Airborne and Ground-based Wake Vortex Measurements with Pulsed Lidar

Thomas Gerz "or" Frank Holzäpfel
Institut für Physik der Atmosphäre
DLR - Oberpfaffenhofen

Honours to:
Friedrich Köpp, Stephan Rahm, Rudolph Simmet, Igor Smalikho, Andreas Wiegele
Outline

• Technical details of DLR's 2µm pulsed Lidar

• Evaluation steps for wake characterisation: position, spacing, orientation, circulation

• Results from ground-based measurements

• Results from airborne measurements on board of Falcon

Thomas Gerz, Institut für Physik der Atmosphäre

Wake vortex detection along flight path (safety)
- MFLAME - scanning the flight corridor during final approach
- I-Wake - first attempt to detect vortices from a/c along flight path
- GreenWake - airborne detection of atmospheric disturbances
- DELICAT - airborne detection of clear-air turbulence

Wake vortex characterisation (physics)
- WakeOP (Wirbelschleppe, 2001), WakeTarbes (C-Wake, 2002)
- Ground (F/T-1) and airborne (ATTAS try-out, F/T-2) meas.(AWIATOR, 03,05,06)
- WakeFRA, WakeIstres (Airbus, 2004)
- Departing a/c at Frankfurt (CREDOS, 2006-07)

Flight corridor monitoring (wake vortex forecast check)
- Test of WV advisory system WSVBS at Frankfurt (Wirbelschleppe, 2006-07)
- Test of WSVBS for single runway in München (Wetter & Fliegen, summer 2010)
Technical details of DLR's Lidar

pulsed Doppler, heterodyne
light backscattered by aerosols

Transceiver MAG-1 (prototype CTI -> LM):
  Tm:LuAG laser
  wavelength  2.022 µm
  repetition rate  500 Hz
  pulse energy  2 mJ
  pulse length  0.5 µs

Off-axis telescope:
  aperture  10 cm

Scanner (2 prisms):
  elevation sector  0 - 30°
  scan speed  2 °/s

Data acquisition:
  early digitising  500 MHz
  with quick-look

Signal processing:
  four-stage algorithm
Evaluation steps for wake vortex characterisation

Four-stage process: Stage 0

Raw data:
- heterodyne signal of laser pulse
- atmospheric backscatter signal
(2 ns/sample)

Doppler spectra:
Fourier transform (256 samples) with zero padding (768 samples)
Stage 1: Spectra at wake vortex location

25 shots accumulated

Definition of velocity minima and maxima:
- selection of threshold
- search of first intersections left and right of main spectral peak
Stage 2:
- eliminate background wind
- determine envelopes

positive and negative envelopes of radial (LOS) velocities
Stage 3:  
(i) range and elevation of max/min signal strength: estimation of core position  
(ii) profiles of tangential velocity at identified ranges
Stage 4: compute circulation

vortex circulation:
integration method
 e.g. 5 - 15 m for vortices of large a/c
**Pulsed Lidar as a vortex characterising field instrument**

*C-Wake and AWIATOR (F/T-1) campaigns in Tarbes 2002/2003*

2 µm pulsed Lidar (DLR)  
10 µm, cw Lidars (QinetiQ 2002 & ONERA 2002-03)
Signatures in LIDAR quick-looks

- Wake vortex
- Wind shear

(a/c altitude 400 m, OGE)

(a/c altitude 60 m, IGE)
Wake vortices of A340-300 over-flight 4-22

Trajectories of the vortex pair

Time dependence of core separation, tilt angle and vortex circulation

- open circles: port vortex,
- full circles: starboard vortex
Influence of Atmospheric Turbulence on Vortex Decay

EDR =

\[(0.5-2)\]
\[(2-5)\]
\[(5-20)\]
\[\times 10^{-4} \text{ m}^2/\text{s}^3\]
Core trajectories
Comparison of cw-lidar triangulation data and pulsed-lidar data
(ONERA, QinetiQ, DLR)

data scatter:
height: \( \sigma = 9 \text{ m} \)
lateral position: \( \sigma = 13 \text{ m} \)
Circulation
Comparison of cw and pulsed lidar data (ONERA, DLR)

data scatter for circulation: 18 m²/s
Wake vortex characterisation by airborne lidar measurements
Strategy of airborne lidar measurements

At measurement altitudes only few aerosols expected
  -> seeding of the vortices with smoke is prerequisite
  -> flight pattern (circuit vs. chase flight) to be optimised

Three campaigns for AWIATOR:
  • ATTAS Try-out Oberpfaffenhofen 2005
  • A340 Toulouse 9. + 15. Nov. 2006
  • ATTAS Oberpfaffenhofen 24. Nov. 2006

plus three campaigns for Airbus
  • A380 side by side with A340-600 or B747-400
AWIATOR strategy of airborne lidar measurements

The nominal flight paths of the A340, NLR Metro and DLR Falcon, side view, from D1.1.3-19, 15.01.07 (NLR report NLR-CR-2006-770)
AWIATOR A340 and Falcon Flight Pattern 15.11.06 /3

Falcon trajectory
A340 trajectory
WV measurement area
Smoke generation area

Y, km (South -> North)

X, km (West -> East)
Measured Doppler Spectra

AWIATOR flight 1, leg 1
9.11.06, 13:59 UTC
Airbus strategy: A340 and A380 side by side in cruise

measured by downward looking lidar on board of Falcon
Circulation of A380 and A340 vortices

Pastis avec un Croque Madame
Conclusions

• 2 µm **pulsed lidar** used for the first time as a **wake measuring** device
• First **airborne** measurements of aircraft wake vortices
• Transceiver, scanner & data acquisition optimised for **characterisation** of wake vortices: four-stage data-processing algorithm
• Precise vortex trajectory, core separation, tilt angle, and circulation can be derived
• Results of pulsed lidar **verified** by comparison with triangulated cw lidars (based upon vortices from A340 and VFW614 -ATTAS- a/c including atmospheric effects):
  - standard deviations of vertical and lateral core positions 9 and 13 m,
  - standard deviation of circulation 18 m²/s
• Augmentation of signal-to-noise ratio is prerequisite for airborne measurements: smoke or contrails
References


Rahm S., Smalikho I. & Friedrich Köpp, F. 2006: Characterisation of aircraft wake vortices by airborne coherent Doppler lidar. J. Aircraft 43,

Vertical profiles of cross wind measured by pulsed lidar

- 12.06.02
  8 profiles (5:46:50 - 6:30:44)

- 13.06.02

- 14.06.02

- 17.06.02
Turbulent energy dissipation rate from pulsed lidar wind measurements

\[
\hat{\varepsilon} = \left[ \frac{\hat{D}(r_2) - \hat{D}(r_1)}{2(r_2^{2/3} - r_1^{2/3})} \right]^{3/2}
\]

where

\[
\hat{D}(r_i) = \langle [V_r(R + r_i) - V_r(R)]^2 \rangle
\]

\(i = 1, 2;\)  \(r_1 = 60\) m;  \(r_2 = 120\) m