Wake Encounter In-Situ Flight Tests in Cruise - Wake Characterization

Dietrich Fischenberg
Carsten Schwarz

DLR - Institute of Flight Systems
Braunschweig, Germany

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Overview

- DLR’s wake encounter flight test campaign in the W&F project (2011)
- Evaluation method & results
- Wake Characterization Sheet
Objectives of Wake Encounter Tests

(a) gathering in-situ flight test data behind different airliners in cruise

(b) determination of wake characterising parameters from encounter test data: strength, descent, and lateral vortex spacing

(c) validation of the flight dynamic model of a swept wing configuration for wake encounters

![DLR Falcon D-CMET](image1)  
![Cockpit view during flight test](image2)
Involved Partners

- **DLR Institute of Flight Systems (Braunschweig)**
- DLR Flight Test (Oberpfaffenhofen)
- Deutsche Flugsicherung DFS (Karlsruhe & Langen)
- DLR Institute for Atmospheric Physics (Oberpfaffenhofen)
- Messwerk (Braunschweig)

**Airlines**
- Lufthansa (DLH)
- Scandinavian Airlines (SAS)
- Austrian Airlines (AUA)
- KLM Royal Dutch Airlines (KLM)
- Wizz Air (WZZ)
- Brussels Airlines (BEL)
- Belavia Airlines (BRU)
- Norwegian Air Shuttle (NAX)
- Malev Hungarian Airlines (MAH)
Flight Test Task

„Fly lateral wake encounters behind cruising airliners, as many as possible, and close to the cores of both vortices“

distance 5...25 nm behind generator

20-30 encounters
Falcon 20 D-CMET

Measurement Equipment for Wake Encounter Flights

Pilot’s inputs:
- column
- wheel
- pedal

Flow direction:
- Alpha
- Beta

Air data:
- Static/dynamic pressure
- Temperature
- Mach number
- altitude, airspeed

Inertial reference system:
- linear accelerations
- rotational rates
- Euler angles

GPS
Contrail Forecast

Schmidt-Appleman (degC) where RH GT 80%, and geop. height (m) at 250hPa
Valid: Fri, 04 Mar 2011, 09 UTC (step 033 hrs from Thu, 03 Mar 2011, 00 UTC)

250 hPa
FL340

flight test area
Wake Encounters Behind a B737-700

Radar ground tracks

- aircraft type
- actual mass
- airspeed
- heading
- wind speed & direction

Airliner data (transmitted once)

wind 270°/40 kt

Measurement corridor ≈90 nm, 11 min

 LATITUDE \[\text{deg}\] \[→\] Longitude [deg] \[→\]

B737-700
Falcon

≈10 nm
≈6 nm distance
≈17 nm
Wake Encounter Behind a B737
## Encounter Statistics

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<th>mass [t]</th>
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<th>number of encounters</th>
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<td>350</td>
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<td><strong>total</strong></td>
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</table>
Single Encounter Evaluation: Method

Characterization of Instantaneous Wake State

Flight test data
wake encounter

flow direction \((\alpha, \beta)\)

lin. accelerations
rot. rates (IRS)
Euler angles
altitude
airspeed

Flight Path Reconstruction (FPR)

Wake Identification

Wake Model

\(\Delta\) flow \((=\) wake\)

motion induced flow

encounter flight path

wake model parameters
Single Encounter Evaluation: Wake Model

- superimposed tangential velocities of two counterrotating vortices:

![Typical vertical velocity profile](image)

- identification of model parameters for each single encounter:
  1. circulation
  2-3. left & right vortex altitude
  4-5. left & right lateral vortex position (= vortex spacing)
  6. optional: core radius
  7. optional: wake system orientation

}; only with appropriate flow instrumentation
Typical Flow Measurements (Lateral Encounter)

Approach / Cruise Flight

Approach
\( \Delta \text{ flow} \approx \pm 8^\circ \)

Cruise
\( \Delta \text{ flow} \approx \pm 3^\circ \)
Result: Wake Position Reconstruction

Single Lateral Wake Encounter Behind an A320

altitude [m]

wake axis system

reconstructed Falcon flight path

core diameter

reconstructed A320 vortex core positions
Result: Wake Model Fit to AoA/AoS Measurements

- good
- ok
- still ok
- not ok, too old

2/3 of encounters: ID possible
Wake Identification Results for One Measurement Sequence

"Wake Characterization Sheet"

**Circulation**
all identified single encounter vortex circulations (left = right vortex) compared to theory

**Lateral vortex spacing**
all identified lateral positions of left & right vortices in wake axis system (projection on x/y wake plane) compared to theory

**Wake descent**
all identified vortex z-positions relative to generator Flight Level

*optional generalization:*

**MTOW extrapolated circulation:**
linear mass scaled circulation to achieve comparable results
Wake Characterization Sheet

Boeing B737-700

Date: 30/3/2011  
Cruise: FL 350  
Wind: 265° / 31 kt  
Weight: 48 t  
Duration: 11 min  
Heading: 140°  
Configuration: CLEAN  
TAS: 429 kt

Circulation

- Total circulation $\Gamma$ [m$^2$/s] vs distance [nm]
- Encounter: 20 / 20 / 32
- Decay theory (diffusion)
- $t^*=4$

Lateral spacing

- Lat. position [m] vs distance [nm]
- Right vortex
- Left vortex
- Elliptical theory

Wake descent

- Flight Level vs distance [nm]
- Right vortex
- Left vortex
- B737 Flight Level
- Initial descent theory
Conclusions & Outlook

- High quality wake encounter flight test data now available for research: 202 encounters behind 12 different ICAO MEDIUM aircraft in cruise

- DLR’s evaluation method for wake characterization was successfully applied to cruise flight test data

- A "Wake Characterization Sheet" is proposed with focus on wake strength, wake descent, and lateral vortex spacing

- International interest on the flight test data & evaluation results (e.g. FAA)

- Presentation invited at WakeNet USA meeting (Memphis) this month