Minutes of the

WakeNet3-Europe Specific Workshop on **RE-CATEGORIZATION**

20th and 21st June 2011
Technical University of Berlin
Flight Mechanics, Flight Control and Aeroelasticity
Berlin, Germany

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1 INTRODUCTION

On June 20th and 21st, WakeNet3-Europe organised an international Specific Workshop on "Re-Categorization" at Technische Universität Berlin. Participants from industry, airports, air navigation service providers, authorities, pilot associations and research discussed how to define safe vortex separations. WakeNet3-Europe is a thematic network funded by the EC.

MOTIVATION

ICAO's definition of aircraft categories (HEAVY, MEDIUM, LIGHT) and corresponding separation distances was initiated by the advent of large jet airplanes (B747, L1011, and DC10) in the late sixties. Since then, national modifications of the rules were enforced in the US after incidents behind B757 (MTOW of the 757 is at the end of the MEDIUM category) and local modifications and interpretation of rules were introduced at certain congested airports. Additionally, a new category SUPER with additional separation was established for A380 by ICAO.

Definition of wake turbulence separation minima was always based on measurements and the interpretation of measured data - supported by models of wake vortex physics. A methodology for the definition of safe separations is lacking.

Obviously, current separation distances are safe. However, it is commonly agreed

- that they are over-conservative under numerous conditions, and
- that risk is not evenly spread over all aircraft pairs, i.e. a 20 to and a 100 to aircraft have the same separation following another 100 to aircraft, but the reaction of the smaller aircraft is certainly more severe, if an encounter occurs.

The RECAT initiative of EUROCONTROL and FAA has the objective to review the existing ICAO wake turbulence categories and associated category-wise separation minima for both departure and arrival operations and to define harmonized safe and adequate minimum wake turbulence separation standards. The task is split into three phases:

- Phase I: Optimised Categories (2011),
- Phase II: Static pair-wise separation (delivered to ICAO in late 2013),
- Phase III: Dynamic pair-wise separation (2018).

RECAT Phase I produced a Technical Report on the Safety Assessment and a Technical Report that describes the Methodology for Re-Categorization of ICAO wake turbulence standards. Both reports are currently reviewed by stakeholders in the ICAO Wake Vortex Study Group and shall be presented to the ICAO Air Navigation Commission for acceptance.

The methodology, which RECAT Phase I proposes for definition of separation standards, uses wake strength (circulation) and rolling moment coefficient as the hazard metric. It takes into account wake decay models derived from joint FAA and EUROCONTROL measurements. The future RECAT Phases, especially Phase III, may require and may benefit from more sophisticated methodologies. Such a methodology must be transparent and validated. Over the last years the available knowledge in wake vortex physics has improved significantly, a huge amount of data has been recorded in a significant number of campaigns and especially the Airbus wake vortex and encounter data base can be essential for model validation.

WORKSHOP OBJECTIVES:

- Stimulate the dialogue on methodologies, technologies, models and severity metrics for RECAT Phase II and III between experts from regulators, air traffic service providers, stakeholders (airlines, airports, pilots, and aircraft manufacturers) and research.
- Identification of research needs.

2 ORGANIZATION AND PARTICIPANTS

ORGANIZATION:

Robert Luckner, Matthias Lauterbach, TU Berlin

PARTICIPANTS:

The following, invited international specialists from Air Navigation Service Providers, Regulators, Industry, Research Centres and Universities participated (in alphabetical order):

Name	First Name	Initials	Organisation
Alkalay	Isa	IA	Skyguide
Bieniek	David	DBI	Technical University of Berlin
Booth	David	DBO	EUROCONTROL
Bryant	Wayne	WB	Federal Aviation Administration (FAA), USA
Delisi	Don	DD	NorthWest Research Associates (NWRA, USA)
Desenfans	Olivier	OD	M3Systems
Eriksen	Peter	PE	EUROCONTROL
Gerz	Thomas	TG	DLR, Oberpfaffenhofen
Goodman	Simon	SG	NATS
Kladetzke	Jan	JKL	DLR, Institute of Robotics and Mechatronics, Oberpfaffenhofen
Konopka	Jens	JKO	DFS
Lang	Steven	SL	Federal Aviation Administration (FAA), USA
Lauterbach	Matthias	ML	Technical University of Berlin
Luckner	Robert	RL	Technical University of Berlin
Meyer	Herbert	HM	EASA
Nicolaon	Jean-Pierre	JN	Federal Aviation Administration
Reinke	Andreas	AR	AIRBUS Operations SAS, Toulouse
Ross	Matt	MR	NATS
Schwarz	Carsten	CS	DLR, Institute of Flight Systems, Braunschweig
Speijker	Lennaert	LS	NLR
Stehen	Meiko	MS	Technical University of Braunschweig
Tittsworth	Jeffrey	JT	Federal Aviation Administration (FAA), USA
Tormey	Peter	PT	CAA
Van Baren	Gerben	GB	NLR
Wahl	Markus	MW	IFALPA
Wendeberg	Steffen	SW	FRAPORT
Winckelmans	Grégoire	GW	UCL

3 AGENDA

1st day: RECAT status and next RECAT Phases

09:00 Coffee, informal get-together (H 2038)

Chairman: Robert Luckner

09:45	**Welcome & Introduction** R. Luckner, Technische Universität Berlin
10:20	**Wake Turbulence Re-Categorization Phase I Methodology and Safety Case** D. Delisi, NorthWest Research Associates / S. Lang, Federal Aviation Administration

12:00 Lunch (H 2038)

Chairman: Robert Luckner

13:10	**Wake Turbulence Re-Categorization Phase I Methodology and Safety Case (continued)** D. Delisi, NorthWest Research Associates

14:15 Coffee break (H 2038)

Chairman: Peter Tormey

14:25	**SESAR Joint Undertaking P6.8.1** P. Eriksen, EUROCONTROL
14:55	**SESAR projects 9.11 and 9.30** A. Reinke, Airbus

Chairman: Jean-Pierre Nicolaon

15:30	**RECAT Phase II & III** J. Tittsworth, Federal Aviation Administration /
16:45	**HELICOPTER OPS AS FOLLOWER & WTS** I. Alkalay, Skyguide

17:05 End of Day 1

2nd day: RECAT Phase III

08:45 Coffee (H 2035)

Chairman: Robert Luckner

09:10 **Remarks on Models, Methods and Metrics for RECAT**
R. Luckner, Technische Universität Berlin

09:45 **Models & Methods for RECAT Phase III - A Perspective**
A. Reinke, Airbus

10:40 **Airport capacity effects of RECAT or: An airport view on RECAT**
S. Wendeberg, Fraport AG

11:45 **ANSP considerations for methodology, models and severity criteria**
S. Goodman, NATS

12:00 Lunch (H 2035)

Chairman: Robert Luckner

13:00 **Aircraft Wake Vortices: Physics and UCL Models**
G. Winckelmans, Université catholique de Louvain

13:40 **DLR's Models and Systems for RE-CATEGORIZATION**
T. Gerz, Deutsches Zentrum für Luft- und Raumfahrt e.V.

14:20 **Wake Vortex Safety at NLR**
G. van Baren, Nationaal Lucht- en Ruimtevaartlaboratorium

14:35 **Considerations for the Methodology to be used for RECAT Phase II and III**
D. Bieniek, Technische Universität Berlin

15:00 Coffee break (H 2035)

Chairman: Robert Luckner

15:25 **Research Needs Towards RECAT Phase II & III**
The objective of this session is to list research needs (methods, models and severity criteria), to identify whether they are addressed in European or American research programmes, and to define and prioritize open issues.

16:00 End of the workshop

4 MINUTES DAY 1

INTRODUCTION, LUCKNER (TUB)

R. Luckner gave a short introduction to the RECAT topic referring back to the workshop on Wake Vortex Encounter Criteria that was held at TU Berlin in 2006, where the idea of re-categorization and a plan for a respective project was first discussed. The objectives of this workshop were presented and the importance to identify research needs for future work towards RECAT Phases II and III was emphasised.

The presentation can be found here: [R. Luckner].

RECAT PHASE I – METHODOLOGY AND SAFETY CASE, LANG (FAA), DELISI (NWRA)

S. Lang presented the background of the RECAT project, the general objectives, the current status of RECAT Phase I and the schedule for Phases II and III. RECAT Phase I has been delivered to the ICAO for review. It was emphasised that both the current ICAO and the RECAT categorization systems can coexist and that each ANSP can decide whether, when and how to implement the RECAT system depending on the individual benefits. RECAT provides a global solution to reduce wake turbulence separation minima, but local implementations may differ among airports.

D. Delisi presented the RECAT Phase I methodology and the safety case giving a detailed talk on the complete process leading to the safety assessment. Assumptions made for Phase I (e.g. vortex decay function, approach speed profiles), the used data and the severity metrics were described and discussed with the audience. RECAT Phase I is based on 61 aircraft that represent 85% of the traffic of the busiest EU and US airports. Wake strength (vortex circulation) is used as the primary severity metric and a linear decay line has been identified from wake vortex measurements (at threshold) at US and European airports. Additionally, the induced rolling moment coefficient is used as a severity metric to justify a separation reduction for follower aircraft that are in the top end of the ICAO HEAVY category. RECAT Phase I proposes a 6 category system that is based on wing span as the primary parameter and on maximum takeoff weight and additional aircraft characteristics as the secondary parameters. For the RECAT Phase I system an average capacity gain of 4% (Europe) and 7% (US) is estimated in comparison to the current ICAO system. However, this benefit analysis does not consider individual procedures (as used by ANSP at highly constrained airports) that differ from the ICAO system.

The presentation can be found here: [D. Delisi].

<u>Discussion (Questions/Answers, Remarks)</u>

Questions were raised during the presentation.

IA: ICAO officially puts A380 into the HEAVY category. It is not in a separate category.

DD: Yes that is correct. It is a HEAVY with special separation minima requirements.

SG: At Heathrow we also see a peak of reported vortex encounters at the glideslope intercept, not only at the threshold. So safety should be addressed along the complete glidepath, especially at the intercept.

JT: The risk of vortex encounters on the final depends on the local procedures implemented by the ANSP. This is difficult to address from a global perspective. Whether there is a change in the risk of vortex encounters through RECAT or whether RECAT will provide a capacity gain depends on the local implementation by the ANSP. RECAT looks at this from a global point of view.

IA: Implementation will be difficult. I am concerned that we are overestimating what a small ANSP can achieve. There should be as much as possible guidance from a global perspective.

SL: ICAO does not go into the implementation of the systems. For example, if an airport has more vortex encounters at glideslope/localizer intercept because of the local procedure (e.g. MEDIUM aircraft turning on lower behind a HEAVY aircraft turning on from above) then the local ANSP has to determine whether the procedure is acceptable or whether it should be changed.

SG: The main assumption for RECAT is that current ICAO separations are safe. Have we really seen enough cases to say that this is true? There are about 5 million possible combinations in the RECAT methodology. Have these been "tested" significantly often at the stated wind conditions with the aircraft at the separation minima? I am not suggesting an answer.

IA: An ICAO state letter requested wake vortex encounter data base. But, only a minority European ANSP were able to establish it.

SL: There is a lot of space for growth and improvement. We have received reports from some ANSPs, other were saying the data are intellectual proprietary.

PT: ICAO is making progress to develop a useful report form for vortex encounters.

SG: There are variations in local practices and procedures and I know that RECAT does not consider these but in order for us to present a safety case for a specific airport we need to consider these. We need to extend the concepts and analysis to the local procedures and also to local data.

TG: (*referring to slide 29*) – Does it reflect the right physics if you normalize all circulation data to Γ_0 at an initial height above ground of b_0. This may be true for vortices IGE but not for those NGE/OGE.

DD: We took data up to $2.2 \cdot b_0$ so the data includes IGE and NGE data. We did not just take IGE data. We then normalized all data to b_0.

TG: Is this really correct? Physics are different for IGE, NGE and OGE vortices.

DD: Do you have data that suggests that it is not correct for IGE and NGE?

JT: We do not consider the methodology to be perfect, but with respect to the ICAO MTOW practice we achieved an improvement with this methodology. We use NGE/IGE data because at this point you cannot avoid the wake any more. On the glideslope the main safety mechanism is wake avoidance.

GW: I agree, however if the RECAT system has to be applicable to the whole glideslope, decay slope will be different at higher altitudes than the one determined with the IGE/NGE data.

SL: We focussed on the threshold as that is the position where the distance between the generator and the follower on approach is minimal – due to the compression.

AR: You focused on the threshold because there is no significant number of pilot reports at other situations. Locally (e.g. Heathrow) we see reports at higher altitudes. It is still not clear when a pilot reports. I think it would be interesting to see additional evidence/prove (other than common sense that an encounter close to ground is most critical) why we do not have to look at situations other than those close to the ground.

JKO: 15 years ago, when we started with the wake vortex warning system, the assumption that we do not have to consider the vortices at higher altitude (because they descend out to the flight path of the follower) was questioned by pilots. No proof has been provided for this assumption in the last years and I am afraid that we will get into the same discussions again if we propose a change of the system that is based on this assumption.

AR: How do you argue that using the upper 95% confidence interval bound (for the decay line) is conservative for the relative safety assessment?

DD: Because the same decay line is used for both systems, ICAO and RECAT.

GW: The decay line of RECAT may be correct for IGE/NGE, but for OGE the decay slope will be much slower. For OGE the decay will decrease.

DD: Yes that is true. For OGE the decay line T* would be higher.

GW: Is it OK for ICAO that you base RECAT only on the wake behaviour IGE/NGE, especially if the system shall be applicable for the whole glideslope? At higher altitudes you may have longer lasting wakes.

DD: Yes, but at higher altitudes the wakes descend. For us the situation close to the ground is the most critical one.

RL: There is a lot of spread in the circulation data for one aircraft. Why is that?

DD: This is just the spread that we have. There may be a variety of reasons for that.

TG: We expect the longest lasting lifetime observations from the pulsed LIDAR, not from windline or continuous wave LIDAR measurements. What you measure is not the lifetime of the vortex, it is the observation time (i.e. the time that the vortex is in the LIDAR range). You should expect longer lifetimes than those you have measured.

DD: There are a lot of questions raised in your remarks. You also have to consider whether at T* = 7 you are already in the region of Crow instabilities or whether the vortex has moved out of the observation region. Do you agree that the decay line we have identified is a reasonable one to use?

TG: Yes, the RECAT report should be more precise. In the report “lifetime” should be replaced by “observation time”.

PT: Should we be concerned about the outliers above the decay line?

DD: Well, these outliers also apply to ICAO, not just RECAT.

RL: (*referring to slide 40*) - I know that many airlines use 1000ft as the stabilization altitude. So is 500ft conservative?

JN: In CAT I you can use 500ft, for CAT II and III you would have to use 1000ft.

DD: I have to think about whether 500ft is conservative.

AR: The results for “max. median allowable circulation under ICAO rules” are mainly driven by HEAVY generator aircraft (A380, B747, A340). How large is the spread if we compare e.g. a MEDIUM follower behind a HEAVY, MEDIUM and SMALL generator? How large is the spread in circulations seen under current ICAO rules?

DD: I don’t have these numbers here right now but they can be calculated quite easily.

SL: We have these numbers available.

IA: How does this methodology and the assumptions (e.g. speed profile, MLW) transfer to the departure case?

DD: We used MTOW and approach speeds + 20kts for departure. We made different assumptions for approach and departure because they are different situation. The departure case is not part of this presentation.

AR: If the large generator aircraft have the most influence on the RECAT results we should look at how well the decay line represents these aircraft.

DD: We did that. It fits very well.

AR: For the optimization of the categories, did you include traffic mix data on the occurrence of specific aircraft pairings?

DD: We included the traffic mix but we do not have data on specific aircraft pairings. If we had that data we would incorporate the traffic mix in a different way.

AR: You use total separation (sum of the 61 x 61 matrix) as a capacity metric. From an airport/airline perspective capacity is a question of payload. This is not reflected by your metric. I think it would be an easy extension of the methodology to use payload or passenger seats as a metric. I assume it would also be easy to convince stakeholders of such an extension.

DD: Operationally you bring in aircraft, not passenger seats. That's why we did not use such measures for RECAT Phase I.

SL: For RECAT Phases II and III it would probably be good to consider such metrics. It is not hard to do that.

PT: In RECAT the capacity gain is calculated in relation to ICAO rules. You really won't get this capacity gain because airports such as Heathrow currently use systems different from the ICAO 3 class system. These procedures already produce a capacity gain in relation to ICAO. Also there are other variables such as runway occupancy time (ROT) that will determine the real capacity gain. The RECAT capacity gain is a pure RECAT vs. ICAO comparison. It does not take the current practice at specific airport into account.

DD: Yes this is correct. We used 50sec ROT and 2.5nm MRS.

SL: There are many other constraints, e.g. taxi way location, that are very specific to airports. So for RECAT we looked at capacity from a global perspective.

SG: I think RECAT Phase I will not facilitate a capacity increase at Heathrow because of the operational procedures and constraints. RECAT Phase II is where we are looking for more tailoring of the categories towards individual airport operations.

PT: Harmonization of the practices around the world is an important element of RECAT Phase I so that we have a common understanding and baseline when moving towards Phase II and III.

IA: In the wake vortex task force we were informed that the RECAT sorting of aircraft is based on multiple parameters such as wings span, wing loading and others. Here I see a sorting based only on wing span.

JT: What was told at the wake vortex task force, that the aircraft are sorted based on multiple parameters (MTOW, wing span, approach speed), is correct. Comparing capacity gain for wing span vs. MTOW sorting was just done for initial sorting prior to the category optimization. This simple wing span sorting was not used in the safety assessment.

GW: Circulation scales like weight divided by span. Did you look at a sorting of this kind?

DD: We looked at one like that. Either weight divided by span or span squared. As I recall it did not produce as much capacity gain as for wing span sorting.

AR: 1. For RECAT you extrapolate the measured circulation data with a linear decay model to a region of $\Gamma^* = 0$. I don't completely agree with that because I have seen other LIDAR data where the curve becomes flat at $T^* > 4$. So extrapolation to T^* around 6 has to be done very cautiously.

2. You state that the data distribution is nearly Gaussian. Did you check whether the distribution is affected by T^* itself, meaning that there is a different data distributions at $T^* = 2$ compared to $T^* = 4$?

DD: No, because I think we don't have enough data for that. If you did that the circulation decay line would come down so what we have done is conservative.

Concerning the decay at later stages ($\Gamma^* < 0.2$): I think there is still a debate in the community whether this is real or a measurement "phenomenon". I am not sure what to do about this region.

AR: But you still use this region for the risk calculation in the same way that you use those parts of the decay line where more data is available.

DD: There is not much data available in this region.

AR: This does not justify the use of a certain model. In the risk calculation this part of the linear model becomes important because it is used for the survival probability. So it contributes roughly 50% to the risk calculation (severity x probability) even though there is not much data to support the linear decay model at these late stages (T* around 6).

DD: I think a decay model that is more flat at the end would not have much effect on the risk calculation results.

AR: I think the biggest changes from RECAT can be seen for the category C generator aircraft, e.g. MD-11, B767-300. MD-11 vortex measurements were not used for the decay line because less than 50 vortex tracks were available. The B767-300 vortex data is not represented well by the decay model. However, both aircraft experience the biggest changes by the RECAT methodology. Did you look at the data of these aircraft specifically?

DD: Yes, we looked very extensively at these aircraft. We convinced ourselves that the results are OK, especially for the MD-11 because it is so different (small wingspan).

JKO: You plot all your data non-dimensional but your actual measurement was not non-dimensional because you measure all the vortex data at the same position. For small aircraft the vortex might not be IGE while for the larger aircraft it is. So for large aircraft the distribution of your data is more towards IGE, while for the small aircraft it might be skewed more towards OGE. However, you fit everything with the same curve.

DD: Yes, but for RECAT we are interested in the heavier generator aircraft because those are the ones that produce the more hazardous wakes. We do not focus so much on the smaller generator aircraft.

JKO: This is not what I meant. I meant that for HEAVY aircraft you measure at $0.5b_0$ while for SMALL aircraft you measure at $2b_0$. Then you fit everything with one dimensionless curve.

AR: RECAT results are mainly affected by the HEAVY generator aircraft. This is where the biggest change happens. To compute results for these heavier aircraft you use a decay curve that also includes measurements from SMALL aircraft. Is it OK to put the smaller aircraft for which you have measurements at larger heights (e.g. > $2b_0$) into a decay model that you then apply to compute results for the heavier aircraft? You could have fitted a model only for those aircraft that matter.

DD: The FAA worked closely with EUROCONTROL on the decay fit, and we looked at it in detail. Over 74% of the measurements of vortex circulation that were used in the fit came from HEAVY aircraft, and the rest came from MEDIUM aircraft. No data from SMALL aircraft were used in the fit. Thus, the decay fit is derived mostly from HEAVY aircraft, but also from MEDIUM aircraft, since those aircraft are also affected by RECAT. Consequently, the idea that we used circulation data from SMALL at large altitudes and combined it with circulation data from HEAVY aircraft at lower altitudes is not correct.

SESAR JOINT UNDERTAKING P6.8.1, ERIKSEN (EUROCONTROL)

P. Eriksen presented the SESAR project 6.8.1 which intends to develop solutions for a flexible use of wake turbulence separations. The project consists of three steps:

1. Time-based separations (2013)
2. Weather dependent separations accounting for transport of vortices (2015)
3. Dynamic pair wise separations (2017)

Implementation of the concepts is not part of SESAR since it is a R&D project. Steps 1 and 2 shall ideally be verified within the timeframe of the project but verification for step 3 will have to take place outside SESAR. Step 3 of the project is closely linked to RECAT Phase III.

The presentation can be found here: [P. Eriksen].

Discussion (Questions/Answers, Remarks)

TG: When does verification of step 3 take place?

PE: Dynamic pair wise separation is a goal but personally I don't think we will achieve the same maturity level for step 3 as we will for steps 1 and 2.

PT: Implementation will be handed over to ANSP?

PE: Yes, implementation is not part of SESAR. It is a R&D project.

PT: So verification in the context of SESAR 6.8.1 is not equal to implementation?

PE: That is correct.

TG: How is this project linked to RECAT?

PE: There is an overlap for RECAT Phase III and SESAR 6.8.1 step 3 as both address dynamic pair wise separations. So we should work together at these stages but that should not be a problem for the partners. RECAT Phases I and II have nothing to do with SESAR 6.8.1 steps 1 and 2.

TG: Can you translate the time-based separation to a space-based separation so that there could be a link between the first phases/steps?

PE: Yes.

TG: I think the link between RECAT Phases I and II and SESAR steps 1 and 2 should be anticipated because SESAR step 3 will not be as mature as the previous steps.

TG: How are NextGen and RECAT linked?

SL: NextGen counts on wake separation solutions. All solutions that are developed in RECAT will go into NextGen.

RL: Aiming at research needs: If we want to have dynamic pair wise separations ready by 2017 we have to start developing the required models and methods now. We see today that only a small number of the models that are available today are used in methodologies such as RECAT. Researchers that develop such models and methods are often not aware of requirements such as conservatism or safety analysis for 9000 aircraft. To have the required models ready by 2017, the research has to be aware of what models are needed.

PE: That is a weakness of SESAR, not only in the area of wake vortex.

SESAR P9.11 AND P9.30, REINKE (AIRBUS)

A. Reinke presented the scope of SESAR projects 9.11 and 9.30. The objective of these projects is to develop wake encounter prevention systems (WEPS) based on vortex encounter prediction, alerting and avoidance (WEPS-P, P9.11) and wake encounter alleviation (WEPS-C, P9.30). WEPS-P requires air-to-air data link and a model based prediction of possible vortex encounters. WEPS-C shall use a new short range on-board LIDAR sensor to detect the vortex disturbance and generate appropriate control surface deflections through improved flight control functions. Aircraft equipped with such a system might be allowed to use reduced vortex separation minima especially when aiming at dynamic pair wise separations. In order to evaluate the effects of WEPS-C in the sense of a RECAT methodology we need severity metrics that account for the dynamic reaction of an aircraft during a vortex encounter.

The presentation can be found here: [A. Reinke].

Discussion (Questions/Answers, Remarks)

AR: A severity model that is part of a methodology such as RECAT should be a dynamic simulation that accounts for a WEPS-C system. It could also be a mathematic generalization of bank angle response that is based on data/parameters/characteristics of different aircraft types.

DD: So you are thinking about a wake encounter model?

AR: Yes, you cannot do without.

DD: You would still use a decay model to get the circulation and then you would use a dynamic wake encounter model to get a bank angle response.

AR: Yes. I think we have to look at both, models and data. If the models show certain behaviour this could generate more confidence in the data and vice versa. For the dynamic pairwise separation we need a simplified wake encounter model that is validated by measurements for different aircraft size classes.

RL: What is the impact of such a system as WEPS-C on RECAT Phase III? If the system is perfect we would not need RECAT Phase III anymore. We could potentially go down to minimum radar separation if we can guarantee that with such as system a wake encounter will not be harmful. Is there a dependency between RECAT Phase II and III and such a system?

DBO: From the ATC side, RECAT Phase II and III will give you the separations to implement. A system like WEPS-C is only available to certain aircraft and is only a safety net. It cannot replace RECAT Phase II and III.

SL: The RECAT solutions are applicable globally without additional funds. Airbus will not provide a system like WEPS-C for free to everybody.

IA: I have a problem with the term “safety net”. There is a clear established policy at the European level on what "safety nets" are and what their purpose is. It is also hard to imagine that ATC can manage selective separations for aircraft with such a system. ATC can only move in small evolutionary steps.

AR: I see RECAT Phase III as an enabler for ATC support systems that could deliver dynamic separations that also account for systems such as WEPS-C. Also, if in RECAT Phase III the metric is the actual aircraft vulnerability to the wake encounter, then this enables to consider something like WEPS-C.

LEADER/FOLLOWER STATIC PAIRWISE (RECAT PHASE II), TITTSWORTH (FAA)

J. Tittsworth presented RECAT Phase II giving details of the schedule and overall objectives with respect to continuing the work started in Phase I. The tentative schedule for RECAT Phase II includes delivery of the recommendations to ICAO by late 2013. It will implement static pairwise separation minima that are independent of fleet mix. In contrast to the 6 category system of RECAT Phase I, the RECAT Phase II system can be optimized specifically to any individual airport in order to achieve further capacity gains. The methodology for Phase II shall use metrics and methods from Phase I, possibly refined and enhanced to include manufacturer provided aircraft performance data. Additional recommendations from stakeholder will also be considered. The presentation raised the question how complex the RECAT Phase II system will actually be. While there are potentially 1200 x 1200 aircraft pairings (based on aircraft types), 25 aircraft might cover 99% of an airport's traffic mix, so a 25 x 25 matrix would be sufficient in that case. Each ANSP is free when and how to implement a RECAT Phase II system as both RECAT systems and the current ICAO rules can co-exist.

The presentation can be found here: [J. Tittsworth].

Discussion (Questions/Answers, Remarks)

RL: If you say "can coexist" does it mean one airport uses ICAO, the other uses RECAT or can it also mean RECAT is used in the morning and ICAO in the afternoon?

JT: I cannot imagine an ANSP wanting to do that (referring to the second option), but they could.

AR: Why does there have to be a separation matrix (possibly as large as 9000 x 9000). With the RECAT methodology we have a mathematical model that computes minimum SD for each aircraft based on a number of important aircraft parameters. Why can't we use such a mathematical model instead of a matrix?

JT: We could. Such a tool is possible and could support the approach controller in separation management. That same tool would not support the management tasks of the controller directing the traffic to the airport. A matrix would simplify things by providing a smaller and simpler set of variables that could support a bigger picture further downstream to prepare the traffic flow when coming into the airport.

You would also have to automate everything at the same time to make it more dynamic.

PT: Human factors issues are going to outweigh some of the things we suggest here if the right controller tools are not available. There is no way a controller can remember and implement a dynamic 25 x 25 or 10 x 10 matrix consistently. You should also be careful suggesting two adjacent airports using different matrices but the same ATM controller feeding both airports.

SL: The goal of RECAT Phase II is not to give specifics on the implementation e.g. for adjacent airports. RECAT will only provide available data for the ANSPs to decide about to implement the system.

TG: But the goal for RECAT Phase II is really to provide the separation for all pairs of the 61 aircraft?

SL: Yes, but not just the 61 as they only make up 85% of the traffic mix.

RL: I understand that harmonization is one of the goals of RECAT Phase II, but if each airport implements an individual system than there is no harmonization anymore.

DBO: From a RECAT perspective harmonization means a common standard. RECAT produces the separation minima for aircraft pairs. The ANSP then has the choice how they interpret these minimum separations, whether they use them directly (if the tools are available), whether they put certain aircraft pairs into a group or whether they stick to the ICAO classes.

DYNAMIC PAIRWISE (RECAT PHASE III), TITTSWORTH (FAA)

J. Tittsworth presented the RECAT Phase III overall objectives. A detailed project schedule or methodology does not exist yet. However, some elements of RECAT Phase III are already underway now (such as CREDOS, Heathrow TBS, WTMA-S). At later stages RECAT Phase III will include wind dependent and vortex decay driven solutions for which ground-based and airborne weather sensors and wake monitoring systems are needed. Also there are plans to apply RECAT Phase III to the en-route situation. Some general thoughts on models and metrics for RECAT Phase III were discussed.

The presentation can be found here: [J. Tittsworth].

<u>Discussion (Questions/Answers, Remarks)</u>

SL: There is no agreement established between SESAR JU and the FAA regarding exchange of data in both ways.

JN: There is an agreement between SESAR JU and the FAA that the systems that are developed shall be interoperable but not that they are developed in cooperation. So, there are no arrangements for cooperation at this moment.

SL: We don’t know yet how we can cooperate for RECAT Phase III. Right now we only have Action Plan 14 (AP14) and we try to use this as best as possible.

AR: Is there a third option (outside SESAR JU, AP14) for cooperation?

SL: There are other options than just being a partner of a consortium. But this has to be defined together with EUROCONTROL. But currently we are prohibited to share data because the agreement between SESAR JU and FAA addresses only the “interoperability” not the cooperation. However, there are other options to agree on data exchange. They have been used in CREDOS for example.

JN: Action Plan 14 has been expanded by one year and in can be expanded more.

GW: You could also ask: Can circulation estimations based on LIDAR data really be validated for ground effect? LIDAR measurements are usually calibrated for OGE. LIDAR data is also sometimes questionable. I think we should talk about this one day.

JT: Again, from a signature authority perspective they currently use a MTOW system. I think if you are better than that, you can justify the models you have used. Of course you can still argue if the models are good enough.

RL: Those who have developed the RECAT Phase I methodology should be in the position to define where further margins for improvements exist and which models and methods are needed for that. We should have a discussion about that.

SL: Maybe we can work together in a way that there are multiple models from different sources/locations but all models give you a result that is “within the ballpark”. It makes a stronger argument when multiple models give similar results.

GW: Models can be validated, they can confirm what we see in the data, but they allow you to go beyond where you have been looking. So we should look at all we have for RECAT Phase II and III. Models and data go hand in hand. We should use both. I think we have improved our models in the same way that LIDAR measurements were improved.

TG: You want to include airborne weather measurements. Does it mean you don’t need weather forecast systems?

JT: No, we absolutely need weather forecast data. We need to use both measurements and forecast data combined.

HELICOPTER OPS AS FOLLOWER & WTS, ALKALAY (SKYGUIDE)

I. Alkalay presented on the application of wake turbulence separation (WTS) minima with respect to helicopter operations. Attention was brought towards the ambiguity of the rules given in ICAO Annex 14 and ICAO P-ATM and that the practices described are very inconclusive. It was also emphasised that, besides providing clarification about the procedures to be used for helicopter operations, scientific studies about the wake turbulence effects on helicopters are needed.

The presentation can be found here: [I. Alkalay].

Discussion (Questions/Answers, Remarks)

JN: Did you talk to ICAO about these inconsistencies?

IA: We tried but we did not get conclusive answers.

JKO: Unfortunately there is no guarantee that assures that the ICAO system of regulations is in itself consistent.

JN: Have you been informed of any incidents related to this topic?

IA: I have talked to different companies operating close to runways but no incidents were reported.

PT: There has been a failure to coordinate material going into ICAO P-ATM with material going into Annex 14. So there is an inconsistency that was not spotted. There are two separate issues: Separations based on operations (e.g. runway clearance) and separations based on wake turbulence separations. It is not easy to put these together. Do we need more research? Yes, I think we do. We do not understand the capabilities of helicopters to withstand wake encounters and what vortices helicopters produce themselves. We know that a helicopter produces significantly stronger wake vortices than an equivalent fixed wing aircraft and we had a number of accidents with LIGHT aircraft following helicopters. FAA carried out a good study in 1996 but guidance was not finalized.

GW: What is the wake of a helicopter? It might be more turbulent but concerning intensity I think it should not be much different from a fixed wing aircraft.

IA: I am trying to put attention on helicopters encountering a wake.

PT: The main issue is: What separation should a FATO be (can it be less than 760m) to allow independent operations of helicopters? If we look at runway and FATO with less than 760m separation, there could be an agreement at ICAO level to include crosswind in the operational practice.

5 MINUTES DAY 2

REMARKS ON MODELS, METHODS AND METRICS FOR RECAT, LUCKNER (TUB)

R. Luckner gave a short introduction to vortex encounter risk assessment. State-of-the-art is, that the complete physical process can be modelled from wake creation to encounter severity and frequency. However, the validation of the sub-models is still an issue. Special focus was put on the nature of models used in risk assessment or RECAT. Models can be either physical (from theory, first principles) or phenomenological (from observation/measurements). Models for safety assessment should be simple, understandable and transparent. However, aviation related processes (such as wake encounters) are often very complex. In order to deal with such complex processes, the models have to be handled by qualified personnel. The models shall be transparent, they have to be documented, reviewed and then accepted by authorities. Everything has to be understandable for all stakeholders. Such processes are used in aircraft system design, where intellectual property rights may put restrictions on model transparency.

The presentation can be found here: [R. Luckner].

Discussion (Questions/Answers, Remarks)

JKO: From the perspective of a theoretical physicist there is a difference between theory and model. A theory is based on first principles and you can derive consequences from these first principles which can then be checked in an experiment. However, if the experiment does not show the predicted outcome the theory is wrong. With models it is much more difficult. If a single experiment does not agree with a model then the model can be adapted. Normally the model will become more detailed and complex. Here, in the context of the wake encounter problem, we have a chain of very detailed/complex models but experience shows that the more detailed models are not necessarily the more accurate models.

SL: Many people think the more complex models are more successful. A researcher may understand his model, but if the regulator does not understand it he won't accept it in the regulatory process. Data to me is much more important than a model, if it is accurate data.

I don't understand how we would get to the point that there is a complex process with very detailed models that are hard to understand and not publically open but still the regulator has to trust that the process is correct.

RL: There needs to be confidence in the process (that is regularly reviewed), even if it is not fully open to everybody. That is how avionic systems are certified today. There needs to be confidence in the people that deal with this process and a company signs that the system is safe.

SL: But it is not a company that does recategorization. It comes back to the question what is for safety, what is proprietary. Safety is not for sale.

RL: Yes, of course such a process has to be open for the authority. You could have a process that is fully understood by everybody but it limits what you can do. In addition you can have a more complex process that is not publically open. If both processes provide similar results it builds confidence. So maybe the solution would be to use both.

There are tools like WAVIR, WAKESCENE, VESA, ATSI available now and we have put a lot of work into them. Do we use them or are they too complex?

WB: I think an important characteristic of a model is “adequate for the task” or maybe “simplest possible model structure that satisfies the requirements of the purpose“. Also, “simple” is in the eye of the beholder. We have discovered that simple to us (FAA) is still complex to some of the people we have to convince. At the end it depends on the people who make the decision. You need simple (“understandable”) models and you need to have people with credibility who present these models to the decision makers.

MODELS & METHODS FOR RECAT PHASE III – A PERSPECTIVE, REINKE (AIRBUS)

A. Reinke presented methods and models towards RECAT Phase III. A comprehensive list of parameters that affect the vortex encounter assessment from wake generation to encounter severity was given to show the complexity of the process, but also to pin point those parameters that should be considered for the upcoming RECAT methodology. Building on the effects of these parameters, possible metrics for RECAT Phase II were proposed. The current rolling moment coefficient could be used but parameters such as core radius of the generators wake should be accounted for. Also, the “static” rolling moment coefficient could be replaced/accompanied by “dynamic” metrics (such as bank angle response) or even more sophisticated metrics that have not been thought of yet. Also a comment on the encounter probability computation for RECAT Phase I was given. It was argued that a circulation of zero should be regarded as a severity of zero and not as an encounter probability/survival probability of zero.

The presentation can be found here: [A. Reinke].

<u>Discussion (Questions/Answers, Remarks)</u>

OD: I understood from yesterday that the en-route phase will also be considered in RECAT Phase III.

AR: The en-route situation is currently under review by the ICAO wake vortex study group whether there is a need to consider it. We still need a decision whether it is important enough to be part of RECAT Phase III. There could also be a solution for the en-route phase that is independent from RECAT.

DD: Do you suggest that the linear decay curve should not be carried down to zero circulation? You would need data to support this.

AR: No, what I meant is that a circulation of zero should be interpreted as an encounter with no severity, but you still have a probability of that encounter. So in RECAT you should separate the severity (driven by the vortex circulation) and the probability (e.g. driven by position in relation to the vortex).

JT: I don’t understand the argument. We deal with severity and likelihood because of the structure that a safety management system (SMS) gives us. The SMS tells us to look for the worst-case outcome and not a near minimum. So why do we have to decay to zero? If you consider a certain threshold above zero and for one aircraft you see a higher likelihood of vortices staying above this level than you see for another aircraft, then you will have a higher likelihood to hit the wake of that aircraft. That is what is done from a relative likelihood. Why do we have to decay to zero?

AR: No, I don’t say you have to decay to zero. I am arguing what we should use a different method to calculate the probability. I think in RECAT Phase I you derive severity and probability from the same data (vortex measurements) and I think for RECAT Phase III we can do better. We can compute severity and probability from different sources.

DD: I agree that we can extend the methodology when we have the data to do so.

TG: LES can provide a mean to validate simple vortex models but I think it can also be used to validate aerodynamic interaction models. We can use it also to simulate the reaction of the aircraft.

AR: Yes, LES data can be an input to wake encounter simulations.

WB: You often mentioned to include the core radius instead of using the potential vortex because it has an impact on the follower aircraft. But from where do you get the data? Especially if for dynamic pairwise separation we talk about hundreds of aircraft.

AR: We all accept the common simple models to compute Γ_0. But who says that this applies to all aircraft? If you say that certain effects (e.g. wing loading) are secondary than you apply the simple "mean" model to all aircraft, but you could do the same for the core radius based on physical understanding. There are simple models for core radius as a function of generator wing span and you can validate these with LIDAR data.

GW: For the core radius it is unfair to say: "Well I don't know what it is so I use zero". I think you can compute r_c/b_0 based on first principles and induced drag. And I think we could find a lower bound for r_c/b_0 and that will not be zero.

RL: If we have a very low circulation that is close to the ambient turbulence, does that contribute to your risk assessment? If the risk is the same as for an aircraft in ambient turbulence it should not contribute to the risk assessment.

AIRPORT CAPACITY EFFECTS OF RECAT OR: AN AIRPORT VIEW ON RECAT, WENDEBERG (FRAPORT)

S. Wendeberg presented the infrastructures and procedures at Frankfurt for the near future and the effect of RECAT Phase I on Frankfurt operations based on fast-time simulations and analytical models. The focus was directed to the "capacity" element of RECAT. Runway occupancy time was used as an example to show the actual RECAT capacity impact at Frankfurt. Frankfurt data of measured ROT indicate a significant increase in additional go-around when using RECAT reduced separations.

The presentation can be found here: [S. Wendeberg].

Discussion (Questions/Answers, Remarks)

RL: What is the reason for the large ROT values?

SW: It is due to the location of the rapid taxiways. The situation at Munich is the same.

RL: A380 has brake-to-vacate. Does that help?

SW: The system is designed for safety. We have seen that the ROT when using brake-to-vacate increases even though a decrease was expected.

PT: When you want to increase capacity at an airport you have to look at separations (e.g. RECAT) but also at ROT. If you decrease separation you have to get the aircraft off the runway quicker (e.g. more rapid taxiways). Was there anything published that requires the pilots to vacate the runway as quickly as possible?

SW: Yes, in the AIP. There are specific rapid taxiways suggested to LIGHT, MEDIUM and HEAVY aircraft. We already have discussions with signature authorities about every small part of concrete that is intended for safety. So I don't think we will get the go-ahead to layout more concrete for capacity reasons.

MW: But you did not tell pilots to leave at a certain taxiway.

SW: No, we made suggestions and discussed these with airlines. We had intensive discussions with Lufthansa about the increased ROT seen for the A380.

SL: I think the focus on the A380 is incorrect, because flight crews still have to gain operational experience.

WB: For ROT you should focus only on the peak hours (and good runway conditions) and see what the ROT is. That would be very useful data.

SL: Again, RECAT is a global evaluation. We used 50sec ROT which is the ICAO standard for 2.5nm separation. We did not focus on Frankfurt or Heathrow specifically.

TG: Did you also investigate the impact of RECAT Phase II?

SW: No.

TG: You showed only data for the west-bound traffic. What about the other direction?

SW: Separation minima are nearly the same.

DBO: RECAT provides wake turbulence separations. It has nothing to do with ROT. So at Frankfurt you don't implement RECAT because of your infrastructure, not because RECAT does not bring benefits at all.

Most approach controllers have no problems implementing a 6 x 6 matrix, but most of the time they use a 4 x 4 lookup table. However, for 25 x 25 we need something else than a lookup table.

SL: At Frankfurt you use a 4 x 4 and you add 1nm for B757, so you actually have 5 x 5. Then the gap to 6 x 6 is not that big.

JT: If you look at RECAT or another individual operational improvement from NextGen by itself then it is easy to say that it doesn't provide everything you want or need. Other constraints exist that also need to be addressed through other operational improvements envisioned in Nextgen. I think we have to gain the capacity from each one and then look at the total result. The experience we have is that you have to try to implement a new system and then solve problems through operational changes where possible.

HM: RECAT is based on the assumption that we are stabilized at 500ft. The Frankfurt data show that speed is stabilized at 1000ft. That should be reconsidered in RECAT Phase I.

JKO: It is not that the approach controllers at Frankfurt can't deal with a 6 x 6 separation matrix. I think it is just not the right time for Frankfurt to implement something like RECAT because we just opened a new tower and have lots of other changes that the controllers have to deal with right now.

ANSP CONSIDERATIONS FOR METHODOLOGY, MODELS AND SEVERITY CRITERIA, GOODMAN (NATS)

S. Goodman presented NATS view on required models and methods for wake separation reduction. It was argued that the evaluations should focus on the "hot spot", which, in the case of Heathrow, besides the threshold also includes the localizer intercept. Validated models to assess the impact of wake encounter (taking the actual intercept path into account) are required and RECAT encounter upsets do not reflect those documented in current wake encounter reports. The need for standard safety methodology and a harmonized concept roadmap that links RECAT and SESAR was mentioned.

The presentation can be found here: [S. Goodman].

Discussion (Questions/Answers, Remarks)

JKO: What do you mean that "RECAT encounter effect doesn't reflect current Ops reporting"?

SG: RECAT has assessed resulting bank angles for reduced separations. We have reported bank angle upsets that don't seem to be consistent with the models in RECAT, which suggests that the models should be validated. But we also still need to look deeper into the data.

DD: Which bank angles are larger?

SG: The reported/observed ones.

RL: There is a lot of knowledge from WVE investigations. There is the vortex impact but then the pilot is also doing something. The maximum bank angles that you see are a result of both vortex-induced rolling moments and the pilot action. Therefore, it should be considered to include the pilot in the analysis.

AIRCRAFT WAKE VORTICES: PHYSICS AND UCL MODELS, WINCKELMANS (UCL)

G. Winckelmans presented research done at UCL with respect to wake vortex modelling and the resulting models. This research includes LES simulation of ground effect under crosswind conditions, circulation decay modelling and LES simulation of Crow instability phenomena. A comparison of the RECAT decay line with results from high-fidelity IGE simulations that show different stages of decay IGE was made to contribute to the discussion on the decay rate at later stages (T* > 4). The Wake4D software tool that includes DVM and PVM vortex models was described and an analytical comparison of vortex induced rolling moments for B747 and A380 aircraft was presented.

The Specific WakeNet3 Workshop on "Operational Wake Vortex Models" was announced for November 7th and 8th, 2011.

The presentation can be found here: [G. Winckelmans].

Discussion (Questions/Answers, Remarks)

DD: Why would you expect the maximum vortex-induced rolling moment for B747 and A380 to be not much different?

GW: This results from computing the rolling moment with a classical static model (analytical integrals).

DD: Is that a static 1DoF model?

GW: Yes, but the message is that the maximum induced rolling moment does not scale with Γ_0. If an aircraft has a Γ_0 that is 25% higher, the maximum rolling moment is not 25% higher. Core radius is also part of the equation.

DD: I am surprised about this result.

AR: I think evaluations and sensitivity studies using wake encounter simulations (that use similar models to compute induced forces and moments) have already given indications on this. And flight test data also supports this trend that the differences in circulation do not directly transfer to the maximum induced rolling moments.

DD: So it's going to be the same behind a B757?

AR: I think this applies to all aircraft if you apply a fixed fraction of r_c/b_0.

RL: If you have all aircraft fly the same flight path you would get these results. However, it is more complicated. In reality small differences in the induced rolling moment in the beginning of an encounter lead to different flight paths of the follower and thus lead to different induced maximum rolling moments.

DD: Does that mean a 1DoF model is insufficient?

RL: Not necessarily. We should have this discussion after the last presentation by D. Bieniek.

DLR'S MODELS AND SYSTEMS FOR RE-CATEGORIZATION, GERZ (DLR)

T. Gerz presented DLR's vortex models P2P and D2P, the simulation tool WakeScene and DLR's wake vortex prediction and monitoring system (WSVBS). The different components of these tools and models were explained in detail and it was discussed how these tools could contribute to RECAT Phase II and III. WakeScene is considered to be beneficial to RECAT Phase II. The WSVBS is a suitable system for RECAT Phase III.

The presentation can be found here: [T. Gerz].

Discussion (Questions/Answers, Remarks)

JKO: I don't agree that based only on the fields of points presented you can argue that WakeScene-D simulates correctly what happens in reality.

TG: Forget the single points but look at the statistics. The median and standard deviation values show that the simulation can reproduce what has been measured. And then you can use the simulation to evaluate those parts where you can't perform measurements. We should combine measurement and models to be able to go beyond where data is available.

WAKE VORTEX SAFETY AT NLR, VAN BAREN (NLR)

G. van Baren presented on the work on wake vortex safety taking place at NLR. NLR has been involved in many wake vortex related activities such as WakeNet, WAVENC, S-WAKE, CREDOS, AWIATOR and others. NLR has a close link with rulemaking authorities and stakeholders around Europe and the US. As part oft the work, NLR is developing a wake vortex advisory system and performing safety and risk assessment. The equivalent roll rate is proposed as a suitable vortex encounter severity metric as it does not require aircraft characteristics other than wingspan. This is an advantage over the commonly used RCR.

The presentation can be found here: [G. van Baren].

Discussion (Questions/Answers, Remarks)

RL: Can you explain what "equivalent roll rate" means?

GB: The following answer was provided by e-mail after the workshop:

The equivalent roll rate as proposed by NLR, is the roll rate in the equilibrium situation where WV induced rolling moment and aircraft roll rate induced rolling moment are in balance. That is why no information on roll inertia is required.

As a by-product of the equivalent roll rate calculation, the roll damping can be estimated, which depends on the assumed basic lift distribution. Because the computed WV induced rolling moment depends on the same assumed lift distribution, the resulting equivalent roll rate is rather insensitive to the actual lift distribution and the associated actual roll damping. Variations in lift distribution have shown to have only minor impact on the calculated equivalent roll rate.

CONSIDERATIONS FOR THE METHODOLOGY TO BE USED FOR RECAT PHASE II AND III, BIENIEK (TUB)

D. Bieniek presented sensitivity study results on the impact of core radius r_c and wing span ratio (b_g/b_f) on vortex-induced roll acceleration. The objective was to stimulate the discussion whether such effects should be considered for the RECAT Phase II and III methodology. Furthermore, a simple way of simulating the roll response during a wake encounter was shown. Such a model could provide necessary data to use additional metrics like maximum bank angle in the RECAT methodology. Finally the question was raised whether sink rate should be used as an additional metric as it has shown to be of importance to pilots of large aircraft.

The presentation can be found here: [D. Bieniek].

Discussion (Questions/Answers, Remarks)

AR: This presentation is inline with what I presented this morning. We should find sufficiently simple models that also take the dynamic part of an encounter into account. Such models exist, so validation is now needed. We need to look at measurements from real encounters to make validation for 1 – 2 specific follower aircraft and then generalize the results to make them usable for a large number of aircraft during the RECAT Phase II and III.

RL: Elements of different presentations today were summarized in this presentation. The next step is to formulate the requirements for the RECAT Phase II and III methodology. I think everyone can see that the effects that were shown are significant. Is it necessary to include the parameters and models into the methodology because their impact on the results cannot be neglected, or is it conservative to do without them? We have to look what data is available to show that such models are generally valid and applicable and to make them usable for 9000 aircraft.

6 FINAL DISCUSSION ON RESEARCH NEEDS

This section summarizes the discussion on research needs. It is amended by contributions that the participants provided after the meeting.

Airbus (AR)

- Cooperation programme (SESAR JU and FAA) for data collection and analysis
- Validation of large and complex encounter models (e.g. WakeScene, VESA)
- Modelling flight control systems in more general models

CAA (PT)

Research projects to address two safety issues (a) helicopter wake turbulence and (b) wind turbine wake turbulence. The outcome of this study will improve the current guidance to aviation stakeholders.

Helicopter wake vortex has caused 6 accidents in the past 5 years in UK and Europe – currently there is limited guidance on wake vortex avoidance distances especially for light aircraft following helicopters. Similarly, there is no guidance for wind turbine wake turbulence as it is a relatively new topic and its effects on aviation, particularly when sited in the vicinity of runways, are as yet undetermined.

The objectives of this research project have been communicated to national and European organisations particularly through the UK Wake Encounter Working Group and WakeNet-Europe.

FAA (WB, SL, DD)

Research requirements for a wake vortex dynamic separation system (Recat Phase III)

While much has been discussed on dynamic wake vortex separation systems (WakeVAS, ATC-Wake, NextGen Self-Separation with Wake Mitigation, Wake Vortex Safety System…), there does not exist a single agreed-upon definition for an operational concept for such a system. It is generally accepted that the system will provide information to avoid significant wake encounters in a fashion that changes depending on weather and operational factors. However, this statement creates a number of questions that must be addressed and agreed upon by systems developers, users, and regulators before clearly-defined research requirements can be formulated. These questions include the following:

- Does the concept have a ground-based component, an airborne component, or both?
- How do the ground and airborne components interact?
- Over what flight regimes does the concept provide wake information?
- Does the wake information include avoidance information only or both avoidance information and severity information?
- If severity is considered, what are the severity criteria?
- What are the data requirements (data set, accuracy, resolution, transmission rate, integrity, etc) for the ground based and airborne components?
- What wake model or models are embedded in the wake information systems?
- What real-time sensors, if any, are required by the operational concept?
- Are the additional costs and complexity of a dynamic wake vortex system justified by a robust business case?

Many of these questions have been addressed at some level by proponents of dynamic wake vortex separation ideas. However, agreement on the operational concept by the developers, users, and regulators has not been accomplished. This is a first step towards identification of definitive research requirements for a dynamic wake vortex separation system. In the absence of this agreement, there are nevertheless important research areas that can be addressed now. These include:

- Establishing confidence from the systems' users and regulators perspectives in wake prediction models for the anticipated full operational regimes (take-off to landing as appropriate).
  - This suggests acquiring more data that represent the full span of relevant operations over long time periods to cover any possible seasonal variability
  - Quantifying data accuracy and integrity for model development. Is the data believable? Is the data convincing to the regulators? What is the evidence to show the data is a valid representation of reality? What are the limitations on data validity?
  - Determining the 'proper' level of model complexity. In general, the simplest model that meets the operational requirements is one way of defining the 'best model'.
  - Flight data on Wake Vortex core radius effects are required to convince users and regulators if this is to be a component of a dynamic wake vortex solution.
- Creating a regulator accepted and approved wake severity metric and establishing values for the metric.
  - Metric is the means by which a wake encounter can be characterized. Examples are aircraft attitude, rates and accelerations; glide slope deviation; others…
  - Values of the metric are the numerical scores beyond which an encounter would be declared unacceptable.
  - A more comprehensive publically-available database on wake vortex encounters for the present air transportation system is a key component of understanding perceived safe levels of wake encounter.
  - Pilot education on the importance of reporting all wake encounters is critical to the success of any voluntary wake encounter reporting system. Alternatively, automated analysis of digital aircraft data for wake encounters can be pursued. This approach requires acceptance by the user community which has not been achieved to date.
- For an airborne component, research is required to determine how to best present relevant wake separation information in the various flight regimes to the flight crews.
  - A decision is required as to whether the dynamic wake information is advisory or command (such as TCAS TA's or RA's)
  - The operational community needs to make a final agreement on the data link message set, transmission rate, and physical link.
- Any ground-based component will require similar research to determine how to best present wake vortex information so that it can be assimilated and used to achieve optimal operations.
  - The operational concept definition is critical to this research, since delegation of separation can radically change ground-based operations' responsibilities.
- Ground based wake sensors identified in the dynamic wake vortex system concept will need to acquire an operational readiness level appropriate for their role in the proposed concept.
- Publically available operational data is required to facilitate establishing safe arrival and departure rates into airports.

- Once wake vortex separations are reduced to the minimum acceptable level, runway occupancy time and other airfield issues will need to be taken into consideration for efficient operations.
- Aircraft mix by time of day analysis is required to optimize operations for specific airports.

TU Berlin (RL)

1. Research on methodologies for definition of separation standards and for safety assessments of wake vortex separations: The methodology of RECAT Phase I (and probably of Phase II) uses simple models and data. That is due to the requirement that those models have to be accepted as state-of-the-art, they have to be public, understandable and available today. As the state-of-the-art has improved significantly over the last years, the advantage should be investigated i) of using more sophisticated models with higher fidelity and ii) of including models for manual or automatic control of the airplane as well as models for severity assessment, which are not included yet. Enhanced models offer higher accuracy and allow reducing safety margins, which simple models need to deliver conservative results despite model uncertainties. Those margins limit potential capacity gains.

   The RECAT Phase I methodology models a limited part of the complete physical process from vortex generation to encounter hazard, thus it is not complete. Among others, a model of the effect of manual or automatic aircraft control is missing as well as an assessment of the encounter severity.

   RECAT Phase III (dynamic pair wise separation) requires more models and methods. Such models and the necessary expertise are available and offer higher prediction accuracy. However, the models need to be validated against RECAT Phase III requirements, for example: they have to address the world's fleet of 9000 aircraft, they need to be conservative, they must be suited for fast-time simulations, they have to be transparent and understandable, and so on. RECAT Phase III requires the models in 2017. To be ready in time, development and validation of such models has to start now. This implies that funding has to be provided now.
2. Wake vortex encounter in cruise are rare, however their occurrence is expected to rise with increasing traffic and their severity is expected to increase as aircraft weight differences are becoming larger (VLJs and HEAVIES above 500to MTOW). Currently, there are no wake vortex separations defined for cruise flight. It has to be investigated whether this assumption is still adequate. To do so, measurements of wake vortex characteristics and evolution (decay and transport) at high altitudes should be performed for model validation. Wake vortex encounters in cruise should be investigated in flight tests and in flight simulators taking the impact of simulator limitations into account.
3. Wake vortex encounters (WVEs) in flight simulators: The development of models for pilot severity assessments, a significant number of vortex encounters have to be recorded and rated by pilots. Analysis of in-flight WVEs during routine airline operations is extremely costly. WVEs in flight tests have the disadvantage that the pilots are prepared for an encounter. The only alternatives are certified full flight simulators with WVE capabilities, in which unexpected encounters during routine pilot training are performed. Simulated aircraft reactions should be validated against flight test results and the impact of flight simulator limitations on pilot ratings should be investigated.
4. Wake vortex awareness and avoidance techniques: The improved understanding of encounter physics and operational implications should be used to enhance regular airline pilot training to address wake vortex awareness and avoidance techniques.

FRAPORT (SW)

- Capacity aspects need more attention
- ATC procedures have to be considered

EUROCONTROL (DBO)

- We don't need perfect models, we need applicable models
- As RECAT provides wake turbulence standards, ROT should not be part of the future process

NATS (SG)

- ANSPs require validated tools to assess operational performance in the presence of operational variations (e.g. local practices and procedures) and that handle assessment of exceptional circumstances e.g. inadvertent under-separation for example:
- A key component of future concepts is the dependency on met data – there is a need for improved standardisation of met capabilities including associated uncertainty in a way that can be combined in the models.
- 'Standard' Methods developed under RECAT need to be more open so that an ANSP can use them to assess wake performance of new concepts – for example if an Approach Procedure with Vertical Guidance is introduced, can we use the 'standard' method for assessment (rather than re-assess models).

Skyguide (IA)

- Research on helicopter wake vortex should be seen as a two fold problem area:
  - Helicopter as follower
  - Helicopter as leader.
- The focus is on the helicopter as a follower problematic. The problem statement: in the absence of the refined separation minima, helicopters departing from helipads spaced less than 760m from the RWY(s), where heavier fixed-wing aircraft are operating, are forced to 3 (4) minutes required separation following the departure of the heavier fixed-wing aircraft. Such a situation at the regulatory level, leads to heavily hampering the helicopter operators efficiency and adding significantly to the ATCO workload through added complexity that, under certain circumstances may become a safety relevant (even critical) factor.
- The following should be understood as a very basic "operational requirement" that - itself would need a more serious effort in order to be fully developed and refined. By no means the ambition is to be prescriptive as to the methodology and/or sequence of actions to be taken to achieve the desired outcome, rather the "trigger" should be understood to be the correct notion, for the effort invested at this stage.
- What is urgently needed is the quantification of the distances and/or time values that would prescribe the minima allowing the helicopter operations (IFR landings and all take-offs) to be conducted independently and/or simultaneously with the heavier fixed wing aircraft operations on the proximate runways. The issue is that at the moment there is no existing quantification on helicopters' sensitivity being greater, equal or smaller to the fixed wing aircraft encountering the wake turbulence. In the lack of these, a very conservative, almost "crippling" separation standards are widely applied, heavily hampering the helicopter operators efficiency and adding significantly to the ATCO workload through added complexity that, under certain circumstances may become a safety relevant (even critical) factor.

- Known experience, so far, indicates that helicopters are more "resistant" to encountering wake turbulence, however, this is nowhere quantified in a manner that would enable development and/or refinement of the existing ICAO wake turbulence separation minima in regard to helicopters as followers. RECAT effort should be extended to cover this missing facet of the ATM procedures related to wake turbulence.

UCL (GW)

- Wake vortex transport and decay models are fairly mature. They can be used for many applications, both IGE and OGE. They can also be used for the en-route phase, but knowledge of stratification level is required.
- Simplified analysis with A/C flying straight through a vortex system is a very simple model and everyone can understand it. It shows that r_c/b_0 effect is not negligible.
- For RECAT Phase III we should find a way of factoring in core radius effect, e.g. find a lower bound for all cases for r_c/b_0. If we use such a bound, we would be on safe side. Research can help to find this r_c/b_0 bound.

DLR (TG/CS)

1. Combine data obtained from measurement systems and data obtained from simulation systems to get a more complete and full picture of the phenomenon.

   Rationale:
   - We assume that the models and simulation systems have a high degree of confidence today. They are fit for the purpose for which they have been built.
   - Data from measurements suffer from the limited conditions under which they have been obtained or from limited measurement infrastructure and instrument capabilities; those data lack to present the full wake vortex and impact reality.
   - Data from verified and confident simulation systems still suffer from model assumptions and simplifications and will not represent the full physics; those data also lack to present the full reality.
   - Combine both methodologies in order reliably increase the range of accessible reality – which may also result in reduced uncertainties and errors.

   Approach:
   - Determine the limits of the applicability of the measurement system.
   - Determine the limits of the applicability of the simulation system.
   - Determine the relevant processes which describe the real phenomenon and determine the relevant parameters and parameter ranges which control the real phenomenon.
   - Search for (sub-) domains in the parameter space which are accessible with high confidentiality to both measurement and simulation.
   - Compare data from both methodologies in that common (sub-) domains and assess the result.
   - If both methodologies show the same "reality" in that common sub-domains, excursions to other non-common domains in the parameter space are justified:
     - a method may now be applied also in other sub-domains which are not accessible to the other method,
     - but each method has to remain well within the parameter range of its applicability.

2. Work towards a common approach ("a standard") for MET in the wake vortex context: methodology, quantities, resolution and accuracy...
3. Derive commonly accepted criteria for wake encounter severity assessment within the global research community with involvement of relevant stakeholders (authorities, operational, etc). This may include to compare the data and results available world-wide so far and conducting additional human-in-the-loop tests with previously agreed conditions and parameters.
4. For the definition of "dynamic pairwise wake turbulence separations" compile a comprehensive overview over existing work. With this basis start a discussion involving relevant stakeholders and the research community. (VERY IMPORTANT !)