Impact of Wind, Touchdown, and Plate Lines on Wake Vortex Evolution in Ground Proximity

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- wake vortex behaviour in ground proximity – impact of wind, ground effect, end effects, plate line
- numerical simulation (LES)
- measurement campaigns WakeMUC & WakeOP
- outlook: plate lines at Munich airport
parameter study of cross-, head-, and diagonal wind on WV & single vortex evolution in ground proximity

\[ z_0 = b_0 \]
**headwind**

\[ (0.5 \, w_0 - 4 \, w_0) \]

with increasing wind/turbulence:

- spiraling decrease
- further lateral transport / lower rebound
- accelerated rapid decay
- decay rate before and after shedding of ground vorticity identical for single vortices
ground effect with crosswind

$(0.5 \, w_0 - 4 \, w_0)$

luff vortex

lee vortex
luff vortex: 
ground contact of separating streamline decreases with increasing CW 
$\Rightarrow$ little generation of secondary vorticity

both vortices: 
CW vorticity is lifted

0.5 $w_0$

4 $w_0$
luff vortex rebound suppressed:
- no complete detachment of GE vorticity
- lifted CW vorticity induces downward velocity

lee vortex rebound continued:
- lifted CW vorticity supports continued rebound
ground effect with diagonal wind

- trajectories can be modeled based on CW contribution:
  \[ \text{traj}(\text{DW}) = \text{traj}(\text{CW}) \]

- decay can be modeled by averaging:
  \[ \Gamma(\text{DW}) = \Gamma((\text{CW} + \text{HW})/2) \]
why consider approach & landing?

- high risk to encounter WV in ground proximity:
  - physics: WV cannot descend below glide path ⇒ rebound
  - lidar, LES: WV may live much longer than 2 min (5 NM)
  - NATS incident reporting: most encounters in ground proximity
  - CDG airport: 3% WV closer than 25 m to follower a/c at threshold (V. Treve)
  - analysis of WSVBS: 57 – 70% of lowest gates impede reduced separations (AIAA Paper 2011-3037)
- possibilities to recover limited by low altitude ⇒ potentially critical situation

⇒ “Why is approach and landing safe under these conditions?”
⇒ “Can we actively promote WV decay in ground proximity?”

- answers crucial for design of optimal WVAS
LES – landing aircraft with end effect & plate line
end effect

YouTube - a very wet arrival at Port Macquarie

http://www.youtube.com/watch?v=PpUftG_mxg8

\[ v_{prop} \sim 50 \text{ m/s (very rough estimate)} \]
LES – landing aircraft with end effect & plate line

Animation Gregor Hochleitner, Thomas Ruppert, DFD
LES – landing aircraft with end effect & plate line

Animation Gregor Hochleitner, Thomas Ruppert, DFD
decay triggered by plate line \((z_0 = b_0)\)

plate dimensions for e.g. A340:
length \(\times\) height: 9 m \(\times\) 4,5 m
spacing: 20 m
key mechanisms
(with and w/o obstacles)

2. $\Omega$ shape causes self-induced **fast approach** to primary vortex (PV)

3. after SV has looped around PV it separates and **travels along the PV** (again driven by self induction)
circulation decay with end effect

w/o plate line

with plate line
WakeMUC – 779 landings (spring 2011)
Institut für Physik der Atmosphäre, Oberpfaffenhofen

WakeNet-Europe Workshop, 15-16 May 2013, Paris

- **height above ground**
- **vortex separation**
- **circulation**
- **number**
  - 1: 0.4 – 0.8
  - 2: 0.8 – 1.2
  - 3: 1.2 – 1.6
  - 4: 1.6 – 2.0
  - 5: 2.0 – 2.4
  - 6: 2.4 – 2.8
  - 7: 2.8 – 3.5

<table>
<thead>
<tr>
<th>number</th>
<th>normalized height range</th>
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<tbody>
<tr>
<td>1</td>
<td>0.4 – 0.8</td>
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<tr>
<td>2</td>
<td>0.8 – 1.2</td>
</tr>
<tr>
<td>3</td>
<td>1.2 – 1.6</td>
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<tr>
<td>4</td>
<td>1.6 – 2.0</td>
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<tr>
<td>5</td>
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<td>2.4 – 2.8</td>
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<tr>
<td>7</td>
<td>2.8 – 3.5</td>
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</tbody>
</table>
WakeOP-GE

flight experiment with research aircraft HALO
at special airport Oberpfaffenhofen on 29 - 30 April 2013
WakeOP-GE – plate line
WakeOP-GE – smoky vortices
$CW = w_0$
$z_0 = b_0$
WakeOP – all flights

WakeOP-GE - plate strikes - all flights

WakeOP-GE - plates down - luff vortex - all flights
WakeOP-GE - all flights

Gain of safety!
WakeOP – longest lived vortex (highest risk)

Gain of safety!
outlook plate lines

- DFS & FMG interested to test plate lines at Munich airport (7/19/13, 8/30/13)
- simultaneous measurement at parallel runways with and w/o plate lines
- plates subject to approval by authorities (Luftamt Südbayern)
- criteria: obstacle clearance, stability, frangibility, localizer, wildlife, grounds maintenance

<table>
<thead>
<tr>
<th>dist. from TDZ [m]</th>
<th>460</th>
<th>560</th>
<th>600</th>
<th>660</th>
<th>960</th>
<th>1260</th>
<th>1560</th>
<th>1860</th>
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<td>360</td>
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<td>1260</td>
<td>1560</td>
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<td>flight altitude [m]</td>
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<tr>
<td>obstacle height [m]</td>
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<td>4</td>
<td>4.4</td>
<td>6</td>
<td>&gt;6</td>
<td>&gt;6</td>
<td>&gt;6</td>
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</tr>
</tbody>
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Conclusions

- plate line to increase safety (mitigation of traffic growth & other measures)
- plate line + WSVBS to increase capacity

- parameter study of wind direction and strength IGE
- lidar & simulation data indicate that end effects trigger rapid vortex decay
- plate lines accelerate decay & interfere favorably with end effects
- WakeOP-GE data confirm functionality of plate line
- simulation of selected WakeOP-GE cases
- WakeMUC will show full potential of plate lines
- optimization of plate line design (DLR & TU Nanyang)
- approval of compatibility of plate line with airport requirements (obstacle clearance, frangibility, ILS, Radar altitude, …)
encounter statistics

WakeScene-Departure

WakeScene-Arrival

NATS: reported encounters
2000 to 2004

En-Route  Inbound  Outbound

Percentage of Encounters

NATS: reported encounters
2008 to 2010

Encounters by Altitude
end effect versus ground effect

\[ p \ [N/m^2] \]

-25.0 -22.7 -20.5 -18.2 -15.9 -13.6 -11.4 -9.1 -6.8 -4.5 -2.3 -0.0

\[ t^* = 0.28 \]
WakeOP-GE
flight experiment with research aircraft HALO
at special airport Oberpfaffenhofen on 29 - 30 April 2013

- purpose: demonstrate functionality of plate line patent DE 10 2011 010 147
- 74 overflights at airport Oberpfaffenhofen
- 4 flights each 1.5 h
- flight altitude $b_0 \approx 22$ m above ground
- HALO heavy and slow (landing with MLW) $\Rightarrow$ strong WV
- high-lift configuration, landing gear deployed
- HALO instrumentation: avionic data, nose boom, 4 cameras
- weather impact minimized by folding away plates alternatingly
- weak wind & turbulence, poor visibility

- Lidar measurements from Falcon hangar
- 2 ultrasonic anemometers with microphones
- smoke/fog visualization documented by video and photo
WakeOP – setup 1

WakeOP-GE - plate strikes - no offset

WakeOP-GE - plates down - luff vortex - no offset
WakeOP – setup 2 (50 m offset)
WakeOP − setup 3 (100 m offset)

WakeOP-GE - plate strikes - offset 4.5 b₀

WakeOP-GE - plates down - luff vortex - offset 4.5 b₀

\[ t \text{ [s]} \]
\[ z \text{ [m]} \]
\[ y \text{ [m]} \]
\[ z \text{ [m]} \]
\[ y \text{ [m]} \]

\[ \Gamma \text{ [m}^2/\text{s}] \]
\[ \Gamma' \text{ [m}^2/\text{s}] \]
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