Wake Turbulence: Managing Safety and Capacity

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Outline

- What’s the problem?
- Present ruling
- Possible changes and benefits
- How to balance safety and capacity?
- Prepare for change: European sponsored research and the role of the Thematic Network WakeNet2-Europe
What’s the problem?

- Flying aircraft generate a wake of two counter rotating vortices (like horizontal ‘tornado’s’)
  - their initial strength depends roughly on the lift and wing span
  - they are transported by the wind
  - they normally descend but may stall or rebound for specific atmospheric conditions and near the ground
  - they decay mostly due to atmospheric turbulence but persist for long time in quiet weather

- When a following aircraft enters a wake, it may result in a severe upset (bank-angle, sink rate)

- Hence ICAO has made rules that prescribe the minimum separation distances

- These rules put a limit to airport capacity
Wake vortex visualised by smoke
(‘IDAHO Falls’ campaign; courtesy NASA)
Present (ICAO) ruling (simplified)

- For VFR conditions separation is determined by the pilot / air traffic controller with the ‘runway occupancy time’ (ROT) as a minimum.

- For IFR conditions separation distances are prescribed by the ATC controller applying rules based on aircraft weight categories for leading and follower aircraft.

- Closely spaced parallel runways (CSPR) are treated as a single runway for separation distances when the runways are less than 2500 ft apart.
ICAO’s weight class dependent separation criteria

- **Heavy** aircraft (> 136 t)
- **Medium** aircraft (7 - 136 t)
- **Small/Light** aircraft (< 7 t)

**Leading aircraft** followed by:

- Heavy: No vortex-related separation
- Medium: Separation criteria
- Small: Separation criteria

Separation, miles:

- Heavy: 3 miles
- Medium: 4 miles
- Small: 5 miles

Aircraft types:

- B747
- A320
- DHC-8
Wake turbulence as loss-of-control factor: many reported incidents

(Boeing: in Aviation Week, August 2002)
But wake turbulence is very rarely the cause of accidents

\textit{(ATM related accident rate's from NLR Aviation Safety Data Base)}
Experience with the present (ICAO or national) separation rules

- There are regular incident reports of wake vortex encounters, mostly non-hazardous

- There are very few wake vortex induced accidents and they occur almost exclusively for VFR conditions

- Occasionally incident reports are filed for encounters beyond the ‘safe separation distances’ e.g. for very quiet weather conditions with a weak tail wind

Present separation distances are safe, possibly too conservative but not always; weather conditions are critical!
Considering a change in the current practice

- Would it be possible to reduce separation distances (by rule change, depending on the weather conditions), while still maintaining the present level of safety?

- Possible benefits are two-fold:
  - **tactical:**
    - reducing delays (whenever they occur) when the weather allows reduced separation distances
  - **strategic:**
    - increasing the declared airport capacity (number of slots / hour)
From simple to complex changes

- **Examples of ‘simple’ (rule) changes**
  - reduce the 2500 ft limit for closely space parallel runways to e.g. 1000 ft for smaller aircraft
  - apply a time based instead of a distance based separation criterion

- **Examples of more complex changes:**
  - weather dependent departures (using weather now-casting)
  - make the separation distances for closely spaced parallel runways dependent on the magnitude and direction of the cross-wind
  - make the single runway separation distances dependent on weather conditions (‘dynamic spacing’)

Wake Turbulence: Aviation Safety and Security Conference, 10-11 November 2004
Example (1): Wake turbulence mitigation for closely spaced parallel runway’s with displaced threshold’s as applied at Frankfort Airport (HALS/DTOP)
Example (2): 2 Modes of Operation (ICAO / ATC-Wake) depending on weather (from European ATC-wake program)

Brussels - 25 L / 25 R

\[
\begin{array}{l}
17:10 \\
14:30 \\
11:50 \\
08:20 \\
07:29 \\
\hline
\text{ATC WAKE} & \text{Arrivals: 2.5 NM} & \text{Departures: 90 s} \\
\text{ICAO} & \text{Arrivals: 2.8 NM} & \text{Departures: 100 s} \\
\text{ATC WAKE} & \text{Mode transition at 07:40} \\
\end{array}
\]

HMI for the Approach Controller
Wake Vortex Vector on Radar Display
Benefits: some numbers

- EU estimates: Air Traffic Delays cost **62 € per minute**; total costs in 2002: 700 M€ - 1000 M€ (from EUROCONTROL Performance Review Report 6)

- NASA study on Dallas/Fort Worth airport (independent runways) indicates **8% capacity increase** for weather dependent Wake Vortex Warning System

- US Business Case Study indicates very favourable **cost / benefit ratio’s** for CSPR situations (sometimes as high as **order of 100**).
Example of runway capacity change due to change from VFR (VMC) to IFR (IMC) conditions (taken from LMI Business case analysis report)

Relates to Cleveland Airport: departures and arrivals / hour

Left: base line for IFF (IMC1 & IMC2) and VFR (VMC1 & VMC2) conditions

Right: effect of Wake vortex advisory system (WVAS)
Example of reduction of delays (minutes per flight on the average) due to wake vortex advisory system (taken from LMI Business case analysis report)

Total airspace including 18 Airports, based on 2005 demand

Blue: Base line

Red: Weather dependent wake vortex advisory system (WVAS)

Ivory: good weather conditions (VFR only)
The playing ground and the actors

- Airport situation
  - (runway layout, route structure, weather conditions)
- Complexity
- Safety
- Capacity

Regulations (assessment, on-line monitoring, incident reporting)
Balancing safety and capacity

- In Europe ESARR4 sets requirements for safety assessment (‘targeted level of safety’ approach)

- wake encounters are very rare events, strongly weather dependent: a probabilistic safety assessment is required

- in European research programs building blocks for such a safety assessment are developed and being refined e.g.
  - wake vortex characterisation including weather effects
  - research to define criteria for severe and non-sever encounters

- for validation of risk assessment methodologies incident reporting is essential

- Real-time and fast-time simulations required to assess the safety of the integrated system
Example of probabilistic wake and encounter modelling (WAVIR, NLR contribution to European S-Wake Program)

- provides a risk number to be compared with a TLS (target level of safety) approach
- tries to model the real world as truthful as possible (ongoing activity)
- compares A/C response resulting from an encounter in the framework of an ‘encounter severity classification’
- calculates the probability of a (catastrophic, hazardous, major, minor) accident / incident in the framework of a ‘risk event classification’
- to be compared with a target level of safety (TLS)
Probabilistic Wake Vortex Evolution Modelling

Vortices generated by a large jumbo jet at 2000m before THR, encountered by a Regional jet at 2000m with 3NM prescribed separation. Elapsed time at encounter 78s, 62% of vortices alive.

Crosswind 0m/s, headwind 0m/s, LAC1_WC0_x5_FAC4_sd3NM_headwind0mpe
## Risk assessment of conflict scenarios

- Interviews with operational experts on the basis of identified conflict scenarios.
- Assess applicable severity classes of conflict scenarios.
- Assess frequency of occurrence for each severity class and evaluate risk tolerability.

### Severity Frequency

<table>
<thead>
<tr>
<th>Severity Frequency</th>
<th>ACCIDENT</th>
<th>SERIOUS INCIDENT</th>
<th>MAJOR INCIDENT</th>
<th>SIGNIFICANT INCIDENT</th>
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<tbody>
<tr>
<td>PROBABLE $&gt;10^{-5}$</td>
<td>UNACCEPTABLE</td>
<td>UNACCEPTABLE</td>
<td>UNACCEPTABLE</td>
<td>TOLERABLE</td>
</tr>
<tr>
<td>REMOTE $10^{-7}$ - $10^{-5}$</td>
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<td>UNACCEPTABLE</td>
<td>TOLERABLE</td>
<td>NEGLIGIBLE</td>
</tr>
<tr>
<td>EXTREMELY REMOTE $10^{-9}$ - $10^{-7}$</td>
<td>UNACCEPTABLE</td>
<td>TOLERABLE</td>
<td>NEGLIGIBLE</td>
<td>NEGLIGIBLE</td>
</tr>
<tr>
<td>EXTREMELY IMPROBABLE $\leq 10^{-9}$</td>
<td>TOLERABLE</td>
<td>NEGLIGIBLE</td>
<td>NEGLIGIBLE</td>
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</tr>
</tbody>
</table>
Encounter severity classification
Results from Monte Carlo simulations
(NLR contribution to European S-wake program)

Bank angle versus loss of height / encounter altitude is used as wake encounter severity metric
Example of risk assessment for a B737 behind a B747 in ‘average’ weather conditions (NLR contribution to European S-wake program)
Safety assessment and validation are required for introduction of new systems and procedures
Research on aircraft based wake vortex detection
(European I-Wake program)

(1) Aircraft ahead: naturally generates wakes and trailing vortices

(2) Shots are made at several known distances from aircraft to obtain “slices” of airmass velocity

(3) Aircraft follows. Receives information on the wake position in the cockpit
Mr Airport Capacity: can you give me some _safe_ advice?

\[ \bar{u}(\bar{x}; t) = \sum_p \frac{\Gamma_p(t) \bar{k} \times (\bar{x} - \bar{Z}_p)}{2\pi \left( |\bar{x} - \bar{Z}_p|^2 + \varepsilon^2 \right)^2} \left( |\bar{x} - \bar{Z}_p|^2 + 2\varepsilon^2 \right) \]
The role of WakeNet2-Europe

- Balancing Safety and Capacity for wake turbulence is complicated and requires research and development involving many different disciplines.

- The European commission is supporting several European projects that deal with aspects of wake turbulence.

- WakeNet2-Europe is a European sponsored Thematic Network to promote contacts and information exchange between specialists and end-users in the operational airport environment.
European wake vortex related programs

- S-WAKE: wake characterization
  - safety assessment

- C-WAKE: on board detection
  - near field vortex

- M-FLAME: encounter modeling
  - on board detection

- WAVENC: minimizing by design
  - ATM implementation

- AWIATOR: on board detection
  - ATM implementation

- I-WAKE: on board detection

- ATC-WAKE: Fundamental aspects
  - ATM implementation

- FAR-WAKE: Fundamental aspects

- EUROWAKE: near field vortex

- WakeNet: STILL ACTIVE

- WakeNet 2 - Europe: STILL ACTIVE

- WakeNet - USA: STILL ACTIVE
Relation with FAA-Eurocontrol Action Plan 14

AIR TRANSPORTATION SYSTEM

Wake Vortex Issues

FAA-EUROCONTROL R&D: ACTION PLAN 14

EUROCONTROL

FAA/NASA

Requests information

Assessment of state of the art

WakeNet2 Europe Focal point

Information exchange, activities

WakeNet USA focal point

Wake Vortex Research Community
Thanks to all WakeNet2-Europe partners

- NLR (co-ordinator)
- IFALPA (Vereinigung Cockpit)
- DLR
- THALES-AVIONICS
- DFS
- UCL
- NATS En-route Ltd
- EUROCONTROL
- AIRBUS (dep co-ordinator)
- UK MetOffice
- QinetiQ
- ONERA

...... and to WakeNet-USA (FAA / NASA)!

WakeNet2-Europe is sponsored by the European Commision
and

THANK YOU

for more information see the WebSite

http://wwwe.onecert.fr/projets/WakeNet2-Europe