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Cranfield Aerospace

Unsteady swirl distortion characteristics in S-duct aero-engine intakes

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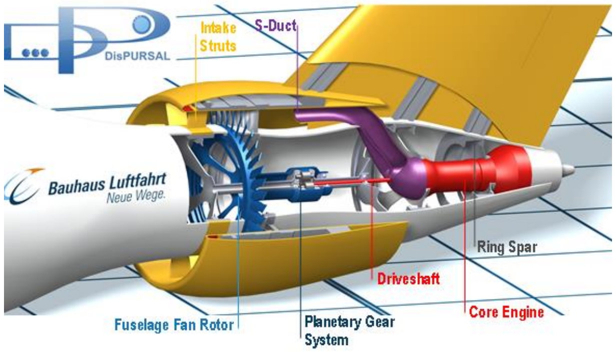
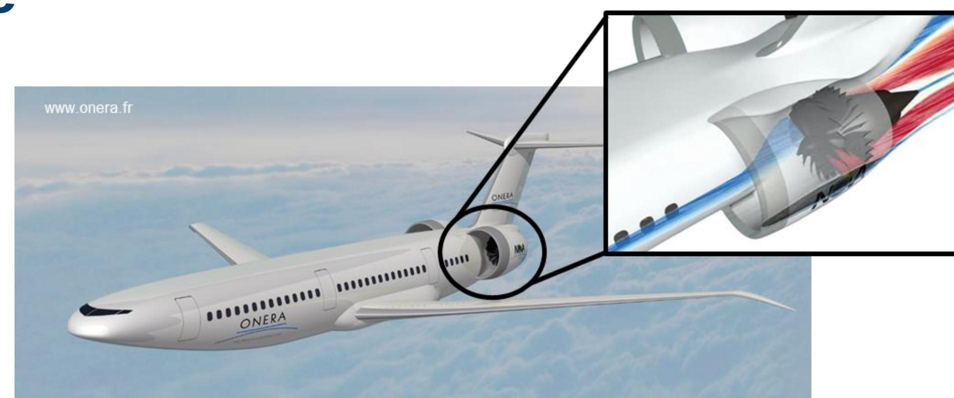
Agenda

- Introduction
- Research rationale
- Experimental facility and methods
- Flow analysis
  - Mean flow & unsteadiness
  - Spectral analysis
  - Coherent structure identification via unsteady POD
  - Distortion descriptor unsteady analysis and spectra
- Conclusions and overview

Research rationale

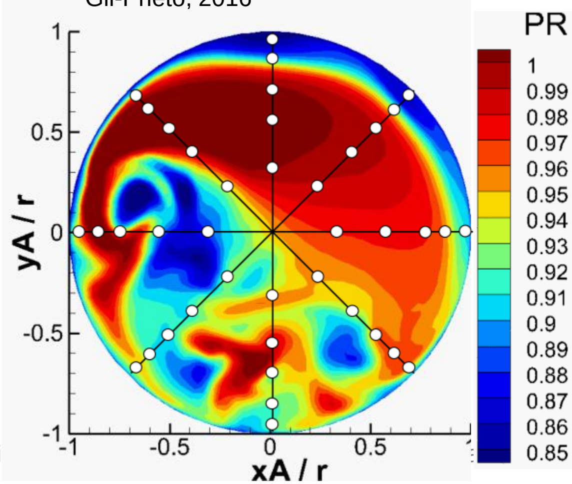


http://www.bauhaus-luftfahrt.net



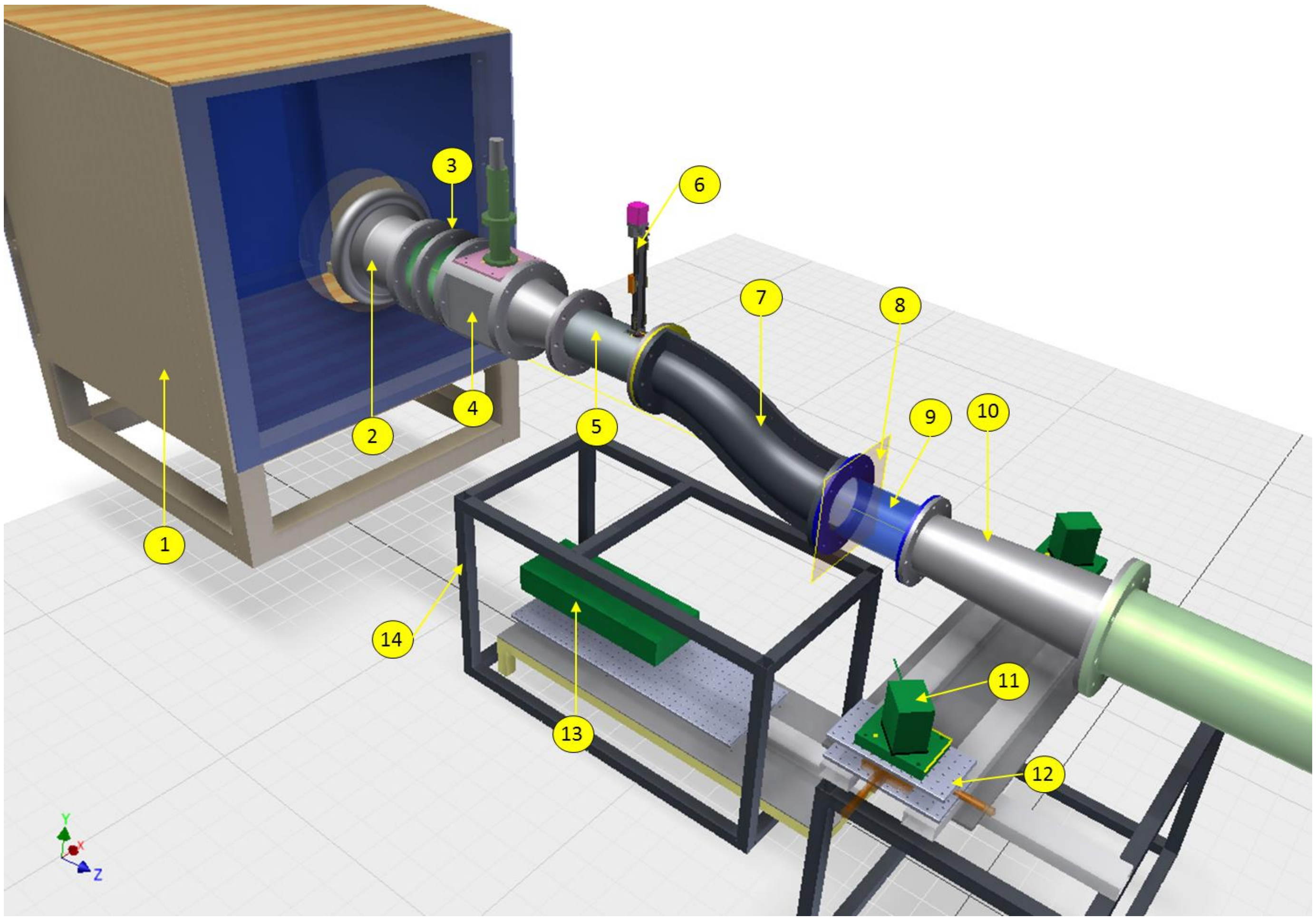
Tanguy, 2017

Gil-Prieto, 2016



- ❑ Future civil embedded and semi-embedded propulsion systems
- ❑ Boundary Layer Ingestion.
- ❑ Distributed, electric or hybrid electric.
- ❑ **<u>Common aspect:</u>** unsteady aerodynamics and flow distortion.
- ❑ Unsteady CFD predictive capability important.
- ❑ Computational cost important.

Complex intake experimental facility



1: Seeding chamber

2: Intake

3: Flow measurement

4: Vortex generator section

5: Straight section

6: Inlet traverse station

7: S-duct

8: Measurement plane

9: Optical working section

10: Suction system

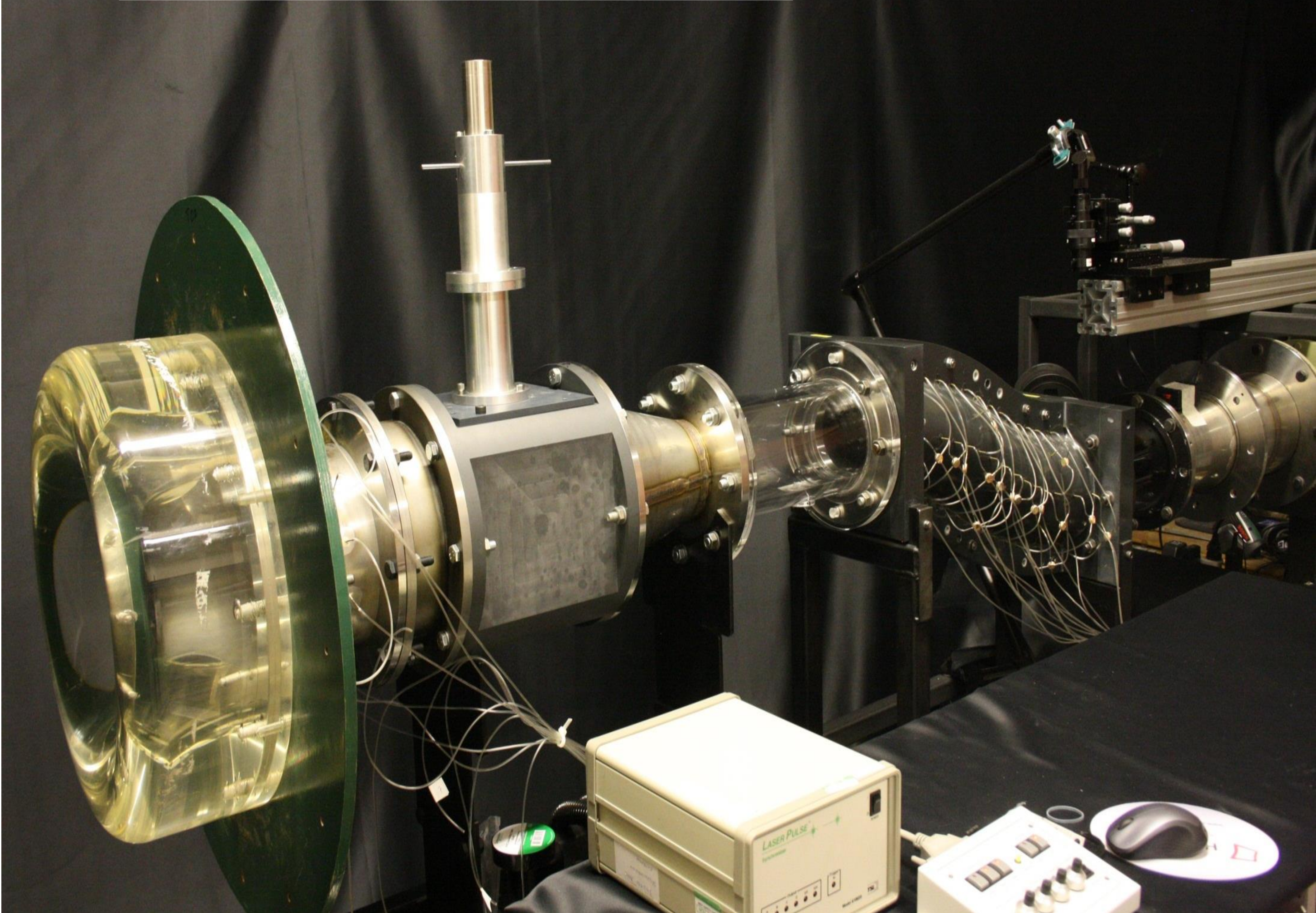
11: PIV camera

12: Camera traverse system

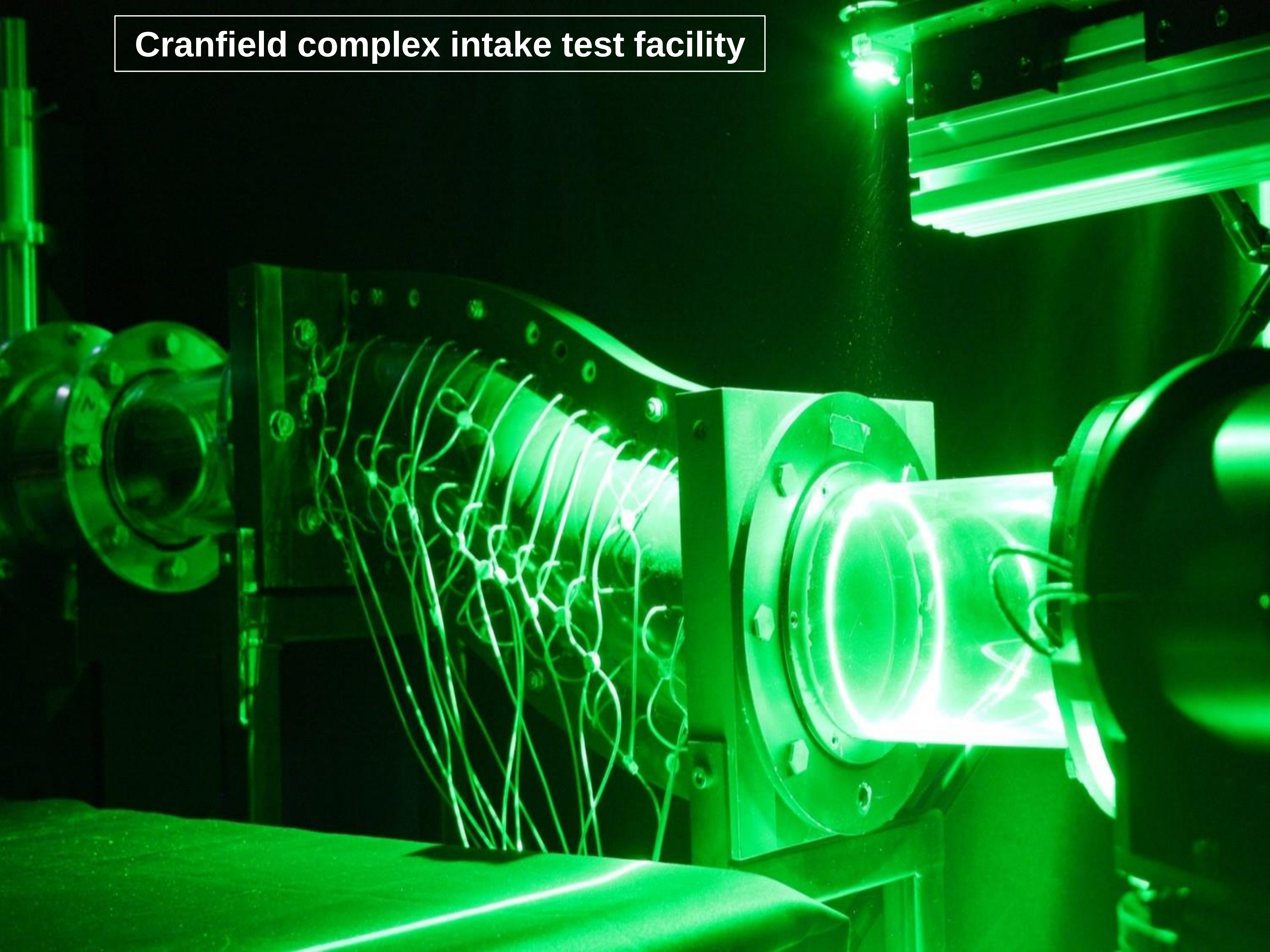
13: Laser

14: Support system

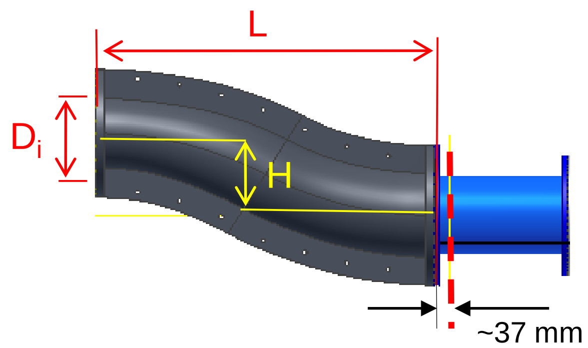
Cranfield complex intake test facility



Cranfield complex intake test facility



Complex intakes



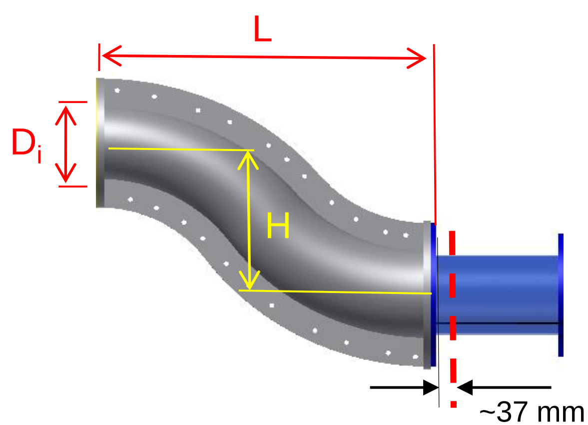
D_i = 121.6 mm

A_{out} / A_{in} = 1.52

H / D_i = 1.34

L / D_i = 5.0

Inlet Mach	Inlet Re_D
0.27	5.9e+5
0.45	9.9e+5
0.6	13.2e+5



D_i = 121.6 mm

A_{out} / A_{in} = 1.52

H / D_i = 2.44

L / D_i = 4.95

Inlet Mach	Inlet Re_D
0.27	6.01e+5
0.45	10.05e+5
0.6	13.8e+5

Time-resolved Stereo PIV

- ❑ 150mm AIP diameter
- ❑ No rotating parts

Camera setup

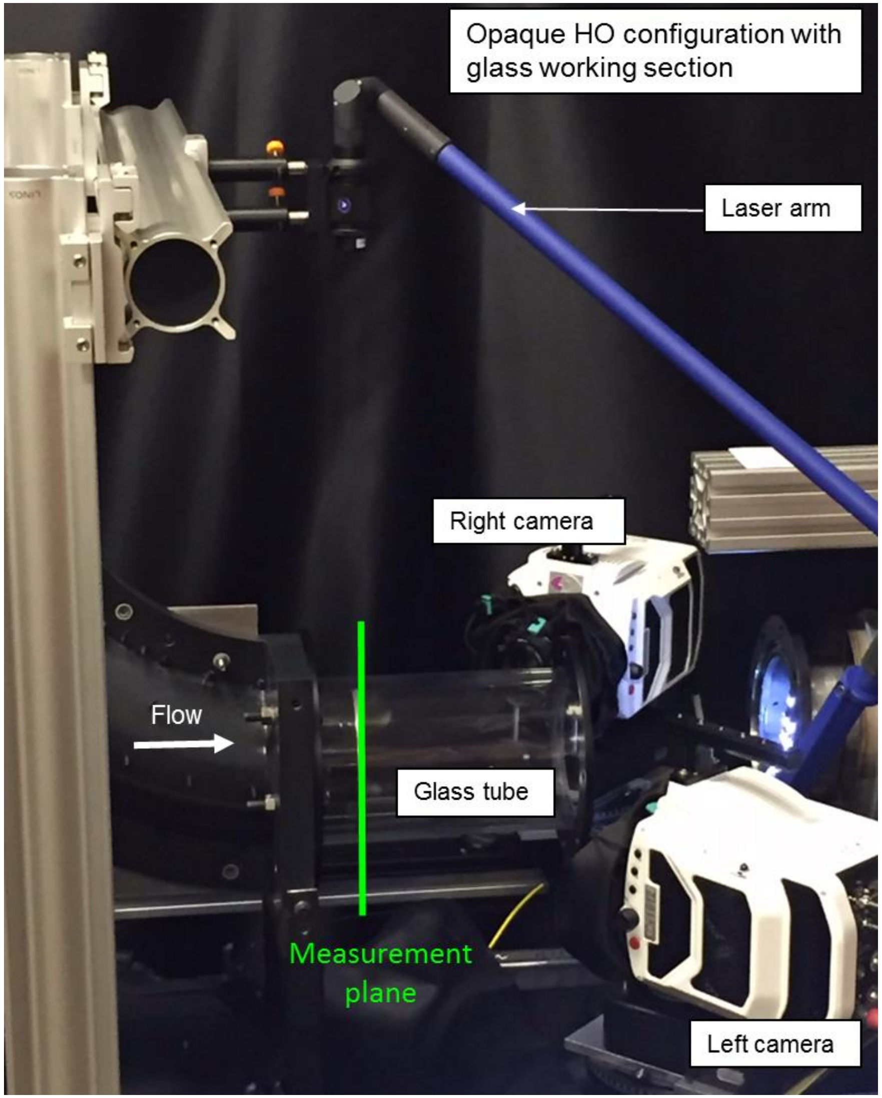
- ❑ 3C-2D Time Resolved Stereo PIV
- ❑ x2 High speed cameras
- ❑ 16,600 fps max frame rate at full resolution
- ❑ 1MP - 800 x 1280 pixel sensor resolution
- ❑ typical final spatial resolution 2.5 x 2.5 mm
- ❑ ~ 4,000 3D velocity vectors across the plane

Laser setup

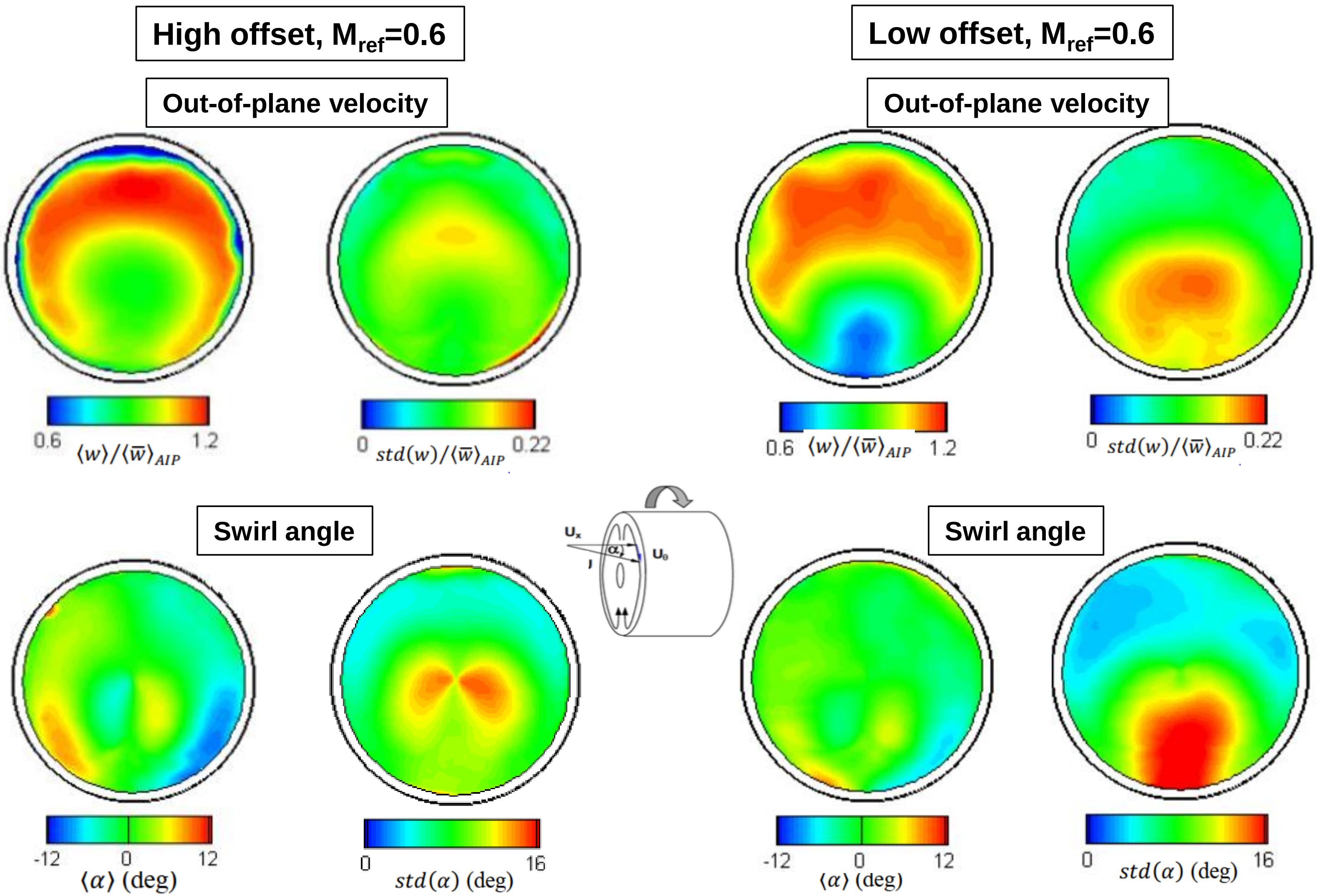
- ❑ High speed laser
- ❑ 10 mJ / pulse at 10 kHz (100 Watt)

Temporal resolution

- ❑ Acquisition up to 8kHz velocity field
- ❑ Fully synchronous across the AIP

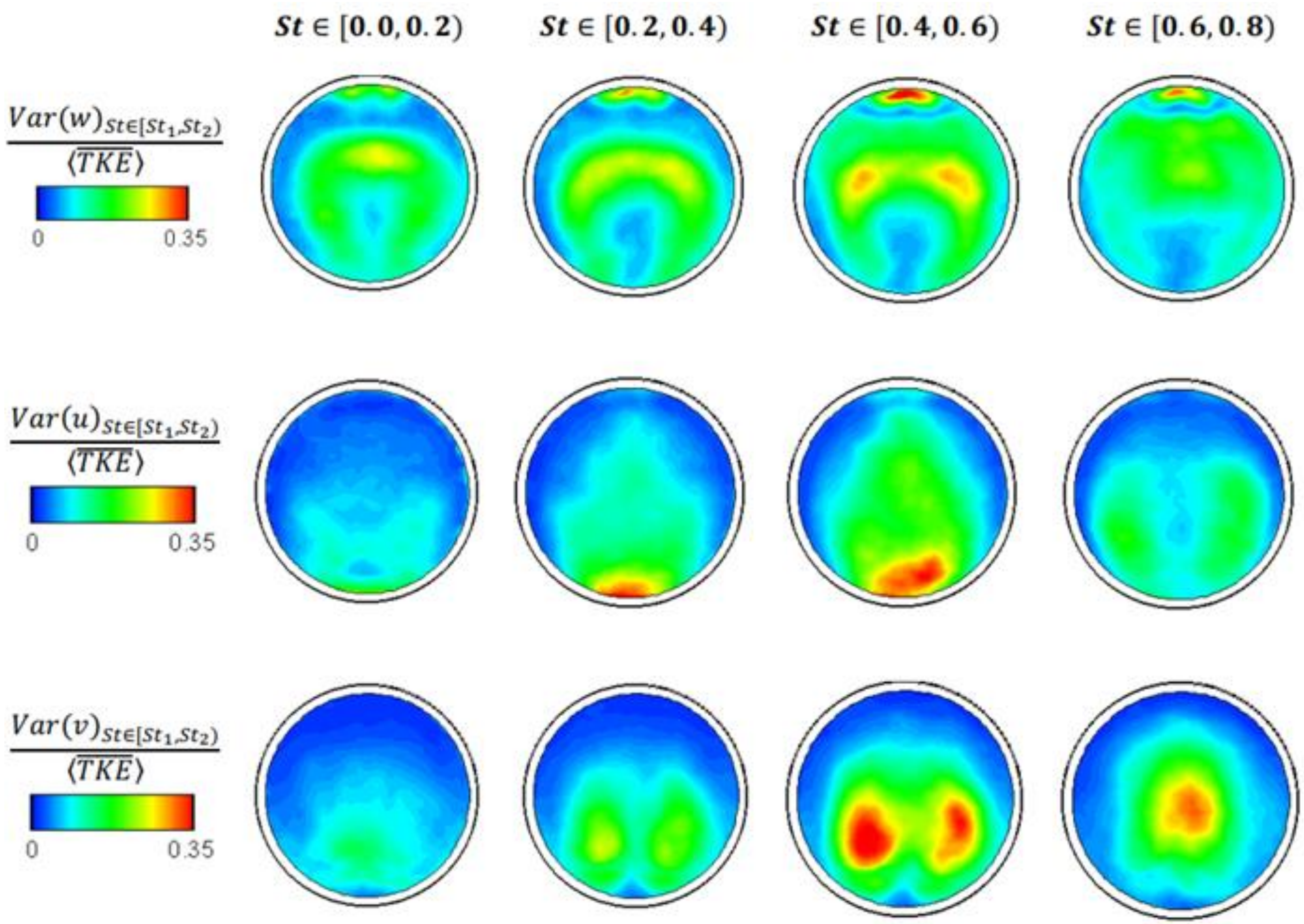


AIP flow field analysis



AIP velocity field spectral analysis

High offset, M_{ref}=0.6



AIP velocity field spectral analysis

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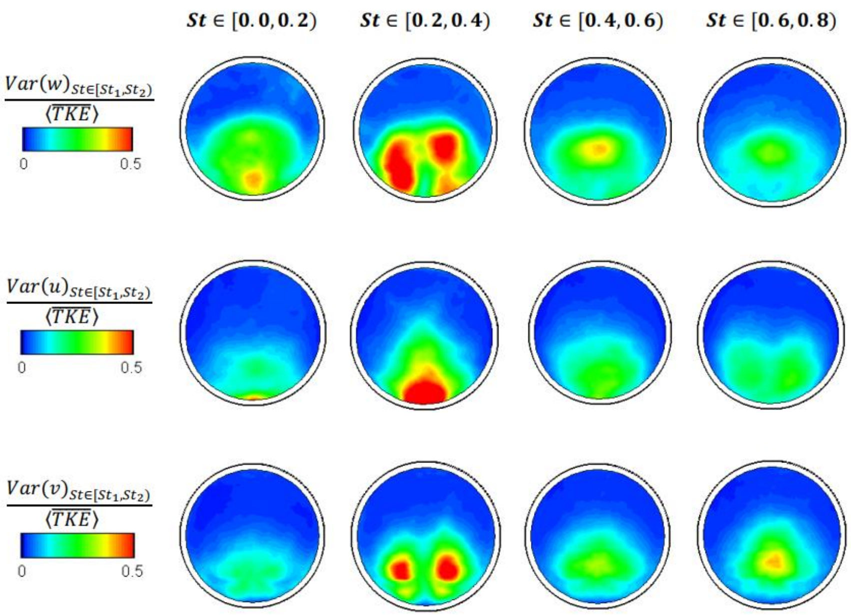
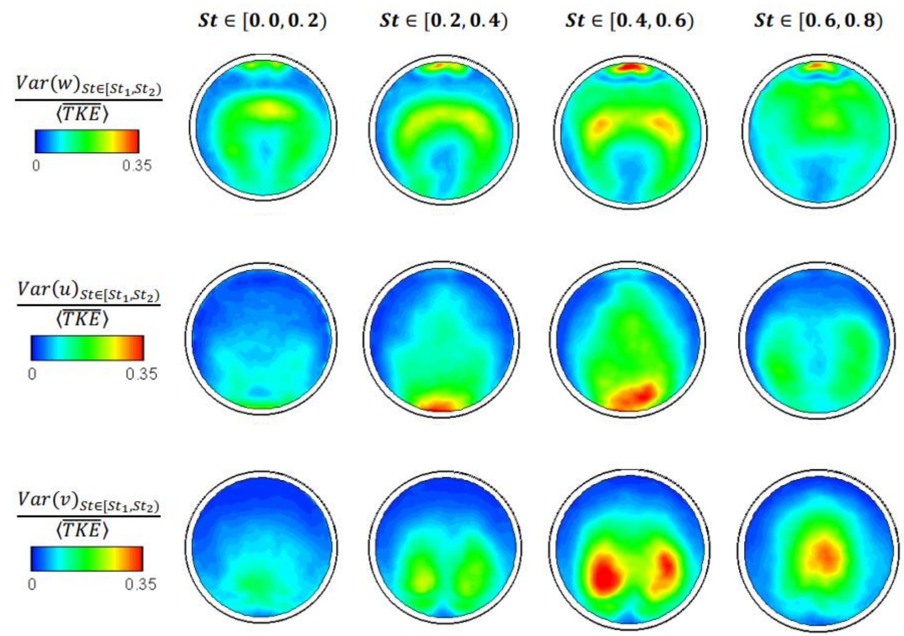


High offset, M_{ref}=0.6



- Critical to fan response (aerodynamic / aeromechanic)
- All observations also valid at low M_{ref}=0.27 → Inlet Mach second order impact
- Main frequencies St<1.2 → within fan response (St_{crit}~ 0.9 – 5.4) → likely to impact fan's operability margin

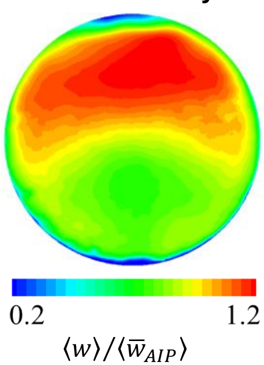
Coherent structure identification

POD spectral analysis

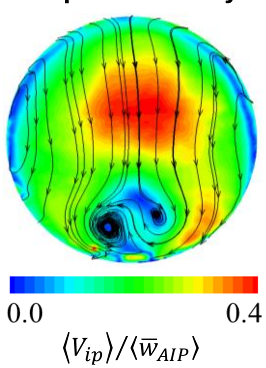
Low offset, M_{ref}=0.6

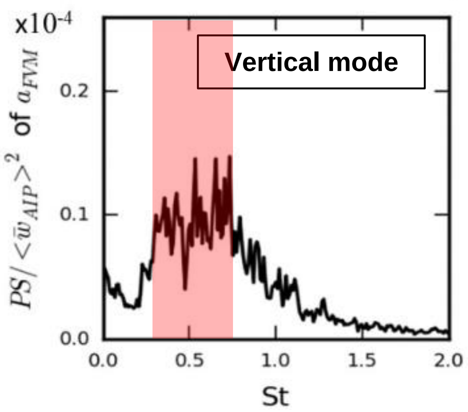
High offset, M_{ref}=0.6

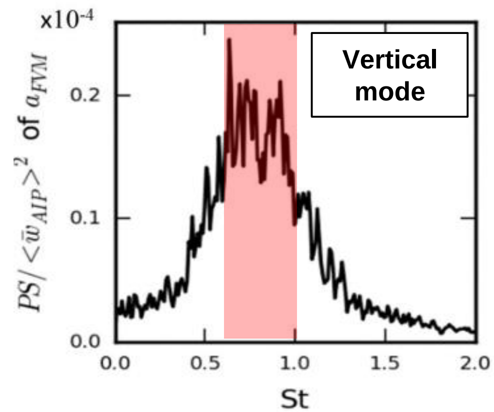
Axial velocity



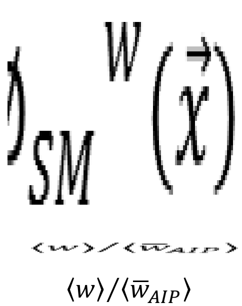
In-plane velocity



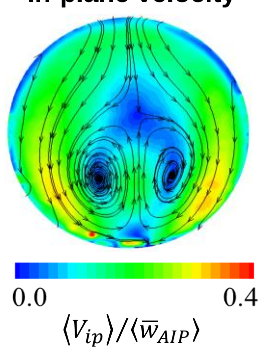


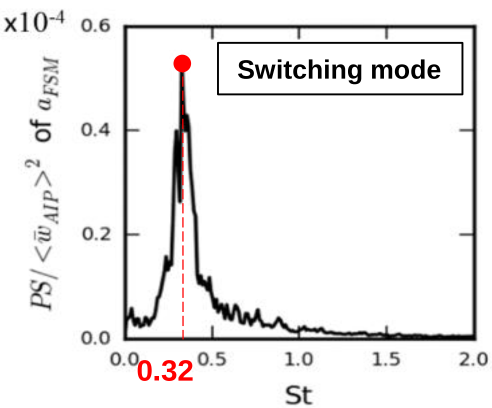


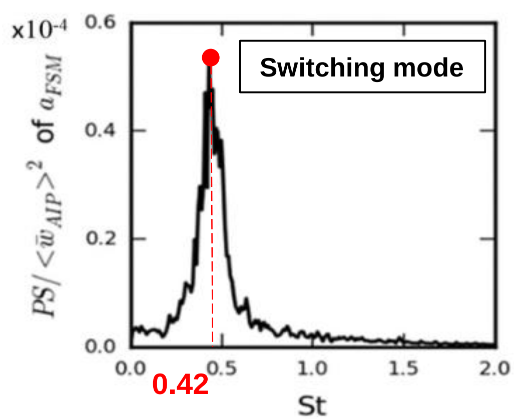
Axial velocity



In-plane velocity



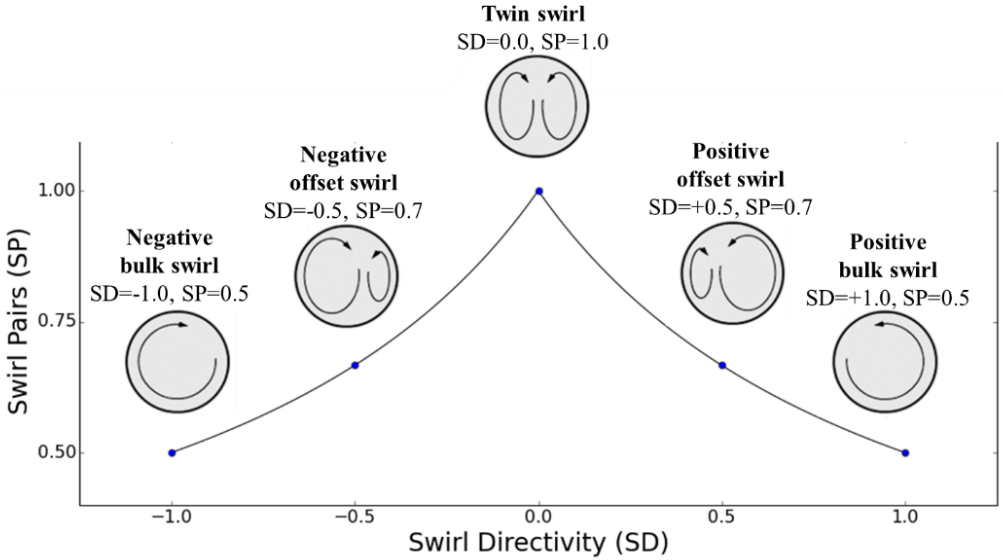


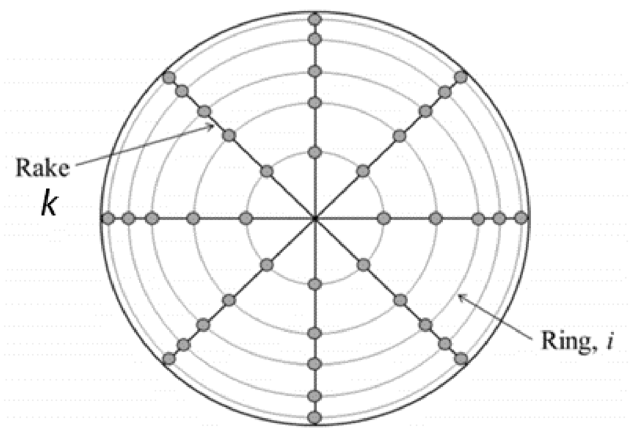


Swirl distortion

SAE swirl distortion descriptors

- Evaluated at rings and rakes
- Swirl Intensity (SI) quantifies the swirl levels
- Swirl Pairs (SP) and Swirl Directivity (SD) characterize the swirl pattern





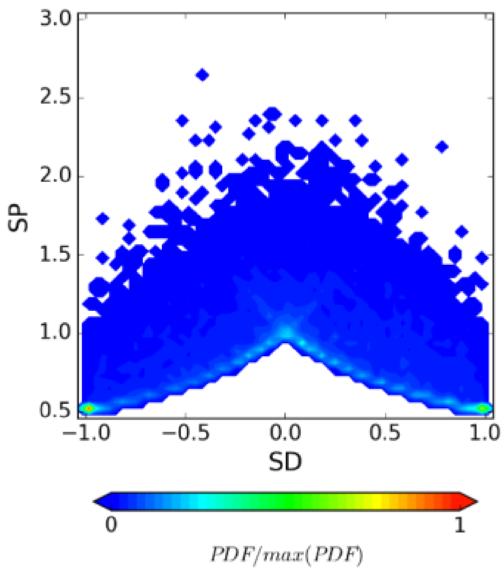
$$SS^{+}_{i,k} = \frac{1}{\theta^{+}_{i,k}} \int_{\theta^{+}_{i,k}} \alpha(\theta)_i \, d\theta \qquad SS^{-}_{i,k} = \frac{1}{\theta^{-}_{i,k}} \int_{\theta^{-}_{i,k}} \alpha(\theta)_i \, d\theta$$

(SAE, 2007)

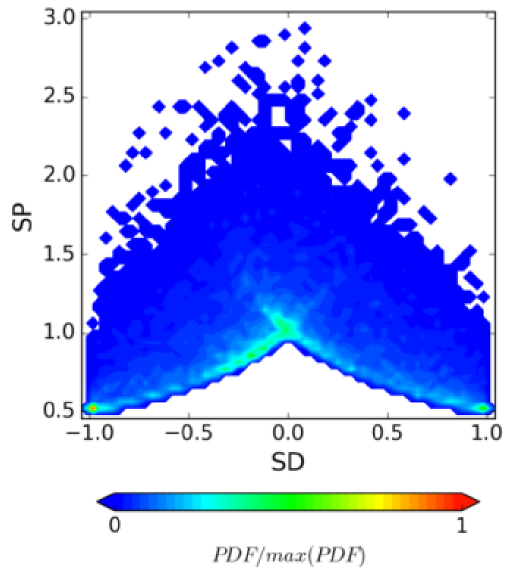
Swirl distortion unsteady analysis and spectra

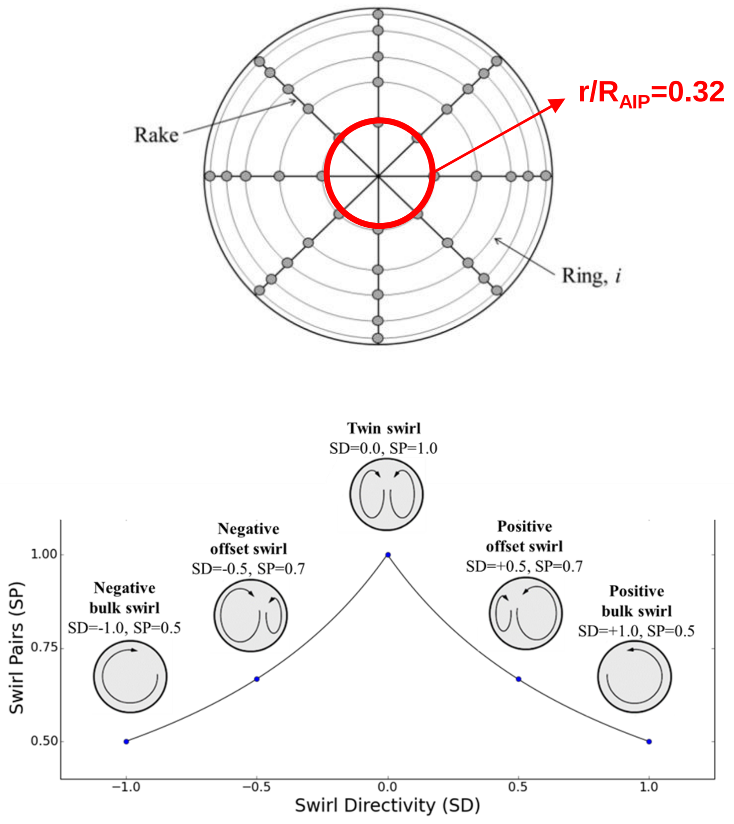
Descriptor maps – Probability Density Functions

Low offset, M_{ref}=0.6, r/R_{AIP}=0.32



High offset, M_{ref}=0.6 , r/R_{AIP}=0.32

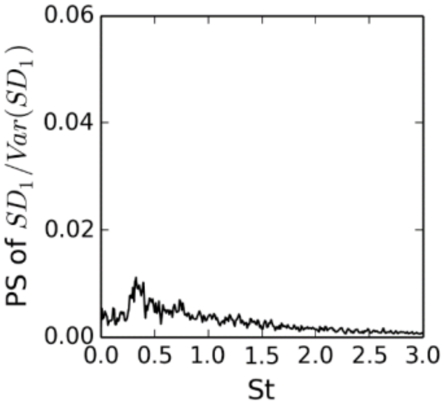




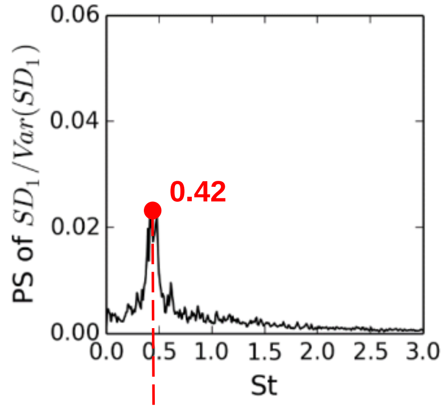
Swirl distortion unsteady analysis and spectra

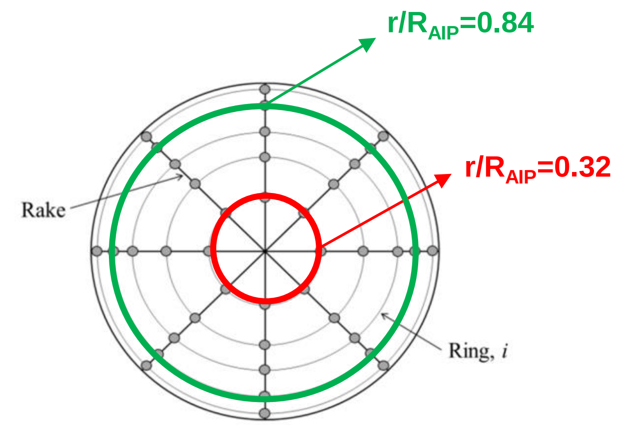
Descriptor spectra - SD

Low offset, M_{ref}=0.6, r/R_{AIP}=0.32

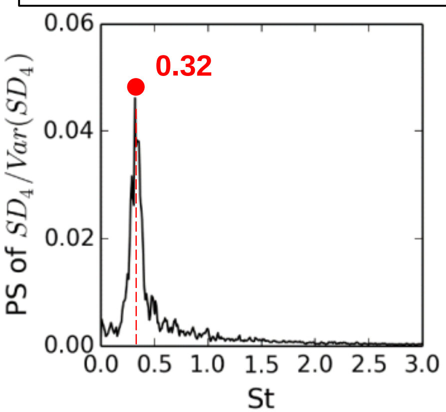


High offset, M_{ref}=0.6 , r/R_{AIP}=0.32

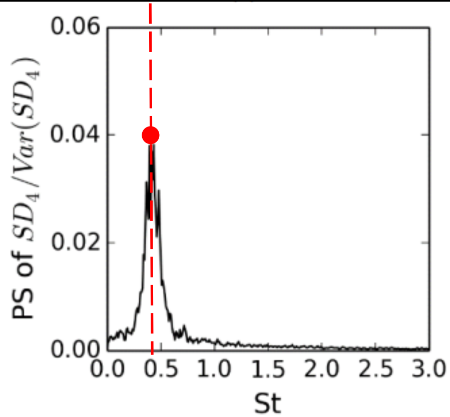


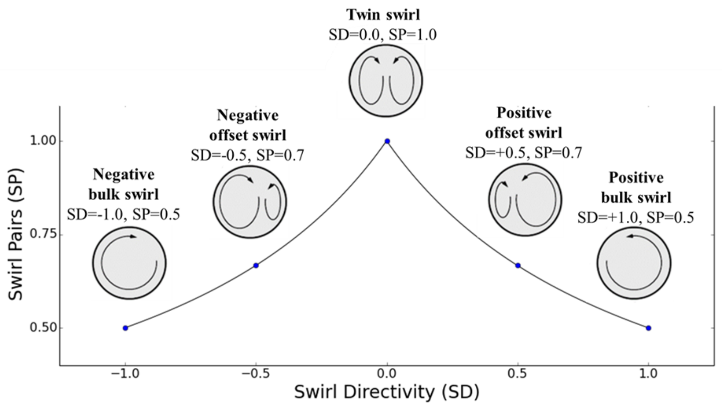


Low offset, M_{ref}=0.6, r/R_{AIP}=0.84



High offset, M_{ref}=0.6 , r/R_{AIP}=0.84





Conclusions and overview

- Main frequencies up to St = 1.2 → within fan's critical range.
- Lateral switching mechanism → primary unsteadiness source.
- Vertical switching mechanism also important → driven by shear layer unsteadiness → more broadband.
- Fundamental frequencies reflected on SD spectrogram.
- Potential impact on fan stability?
- Inlet Mach → second order impact on unsteady swirl.

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The End…

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