WakeVAS: Wake Vortex Avoidance System

The Importance of EDR in An Operational Scenario

EDR Workshop
DLR Oberpfaffenhofen
February 17 - 18, 2004

Wayne H. Bryant
NASA Langley Research Center

Background

- All aircraft produce trailing wake vortices
- Heavy aircraft vortices are hazardous to lighter aircraft
- ATC procedures protect following aircraft by providing more space behind heavier aircraft
Problem Description

- Wake Vortex Encounter Hazard is the Primary reason for Required aircraft separation in excess of 90 Seconds for Heavy leading Small Aircraft

- Problem has a Major impact on Airport Capacity at Large Hub Airports
  - Increasing Mixture of Heavy and Small Commuter Planes
  - IMC for 15-20 % of Operations
  - Network Effects Propagate Delays System Wide under ALL Weather Conditions

An Opportunity to Change the Existing Wake Vortex Separation Philosophy

- Existing wake separation rules are *static*
  - Based on Limited Empirical Observations
  - Represent a response to worst-case persistence of wake hazard

- Over 30 years of wake research have produced the potential for a dramatic increase in knowledge about the persistence of wake hazard
  - New Data and Technologies demonstrated in both European and NASA Programs

- Introduction of systems and procedures that utilize this improved knowledge of wake hazard durations could allow for *Increases in Capacity at a Specified Level of Safety!*
**WakeVAS Vision**

Enable the increase of capacity with no decrease in safety for the International Airspace System in the terminal area through new, internationally-agreed upon standards for wake vortex operations (modify ICAO SARPs - Standards and Recommended Practices).

**Project Goal**

- Develop the Field Test Data and Analysis Required to:
  - Safely Change the ICAO Definitions for WV Separations Standards
  - Provide the Systems Engineering Data Necessary for the FAA to make a Favorable Acquisition Investment Decision for Full Scale Development of an Aircraft Wake Vortex Avoidance System
1. Establish the need for change to existing wake vortex standards

2. Develop Detailed WakeVAS ConOps, Operational Requirements, and Systems Specifications & Analyze Impact to Existing Standards and Regulations

3. Develop & Evolve Active Wake Vortex Predictor (AVOSS+) to meet ConOps Operational Requirements

4. Deploy WakeVAS, Collect Long-term In-Service Data, and Assess Performance

5. Conduct and Articulate Safety Analysis/Risk Assessment

6. Manage the project/collaborate with national & international partners

**WakeVAS Key Elements**

- Weather Subsystem
  - Weather sensors to measure wind and wind stability along track
    - Wind profiler
    - Aircraft-based wind, temperature and turbulence data
- Aircraft Information Subsystem
  - Aircraft type and position tracking
- Vortex Tracking Subsystem
  - Vortex tracking systems
    - Measurement and monitoring at stabilized approach point and between runways
- Predictive algorithms and alerting criteria
  - Controller display interface

**3. Develop & Evolve Active Wake Vortex Predictor (AVOSS+)**
3. Develop & Evolve Active Wake Vortex Predictor (AVOSS+) - Weather Subsystem

- Creating a robust Weather Subsystem is key part a viable WakeVAS
- Need to coordinate closely with FAA and International partners (e.g., ATC-Wake, WakeNet2-Europe, SWake2, I-Wake... )
- May need to extend Nowcasting weather predictions to 2 hours or more (30 minutes demonstrated at DFW)
- Better knowledge of Eddy Dissipation Rate is key to predicting wake vortex demise - EDR Accuracy Must Be Driven by Operational Requirements
- Actual Weather Subsystem requirements will be driven by safety and benefits analyses and by ConOps requirements

3. Develop & Evolve Active Wake Vortex Predictor (AVOSS+) - Wake Predictor

- “Tune” wake predictor parameters to meet performance requirements identified by ConOps, Safety, and Benefits Interactions
- Extend point estimate wake predictor used at DFW to realize probabilistic wake estimation
- May use aircraft-measured winds and other data on approach & departure to improve wake predictions
3. Develop & Evolve Active Wake Vortex Predictor (AVOSS+) - Wake Detection Subsystem

For the foreseeable future, a “Safety Net” will be required for any active wake vortex prediction system.

- IFALPA Policy Statement
  - Current solution is to directly detect vortex and compare with predictions.

Use an effective, fair, and accurate down-select mechanism for “best” sensor(s) complement:

- Performance (detect, track, quantify vortex strength)
- Cost, size, reliability, maintainability, etc.
- Others…

Candidate Sensors

- 35 GHz Radar
- SOCRATES (Acoustic)
- Lidar (Single Pulse, Double Pulse, CW)
- Sodar
- Wind Line
- RASS
- UHF Profilers
- Met Towers
- TDWR
- Satellite wind shear sensors
- Aircraft based weather sensors

3. Develop & Evolve Active Wake Vortex Predictor (AVOSS+) - ATC Interfaces

- AVOSS at DFW had no ATC Interface
- Preliminary design of “Nominal/Wake Vortex Separation” ATC interface under consideration
- Controller interface seems very likely
- Pilot interface, particularly wake vortex info presented in flight deck, is not so clear
- Much work is required in this area to convince users (Pilots and Controllers) that system is safe and effective
NASA Interest in Eddy Dissipation Rate

- Key parameter in wake demise prediction in AVOSS Prediction Algorithm (APA)

- One of two atmospheric turbulence measurements used by European VFS (EDR & TKE); Also used by P2P

- It is clear that the US will strongly favor the use of APA and Europe will strongly favor the use of VFS and/or P2P in Wake Vortex Avoidance systems

- ICAO wake separation standards changes will not likely occur without US/European agreement on wake predictor performance standards

---

NASA Interest in Eddy Dissipation Rate

- Turbulence estimate quality should be based on ConOPS operational requirements - fully meeting overall systems requirements
  - But what is the value in exceeding the performance requirements?
  - Do we know how well these estimates need be made?
  - What do we need to do to define the actual level of accuracy of these measurements?
  - How can we implement required atmospheric turbulence measurements in an operational system for a specific Concept of Operations?

- Desired outcome from this workshop
  - International agreement on any remaining research issues with regard to the use of EDR in a wake vortex prediction algorithm
  - Agreement on viable concepts to derive EDR for operational systems using currently favored wake predictors
Project Approach - 1

- Collaborate with FAA and the European technical community to facilitate transition to the NAS and leverage on international investments for wake vortex solutions
  - WakeNet-USA led by NASA/FAA with industry partners from NATCA, ALPA, APA, ATA, ACI, Boeing ATM, Boeing commercial, CTI, …
    - Provides frequent peer review of activities focused on implementing wake vortex solutions
  - EUROCONTROL/FAA/NASA R&D committee (plan for WV R&D)
  - Wakenet2-Europe membership
    - Provides forum for exchange of concepts, data. Leverages U.S. And European investments in wake vortex R&D. Provides means to build consensus for ICAO recommendations.

Project Approach - 2

- Employ a Structured, Spiral Systems Engineering Process
  - Develop a Viable Concept of Operations
  - Obtain Sufficient Experimental Data to Perform an Adequate Safety Analysis
  - Develop an Affordable set of System Requirements and Specifications
**NASA/FAA Collaboration**

NASA uses a Phased Approach to Reduce Risk and Maximize the Probability of Transition to the FAA

- FAA is conducting a Phase I Data Driven Program to implement ATC Procedural Changes Only
- NASA is participating in Phase I FAA Program as an Observer in All FAA activities and is using FAA collected data for Initial CONOPS Development, Initial Safety Analysis, and Wake Predictor Evolution
- NASA plan has Two Phases of increasing complexity:
  - Weather Dependent Procedures without safe aircraft-pair time estimates (Jointly with the FAA)
    - Phase II A Departures; II B Arrivals
  - Operational Separation Based upon Safe Time Separation Predictions (NASA led)
    - Phase III A Departures; III B Arrivals

**Wake Conops Evaluation Team: Goals**

Maximize the effectiveness of the FAA/NASA Wake Program, by focusing resources on:

1. Developing concepts of operations (Conops), including functional systems requirements, that will meet FAA and stakeholder safety requirements; and
2. Providing answers through the NASA research program to the safety questions of all decision makers who must approve or accept any wake-related policy or procedure change based on their conclusion that it maintains or improves safety.
Wake Conops Evaluation Team: Objectives

- Identify research issues of decision makers who must make safety findings, a plan for collecting and analyzing supporting data, and an appropriate risk analysis methodology.
- Analyze paired Conops and functional systems to achieve Wake Program phased objectives.
- Rank the Conops that appear to be able to meet safety requirements.
- Define the functional system requirements and procedures necessary for safety.
- Record transition and implementation issues.

WTRMP Wake Capability Enhancements

- **Phase I. Near Term: 2003 + 2 – 3 yrs (Procedures Changes)**
  - A. Arrivals, CSPR, <2500 ft (1000 ft?) static, 1.5 NM diag. dep. Lrg. lead
  - B. Arrivals, Ph. I A with staggered thresholds

- **Phase II. Mid-Term: 3 – 7 yrs (Procedures Changes and Ground Systems)**
  - A. Departures
    - Candidate Operational Enhancement (COE) 1: CSPR, static, <2500 ft (1000?)
    - COE 2: CSPR, <2500 ft, dynamic, cross-wind sense & prediction
    - COE 3: 1-Rwy, <2-3 minutes, dynamic, cross-wind sense & prediction
  - B. Arrivals
    - COE 1: CSPR <2500 dynamic, cross-wind sense & prediction

- **Phase III. Far-Term: 7 – 10 yrs (Procedures Changes, Ground and/or Air Systems)**
  - A. Departures
  - B. Arrivals
    - COE 1: CSPR, <2500, dynamic, weather sense & prediction
    - COE 2: 1-Rwy, dynamic, weather sense & prediction
  - C. Arrivals, Departures, & Intersections
    - COE 1: Turbulence prediction for wake demise

Note: Phase II “Dynamic” COEs involve simpler, wind sensing and persistence-forecast wind - wake predictions; Phase III involves more complex weather sensing and longer-term weather and wake predictions.
Analysis Schedule

1. 7/15 – 9/25: Baseline CSPR 1000’ CL Arrivals
3. 11/18 – 12/9: Baseline 1-Rwy Departure
5. 4/15 -- 6/15: Phase III -- B -- 1 or 2
6. 6/15 – 8/15: TBD
7. 8/15 – 10/15: Down select analysis & recommendations
8. 10/15 – 11/15: Finalize all Reports

Candidate Phase III System CONOP

- Aircraft Meteorological & State Data
  - Sensor Data Fusing Algorithm
  - Wake Prediction Algorithm
  - Terminal Weather Predictor
- NWS Data
- Wake Hazard Computations
- Safety Monitor
- Protected Airspace Definition
- Airport Wake and Weather Sensor Suite
- Controller Tool
WakeVAS FOQA Processing

- Final products from proposed FOQA processing are statistical averages of wind speed & direction, Eddy Dissipation Rate (EDR) and static temperature variations with altitude.

- Aggregate meteorological data output.

- De-identified aircraft data as input.

- Require multiple approach and departures, closely spaced in time to produce good average variations with height.

WakeVAS FOQA Processing

**Desired Parameter List**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Sideslip</td>
</tr>
<tr>
<td>Weight</td>
<td>Wind speed</td>
</tr>
<tr>
<td>Baro. Altitude or Pressure Altitude</td>
<td>Wind direction</td>
</tr>
<tr>
<td>True airspeed (Left &amp; Right Computers)</td>
<td>Static temperature</td>
</tr>
<tr>
<td>Longitudinal body acceleration, (a_l)</td>
<td>Radio Altitude</td>
</tr>
<tr>
<td>Lateral body acceleration, (a_y)</td>
<td>Mach Number (Left &amp; Right Computers)</td>
</tr>
<tr>
<td>Normal body acceleration, (a_n)</td>
<td>IRU Latitude</td>
</tr>
<tr>
<td>Heading angle, True, (\theta)</td>
<td>IRU Longitude</td>
</tr>
<tr>
<td>Heading angle, Magnetic, (\psi)</td>
<td>Track Angle</td>
</tr>
<tr>
<td>Roll angle, (\phi)</td>
<td>North/South Inertial Velocity</td>
</tr>
<tr>
<td>Pitch angle, (\theta)</td>
<td>East/West Inertial Velocity</td>
</tr>
<tr>
<td>Groundspeed</td>
<td>Flap Deflection Angle</td>
</tr>
<tr>
<td>Inertial vertical speed</td>
<td>Body Pitch Rate</td>
</tr>
<tr>
<td>Angle of attack (Left &amp; Right Computers)</td>
<td>Computed Airspeed (Left &amp; Right Computers)</td>
</tr>
<tr>
<td></td>
<td><em>(If true airspeed is not available)</em></td>
</tr>
</tbody>
</table>

The above constitutes a “wish list”. Some of these parameters are not available on some aircraft, and the update rates may vary from aircraft to aircraft (depending on the recording system). It is preferable to get as many of these parameters at as high a data rate as possible.
WakeVAS FOQA Processing

Sample Result

**Summary**

- **Regulation Change Requirements**
  - Develop Consensus on Wake Hazard Definition and Target Level of Safety Desired
  - Amend Current wake separation rules to incorporate Dynamic, Weather-Dependent Spacing

- **System Development Requirements**
  - Standards for aircraft weather data and data links
  - Wake and weather sensor maturation
  - Closed-Loop, probabilistic wake predictor design/
    Experimental Prototype System (EPS) Development
  - Human Interface design/EPS Demonstration