WakeNet3-Europe

Specific Workshop

“Wake Vortex Encounter Severity Criteria”

07 FEB 2012
Institute of Flight Systems
Germany Aerospace Center DLR
Braunschweig, Germany

Synopsis document

Dissemination level: public

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Specific Workshop
Wake Vortex Encounter Severity Criteria

Monday, 06 FEB 2012

19:00 **Social Event – Dinner (Restaurant “Anders”, Am Magnitor 7, Braunschweig)**

Tuesday, 07 FEB 2012

Workshop Agenda

09:20 **Workshop Opening, Welcome and Logistics**

09:35 **Presentation Session**

09:35 **Wake Vortex Encounter Severity Criteria**
CARSTEN SCHWARZ, DENNIS VECHTEL (DLR)

10:20 **Airbus View**
ANDREAS REINKE (AIRBUS)

10:50 **Coffee Break** *(20 min)*

11:10 **Assessment of Wake Vortex Encounter Severity**
ROBERT LUCKNER (TU BERLIN)

11:40 **Wake vortex severity criteria - The search for a single metric: The potential of equivalent roll rate**
PETER VAN DER GEEST (NLR)

12:10 **Discussion Session**

12:10 **„No Encounter“ - Policy 2012 – Thoughts and Ideas from an Email-Brainstorming**
NIKOLAUS BRAUN (ECA) AND ALL

12:35 **Lunch** *(1:15min)*

13:50 **Discussion on next steps towards commonly accepted severity criteria: The WHAT**
“What is needed?” (requirements, applications, levels of severity)
CARSTEN SCHWARZ (DLR) AND ALL

14:30 **Coffee Break** *(20 min)*

14:50 **Discussion on next steps towards commonly accepted severity criteria: The HOW**
“How to get there?” (evaluation parameters, criteria design, threshold identification, validation)
CARSTEN SCHWARZ (DLR) AND ALL

15:30 **Closing Session**

15:30 **Summary & wrap-up**
CARSTEN SCHWARZ (DLR), ANDREAS REINKE (AIRBUS) AND ALL

16:00 **End of Workshop**

WakeNet3-Europe
A network on Aircraft Wake Turbulence

1 Background information and related activities

Note: This background information and the related documents listed (document names in “<…>”) were distributed to the participants before the workshop.

1.1 Previous similar events (with minutes/ documentation available)

Hamburg 2004
10 - 11 MAY 2004 Hamburg (Airbus) WN2E WG5 workshop "WVE in flight and in flight simulation"
(http://wwwe.onecert.fr/projets/WakeNet2-Europe/wg5/agendaWG5May2004.htm)
minutes <Wakenet2-Europe_WG5_Minutes_1st-Workshop_v1.pdf>

Berlin 2006
19 - 21 APRIL 2006 Berlin (TU Berlin, EADS/ Airbus) "Wake Encounter Criteria Work-Shop"
summary <Summary of the Berlin WVE Criteria Work-Shop April 2006 v1.pdf>

Amsterdam 2010
19 NOV 2010 WN3E specific workshop "Wake vortex regulation and safety requirements" (NLR, Amsterdam, http://www.wakenet.eu/index.php?id=172)

1.2 Related documents

Wake vortex pilot policies
IFALPA (July 1998) <IFALPA wake vortex policy.pdf>
Vereinigung Cockpit (Germany, http://www.vcockpit.de/index.php?id=93 > "VC-Policies" > "Policy zur Wirbelschleppenstaffelung"

FAA wake hazard severity matrix development
http://wakenet.eu/fileadmin/user_upload/SpecificWorkshop_WV_EncounterSimulation/2nd_day/Richard_Greenhaw.pdf

draft document "Wake Vortex Encounter Assessment - Literature Overview and Applications"
(based on Part II Section 5.1 and 5.2 of the WakeNet2-Europe Research Needs Document)
This literature overview document could be extended by different contributors, to be discussed (it has a different focus than the corresponding WakeNet3-Europe state-of-the-art and research needs document section 4.5). The idea is to list references comprehensively with a brief description, not to summarise in detail/ evaluate the state-of-the-art. Especially section "2. Applications and Tools" (currently not up to date) could/ should be strongly modified or even removed.
<DLR_IB_111_2012_00_WVE_assessment_Schwarz_v03.doc>

Evaluated piloted wake vortex encounter data overview
This is a list of existing wake encounter data with pilot evaluations (encounters not intended by pilots, i.e. "unexpected" for pilots). This list might be helpful to consider before new piloted trials are planned.
<DLR_IB_111_2012_00_WVE_assessment_Schwarz_v03.doc>

2 Motivation/ focus/ goals of workshop

2.1 Why this workshop on wake encounter severity criteria?

- (still) no commonly accepted severity criteria available, e.g. for differentiation between “acceptable” and “unacceptable” WVEs
- severity criteria important element of any WVE safety assessment
- need for agreement on international level

2.2 Workshop focus

- Focus of workshop was on severity criteria, not on complete safety assessments.
- topics to be considered
  - requirements & target applications
  - classes of severity criteria (a priori vs. a posteriori criteria)
  - associated severity levels
  - flight dynamic evaluation of wake encounters and fundamental parameters
  - criteria design and identification of thresholds
  - validation requirements and means

2.3 Goals

- agreed next steps towards commonly accepted severity criteria, requirements, definitions
- overview on available data, tools/ methods
- create short synopsis document (no minutes) with few consolidated agreed statements

3 Presentations

- Both order and timing of the presentation differed considerably from the planned agenda due to extensive and valuable discussions taking place during the presentations.
- All presentations are on a workshop/ discussion level and are not necessarily distributed publicly.

3.1 Wake Vortex Encounter Severity Criteria (Carsten Schwarz, Dennis Vechtel - DLR)

- Introduction (background, motivation/ focus/ goals, synopsis document, related activities and documents)
- Severity assessment/ criteria general considerations
  - Application types: “a priori” vs. “a posteriori” assessment
  - Evaluation types: subjective vs. objective assessment
  - Possible steps:
    1. survey of quantitative limits applicable for passenger air transport
    2. selection of limit values relevant for wake vortex encounters
    3. development of severity criteria
  - Severity boundaries/ limits: acceptability vs. unacceptability
- Severity Assessment state of the art
  - pilot evaluation rating scales
  - pilot view (IFALPA policy)
  - severity analysis/ assessment activities: analytical studies, offline simulations, pilot-in-the-loop simulations, wind tunnel studies, flight tests

  - severity criteria state of the art
  - vortex deformation: influence not necessarily negligible
  - FAA activities: “Characterizing wake vortex encounters for hazard analysis” for Safety Management System (SMS) purposes and developing models/ analysis tools to determine today’s wake vortex encounter frequency/ intensity (NAS - US National Airspace System)
- Applications/ tools: airspace simulation, encounter assessment, ATM advisory systems
- Available data: evaluated piloted wake vortex encounter data, wake vortex aircraft data
- Conclusions
  - status: no commonly accepted severity criteria available
  - need: agreed next steps towards commonly accepted severity criteria, requirements, definitions
  - to be considered: available data, tools/ methods, applications

3.2 Wake vortex severity criteria - The search for a single metric: The potential of equivalent roll rate (Peter van der Geest - NLR)

- Desirable characteristics of WV severity metric
- What is used today: circulation, rolling moment, RM coefficient, RC ratio, (roll) response
- Metric evaluation: discriminative power, independency, meaningful, computable, absolute, validation
- Proposed (new) metric: Equivalent roll rate. Is a measure for induced rolling moment, but presented in a (physically and easily) understandable quantity. It can be computed with a minimum of information concerning aircraft properties, but yet provides a metric with which aircraft mutually can be compared. Initial research indicates that a single, absolute, criterion discriminates well between acceptable and non-acceptable encounters.
- Example application of equivalent roll rate to RECAT scenario
- Conclusion & Recommendations: equivalent roll rate appears to have very good potential, should be further considered, analysed and validated

3.3 Assessment of Wake Vortex Encounter Severity (Robert Luckner - TU Berlin)

Conclusions:
- Methods and criteria to assess WVE severity have been extensively investigated. They exist and have been demonstrated in research projects.
- Limits that distinguish acceptable and unacceptable encounters have been proposed
- However, an agreed definition of what is acceptable does not exist. Therefore, methods and criteria have not yet been applied in safety assessments of ATC procedures and in rule making; instead indirect measures are used (MTOW, circulation, …).
- FAA has proposed a way ahead on the methodology to develop severity criteria that are accepted by all stakeholders [R. Greenhaw et al. The New FAA Flight Systems Laboratory's Impact on Flight Procedure Design. Paper AIAA 2005-5880, AIAA Modeling and Simulation Technologies Conference and Exhibit, San Francisco, California, 2005.

3.4 Airbus View (Andreas Reinke - Airbus)

- revisiting Airbus presentation from Berlin 2006 workshop, many statements are still true

additional thoughts on severity criteria:
- categories acceptable (“green”)/ reportable (“amber”)/ unacceptable (“red”)

- for evaluation of design changes a posteriori multi-parameter criteria appear essential
- candidate a priori indices:
  - allow variations of all primary wake vortex parameters (circulation, core radius, vortex separation)
  - allow variations of only a few key follower parameters
- roll inertia radius as a measure of follower vulnerability (inversely proportional) is surprisingly constant

3.5 „No Encounter" - Policy 2012 – Thoughts and Ideas from an Email-Brainstorming (Nikolaus Braun - ECA)

- IFALPA PANS-ATM (version April 2011), Policy Statement of 2004: "Wake turbulence separation standards should ensure that aircraft are not exposed to known wake turbulence caused by preceding aircraft (= "No Encounter" Policy)."
- pilot thoughts on encounters:
  - "The clearest dividing line is between no encounter and an encounter."
  - "… not intentionally put our crews and passengers at risk by trying to assign an exact separation number to an inexact natural hazard without better understanding it."
  - "… suggestion for a way forward would be to go along with the existing definitions for turbulence effects (PANS-ATM Appendix 1) … MODERATE (and more) should continue to be avoided."
- pilot thoughts on systems:
  - need for predictive equipment, DFDR analysis, WV reporting
  - reporting is "inadequate", FDR screening "may provide a more accurate baseline"
  - visualisation on "HUD might be a nice option to have", "upgraded DFDR would help"
  - "(…)First steps in this area could be to get rid of Preventive Windshear Detection (PWS) inhibition at higher altitudes."
- Disclaimer: *All (pilot) statements (quoted above) represent individual pilot's views and are not considered as official IFALPA statements!*

3.6 Next Steps Towards Commonly Accepted Severity Criteria (Wayne Bryant - FAA)

Note: FAA was not able to attend this workshop. Presentation slides were provide by FAA but for timing reasons it was not possible to discuss this presentation during the workshop. The presentation was made available to the participants after the workshop.

- An international policy is needed that recognizes wake encounters
  - occur daily
  - are tolerated by stakeholders (pilots & passengers)
  - do not detract from the overall safety of the airspace system
- severity criteria comprising two parts
  - severity metric (a mathematical formulation)
  - specific values of that metric that allow wake encounters to be graded (e.g. correlate with minor, major, hazardous pilot or passenger assessments)
- severity criteria can take more than one formulation (Multi-factor criteria, Eigen axis formulations, Other)
- key points of criteria (based on large data sets)
  - robust in ability to discern wake encounters from other events

  - robust in ability to properly categorize a wake encounter event into agreed-upon groupings
- Simulators are critical in establishing the framework for the severity criteria formulation and define initial values of those severity criteria
  - but there are not enough simulators or simulator time to develop the required large data sets to demonstrate the criteria robustness
  - user community can always challenge simulator findings
  - establishing a baseline of both frequency and severity from flight data is considerably more convincing
- To assess the robustness of candidate metrics, large sets of aircraft digital data are essential
- Two categories of these large data sets are needed
  - A large data set of deliberate wake encounters (to establish the criteria's ability to discern encounters)
  - Operational airspace system digital aircraft data (such as Flight Operational Quality Assurance – FOQA Data) to 'tune' the severity criteria
- The Operational Airspace System flight data can facilitate making the argument that wake encounters occur daily and are tolerated and safe

4. Workshop conclusions - Next steps towards commonly accepted severity criteria

Note: The following statements are generally agreed by the workshop participants either during or after the workshop in the course of the preparation of this synopsis document.

4.1 Next steps towards commonly accepted severity criteria: The WHAT ("What is needed?")

- The following applications are targeted for utilising wake encounter severity assessment:
  - system/ procedure (including separation minima) development (e.g. ATM advisory, onboard warning, avoidance, flight control)
  - safety cases
  - monitoring of operations
- The following requirements apply for severity criteria:
  - authorities will only accept safety cases for specific applications, but not issue general statements on wake encounter severity assessment, existing safety regulatory guidelines (e.g. ESARR) do not include wake encounter specifics
  - evaluation could be relative, but absolute evaluation is important and is desirable
  - several safety cases have been accepted by authorities (using some kind of criteria)
  - for short term applications short term solutions (i.e. less complex) are required, however long term solutions may still be developed
- Properties/ characteristics of severity criteria
  - definition/ properties of the term "criteria":
    - simplification: severity criteria simplify a complex event
    - model: Severity criteria are not necessarily considered to be a model. A model is a representation of a process or object. By contrast criteria allow evaluation or categorisation and comparison on an abstract level.
    - definition of "criterion" [source: merriam-webster.com]:
      - "a standard on which a judgment or decision may be based"

- severity criteria should be reasonably conservative
- severity criteria should be designed in a reasonably simple way/reasonably transparent
- severity criteria should be discriminative (strong relationship between severity and metric)
- severity criteria should be aircraft independent/ possible to determine for numerous aircraft types
- severity criteria should be for absolute assessment (opposed to relative)
- severity criteria should be meaningful, i.e. directly relating to relevant parameters/ effects
- validation of thresholds must be possible
- classes of severity criteria
  - encounter severity application types

    <u>a priori severity assessment</u>
    - severity „prediction“
    - severity assessment before an encounter takes place
    - assessment based on limited data, e.g. estimated vortex strength and position
    - application e.g. for
      - warning and avoidance
      - ATM advisory systems
      - risk analysis with limited level of detail, i.e. without 6 DoF aircraft simulation

    <u>a posteriori severity assessment</u>
    - severity „analysis“
    - severity assessment after a (simulated) encounter takes place
    - assessment based on detailed data including time histories of aircraft parameters
    - application e.g. for
      - piloted simulations
      - offline simulations
      - flight tests
      - FDR/ incident analysis
  - evaluation types

    quantifiable/ measureable and objective evaluation is independent of direct human opinions (pilots, cabin crew, passengers, engineers) and an additional/ complementary assessment in addition to subjective assessment by humans
    - subjective (human ratings)
    - quantifiable/measureable, with limits obtained by convention/ agreement (e.g. sink rate, flight path deviations)
    - objective, with technical/ physical limits (e.g. structural load limits, stall)

- Associated severity levels, types of boundaries/ limits
  - acceptability vs. unacceptability (or safe vs. unsafe)
    - acceptable severity is related to probability, otherwise it is very conservative (undefined probability implies it could occur with a very high probability)
    - a single severity boundary is unlikely to be derived from typically very stochastical human ratings, rather an “acceptability boundary” (bounding the majority of acceptable encounters but not necessarily at the same time bounding the unacceptable ones) and an “unacceptability boundary” (bounding the majority of unacceptable encounters but not necessarily at the same time bounding the acceptable ones) is to be found
  - quantification/ severity levels
    - quantifiable criteria could possibly be applied without a limit, at least for relative evaluation
    - more than one severity boundary is likely to make sense, e.g. 3 levels (2 boundaries)

4.2 Next steps towards commonly accepted severity criteria: The HOW ("How to get there?")

- Pilot views/ policies
  - IFALPA technical manual PANS-ATM (April 2011) section "reduced wake turbulence separation minima"
    - „1.2 Wake turbulence separation standards should ensure that aircraft are not exposed to known wake turbulence caused by preceding aircraft (= "No Encounter" Policy)." (2004)
    - "1.4 IFALPA supports the 1997 US FAA Flight Standards position that no planned penetration of wake vortices of any intensity is permitted." (1998)
  - pilot views/ policies should be considered for future activities/ possible new definitions of severity
  - Analysis of operational limits by operator / airframer
  - Analysis of actual aircraft movement in other conditions (turbulence) as a comparison for WVE scenarios
- Flight dynamic evaluation of wake encounters
  - definitions
    - to be defined: "acceptable"/ "unacceptable" encounter (or safe vs. unsafe)
    - encounter simulation types
      time fixed: wake induced effect on aircraft is imposed based on predefined time histories without influence of actual encounter dynamics, e.g. flight path, control inputs
      space fixed: wake vortex is at a position fixed in space, wake induced effect on aircraft is imposed based on actual aircraft position and attitude in wake flow field
  - relevant encounter scenarios shall be covered
  - relevant flight phases shall be covered
  - appropriate aerodynamic interaction model (AIM) to be selected to represent aircraft reaction
  - wake deformation: influence not necessarily negligible
  - reproducible/ well defined situations mandatory
  - it may be necessary to evaluate wake encounters in combination with other failures (e.g. engine out, control system failures)
  - evaluation
    - numerous wake encounter pilot rating scales exist and should be considered for further piloted tests before developing new ones
    - workload evaluation is mainly subjective
    - workload evaluation with NASA TLX is designed for long term tasks, may be less suitable for wake encounters (too many increments)
    - for subjective evaluation large data bases are required
- Fundamental wake encounter evaluation criteria/ parameters (subjective/ quantitative)
  - roll control ratio RCR
  - equivalent roll rate
  - wake induced rolling moment coefficient
  - static/ equivalent roll acceleration
  - roll response (i.e. bank attitude)
  - note: parameters only related to wake generating aircraft/ wake vortices, like MTOW, vortex strength/ circulation do not directly describe wake encounters
- Criteria design and identification of thresholds
  - derivation of criteria could be based on today's situation (ICAO rules) which are considered to be safe for the existing traffic mix, proven by decades of operations

  - for bank angle limits is has to be distinguished between coordinated turns and turbulence encounters
  - Possible steps (DLR view):
    1. survey of quantitative limits applicable for passenger air transport (flight phase dependent)
    2. selection of parameters and limit values relevant for wake vortex encounters
    3. development of severity criteria, containing the relevant limits from step 2, i.e. not violating the severity criteria ensures not to violate any of the relevant limits from step 2
  - Possible steps (TU Berlin view):
    1. combined evaluation of piloted WVE data, manual/ procedure information, literature references
    2. selection of metrics and envelope limits
    3. criteria validation
    4. derive severity criteria model
- Validation requirements and means
  - large data base of piloted trials with defined scenario (e.g. simulations) required
    - large data sets of evaluated piloted wake vortex encounter data are existing, e.g. EU S-Wake 1600+ WVE, EU CREDOS 1200+ WVE, DLR Wake Vortex II 100+ WVE, DLR Weather and Flying 200+ WVE
  - large data base of operational/ real world data required

4.3 Final conclusions

Future research activities towards commonly accepted wake vortex encounter severity criteria are encouraged. Revisiting what has been done and is already available is recommended.

For the application of wake vortex encounter severity criteria the following is required:
- involvement of all stakeholders
- a road map that describes the procedure for criteria development and validation (possibly based on considerations like in this document, section 4) as well as the required data for validation

Experience shows that research results may not be applied in rule making and certification otherwise. Therefore, the commitment of all stakeholders, especially the regulators, is essential for this approach.

The objective to develop commonly accepted wake vortex encounter severity criteria should be part of the future EC framework programmes in order to advance European know-how.

5. Abbreviations

AIAA	American Institute of Aeronautics and Astronautics
AIM	aerodynamic interaction model
ATC	air traffic control
ATM	air traffic management
CREDOS	Crosswind - Reduced Separations for Departure Operations (EU FP7 project)
DFDR	digital flight data recorder
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)

DoF	degree(s) of freedom
FOQA	flight operational quality assurance (data)
ECA	European Cockpit Association
ESARR	Eurocontrol Safety Regulatory Requirement
FAA	Federal Aviation Administration
FDR	flight data recorder
HUD	head-up display
ICAO	International Civil Aviation Organisation
IFALPA	International Federation of Air Line Pilot’s Associations
NLR	Nationaal Lucht- en Ruimtevaartlaboratorium
MTOW	maximum takeoff weight
PANS ATM	Procedures For Air Navigation Services Air Traffic Management
RCR	roll control ratio
RECAT	wake turbulence re-categorisation activities
TU	technical university
VC	Vereinigung Cockpit (German Cockpit Association)
VCockpit	Vereinigung Cockpit (German Cockpit Association)
WN2E	WakeNet2-Europe (EU FP6 coordination action)
WN3E	WakeNet3-Europe (EU FP7 coordination action)
WV	wake vortex
WVE	wake vortex encounter