WakeNet3-Europe

Evaluation of wake encounter flight tests in support of defining safe A380 separations

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Presentation outline

• Background & Introduction

• Direct Wake Impact Method (DWIM)

• Summary & Outlook
Background & Introduction

During 2005 - 2010, Airbus has conducted more than 1,400 real wake vortex encounters in flight trials

- various generator aircraft (A380, B747, A340)
- various encountering aircraft (A380, A340, A300, A320, A318)
- conditions representative of cruise flight as well as approach

This is the *largest campaign ever* conducted to investigate all aspects of the wake vortex characteristics

- to establish safe separation minima for A380 operations
- to advance knowledge of the wake turbulence phenomenon, aiming at reducing separations when safe to do so
Background & Introduction

• The wake vortex encounter hazard chain
  • Complex chain of events with many influencing factors

CAUSE
  Generator aircraft
  Initial, rolled-up wake
  Evolved wake
  Wake impact
  Aircraft reaction
  Hazard

CONSEQUENCE
  Creation & roll-up
    • Air speed
    • Air density
    • Configuration / lift distribution
  Evolution
    • Atmospheric turbulence
    • Stratification
    • Ground effect
  Encounter
    • Encounter geometry
    • Wake / aircraft interaction
    • Aircraft size
  Reaction
    • Pilot / AP reaction (Flight control system)
    • Aircraft inertia
    • Aircraft aerodynamics
  Situation
    • Height above ground
    • Configuration
    • Air speed

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Background & Introduction


- Relative safety assessment versus Heavy (B744, B773) reference aircraft

  - Primarily based on vortex circulation measured by LiDAR
Background & Introduction


- ICAO recommendation to add 2 NM separations behind A380 approach operations for Heavy, Medium and Light follower aircraft compared to other Heavy leader aircraft

- Today's strange situation:
  - A light aircraft can fly 6 NM behind a B747
  - A B747 has to remain 6 NM behind the A380

- First encounter flight tests have been performed by Airbus in 2006 (cruise) and 2007 (approach). Raw upset data and pilots impression showed no difference between A380 and A340-600 at equal separation distances ...
Background & Introduction

• Updated A380 Wake Vortex Safety Case (expected 2012)

• Relative safety assessment versus Heavy (A346) reference aircraft

• Primarily based on measured wake impact from encounter flight tests
Direct Wake Impact Method (DWIM)

• In order to measure wake impact from encounter flight tests, Airbus has developed the Direct Wake Impact Method.

• DWIM derives forces & moments impacting the encountering aircraft.

... and which are a direct result of the wake encounter.
Direct Wake Impact Method (DWIM)

- If an aircraft enters a region of wake vortex flow:
  - The vortex flow field interacts in a complex way with the structure and the aerodynamic surfaces of the aircraft.
  - This complex aerodynamic interaction exerts forces & moments on the aircraft.
  - All further aircraft reactions are a consequence of these forces & moments.
Direct Wake Impact Method (DWIM)

• Background: How to simulate a wake vortex encounter?

• Wake encounter simulations have been performed for many years, e.g.

  • Offline simulations

  • Piloted wake encounter simulations (WaveEnc & S-WAKE projects)

  • Airbus Vortex Encounter Severity Assessment (VESA) method
Direct Wake Impact Method (DWIM)

• Background: How to **simulate** a wake vortex encounter?

1) Define a vortex velocity flow field using a model

2) Establish local flow velocities (wind kinematics)
Direct Wake Impact Method (DWIM)

- **Background:** How to simulate a wake vortex encounter?

3) Apply a suitable multi-point aerodynamic aircraft model
   - E.g. Strip Method
   - E.g. Panel Method

4) Use a standard flight dynamic simulation loop
Direct Wake Impact Method (DWIM)

- Background: How to simulate a wake vortex encounter?

**Standard 6-DoF Flight Simulation**

Background wind

\[
\begin{align*}
V_W & \quad V_A = V_K - V_W \\
F_i, M_i & \quad \dot{V}_K, \dot{\Omega}_K \\
V_K, \Omega_K, \Theta_K, X_K & \quad \text{Integrations} \\
& \quad \text{Attitude, flight path}
\end{align*}
\]

Flight simulation loop (simplified)
Direct Wake Impact Method (DWIM)

• Background: How to simulate a wake vortex encounter?

Wake Encounter Flight Simulation

Modeled wake vortex flow field

\[ \vec{V}_{wv} \]

Background wind

\[ \vec{V}_w \]

\[ F_{t,M_t} = F_{b,M_b} + F_{wv,M_{wv}} \]

Flight simulation loop (simplified)

Background Wind

Velocities

Aerodynamic model

Sum forces & moments

Eq. of motion

\[ \rightarrow \] Accelerations

Integrations

\[ \rightarrow \] Attitude, flight path

Multi-point aero model

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Direct Wake Impact Method (DWIM)

• How to measure wake impact from a wake vortex encounter?

- Flight test aircraft
- Unknown wake vortex flow field

• Five steps are required to derive wake impact from flight tests.
Direct Wake Impact Method (DWIM)

• How to measure wake impact from a wake vortex encounter?

1) Derive total forces and moments
Direct Wake Impact Method (DWIM)

• How to **measure wake impact** from a wake vortex encounter?

  1) Derive **total forces and moments** from measured aircraft dynamics

Flight test example

![Diagram showing roll rate over time](image-url)
Direct Wake Impact Method (DWIM)

- How to measure wake impact from a wake vortex encounter?
  1) Derive total forces and moments from measured aircraft dynamics

**Flight test example**

![Graph showing rolling moment over time](image)

**Diagram showing process:**
- Measurements → Sum forces & moments → Eq. of motion → $F_t, M_t$ → Total Mx

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Direct Wake Impact Method (DWIM)

• How to measure wake impact from a wake vortex encounter?

2) Identify wake encounter time segment
Direct Wake Impact Method (DWIM)

• How to measure wake impact from a wake vortex encounter?

2) Identify wake encounter time segment from measured winds

Flight test example

Region of wake influence

Region of no wake influence prior to the encounter

Region of no wake influence following the encounter

Time [sec]

Measured vertical wind [m/s]

Vertical wind

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Direct Wake Impact Method (DWIM)

• How to measure wake impact from a wake vortex encounter?

3) Identify the background wind
Direct Wake Impact Method (DWIM)

- How to measure wake impact from a wake vortex encounter?

2) Identify the **background wind** from measurements prior and after the wake encounter (for all three axes)

- **Flight test example**

  - Region of wake influence
  - Region of no wake influence prior to the encounter
  - Region of no wake influence following the encounter

**Disregard**
Direct Wake Impact Method (DWIM)

• How to measure wake impact from a wake vortex encounter?

Wake Encounter Flight Test

Flight test aircraft

F, M

Unknown wake vortex flow field

Background wind

4) Derive base forces & moments
Direct Wake Impact Method (DWIM)

• How to measure wake impact from a wake vortex encounter?

4) Derive base forces & moments from known aircraft behaviour applied to recorded aircraft attitudes and background wind

Flight test example

\[ \frac{V_w}{V_k, \Omega, \Theta, X_k} \]

Background Wind

Measurements
Direct Wake Impact Method (DWIM)

- How to measure wake impact from a wake vortex encounter?

4) Derive base forces & moments from known aircraft behaviour applied to recorded aircraft attitudes and background wind

Flight test example

\[ V_W \quad V_A = V_K - V_W \]

\[ V_K, \Omega_K, \Theta_K, X_K \]

Background Wind → Velocities → Aerodynamic model → Sum forces & moments → Measurements

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Direct Wake Impact Method (DWIM)

• How to measure wake impact from a wake vortex encounter?

5) Subtract base and total forces & moments

Wake impact is the difference between measured (total) effects and effects resulting from aircraft movement versus the background wind.
Direct Wake Impact Method (DWIM)

- How to measure wake impact from a wake vortex encounter?

5) Subtract base and total forces & moments

Flight test example

\[
\begin{align*}
\mathbf{F}_{\text{wv, M}_{\text{wv}}} & = \mathbf{F}_{t, M_{t}} - \mathbf{F}_{b, M_{b}} \\
\end{align*}
\]
Direct Wake Impact Method (DWIM)

- How to measure wake impact from a wake vortex encounter?

5) Subtract base and total forces & moments

\[ \begin{align*}
F_{wv}, M_{wv} &= F_t, M_t - F_b, M_b \\
\end{align*} \]

Flight test example

Example of a double vortex encounter
Direct Wake Impact Method (DWIM)

• How to measure wake impact from a wake vortex encounter?

Outside the vortex influence, the total forces & moments equal the base forces & moments.

Under the wake influence, the total forces & moments differ from the base forces & moments. The difference is the Direct Wake Impact.
Direct Wake Impact Method (DWIM)

• How to **measure wake impact** from a wake vortex encounter?

• Five step process:
  1. Derive **total forces and moments**
  2. Identify **wake encounter time segment**
  3. Identify the **background wind**
  4. Derive **base forces & moments**
  5. Subtract **base and total forces & moments**

• This process
  • Makes no assumptions on the vortex flow field
  • Does not require a model of aircraft-wake interaction
  • Allows to perform tests with control surface movements without this biasing the result
Direct Wake Impact Method (DWIM)

• Application

• All Airbus back-to-back wake encounter flight tests (2007, 2010) have been evaluated using the Direct Wake Impact Method
• From all wake-induced forces & moments, the peak value of the rolling moment is the key severity metric.

Flight test example

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Direct Wake Impact Method (DWIM)

• Comparison of peak roll impact with independently identified vortex circulations shows a relevant effect of different vortex core sizes – in line with theory.
Summary

• Wake encounter flight tests have been performed by Airbus in order to define safe wake turbulence minima for A380 operations.

• Flight tests are evaluated using the DWIM which derives peak wake-induced roll impacts acting on an encountering aircraft.
  
  • DWIM makes no simplifying assumptions about the structure of the vortex flow field or its interaction with the encountering aircraft.

• DWIM assesses the impact of a vortex on the follower instead of only the circulation characteristics of a wake.

• Wake impact in roll not only depends on vortex circulation but vortex core size plays a relevant role as well.
## Outlook

- Airbus is currently updating the A380 Safety Case & Safety Assessment Report together with EASA, ECTL and FAA
  - Primary evidence comes from wake encounter flight tests
  - The Direct Wake Impact Method is used to assess these tests
- Reduced wake turbulence separations behind A380 operations versus the 2008 Safety Case are expected.
- Encounter flight test results allow validating wake impact models in support of other safety assessments, e.g. recategorisation