Report of the Workshop
Wake Vortex Encounters
in
Flight & Flight Simulation

May 10-11, 2004, AIRBUS Deutschland, Hamburg, Germany

Organised by WakeNet2-Europe, Working Group 5
(Wake Vortex Effects: Aircraft Responses and Pilot’s Perception)
in cooperation with
WakeNet-USA
and
DGLR committees S1.2 ‘Flight Operations’ and
T5 ‘Flight Mechanics and Guidance and Control’

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Summary

On May 10-11, 2004 a group of 16 experts from industry, airlines and research institutes participated in a workshop organised by Working Group 5 of WakeNet2-Europe ‘Wake Vortex Effects: Aircraft Responses and Pilot Perception’. The objectives of the workshop were:

- to share information between participants, which have experience in the field of wake vortex encounters (WVEs) in flight or in flight simulators, either as a pilot or as an engineer,
- to identify and discuss techniques that may contribute to a universal and complete methodology to derive wake vortex separation distances,
- to give recommendations to direct future activities.

In the workshop pilots reported on their experiences with wake vortex encounters whereas various researchers from industry and research laboratories reported on their work to investigate wake vortex encounters in flight tests, to develop realistic wake vortex models in flight simulators and to use the simulator to study WVEs.

All participants felt that the information exchange between pilots and researchers greatly contributed to a better understanding of the wake vortex issues. At the end of the meeting some participants remarked that their views had changed during the two days.

This report, which should be read together with the handouts of the presentations, summarises the discussions that resulted in the following recommendations:

1. **Reporting System**
   Reporting of WVEs should become mandatory and a system should be established to collect and analyse pertinent information, such as recorded radar data, atmospheric data, and operational information, including selected flight data recorder data as requested in NTSB recommendation A-94-57. A rating scale that should allow pilots to unambiguously assess the severity of the encounter should be developed. To better understand the scope of the problem and the frequency of WVEs, it is essential to collect more information, for example from a pilot questionnaire as NASA intends or from a systematic, automatic analysis of flight data recordings.

2. **Hazard Criteria**
   Definition of hazard criteria is essential. They are the key (and currently the bottle neck) for assessing improved procedures for wake vortex avoidance, which guarantee safety without unnecessary negative impact on capacity. More work has to be done in the line of the (finished) S-Wake and (ongoing) Airbus studies (e.g. flight simulator studies, correlation with flight tests) to define hazard criteria. All participants were optimistic that this can be achieved.

3. **Pilot Training**
   The available knowledge on the wake vortex issue should be included in airline pilot training to improve risk awareness. That means to learn about factors and situations, which make a WVE more probable. Such training can be done in classroom or as computer-based training (CBT) and does not necessarily require a flight simulator. The flight simulator can be used additionally for demonstration of wake vortex effects.
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1 Introduction

1.1 Background

The wake vortex separation problem is known since the early 1950s. With the event of large jet airplanes in the 1960s, flight test programs were performed in the U.S. with small aircraft such as Lear Jet and Cessna 210 behind a variety of large military transport aircraft (B-52, C-5A, CV-990, DC-9). The following aircraft intentionally penetrated the vortex of the large jet in order to characterize the vortex and to determine its hazard. In the early 1970s, Boeing probed the vortices of its 747 and 707 airplanes with 737, CV90 and F-86 and NASA performed tests with an OV-10 behind a Lockheed C-130. Test pilot’s tasks were either to penetrate the vortex or to stay within the vortex in order to find hazardous regions and to determine hazard levels. As flight tests included a lot of uncertainties, further studies were performed in simulators under better controllable and repeatable conditions. Simulation models that had been validated by flight tests were used to investigate WVEs under predefined conditions and to determine hazard criteria.

Although this research contributed to a good understanding of the vortex effects on trailing aircraft and to the current wake vortex separation rules, no methodology that allows deriving wake vortex separation distances or times from physical parameters exists today. The lack of an adequate methodology makes it difficult to improve the current system of static approach separation criteria that reduces the air transportation system capacity under IFR conditions. Furthermore, there are no state-of-the-art methods to prove that current rules are adequate for new and larger airplanes.

The key to progress is the definition of such a methodology that is accepted by all stakeholders. The characterisation of vortex effects and the classification into non-severe or tolerable and severe and not tolerable consequences is part of it.

A literature survey on Wake Vortex Encounters in flight and flight simulation has been prepared (APP 00c). Comments are welcome (Robert.Luckner@tu-berlin.de).

1.2 WakeNet2-Europe

It is the purpose of WakeNet2-Europe (WN2E) to promote multidisciplinary contacts and information exchange between specialists active in the field of wake turbulence and end-users of this knowledge in the operational airport environment. Furthermore, WN2E shall enable the development of a shared view on research needed to address the existing and foreseeable safety and capacity related problems caused by wake turbulence.

This is done by organising yearly a large workshop and by the activities of various Working Groups that address specific aspects of the problem. More information can be found on the WakeNet2-Europe Internet site http://www.eonecert.fr/projets/WakeNet2-Europe.

One of the WakeNet2 Europe working groups is WG-5 named “Wake Vortex Effects: Aircraft Responses and Pilot Perception”, chaired by Robert Luckner (Airbus-Deutschland).
1.3 Workshop organisation

WG5 organised the workshop ‘Wake Vortex Encounters in Flight & Flight Simulation’. Participation was on invitation only with the aim to have the relevant experts around the table (see list of participants, Appendix B).

The workshop was organised in co-operation with WakeNet-USA and the DGLR committees S1.2 ‘Flight Operations’ and T5 ‘Flight Mechanics and Guidance and Control’. Two ‘moderators’ (Claus Cordes, pilot for Lufthansa Cargo and co-ordinator of the DGLR committee S1.2 ‘Flight Operations’ and Bram Elsenaar, co-ordinator WakeNet2-Europe) were invited to direct the discussions and to summarise their observations.

The workshop comprised six sessions with the following topics (see agenda, Appendix A):

1. Pilots’ answers to questions regarding ‘piloting’
2. WVE in airline operation and flight tests
3. Pilot questionnaire
4. WVE in flight simulations
5. Wake vortex encounter (WVE) simulation
6. Hazard criteria

Sessions 1 to 3 were moderated by Claus Cordes, and sessions 4 to 6 by Bram Elsenaar. Discussions took place after each presentation and more extensively in dedicated Working Group and panel sessions.

1.4 Objectives of the workshop

The objective of the workshop is to share information between participants, which have experience in the field of wake vortex encounters (WVEs) in flight or in flight simulators, either as a pilot or as an engineer. Taking into account pilot experience in wake vortex encounters and experience with flight simulations, techniques that may contribute to derive a universal and complete methodology to derive wake vortex separation distances shall be identified and discussed. Finally, recommendations shall be given to direct future activities.

1.5 List of questions

A list of questions that was addressed during the Workshop was prepared and distributed to the participants before the workshop. The objective of these questions was to stimulate discussions. The questions were split into two different categories: one is addressing WVE from a pilot’s perspective and the other one addresses general topics.

Questions regarding ‘piloting’:
The questions regarding piloting address experience with wake vortex encounters and operational aspects. Only pilots can answer them. The answers are not expected to be statistically significant. If the questions are found to be useful, they might be distributed as a questionnaire to a larger number of pilots in the U.S. and Europe.

1. How often do encounter happen?
2. Are they a surprise or is the pilot mentally prepared?
3. Are there typical characteristics, which tell a pilot that a WVE is more likely?
   Consider: type of aircraft, phase of flight, geographical location, weather conditions, traffic density, time of day, time of year, type of leading a/c
4. How did you know it was a wake vortex encounter (WVE)?
5. How would you classify WVEs? Why?
6. What type of scale would you use to describe WVEs? Define the gradations.
7. Which consequences of a wake do you assess when classifying its severity? (E.g. effect on a/c control, work load, passenger comfort, cabin crew and passenger safety. other)
8. How can a pilot avoid WVEs? (Anything more than in the FAA circular)
9. What can a pilot do in case of an encounter?
10. Did you observe a relation between flight phase and weather conditions and WVE’s? Which?
11. Shall WVEs be trained? Why? What are the training requirements?

Questions to all participants:
The questions all participants address available and required knowledge on WVE simulations, test analysis and results.

1. Why do we need flight tests and why do we need simulator tests?
2. Model validation: How did you validate the models. What are the requirements for model validation?
3. Hazard criteria:
   o Do hazard criteria depend on flight phase?
   o Which flight phases have to be distinguished?
   o Which graduation is needed? (‘non-severe’, ‘severe’; ‘tolerable’, ‘not tolerable’; minor, major, hazardous? Why?
4. Is it possible to determine a vortex strength threshold (specific for each aircraft) that excludes severe encounters? How can it be used?
5. Is it useful to prepare and distribute a questionnaire on WVEs to a wide pilot community?

1.6 Structure of this report

This report reflects the main outcome of the meeting. It is published on the WakeNet2-Europe Internet Site together with the slides of the presentations.

The notes are grouped according to the various topics that have been discussed and do not reflect the actual order of the contributions.

WakeNet2-Europe has the objective to facilitate the exchange of information. Therefore, the readers of this report are invited to send their comments to WakeNet2-Europe (elsenaar@nlr.nl) and to Working Group 5 (Robert.Luckner@tu-berlin.de).
2 Workshop report

2.1 Introduction

Welcome of the participants by the local host, Robert Luckner (Airbus) APP 00a, and by the WakeNet2 Europe coordinator, Bram Elsenaar (NLR), APP 00b.

The workshop had the following objectives:

• To share information between participants, which have experience in the field of wake vortex encounters (WVEs) in flight or in flight simulators, either as a pilot or as an engineer,
• To identify and discuss elements that should be part of a universal and complete methodology to determine wake vortex separation standards,
• To give recommendations for future research activities.

A literature survey was distributed before the workshop, APP 00c.

2.2 Pilots’ experience (answers to questions)

To stimulate the discussions all participating pilots were asked to answer the eleven questions that were distributed before the meeting (see section 1.5). The answers – with anonymous authors - are given in Appendix C:

Summary of answers and discussion:

• The participating pilots represent a good sample of pilots (airline pilots with experience in flying turbo props, medium and heavy jets, airline training pilots, cargo pilots, test pilots, all with flight experience ranging from thousands to more than 10,000 hours). However, there might be additional inputs especially from pilots, which fly smaller aircraft - like regional jets.
• The pilots mentioned that their experience (flight hours), the type of aircraft they have been flying (large or small) and the operational environment (e.g. small or major airports) has a significant impact on the number of encounters they had experienced. These factors have also an impact on how strong the encounters were. (Question 1)
• WVEs cannot be seen, they happen unexpectedly although some mental preparation is possible making use of clues like longitudinal and vertical separation to surrounding traffic, airport layout (parallel runways), wind and weather conditions. (Question 2)
• The WVE identification is based on pilot judgment. If there is no other disturbance possible, if there is another aircraft in the vicinity and if the a/c reaction is typically in the roll axis, they might attribute an uncommanded a/c reaction to a wake vortex. (Questions 3 and 4)
• A classification of vortex encounters seems to be possible. It will be based on pilot’s perception – hence subjective. (Questions 5 and 6)
  o WVEs have consequences on a/c control (attitude control maintaining flight path), cabin crew and passenger safety. (Question 7)
  o The pilot has options to reduce the probability of a WVE. Therefore, training and preplanning is required. (Question 8)
• No specific rules for coping with a WVE exist. It has to be handled by basic airmanship. (Question 9)
• WVE probability is higher in 'calm' weather, light crosswind (combined with tailwind) on final, terminal area. (Question 10)
• Training can improve pilots' situational awareness. Tools (like weather radar and TCAS) are also welcome. (Question 11)

2.3 WVE in airline operation and flight tests

WVE experience in a Fokker 100 tests aircraft behind 747, Wim Huson (WH), APP 8:
• Low altitude wake encounter during approach in tailwind operations: During autoland trials, WH who was at that time Fokker chief test pilot flew the fully instrumented Fokker 100 when a WVE occurred behind a 747 (5nm). Wake effects started at 300ft above ground causing a washboard ride that was not associated – in that moment - with a wake vortex. The main encounter was below 190ft. The autopilot compensated the induced rolling moment with up to 18° aileron deflection, which the pilots observed as control column deflection (such a command would result in 40° bank in calm air). Bank angle reached 8°. At the same time the sink rate increased, which was much more frightening than banking. This behaviour at low altitude caused the crew to disengage the AP and to perform a manual go-around at 95ft. NLR (re-) calculated vortex strength from the measured data: initial vortex strength = 813 m²/s; vortex strength at encounter point = 147 m²/s. Also the washboard effect is visible in the time histories.
• Encounter during cruise flight: MD-11 5NM behind a B-747 in the Ocean Track System (OTS) around FL 350 when suddenly “washboard ride” occurred upon leg change into the wind. Deviating 1/10th of a NM (FMS function) resolved it.

Conclusions:
- Washboard rides were experienced by the crew in both encounters. It has also been reported by other pilots (ASRS) and seems to be an indicator of an upcoming WVE.
- Recognising pre-encounter phenomena is very important.
- Training is essential for situational awareness and should help to avoid encounters. The “washboard characteristics” could be presented in simulators (technically it should be feasible).
- Is 5 NM separation between heavy and medium / large category aircraft in tailwind conditions sufficient in all cases?

A case study of a WVE: RJ behind 747, Don Sullivan, APP 7:
• The briefing was prepared by Jim Duke, ALPA, International Staff Engineer
• In the US the following three reporting systems exist:
  - Reports to ALPA (24 hour availability; Accident/Incident Hotline, no time limit to report safety concerns,
  - Reported in ASAP (Aviation Safety Action Program): Generally a 24 hour limit to report an event/safety issue; Event Review Committee (ERC) FAA, Company designee, Pilot Union member, ASRS ‘lag’ typically 5-7 months
• A WVE of a RJ behind a 747 during approach to Chicago O'Hare runway 09R in spring 2003 that was reported to ALPA (also reported to ASAP, but not to ASRS) was analysed by Jim Duke (ALPA). The reconstructed trajectories of both aircraft
showed multiple phases were WVEs might have happened during manoeuvring in terminal manoeuvring area, when the RJ crossed the 747 trajectory a few 100ft below. Separation was lower than the 5nm ICAO separation. The WVE happened on the final at app. 3700ft AGL (4200 MSL).

- Animated simulations of the RJ's approach with cockpit view and animation of ATC display were shown. It was emphasized that ATC controllers and pilots have different views on traffic scenarios (cockpit view flight instruments versus the two dimensional ATC radar screen).

- Conclusions:
  - Mandatory reporting of WVEs and establishing a system to collect and analyse pertinent information, such as recorded radar data, atmospheric data, and operational information, including selected flight data recorder data as requested in NTSB recommendation A-94-57

**S-WAKE WVE in flight test with NLR’s Cessna Citation, Wim Bonnee, APP 9:**

- Test objectives were to collect data for model validation.
- Preparation of flight tests included the identification of potential risks for the Citation. 11 risks were identified and addressed.
- In S-WAKE, NLR’s Cessna Citation flew 35 WVEs behind ATTAS with separation varying between 0.4 and 2.7 NM at flight level 150.
- The aircraft was equipped with a sensor system including a nose boom with 2 angle-of-attack and 2 sideslip vanes.
- The smoke trail that should facilitate precise encounters was faint.
- The washboard effect was observed during the encounters.

**Discussion ‘WVE in airline operation and flight tests’:**

- Separation standards in the US and in Europe are different and differ also from ICAO separation standards. Normally, ATC guarantees wake vortex separation until runway threshold. In order to optimise runway throughput under VMC, ATC can delegate maintaining of adequate separation to the pilots. Then less separation distances are possible. This happens often in the US, but it is also possible in Europe.
- Furthermore, specific procedures for closely spaced parallel runways have been designed to enhance throughput, for example in the US the SOIA approaches for San Francisco and Saint Louis and in Europe the HALS/DTOP approach for Frankfurt. At some European airports WV separation is provided only until the FAF (Final approach fix, about 4nm before threshold). If the trailing a/c is faster than the leader, separation will be reduced from there on (compression effect).
- It was also remarked by pilots (e.g. Wim Huson) that incidences similar to wake vortex encounters are more often experienced (e.g. due to turbulence or wind shear) with only 10 to 20 % of these incidences probably related to WVEs.

**2.4 Pilot questionnaire**

*Proposal for a pilot questionnaire on WVE during airline flights, Anna Trujillo, no slides, after workshop amendment in APP 10:*

- NASA is considering a pilot questionnaire on WVE during airline flights
- Audience: pilots flying in different international arenas
Options are:
  - Questionnaire
  - Interviews: much higher effort but may be more appropriate

Discussion 'Pilot questionnaire':
The discussion addressed a wake vortex reporting system and the pilot questionnaire proposed by NASA.

- Severe encounters have been reported occasionally even beyond the actual (considered) safe separation distances. The present situation is considered safe but detailed statistical information is lacking.
- All participants agreed that a vortex reporting system is needed. It will allow establishing a reliable WVE database.
- All participants agreed that in order to quantify the wake vortex safety problem, a rating scale has to be established.
- As a pilot cannot always positively identify a WVE, additional information (the proximity of other A/C, weather conditions) is required. Pilot reporting will be subjective, depending on the pilot's perception, differences between A/C (e.g. the sophistication of the FCS).
- It was suggested (Bram Elsenaar) to incorporate wake vortex reporting into the present incident reporting schemes and that they should only be reported when safety was a direct concern (with some classification to be defined more clearly).
- Bernd Schäfer mentioned that the cause of uncommanded and unwanted aircraft motions whether turbulence or WVE is not important for pilots while recovering the aircraft. It is important for post-encounter assessments, lessons learned, etc.
- Flight data recordings might possibly be used to provide more objective information over wake encounters (as done in S-WAKE by NATS and NLR). However, some participants (e.g. Bernd Schäfer, Robert Luckner) doubt that the quality of current recordings is sufficient.
- NASA / WakeNet-USA is considering a pilots questionnaire (Anna Trujillo) to obtain more information how wake vortex problem is actually perceived by the pilots. The idea of a pilot questionnaire was generally endorsed. However, the objectives of the questionnaire have to be specified and then it has to be assessed whether they can be achieved by a questionnaire. Also the 'core group' that should be addressed has to be identified. The FALPA and IFALPA representatives indicated that their organisations are willing to participate and that they are interested to be involved in defining the objectives of such a questionnaire.
- It was generally agreed that the questionnaire would not replace the reporting schemes but that the two should reinforce each other.

2.5 WVE in flight simulations:

Wake vortex in flight simulation, Stefan Simon, APP 12:

- WVE simulations are available in the following LFT simulators: 737-300/400/500 (CAE), A319 (CAE), 767-300ER (Thales)
- All WVE simulations are based on a mathematical model that was prepared by Advanced Simulation Corporation for FAA AFS-408 (Archie E. Dillard). Model inputs are: altitude, lateral and horizontal encounter angle, and lateral and vertical offset between aircraft and vortex.
For pilot training easy reproducibility of a WVE is important. Therefore three scenarios are pre-configured that can be directly selected by the instructor at his console:
  o Altitude vortex: direct entry,
  o Altitude vortex: skew angle 5°,
  o Approach vortex: skew angle 5°.

Currently, the WVE simulation is not used for pilot training, as no legal requirement by FAA exists.

**Flying WVE in different flight simulators, Stefan Wolf, APP 11:**

- Stefan Wolf reported of WVES flown in the following flight simulators:
  - TsAGI simulator with Ilyushin 2 model (desktop solution (OTS), focus on onboard warning devices, no motion / sound, generic airfield, very limited visual (19 in CRT))
  - FFS (Full Flight Simulator) at the Lufthansa Flight Training centre (aircraft with conventional flight controls, full motion, visual and sound system, real airports, exact aerodynamic model, multiple simulation features available (reset, playback, etc.))

- Video of WVE simulator tests was shown.

**Conclusion:**
  - All simulations showed realistic aircraft responses. However, there is no question that a full-flight simulator is preferable for demonstration of WVEs during pilot training and WVE investigations fro research.
  - The complex scenarios behind WVEs: dense traffic, time pressure, etc is not represented in simulators.

**Animations of WVE in flight simulators, Robert Luckner:**

- The animation capability is needed to analyse WVEs (e.g. from simulator tests or computed with VESA)
- 4 WVEs were shown using the tool SimVis3D (developed by TU Berlin):
  - Marginal disturbance
  - Under-critical disturbance according to NASA bank angle hazard criterion
  - Over-critical disturbance according to NASA bank angle hazard criterion (with go-around)
  - Extreme encounter with go-around

- The same WVEs were later replayed at the THOR flight simulator

2.6 WVE simulation:

**WVE simulations in S-WAKE and for VESA development, Michael Fuhrmann, APP 15:**

- The S-WAKE partners developed a WVE software package that included the wake vortex model (vortex-induced velocities) and the aerodynamic interaction model (Strip Method and Lifting Surface Method), which have been developed and validated in the project.
- This s/w package was implemented on 4 simulators for simulation of 5 different airplanes that cover the range from MTOWs of 5,600kg to 230,000kg, namely:
  - A330 on the certified A330 training simulator (TU Berlin)
  - VFW614 on Airbus development simulator THOR
  - Fokker 100 and Cessna Citation on NLR’s development simulator
• Dornier 228 on the certified Dornier 228 training simulator (TU Berlin, Simtec)

Based on the flight simulator software, Airbus developed a high-fidelity offline version, which is implemented in the VESA tool.

Conclusion:
• Unique WVE simulation capabilities exist.

Flight simulator study of airplane encounters with perturbed trailing vortices, Jeff Crouch, APP 16:

• The objective of the vortex-encounter study was to investigate the effect of forced or natural vortex break-up using active control.
• WVE simulations of 737-300 with a standard 737 autopilot engaged behind 767, 737, and 747 at different separation distances.
• Consideration of different vortex shapes:
  o straight vortices,
  o wavy vortices,
  o vortex rings.
• Contour plots for maximum vortex-induced bank angle excursions versus vertical and lateral encounter angle show that WVE severity decreases from straight to wavy and ring shaped vortices (for same separation distances).
• The effect of the active control system was demonstrated by an animation.
• Conclusions:
  o Significant reduction in maximum bank angle, as experienced by an encountering airplane, due to vortex break-up,
  o Most significant reduction due to formation of vortex rings: reduced magnitude, reduced likelihood of occurrence.

Validation of WVE simulation models using flight-test data, Klaus-Uwe Hahn, APP 17:

• Presentation held in behalf of Dietrich Fischenberg, DLR Braunschweig
• Flight test data analysis performed within the S-WAKE project:
  o Determination of vortex model parameters to characterize vortex flow field.
  o Validation of flight mechanic and aerodynamic interaction models based on 116 in-flight WVE of the Dornier 128 and the Cessna Citation behind VFW614-ATTAS.
  o Parameter identification and flight path reconstruction techniques were used to determine parameters of three different wake vortex models: Rosenhead& Burnham-Hallock, Lamb-Oseen, and Winckelmans.
  o Comparison of flight test data with results from theoretical models allowed validating two aerodynamic interaction models (AIMs) for near parallel encounter cases: strip method, lifting surface method.
  o Deficiencies in matching lateral acceleration and yaw rate is attributed to missing fuselage effects in both models.
• Conclusions:
  o Both aerodynamic interaction models are suited to simulate WVEs (especially effects in roll and vertical axes). Both methods show equally good results.
**In-flight simulations of WVEs with ATTAS, Andreas Reinke, APP 18:**

- 32 simulated wake encounters have been conducted during in-flight simulated ILS landing approaches (raw data) with encounter heights varied between 1200 und 1600 ft above ground. (2 test pilots, 2 flights, 5 pre-defined scenarios, each scenario flown 3 times with each pilot)
- As a safety precaution the actual flights took place at FL110 - 130
- Tests have been conducted with time-fixed disturbances that were determined in offline tests with AP before the flights. This guaranteed repeatability, as pilot control inputs and pilot’s hazard ratings were of main interest.
- A model that predicts pilot hazard ratings (from a/c and pilot response) was developed.
- The recorded data have also been used to develop a dedicated WVE pilot model for the ATTAS aircraft.

**2.7 Hazard criteria**

**Investigation of WVE hazard zones on the A330 simulator at TU Berlin, Klaus-Uwe Hahn, APP 20:**

- The concept of ‘Hazard Zone’ defines a region outside which the wake vortex flow field is no danger to the follower aircraft. Note: This does not imply that each encounter of the Hazard Zone will always result in a hazardous situation.
- The boundaries of the Hazard Zone are investigated in offline simulations, simulations on the ZFB A330 flight simulator and in In-flight simulations with DLR’s test bed ATTAS (in preparation).
- Conclusions:
  - Numerous offline simulations with automatic control (AP / AT), have shown that a normalized aileron deflection of $|\alpha| \leq 0.3$ provides safe margins to hazardous situations.
  - 82 approaches in a full flight simulator have shown that for manual control a normalized aileron deflection of $|\alpha| \leq 0.2$ provides acceptable margins for a safe approach and successful landing. This boundary will be validated by in-flight simulations with ATTAS.
  - The normalized aileron deflection / RCR is a well suited measure for hazard avoidance (for small values of RCR it seems to cover all other parameters of interest)

**Development of hazard criteria, Robert Luckner, APP 19:**

- Hazard criteria allow classifying the severity of a WVE taking into account the following effects:
  - Attitude deviations (bank, pitch, …) and their rates,
  - Flight path deviations (altitude, ILS localizer / glide slope, …),
  - Pilot workload and required piloting skills,
  - Effort to recover from attitude and flight path deviations,
  - Effort to maintain flight path,
  - Effects on performing the flight task (go-around),
  - Effects on aircraft (loads),
  - Effects on passengers, cabin crew,
  - Accelerations (discomfort, injuries).
Methodology for the development of WVE hazard criteria was explained.

The requirements for hazard criteria validation are less stringent when they are used to compare WVE severity behind different aircraft (VESA) compared to the definition of absolute values for safe separation standards.

Criteria for the landing approach and preliminary criteria for cruise were discussed.

Conclusions:
- Based on simulator results, different hazard criteria were developed.
- The best predictions for VFW614 were achieved with the combined RCR / glide slope criterion and $\Phi$ / glide slope criterion.
- For all investigated aircraft the NASA bank angle criterion (VFR, 707/720) achieved acceptable results.
- For pragmatic reasons, the NASA bank angle criterion will be used for investigations with the Airbus Tool VESA for the assessment of the Airbus A380 in the frame of the Eurocontrol, FAA, ICAO, JAA Steering Group.

**Vortex Encounter Severity Assessment (VESA), Gordon Höhne, APP 21:**

- VESA is a software tool developed by Airbus; it is based on high-fidelity simulations of the follower aircraft; it is capable of determining the WVE severity and can be used to assess the adequacy of separation standards for new and larger aircraft.
- VESA was selected by the A380 wake vortex Steering Group (FAA, JAA, Eurocontrol, ICAO) as part of the A380 wake vortex risk assessment methodology, which assesses WVE severity behind A380 and other aircraft in a comparative way.
- Two VESA analysis types were shown with the help of examples:
  1. Assessment of the WVE severity based on Monte Carlo simulations and
  2. Determination of the worst-case encounter conditions.

Conclusions:
- Preliminary computations with VESA for the VFW614-ATD behind different generator aircraft provided reasonable results and confirmed observations in the flight simulator tests.
- A combination of an air space simulation tool (such as ASAT) and VESA has the potential to be used to determine safe aircraft separation distances in the future.

2.8 Working Group sessions

To give answers to the questions that were raised to all participants, 2 sessions were held. During the first one (first day), three working groups discussed in parallel one question each. Their findings were reported and discussed in the panel. The results are summarised below.

**How do pilots identify WVE? What is the hazard?**

Participants: Höhne, Schäfer, Huson, Hahn, Reinke, Cordes

Summary of results:
- IDENTIFICATION is positively not possible. Instead, the pilot can deduce that an uncommanded aircraft motion is likely to be resulting from a WVE. Clues are: the absence of turbulence, the absence of other phenomena that cause aircraft motions, specific weather conditions (e.g. calm air) and the presence of other traffic in the vicinity.
- HAZARD (assessment)
The hazard results from uncommanded aircraft state and/or flight path changes. The following parameters have a strong influence on the hazard:

- Height above ground
- Control activity (control margin, saturation?)
- Vertical acceleration
- Bank angle upset

The “hazard feeling” is very subjective, depending on many factors:

- Environmental conditions
- Aircraft (size and mass)
- Risk awareness of the crew

Panel discussion:

- All agreed that the definition of hazard criteria is essential. Research has made good progress in identifying the relevant parameters and defining hazard criteria – especially for landing approach. Such criteria can be used in comparative studies, for example WVEs behind different leading aircraft. However, an agreement on absolute safety limits is missing. Currently this is a bottleneck and limits what we can achieve in terms of developing improved procedures that guarantee safety without unnecessary negative impact on capacity.

WVE questionnaire
Participants: Anna Trujillo, Don Sullivan, Stefan Wolf, Michael Fuhrman, Bram Elsenaar.

The discussions in the group encompassed questionnaires and methods to obtain relevant information about WVE. The pertinent points are detailed below:

1. The objectives and goals of the questionnaire and the research in general must be communicated clearly to the pilot community. If we do not do this, we run the risk of not getting full cooperation or a good exchange of ideas. Pilots should understand that we want to maintain or improve safety, increase capacity, and develop a baseline of how many WVE there are with the current operating procedures before new procedures are put in place.

2. Cooperation of the airlines and unions is necessary in order to be able to get data from the relevant pilot populations.

3. Since WVE have the ability to affect RJs more often, we must make sure we include smaller regional pilots and carriers in the survey on WVE.

4. We need enough participation in order to get statistically relevant results. This will help the effort by legitimising our subjective survey results.

5. In order to further legitimise our subjective survey results, a method to obtain data that are more objective would be beneficial. The objective data may take the form of flight-data recorder data or some other automatic recording device.

6. As a bridge between subjective surveys and objective data recorders, some type of pilot reporting system similar to the ASRS would be helpful. This type of reporting system could help align the subjective data with the objective data. This reporting system would take time to put into place (especially since we would want an international effort) and we would have to debate whether the reporting system should be voluntary or mandatory.

WVE & training
Participants: Stefan Simon, Robert Luckner, Axel Graumann, Wim Bonnee, Jeff Crouch

Summary of results:
Training flight simulators have some restrictions, which have to be taken into account when training of WVE is discussed:
- Not all flight simulators can simulate WVEs
- For large upsets (caused by a WVE) the flight simulation may become invalid; parameters may exceed the flight simulator's envelope (e.g. exceed the range of the aerodynamic data base)
- g-loads are not felt correctly in the simulator
- Surprise effect may be missing

Simulators are considered as well-suited for pilot training but not for simulation of extreme attitudes (as the validity of the simulation is not guaranteed)

Lufthansa Flight Training uses its WVE simulation capabilities only for demonstration not for training. The LH line-training syllabus covers WVEs.

Commercial airline pilots fly 4 simulator check flights per year:
- two required by authorities (recaller),
- two required by airline (refresher).

Each year, every pilot has to pass an examine with 10 to 20 questions. Training is done by computer-based training CBT.

Upset recovery:
- stabilise the aircraft (aviate)
- navigate the aircraft (e.g. localiser, glide slope tracking)

Part of the yearly refresher/recaller training is windshear, EGPWS, approach to stall – not wake vortex.

No legal requirements regarding training of wake vortex encounter

Risk awareness can be trained. That means to learn about factors and situations, which make a WVE more probable. Such training can be done in classroom or as CBT and does not necessarily require a flight simulator. The flight simulator can be used additionally for demonstration of wake vortex effects.

Scenarios have to be realistic

Summary: The need for pilot training was extensively discussed and it was felt that specific training for wake vortex encounters is not needed. Instead it is recommended to train risk awareness using a theoretical computer-based training program. This should include awareness for weather conditions that are favourable for long living wakes, wake transport characteristics and possible effects of vortex encounters. Vortex encounter simulations should be used for illustrating typical encounter characteristics. The WakeNet2-Europe network should be used as one source that provides the relevant information.

During the second session (second day), the remaining questions were discussed in the panel.

How can WVE simulations be validated?
- Validation is a stepwise process that is performed on sub-model and on complete model level:
  - Validation using wind tunnel data as it was done in WAVENC and S-WAKE and by NASA with a free-flight 737 model
  - Validation using flight test data as it was done in S-WAKE and by NASA
- A 100% validation may be prohibitive as it will be too costly. However, it is feasible to achieve good-enough models as the model validation in S-WAKE has shown.
Validation has to cover models (represented by mathematical algorithms) and their parameters, which depend on aircraft configuration (e.g. flap settings).

A generic validation of the models (wake vortex model and aerodynamic interaction model) has been achieved in S-WAKE at least for aircraft configurations similar to Do228 and Cessna Citation.

An individual validation is required for other specific design configurations, such as swept wing aircraft, propeller aircraft (slip stream effects), etc.

To validate WVE models, it is essential that the wake vortex flow field, which is acting on the encountering aircraft, is measured simultaneously (e.g. by 5-hole probes).

The system identification method by DLR for the validation of WVE simulation models is advocated.

What can we achieve – regarding encounter severity – by investigating WVE in flight tests and what in flight simulations?

- The flight tests in the past were important to gain practical experience with WVEs and to develop adequate models. However they were not sufficient to define adequate separation distances directly. There are too many uncertainties, which cannot be fully measured and the number of tests is limited.
- Systematic investigations of parameter effects can only be achieved in simulations. This requires high quality models.
- If a good visual system is available in a simulator, the ratio of visual cues/motion cues is equivalent to 80%/20% (according to NASA studies).
- In general, motion systems increase the fidelity of flight simulations. However, it is not clear how important the impact of motion on pilot perception and rating of a WVE is. It was also noted that ‘wrong motion’ or bad motion fidelity is worse than ‘no motion’. Also for AP assessment during aircraft development, fixed-base simulators are successfully used to investigate similar problems. S-WAKE investigations gave no clear indication on the impact of motion on the results.
- Due to safety and budget constraints, simulators are the only means to investigate WVE; furthermore, only in simulators the WVE conditions can be controlled.

Hazard criteria: What are appropriate hazard criteria for other flight phases than approach? Is it possible to classify encounters, e.g. by duration, axes of main aircraft response? How?

- Hazard criteria relate objective data (flight data) and subjective data (pilot perception).
- Hazard criteria have to be ‘online’ criteria that assess the current situation (and have knowledge of the past). They can be used in batch simulations to predict pilots’ ratings. Online criteria are opposite to ‘offline’ criteria, which assess encounter severity in post-processing (so they need to know the future). They are less valuable.

All agreed:

- Hazard criteria are absolutely necessary; they are needed for every WVE severity assessment; in the moment, missing (agreed) criteria are the ‘bottle neck’.
- Criteria for the pitch axis (in addition to the existing criteria for the roll axis) and for other flight phases (cruise and take-off) have to be developed – as Airbus does.
- More work on hazard criteria is necessary.
2.9 Moderators’ statements

Claus Cordes: summary
- This workshop, which facilitated discussions between airline pilots, tests pilots, engineers and simulator operators, was highly beneficial.
- The participants learned much; especially the understanding between the groups was significantly improved.
- A WVE reporting system is required.
- Future flight data recorders shall be capable of recording WVE (current recorders lack sufficiently high sample rates); recording and reporting of WVE would lead to further insight into WVE phenomenon.
- Identification of WVE by pilots is not possible; the occurrence of WVE can only be deduced on the basis of certain characteristics after the encounter.
- Models, such as models for the wake vortex velocity profile or the aerodynamic interaction, are the basis of WVE research. They have reached some maturity.
- Hazard criteria are the key of WVE research; therefore, future activities shall be focused on their improvement and development.
- It is suggested to consider WVE during pilot simulator training; hence, recommendations have to be made; simple solutions that cover a great deal of the problem have to be found.
- Improvement of pilot’s knowledge about WVE is recommended because insufficient knowledge leads to fear and prejudices.
- For the future, the growth of air traffic has to be kept in mind; it is important to find an adequate balance between safety and capacity.
- As in the U.S. actually applied separation distances are usually smaller than required by ICAO, i.e. smaller than in Europe; and as air traffic in the U.S. is as safe as in Europe, it is assumed that air traffic capacity is wasted in Europe.

Bram Elsenaar: outlook
This workshop has brought up questions, which should be answered, and suggestions, which should be further investigated. These are as follows:

1. WVE reporting, rating / classification scale for assessing WVE hazard
   Pilot reports should be based on the pilots’ personal experience of the perceived danger. Some kind of ‘rating’ is essential here. In this way reporting schemes will provide information on the actual perceived safety rather than on the statistical occurrence of vortices. The latter cannot be obtained from pilots’ reports (too subjective). What rating / classification is required here and how to incorporate wake vortex reporting in (which?) existing safety / incident reporting schemes?

2. Pilot Questionnaire
   Start a discussion within WakeNet-USA (having the lead) and WakeNet2-Europe, and subsequently with IFALPA and FALPA on objectives and organisation of a pilots questionnaire on wake vortices.

3. Improvement of pilot’s risk awareness
   WakeNet2-Europe (WN2E) could help to provide the necessary information to increase the awareness for pilots with respect to wake vortex risk. However, it is has to be noted
that WN2E does not have sufficient budget to provide extensive assistance. WN2E has to discuss how this can be organised.

Remark: Different options exist: currently WN2E spreads information by organising workshops and writing reports. If more has to be done, WN2E can propose a new EC research project on this issue. It would be a practical research project and would have a different character than previous vortex projects like S-WAKE. For example airline training and authorities (like European pendants of FAA flight standards) could be involved. In the end a bulletin of the authorities, guidance material for pilot training could be the result. WN2E could write a letter to the EC recommending such a project and could explore its chances for success.

4. Hazard Criteria

For definition of new ATC procedures, which have an impact on separation, agreement is necessary on hazard criteria and on the limits, which must not exceeded, Is this agreement possible already today and if not which process is needed to get those limits accepted?

Remark: System safety assessment during aircraft development is an example of such a process: Test pilots have the task and responsibility to assess the effects of system failures (hazards) is assessed in different steps: The first assessment is done by stability and control engineers. If they assume that a system failure has hazardous or catastrophic consequences, it is assessed in the flight simulator by test pilots. Finally, pilots of the authorities check their assessment. In his way, the consequences of each possible system failure (electronic board, actuator, computer, hydraulic power, engine, etc. is assessed.

The necessary actions fulfil these recommendations will be discussed in WakeNet2 Europe and in WakeNet-USA.
3 Recommendations

1. Reporting System
   Reporting of WVEs should become mandatory and a system should be established to collect and analyse pertinent information, such as recorded radar data, atmospheric data, and operational information, including selected flight data recorder data as requested in NTSB recommendation A-94-57. A rating scale that should allow pilots to unambiguously assess the severity of the encounter should be developed. To better understand the scope of the problem and the frequency of WVEs, it is essential to collect more information, for example from a pilot questionnaire as NASA intends or from a systematic, automatic analysis of flight data recordings.

2. Hazard Criteria
   Definition of hazard criteria is essential. They are the key (and currently the bottle neck) for assessing improved procedures for wake vortex avoidance, which guarantee safety without unnecessary negative impact on capacity. More work has to be done in the line of the (finished) S-Wake and (ongoing) Airbus studies (e.g. flight simulator studies, correlation with flight tests) to define hazard criteria. All participants were optimistic that this can be achieved.

3. Pilot Training
   The available knowledge on the wake vortex issue should be included in airline pilot training to improve risk awareness. That means to learn about factors and situations, which make a WVE more probable. Such training can be done in classroom or as computer-based training (CBT) and does not necessarily require a flight simulator. The flight simulator can be used additionally for demonstration of wake vortex effects.
A. Agenda

WVE in flight and in flight simulation

Monday 10 May 2004

9:00 Introduction
  • Welcome (R. Luckner)
  • WakeNet2-Europe, WakeNet-USA, DGLR committees S1.2 and T5 (B. Elsenaar)
  • Introduction of participants and moderators
  • Workshop objectives
  • Literature overview
  • Logistics

9:30 Pilot’s answers to questions regarding ‘piloting’ (75 min)
  • Huson, Sullivan, Graumann, Wolf, Bonnee, Cordes

10:15 WVE in airline operations and flight tests (90 min)
  • D. Sullivan: RJ vs. 747: A case study of a wake encounter
  • W. Huson: WVE experienced in a Fokker 100 test aircraft
  • W. Bonnee: S-WAKE WVE in flight test with NLR’s Cessna Citation

12:45 Pilot questionnaire (45 min)
  • Trujillo: Proposal for a pilot questionnaire on WVE in airline flight

14:30 WVE in flight simulations (75 min)
  • S. Wolf: Flying wake vortex encounters in different flight simulators
  • S. Simon: Wake vortex in flight simulation at Lufthansa Flight Training
  • R. Luckner: Animations of WVEs in flight simulators

16:00 Three working groups
  • How do pilots identify a WVE, what do they perceive as the hazard (Chairman G. Höhne)?
  • What can be expected from a questionnaire on WVE experience that is distributed to a large number of pilots? (Chairman A. Trujillo)
  • Is it necessary to train procedures and/or pilot reaction during a WVE in the simulator? Why (yes or no) and what is needed. (Chairman S. Simon)

17:00 Presentation of working group results, discussion

18:00 End
Tuesday 11 May 2004

9:00  Wake vortex encounter (WVE) simulation  
      (100min)
      • M. Fuhrmann: WVE simulations in S-WAKE and for VESA development
      • J. Crouch: Flight simulator study of airplane encounters with perturbed trailing vortices
      • K.-U. Hahn: Validation of WVE simulation models using flight test data
      • A. Reinke: In-flight simulations of WVEs with ATTAS

10:50  Hazard criteria  
       (70min)
       • R. Luckner: Development of hazard criteria
       • K.-U. Hahn: Investigation of WVE hazard zones on the A330 simulator at TU Berlin
       • G. Höhne: VESA methodology to compare the effects of different vortices on trailing a/c

14:00  Round table discussion
       • How can the WVE simulation be validated?
       • What can we achieve - regarding encounter severity - by investigating WVE in flight tests and what in flight simulations?
       • Hazard criteria: What are appropriate hazard criteria for other flight phases than approach? Is it possible to classify encounters e.g. by duration, axes of main a/c response? How?

15:00  Final Session
       • General discussion
       • Synthesis
       • Dissemination of results

16:00  End of Workshop

Visit of the AIRBUS THOR flight simulator until 18:00
List participants

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<td>Robert Luckner</td>
<td>Airbus-D, Coordinator WakeNet2 Europe, chairman WG5, DGLR committee T5 ‘Flight Mechanics, Guidance and Control’</td>
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<td>11</td>
<td>Anna Trujillo</td>
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<td>Claus Cordes</td>
<td>LH Cargo, DGLR committee S1.2 ‘Flight Operations’</td>
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<td>Bram Elsenaar</td>
<td>NLR, Coordinator WakeNet2 Europe</td>
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C. Answers to questions regarding piloting

1. How often do encounters happen?
   A: In 30 years: 2 encounters, 2003-1996 MD-11, 1996-1973 Fokker 27,28,50,60,70 and 100. One encounter at low altitude that will be presented, Also one washboard ride in the Oceanic Track System
   B: I believe that encounters happen all the time but since there are various levels of intensity, they are not always recognized. Wake in some form exists behind all (most) aircraft. Depending on the size of the trailing aircraft, the encounter may not be significant and therefore not recognized.
   C: Around 15 times to remember within the last 20 years, with about 3 with stronger impact: one during cruise descent (app. Fl 150), two during final approach 4000 ft and approx. 2000ft
   D: I personally can remember 3 encounters, 1 at low altitude
   E: I experienced one ‘real’ encounter and some minor occurrences. I have to add that I am not an airline pilot but a research test pilot at NLR. The said encounter involved a B747 on a crossing track at 3000’ or possibly less (descending to 2000’) intercepting the ILS. We were flying our Fairchild Metro II at 2000’ on a calibration flight of another ILS at night. The encounter was not severe. Moments later ATC mentioned the possibility of encountering the wake.
   F: From my personal experience of 21 years in line flying, I can report an average of one occasion per year, where I encountered a phenomenon that, according to the prevailing circumstances, was likely to be a WVE. Since flying heavy long-range transport aircraft (MD 11) and especially operating at “off-peak”-times (cargo), the number seems to decrease.

2. Are they a surprise or is the pilot mentally prepared?
   A: Even after entering a kind of washboard ride initially the real vortex encounter at low altitude came as a complete surprise in all its intensity.
   A: The experience in the MD-11 behind the B - 747 in the OTS was not a surprise. We had been following that traffic for approximately 3 to 4 hours over the North Atlantic.
   B: If the pilot knows what type of aircraft he is following and how far he is in trail, he can be mentally prepared. In a couple of cases where I have encountered wake, however, it was a surprise because the type aircraft was such that I did not expect it...B737, ERJ.
   C: Always a surprise in the moment, some not especially in cruise
   D: Use all information available (e.g. TCAS) to build a mental picture – use information on preceding traffic and type (by ATC) to determine risk. Best condition for this is VMC. REM: not every a/c especially in the light fraction (i.e. “receiver”) is equipped with the best instruments.
   E: Sometimes you are, sometimes you are not. For us that occasion was a surprise. Although we had the 747 in sight, we probably assumed an altitude difference of at least 1000’ and therefore considered it not a factor.
   F: As long as the pilot has the chance to monitor the traffic situation visually or by technical means (TCAS) plus the overall wind situation, he is aware of a potential encounter, as well as he is able to adjust his flight path within the limits of or in accordance with a granted clearance so as to avoid WVE.
3. Are there typical characteristics, which tell a pilot that a WVE is more likely?
Consider: type of aircraft, phase of flight, geographical location, weather conditions, traffic density, time of day, time of year, type of leading a/c

A: 1) Flying a light or medium aircraft
   2) Close separation in calm wind conditions and stable atmosphere
   3) Some crosswind (how much) [on final]
   4) Time pressure (slot times)

B: Certainly type of aircraft plays a significant role. Winds also have to be taken into consideration and distance behind leading aircraft on approach and departure. If the traffic density is high and departures are leaving with minimum spacing, one would also expect possible WVE’s.

C: Parallel approach with lower intercept regardless of A/C type, knowledge about preceding, enroute visible condensed trail, light crosswind, stable weather condition

D: Special focus on the capacity issue - high-density traffic airport more likely due to tight spacing and time pressure on pilots an ATC controllers. Human factor issue to be discussed (maintain visual separation – complacency in team working together for a couple of days.

E: I fly small aircraft (Metro and Citation), so we are always vulnerable, especially on days with calm weather.

F: In general : yes
A typical situation, that makes it likely to enter wakes is characterised by:
- type of a/c: proceeding is of same kind or heavier
- phase of flight: mainly departure or arrival, as lower separations are applied by ATC
- geogr. loc.: orography may trigger local wind systems, that increase / decrease probability of WVE
- weather cond.: the current crosswind component is the main advice to an impending WVE, thermal upwind may cause an unexpected WVE, strong vertical motions (convection) are believed to shorten vortex life cycle.
- traffic density: although a dense traffic environment principally increases the probability of an WVE, it finally is the relative position to a potential generator a low traffic density, however, offers more possibilities to vary the flight path in order to avoid positions, where an encounter can be expected
- time of day: has an effect in so far, that during daylight and VMC the preceding aircraft, including relevant configuration changes, can be observed, and that a granted clearance “maintain visual separation” very efficiently can help to avoid
- time of year: only in so far, as met-conditions are a function of time of year

4. How did you know it was a wake vortex encounter (WVE)?
A: For both cases: no doubt
Low altitude case was documented and happened on an instrumented aircraft. For the OTS case deviating 1/10th of a Nautical Mile solved the situation confirmed our point of view.
B: Upon entering the actual vortex, the aircraft would roll to the left or right un-commanded and possible climb or descend. This would be a bit more “crisp” than turbulence although WVE’s can be combined with turbulence and be a bit more difficult to define.

C: Special characteristic, smooth air, sudden turbulence or bank onset

D: Basic problem: wake is not visible – mainly assumption and “reconstruction” of the encounter based on traffic situation and environmental parameters (wind, surface heating close to the ground etc)

E: It was a smooth flight up to the moment of the encounter. So it was obvious. In addition ATC made a remark on the possibility of hitting the wake.

F: Thinking to have entered a WV is a conclusion, resulting from the overall weather and traffic situation and the aircraft response.
   Typical aircraft behaviour is either:
   - rolling around the longitudinal axes to bank angles unsuitable with flight phase, either once to one direction or altering
   or
   - an abrupt and short bump in direction of the vertical axes.
   Both reactions have a clear beginning and end.

5. How would you classify WVEs? Why?
   A: No generic answer possible.
      - Range from life threatening to discomfort
      - Cannot see them until now thus more threatening
      - Economically a substantial cause for “unnecessary” delay in take-off sequencing
   
   B: A significant WVE is basically taking control of the aircraft out of the pilot’s hands. Since they cannot be seen and thus avoided, depending on the aircraft’s position, the uncontrolled aircraft may or may not be recoverable...low altitude, etc.

   C: Difficult to tell, question of intensity, possibly there have been more not regarded as WVE

   D: Classification mainly based on pilots perception, so it is subjective. Range will be from “slight disturbance” to active interaction and then loss of control – maybe analogue to turbulence criteria.

   E: Classification [could be] in terms of g-loading and/or roll/pitch/yaw angle. In generally roll angle will be most pronounced. A wake encounter ranges from a situation where g-loading takes place but no control problems (perpendicular encounter with the wake) to a situation where control is the only issue (in trail encounter).

   F: see answer under 6

6. What type of scale would you use to describe WVEs? Define the gradations.
   A: No general answer possible.
      ..- Depends on the type of aircraft you fly yourself
      ..- A wide body crew member has different perception than a light turboprop crew member

   B: It would be hard to assign a scale to a WVE. An encounter by one size aircraft could be completely different than an encounter by a larger or smaller aircraft. A large behind a small may classify an encounter as insignificant whereas a
small behind a large/heavy may classify (or the NTSB may classify) the encounter as catastrophic.

C: One to five ….1. as light turbulence, 2. slight bank onset, 3. as moderate turbulence of short duration, 4. nearly uncontrollable bank onset with more than 20°bank or flight control problems to level wings near ground, 5. uncontrollable

D: No idea – don’t see a chance for this

E: Many factors play a role. It should be a scale based on objective parameters.

F: according to the scale for “normal” turbulence, with which pilots are familiar:
- “light wake turbulence”: only low acceleration(s) felt and no or only low control inputs required to maintain intended flight path or attitude
- “moderate wake turbulence”: reasonable acceleration(s) felt or considerable control inputs required to maintain intended flight path or attitude
- “severe wake turbulence”: strong acceleration(s) felt or full / large control inputs required to maintain control of the aircraft, major deviation from intended flight path occurs
- “aircraft out of control”

7. Which consequences of a wake do you assess when classifying its severity? (e.g. effect on a/c control, work load, passenger comfort, cabin crew and passenger safety. other)

   A: effect on a/c control
cabin crew
   passenger safety

   B: Initially recoverability is the main concern. Passenger safety, crew safety, etc comes as a second thought. Considering passenger and crew safety and comfort, we would have to ensure that we NEVER encountered a WVE.

   C: See above in 6, in addition enroute danger for passengers and cabin crew without seat belts on

   D: The range is from affecting passenger comfort to severe deviation from intended flight path thus affecting flight safety – depends on what your priority is at the given situation

   E: Mainly aircraft control.

   F: The control and the comfort aspect.
   From a pure pilot’s view it is the effect on aircraft control in terms of controllability of attitude and flight path, respectively the efforts to regain intended attitude / flight path.
   From the airline operational view it is passenger and cabin crew (dis)comfort.

8. How can a pilot avoid WVEs? (Anything more than in the FAA circular)

   A: Delay taking off behind a heavy colleague
Avoid landing in tailwind, but if necessary extra vigilance!
Be trained to recognise precursors (washboard ride?)

   B: To absolutely avoid a WVE, one should take a job as an accountant and stay on the ground. But since we are all addicted to flying, we need to insist on more spacing from ATC. Make sure they apply the required FAA spacing on all approaches and departures. Take into account the winds when accepting an approach and do not accept a visual approach, which puts the burden on the pilot to maintain adequate spacing from the leading aircraft unless you can absolutely identify you distance behind the leader and maintain that. Do not
get bullied by ATC to keep your speed up and accommodate aircraft behind you to expedite the ATC system when this would encroach on the proper spacing ahead of you.

C: Clear preplanning, knowledge, weather, TCAS, stay above, avoid visible vortex

D: Prepare mental model, monitor traffic situation and wind. Evaluate conditions at the airport

E: I have no additional rules.

F: No additional comment

9. **What can a pilot do in case of an encounter?**

   A: No general answer possible
   
   Needs a detailed discussion regarding: GROUND CLEARANCE & VERTICAL SPEED

   B: Fly the aircraft. Do whatever it takes to regain control of your aircraft. This procedure will be different every time. Many variables here. Then one needs to report the encounter and this opens up a whole new discussion…reporting of encounters.

   C: Keep wings level with aileron, immediate GA near GND

   D: The questions to be answered in this workshop should be more like: „What must the pilot know / learn / train to handle the aircraft in case of an WVE. Other than that, a go around especially close to the ground is most probably the safest counter-reaction.

   E: Strongly depends on where it happens (altitude main factor).

   F: The pilot’s reaction should depend on the a.m. severity of the WVE and reach from ignoring the airplane’s reaction, via applying correcting flight control inputs to initiation of an escape manoeuvre to leave the suspected area of wake vortex.

10. **Did you observe a relation between flight phase and weather conditions and WVE’s? Which?**

   A: Approach, quiet weather, light cornering tailwind

   B: Too many variables. Winds may be calm on the ground and higher on approach or departure. Winds on the ground may also be from one direction and on the approach, just the opposite. I have noticed this often in St. Louis when landing on the 12’s.

   C: Nearly always smooth air (stable atmosphere) usually no clouds

   D: stable stratification and light crosswind near ground and stable stratus layers with low wind speeds at altitude (e.g. in the TMA)

   E: Approach and calm weather.

   F: My personal experience of the most remarkable encounters is as follows: All in the approach phase established or almost established on the ILS.

   flying B 737: Following a heavy jet in parallel approach into Frankfurt under smooth weather conditions with low advection and convection, aircraft rolled to high left bank angle once, recovery by aileron application, minor deviation from intended flight path

   flying A 321: crossing the flight path of a MD 11 on intercept heading to the ILS, smooth weather with low advection and convection, aircraft experienced strong bump in direction of vertical axes, no application of flight controls, no deviation from flight path, high cabin crew and passenger inconvenience
flying MD 11: following an A 300 in parallel approach to FRA in the vicinity of a heavy shower with moderate, however steady wind, no thermal convection, aircraft rolled to the left, max bank angle about 20 degrees, autopilot was and remained engaged, no deviation from intended flight path.

As it can be expected, the severity increased as aircraft size decreased.

11. Shall WVEs be trained? Why? What are the training requirements?

A: Yes, consider including precursors as triggers  
   “Expect the unexpected” makes you a safer crew  
   Requirements:
   - Mental picture of danger area  
   - Precursor awareness / early escape  
   - Upset recovery & self confidence  
   - Communication / reporting

B: Yes, they should be trained. To what level is the question. Surely they should be trained in the classroom environment to teach the basics of what an encounter is and how to avoid. Also what to do in an encounter situation should be taught in the classroom. The key thing to teach is to AVOID an encounter. It would also be nice (great) to teach the same thing in a flight simulator. My problem with this is, like any other training event in a simulator, you know what is being taught and have learned how the simulator will behave and when the encounter will happen. Therefore, when it does happen you recover as you are taught. In the real world, you are usually caught off guard and each encounter is different which requires a different recovery technique. Bottom line, however, is that we should do training. We just need to fine-tune it to make it better.

C: No training seems to be possible except theoretical knowledge about induction, distribution and development. LH B737 SIM has a vortex induction as a way of disturbance – not more, no training effect, demo only

D: YES – contents of the programme should be theory basics/physics and simulator encounter reaction strategies. Part of it will lead to an “upset recovery/unusual attitude discussion. Proper reaction and the go around commitment will give additional confidence for the aircraft type the pilot is qualified on. Last but not least the introduction of a mandatory reporting scheme should accompany these efforts.

E: Yes, pilots should at least feel what a wake could do to you. It helps crews to be aware.

F: Yes, they shall be trained!

Following matters shall be trained by adequate means:
   - avoidance of WVE by theoretical knowledge of generation and spreading out from the generator,
   - effects on own aircraft,
   - recovery procedures through proper application of flight controls, considering design of flight control system,
   - reporting through use of established reporting schemes.