WakeNet3-Europe

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Aircraft Wake Vortex
State-of-the-Art & Research Needs

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4.1 Ground-based Advisory Systems

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4.1.1 Overview

The main objective of a Ground-Based Advisory Systems is to punctually or permanently reduce landing and departure wake turbulence separations and, therefore, to increase the runway throughput in such a way that it safely absorbs arrival demand peaks and/or reduces departure delays without jeopardizing flights safety.

The Ground-Based Advisory System will be able to deliver in real time, the position and strength of the wake vortices, predict their behaviour, monitor the air traffic situation with regard to the hazard of wake encounters and possibly alert ATC controllers in case the flight safety is, or is predicted to be affected.

4.1.2 State-of-the-art

4.1.2.1 SESAR project 12.2.2 : Runway Wake Vortex Detection, Prediction and Decision Support Tools

The main objective of this project is to define, analyze and develop a verified wake turbulence system according to the operational concept developed by the SESAR Project 6.8.1. The aim is therefore to punctually or permanently reduce landing and departure wake turbulence separations and, therefore, to increase the runway throughput in such a way that it safely absorbs arrival demand peaks and/or reduces departure delays without jeopardizing flights safety.

This global objective will be achieved by means of developing a Wake Vortex Decision Support System (WVDSS). This later will be able to deliver, in real time, the position and strength of the wake vortices, predict their behaviour, monitor the air traffic situation with regard to the hazard of wake encounters and possibly alert ATC controllers in case the flight safety is, or is predicted to be affected. The WVDSS will take into account actual and forecast weather information as well as airport specific meteorological conditions, aircraft characteristics (generated wake vortex and encounter vulnerability), air traffic situation and airport runway layout. The WVDSS will be composed of several components; sensors, weather data base and wake vortex advisory system (WVAS). These components included in the WVDSS will be validated and deployed at airports in order to optimise the runway throughput and reduce delays.

As the WVDSS will be developed in conjunction with P6.8.1 (discussed in §3.4) it will be used for verification and validation purposes.

The P12.2.2 addresses the three steps of the SESAR concept story board:

- Step 1 refers to Time Based Separation (TBS) – Acquisition and processing of wake vortices information as well as headwind. The aim is to verify the position, strength and behaviour of the wake vortices depending on headwind strength in arrivals in order to evolve from distance based separation to time based separation. As well, a first release of the WVDSS prototype will be developed which will demonstrate this capability. This demonstration will include an in-situ verification campaign (XP1 in CDG).
- Step 2 refers to Weather Dependent Separation (WDS) – Prediction of wake vortex behaviour in changing weather conditions. The system will be updated with all the components linked to wind, weather nowcast and forecast, including real-time prediction of micro-scale terrain-induced turbulence close to the airport. The goal is to assess in real-time the position and strength of the wake vortices and to predict their behaviour for both departures and arrivals, in order to demonstrate the possibility to evolve from a time based separation to a weather dependent separation taking advantage of any favourable meteorological conditions (e.g. crosswind). This demonstration will include an in-situ

verification campaign (XP2 in CDG). All building blocks regarding weather monitoring will be developed / customized.

- Step 3 refers to Pair Wise Separation (PWS) – Demonstration of the capacity of the WVDSS to dynamically deliver separation for each aircraft pair. This requires an aircraft characteristics database and the customisation for different airports and runway configurations. The system will be refined to reach two main goals:
  - Perform a first demonstration of the pair wise separation concept. With a partial aircraft wake vortex characteristics database provided by P6.8.1, it will be demonstrated that the WVDSS could determine a dynamic pair wise separation, taking in account the real-time weather conditions as well as the aircraft sensitivity to wake vortex.
  - Demonstrate the system adaptability to other runway layouts.

The demonstrations of step 3 will be performed in platform tests and verified in an in-situ campaign. Building blocks related to pair wise separation (aircraft characteristics database, algorithms…) will be developed or customized.

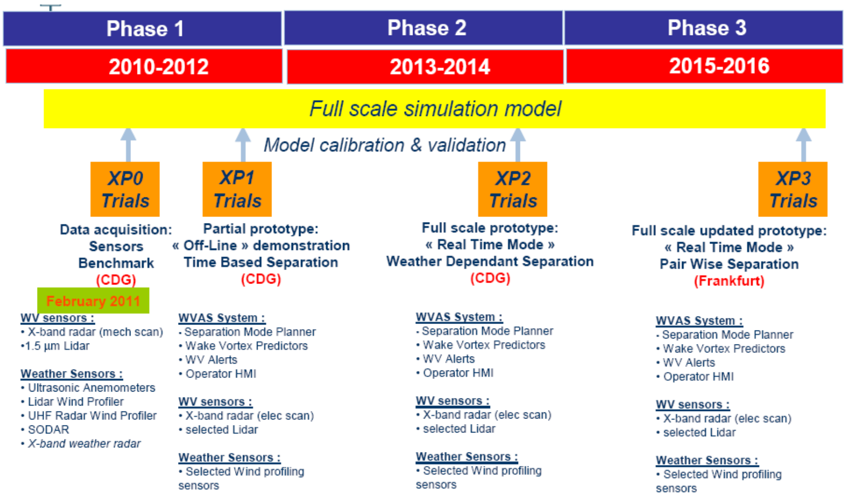

Figure 11: Project Overview SESAR WP 12.2.2.

Current Status

The global architecture of the WVDSS is depicted in Figure 11. It is composed of several components, for instance meteo sensors, meteo nowcast and forecast, wake vortex sensors, WVAS, likewise interface with the external weather observations, ATC system and stakeholders' HMI.

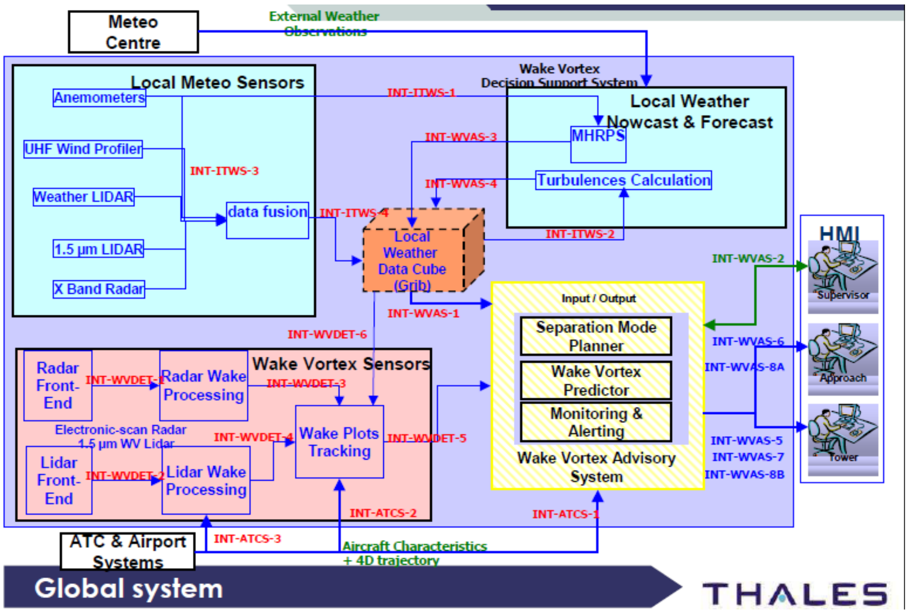

Figure 12 : Global Architecture of WVDSS

Ground-based Wake Vortex Advisory System (WVAS) aims at processing meteorological information and air traffic situation in order to provide ATC stakeholders the means to decide and apply reduced aircraft separation instead of current ICAO separation relative to wake vortex issue. The WVAS is composed of several components, for instance an Input/Output module, Separation Mode Planner, the Wake Vortex Predictor and the Monitoring and Alerting functions. A set of warning functions is also in force in order to provide encounter advisories in case an aircraft is, or is predicted to be, within a wake vortex hazards.

Meteorological information are forecast as well as nowcast information, these latest provided by means of sensors spread over the airport area and final approach area; i.e. along the glide slope. These information are gathered in a Local Weather Data Cube for further use by WVAS.

The WVAS is promised to provide real improvement in the way to monitor wake vortices transport and decay looking for reducing separations between aircraft as well as to increase flight safety by monitoring flight progress, alerting ATC stakeholders' in case one aircraft is, or is predicted to be within a wake vortex hazard and then for the ATC controllers to initiate appropriate action to resolve the situation. Then, this system will enable to reduce separation between aircraft in the final approach or departure, therefore will allow to increase runway throughput, and as a matter of fact increase airports capacity and reduce delays without jeopardizing flights safety.

The WVAS will be able to:

- Propose the separation mode to the supervisor: e.g. ICAO separation minima or reduced separation minima and time applicability of separation mode
- Process wind data including turbulence information and aircraft trajectory to provide spacing (chevron position for display purpose)
- Monitor wake vortices (wake vortex predictor output, decay and transport) against aircraft trajectories and provide encounter advisories to controller HMI for display purpose in case of actual or predicted wake vortex hazard
- Manage the wake vortex data (4D data) from wake vortex sensors function. In case of discrepancies between wake-vortex sensors and predictor an alert being generated

There are a number of tasks which have been achieved in 2010 and 2011 as part of Phase 1 of the work package:

- Preliminary system requirements definition
- System requirements definition for phase 1 (Time Based Separation)
- Preliminary system architecture analysis
- Initial technology studies
- Testing platform and tools requirements for phase 1 (Time Based Separation)

A sensors benchmark campaign has been conducted at Paris Charles de Gaulle airport (XP0 trials) and weather related studies will be performed in conjunction with SESAR project 15.4.9a.

Currently, the WVAS is in the development phase. It is foreseen that the components part of the WVAS i.e. I/O module, Separation Mode Planer, Wake Vortex Predictor and Monitoring and Alerting will be integrated as well as being connected to Local Weather Data Cube, Wake Vortex Sensors, Air Traffic Situation and Human Machine Interface by mid-2012. Off-line experimentations are planned for Q3 and Q4 2012 in Paris CDG.

Capacity Analysis

This SESAR Work Package takes up the findings of numerous weather dependent projects as ATC-Wake and CREDOS but also benefits from knowledge of the project partners (e.g. parts of DLR WSVBS will be further developed and tested during the project). The different evolution phases (Phase 1 to Phase 2) will provide demonstrations of system capabilities and evolve gradually from a Time-Based Separation to a Weather Dependent Separation to a Dynamic Pair Wise Separation concept as shown in Figure 11. Therefore, a need to assess the capacity benefit of the system will arise for each implementation phase.

4.1.2.2 Wake Vortex Prediction and Monitoring System (WSVBS)

The Wake Vortex Prediction and Monitoring System (WSVBS) (Holzäpfel et al. 2009, Gerz et al. 2009) has been developed to tactically increase airport capacity for approach and landing on closely-spaced parallel runways and single runways. The WSVBS supports dynamic adjustment of aircraft wake vortex separations dependent on weather conditions and the resulting wake vortex behaviour without compromising safety. WSVBS uses meteorological measurements and dedicated numerical weather prediction (see section5.3) in order to predict envelopes for probabilistic wake vortex behaviour (with P2P, see §5.1) and the resulting safety areas (with SHAPe, see §5.6) in several gates extending from final approach fix to threshold. A LIDAR monitors the correctness of WSVBS predictions in the most critical regions at low altitude. Integration with the DLR's arrival manager AMAN has also been demonstrated.

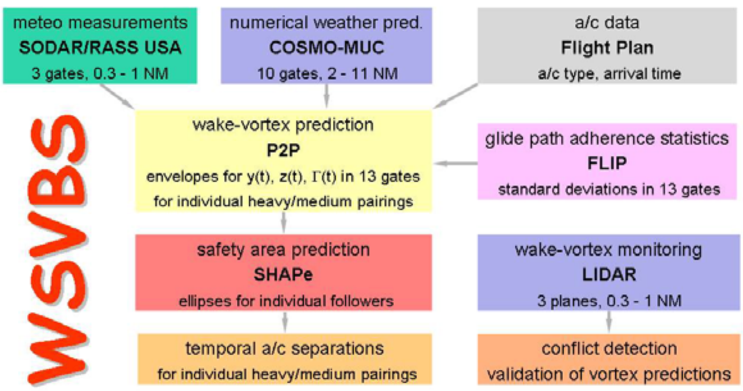

Figure 13: Flowchart of the WSVBS.

The aim is for a tactical increase in airport capacity for both approach and landing phases of flight. Every 10 minutes the WSVBS delivers minimum safe aircraft separation times for the next hour, which are translated into operational modes aiming at tactically improving capacity to reduce delays. During a performance tests at Frankfurt and Munich airports the system was stable and the predicted minimum separation times were confirmed by measurements.

The WSVBS system allows for various capacity-improving procedures to be applied, such the “Staggered” (STG) procedure, which allows parallel runways to be used independently from each other, but obeying the radar minimum separation; the “Modified Staggered Left” (MSL) procedure, whereby the aircraft on the right (windward) runway are separated by the radar minimum from aircraft on the left (lee) runway; and the “Modified Staggered Right” (MSR) procedure, whereby aircraft on the left (windward) runway are separated by the radar minimum from aircraft on the right (lee) runway.

Current Status

From scientific and technological perspectives, the WSVBS has reached a mature and useful state. The elements of the WSVBS are generic and can therefore be adapted to other runway systems and airports. Recently the components of the WSVBS have been extended to the prediction of dynamic and time-based separations for individual aircraft type pairings landing on single runways (dynamic pairwise separations). Dynamic pairwise separations correspond to the favoured procedure foreseen in the final development stage of NextGen and SESAR. Improved weather prediction has been achieved employing time-lagged-ensemble prediction systems with assimilation of local meteorological measurements.

The capabilities and functionality of the advanced WSVBS were demonstrated during a field measurement campaign at Munich airport between 23 June and 15 September 2010 (Holzäpfel et al. 2011).

There are a number of further activities planned for the WSVBS within the Weather & Flying project which include:

- The preparation for implementing the WSVBS at an airport.
- A risk analysis and an assessment of the capacity gain of the WSVBS.
- Components of the WSVBS are also to be developed and tested within WP12.2.2 of the SESAR SJU.

Capacity Analysis

The system was tested and evaluated at Frankfurt International Airport (FRA) in 2007 for the closely-spaced parallel runway system 25L/25R within a performance test that lasted for 66 days (Gerz et al. 2009). The tests revealed that separations could have been decreased for 75% of the time. Taking into account the usual traffic mix, a capacity gain of *3%* could be reached. Additionally, delays could be significantly reduced using the WSVBS. The capacity investigations are based on the real-time and fast-time simulation tools ATMOS II (Air Traffic Management and Operations Simulator) and SIMMOD of the DLR, where the potential capacity benefit for FRA was assessed.

To establish a baseline, the simulations were initially performed using ICAO separations. The simulations were then matched with separations derived from WSVBS and re-run. The simulations included actual aircraft types and flight characteristics spanning a realistic distribution of wake vortex categories, demand peaks throughout the day, weather data, and the WSVBS proposed minimum wake vortex separations. The fast-time simulations covered a period of one month. New fast-time simulations are also planned, which will be based on the WSVBS predictions of the three-month Frankfurt campaign.

Currently the capacity gain is seen as *tactical* by the project consortium, i.e. delays and holding patterns could be decreased and avoided. Based on potential experience within such an operational system, even an increased number of flights could be allowed, yielding a strategic capacity gain.

4.1.3 Research Needs

Nevertheless, beyond SESAR, some hot spots may arise when deploying the WVDSS in TMAs.

- Some areas will not be (or sufficiently) equipped by sensors. This would prevent having enough meteo or wind information to feed WVAS, as well, prevent having information on the wake vortex decay, especially in the ILS interception point upstream areas, these information being mandatory in order to organize and increase traffic capacity well ahead from the ILS interception. If not, it will not be possible to derive maximum benefit from capacity gain possibly got in along the glide because of the scattered arrival traffic converging towards the ILS interception point. Therefore it could impede from spreading the system in the extended terminal major areas (TMA),
- Some models used in the WVAS i.e. Wake Vortex Predictor might be put on the spot when it is facing to high traffic capacity, especially in very dense TMAs,
- The Human Machine Interface (HMI) must be subject to Human Factor analysis and suite the ATC controllers. WVDSS focuses on sensors, meteo and WVAS sub systems rather than HMI.

As well, it might be of interest to ensure interoperability between wake vortex advisory system and its sister system i.e. the weather hazard advisory system.

Therefore, it is suggested that several studies and research are made in the coming years:

4.1.3.1 Aircraft used as a sensor

To derive maximum benefit from capacity gain possibly got in along the glide requires spreading WVDSS in the extended TMA.

The use of aircraft as a meteorological sensor, studies of meteorological data and aircraft trajectories downlink from aircraft by means of ADS-B or Mode-S radar as well as processing these data in the WVAS will be a means to enhance and refine wake vortex predictions, monitoring and alerting functions. It will allow spreading the WVDSS over the extended TMA, as such it might be considered as an enabler to increase WVDSS use over the TMA.

Studies and research will cover : Definition, standardization and use of meteo and aircraft trajectories in Downlink Aircraft Parameters (DAP), use of DAP in WVAS components i.e. separation mode planner, wake vortex predictor, monitoring and alerting functions, refinement of WVAS processing to cope with extended TMA needs.

4.1.3.2 Wake vortex model performances

Deploying the WVDSS in complex medium or high sized TMA requires the capability to process in real time huge number aircraft trajectories as well as to compute wake vortex prediction. Time consuming algorithms must be efficient in order to be in line with real time constraints of an ATC system. Therefore, studies and research will cover benchmarking, possibly adaptation and refinement of wake vortex predictor algorithms must be conducted to guaranty that WVAS could to be used in a real time Safety Nets system.

Identification of the required accuracy of the meteorological measurements and predictions and of the wake vortex predictions in order to achieve the required capacity gains. This approach may answer questions like: “Is an intended concept of operations likely to be realisable at all?” and “To which extent must the performance of the different sub-models be improved to enable a particular concept of operations.”

4.1.3.3 HMI ergonomic

Conduct operational experimentation on WVDSS HMI will enable ATC Controllers to suit the HMI. Studies and research will cover HMI refinement driven by ATC Controllers.

4.1.3.4 Integrated Weather Hazard solution & Sub-System Interoperability

In addition, some sub-systems related to WVAS are currently under definition, research and development phases e.g. Weather Hazard Advisory System (WHAS) or Integrated Terminal Weather System (ITWS). Another means to increase flight safety will be to :

- Study and develop Advisory System i.e. ITWS, for wind-shear, convective storm, volcanic ashes advisories, based on experience gained through WVAS.
- Fed and enhance WVAS sub-system with ITWS outcomes e.g. wind-shear, convective storm, possibly volcanic ashes for studying the interoperability between the two sub-systems i.e. WVAS and ITWS.

4.1.3.5 Risk Analysis

For any operational concept there is a need to establish a generally accepted methodology for a comprehensive risk analysis. Such a methodology can also be used to adjust all components of a wake vortex advisory system to appropriate and consistent confidence levels. The required confidence levels have a strong impact on the potential capacity gain of a wake vortex system and thus on the business case of wake vortex advisory systems.

4.1.3.6 Warning System for Increased Safety

ATC has notified interest in a wake vortex warning system that may prevent wake vortex encounters for the currently used aircraft separations in order to further increase safety. For this purpose the components of a warning system would have to be adapted to predict corridors of maximum risk combined with a risk threshold controlling the issue of warnings.