Towing tank investigations on 2- and 4-vortex systems in ground effect using PIV
(FAR-Wake Subtask 3.1.2)
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Introduction

- The behavior of wake vortex systems in ground proximity is of particular interest to improve operational models for airports.

Objectives

- Measure and analyze flow fields of spatially evolving wakes in ground proximity.
- 2-vortex as well as 4-vortex systems consisting of co- and counter-rotating vortex pairs are considered.
Outline

 Crate Experimental setup

 Crate Results of 2-vortex system in ground proximity
   Crate Flow fields showing the vortex interaction with the ground
   Crate Vortex trajectories and development of circulation

 Crate Results of 4-vortex systems in ground proximity
  Crate Co- and counter rotating vortex pairs
   Crate Flow development
   Crate Tip vortex trajectories and development of circulation

 Crate Conclusions
Experimental setup
Towing tank facility in Göttingen (WSG) & PIV setup

Cameras (1600 x 1200 Pixel)

Model carriage:
Speeds \( \leq 5 \text{ m/s} \)

Tank cross section:
1.1 m x 1.1 m

Additional floor is installed to simulate a ground
Experimental setup
DLR F13 wing model for generation of 2- and 4-vortex systems

Rectangular wing
Span width = 0.3 m
$C_L = 1.1$

Fuselage with different horizontal tail wings can be attached to generate 4-vortex systems with specific circulation and span ratios
Measurement conditions

- Model velocities: $U = 1.5 \text{ m/s}$; $0.65 \text{ m/s}$
- Reynolds numbers: $R_c = 74000$; $32000$  
  $R_{\Gamma} = 52000$; $22500$

- Horizontal floor  
  $h/b = 0.5$; $0.25$; $0.196$; $0.125$

- 4-vortex system (co- & counter-rotating)  
  Circulation ratio $\Gamma_0 / \Gamma_1 = \pm 0.3$  
  Span ratio $b_0 / b_1 = 0.3$
Spatial-temporal evolution of 2-vortex-system
Velocity vector & vorticity distributions

U = 1.5 m/s; H/b = 0.25;

Moving direction of model

\[ t^* = \frac{t \, U}{b} = 1.0 \]
Spatial-temporal evolution of 2-vortex-system
Velocity vector & vorticity distributions

\[ U = 1.5 \text{ m/s}; \frac{H}{b} = 0.25; \]

Moving direction of model

\[ t^* = \frac{t U}{b} = 4.5 \]
Spatial-temporal evolution of 2-vortex-system

Velocity vector & vorticity distributions

\[ U = 1.5 \text{ m/s}; \frac{H}{b} = 0.25; \]

\[ t^* = \frac{t \, U}{b} = 5.0 \]
Spatial-temporal evolution of 2-vortex-system
Velocity vector & vorticity distributions

\[ U = 1.5 \text{ m/s}; \; H / b = 0.25; \]

\[ t^* = \frac{t U}{b} = 6.0 \]
Spatial-temporal evolution of 2-vortex-system
Velocity vector & vorticity distributions

U = 1.5 m/s; H / b = 0.25;

Moving direction of model

\[ t^* = \frac{t U}{b} = 7.0 \]
Spatial-temporal evolution of 2-vortex-system
Velocity vector & vorticity distributions

\[ U = 1.5 \text{ m/s}; \frac{H}{b} = 0.25; \]

\[ t^* = \frac{t U}{b} = 7.5 \]
Spatial-temporal evolution of 2-vortex-system
Velocity vector & vorticity distributions

\( U = 1.5 \text{ m/s}; \ H / b = 0.25; \)

\( t^* = \frac{t \ U}{b} = 8.0 \)
Spatial-temporal evolution of 2-vortex-system
Velocity vector & vorticity distributions

\[ U = 1.5 \text{ m/s}; \ H / b = 0.25; \]

\[ t^* = \frac{t \ U}{b} = 9.0 \]
Spatial-temporal evolution of 2-vortex-system
Velocity vector & vorticity distributions

$U = 1.5 \text{ m/s}; \ H / b = 0.25$;

$\frac{t U}{b} = 9.5$
Spatial-temporal evolution of 2-vortex-system
Velocity vector & vorticity distributions

\[ U = 1.5 \text{ m/s}; \quad H / b = 0.25; \]

\[ t^* = \frac{t U}{b} = 11.5 \]
Spatial-temporal evolution of 2-vortex-system
Vortex trajectories

U = 1.5 m/s
Spatial-temporal evolution of 2-vortex-system
Vortex circulation

$U = 1.5 \, \text{m/s}$
Spatial-temporal evolution of 2-vortex-system
Vortex circulation

\[ U = 1.5 \, \text{m/s} \]
Spatial-temporal evolution of 4-vortex-system
Co-rotating vortex pairs
Velocity vector & vorticity distributions

$U = 1.5 \text{ m/s}; \ h/b = 0.5; \ \Gamma_0 / \Gamma_1 = 0.3; \ b_0 / b_1 = 0.3; \ t^* = 1.5 - 20.5$
Spatial-temporal evolution of 4-vortex-system
Co-rotating vortex pairs
Vortex trajectories

U = 1,5 m/s
Spatial-temporal evolution of 4-vortex-system
Co-rotating vortex pairs
Vortex circulation

$U = 1.5 \, \text{m/s}$
Spatial-temporal evolution of 4-vortex-system
Co-rotating vortex pairs
Vortex circulation

\( U = 1.5 \text{ m/s} \)
Spatial-temporal evolution of 4-vortex-system
Counter-rotating vortex pairs
Velocity vector & vorticity distributions

\[ U = 1.5 \text{ m/s}; \ h/b = 0.5; \ \Gamma_0 / \Gamma_1 = -0.3; \ b_0 / b_1 = 0.3; \ t^* = 1.5 - 20.5 \]
Spatial-temporal evolution of 4-vortex-system
Counter-rotating vortex pairs
Vortex trajectories

$U = 1.5 \text{ m/s}$
Spatial-temporal evolution of 4-vortex-system
Counter-rotating vortex pairs
Vortex circulation

\[ U = 1.5 \text{ m/s} \]
Spatial-temporal evolution of 4-vortex-system
Counter-rotating vortex pairs
Vortex circulation

$U = 1.5 \text{ m/s}$
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Conclusions

- Differences between 2- and 4-vortex configurations at h/b = 0.5 (Trajectories, circulation)

- Inner vortices of 4-vortex systems are already IGE at h/b = 0.5
  - Co-rotating vortex pairs
    - Inner vortices merges quickly with tip vortices
  - Counter-rotating vortex pairs
    - Inner vortices vanishes and do not orbit around tip vortex
    - Higher descent rate of tip vortices leads to lower altitudes
    - Decrease of circulation

- Differences between 2- and 4-vortex configurations vanishes for h/b ≤ 0.25