All-weather sensors (lidar + radar) for Wake-Vortex hazards mitigation on Airport

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RADAR and LIDAR sensors are complementary in terms of ambient weather conditions : X-band Radar performances are optimal under rainy conditions whereas Lidar performances are optimal in dry air. During SESAR XP0 and XP1 trials in CDG airport, a multi-function (wake-vortex, weather) Electronic scanning X-band Radar (THALES), and a multifunction 1.5 micron Lidar with a 3D Scanner (Leosphere with Onera signal processing) have been used together to detect and follow aircraft wake vortices. These sensors were associated in an all-weather conditions system. Trials configuration is presented and test results are analysed.

Introduction

Detecting atmospheric hazards such as wind shear, clear air turbulence and wake vortices has been a major concern for twenty years. Wake vortices being created systematically behind each aircraft, are probably the most obvious ones. Lift force exerted on the aircraft wings creates a counter-rotating pair of trailing vortices (wake vortices) which constitute a potential hazard to following aircrafts. These hazardous flows usually dissipate quickly because of air turbulences or are transported by cross-wind. However, due to safety reasons, most airports assume a worst-case scenario and use very conservative separation distances between aircraft, which means that the times interval between aircraft taking off or landing often amounts to several minutes. With the aid of accurate wind data and precise measurements of wake vortices, more efficient intervals can be set, particularly when weather conditions are stable. Depending on traffic volume, these adjustments can generate capacity gains, which have major commercial benefits.

For the detection of wake vortices, RADAR and LIDAR sensors are complementary in terms of ambient weather conditions: X-band Radar performances are optimal under rainy conditions when Lidar performances are optimal in dry air. Wake-Vortex Advisory System 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.

Within European SESAR P12.02.02 project, two trials occurred in May 2011 (XP0) and October 2012 (XP1). During those measurements campaigns, a 1.5µm Leosphere scanning Doppler Lidar and Thales X-band radar have been successfully tested.

XP0 and XP1 trials at CDG

XP0 was a sensors assessment campaign where many wind sensors were benchmarked (two UHF wind profilers, one SODAR, one LIDAR wind profiler, two type of Anemometers). Additionally Wake Vortex sensors were also benchmarked during XP0: X-band RADAR (THALES), LIDAR (WINDCUBE 200S of LEOSPHERE). During XP0 both take off and landing configurations were experimented.XP0 results confirm that at “high” altitudes the wake vortex behaviour is predictable (see Figure 1), being affected only by the wind and turbulence level. Out of ground effect, wake vortex predictors will be able to compute wake vortex behaviour based on theoretical models. They need as inputs accurate wind speed and direction.

On the opposite, close to the ground, where wake vortex behaviour is affected by IGE (In Ground Effect) and low wind shear, which can lead to unexpected wake vortex behaviour like complex rebounds. In that case, behaviour cannot be accurately predicted and modelled and a real wake vortex monitoring seems mandatory. Sensors scanning domain must be large enough to cover both landing & take-off. The best sensors position is demonstrated to be sideways, few hundred meters upstream from the touch down area.

XP1 focused on landing scenario, with IGE vortex. A new multifunction X-band Radar (wake-vortex, weather, traffic) with electronic scanning capability was deployed in order to simultaneously monitor Wake-Vortex close to the runways and assess the wind values in the glide and around the airport.

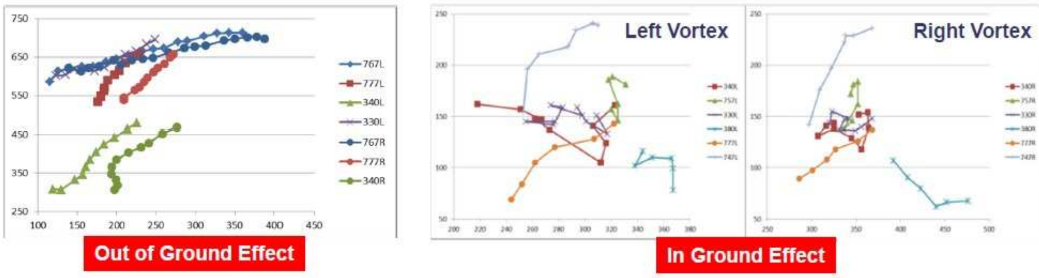

Figure 1: XP0 Lidar measurements of wake vortex trajectories. Vertical scale is the height above ground level in meters, Horizontal scale is the horizontal distance to the Lidar in meters.

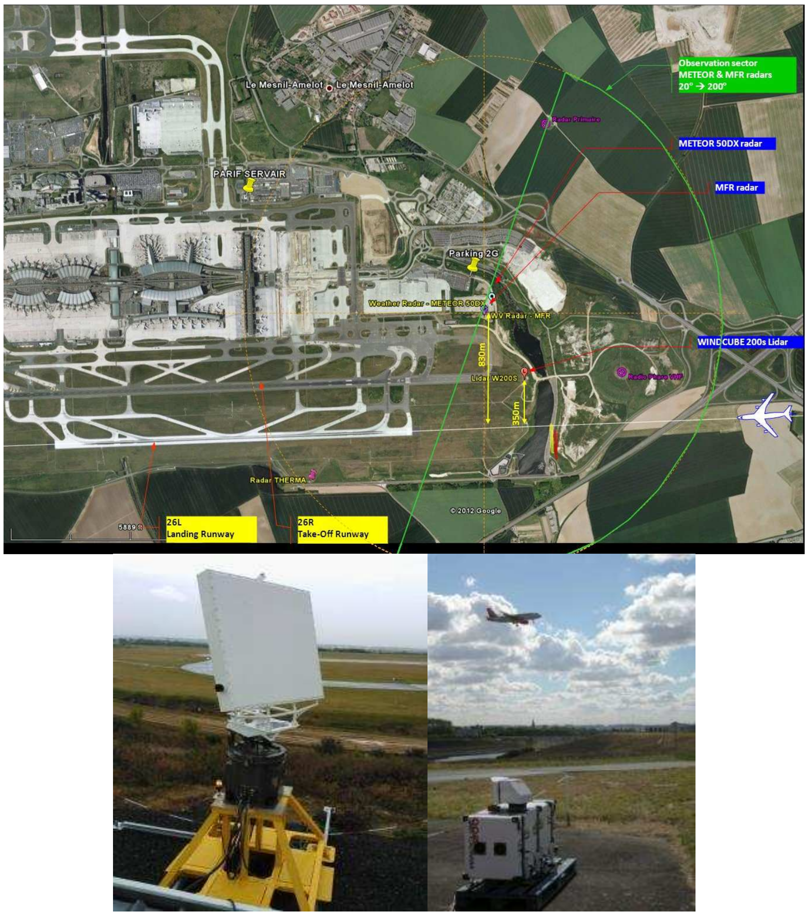

Figure 2: (top) Radar & Lidar Sensors deployment for XP1 Trials, (down left) Multi-Function (wake-vortex, weather) Electronic scanning X-band Radar, (down right) Multifunction Leosphere 1.5 micron 3D Scanner

Radar configuration for Wake Vortex and Weather / Wind Monitoring applications

X-band radar with electronic scanning antenna has been deployed close to the runways. Based on an already existing hardware radar platform, a dedicated Electronic scanning antenna and signal processing have been developed to simultaneously monitor wake-vortex, weather and air-traffic. This multifunction capability enables both wake-vortices monitoring in the most critical part of the glide, i.e. just before landing (Figure 3) and to assess the weather (wind and rain rate) around the airport (Figure 4). Radar then offers in real-time wake vortex detections (3D position & strength) with a fast update rate (7.5 s) to a tracker-predictor system.

Results show that X-band radar performances are optimal under rainy conditions, since radar is able to detect with a high sensitivity the effect of wake vortices on raindrops. This feature is complementary to Lidar performances that are optimal in dry air.

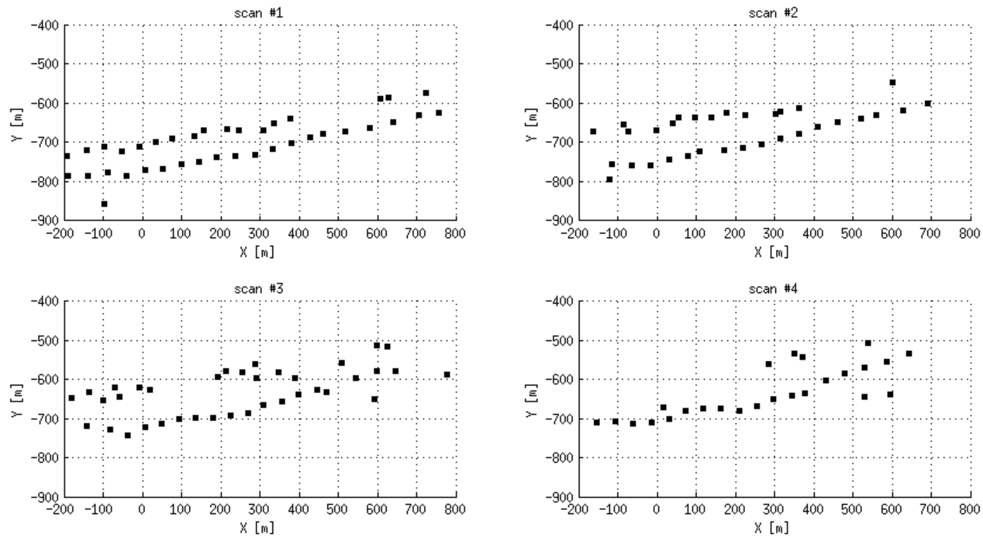

Figure 3: Wake vortex measurements with X-band radar: A340 during 4 successive antenna scans. Vertical scale is the height above ground level in meters, 1000 m offset. Horizontal scale is the horizontal distance to the Radar in meters, 1000 m offset.

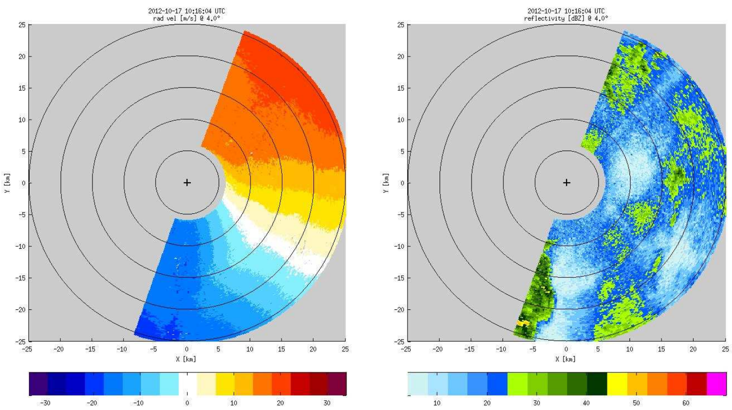

Figure 4: Weather measurements with X-band radar: wind radial velocity in m/s (left); rain rate/reflectivity in dBz (right) vertical and horizontal scales being centered on the Radar.

Lidar configuration for Wake Vortex real time measurement

The lidar is a 1.55 µm fibered coherent Doppler LIDAR. The average output power is 1 Watt. The pulse length is 200ns, as a compromise between velocity resolution and range resolution and is adapted to the application (wind measurement or wake vortex measurement). The scanning angular resolution depends on the scenario. For IGE vortices detection, the angular resolution is about 0.5 mrad.

During XP0, real time display of the average wind field was performed. The positions of wake vortex cores and circulations calculations were automatically post processed. A range resolution of 4 m for wake vortex detection was obtained by overlapping the larger range gates defined by the pulse length.

The goal of XP1 was to achieve real time wake vortex monitoring. Therefore, real time processing of wake vortex has been implemented thanks to:

1) Range resolution's reduction. XP0 results analysis and simulations showed that this range resolution can be relaxed. In XP1 the range resolution was 8 m, allowing real time display of wind fields.

2) Reduction of the analysis window for wake vortex detection. For landing configuration, the first wake vortex detection is located in a small window (50 m wide) around the glide path. For older wake vortices detection, this window is shifted according to the average wind (measured on the previous average wind map).

3) Parallel computing on 8 cores PC. For departure configuration, where the first detection analysis window is much larger, processing speed can also be increased by the use of a GPU card.

During XP1, 339 aircrafts were measured, corresponding to 1341 wake vortex pairs detected. The percentage of detection is 86 %. Most undetected events were during rainy period. The histogram of following duration is given in Figure 7 (left). Because wake vortices were IGE, they were followed during 2 scans in most cases. But, the wind was often in the Lidar direction pushing the vortex towards it. Then on this typical example one vortex is rapidly destroyed while the other one rebounds and is transported by the wind, hence the greater observation time, e.g. up to 90 s.

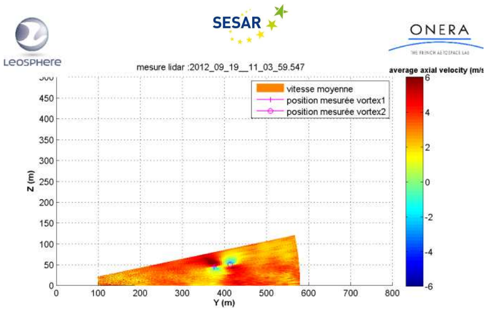

Figure 5: Example of wake vortex measurement during XP1 with the Doppler lidar

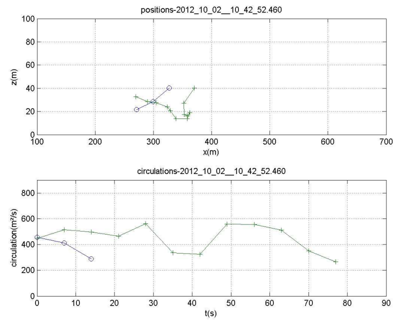

Figure 6 : example of wake-vortices followed during 12 scans. Top: wake vortex cores positions in the measurement plan. Bottom: absolute value of the circulation as a function of time after the first detection**.**

Aircraft's information such as the type of aircraft and the aircraft speed were available. Theoretical circulations have been calculated assuming an average landing weight and knowing the wing span for each aircraft type. Figure 7 (right), shows the histogram of the normalized circulation for the first detection and for the heavy category.

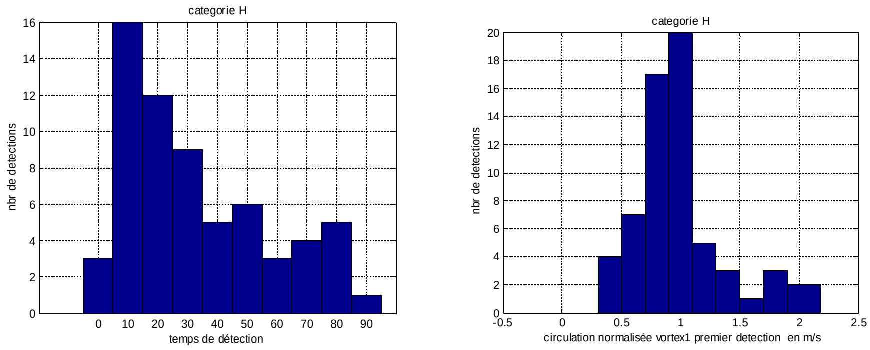

Figure 7: Left: observation time histogram for the category heavy. Right: first detection normalized circulation for the category heavy.

Conclusions and prospects

For wake vortex detection, RADAR and LIDAR sensors are complementary in terms of ambient weather conditions: X-band Radar performances are optimal under rainy conditions when Lidar performances are optimal in dry air. Both were successfully tested during two measurements campaigns at CDG airport. The Lidar performs real time measurements of wake vortex positions and circulations.

The next SESAR campaign will take place in 2014, with the objective of deploying a fully operational system.

Another European project has begun this year: UFO ("UltraFast wind sensOrs for wake-vortex hazards mitigation") led by Thales with ONERA and Leosphere as partners. The goal of UFO is to address context measurements such as turbulence (EDR), 3D wind maps, etc, thanks to Lidar and Radar sensors. These measurements are required as inputs to wake vortex predictors.

Acknowledgments

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