

Synthesis Report

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ACRONYM : **WakeNet**

TITLE : Thematic Network Wake Vortex

PROJECT CO-ORDINATOR : Airbus Deutschland GmbH

PARTNERS :	NLR	NL
	Cerfacs	F
	Thales	F
	ONERA	F
	DLR	D
	QinetiQ	UK
	IFALPA	UK
	Airbus UK	UK
	NATS	UK

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1. Introduction

The aviation community - industry, airlines, airports, and authorities alike - is increasingly concerned about the limitation in airport capabilities and airspace availability. Due to the growth of air traffic over the last decade, and an expected further duplication by the year 2010, large efforts are required not only to prepare for the future, but even to cope with rising difficulties of today.

One significant area where concern is raised over air traffic growth limitation is *wake turbulence*. Aircraft flying behind other aircraft, or crossing their flight path sometime thereafter, may encounter severe turbulence from a preceding aircraft.

WakeNet, the Thematic Network Wake Vortex, brought together a variety of stakeholders in the field of wake vortex: aircraft manufacturers, air traffic management, airports and pilots. The network organised six workshops on this topic. All of them were very positively received. Each workshop was summarised and evaluated by a specialist in the respective topic.

WakeNet produced a position paper providing a consolidated view of research and industry partners on wake vortex issues and research in Europe.

The network was active for 4 years, from 15 April 1998 to 14 April 2002. Due to the large interest, a successor, WakeNet2, will start in the second half of 2002, being co-ordinated by NLR.

In addition to the workshops, WakeNet supported the following wake vortex related RTD projects:

- WAVENC (4th FP); final meeting on 19 January 2001
- S-WAKE (5th FP); kick-off on 20 January 2000
- C-WAKE (5th FP); kick-off on 21 January 2000
- I-Wake (5th FP) ; kick-off on 17 May 2002

The WakeNet thematic network has been very useful for exchanging ideas and strategies which led to defining projects like "ATC-Wake" and the wake vortex activities in "AWIATOR", the technology platform on Aircraft Wing With Advanced Technology.

A WakeNet internet site was set up and maintained during the project period under [http://www.cerfacs.fr/ " wakenet](http://www.cerfacs.fr/).

There was the request from the community and support from the EC to continue with this network which actually resulted in the prolongation of WakeNet by 12 months and the set up a follow on network, WakeNet2.

2. Objectives

During the lifetime of the network Airbus decided to go ahead with the A380, which will become the largest commercial passenger aircraft. This super heavy aircraft assigns new importance to wake vortex research. Hence, at the end of WakeNet I, the wake vortex issue is still high on the agenda and will most likely remain there for many more years for three reasons:

- the need for a more efficient use of the air space
- the need for larger aircraft
- the need for improved prediction capability

Aircraft manufacturers, pilots, air traffic management and airports are all concerned by the wake vortex phenomena making it a research object of true interdisciplinary dimension. This is reflected in the contributions to the WakeNet workshops which emerged as the most significant instrument of the network.

The overall objectives of the Thematic Network Wake Vortex (WakeNet) are

- to cluster related research projects like Eurowake, Mflame, Wavenc followed by C-Wake, S-Wake, I-Wake which started later in time
- to Identify know-how deficits & Improve the physical understanding
- to disseminate information to all involved stakeholders
- to guide EC research activities toward industrial needs

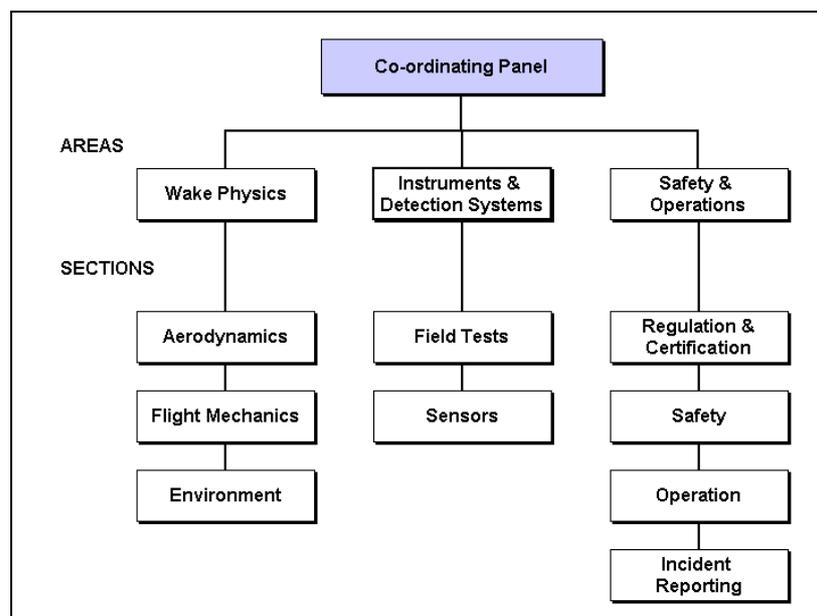


Fig. 1 WakeNet organisation as defined by the consortium

3. Technical Achievements & Status

The topics covered by the network are reflected by the organisational set up as shown in Fig. 1.

The achieved work may be summarised as follows:

- Definition, organisation and summary of six successful Wake Vortex workshops attracting participants/representatives from all stake holders: aircraft manufacturers, air traffic management, airports and pilots.
- Preparation of a WakeNet position paper on wake vortex research in Europe.
- Stimulation and strategy for a number of wake vortex research activities
- Effective dissemination of the international state of the art technology
- Definition and installation/maintenance of WakeNet homepage

The following topics were treated in workshops organised by WakeNet:

1. **European Wake Vortex Research in Europe**
1 - 2 December 1998; European Wake Vortex Research in Europe; ONERA, Paris
2. **Prediction of far field Vortex location and decay**
11 - 12 Oct 1999; DLR, Oberpfaffenhofen
3. **Measurement Techniques for Vortex Wakes**
22 - 23 May 2000 at DERA, Malvern
4. **Wake Vortex Encounter**
16 - 17 October 2000 at NLR, Amsterdam
5. **Wake Vortices and the Airport Environment**
2 - 3 April 2001 at DFS (Deutsche Flugsicherung) in Langen, Germany
6. **Challenges in Wake Vortex Research,**
17 - 18 June 2002, THALES, Toulouse, France

Proceedings have been made available for each of these workshops including a technical evaluation of each workshop.

The WakeNet position paper has been made available on the WakeNet Internet site. It provides a common view on wake vortex research and is used in many occasions as a reference document.

G. Winckelmans of the Université catholique de Louvain, Belgium, presented, in his review of the final workshop, a valuable summary of WakeNet topics of which parts are presented here:

The final review workshop provided a good picture of the European achievements, especially over the past four years. The workshop also provided a basis for sharing ideas on the things to do in the future.

The WakeNet position paper is very useful: it provides a consolidated view of research and industry partners on wake vortex issues and research in Europe.

It appears that Europe has caught up on wake vortex research, and is even in advance in some areas. Europe is also leading the way in many new initiatives. It is very good that Eurocontrol (an ATM authority) is present [in WakeNet] and is getting involved, as partner, in new projects (such as ATC-WAKE). It is also good that a new Action Plan is being elaborated by the combined action of FAA and Eurocontrol.

There is a nice complementarity of the ground testing methods used: catapult, towing tank, wind tunnel. Those testing facilities are lower in Reynolds number, compared to the real aircraft situation (typically 100 times too low), yet they provide very valuable results.

Numerical modelling and CFD is also put to good use in many investigations, and significantly helps the understanding and the operational modelling of wake physics.

There is a lack of global view with respect to previous work by other teams: such as the work in the USA, that in Canada (also with the group of Belotserkovsky of Russia and Winckelmans of Belgium), that in Russia. This is particularly true in areas such as CFD studies of ground effects, atmospheric effects (turbulence effects, wind shear effects, stratification effects) and the development and validation of operational models (transport and decay, including abrupt collapse).

There is also a lack of proper referencing to previous work and knowledge in the same subject. This will hopefully improve with the FAA-Eurocontrol Action Plan and with WakeNet II.

One important issue is the robustness of new concepts. For instance, wake vortex reducing span loading concepts, supposed to lead to enhanced wake decay (e.g., through tailored long wavelength instabilities) can be influenced by the landing gear. Turbulence is a good wake destructor, but it can also influence the robustness of some specific new concepts. Notice that the robustness of some wake vortex alleviating concepts/devices will also be studied in the new AWIATOR project.

Researchers still use a variety of velocity distributions (or, equivalently, circulation distributions) for the vortices after rollup: low order algebraic distribution of Rosenhead (used by Burnham and Hallock), Gaussian distribution (used by Lamb and Oseen), distribution by Proctor (also improved with smooth blending by Winckelmans), etc., see also the review in the position paper. It doesn't matter that much which distribution one uses as long as the scaling of the effective core size is done properly.

Indeed, the core size (here defined, for convenience, as the radius where the vortex-induced azimuthal velocity is maximum) is important. For instance, it appears (from modelling and from experiments) that it has a significant influence on the induced rolling moment on a follower aircraft. Wake vortex hazard would thus be better defined by the couple "circulation + core size" (thus not by "circulation" only, as has often been the case in the past).

Whatever the span loading, one must recall that the lift of the aircraft is proportional to the air density, the flight velocity, and the "wake vorticity first moment" (i.e., the integral

of the wake vorticity weighted by its distance to the aircraft center-plane), the result of which will here be denoted as the product $b_0 * \Gamma_0$ (Γ_0 being the integral of the half wake vorticity). Some span loading could favour obtaining a smaller rolling moment induced on a follower aircraft, and/or a faster time to decay and collapse. Inner loading is interesting in that respect (Elsenaar), as the effective time, T_0 , at fixed lift, scales as the cube of b_0 .

The wake physics in calm environment is still not completely understood. Significant progress has however been achieved in the past years, thanks to experimental work and to computational work.

The knowledge of weather effects has improved significantly, also thanks to large scale CFD simulations using the LES (Large-Eddy Simulation) approach. Significant work has been achieved in Europe and in North America (USA and Canada). This remains a complex subject and there is still more to be done. Yet, it is important to recognise that the achievements are such that they already allow to develop good operational decay models.

The concept of using ATC based on “weather classes” is interesting and promising. However, it is also necessarily a little restrictive, and it could miss up on cases corresponding to hazardous non-linear combinations of effects (e.g., a low level jet, thus with non-uniform wind shear effects, combined with ground effects can lead to a complex behaviour of the wake).

For ATC use, we often talk about the need for 20 to 30 Minutes forecast. The question is forecast of what precisely? What kind of level of precision is required for operational use? This will become significantly clearer with the project ATC-WAKE.

It was reminded (not new) that there are two steps to decay: the slow decay phase, and the abrupt decay phase (wake collapse). This is sensitive to the level turbulence of the atmosphere, the level of stratification, the gradient of mean wind, etc.

Vortex transport is still the dominant mechanism for developing ATC concepts: indeed, if a vortex wake is out of the flight corridor, it is not important to worry about its strength. It is however important to recognize that the vortex decay significantly influences the vortex transport.

Acoustic vortex detection has been tried with interesting preliminary results. This certainly deserves further investigations.

It was also reminded (not new) that the ground effects are important: near ground effect (NGE), and in ground effect (IGE) with secondary vorticity of opposite sign being produced at the ground, eventually leading to vortex rebound. Ground effect is certainly very beneficial to wake vortex decay. Its effects on the wake lateral transport and eventual rebound are also very important. CFD studies were conducted. Again, significant work has also been done in North America (using LES and also using viscous vortex methods). The subject still calls for more work, with validation using real flight data. Notice that towing tank studies and/or catapult studies could here prove very valuable.

It was reminded (not new) that we need to treat things statistically, and to predict on probabilistic grounds. The P2P model (DLR) is specifically designed for that. It provides

upper and lower bounds on the histograms of vortex circulation and transport, and some typical results were shown. The deterministic models (VORTEX, VFS) can also be run in a statistical way, by varying the parameters (circulation level, turbulence level, precision on the wind profile, on the aircraft characteristics, etc.) and thus obtaining an envelope of the possible cases. It would also be of high value to be able to put probability numbers on the upper and lower bounds obtained by P2P and the others.

There is also a strong need for on board sensors for wake vortex detection and warning. This also corresponds to a strong pilot demand. This is the aim of the new I-WAKE project (follow up on FLAME and M-FLAME).

The pilots (IFALPA) are participating and willing to communicate. They have “different approaches and points of view, but not different opinions”. We have common goals and the same issues, and we need to communicate more. There is also a IFALPA wake vortex policy document (1998): it is a vital document and it will be further extended. It is important to also address training issues: anticipate situations, react accordingly (procedures), reorganise work during the flight, etc.

There are now many databases (Idaho Falls, Memphis, DFW, SFO, S-Wake). They are very useful and should be used more. They are also of a limited use as not all relevant information is there. As for CFD studies, they must also be exploited with care and criticism. These are complementary.

It was proposed that we should use separation based on time instead of separation based on distance (Eurocontrol Experimental Center EEC)). This makes sense since it is the “vortex age” that determines its potential hazard. As aircraft significantly decelerate along the glide slope (from intercept speed to threshold speed), the distance between consecutive aircraft on approach decreases with time. Recall that current ICAO separation is imposed at threshold. It can be shown (EEC) that current ICAO separation leads to a significant penalty in airport capacity when there is a head wind, and that time-based separation would then be beneficial.

The dynamic separation will most likely be used in future ATC systems. Operational issues are then very important. This will be addressed in ATC-WAKE and is also a main focus for WakeNet2. Information and exchanges on what can be accepted by the pilots and the ATC controllers is most important for the success of future programs.

Incident reporting was presented by NATS, the National UK Air Traffic Services Ltd. Issues were raised concerning the fact that the number of reported wake vortex encounters is much less than the actual number of encounters. Along the same lines, it was mentioned that a recent study in the US (Prof. Donohue) indicates that separation rules are already violated routinely on take-off and landing (maybe as much as 30 % of the time), yet with little, if any, problems. It thus appears that flying into wake vortices is something that happens routinely. It was also mentioned that the regions of danger are quite small and that the exposure time is quite short. Again, what is the acceptable level of “circulation + core size” for an OK encounter, given that it is also a dynamical process?

The importance of this work is that “the static ICAO standards are no longer adequate”, leading to focusing the work on “what should new standard be” (Donohue). Local meteorological data can also have a very strong influence (e.g., DFW has high

temperatures, high winds, high thermals: no wake in the DFW database survived more than 60 s): new standards should thus, at least, be airport dependent..

A concern (Donohue) was also raised concerning the fact that the ICAO separations came out shorter than the actual separation computed by DLR using the “conservative decay model”: this is surprising as one would expect that the rules were designed based on the worst case scenario: thus based on decay only (not on decay + transport) . However, nobody in the room was able to tell what was the procedure that served to define the ICAO standards. It was also mentioned (DLR) that many cases in the Memphis database also do not respect ICAO separation.

4. The Future

Following the success of WakeNet, the follow-on network WakeNet II is expected to start in late 2002.

5. Acknowledgements

The WakeNet consortium would like to thank the European Commission for the support of WakeNet I and II.

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