Candidate Technologies Survey of Airport Wind & Wake-Vortex Monitoring Sensors

Sensors for Weather & Wake-Vortex Hazards Mitigation

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***Abstract*— A new generation of low cost sensors has recently emerged, boosted by technological breakthroughs. These sensors will be key building blocks of critical Wake Vortex Advisory System and Integrated Terminal Weather Systems for Airport. We propose to make a survey of candidate technologies based on invited international guest keynote speakers & experts from Europe, USA & Asia for WAKENET-3 Europe workshop.**

Keywords- wind monitoring, wake-vortex monitoring, lidar, radar, weather channel of PSR radar, ADS-B Downlink.

I. INTRODUCTION

In March 2010, a specific workshop on "Wake-vortex & wind monitoring sensors in all weather conditions" (http://www.wakenet.eu/index.php?id=125) has been organized at Thales Research & Technology in south of Paris, France.

The conference was organized in the frame of the European relations set up between partners involved in WAKENET-3 Europe Coordination Action project (http://www.wakenet3-europe.eu/), and GREENWAKE project (http://www.greenwake.org/), both funded by European FP7 program.

WAKENET-3 Europe Workshops cycle, initiated in January 2009 with a first plenary workshop on "Wake turbulence safety in future aircraft operations" coordinated by Thales & Airbus and hosted in Thales University Campus (http://www.wakenet3-europe.eu/index.php?id=63) with more than 120 attendees, has dedicated this 2010 specific workshop to Radar, Acoustic and Lidar Sensors for monitoring Wake-Vortex hazards and Wind on airport in all weather conditions.

A new generation of low cost sensors has recently emerged, boosted by technological breakthroughs (e.g. : Electronic scanning and/or High Power X-band Radar, Electromagnetic Multi-static Radars, Coherent 1.5 micron Lidar, UV Lidar, Forward-Looking Interferometer, …). These sensors will be key building blocks of critical Wake Vortex Advisory System that will be developed in SESAR P12.2.2 "Runway Wake Vortex Detection, Prediction and decision support tools". In this future system, that should be operational in all weather conditions, Wind measurements with accurate/high space resolution and fast time update rate will be required to be ingested in "Wake Vortex Predictor". Wake-Vortex detection/localization and strength assessment (circulation in m^2/s) will be a second fundamental requirement for system Safety Net.

We propose to make a survey of candidate technologies based on invited presentation of international guest keynote speakers & experts from Europe, USA & Asia (34 talks, equally distributed between academic labs, SMEs, Industries and End-Users, have covered international state-of-the-art and testify the world wide interest for topics covered by WAKENET-3 Europe).

The European Air Traffic Management Plan [14] of the Single European Sky Research (SESAR) project foresees at ATM Service Level 2 the implementation of dynamic adjustment of Separations based on real-time detection of wake vortex. The combination of Radar and Lidar sensors is an important enabler to implement this service level in all weather conditions.

For the detection of wake vortices, RADAR and LIDAR sensors are complementary in terms of ambient weather conditions. Wake-Vortex Advisory Systems could integrate both sensor technologies utilized in a hybridized approach to detect this hazard in all weather conditions. For Integrated Terminal Weather Systems, LIDAR and RADAR are also mandatory to monitor wind in wet and dry weather conditions.

II. RATIONALE

Adverse meteorological conditions & weather hazards have a tremendous impact on ATM with limitations of: Capacity, Flexibility and Safety. Impacts of weather on aviation are huge and are causes of delays (1/3 of all), extra fuel consumption & associated costs and Greenhouse emission increase. Main consequence is more than 900 Meuros overall extra costs per year in Europe. The fuel savings by aircraft delay absorption impact significantly on: New Green constraints, Airline costs and Airport revenues.

A significant part of these costs could be reduced by improving Wind nowcasting/forecasting (e.g. wind-shear

event,…), monitoring & alerting Wake Vortex hazards, tracking of convective weather evolution (heavy rain, hail, Lightning stroke,…), detecting Icing conditions and reducing Low-visibility conditions. But, Implementation of solutions requires a tight cooperation of MET service providers, ATM (ANSPs, industry), Airlines and Aircraft (pilots, industry).

Improving exploitation of Meteorological information during flight planning (e.g. flight route optimization), flight execution (e.g. through ATC, AOC and pilots increased collaboration) and flight critical phases (e.g. through wake vortex & wind hazard alerts from ground to aircraft) would directly impact flight flexibility, capacity and safety

Better Weather Information exploitation will favor emergence of new or improved services :

- Weather CDM (Collaborative Decision Making): prediction of capacity based on winds, icing, visibility / ceiling, …
- ITWS (Integrated Terminal Weather Systems): dedicated nowcasting / forecasting infrastructure to improve safety and capacity
- AMAN / DMAN tools using MET data (wind, windshear, visibility, wake vortex transport & decay, runway surface conditions,…)

In this framework, new solutions need to be introduced in a stepwise approach: Extension of weather observation infrastructure (e.g. turbulence, icing, wind shears,… with accuracy relevant to system requirements), Observation assimilation: in weather nowcasting / forecasting for high confident prediction, Progressive exploitation of MET information (Semi-automated with « man in the loop », Shared by all users), Enhanced weather global picture in cockpit (ground / on-board merge of MET information, Safe re-routing proposals) and Extension of ground-air datalink capacity.

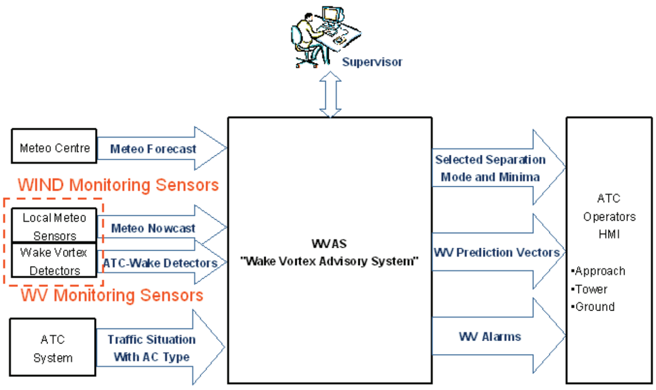

Figure 1. Wind & Wake-vortex sensors mandatory for Wake-Vortex Advisory system

These new capabilities will depend on budget investment on following R&D topics: Sensors (Radar, Lidar,…) to monitor weather information and hazards, Weather models (Nowcasting & Forecasting) to match aviation requirements, ATM system evolution to process new MET information, SWIM, Data-links, Standards

Weather resilient Air Traffic Management should be based on new dedicated systems : ITWS (Integrated Terminal Weather Systems), WVAS (Wake Vortex Advisory Systems).
These systems will be dependent of new sensor equipments with advanced performances: High resolution wind monitoring sensors and High resolution wake vortex monitoring sensors
These new sensor will provide observation that will be assimilated to improve Nowcasting performance and Forcasting confidence

In this framework, LIDAR and RADAR sensors are key enablers for wind monitoring and wake-vortex hazards mitigation capability.

III. NEW SENSOR MONITORING REQUIREMENTS

Airport Wind Monitoring Requirements are the following:

- Information: 3D Wind Vector (Head-Wind, Cross-Wind, Up/Down Wind) (Ac. : 0.5 to 1 m/s), Atmospheric Turbulence
- Time Constraints: Update Rate: 10 s to 1 mn, Soft Real-Time (low latency)
- Availability of Data in: 3 Dimensional Volume, All Weather Conditions, an Enlarged Airport Area (12 to 25 NM, 4000/5000 feets)
- Fusion of Multi-Sensors measurements in a « Common 3D Wind Operational Picture »

Progressive Information Exploitation of wind data will be used by Wake-Vortex Predictor (Wake-Vortex Position / Strength Prediction) and Nowcasting/Forecasting Weather Systems by assimilation.

Airport Wake-Vortex Monitoring Requirements are the following:

- Information: Position of each roll-up (Ac. : 10 to 50 m), Strength (Circulation in m2/s) (Ac. : 5 m2/s), Extrapolated Positions (WV detection tracking) (Ac. : 10 to 50 m), Decay Phase
- Time Constraints: Update Rate : 1 s to 10 s, Hard Real-Time (very low latency)
- Availability of Data in: 2D (along runways) or 3D (Final Approach & Initial Climb), All Weather Conditions, Critical Area (along runways, ILS interception, Initial Climb)
- Multi-Sensors Tracking

Progressive Information Exploitation of Wake-Vortex Detection will be used by Wake-Vortex Alert Server and Wake-Vortex Predictor (Atypical Behavior, Model Failure).

Radar & Lidar Candidate technologies could be based on different engineering approaches :

- Sensor Mode : Active / Passive (mainly in acoustic), Collaborative or Multi-sensors
- Sensor Configuration : Mono-Static / Multi-Static
- Sensor Exploration : Profiler 1D, Scanner 2D/3D (Mechanical scanning or Electronic scanning)
- Mono/Multi-Beams
- Measurements on : Scattering or Air Index variations

Some acoustic sensors are also candidates but less efficient and limited to short range detection.

In the following figures, we give a short survey of sensors that have been presented in WAKENET-3 Europe Workshop:

Figure 2. Survey of available Wind Monitoring Sensor

Figure 3. Survey of available Wake-Vortex Advisory Sensor

To compare candidate sensors, we have listed the following criteria: TRL (Technology Readiness Level), Update-rate, Latency, 1D/2D/3D Coverage, Range, Accuracy, Weather Resilience, Cost. For classification for each of these criteria, we have given a rank: Low/Medium/High.

We provide in the following figure, ranking for Wind Sensors:

	TRL	Update-Rate	Latency	Coverage 1D/2D/3D	Range	Accuracy	Weather Resilience Very Clear / Clear / Haze / Fog /Very Low Visibility / Heavy Rain	Low Cost
Anemometers	High	High	High	Low	Low	High	High	High
Windlines	High	High	High	Medium	Low	High	High	High
Sodar/Rass	High	Medium	Medium	Medium	High	Medium	High	High
Bi-Static Radio-Acoustic	Low	Medium	High	High	High	High	Medium	Medium
VHF Wind Profiler	High	Medium	Medium	Low	High	Medium	High	High
UHF Wind Profiler	High	Medium	Medium	Low	High	Medium	High	High
S-Band PSR radar	High	High	High	Medium	High	Medium	Medium	High *
C-Band radar	High	Medium	High	High	High	High	Low	Medium
M-Scan X-Band radar	High	Medium	High	High	High	High	Low	Medium
E-Scan X-Band radar	High	High	High	High	High	High	Medium	High
1.5 µm Lidar Profiler	High	Medium	Medium	Low	Medium	High	Medium	High
1.5 µm Lidar Scanner	Medium	High	High	High	Medium	High	Medium	High
Coll. Multi 1.5 µm Lidar	Medium	Medium	Medium	High	High	High	Medium	Low
1.6 µm Lidar Scanner	Medium	High	High	High	Medium	High	Medium	Low
2 µm Lidar Scanner	High	High	High	High	Medium	High	Medium	Low

* : Existing radar on airports (processing Upgrade)

Figure 4. Comparison study of Wind Sensors

1.5 µm Lidar Scanner and Electronic Scanning X-band Radar are best ranked candidate technology, completed by upgraded weather channel of Primary Surveillance ATC Radar.

We provide in the following figure, ranking for Wake-Vortex Sensors:

	TRL	Update-Rate	Latency	Coverage 1D/2D/3D	Range	Accuracy	Weather Resilience Very Clear / Clear / Haze / Fog /Very Low Visibility / Heavy Rain	Low Cost
Passive Acoustic	Medium	High	High	Low	Low	Medium	High	High
Passive Ac. Phased Array	Medium	High	High	Medium	Low	Medium	High	High
Multi-Static Acoustic 1 KHz	High	Medium	Medium	Low	Low	Medium	High	High
Active Acoustic 57 KHz	Low	Medium	Medium	Low	Low	Medium	High	High
M-Scan X-band Polar	High	High	High	Medium	Medium	High	Medium	High
M-Scan X-band Pcomp	High	High	High	Medium	High	High	Medium	High
E-scan X-band Pcomp Pol	High	High	High	High	High	High	Medium	High
M-Scan Ka-Band radar	High	High	High	Medium	High	High	Low	High
M-Scan W-Band radar	High	High	High	Medium	High	High	Low	High
Passive Forw. Look. Inter.	Low	High	High	High	Medium	High	Low	High
1.5 µm Lidar Scanner	Medium	High	High	High	High	High	Medium	High
1.6 µm Lidar Scanner	Medium	High	High	High	High	High	Medium	Low
2 µm Lidar	High	High	High	High	High	High	Medium	Low
UV Lidar	Low	High	High	Medium	Low	High	Low	High

Figure 5. Comparison study of Wake-Vortex Sensors

Sensors suite of 1.5 µm Lidar Scanner and Electronic Scanning X-band Radar is a good compromise for Wake-Vortex monitoring in all weather conditions.

As observed previously, Radar and Lidar are good complementary sensors in all weather operations. THALES has proved by derisking campaign (Paris CDG-2008) that X-band Radar & Lidar are complementary for Wake Vortex Monitoring. Lockheed Martin has proved by derisking Campaign (Westheimer Aiport) that X-band & Lidar are complementary for Wind Monitoring (& Wind-shear)

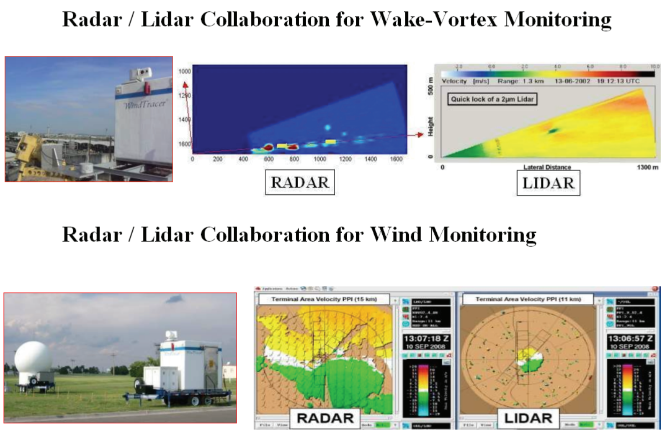

Figure 6. Lidar/Radar technologies for Wind and Wake-Vortex monitoring

IV. RADAR MONITORING IN CLEAR AIR

Existing observations by Weather Radars have proved that Radar can monitor Wind in Rain (light to heavy rain, hail) but also in Clear-Air with an availability around 50 % (Meteo-France has observed that their Weather C-band Radar is able to assess wind in clear air from 40 to 55% until range of 15 km and altitude of 500 m).

New High-Power X-band Emitter Weather Radar can monitor Wind in Very Clear-Air with an availability of 100% until range of 15 km. Toshiba GaN Weather Radar detects air

conditions including wind speed even in very clear weather, a very difficult task for most weather radars.

V. MOST ADAPTED LOW COST SENSORS SUITE : X-BAND RADAR / 1.5 MICRON LIDAR

Taking into account jointly cost constraint and system requirements (wind & wake monitoring in operational all weather conditions), best compromise is given by Low-Cost Multifunction Radar/Lidar Scanners, with following properties:

- Main Characteristics: High-Power 1.5 µm Scanner in Clear Air or Very Clear air, Low-Cost E-scanning X-band Radar with Pulse Compression in Low Visibility (Fog, Heavy Rain)
- Main Advantages: Multifunction in All weather Conditions (Wet & Dry) for Wind/Windshear, Rain Cloud & Wake-Vortex Monitoring , 3D Scanning, High Update-Rate, High Resolution/Accuracy, Low Cost and compact integrated system

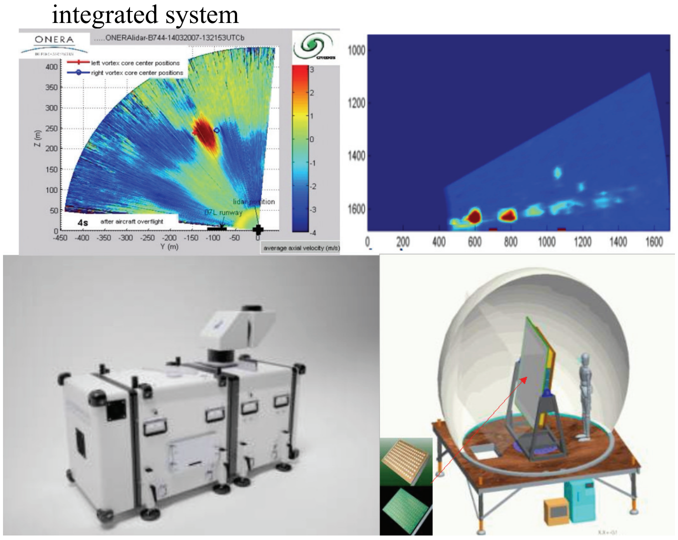

Figure 7. Lidar & Radar Wake-Vortex Monitoring

To benchmark all these candidate technologies, sensors trials campaigns have been scheduled in SESAR P12.2.2 "Wake turbulence safety in future aircraft operations".

Developments of this kind of sensors need specific studies to increase their TRL:

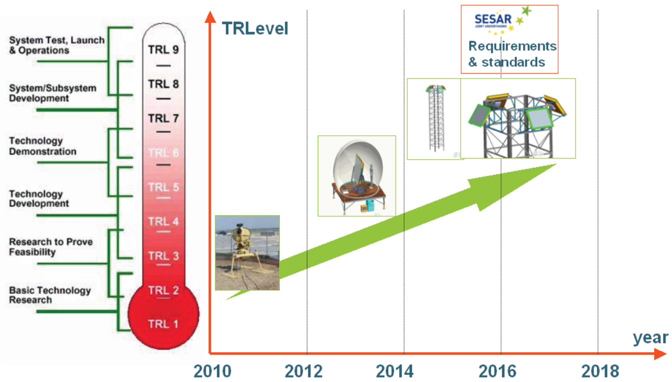

Figure 8. TRL Evolution of Wake-Vortex/Wind Radar Sensor

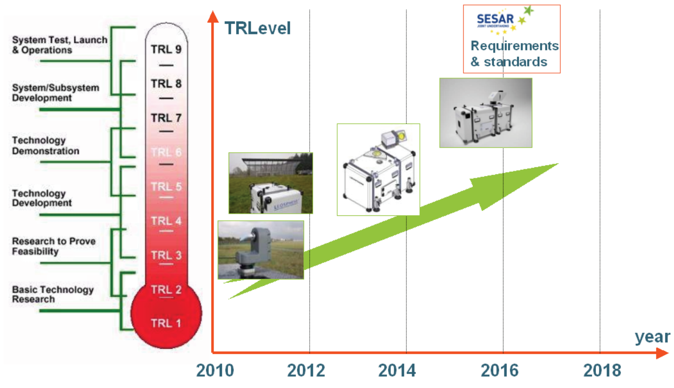

Figure 9. TRL Evolution of Wake-Vortex/Wind Lidar Sensor

VI. RADAR SENSOR TECHNOLOGY

As example of Low Cost E-scan X-band Radar, Raytheon is developing a low cost X-Band radar for a wide variety of applications, which includes wake vortex and wind monitoring. The electronically scanned radar structure is based on a building block 128 transmit/receive channel panel array that is nominally 20cm x 26cm x 0.5cm thick. As in many COTS products, the panel array leverages high volume commercial manufacturing techniques.

Active Electronically Scanned Arrays (AESAs) have generally been a preferential alternative to mechanically scanned radars, but in the past, cost has prevented their application into the commercial environment. The need was recognized for low cost AESAs in many different applications, and has launched active industry engagement in developing affordable X-Band array technology . AESAs provide unprecedented capabilities in beam pointing, sidelobe control, polarization versatility, instantaneous bandwidth, and packaging. AESAs are also known to be highly reliable due to their inherent distributed nature, ie RF, Power and Control subsystems are all distributed, promoting 'graceful' degradation.

Focus areas for achieving low cost affordable arrays, have been the development of a fabrication and assembly process for the panel array using computer board processes, in combination with development of a fully integrated weather radar transceiver (T/R) MMIC design optimized for low power wake vortex and weather radar requirements. The panel array consists of a mixed-signal multilayer printed wiring board fabricated in a single lamination step, and the SiGe T/R MMIC provides the full functionality of a T/R module integrated into one chip.

The T/R MMIC is a mixed signal circuit, containing microwave, analogue, and digital circuitry. It has been designed for IBMs SiGe 7HP BiCMOS process, and is followed by proprietary topside processing. The SiGe T/R MMIC provides the final output power in transmit, sets the Noise Figure in receive, provides amplitude / phase control for beam steering, synchronized with horizontal / vertical polarization switches. The microwave circuitry specifically consists of a Power Amplifier, Low Noise Amplifier, a

Common Leg Circuit consisting of two gain stages, a 4 bit phase shifter, a 5 bit attenuator, and a transfer switch, Transmit / Receive switches, and Horizontal / Vertical polarization switches. The analog circuitry supports the amplifier functions, and the digital circuitry decodes incoming commands and controls the states of the phase shifter, attenuator, and switches.

For the Wake Vortex and Weather / Wind Monitoring applications, the radar is configured as a $1m^2$ single face aperture, providing 10's watts of average power. The future radar production configuration will be environmentally self contained, and will be mountable on small towers or buildings, depending on application. The prototype radar used for the SESAR testing will be supported on mechanical manually rotable hardware within a radome so that it will be environmentally protected. It can thus be easily aligned for either wake vortex or weather application, and beam scanning parameters can be programmed as required. Signal generation and weather processing for the radar is configured using the integrated multichannel RPV900 Vaisala Sigmet digital signal receiver and processor.

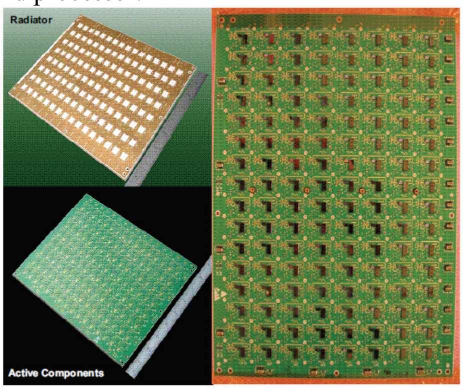

Figure 10. Panel CCA Assembly Overview

VII. LIDAR SENSOR TECHNOLOGY

The 1.5µm fiber laser technology is a new but promising candidate for wind monitoring lidars on airports. Based on reliable telecom components, this innovative technology provides a wide flexibility on lidar parameters allowing various applications such as wind vertical profiling, long range wind shear and turbulence measurements, or fast wake vortex monitoring.

Onera has developed the first 1.5 µm pulsed fiber lidar for wake vortex monitoring and characterization in 2006 [11,12]. This new lidar was successfully validated at Frankfurt airport field in February 2007 for aircraft departures as part of the CREDOS EU project. In the same time, the pulsed fiber laser technology was transferred to Leosphere for industrialization and commercial production. Parallel improvement in laser energies and signal processing give now an operational range of several kilometers for wind measurement.

The airport lidar is composed of three innovative sub-systems: a pulsed fiber laser based on a Master Oscillator Power Fiber Amplifier (MOPFA) architecture, a fast signal processing board with real-time spectral processing and wake vortex monitoring, a fully programmable hemispherical scanner to map the wind fields in horizontal or vertical plans. VAD (conical scan) is used for wind vertical profiling in the Windcube70. PPI (constant elevation) scanning is used for long range wind shear detection and RHI (constant azimuth) for wake vortex monitoring in the Windcube200S.

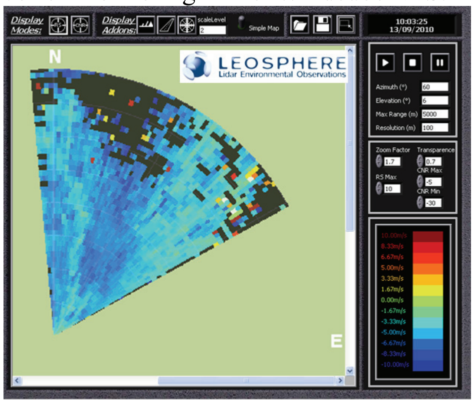

Figure 11. Radial wind speed up to 5km with WLS200S

VIII. SENSORS SIMULATORS

To study best sensor parameters/modes tuning and best sensors deployment on airport, simulators are mandatory.

Different 1.5 µm Lidar Wake-Vortex Simulators have been developed in Europe: from UCL (Belgium) re-used by THALES in SESAR and from ONERA (France)

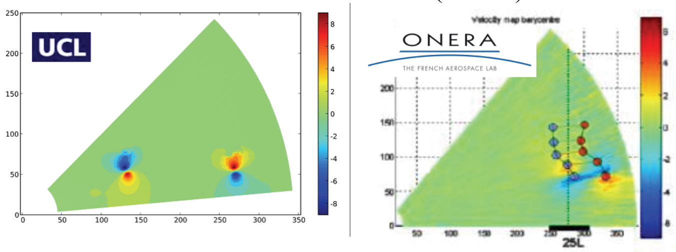

Figure 12. Wake-Vortex Lidar Sensor Simulation

Radar Wake-Vortex Simulator activity is relatively new and different are actively engaged on their development: High Resolution Simulator: from NUDT (China) upgraded with THALES/ONERA (in Rain, Doppler Signature), Generic Simulator: from UCL(Belgium) re-used by THALES in SESAR.

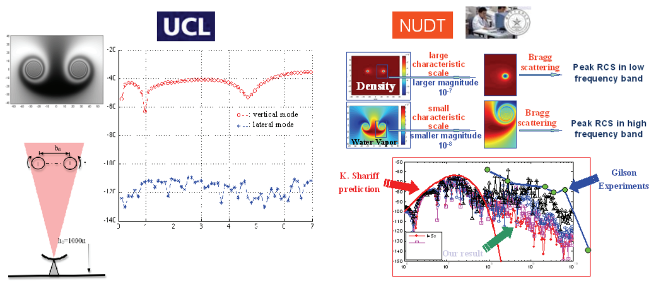

Figure 13. Wake-Vortex Radar Sensor Simulation

IX. Model/Sensors Collaboration for Wake-Vortex Tracking

As previously explained, for the detection of wake vortices in all weather conditions, a combination of LIDAR and RADAR sensors is most promising. While LIDAR sensors are adequate for good weather conditions, RADAR sensors outperform LIDAR sensors in bad weather conditions, i.e. in rainy and foggy conditions.

The combination of LIDAR and RADAR is challenging, since the detection of wake vortices with both sensors differs in space and time. Thus, a fusion of both sensors is needed, which takes into account the different scanning planes in space and time. Therefore, also the different behavior of the wake vortices in space and time has to be considered for creating a spatially and timely combined sensor output. Based on this output, a short time prediction of the wake vortex behavior can be conducted, like presented in [1][13].

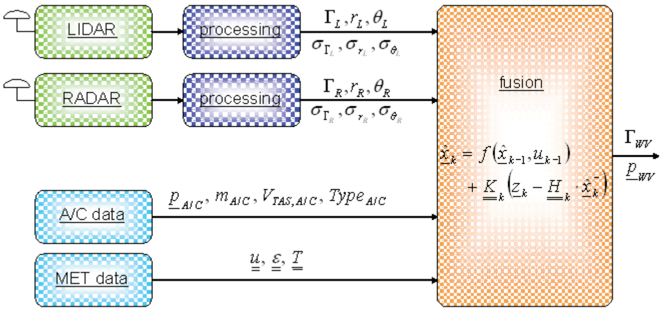

Figure 14. Collaborative system layout

For this hybridization, a KALMAN filter framework can be used like in classical tracking problems. Such filters work in two consecutive steps: a propagation part, where the system state is estimated based on model assumptions, and a measurement update part, where the system state is corrected by a physical detection of an object. During the measurement update, LIDAR and RADAR sensors are delivering wake vortex strength Γ, range r and angle Θ, e.g.:

$$\underline{z} = \begin{bmatrix} \Phi & \Theta & r \end{bmatrix}^T \quad (1)$$

The azimuth angle Φ of the sensors is usually a fixed value, since the sensor scanning is only conducted in the vertical plane. In addition, information on the reliability of the measured information can be delivered to the system in terms of standard deviation:

$$\underline{\sigma} = \begin{bmatrix} \sigma_\Phi & \sigma_\Theta & \sigma_r \end{bmatrix}^T \quad (2)$$

In order to generate the short time prediction of vortex decay and transfer, additional information about the generator aircraft as well as the ambient conditions is required. For the aircraft, parameters as aircraft position $\underline{p}_{A/C}$, type and mass $m_{A/C}$ as well as its true air speed $V_{TAS,A/C}$ should be provided to the filter. The atmospheric conditions in terms of profiles of wind $\underline{u}$, turbulence $\underline{\varepsilon}$ and temperature $\underline{T}$ are necessary for propagation of vortex state between sensor measurement updates and for the short time prediction. The proposed system is estimating the relevant wake vortex data, like wake vortex strength, decay rate, wake vortex position and is additionally modeling errors. These quantities are used within the system state vector:

$$\underline{x} = \begin{bmatrix} \Gamma & \dot{\Gamma} & x & y & z & \underline{\Delta} \end{bmatrix}^T \quad (3)$$

During the propagation step:

$$\hat{\underline{x}}_k^- = f(\hat{\underline{x}}_{k-1}, \underline{u}_{k-1}) \quad (4)$$

the system quantities are predicted based on the current state, where the non-linear function f relates the state at time $k-1$ to the state at time k. Aircraft and meteorological information for the short-time wake vortex prediction is fed into the hybrid system via the input vector $\underline{u}_k$. During the measurement update step:

$$\hat{\underline{x}}_k = \hat{\underline{x}}_k^- + \underline{\underline{K}}_k(\underline{z}_k - \underline{\underline{H}}_k \cdot \hat{\underline{x}}_k^-) \quad (5)$$

the estimated system is corrected based on the RADAR and/or LIDAR data $\underline{z}$. The difference between the sensor and the estimated measurements is fed back to the system state, i.e. the system values are corrected by the sensor data. The difference between the coordinate systems of the hybrid state and the sensors is taken into account by the measurement matrix $\underline{\underline{H}}$, which relates the spherical coordinates of the sensors to the cartesian coordinates of the system state:

$$\hat{\underline{z}}_k = \underline{\underline{H}}_k \cdot \hat{\underline{x}}_k^- \quad (6)$$

The measurement matrix also relates the standard deviation of the measurements to the system state during the calculation of the KALMAN gain.

Since the proposed system uses two sensors with different scanning planes, a transformation of the measurements is needed at least for one sensor. This could be solved by defining the coordinate system of one sensor as the master coordinate system, while the information of the second sensor is transformed into the master coordinate system during the measurement update step. For this purpose, information of the system state can be used to take into account the different wake vortex positions and strengths between the two scanning planes.

The system outputs the current wake vortex strength Γ_{WV} and position $\underline{p}_{WV}$. In addition, a new forecast is conducted based on the last incoming LIDAR and/or RADAR measurement.

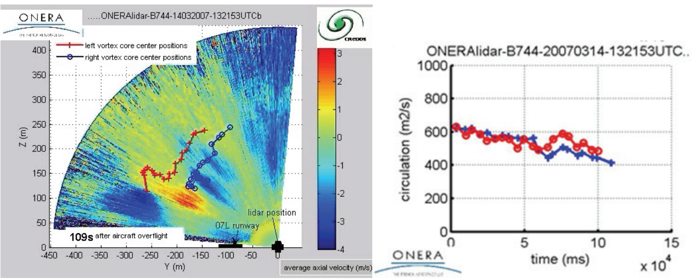

Figure 15. radial wind map with vortex trajectory extracted from 1.5 µm lidar at left and Circulation vs time for a B747-400 during take off at Frankfurt, recorded with the prototype of Windcube200S, at right

X. WEATHER CHANNEL UPGRADE OF ATC PRIMARY SURVEILLANCE RADAR

An intermediary and complementary solution for weather hazards monitoring on airport could be to upgrade ATC PSR Radar Weather-Channel with the following functions :

- Rain Cell Tracking
- Doppler Wind Monitoring
- Doppler Turbulence Map

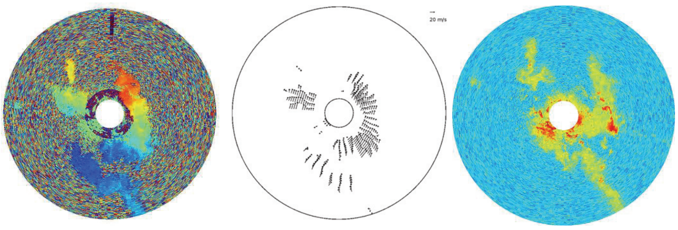

Figure 16. Wind Field Monitoring with PSR Radar weather Channel. (Left) Doppler Radial Velocity in Rain cloud, (Middle) Wind Field Assessment based on Doppler information, (Right) Atmospheric Turbulence Map based on High Resolution Doppler Processing

XI. DOWN-LINK OF WIND INFORMATION BY ADS-B OR BY MODE S

A first step to test availability and quality of airborne weather data could be to Wind Information retrieval by Mode S Data-link (Monopulse Secundary Surveillance Radar). For this purpose, THALES has made first tests of Mode S weather information downlink in ASTERIX format based on RSM 970 S Secondary Radar equipment.

In Mode S "Enhanced Surveillance" (EHS), Surveillance Radar can extract 1 to 5 BDS per scan :

- Register 50 hex (Track and Turn Report) : ground speed, true track angle, true airspeed, and the roll angle.
- Register 60 hex (Heading and Speed Report) : magnetic heading, indicated airspeed, and Mach number.

BDS 4/5,6 RSM 970 S have then be recorded by Thales in July 2010.

Main objective is the retrieval of Wind information by ADS-B Data-link (Automatic Dependent Surveillance – Broadcast) using 1090 MHz Extented Squiter Link .

Existing ADS-B Messages are Aircraft emitter category, Aircraft position & Pressure , Altitude Aircraft speed, and heading. New requirements will be (update-rate : 10 s to 20 s):

- Wind speed and direction
- Static temperature
- Barometric pressure
- Aircraft weight and configuration
- Atmospheric turbulence (eddy dissipation rate and total kinetic energy)

The challenge is high because the approach is constrained by bandwidth limitations in high density of aircrafts case and by data latencies that should be compliant of final system requirements (Integrated Terminal Weather System and Wake-Vortex Advisory System).

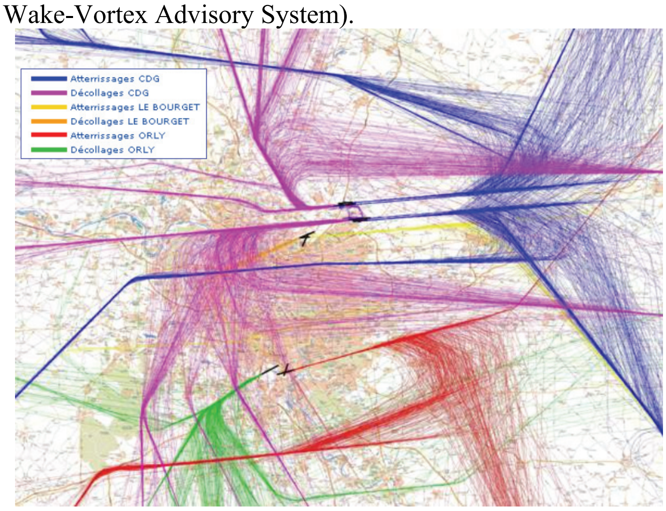

Figure 17. Potential coverage density of ADS-B Met Info Downlink in Paris Airports Area

XII. VERTICAL WIND SHEAR DETECTION

Wake-Vortex is the not the only weather hazard on Airport, but there is also Wind shear that poses dangers to aircraft in flight, especially during take-off and landing. Generally wind shear is measured and reported in horizontal wind terms, whereas vertical wind shear reporting has been largely neglected. Vertical wind shear is mainly related to topography, land and seas breezes, and low jet streams, but can also be related to microbursts, which have been identified as hazardous to flight. Vertical wind shear has a profound effect on the Wake Vortex advection and decay. Therefore it is imperative that vertical wind shear can be detected and reported correctly. Several trials have been conducted in order to enhance the detectability of vertical wind shear events. It has been found that quite aggressive filtering techniques have to be utilized in order to limit false-alarm rate for vertical wind shear detection. The trials to find the right filtering schemes to balance between over- and under reporting are still going on.

As example, VAISALA has developed AviMet® with Configurable display of data. The lower and upper limits of the measured vertical airspace can be selected to display the vertical wind shear data. The limits can be set as height and altitude. Wind shear is identified as a significant change in speed or direction between these upper and lower limits, which are pre-set. There are at least 5 layers between these limits. Data can be shown as a vertical profile of wind barbs, or in table format with wind data, or wind shear warnings, for

every layer measured on a separate row. Color -coding is used to easily identify the severity of the wind shear. The layers can overlap, totally or partially.

Alerts should be displayed to controller:

- The vertical wind shear displays alerts (when wind difference between two height levels exceed pre-set wind limits, on cross-wind and headwind/tailwind vertical wind shear separately, on temporal changes in vertical wind shear)
- turbulence

Both the high-low altitude levels and the wind difference amount are user configurable through password protected UI. There are at least five vertical shear warning layers.

The wind information is provided by UHF wind profilers. A wind profiler can measure wind speed up to height of 3000 m, at intervals of about 100 m. Low altitude could be complemented by Lidar Wind Profilers.

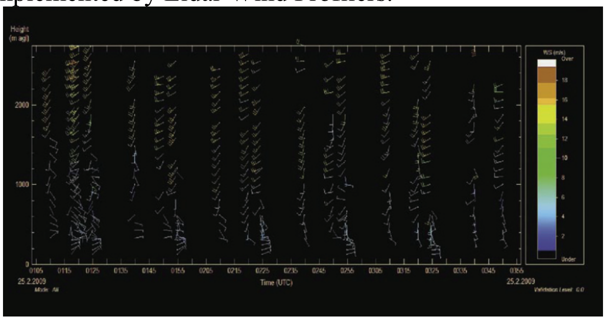

Figure 18. UHL Wind wind profile provided by LAP 3000

XIII. European Research Needs

According of previous analysis, we can identified following European research needs :

- Simulators study: Wake-Vortex Monitoring Radar Simulator (VHF to W bands) including Reflectivity and RCS (Radar Cross Section) signature in clear-air/rain, Doppler signature, High Range Resolution signature
- Sensors study: Technology for Low-Cost Polarimetric X-band Electronic scanning Radar Antenna, Technology for High-Power 1.5 micron Lidar Scanner
- Processing study: Advanced Wake-Vortex Detection / Fusion based on multi-sensors Radar/Lidar data, Tracking with Model/Sensors Collaboration, Advanced Weather Channel of ATC PSR Radar
- New standard study for Met Data Downlink by Mode S and ADS-B

XIV. Acknowledgment

We would like to acknowledge all the Organizing Committee members from WAKENET-3 & GREENWAKE for their help, in workshop elaboration.

XV. Conclusions

A new generation of low cost sensors has recently emerged, boosted by technological breakthroughs & Renewal Wind Energy Market: Electronic scanning Low Cost X-band Radar and High Power 1.5 micron Lidar scanner. Existing Equipments can be upgraded like Weather channel of S-band ATC PSR Radar or Met Data from ADS-B/Mode S Extented Squiter. These sensors and data-links will be key enablers for critical Wake Vortex Advisory System and Integrated Terminal Weather system that will be developed in SESAR. In future systems, operational in all weather conditions, Wind data will be ingested in "Wake Vortex Predictor" and will require accurate/high space resolution and fast time update rate

Wake-Vortex monitoring sensors will improve confidence of Safety Nets with Wake vortex position, Wake vortex strength (circulation in m2/s) and Wake vortex phase (transport & decay). Wind monitoring sensors will improve Safety & Capacity with Wind hazards alerts (wind-shear,…) and Wind ingestion in Time Based Separation systems

The future systems should integrated both LIDAR and RADAR sensors for wind assessment and wake vortices detection in a hybridized sense in all weather conditions. By combining the favorable characteristics of each sensor, the hybrid system provides a highly reliable wind assessment and wake vortex detection and short-time prediction.

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