :</i>
<i>Verification method : feasibility test</i></td></tr>
<tr><td>SS – 16</td><td>ATC-WAKE IP MIDDLEWARE FUNCTIONING</td><td>IA</td><td>Ess</td></tr>
<tr><td colspan="4">The ATC-Wake middleware shall
• Chain local/remote ATC-Wake components into workflows;
• Group input/output data files into input/output data containers;
• (Automatically) execute workflows with local/remote ATC-Wake components and data converters;
• (Automatically) activate local/remote ATC-Wake components and data converters;
• (Automatically) set default options, arguments, and parameters of local/remote ATC-Wake components and data converters;
• (Automatically) transfer input/output data files between local/remote ATC-Wake components;
• (Automatically) filter input/output data files between local/remote ATC-Wake components.</td></tr>
<tr><td colspan="4"><i>Traced to :</i>
<i>Verification method : feasibility test</i></td></tr>
<tr><td>SS – 17</td><td>ATC-WAKE IP MIDDLEWARE CONTROL</td><td>IA</td><td>Ess</td></tr>
<tr><td colspan="4">The ATC-Wake middleware shall monitor and control the ATC-Wake components and data converters.</td></tr>
<tr><td colspan="4"><i>Traced to :</i>
<i>Verification method : feasibility test</i></td></tr>
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<tr><th>ID</th><th>Description</th><th>Status</th><th>Priority</th></tr>
<tr><td>SS – 18</td><td>ATC-WAKE IP MIDDLEWARE SECURITY</td><td>IA</td><td>Ess</td></tr>
<tr><td colspan="4">The ATC-Wake middleware shall support restricted access to the ATC-Wake platform and its components (including data), and secure data exchange.</td></tr>
<tr><td colspan="4"><i>Traced to :</i>
<i>System requirements : SS-05 and SS-06</i>
<i>Verification method : feasibility test</i></td></tr>
<tr><td>SS – 19</td><td>ATC-WAKE IP MIDDLEWARE SECURITY</td><td>IA</td><td>Ess</td></tr>
<tr><td colspan="4">The ATC-Wake middleware shall support restricted access to the ATC-Wake platform and its components (including data), and secure data exchange.</td></tr>
<tr><td colspan="4"><i>Traced to :</i>
<i>System requirements : SS-05 and SS-06</i>
<i>Verification method : feasibility test</i></td></tr>
<tr><td>SS – 20</td><td>DATABASE IN ATC-WAKE IP MIDDLEWARE</td><td>IA</td><td>Ess</td></tr>
<tr><td colspan="4">The ATC-Wake Integrated Platform shall integrate and connect the ATC-Wake database, and the ATC-Wake middleware shall be stored on the host of the ATC-Wake database in order to integrate this database with the middleware.</td></tr>
<tr><td colspan="4"><i>Traced to :</i>
<i>Verification method : feasibility test</i></td></tr>
<tr><td>SS – 21</td><td>ATC-WAKE IP DATABASE</td><td>IA</td><td>Ess</td></tr>
<tr><td colspan="4">The ATC-Wake database shall mainly be used for data exchange between ATC-Wake components.</td></tr>
<tr><td colspan="4"><i>Traced to :</i>
<i>Verification method : feasibility test</i></td></tr>
<tr><td>SS – 22</td><td>ATC-WAKE IP DATABASE FORMATS</td><td>IA</td><td>Ess</td></tr>
<tr><td colspan="4">The ATC-Wake database shall consist of data structures, data definitions, data formats, and management system.</td></tr>
<tr><td colspan="4"><i>Traced to :</i>
<i>Verification method : feasibility test</i></td></tr>
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