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Coordination Area "Technologies" Yearly Report N° 2

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	TR6	Thales Air Systems
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	DLR	Deutsches Zentrum für Luft- und Raumfahrt
	NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
	DFS	DFS Deutsche Flugsicherung GmbH
	ONERA	Office National d'Etudes et Recherches Aérospatiale
	NERL	NATS En-Route Plc.
	UCL	Université catholique de Louvain
	TUB	Technische Universität Berlin
	ECA	European Cockpit Association
	TU-BS	Technische Universität Braunschweig
	A-D	Airbus Operations GmbH

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Table of content

1. Executive Summary

The Coordination Area “Technologies” (lead DLR) has seen interesting developments in the Task Groups “Operational Wake Vortex Models”, “Wake Vortex Sensors & Advisory Systems”, “Weather Prediction and Monitoring”, and “Encounter Mechanisms & Simulation”. Due to a lack of national and international activities there was little development in the Task Group “Wake Vortex Alleviation”. The maturity and the validation status of the respective models and systems have been improved. The achieved results have been disseminated in terms of many presentations and publications at many specific and the two WN3E major workshops, external workshops, conferences, and in Journal publications. The Task Group members contributed to the partner meetings, the flyer, the WN3E website, the project management updates, the concepts bulletin, the description of work in its version 3, and the link reports. Considerable effort has been spent for the elaboration of the yearly report No. 1 of the coordination area "technologies" and in particular for the drafting and editorial refinement of the research needs report. Links have been fostered to different organizations and projects. Meetings with representatives of a large number of organizations including DWD, EASA, EUMETNET, EUROCONTROL, FAA, JAXA, Lufthansa, Munich Airport, NCAR, NRC Canada, NWRA, WakeNetRussia have been organized in order to exchange developments with respect to wake vortex activities and to identify/deepen cooperations for wake vortex research. Considerable activities were also in the preparation and coordination of the research foreseen in Sesar in WPs 6.8.1, 9.11, 9.30, 11.3, and 12.2.2. In some of these work packages the project work has already started or is about to start.

Selected highlights:

- 2nd Wakenet3-Europe International Workshop on ""Developments in Wake Turbulence Safety" has been held on 28th and 29th of June, 2010 at Airbus premises in Toulouse. The Task Group members contributed to the elaboration of the program and presented several talks.
- Specific workshop “Wake Vortex & Wind Monitoring Sensors in all weather conditions” has been organized and hosted by Thales Air Systems on 29-30 March 2010 at Thales Research and Technology, Palaiseau with about 100 attendees. One of the main outcomes is an overview on available instruments and their capabilities.
- Specific workshop “Short-Term Weather Forecasting for Probabilistic Wake-Vortex Prediction” has been organized and hosted by DLR on 10-11 May 2010 at the Institut für Physik der Atmosphäre, DLR Oberpfaffenhofen. Participation in the workshop was limited to 22 invited experts from France, Belgium, England, Germany, Italy, Japan, USA, Russia belonging to universities, research institutes, and small enterprises. These group of experts conducted comprehensive discussions in order to identify the major scientific questions, feasibility and priorities of different methods with respect to future meteorological research.
- Specific workshop “Models and Methods for Wake Vortex Encounter Simulations” has been organized and hosted by Technische Universität Berlin on 1-2 June 2010, Berlin with 26 attendees and a broad participation of US colleagues. The main outcomes of the first topic “Wake vortex models for encounter simulations” are that significant progress in model fidelity has been achieved, yet the steep gradient of the learning curve has been left. Validation of wake vortex models appears impossible; instead confidence has to be built. The second topic “Models of pilot behaviour for encounter simulations” has shown that research on hazard metrics and on limits of acceptable wake vortex encounters is still on-going, the definition of hazard boundaries requires an agreement of

all stakeholders regarding metrics and limits and the choice of right models is essential for the Re-Categorization effort.

- Research visit of Carsten Schwarz with the NIA/ FAA in Hampton, VA, USA where he conducted research dealing with the assessment of the severity of near-field wake turbulence encounters.

2. Terms of Reference, activities and developments

2.1. Coordination Area Technologies

2.1.1. Terms of Reference

The coordination area includes the following Task Groups:

Task Group "Operational Wake Vortex Models"

Task Group "Wake Vortex Sensors & Advisory Systems"

Task Group "Weather Prediction and Monitoring"

Task Group "Wake Vortex Alleviation"

Task Group "Encounter Mechanisms & Simulation"

The Coordination Area "Technologies" coordinates the activities in the Task Groups that are related to "technologies". This includes keeping track of the developments in the various disciplines, promoting communication between the various partners and interest groups, suggesting, organising and accomplishing workshops, elaboration of reports and position papers of topics of specific interests, contributing to the WakeNet3-Europe internet site, fostering links to wake vortex related European projects, and to national projects like the DLR project "Wetter & Fliegen" (Weather & Aviation), revision of wake vortex related public information (e.g. wikipedia, internet pages of agencies, …), and reporting to the commission.

2.1.2. Activities, achievements and developments

- Contribution to planning of 1st, 2nd, and 3rd WN3E Major Workshops (scope, organization, choice of talks, agenda).
- Contribution to establishment of Website, amongst others provided descriptions of DLR Projects Wake Vortex and Weather & Flying. A new folder for News/Publications has been installed on the website that increasing its up-to-dateness.
- Presentation of activities within "Coordination Area Technologies" on Partner Meetings 1 to 5.
- Comprehensive editorial activities for elaboration of WN3E Research Needs Report: guidelines for style and contents, collection of contributions, adaptations of layout, addition of cross-references, partly revision of contributions, rearrangements, own contributions to several sections, elaboration of abstract, acknowledgements, glossary, and introduction, …
- Responsible for Yearly Report No. 1 of Coordination Area "Technologies".
- Contributions to Concepts Bulletins.
- Presentation at 1st WN3E Workshop entitled: "On the maturity of wake vortex observation, prediction, and validation".
- Presentation at 2nd WN3E Workshop entitled: "Short-Term Weather Forecasting for Probabilistic Wake-Vortex Prediction".

- Presentation at 3rd WN3E Workshop entitled: “Wake-Vortex Topology & Decay – New Insights from Observation & Simulation “.
- One or several presentations at specific workshops of Task Groups in WPs 1.2, 1.3, 1.5, 3.1, 3.3.
- Meetings with representatives of a large number of organizations including DWD, EASA, EUMETNET, JAXA, Lufthansa, Munich Airport, NASA, NCAR, NRC Canada, NWRA, WakeNetRussia have been organized in order to exchange developments with respect to wake vortex activities and to identify/deepen cooperations for wake vortex research.
- Participation to several conferences and meetings, e.g.:
    - WakeNet-USA Meeting, 22./23.10.2010, Cambridge, Massachusetts, USA, Presentation: "DLR Wake Solutions in Development"
    - Global Wake Vortex Conference II, 1./2.12.2010, San Diego, CA, USA, Presentation: "Wake Vortex Modeling and Applications - Wake Vortex Advisory and Pilot Assistance"
    - AIAA Atmospheric and Space Environments Conference, 2–5 August 2010, Toronto, Ontario, Canada. Summary & Research Needs by Anthony Brown, NRC Canada with contributions from WN3E partners who attended the conference.
- Research visit of Carsten Schwarz at NIA, FAA, Hampton, Virginia, 2010 working on the topic "near-field wake turbulence encounter severity assessment".
- Information regarding activities with respect to the link to the Working Group “Aviation and Weather” and to DLR project “Wetter und Fliegen” has been provided twice.
- Project Management Updates.

2.2. Task Groups

2.2.1. Task Group “Operational Wake Vortex Models”

There was continued development, by UCL and DLR, of the operational wake vortex models in Europe. A note was also written for the 2nd PM meeting. There were also discussions with EUROCONTROL and FAA concerning the use of operational models in support of various future projects, also within SESAR: RECAT, continuation of TBS, CROPS, WAKEVAS and with JAXA.

Presentation of UCL at the EUROCONTROL Wake Vortex Workshop in Sept 2008: “The basics of the wake vortex phenomenon” [Winckelmans, 2008]. At that workshop DLR presented the “Performance of the Wake-Vortex Prediction and Monitoring System WSVBS at Frankfurt Airport” [Holzäpfel, 2008].

Presentations at the 1st WN3-E workshop in January 2009: presentation of UCL entitled “Some reflections of the achievable quality of operational wake vortex prediction using operational met and a/c inputs” [Winckelmans, 2009]; presentation of DLR entitled “On the maturity of wake vortex observation, prediction, and validation” [Holzäpfel, 2009].

Participation of UCL and of DLR at the “Global Wake Vortex Conference” at EUROCONTROL in November 2009 with a presentation entitled “The Wake-Vortex Prediction and Monitoring System WSVBS – A Wake Vortex Advisory System for Frankfurt and other Airports – a step towards dynamic aircraft spacing” [Gerz and Holzäpfel, 2009].

Concerted DLR-UCL presentations at the CREDOS Final Dissemination Forum in November 2009: presentation of UCL entitled “Wake vortex behaviour” [Winckelmans, 2009]; presentation of DLR entitled “Modelling of meteo impact on wake turbulence” [Holzäpfel, 2009].

The EDDF-1 and EDDF-2 measurement campaign databases, as collected at Frankfurt Airport during the CREDOS campaigns (see D1-1 and D1-2), were much exploited, also in support to operational wake vortex modeling. Those databases constitute a significant basis for the investigation of wake vortices behavior (transport and decay) NGE and IGE, including confronting the data with the results of the operational prediction models of UCL and of DLR. The deliverable report D2-5 [De Visscher et al., 2009] includes the contributions of UCL, DLR and Airbus-D concerning the use of the two measurement campaign databases. The deliverable includes a detailed analysis of the EDDF-2 database, and a performance assessment of the operational prediction models (DVM/PVM of UCL and D2P/P2P of DLR) as compared to the data of the two campaigns. The results of a benchmark of the two deterministic models (DVM and D2P), performed by Airbus using some selected cases of the EDDF-1 database, are also reported. Because of the importance of this work for this task group, an executive summary is here given:

The EDDF-2 database contains many (10442) wake vortex cases generated by heavy and medium aircraft in a height range from near ground up to 150 m. Due to the large sample, and to the large range of meteorological conditions, this database enables to perform well-converged statistical analyses. Here, the LIDAR processed circulations refer to the total wake vortex circulation, Γ_tot. As in EDDF-1, a significant scatter of the circulation data is observed, even at early times. The level of scatter in EDDF-2 is comparable to that of EDDF-1. It is also noted that both levels are significantly higher than the level observed in previous databases, such as the WakeFRA 2004 campaign database also analyzed within the FAR-Wake project.

The first part of the report provides the UCL analysis of the EDDF-2 database. Since the number of cases is large, the whole database was first screened, using well-defined criteria, in order to retain the cases (6950 cases) which were considered relevant for further analysis and use within CREDOS. The wake vortex lateral transport was correlated with the crosswind, using different (operational and not operational) “crosswind definitions”. The effective vortex drift velocity was then also obtained and also compared to each crosswind definition. The time evolution of the envelopes containing the wake vortices, with defined probability level (90, 95 and 99 percent envelopes) and for each crosswind definition, were then also obtained. The results show that the growth of the envelope width is linear in time, at least for the times 40 to 120 s of interest to CREDOS. Based on those results, a simple mathematical model was proposed and the model was calibrated on the data. A potential use of this model for the envelopes was also proposed for use within CREDOS. Finally, an analysis of the wake vortex circulation decay, depending on the wind amplitude, was also performed: those results can also be related to the recent Large-Eddy Simulation (LES) studies carried by UCL on wake vortices IGE and with different crosswinds (see details below).

The prediction models of UCL were then also presented (Deterministic/Probabilistic wake Vortex Models, DVM/PVM) and assessed, on both the EDDF-1 and the EDDF-2 databases. The simulations were run using inputs as close as possible to the measurement conditions, and also using the “declared” measurement uncertainties. The results were compared with the provided experimental data, and quantified comparisons on the wake vortex positions and circulations were provided and discussed, using statistical means. The difference between the LIDAR processed $\Gamma\_5\text{-}15$ circulation (as provided in the EDDF-1 database) and the LIDAR processed total circulation Γ_tot (as provided in the EDDF-2 database) was also highlighted. In that respect, the influence of the distinction between the $\Gamma\_5\text{-}15$ circulation and the Γ_tot circulation on the prediction results (i.e., altitude and circulation predictions) was further studied using the EDDF-1 database. Also studied was the influence, on the DVM results, of the extrapolation of the met. data, when not available. Finally, and for completeness because the “benchmark exercise” (see details below) was performed only on a limited subset of the EDDF-1 database (16 cases as chosen by Airbus), the agreed upon “benchmark procedure” was also applied to the whole EDDF-1 database. For the DVM, using both databases, due to the high variability of the provided data (both on met and on the wake vortex measurements, that are input to the model), the obtained differences between the measurements and the model predictions were found to be higher than those obtained in previous work: confronting the DVM results to the WakeFRA 2004 data and to the results of LES, as performed in FAR-Wake. Considering the quite high variability of the present data, the agreement between the DVM predictions and the measurements data was considered as quite good. For the PVM, using both databases, it appeared that the predicted envelopes, obtained using the declared measurement uncertainties, were also reliable, again considering the high variability of the provided circulation data. In order to obtain "better" predicted results, yet of course larger envelopes, one should rerun the PVM using input uncertainties which better reflect the true uncertainty of the provided data.

The second part of the report contains the performance analysis of the Probabilistic/Deterministic Two-Phase wake vortex decay and transport model of DLR (D2P/P2P). The model was first presented. The performances of the D2P was then assessed using the EDDF-1 database. Different parameterizations and inputs of the model were also tested to investigate the effects of: the onset of ground induced rapid decay, the headwind/tailwind modeling, the crosswind shear model, the vortex decay models, the input wind profile (SODAR/RASS or WTR/RASS). A scoring procedure was used to compare the obtained results. A good compromise of parameterizations of the model was also proposed in order to be as close as possible to the measured wake vortices. The analysis of the EDDF-1 dataset does not allow to unambiguously conclude on any peculiarities of wake vortex behaviour of departing aircraft, as compared to landing aircraft. However, the non-optimal quality of the wake vortex and meteorological data, together with the strong headwinds, somewhat hamper the potential of the analysis. The D2P performances were then also evaluated using the EDDF-2 database. First, an assessment of the wake vortex measurement data, of the aircraft departure track data, and of the meteorological data was performed. The data analysis revealed several aspects which are considered critical regarding the usage of the data for wake vortex model performance assessment and improvement of its parameterization. The measurement devices are not optimal to obtain met data at the altitudes of wake vortex evolution. Also the large distance between the wake vortex measurement site and the meteorological measurement site likely introduces significant differences between the measured and the meteorological data actually sensed by the wake vortices. Due to the large scatter of the data, a procedure was also developed to smooth the circulation data used to initialize the predictions. The detailed analysis also lead to establish a selection procedure for the EDDF-2 cases used for the scoring of the D2P wake vortex model. The wake vortex prediction skill was then analyzed and compared to the model performance achieved during other campaigns, using the same scoring procedure as used with the EDDF-1 database. Again, different parameterizations and input of the D2P were tested and the influence on the prediction results was studied. The comparison to scoring results achieved with EDDF-1 data indicated on average better model performance for EDDF-1, although wake vortex prediction OGE was subjected to larger uncertainties than IGE and although the measurement conditions during EDDF-1 were complicated by very strong winds. The comparison to the WakeFRA data showed much higher differences of the prediction skill. The scoring results also confirmed that crosswinds measured by LIDAR yield superior prediction skill of lateral transport compared to WTR/RASS measured crosswinds; this is as expected.

The third part of the report concerns the "benchmarking exercise" of the two deterministic models (DVM of UCL and D2P of DLR), based on a small subset of the EDDF-1 database. Model input values were taken from the mean experimental values corresponding to the time of over-flight, and here considered as the "true" reference (of course, not necessarily the case due to the measurement uncertainties). First, the selection of 16 cases, out of the 147, was presented. The selection objective was to choose a good representation for each crosswind condition at various headwind classes, depending on availability. For the benchmarking exercise, both wake vortex models were run from identical initial conditions specified by Airbus and based on aircraft and LIDAR data. The predicted vortex characteristics (lateral and vertical positions, and circulation) of both models were confronted to the LIDAR measurements, comparing the running average of vortex characteristics (predicted by both models and "measured") and computing the rms deviation between the predictions and the measurements. An assessment depending on crosswind and headwind categories was also performed and reported. It was noted that the sample size is really not sufficient for robust conclusion. However, for both models, the vortex predicted characteristics were in the range of the LIDAR data, under the given challenging atmospheric conditions. It was concluded that the both models represent well the wake vortex transport and decay. From the data, an opportunity is indicated that the models could indeed be used for the transport prediction under cross wind conditions, together with the appropriate probabilistic versions (PVM and P2P) or using an appropriate safety margin to be defined and applied (a proposition being also reported).

The investigations done by UCL and DLR to estimate the required crosswind thresholds for different departing aircraft separation times were then usefully completed by an investigation done by DFS using EDDF-2. The obtained results were then further discussed and compared. The DLR approach was also further improved. Final results were then produced and put together: a common paper [Dengler et al., 2010] is being completed and will be submitted soon.

Another contribution was the use of both D2P and DVM modules in the WakeScene-D software package of DLR, as part of the work in CREDOS on "Risk Modeling and Risk Assessment". This used the updated and validated wake vortex behaviour models to realistically simulate takeoff scenarios with complex flight path, involving wake vortex evolution and decay in and out of ground effects. WakeScene-D is a software package to determine wake vortex encounter probabilities for departures. The severity of potential encounters identified by WakeScene-D can subsequently be evaluated with the Airbus tool VESA.
Measured vortex tracks of about 10,000 departures from runway 25R of Frankfurt airport have been compared with WakeScene-D simulations. For lateral vortex transport, which for crosswind departures constitutes the most important quantity, good agreement between the characteristics of measurement and simulation has been achieved. This good agreement indicates that WakeScene-D is an instrument which allows investigating realistic wake vortex behaviour in domains and height ranges that are far out of reach of measurements.
Monte Carlo simulations of the Frankfurt traffic mix with a sample size of 1,000,000 cases indicate that for current operations 66% of the potential encounters are restricted to heights below 300 ft above ground. Within this altitude range clearance of the flight corridor by descent and advection of the vortices is restricted: stalling or rebounding vortices may not clear the flight path vertically and weak crosswinds may be compensated by vortex-induced lateral transport. Further, minor peaks at altitudes of 1300 ft and at 1800 ft occur which can be attributed to flight path diversions (change of climb rate and heading) in combination with adverse wind conditions (headwind and crosswind) which increase the encounter risk compared to approximately parallel flight of the leader and follower aircraft. For example, increased encounter frequencies are observed when the leading aircraft conducts a turn towards the main wind direction. The resulting headwind component may compensate wake vortex descent and may advect the vortex trail into the flight path of the follower aircraft.
Statistics of encounter frequencies and encounter conditions have been established for 60 s and 90 s departure separations and minimum crosswinds from 0 to 10 knots in 2 knot increments, respectively. The reduction of aircraft separations from 120 s to 60 s approximately triples the number of encounters, whereas the fraction of strong encounters increases due to the reduced time for vortex decay.
If aircraft separations are reduced to 60 s and crosswinds at 10 m height above ground exceed a threshold of 8 knots, the overall frequency of potential encounters of 3.1% clearly is falling below the corresponding frequency of 7.0% of the reference scenario. The strong crosswind in ground proximity very efficiently reduces the encounters below 300 ft from 4.6% in the reference scenario to 0.0056%. Unfortunately, the 10 m crosswind criterion alone is not sufficient to reduce encounters which are related to flight path diversions along the departure routes. Due to the by 50% reduced time for vortex transport and decay, encounters with circulations stronger than 350 m^2/s are still 2 to 4 times more frequent than in the reference scenario.
An investigation of wind direction effects on the encounter frequencies reveals an intriguing phenomenon: Headwind situations lead to the highest encounter probabilities because headwind transport of the wake vortices may compensate wake vortex descent or even lead to rising wake vortices with respect to the generator aircraft trajectory. This effect increases encounter frequencies because the medium weight class followers usually take off earlier and climb steeper than the leading aircraft and therefore usually fly above the wake vortices. In contrast, the encounter frequencies for tailwind situations are much lower because tailwinds support wake vortex descent.
Initially surprising, the beneficial effects of crosswinds are not symmetric. The smallest encounter frequencies are observed for crosswinds from the starboard side. Here the crosswinds close to the ground reduce encounter frequencies. With increasing height the wind direction turns on average to the

right. Consequentially, a tailwind component is added to the crosswind which supports relative vortex descent and thus reduces encounter frequencies aloft. This turning of the wind direction with height is related to the concept of the Ekman spiral which describes the resulting wind direction in the atmospheric boundary layer by equilibrium of the driving pressure gradient force, the Coriolis force, and the friction force. Due to the same mechanism crosswinds from port side receive a headwind component with increasing height. As a consequence, the port crosswind situation leads to significantly more encounters than the starboard side crosswinds.
From a WakeScene-D perspective it can be concluded that for 60 s departure separations along the northern departure routes as used routinely at Frankfurt airport acceptable encounter frequencies are found for crosswinds below -6 knots (wind from starboard side) and for crosswind magnitudes above 8 knots. The respective assessment of the related encounter risks with VESA leads to the same conclusions also for straight departure routes. Crosswind departure procedures could be refined by using only departure route combinations where the leading aircraft is flying on the downwind route.
Crosswind transport certainly is the most effective mechanism to clear a flight corridor from wake vortices. However, the applicability of purely crosswind based wake vortex advisory systems covering vertically extended domains is impeded by the veering wind with altitude. As a consequence, either the flight tracks of subsequent aircraft must be separated already at quite low altitudes such that the crosswind does not change significantly within the considered height ranges or the advisory system must also consider vortex descent and/or vortex decay either explicitly or implicitly as in the presented concept. The design of WakeScene is described in [Holzäpfel et al., 2009] and the conducted investigations are available in [Holzäpfel and Kladetzke, 2009].

LES investigations of wake vortices IGE and with realistic turbulent cross-wind were also further carried out by UCL, in collaboration work with Airbus, and to further support the operational wake vortex modelling. This adds to the knowledge acquired in FAR-Wake [Holzäpfel et al., 2008]. The lateral domain of the LES was also enlarged (by a factor of 2), thus further reducing the parasitic effects of the periodic boundary conditions; a further improved subgrid-scale model [Bricteux et al., 2009], valid for both vortex flows and wall-bounded flows, was also used. Three cases were considered: a case where the wind amplitude at wake vortex initial release height h_0 (and here taken equal to the initial vortex spacing b_0) is equal to the wake descent velocity OGE, V_0 (thus the same case as that investigated in FAR-Wake); a case where the wind is twice stronger; and a case where the wind is twice weaker. For all cases, detailed analyses were done of the wake vortex transport and decay. In particular, the circulation distribution, Gamma(r) of the longitudinally averaged vortex (flow averaged over the 256 computational plane of the longitudinal direction) was measured as a function of time, thus allowing to obtain both $\Gamma_{5\text{-}15}$ and Γ_{tot} of each "mean vortex". In addition, the circulation distribution was also measured in each computational plane: this allowed to also obtain the both $\Gamma_{5\text{-}15}$ and Γ_{tot} diagnostics in each plane, and thus also the statistics of those quantities. The results also allow to quantify the loss of coherence of each vortex IGE as a function of time and depending on cross-wind intensity. It also allows to estimate the spread that can be expected in lidar measurements of $\Gamma_{5\text{-}15}$ or Γ_{tot} for wake vortices IGE and with cross-wind (as a lidar measurement scans a plane, not a mean vortex). Those results also served to further calibrate the DVM/PVM transport and decay parameterizations IGE and with cross-wind. It is planned that part of the report by UCL to Airbus [Bricteux et al., 2009] will be used to produce a publication. Some of this work was also presented at the ASME International Mechanical Engineering Congress & Exposition in November 2009.

LES investigations of wake vortices evolving in a stably stratified atmosphere were also done by UCL. Three stratification cases were investigated, from moderate (N* = 0.75) to very high (N* = 1.4). The wake vortex system evolution was analyzed using global diagnostics (trajectory and circulation of the primary wake vortices). The results were compared and discussed. The work was presented in [DeVisscher et al., 2009]. The results of this work were also used for further improvement and calibration of the DVM/PVM stratification model with two-phase decay.

In further LES studies by UCL, still ongoing, the influences of combined atmospheric weak turbulence and stable stratification on wake vortex behaviour were investigated. In order to best represent the atmospheric conditions, the stratified turbulent fields are here first generated using LES of forced and stratified turbulence, evolving until it reaches a statistically converged state. Different stratification levels are investigated, from low to high. The chosen ambient turbulence level is weak in all cases. The simulations are performed at very high Reynolds number (much higher than in previous work), thus also more realistic. Part of the work was presented in [De Visscher and Winckelmans, 2010]. More work has been done since, also for submission to a journal publication. The results have also been used to further improve and calibrate the DVM stratification-turbulence models for both the transport and the two-phase decay. When the stratification level is from medium to high (N* >= 0.75), the instabilities have short to medium wavelengths and the turbulence integral scale has a weak impact: one obtains a clear two-phase decay that is essentially uniform along the vortex longitudinal direction. When the stratification is absent or low (e.g., N* <= 0.35), the long wavelength Crow type instabilities are also triggered and this leads to vortex linking. The decay is then non uniform along the vortex and it must be measured and characterized in various cross-planes (e.g., measure the circulation distribution, $\Gamma(r)$, perpendicular to the detected deformed vortex core line in each cross-plane, and thus obtain local values of Γ_{5-15} and Γ_{tot}): some planes then exhibit a clear and strong second phase of decay starting at the time of vortex linking, while others still only exhibit a weak (yet stronger than phase 1) second phase of decay.

The resulting detailed velocity fields of such LES, OGE and NGE/IGE correspond to wake vortices in specific and realistic conditions. As such, they can also be stored and used operationally as input in “fast time velocity field evaluation” routines for flight simulator encounter studies. This comes in addition to the functionalities that can already be provided by simpler models: analytical velocity models (one scale or two-scales models), but also fast-time evaluation routines for the Biot-Savart velocity field induced by wake vortices generated by aircraft with complex trajectory or even with space-developing Crow instability as in [De Visscher and Winckelmans, 2010] and [De Visscher et al., 2010].

Such LES fields have also been used with very good success as databases for LIDAR simulator studies, as in [Brousmiche, 2009 and 2010] and [Lugan et al., 2010], and also for radar simulator studies, as in [Vanhoenacker-Janvier et al., 2010]. Such LES fields have also been provided to GreenWake and are used for new UV LIDAR sensor design and evaluation.

DLR has also conducted LES of wake vortex evolution in environments with various degrees of atmospheric turbulence and stable temperature stratification [Hennemann and Holzäpfel, 2009]. Prior to the inset of the counter-rotating vortex pair the atmospheric turbulence was allowed to develop a state with a distinct inertial subrange and a constant eddy dissipation rate. A post processing method has been developed that is capable to identify the vortices even in progressed states of vortex decay where the coherent vortex structure is getting lost.

In contrast to the well known two-phase circulation decay characteristics, the vortex circulation estimated perpendicular to the detected deformed vortex core line reveals a three-phase decay sequence. The initial phase of gradual decay termed “diffusion phase” is followed by a “rapid decay phase” which typically commences at the time when the vortices link. In neutrally stratified environments long-living vortex rings are observed with gradual vortex decay. This third phase may be termed “ring diffusion phase”. The evolution of the vortex topology from the initial sinusoidal oscillations, the subsequent vortex linking and vortex ring formation up to the axial contraction and the lateral spreading of the vortex ring can be explained phenomenologically by mutual velocity induction.

From Lidar observations it is known that wake vortices may frequently live much longer than anticipated by the aircraft separations that have to be obeyed during approach and landing or during departures. One potential reason why flying is safe nevertheless is the fact that the vortices do not remain straight but are rapidly deformed by the relatively strong turbulence prevailing in the atmospheric boundary layer. The deformation of vortex segments may reduce the impact time of adverse forces and moments experienced by an encountering aircraft and thus may alleviate the severity of the encounter.

We characterize the vortex deformation in terms of curvature radii. At a late stage of vortex evolution the established statistics indicate a predominance of curvature radii on the order of one initial vortex separation, b_0, for a variety of environmental conditions. It still has to be investigated thoroughly whether such strongly deformed vortex segments may still pose a risk to follower aircraft. Encounter flights of the DLR research aircraft Falcon behind an A380 indicate that already pronounced sinusoidal oscillations prior to vortex linking might significantly reduce the severity of encounters.

We also found that the ratio of the integral length scale of turbulence and initial vortex separation, L_t/b_0, has a strong effect on vortex decay characteristics and vortex topology. For L_t/b_0 ratios approaching a value of one, the decay rate already in the diffusion phase is increased and the vortex topology is becoming more complex.
Finally, also DLR has been working on subgrid-scale models and has found that the Lagrangian Dynamic Model is well suited to predict sustained tight vortex cores in turbulent environments.

A new series of large-eddy simulations of a wake vortex evolution in different environments have been performed by DLR [Holzäpfel et al. 2010, Misaka et al. 2011, Holzäpfel 2011]. The environmental background is characterized by varying turbulence intensities and stable temperature stratifications. Turbulent exchange processes between the vortices, the vortex oval and the environment, as well as the material redistribution processes along the vortex tubes are investigated employing passive tracers that are superimposed to the initial vortex flow field. Various features of three-dimensional wake vortex evolution are well captured by the series of simulations, i.e., Crow instability, vortex reconnection, propagating helical vorticity structures, vortex ring formation and generation of secondary vorticity structures, vortex bursting and detrainment of passive tracers. It is revealed that the "vortex bursting" phenomenon, known from photos of aircraft contrails or smoke visualization, is caused by collisions of secondary vortex structures travelling along the vortex centreline which dash material out of the vortex but do not result in a sudden decay of circulation. Evidence is provided that these secondary vorticity structures may also generate funnel-shaped vortex core features that are surrounded by vortex bursting structures.

The interaction of helical instabilities, generated by pressure disturbances from the vortex reconnection process, and the secondary vortex structures results in rapid vortex decay in stably stratified environments. This interaction does not occur under neutrally stratified and weakly turbulent conditions and a long-lived vortex ring may form revealing intriguing effects: the vortex ring links a second time and a short time later the established double rings merge again into a single vortex ring. Evidence of key phenomena observed in the simulations is brought about by photographs of contrails. The vertical and lateral extents of the detrained passive tracer strongly depend on environmental conditions where the sensitivity of detrainment rates on initial tracer distributions within the wake appears low. The degree of stable temperature stratification mainly controls the detrainment rate, while the strength of (generally weak) ambient turbulence affects the onset time of detrainment. Circulation decay and passive tracer detrainment are driven by similar mechanisms and thus are well correlated.

A workshop on "Wake Vortex Dynamics, Chemistry and Microphysics from Aircraft Leading Edge to Wake Vortex Dissolution" has been conducted at the DLR - Institut für Physik der Atmosphäre, Oberpfaffenhofen on 28th of July, 2009. The purpose of the workshop was to prepare for a cooperative initiative between various engineers and scientists interested in predicting, understanding and quantifying the details of wake vortex dynamics and contrail formation. The workshop was set-up to prepare for a consistent chain for the simulation and experimental assessment of the flow around realistic aircraft configurations including the engines and exhaust jets followed by wake-vortex roll-up and the subsequent vortex evolution from the trailing vortex pair and onset of the Crow (and short-wave) instabilities to the formation of vortex rings and final vortex decay. The Workshop's objectives were (i) finding of the right scientific questions (in detail and depth), (ii) determining the methods to tackle these questions and (iii) exploring ways of collaboration and funding.
The workshop was attended from experts in the various topics. The workshop started with two introductory lectures on wake vortex and contrail aspects. Thereafter, the participants presented recent findings and contributions to the objectives of the workshop. Finally a discussion covered the whole set of topics, including partial identification of further partners and funding opportunities (informal cooperation, national funding, joint EC project, etc.). Because so far funding of the suggested research was not possible, voluntary bilateral research activities have been initiated.

The UCL document describing the UCL operational tools for predicting aircraft wake vortex transport and decay (DVM/PVM models and the WAKE4D platform) was also significantly updated, reflecting all the recent developments/improvements made to the physical models, to the probabilistic procedure, to the

WAKE4D for simulating complete scenarios, as well as the results obtained in the recent validation/benchmarking studies carried during FAR-Wake (using the WakeFRA 2004 database) and CREDOS (using the EDDF-1 and EDDF-2 databases). Some of this material served as contribution to workshop presentations. Some of this material was also be used for contributions to the Research Needs Report. A Graphical User Interface (GUI) was also developed for easy use of the DVM/PVM. This GUI is also useful for demonstration or training purposes. These developments are aimed at allowing more easily a transfer of the simulation tools to other users. A pre-processor was also developed: it builds all required WAKE4D input files for a complex aircraft trajectories which is defined “as pilots fly them” (i.e., pass through given way points, at a certain IAS, do a turn with a provided turning rate, climb at a give rate, etc.) and under given wind conditions. A post-processor has also been developed that computes, using a horseshoe vortex filament approach, the 3-D velocity field induced by a wake rolling up and simulated by the DVM using a the initial “vortex sheet model” option instead of the usual “rolled up” wake model. A User Guide of all tools was also produced.

The vortex sheet initialisation and the velocity evaluation tool were also used in collaboration work of UCL with C. Schwarz of DLR Institute of Flight Systems, and Wayne Bryant of FAA Flight Systems: development by UCL and sharing of a simplified and analytical model for effective span loading of heavy aircraft in landing configuration (with flaps and HTP effects), which was then used by DLR/FAA as initial condition in WAKE4D simulations (using the DVM mode with near wake vortex sheet model) for “near-field wake turbulence encounter severity assessment” by FAA/NIA/DLR.

There was a participation of DLR and UCL to the specific workshop of Task Group 1.3 “Short-Term Weather Forecasting for Probabilistic Wake-Vortex Prediction”, organized and hosted by DLR - Institut für Physik der Atmosphäre, Oberpfaffenhofen, on May 10-11, 2010, with contributions: [Winckelmans and Bourgeois, 2010] by UCL, [Gerz , 2010] and [Holzäpfel , 2010] by DLR.

There was a participation of UCL and DLR to the specific workshop of Task Group 1.5 “Models and Methods for Wake Vortex Encounter Simulations”, organized and hosted by TU Berlin in Berlin, Germany, on June 1-2, 2010, with contributions: [De Visscher et al., 2010] by UCL, [Hennemann and Holzäpfel, 2010], [Steen and Holzäpfel, 2010] and [Kladetzke, 2010] by DLR and TU-BS.

There was a participation of DLR and to the WN3-E 2nd major workshop “Developments in Wake Vortex Safety”, organized and hosted by Airbus in Toulouse, France, on June 28-29, 2010, with contributions by DLR: [Kauertz and Holzäpfel, 2010] (joint Airbus-DLR contribution) and [Holzäpfel, 2010].

There was a participation of DLR and UCL to the ASE/AFM joint Invited Session “Managing wake vortex encounters” of the Joint AIAA GNC/AFM/MST/ASC/ASE 2010 Conference, Toronto, Ontario, Canada, August 2-5, 2010, with contributions: [De Visscher et al., 2010] by UCL, [Holzäpfel et al., 2010] and [Schwarz et al. 2010] by DLR. DLR and UCL also participated in the writing of a “review” report of the achievements and future required work, by A. P. Brown et al.; report also made available to WN3E.

There was a participation of UCL and DLR to the WakeNet-USA meeting in Boston, USA, on October 20-21, 2010, with a contribution by DLR [Schwarz et al, 2010] .

There was a participation of UCL and DLR to the WNE3E 3rd major workshop “Wake Turbulence Achievements and Future Research Needs”, organized by NATS in Southampton, UK, 10-11 May 2011, with contributions by UCL [Winckelmans and Chatelain, 2011] and by DLR [Holzäpfel, 2011].

The operational models have come to a sufficient level of maturity that they are being used in support of various projects. For instance, operational models were used by UCL very extensively (7.4 million WAKE4D simulations, each using many PVM computational gates) in support to wake vortex encounter risk assessment studies of EUROCONTROL (ECTL) and DSNA for the CDG WIDAO (Wake Independent

Departure and Arrival Operations) safety case, finally leading, when combined with LIDAR data, to an acceptance of WIDAO by the regulators. The models are also used by UCL and EUROCONTROL (ECTL) in support to studies conducted in SESAR P6.8.1 (TBS, CROPS, etc.) led by EUROCONTROL, by UCL and DLR in support to a WAKEVAS (Wake Vortex Advisory System) in SESAR P12.2.2 led by Thales, and by DLR and UCL in support to a WEPS-P (Wake Encounter Prevention System based on Prediction) in SESAR P9.11 and/or P9.30 led by Airbus.

2.2.2. Task Group "Wake Vortex Sensors & Advisory Systems"

Task Group Terms of Reference are the following:

- Wind Monitoring Sensors (information ingested by Wake Vortex Predictor for forecasting wake turbulence)
- Wake Vortex Monitoring Sensors

- Thales Air Systems (TR6) has organized and hosted at Thales University the 1rst Wakenet-3 International Workshop in coordination with AIRBUS on "Wake Turbulence Safety in Future Aircraft Operations" with more than 120 attendees (FAA, Eurocontrol, DSNA, DFS,NATS, ADP, …). All details are given on the web page : http://www.wakenet3-europe.eu/index.php?id=63
- Thales Air Systems (TR6) is preparing a Dedicated Workshop on "Wake Vortex & Wind Monitoring Sensors". Agenda of this workshop has been initiated in 2009 by selection of guest speakers to give a talk on radar, lidar and acoustic sensors for wind or wake-vortex monitoring. This event will take place at Thales Research & Technology in Palaiseau, France (South of Paris), 29th-30th of March 2010.
- Thales Air Systems (TR6) has attended following Workshops :
  - WakeNet USA 21-22 October 2008 (San Francisco)
    - TR6 gave a talk on "*European Wake Vortex Advisory System : System Architecture & Sensor Measurement campaign*" . Slides are available on WakenetUSA website : https://ksn.faa.gov/km/ATO/coo/opsplan/Research/planning/wakenet
  - WakeNet USA 25-26 March 2009 (Miami)
  - WakeNet USA 14-15 October 2009 (Washington)
  - Global Wake Vortex Conference, EUROCONTROL HQ, Brussels , Belgium, 09 - 10 Nov 2009
    - TR6 gave a talk on "Runway Wake Vortex Detection and Advisory Systems". Slides are available on Global Wake website : http://www.eurocontrol.int/corporate/public/event/2009_11_9_wake_vortex.html
  - FP6 CREDOS (Crosswind - Reduced Separations for Departure Operations), Final Dissemination Forum, 18-19 November 2009, Chantilly
- Thales Air Systems has coordinated actions with SESAR program. TR6 is active in the following WPs related with Wake Vortex :
  - WP12.2.2 Runway Wake Vortex Detection, Prediction and decision support tools (THALES is leader of this WP) :
    - The main objective of this project is to define, analyse and develop a verified wake turbulence system according to the operational concept developed by P 6.8.1 in order 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. This global objective will be achieved by means of developing a wake vortex advisory system able to deliver in real time position and strength of the wake vortices and to predict their behaviour and potential impact on safety and capacity, taking in account actual weather information as well as the airport specific climatological conditions, aircraft

characteristics (generated wake vortex and wake vortex sensitivity) and airport runways layout. These functionalities will be progressively included in the wake vortex advisory system to be validated and deployed on airports in order to optimise the runway throughput and reduce delays.

- Elaboration of state-of-the-art Wake-Vortex & Wind sensors in coordination with SESAR on WP12.2.2
- Feedback from SESAR P12.2.2 XP0 trials preparation on CDG Airports from sensors providers and sub-contractors

- WP6.8.1 Flexible and Dynamic Use of Wake Vortex Separations (THALES is contributor with EUROCONTROL as leader) :
  - This project will develop wake turbulence related operational concept and specify user and high level system requirements in order to, conditionally or permanently reduce landing and departure wake turbulence separations and, consequently, to increase the runway throughput in such a way that it safely absorbs arrival demand peaks and/or reduces departure delays. The proposed 'Dynamic Pair-wise Separation' concept and system shall allow for controllers to sequence arriving or departing aircraft using Time-Based Weather Dependant Pair-wise wake turbulence separations consisting of the three following concept functionalities:
    - Time-based separations will ensure a more consistent runway throughput independent of (in particular) headwind conditions on the day of operations.
    - Weather-dependent application of wake turbulence separations will increase runway throughput in favourable weather conditions and introduce dynamic spacing concepts
    - A definition of wake turbulence separations per pair of aircraft type will increase runway capacity. This will be achieved by taking into account the potential wake vortex encounter severity as a function of the leading aircraft's wake generation and the following aircraft wake response characteristics

  These functionalities will be progressively developed and integrated in the concept and system along the three proposed phases of the project.

- Thales Air Systems (TR6) has published some papers on International Conference or Publication:
  - International Radar Symposium (IRS'09), 09 - 11 September 2009, Hamburg, Germany : Paper on "Wake Vortex Monitoring Campaigns Using X-Band RADAR"
    Website : http://www.irs-2009.de/
  - International IEEE Radar Conference (Radar'09), 12th-16th October 2009, Bordeaux, France. Paper on "Wake Vortex X-Band Radar Monitoring: Paris-CDG Airport 2008 Campaign Results and Prospectives"
    Website : http://www.radar2009.org/
  - URSI Conference on "Propagation and Teledetection", 24th-25th March 2009, Paris.
    Paper on "Télédétection Radar de turbulences de sillage : retro-propagation en air clair"
    Website : http://ursi-france.institut-telecom.fr/index.php?id=44
  - Météo-France Toulouse, France, 09 & 10/11/2010, Air Traffic & Meteorology Workshop, Poster of WP1.2 synthesis on Sensors Research Needs
  - EUROCONTROL Research Centre, Bretigny, France, 8 & 9/12/2010, EUROCONTROL 9th Innovation Workshop, Presentation of WP1.2 synthesis on Sensors Research Needs
- Thales Air Systems (TR6) has contributed to Position Papers :
  - Publication on " Radar Monitoring of Wake Vortex : Electromagnetic reflection of Wake Turbulence in clear air " in Compte-rendus Physique de l'Académie des Sciences, to be published in First semester 2010
  - Opening session of European EURAD Conference by THALES on (+ publication):"Airport Radar Monitoring of Wake Vortex in all Weather Conditions"
  - Oral presentation for SESAR WPE Eurocontrol 9th Innovation Workshop on (+ publ.): "Candidate Technologies Survey of Airport Wind & Wake-Vortex Monitoring Sensors"
  - THALES Paper submission for EASV'11 Conference:"Optimising Runway Throughput through Wake Vortex Detection, Prediction and decision support tools"

- o THALES publication in CRAS, French Science Academy, edited by Elsevier: "Radar Monitoring of Wake Vortex: Electromagnetic reflection of Wake Turbulence in clear air"

Thales Air Systems (TR6) is preparing a Dedicated Workshop on "Wake Vortex & Wind Monitoring Sensors". Agenda of this workshop has been initiated in 2009 by selection of guest speakers to give a talk on radar, lidar and acoustic sensors for wind or wake-vortex monitoring. This event will take place at Thales Research & Technology in Palaiseau, France (South of Paris), 29th-30th of March 2010.

For Wind & Wake Vortex Monitoring Sensors, we have investigated following products :

- **Radar Technology**
  - ***THALES*** with X-band BOR-A550 Radar for wake vortex monitoring
  - ***RAYHTEON*** with X-band Electronic Scanning Radar for wind & wake vortex monitoring
  - ***TOSHIBA*** with X-band High Power GaN Radar for Wind Monitoring in clear Air
  - ***TRIAD*** Multi-static X-band Radar for turbulence monitoring
  - ***DLR*** C-band mono/bi-satic weather radar for wind monitoring
  - ***NOVIMET*** Polarimetric Doppler X-band HYDRIX radar for wind monitoring
  - ***NUDT (China)*** X-band radars (weather & simultaneous bi-polar KDIPR radars) for wake Vortex Monitoring + Wake Vortex Radar Simulator in different bands
  - ***VAISALA*** UHF Wind Profiler
  - ***DEGREANE*** UHF Wind Profiler
  - ***LaMP*** ST VHF Wind Profiler
  - ***UCL*** Wake Vortex Radar simulator
  - ***Boston Airport*** W-band Radar for wake vortex monitoring
  - ***NASA*** 35 GHZ radar simulator for Wake Vortex Monitoring
- **Lidar technology :**
  - ***NATURAL POWER*** (http://www.naturalpower.com/zephir-laser-anemometer) with Lidar ZEPHYR product from prototype developed by QinetiQ
  - ***HALO Photonics*** (http://www.halo-photonics.com/) with Lidar Galion Product
  - ***CATCH-THE-WIND*** (http://www.catchthewindinc.com/) with Vindicator® Laser Wind Sensor
  - ***WindScanner***, based on 3 synchronized M-scan Lidars for 3D volume scanning (http://www.risoe.dtu.dk/research/sustainable_energy/wind_energy/projects/vea_wind_scanner.aspx?sc_lang=en/).
  - ***LEOSPHERE*** (http://www.leosphere.com/) with Wind Lidar WindCube7 and Windcube70 but also development of Wake vortex Lidar WLS200
  - ***Lockheed CT*** with Windtracer Lidar for Wind & Wake Vortex Monitoring
  - ***Mitsubishi Electric*** with Wake Vortex Lidar
  - ***THALES*** Airborne IR and UV Lidar for short-range wind and turbulence monitoring
  - ***GTRI*** Forward Looking interferometers –Passive Infra-red radiometers for Wake vortex Monitoring
  - ***DLR*** Lidar for Wake Vortex Monitoring
  - ***Lidar Technologies*** UK with UV Lidar for Airborne Wake Turbulence Monitoring
- **Acoustic Technology**
  - ***SONDEI*** active acoustic sensor for wake vortex monitoring
  - ***Flight-Safety-Technology*** passive acoustic sensor SOCRATES based on Laser acoustic antenna
  - ***TRIAD*** bi-static Radio-Acoustic System for Wake Vortex Monitoring
  - ***Worcester*** Acoustic sensor for wake vortex monitoring

We have also requested information from :

- Meteo-France : NICE Airport Campaign for Wind-shear Monitoring
- Hong-Kong Meteorologic Center : Hong-Kong Wind-Shear Monitoring
- DFS : Wind Profilers & Windlines
- NATS : London Heathrow Wake Vortex Campaign

- EUROCONTROL : CREDOS & WIDAO Campaigns

In the area “Wake Vortex Advisory Systems” Task Group activities are related to:

- Wake Vortex Advisory System architecture:

Different kind of functionalities shall be integrated and aggregated in a single ‘black box’ i.e. Separation Mode Planner, Wake Vortex Predictor and Advanced Thales Alert Server (ATLAS) with Wake Turbulence alerting function.

- Wake Vortex Advisory System integration in ATC platform:

Interfaces and protocol within upstream components such as meteo data, Lidar, Radar and air traffic situation as well as downstream components such as Controller Working Position and Supervisor shall be defined and standardized.

For Wake Vortex Advisory System, we have investigated the following products:

1. Strategic adaptation of separation between aircraft
    - *NLR Separation Mode Planner*
2. Tactic adaptation of separation between aircraft
    - *UCL Wake4D (Wake Vortex Predictor)*
    - *DLR P2P (Wake Vortex Predictor)*
3. Alerting function
    - *Thales Safety Nets (ATLAS: Wake Turbulence Encounter Advisory functionality): Outputs from Separation Mode Planner as well as Wake Vortex Predictor; Air traffic situation, wake vortex sensor will be used by alerting function for providing ATM human actors the appropriate information to handle air traffic situation.*

In addition to last reported period activities (Wake Vortex Advisory System architecture, contribution to Wakenet3, Wakenet USA, Global Wake Vortex conference) Thales Air Systems is preparing in 2010 its activities in the field of

- Wakenet3 “Wake Vortex & Wind Monitoring Sensors”. This event will take place at Thales Research & Technology in Palaiseau, France (South of Paris), 29th-30th of March 2010 cf. 2.2.1.
- Wakenet USA conference planned in March 2010 in Miami.
- Refining previous investigations taking into account SESAR P6.8.1 and P12.2.2 projects. Wake Vortex Advisory System specifications in SESAR P12.2.2 will be elaborated based on the outcomes of operational requirements defined in the SESAR P6.8.1.

Technical meeting organized with DSNA and ADP-Paris (CGD Aiport) with site survey of existing weather equipments, in the framework of SESAR XP0 Trial campaign preparation. Technical Meeting with Meteo-France at CDG Airport.

2.2.3. Task Group “Weather Prediction and Monitoring”

A WakeNet3-Europe Specific Workshop on “Short-Term Weather Forecasting for Probabilistic Wake-Vortex Prediction” has been organized and hosted by DLR on 10-11 May 2010 at the Institut für Physik der Atmosphäre, DLR Oberpfaffenhofen. Participation to the workshop was limited to 22 invited experts from France, Belgium, England, Germany, Italy, Japan, USA, and Russia belonging to universities, research institutes, and small enterprises. These group of experts conducted comprehensive discussions in order to identify the major scientific questions, feasibility, and priorities of different methods with respect to future meteorological research. The list of attendees, the agenda, the presentations, and detailed minutes of the workshop representing a consolidated view on the state of the art of probabilistic wake vortex prediction and probabilistic weather prediction, related scientific questions, and the feasibility and priorities of different methods with respect to future research are available at http://wakenet.eu/index.php?id=129.

A brief summary of the major findings is recapitulated here:

- nowcasting methods are preferred to numerical weather prediction (NWP) if measurement instrumentation available
- added value can be obtained from spatial ensembles based on measurements (Radar, Lidar, suite of instruments) which possibly can be enhanced by four-dimensional data analysis
- NWP is necessary, if air volumes cannot be covered by instrumentation
- data assimilation increases forecast skill of NWP
- economical approach for NWP could consist of a combination of time-lagged ensembles, data assimilation schemes, and spatial ensembles
- alternatively, uncertainties can be derived from subgrid scale variability of deterministic NWP
- blending of nowcasting and NWP bridges the gap between both methods and improves prediction quality
- all types of NWP may benefit from improved boundary layer physics, parameterizations, and initial conditions
- weather prediction products can be enhanced by careful calibration

In order to provide probabilistic weather predictions the COSMO-FRA and the COSMO-MUC model of DLR have been applied in a "time-lagged-ensemble" mode (Dengler et al. 2009, Dengler et al. 2011). The numerics and physics packages of these model versions follow the operational configuration of COSMO-DE of the DWD. Every hour a 6-hours prediction run is launched such that always six different predictions are available. From these predictions the ensemble mean and the ensemble spread can be used for probabilistic wake vortex predictions. COSMO-MUC calculates initial conditions assimilating local available data from the precipitation radar, AMDAR (Aircraft Meteorological Data Relay), SYNOP (surface synoptic observations), and TEMPS (radiosonde observations) with an hourly update rate. The methods yield on average improved predictions but for specific cases the prediction skill depends very much on the meteorological situation.A method has been developed how the P2P wake vortex can use the time-lagged-ensemble prediction data and different skill scores have been developed and tested (Holzäpfel 2010).

A diploma thesis on the comparison of the accuracy of wind data measured by WTR/RASS, AMDAR and the NWP NOWVIV along the approach paths of runways 07 and 25 of Frankfurt airport has been conducted (Frey 2011). Both the WTR/RASS and the NOWVIV data demonstrate veering of the wind of slightly more than 45° in a height range from the ground up to 1500 m above ground in a three months time frame of September to November 2004. Further it was found that for the investigated days the deviations between WTR/RASS and NOWVIV data do not degrade with increasing distances along the glide slope; this means that the hypothesis for spatial homogeneity of wind data along the glide slope can be very good. The RMS deviations between the different data sources for wind speed, headwind, and crosswind vary between 2.3 m/s and 4.3 m/s.

In Sesar WP 11.2 “Meteorological Services” 11 Meteorological Services of the EUMETNET Consortium together with AustroControl, BelgoControl, DLR, and NLR have established a proposal for research activities that will also contribute to improve meteorological information along the flight routes and in the terminal manoeuvring areas. The high level goals are: identify sensitivities of the flight life cycle to meteorology; understand how these sensitivities will change as ATM, aircraft, airport and meteorological systems evolve; provide proof-of-concepts; develop dedicated and innovative MET services; integrate these MET services into future ATM system in an optimal way. At this time the proposal was not yet successful because too many partners are involved in the team. Currently the team is discussing the proposal with Sesar and is adapting it accordingly.

2.2.4. Task Group "Wake Vortex Alleviation"

Numerous EC projects, partially devoted to Wake Vortex Alleviation had been launched in the preceding FP5 / FP6 calls, e.g.: Eurowake, C-Wake, S-Wake, AWIATOR, and FAR-Wake. FAR-Wake ended in May 2008. Following the final review meeting, an International Workshop on "Fundamental Issues Related to Aircraft Trailing Wakes" was organised by the FAR-Wake coordinator at IRPHE Marseille, France (27-29 May 2008). One of the objectives was to sum up and try to define a follow-up of the wake vortex activities, knowing that FAR-Wake project addresses i) jet-vortex interaction, ii) vortex interaction with wakes, iii) short, medium and long-wave instabilities, iv) ground effects as well as v) dynamics and decay in real conditions.

As the main conclusion for all research performed in the afore-mentioned EC projects related to Wake Vortex Alleviation, the most promising results have been obtained for the following concepts:

Jet-vortex interaction mechanisms might be exploited during take-off because of engine being close to flap tip;

inboard loading using differential flap settings: closer vortex spacing gives more diffused, faster decaying vortex;

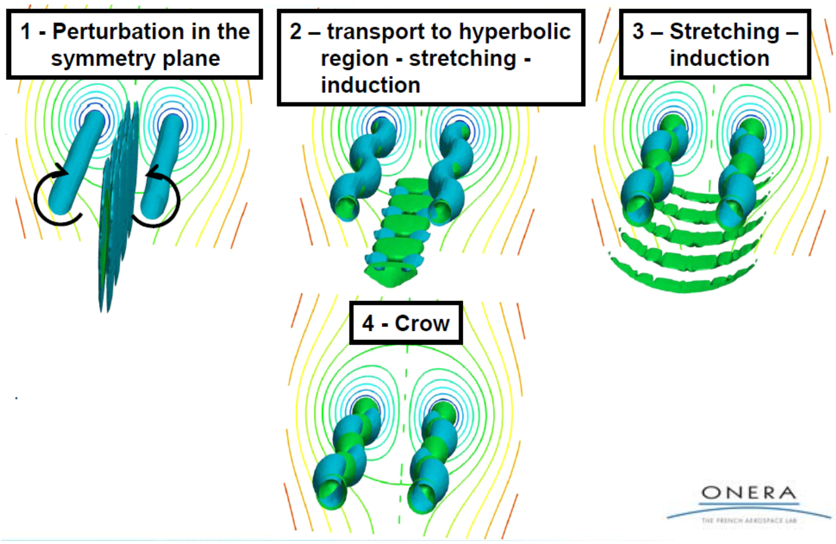
outboard loaded configurations with multiple counter-rotating vortex pairs from differential flap settings: enhanced dissipation due to violent non-linear vortex interactions, the so called omega-loops; requires large configuration changes (realistic?);

outboard spoilers: significantly more diffused vortex observed but the underlying causes not clear: favours inboard loading, turbulence or specific multiple vortex interactions ?;

active control: moving flaps or ailerons, pulsed blowing to enhance instability modes like the Crow instability giving faster linking of the left and right vortex;

last, but not least, optimum perturbation forcing of multiple vortex system could provide much enlarged growth rate compared to Crow mode and should be further explored.

Indeed, the concept which appears to have the biggest potential is related to the dynamics of four-vortex systems, characteristic of aircraft wakes in take-off/landing configurations. It was demonstrated that medium- and long wavelength instabilities could be used to enhance the global wake decay. LES of various 4-vortex systems showed that significant enhanced vortex decay can already be obtained for a lower-than-optimal, but much more practical, circulation strength ratio. Interesting results were notably recorded in FAR-Wake from linear stability theory and numerical simulations for the optimum forcing of counter-rotating 4-vortex wakes with respect to the long-wavelength Crow modes of the resulting final vortex pair (cf. Figure below).



Optimal perturbation in dipolar vortices; iso-vorticity.

The optimum forcing location was found to be close to the wake symmetry plane, which has implications for a possible practical exploitation to be investigated further. This point would at first need to be validated using the developed methodology, first sub-scale tests coupled with numerical simulations including non-linearity and turbulence effects. This would allow performing a realistic evaluation of first interest and then feasibility of such an optimal perturbation concept.

Therefore, it was noted too that future research should be pursued to carefully understand the mechanisms and check the efficiency of such concepts and devices in order to reach sufficiently high TRLs. But, at the end of the FAR-Wake project, no continuation was decided in 2009, although some interest was pointed out.

Unfortunately, there are no more EC research projects, national activities as well as collaborative research programs on Wake Vortex Alleviation on this topic nowadays for several reasons, one of them being the safely reduced minimum aircraft separation rules for the A380 aircraft with the summer 2008's ICAO recommendation letter.

National activities as well as collaborative research programs (for instance, DLR-ONERA) on Wake Vortex Alleviation had lasted for almost 10 years, closely linked to some above-cited EC-funded projects, and had stopped now. This Wake Vortex alleviation research field was at first part of the FP7 JTI "Clean Sky" SFWA "Smart Fixed Wing Aircraft" Integrated Technology Demonstrator. It was then removed because of higher priorities fixed for new innovative flow and load control technologies, yet.

Finally, the tracking of possible future activity related to this Task group would be pursued until the end of WakeNet3-Europe. Though not so many scientists are working in this research area, a brainstorming workshop, including non-European colleagues, could be organised since the last one was in the framework of WakeNet2-Europe (2005). The objective would be to establish a clear statement on the needs for a future collaboration programme with the main potential candidates related to WakeNet3-Europe coordination action: Airbus Operations S.A.S., CERFACS, DLR, IRPHE, NLR, ONERA, TUM, UCL, …
At last, the first draft of contribution from the "Wake Vortex Alleviation" Task Group was provided in January 2011 to feed the Research Needs Report.

2.2.5. Task Group "Encounter Mechanisms and Simulation"

The Terms of reference of the Task Group are as follows

- Contributing to the ToR of the area
- Keeping track of the developments in the flight simulation community
- Promoting communication between the partners and interest groups
- Organizing a workshop on "models and methods for wake vortex encounter simulations"
- Elaboration of respective reports
- Contributing to the WakeNet3-Europe internet site (publish workshop details and refer to related articles)
- Reporting to the commission

TU Berlin delivered the following reports:

- WN3-E Project Management Update – Report by individual beneficiary, reporting period from April 2009 to December 2009.
- WN3-E Project Management Update – Report by individual beneficiary, reporting period from January 2010 to December 2010.

TU Berlin has attended following workshops and partner meeting:

- Participation at partner meeting in Paris on the 7th January 2009
- Participation and session chair at 1st WakeNet3 Workshop in Paris on the 8/9 January 2009
- Presentation "Pilot modeling and severity criteria development for wake vortex encounter" at the CREDOS (Crosswind - Reduced Separations for Departure Operations) Final Dissemination Forum, 18-19 November 2009, Chantilly.
- Participation at Wakenet US Workshop March 2010, Miami. A report of the Workshop was compiled together with NATS and distributed to all Wakenet3 Europe partners.
- Participation at the 2nd WakeNet3-Europe workshop at Toulouse (28/07-30/07/2010)
- Participation at invited sessions on wake vortices at the AIAA Guidance Navigation and Control Conference in Toronto (30/07-06/08/2010) and presentation of a paper on wake encounter in cruise. Contribution to a report of those sessions. The report has been distributed to the WN3E partners and is available on the WN3E website.
- Presentation at Global Wake Vortex Conference, Dan Diego with Anthony Brown, NRC Canada
- Participation at the 3rd WakeNet3-Europe workshop at Southampton (10/05-11/05/2011)

Recent developments in the area of the Task Group:

- The CREDOS project was closed in November 2009 with the Final Dissemination Forum, 18-19 November 2009, Chantilly. As part of the project, models and methods for risk assessment of departure simulations with reduced separation distances were developed.
- From Wake-Net USA: The FAA at Oklahoma performs flight simulator tests with the Airbus 330 and the Boeing 737 for characterizing wake vortex encounters for hazard analysis. See presentation given by Stephen Barnes at the WakeNet USA workshop on the 14th of October 2009 at Washington DC and March 2010 at Miami.

Specific Workshop

- TU Berlin has organised a specific 2 day workshop on "Models and Methods for Wake Vortex Encounter Simulations" at Berlin on June 1st and 2nd, 2010.
- The topic for the first day was: "Wake vortex models (WVM) for real-time and fast-time encounter simulations"

- Overview of existing wake vortex models that are already successfully integrated into:
  1) 6 DOF flight simulators (real-time models) or
  2) risk assessment tools, like ASAT, VESA, WakeScene, WAVIR (fast-time models)
  with focus on the differences between the wake vortex models for both application and in view of the diverse requirements, which the models have to fulfil.
- Definition of advantages and disadvantages of the existing WVM.
- Discussion on how the models can be validated and on the status of validated models.
- Which model improvements are necessary for future real-time and fast-time wake vortex simulations, and how can these improvements be reached?

- The topics of the second day have been “Models of pilot behaviour for real-time and fast-time wake vortex encounter simulations and models for pilot’s severiry assessment” comprising:
  - Overview on existing behavioural pilot models that have been successfully integrated into:
    - flight simulators (real-time models)
    - risk assessment tools, like VESA (fast-time models)
  - Specify the advantage and disadvantage of the existing PM used for tracking tasks and wake encounter simulations or high and low dynamic tasks.
  - How can the models be validated and how is the actual state for validated models
  - What kind of improvements are necessary for future work with fast-time pilot behavioural models in the purpose of risk assessment and how can these improvements be reached?
- The outcome of this workshop was the state-of-the-art regarding
  1) existing wake vortex models
     a) that are suited for flight simulator investigations (real-time models)
     b) that are applicable for fast-time Monte Carlo simulations (fast-time models)
  2) existing pilot behavioural models, which allow simulation of pilot behaviour in WVEs and to model their severity rating of a WVE.
- Based on the workshop results, TU Berlin edited two sections to the Research Needs Report on
  - “Wake vortex model that are useful for wake encounter simulations in real-time piloted simulator tests and for fast-time MCS for risk assessment”,
  - “Pilot behavioural models for fast-time encounter simulation”.

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