Aircraft Wake Turbulence
State of the Art
&
Research Needs
2012

F. Holzäpfel (DLR) & A. Reinke (Airbus)
on behalf of the WakeNet3-Europe Team

• Predecessor research needs reports
• Outline of 2012 research needs report
• Review of main research needs indicated

Position Paper (Gerz et al. 2001)

Scope: consolidated European view on the status of knowledge of the nature and characteristics of aircraft wakes and of technical and operational procedures of minimizing and predicting the vortex strength and avoiding wake encounters


previous Research Needs Reports

**Wakenet2-Europe** (2003 – 2006)

**Wake Vortex Research Needs** (Elsenaar et al. 2006)

**Scope:** Part I provides a general overview emphasizing the necessary links between the various themes.

Part II describes for the respective specialists the state of the art in more detail as well as the research needed to better understand various aspects of the problem of wake vortices and means to mitigate its effects.
Wake Vortex Research Needs (Elsenaar et al. 2006)


**Scope:** Consolidated European view on the State of the Art & Research Needs related to aircraft wake turbulence and specifically aiming at operational benefits with regard to safety and capacity

Collection of diverse contributions from the various involved disciplines

Trial to consolidate research needs in order to provide directions for future European research activities
First, non-public version prepared by WakeNet3-Europe partners released towards the European Commission in July 2011.

WN3E Research Needs Report

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Current list of contributors.
WN3E Research Needs Report

WN3E Coordination Areas (2008 view)

- Operational concepts
- Recategorisation
- Capacity analysis

Concepts

- Safety
  - Safety requirements & regulatory framework
  - Safety assessment & metrics
  - Incident monitoring and analysis

- Technologies
  - Operational wake vortex models
  - Wake vortex sensors & advisory systems
  - Weather prediction and monitoring
  - Wake alleviation
  - Encounter mechanisms & simulation

- Safety requirements & regulatory framework
- Regulators
- ANSPs
- Aircraft manufacturers
- Research institutes
- Pilot unions
- Airports & Airlines
- Regulators
- Aircraft manufacturers

Research institutes
Equipment manufacturers
Aircraft manufacturers
WakeNet3-Europe - 4th Major Workshop - 28/29 February 2012 - DFS, Langen, Germany

WN3E Research Needs Report

Structure of WN3E Research Needs Report

**Concepts**
- Operational concepts
- Business case

**Systems**
- Ground-based systems
- Airborne systems

**Safety**
- Safety requirements & regulatory framework
- Safety assessment & metrics
- Incident monitoring and analysis

**Technologies**
- Wake vortex models
- Wind & wake vortex sensors
- Weather prediction and monitoring
- Wake alleviation
- Encounter mechanisms & simulation
- Capacity analysis

WakeNet3-Europe - 4th Major Workshop - 28/29 February 2012 - DFS, Langen, Germany
WN3E Research Needs Report

Overall document structure

1. Introduction
2. Operational Concepts
3. Enabling Systems
4. Technologies and Methodologies
5. Safety
6. Summary
2. Operational Concepts

2.1. Crosswind Operations  P. Choroba (ECTL)

2.2. Time-based Separations  C. Morris (NATS)

2.3. CSPR Procedures  S. Schönhals, M. Steen (TUBs)

2.4. Dynamic Separations  C. Morris (NATS), J-F. Moneuse (Thales), F. Holzäpfel (DLR)

2.5. Re-Categorisation  R. Luckner (TUB)
2. Operational Concepts 

**Research needs highlighted**

- **Support to ATC controllers & pilots** → Link to Systems, Chapter 3.1
  - Definition and assessment of the HMI and ATM component requirements (2.1)
  - Provide the controller with a supporting function (2.3)

- **Wake vortex behaviour modeling** → Link to Technologies, Chapter 4.1
  - WV behaviour analysis [*and validation*] [...] to generate the understanding and the evidence [...] to support the WVE safety arguments (2.4)
  - Impact of wind shear and other effects (such as low level topological effects such as buildings) (2.4)

- **Wake vortex and wind sensors** → Link to Technologies, Chapter 4.2
  - Weather data acquired by airborne measurements (2.3)
WN3E Research Needs Report

2. Operational Concepts

Research needs highlighted

• Weather prediction & monitoring → Link to Technologies, Chapter 4.3
  ‣ Assessment of spatial and temporal stability of the weather conditions (2.1)
  ‣ A stable and reliable prediction of the weather (2.3)

• Wake encounter risk assessment → Link to Safety, Chapter 5.2
  ‣ Assessment of the wake vortex encounter risk associated to the reduction of wake turbulence separations under pre-identified weather conditions (2.1)
  ‣ Validate large and complex encounter models for risk assessment (2.5)

• Wake encounter safety & severity metrics → Link to Safety, Chapter 5.2
  ‣ Safety metrics need to be developed against which to assess the safety analysis results (2.4)
  ‣ Metrics and Criteria for severity assessment (2.5)

• Data collections for validation & development
  ‣ Wake turbulence behaviour measurement data collection in a fully controlled manner (2.4)
2. Operational Concepts

- **Networking & cooperation** → Link to WakeNet
  - Continue the international networking and cooperation between industry, airlines, airports, aircraft manufacturers, suppliers, air navigation service providers, authorities, pilot associations and research. (2.5)

- **Training**
  - Wake vortex awareness and avoidance techniques (2.5)

- **Reporting** → Link to Safety, Chapter 5.3
  - Supplement the current subjective WVE reporting of pilots with more systematic approach for monitoring for WVEs (2.4)

- **Specific flight phases and aircraft**
  - Wake vortex encounters in cruise (2.5)
  - Helicopter wake vortices (2.5)
3. Enabling Systems

3.1. Ground-based systems  J.-F. Moneuse (Thales)

3.2. Airborne systems  A. Reinke, S. Kauertz (Airbus), D. Vechtel, T. Bauer et al. (DLR)
3. Enabling Systems

**Research needs highlighted**

- **Wake vortex and wind sensors** → Link to Technologies, Chapter 4.2
  - Aircraft used as a sensor in the extended TMA (3.1)
  - Airborne, short-range forward-looking air data sensors (3.2)
  - Airborne, mid- to long-range wake vortex sensors (3.2)
  - Online wake characterisation (3.2)

- **Wake vortex behaviour modeling** → Link to Technologies, Chapter 4.1
  - Wake Vortex Model performances (3.1)
  - Operational, probabilistic wake vortex prediction models (3.2)

- **Weather prediction & monitoring** → Link to Technologies, Chapter 4.3
  - Real-time, on-board meteo data fusion (3.2)
3. Enabling Systems

- **Support to ATC controllers & pilots**
  - HMI ergonomic (3.1)
  - Flightdeck alerting and conflict resolution (3.2)

- **Wake encounter risk assessment** → Link to Safety, Chapter 5.2
  - Airborne system treatment in wake turbulence safety assessments (3.1)

- **Alleviation by flight control**
  - Flight control alleviation of wake-induced disturbances (3.2)

- **Integrated concepts**
  - Integrated Weather Hazard solution – Sub-System Interoperability (3.1)
  - New operational concepts with links to wake vortex (SESAR & NextGen) (3.2)
## 4. Technologies and Methodologies

### 4.1. Wake Vortex Behavior Modeling
G. Winckelmans, De Visscher (UCL), F. Holzäpfel (DLR)

### 4.2. Wake Vortex and Wind Sensors
F. Barbaresco, H. Barny (Thales)

### 4.3. Weather Prediction and Monitoring
F. Holzäpfel (DLR), G. Craig (LMU), M. Steiner (NCAR)

### 4.4. Wake Alleviation
E. Coustols (ONERA)

### 4.5. Encounter Mechanisms and Simulation
R. Luckner (TUB), T. Bauer, D. Fischenberg e.a. (DLR)

### 4.6. Capacity Analysis Methods and Metrics
S. Schönhals, M. Steen (TUBs)
4.1. Wake Vortex Behavior Modeling

- "Validation" of the wake vortex models
  - Define the required "validation level" & metrics

- Vortex models and wake vortex encounter studies
  - Wake vortex models in flight simulators → severity assessments, sensor evaluations

- Data collections for validation & development
  - Need of high quality, combined measurement databases (incl. error estimates)
  - Flight experiments
  - Determine vortex core sizes and tangential velocity distributions for real aircraft
4.1. Wake Vortex Behavior Modeling

- Further improvement of the wake vortex behaviour modelling
  - Effects of stable stratification and turbulence on wake vortex behaviour OGE
  - Effects of convective boundary layer on wake vortex behaviour OGE
  - Further improvement of the modelling of wake vortex behaviour NGE/IGE
  - Modelling of the near-wake behaviour
4.1. Wake Vortex Behavior Modeling  

- Miscellaneous  
  - It should be investigated in which limits the classical normalization of wake vortex parameters based on initial vortex spacing and on initial circulation is valid. The question arises in particular when considering wakes generated near the ground.
4.2. Wake Vortex and Wind Sensors

- **Wake-Vortex Monitoring Radar/ LiDAR Simulators Study**
  - Wake-Vortex Radar Cross Section, Reflectivity and Doppler Radar signature in clear-air and rain
  - Wake-Vortex LiDAR signature in humid weather conditions

- **High Power, Low-Cost 3D scanning Radar/ LiDAR Technology study**
  - Electronic scanning X-band Radar Antenna based on Tile Technology
  - High Power 1.5 micron laser source for pulsed LiDAR in Fibered technology

- **Advanced Sensors Processing studies**
  - Doppler Radar Processing for WV Detection, Circulation Retrieval and Wind/EDR assessment
  - Multi-Doppler Radar/LiDAR Processing for wind/EDR retrieval
  - Collaborative/Coordinated Radar/Lidar Sensors 3D Scanning Strategies
  - Upgrade of Primary Surveillance Radar Weather Channel
4.2. Wake Vortex and Wind Sensors

- New standard study for Met Data Down-link by Mode S and ADS-B
  - Study of new ADS-B Data-Link standard for Met Data Down-link at high tempo

- Airborne Forward Looking Lidar study
  - Airborne LiDAR Model study
4.3. Weather Prediction and Monitoring

- Wake vortex and wind sensors → Link to Technologies, Chapter 4.2
  - Provide a consistent weather data base for wake vortex predictions
  - Provision of weather data from aircraft as sensors

- Numerical Weather Prediction
  - Ensemble prediction methods
  - Combination of time-lagged ensembles and spatial ensembles enhanced by data assimilation schemes

- Combined Weather Monitoring and Prediction Systems
  - Various measurements sensors (in-situ, remote, airborne), by nowcasting methods, and by weather prediction models should be determined and compared to guide the selection of the weather monitoring and prediction methods
4.4. Wake Alleviation

Research needs highlighted

- Pursue research to fully understand the mechanisms and efficiency of promising concepts
  - Effects of wing load distributions
  - Active control
  - 4 vortex systems
4.5. Encounter Mechanisms and Simulation Research needs highlighted

- **Wake Vortex Models for flight simulations**
  - Validation plan & validity of models against flight test results

- **Aerodynamic Interaction Models**
  - Validation for swept wing configurations
  - Generic model for fast-time applications
  - Local stall effects (small and slow aircraft in a large vortex)
  - Vortex effects on aircraft sensors
  - Encountering aircraft impact on wake (distortion and deformation)
4.5. Encounter Mechanisms and Simulation Research needs highlighted

- Models of pilot control behaviour
  - Requirements
  - Fidelity and validity of models

- Models for Severity Assessment
  - Which metrics should be considered as a measure of safety?
  - Do subjective pilot severity ratings from flight simulator studies validate severity criteria?

- Flight Simulator Experiments
  - In-flight simulation of wake encounters to allow controlled & realistic experiments
4.6. Capacity Analysis Methods and Metrics **Research needs highlighted**

- **Finding the right capacity metric**
  - E.g. Selected metrics to quantify capacity (e.g. influence of metrics related to payload/passengers)
  - Relation of capacity metric to the aircraft type (payload/passenger)
  - Weighting between arrivals and departures

- **Scheduled capacity increase versus delay reduction**
5. Safety

5.1. Regulation & safety requirements

P. van der Geest, L. Speijker (NLR)

5.2. Safety Assessment

L. Speijker, P. v. d. Geest (NLR), F. Holzäpfel, C. Schwarz (DLR), A. Reinke, S. Kauertz (Airbus), O. Desenfans (M3 Systems), E. Freville (ECTL)

5.3. Incident Monitoring and Analysis

M. Ross (NATS), L. Speijker (NLR), J. Konopka (DFS)
5.1. Regulation and Safety Requirements

- **Answer to the concerns of all stakeholders**
  - Establishing wake vortex encounter safety arguments that will satisfy the concerns of all stakeholders

- **Certification processes for actual implementation of new ground and aircraft wake vortex advisory systems**
  - Unavailability of detailed Acceptable Means of Compliance (AMC) and detailed requirements from regulators regarding the development of associated safety cases.
5.2. Safety Assessment

• Compare the available Safety Assessment models
  ‣ Define a benchmark scenario and apply the various models to conduct a risk assessment for this scenario.
  ‣ Provide a baseline for modelling requirements that would be acceptable as a means of compliance in future approval (or certification) processes.

• Assess the impact of new operational concepts envisaged by SESAR and NextGen
  ‣ 4D-Reference Business Trajectories (RBT)
  ‣ ASAS Self Separation
5.3. Incident Monitoring and Analysis  

Research needs highlighted

- Supplement the current WVE reporting by pilots and controllers with a more systematic approach for monitoring WVEs
  - Human factors research to increase the reporting rate and to improve feedback given to pilots and air traffic controllers reporting wake vortex encounters
  - Develop on-board automatic recording of WVE events in such a way that they can be systematically processed after every flight and collected into a global WVE database
6. Summary

6.1. Comprehensive summary of research needs

F. Holzäpfel (DLR), A. Reinke (Airbus)

6.2. Contribution to Flight Path 2050

6.3. Road map
Summary

• All "traditional" fields of activity have identified research needs to be pursued

• The aircraft as a sensor may answer several needs:
  - Atmospheric measurements
  - Reporting of wake encounters

• Additional data needs to be collected in a concise and controlled manner

• Networking & standardisation need to be continued and fostered

• Missing Acceptable Means of Compliances and Safety Criteria may have replaced technology aspects as the most critical item
Thank you for your attention!