WAKE VORTEX DATA COLLECTION AND ANALYSIS USING X-BAND RADAR

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OVERVIEW

In order to improve the capacity of airports in view of the expected increasing amount of traffic the knowledge about the safety issues caused by wake vortices has to be improved. The final goal is to build up a wake vortex alert system to ensure the application of appropriate but not oversized safety distances all the time. It is necessary to perform long time data collections of wake vortex encounters on one or more large airports. Lidar systems are able to deliver very accurate data, but are also sensitive to the weather conditions like rain and fog. THALES did trials with the X-band radar BOR-A 550 on Orly Airport in November, 2006. It was possible to detect wake vortices up to a range of 700 m. The Doppler resolution of around 0.2 m/s used with regularized high Doppler resolution techniques is able to characterize the wake vortex speed distribution in detail. X-band Radar is a full-fledged alternative, which can make a significant contribution to a wake vortex alert system.

1. INTRODUCTION

The main objective is to develop a ground or board collaborative wake vortex advisory system that would allow variable aircraft separation distances, as opposed to the fixed distances presently applied at airports. This Wake Vortex Advisory System should integrate wake vortex detection and monitoring sensors used in decision-support systems and procedures that will help air traffic controllers to decide how long the separation intervals should be. Currently Lidar sensors are used for wake vortex measurements, but their performance is limited in adverse weather like rain or fog.

On the other hand, a Radar is a good complementary sensor, which can be used for turbulence remote sensing as well. It is able to work in different weather conditions like fog, rain, wind, and dry air. To achieve as much reliability as possible, sensors for the desired Collaborative Wake Vortex Advisory System could be based on ground Lidar and Radar technologies. These sensors could be used to permanently monitor wake turbulence on runways. Wake turbulence data are combined with meteorological data and a wake vortex predictor [1] to generate recommendations for intervals, which are displayed on the air traffic controller's screen.

Up to now, there was a lot of research on wake vortex detection with Radar on different frequency bands [2]. To collect data on different weather conditions, the X-band Radar BOR-A 550 was deployed near to a runway of a large airport. In this scenario Radar measurements on different weather conditions were performed.

2. DESCRIPTION OF THE BOR-A 550 RADAR

FIG 1. X-band Radar BOR-A 550 provided by THALES

The BOR-A 550 in FIG 1 is a fully coherent pulse-Doppler Radar system with an instrumented range of 40 km for ground and coastal surveillance. With a total weight of around 80 kg it can be transferred to almost any location. Additional data recording facilities accomplish data collection activities to support research.

3. DATA RECORDING AT ORLY AIRPORT

In November 2006, BOR-A was deployed on Orly Airport by permission of ADP (Aéroport de Paris) and DGAC/ DSNA near to runway 07. It was possible to monitor wake vortices caused by medium sized planes like Boeing 737 and Airbus A320. Since the trial was scheduled in November, a variety of different weather situations like dry air, fog, rain, and wind did occur.

FIG 2 shows the Radar location used for the trial. BOR-A 550 was located on the roof of a building about 500 m away from runway 07. During the trial the take-off area was monitored for wake vortex encounters. The data were recorded in staring mode as well as in scanning mode. At the end of the trial, the surveillance area was set to the area below the glide path for landing planes.

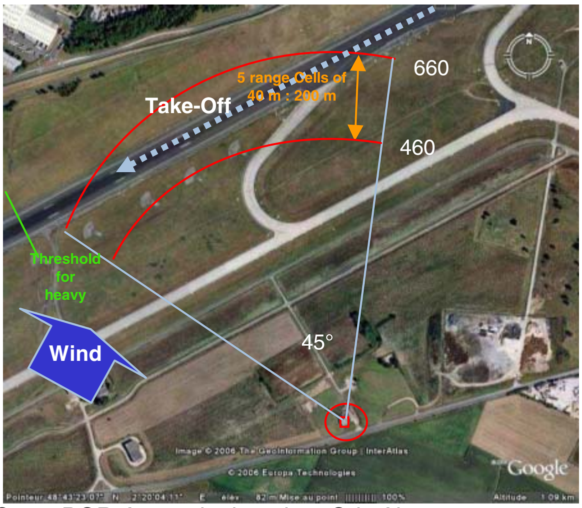

FIG 2. BOR-A 550 deployed at Orly Airport

4. DISCUSSION OF THE RECORDED DATA

The data recording unit stores the complex Radar video signal with a range gate size of 40 m. This allows the recording of a 200 m range swath using a peak pulse power of 20 Watts. With the applied PRF a Doppler velocity resolution of 0.2 m/s is achieved.

According to [3] the radial velocity of a wake vortex in FIG 3 is a function of the radius as well as a function of time. In general, the radial speed will increase for several seconds, and after reaching a maximum, it will decrease again. The results of this model can be compared with the recorded data. The Doppler signatures of the recorded data are presented in form of spectrograms. They show the internal roll-up structure of the wake vortex, their age, and the logarithmic spiral geometry.

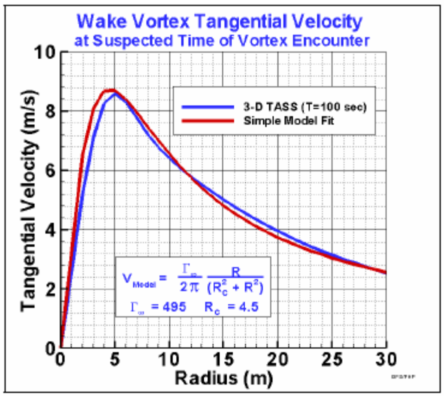

FIG 3. Wake Vortex Tangential Velocity

4.1. Data recording in staring mode

In staring mode the direction of the antenna beam is fixed with a beam width of 2.8°. It was directed towards a point below the starting path after take-off. FIG 4 shows the Doppler signature of a young wake vortex. The sharp lines are indicators for the internal structure. The following figures are showing the next life stages. FIG 5 contains the Doppler signature of a mature wake vortex. The radial speed remains almost constant over time.

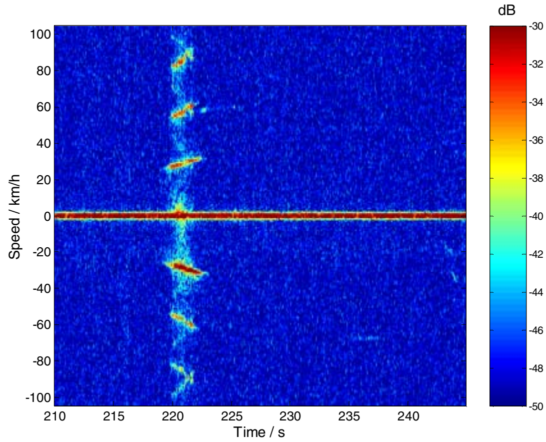

FIG 4. Doppler signature of a young wake vortex

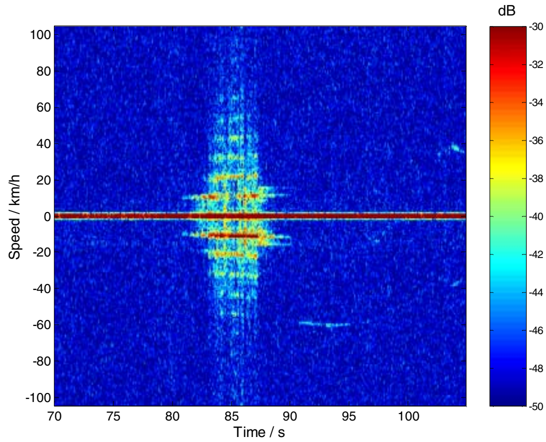

FIG 5. Doppler signature of a mature wake vortex

Moreover, the following FIG 6 shows a recording of a wake vortex which has started to decay. FIG 7 presents the spectrogram of an almost decayed vortex. The radial speed of the turbulence has decreased significantly. Roll-ups are interlacing fences of air from surrounding and from higher altitude (adiabatic transport of fluid within vortex pair). When each roll-up rotates, the ranges of reflecting points at each fence will increase. According to the age of the wake vortex and the tangential speed law, this range evolution induces positive time/Doppler slopes (young vortex), jointly positive/negative slopes (mature vortex), and negative slopes (old vortex).

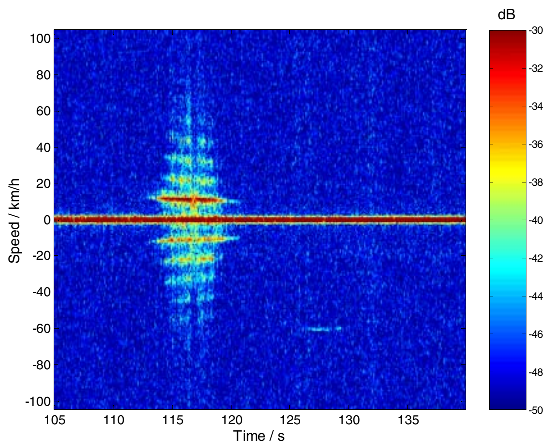

FIG 6. Doppler signature of a decaying wake vortex

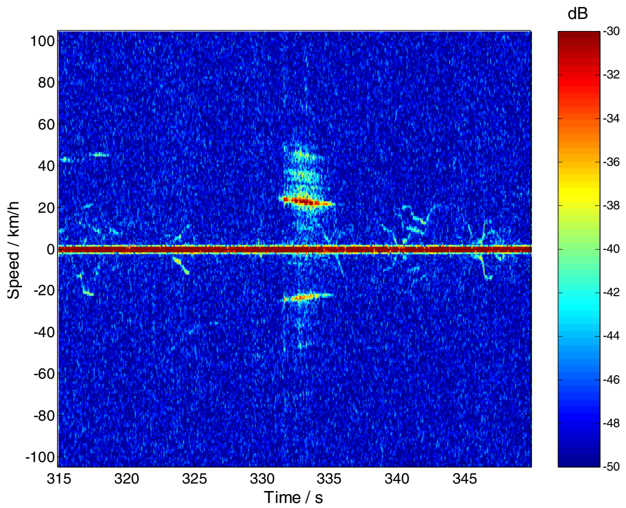

FIG 7. Doppler signature of a decayed wake vortex

4.2. Data recording in scanning mode

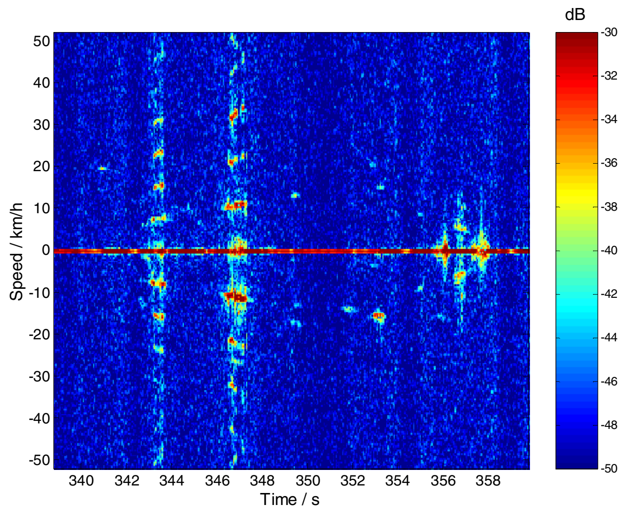

FIG 8. Doppler signature in scanning mode

In scanning mode the radar was continuously scanning a surveillance area of 45° as shown in FIG 2 with a speed of about 8°/s. In this area wake vortices of medium sized planes could be detected. Due to the scanning process a number of sparse samples of the vortices are visible. Nevertheless, the speed components of the wake vortex can be tracked from scan to scan. The analysis of the data obtained from scanning mode gives the same kind of information, than in staring mode, on the wake vortex geometry.

FIG 8 contains traces of the same wake vortex within different life stages. Over a time interval of 30 s it appears as young, mature, and decaying wake vortex. FIG 9 presents another example for different life stages of the same wake vortex. Here it can be identified as mature and as decaying wake vortex.

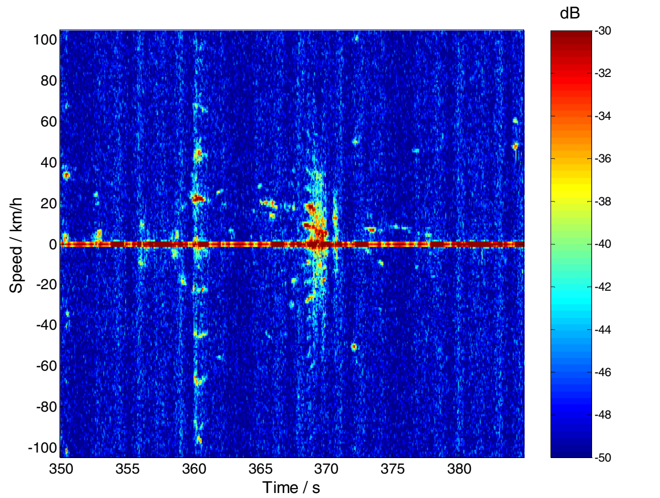

FIG 9. Another Doppler signature in scanning mode

4.3. Data recording during rain

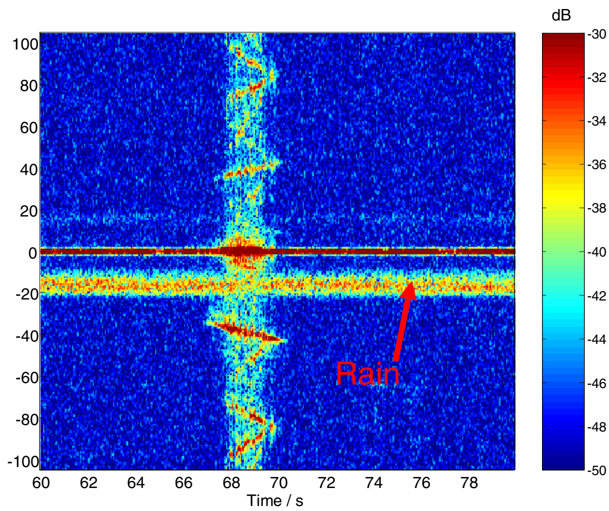

FIG 10. Wake vortex recording during rain

FIG 10 contains a data sample from a decaying wake vortex. The Doppler spectrum is disturbed by the combination of wind and rain. A wake vortex monitoring system has to be robust enough to deal with this kind of noise. The wake vortex entropy thresholding detection algorithms described in [3] were applied to these data. The resulting detections and Doppler entropies are shown in FIG 11.

The upper part of FIG 11 contains the detection results of the young wake vortex known from FIG 4, while the lower part shows the results of FIG 10. Since in this case the SNR[1] of the data sample recorded during rain is smaller than the SNR of the sample without rain, the detection results are looking sparser but still sufficient.

[1] Signal to Noise Ratio

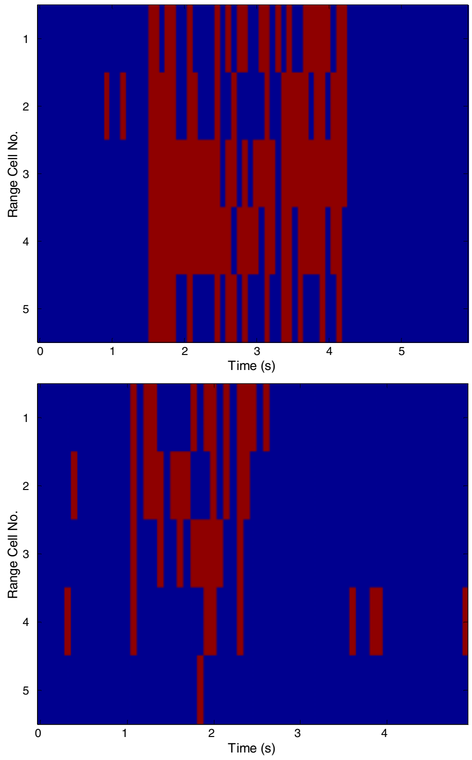

FIG 11. Detection with and without rain

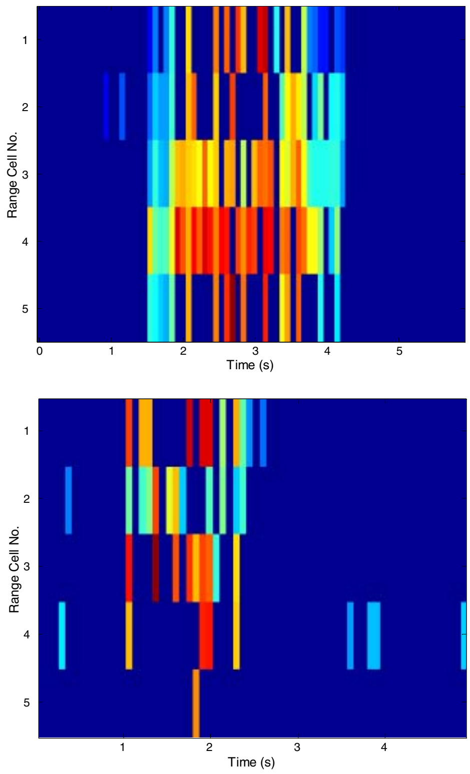

FIG 12. Doppler entropy with and without rain

FIG 12 contains the Doppler entropy from the data samples from FIG 4 and FIG 10. Similar to the detection results, the Doppler entropy image defined in [3] is looking sparser because of the lower SNR, but it is still useful.

4.4. Data recording of distant targets

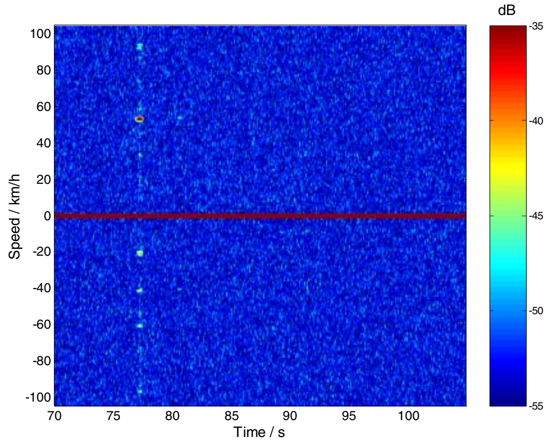

FIG 13. Trace of a wake vortex at 7 km

The data recordings described above covered a range from 500 to 700 m. With the signal format used in this case a detection range up to 1000 m for wake vortex encounters can be assumed. At the end of the Orly trial the area beneath the glide path for landing planes was monitored in scan mode. In that case a longer pulse was used. Some very short wake vortex detections were obtained at a distance of 7000 m using a sector width of 45°. The line of sight was about 200 m south of the south terminal in parallel to the runway 26. An elevation angle of 4° has been used. FIG 13 is the spectrogram of a sample of the recorded data. It should be noted that in this case the landing path was in parallel to the radar beam, causing a receiving position which was clearly far from optimal. The distance and the angle caused a very low detection probability, but still some traces of wake vortex encounters could be found.

5. CONCLUSION

The X-band Radar campaign on Orly Airport using the BOR-A 550 Radar has clearly proved its capability to do wake vortex detection in wet and dry weather conditions. Currently, the range for safe detection is lower than 1 km. The Radar can be deployed on ground perpendicular to runways or vertically for observation of the ILS interception area. Within the near future it is planned to implement an on-line processing chain (in C code on a Linux PC) for wake vortex detection and monitoring for semi-automatic data collection on wake vortex position and strength for all weather conditions.

REFERENCES

[1] F. Barbaresco & al., "The ATC-Wake Predictor system", JISSA Conf., June 2005, Paris, France.
[2] K. Shariff & A Wray, „Analysis of the Radar Reflectivity of Aircraft Vortex Wakes",J. Fluid Mech.,vol.463, pp.121-161, 2002.
[3] U. Meier, A. Jeantet, F. Barbaresco, "Wake Vortex Detection & Monitoring by X-band Doppler Radar: Paris Orly Radar Campaign Results", IET Conference, October 2007, Edinburgh, Great Britain.