The impact of inlet flow profile on the unsteady distortion characteristics of S-duct aero-engine intakes

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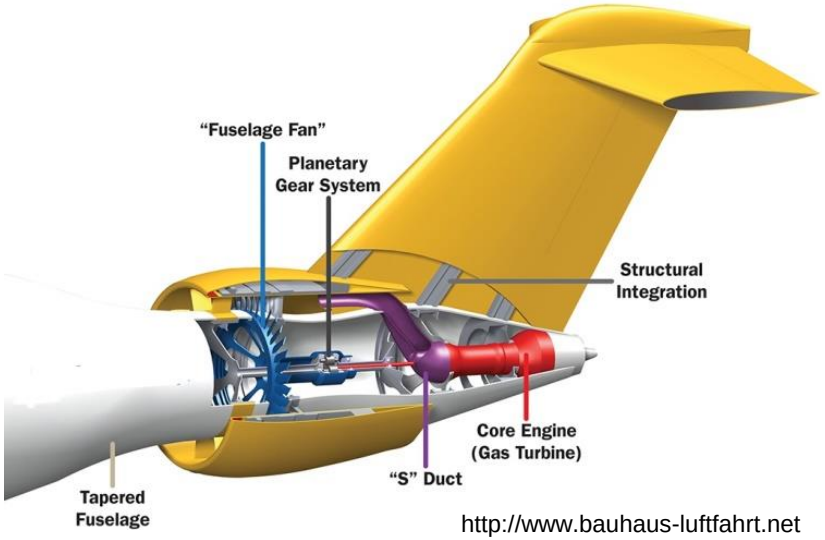
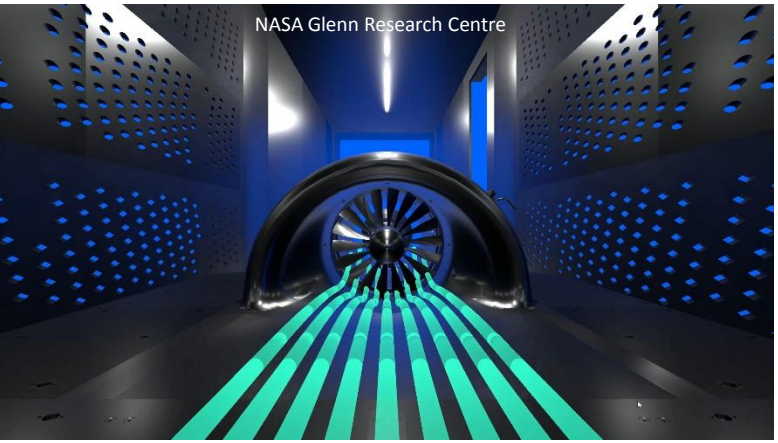
Agenda

- Introduction
- Research rationale
- Distortion screen design and verification
- Experimental capability
- Time-Resolved PIV at the AIP
- Results and discussion
- Conclusions

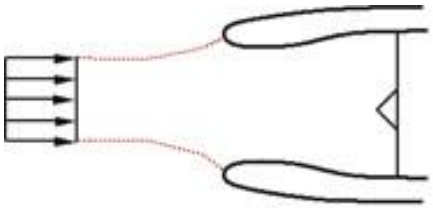
Research rationale



http://www.bauhaus-luftfahrt.net

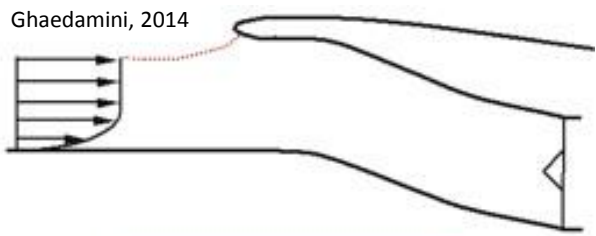


- Synthetic method to generate non-uniform flow profiles.
- Quantification of flow distortion for range of inlet profiles.
- Boundary layer ingestion configurations.
- Across-the-range intake operation.



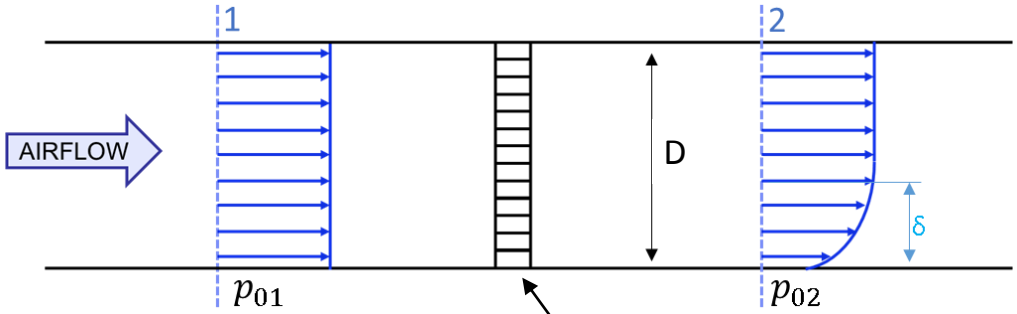
Conventional Inlet Flow

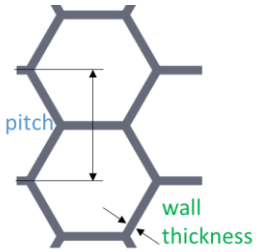
Ghaedamini, 2014

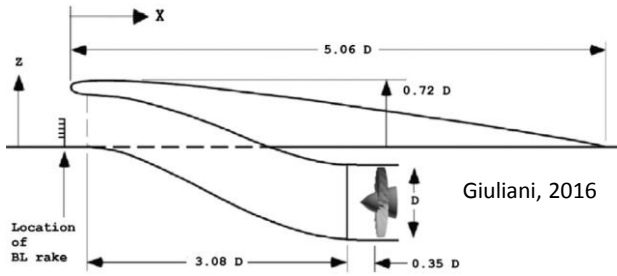


Boundary Layer Ingestion

Distortion screen design







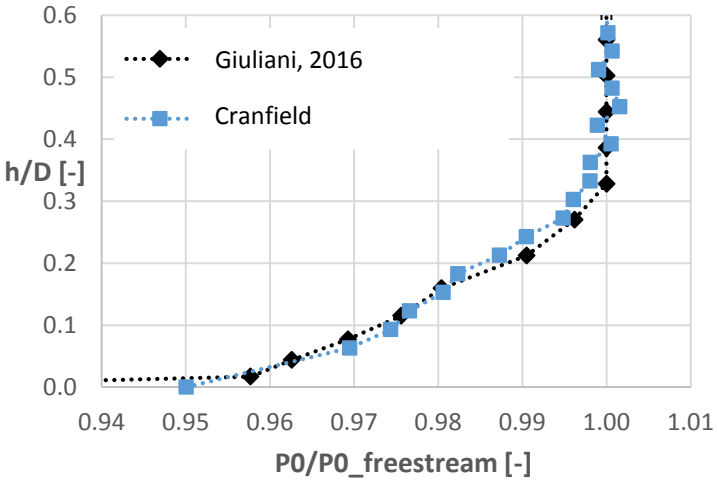
Giuliani, 2016

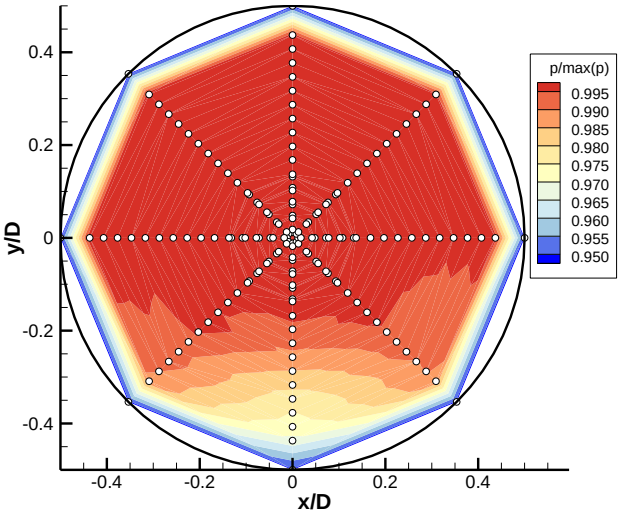
Target profile characteristics	
δ/D	0.336
D (mm)	121.6
Inlet Mach	0.27

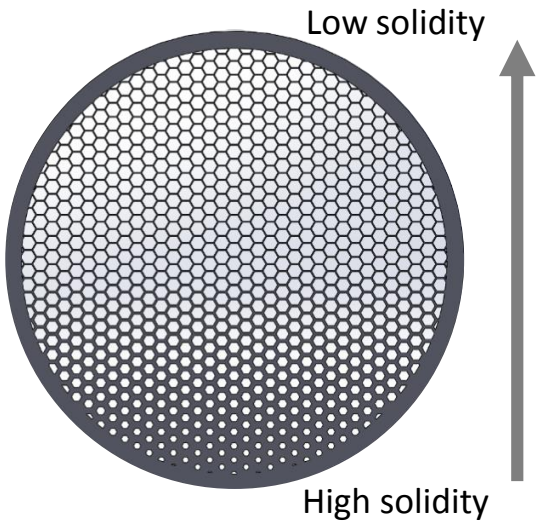
$$K = \frac{p_{01} - p_{02}}{\frac{1}{2}\rho V_2^2}$$

- Constant pitch.
- Variable wall thickness.

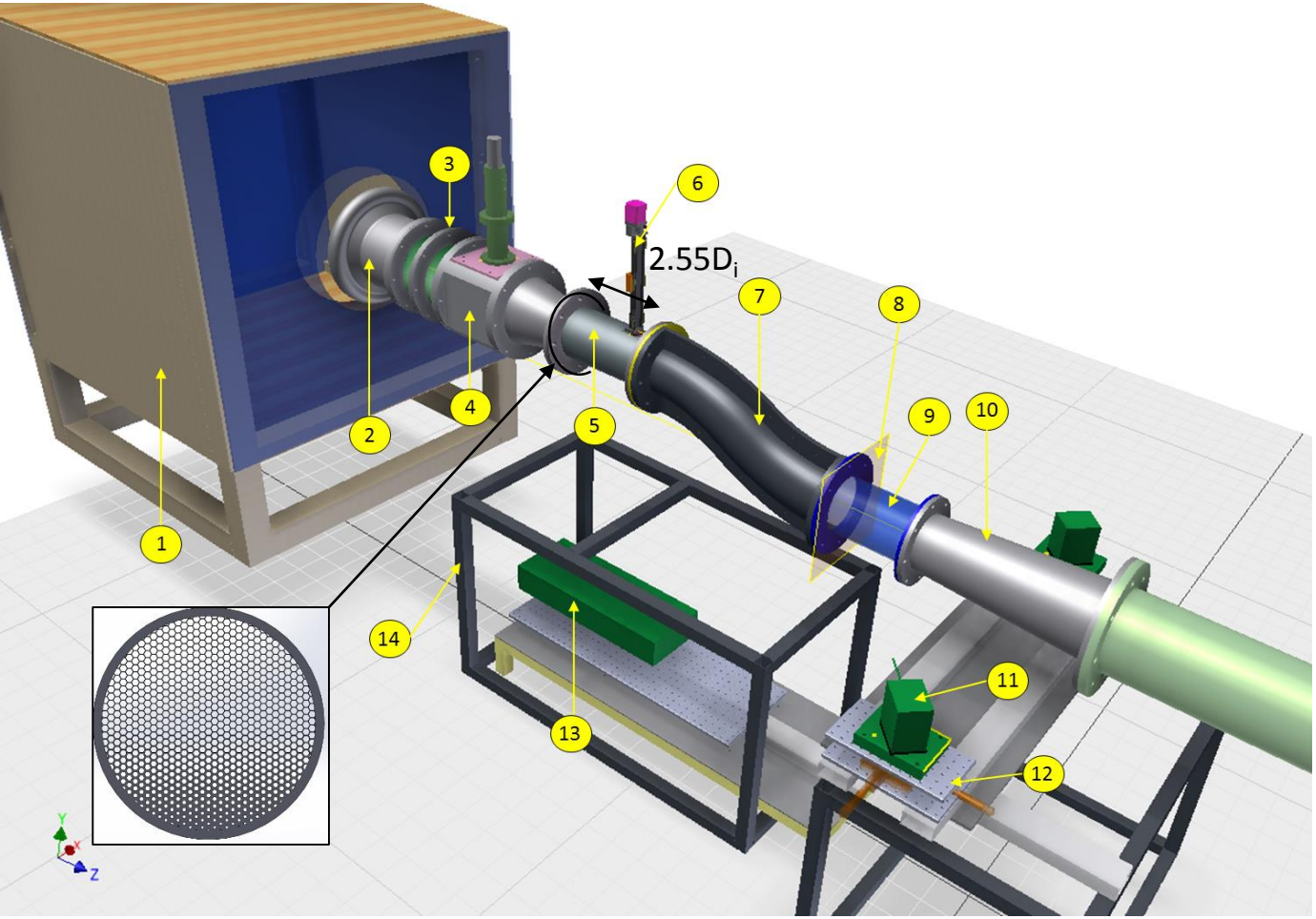
- Variable solidity final screen design.
- 3D printing production.







Experimental facility for bended intakes



1: Seeding chamber

2: Intake

3: Flow measurement section

4: Vortex generator section

5: Straight section

6: Inlet traverse station

7: S-duct

8: Measurement plane

9: Optical working section

10: Suction system

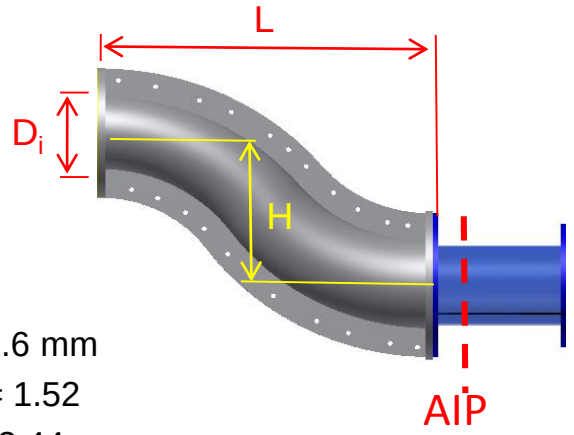
11: PIV camera

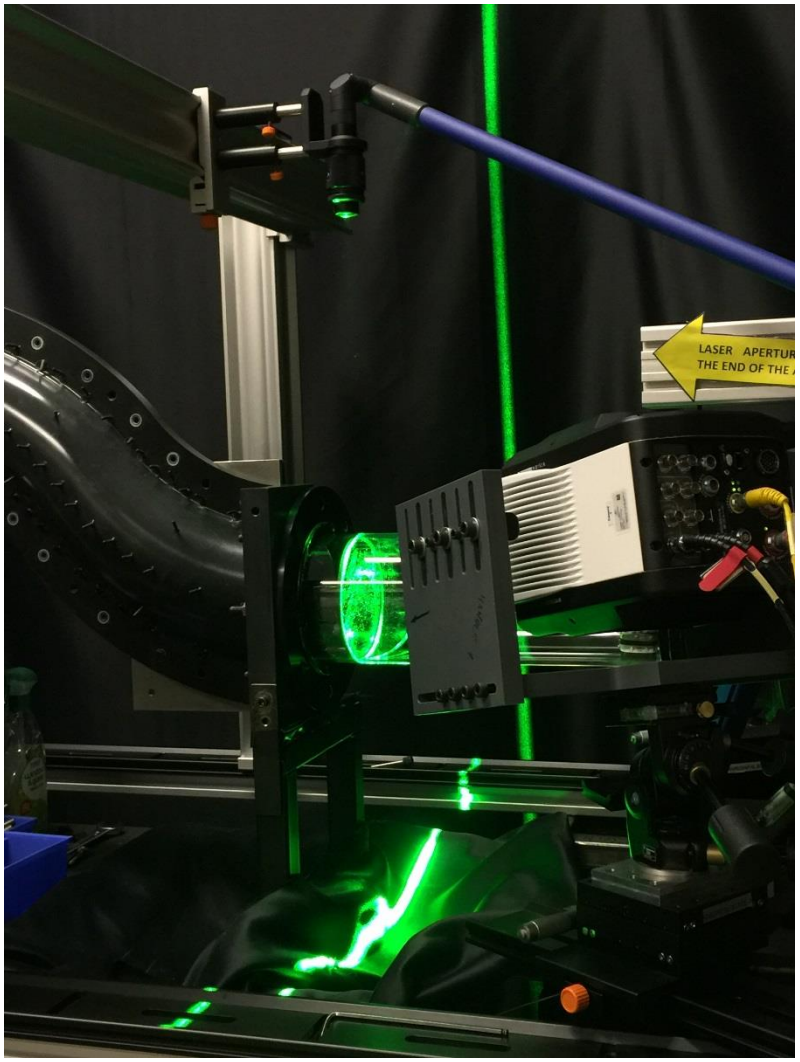
12: Camera traverse system

13: Laser

14: Support system

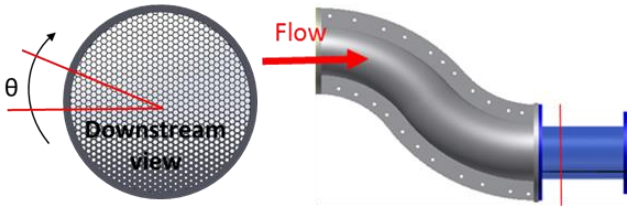
Time-Resolved PIV specifications





- **S-duct specifications**
  - Inlet diameter - D_i = 121.6 mm
  - Aspect ratio - A_{out} / A_{in} = 1.52
  - Vertical offset - H / D_i = 2.44
  - Length - L / D_i = 4.95
  - Inlet Mach - M_i = 0.27
  - Inlet Reynolds - Re_D = 7.48e+5
  - Screen distance from inlet - $L_S = 2.55D_i$
- **PIV measurement plane**
  - AIP diameter - D_{AIP} = 150 mm
  - Distance from S-duct outlet – $0.41D_{AIP}$
  - AIP Mach - $M_{AIP} \approx 0.21$
  - Velocity rep rate = 4 kHz
- **Time resolved stereo PIV (TR-S-PIV)**
  - Spatial resolution: ~2.3 x 2.3 mm
  - ~3,000 velocity vectors across D_{AIP}=150 mm
  - Fully synchronous data across the plane
  - 3-component velocity vector at cross-flow plane
  - Software: LaVision Davis v8.3

Time-resolved PIV – out of plane velocity

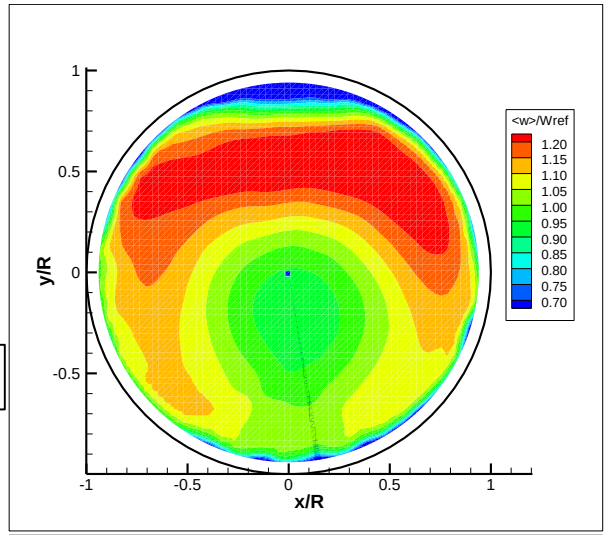


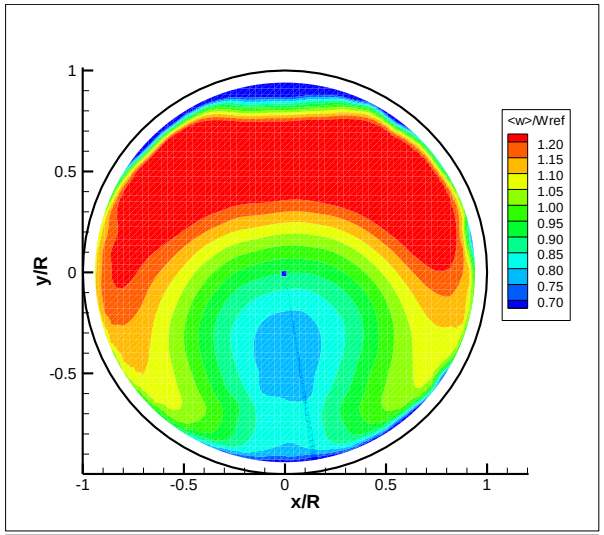
Time averaged out of plane velocity

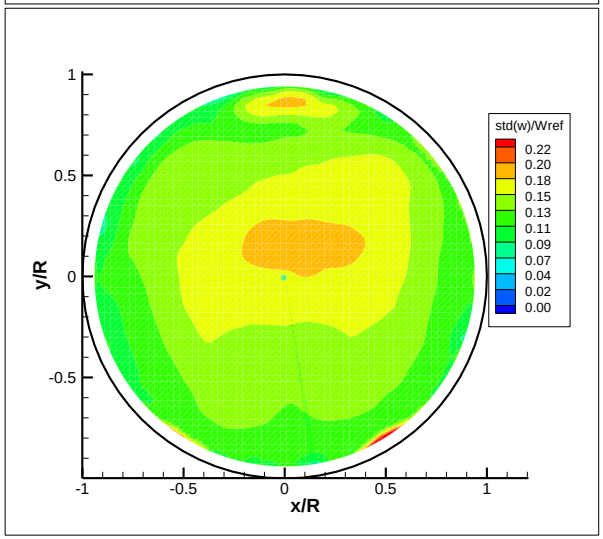
Out of plane velocity unsteadiness

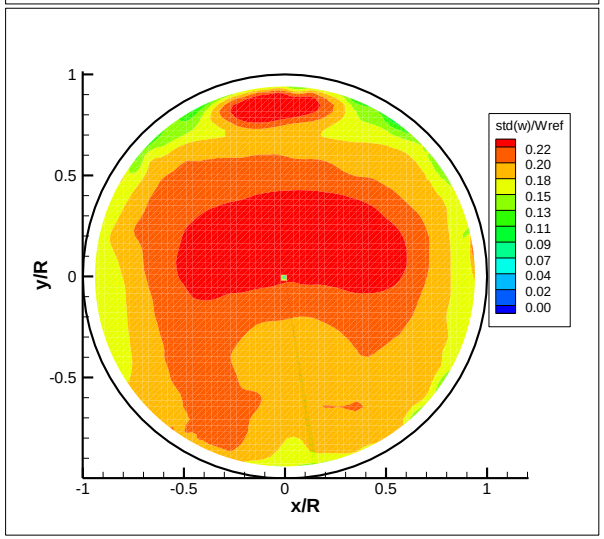
δ/D=0.04 - Clean

δ/D=0.336, θ = 0 deg

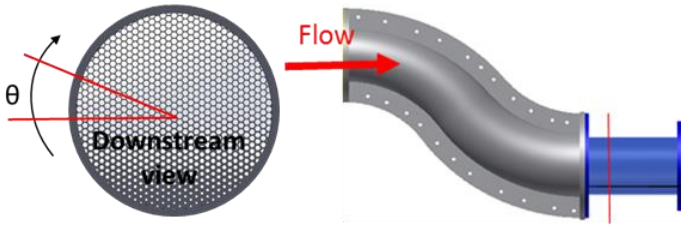








Time-resolved PIV



Time averaged velocity components

δ/D=0.336, θ=0º | δ/D=0.336, θ=45º | δ/D=0.336, θ=90º | δ/D=0.336, θ=135º | δ/D=0.336, θ=180º

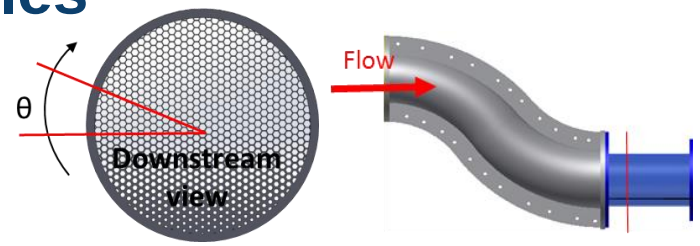
w/w_{ref}

v/w_{ref}

u/w_{ref}

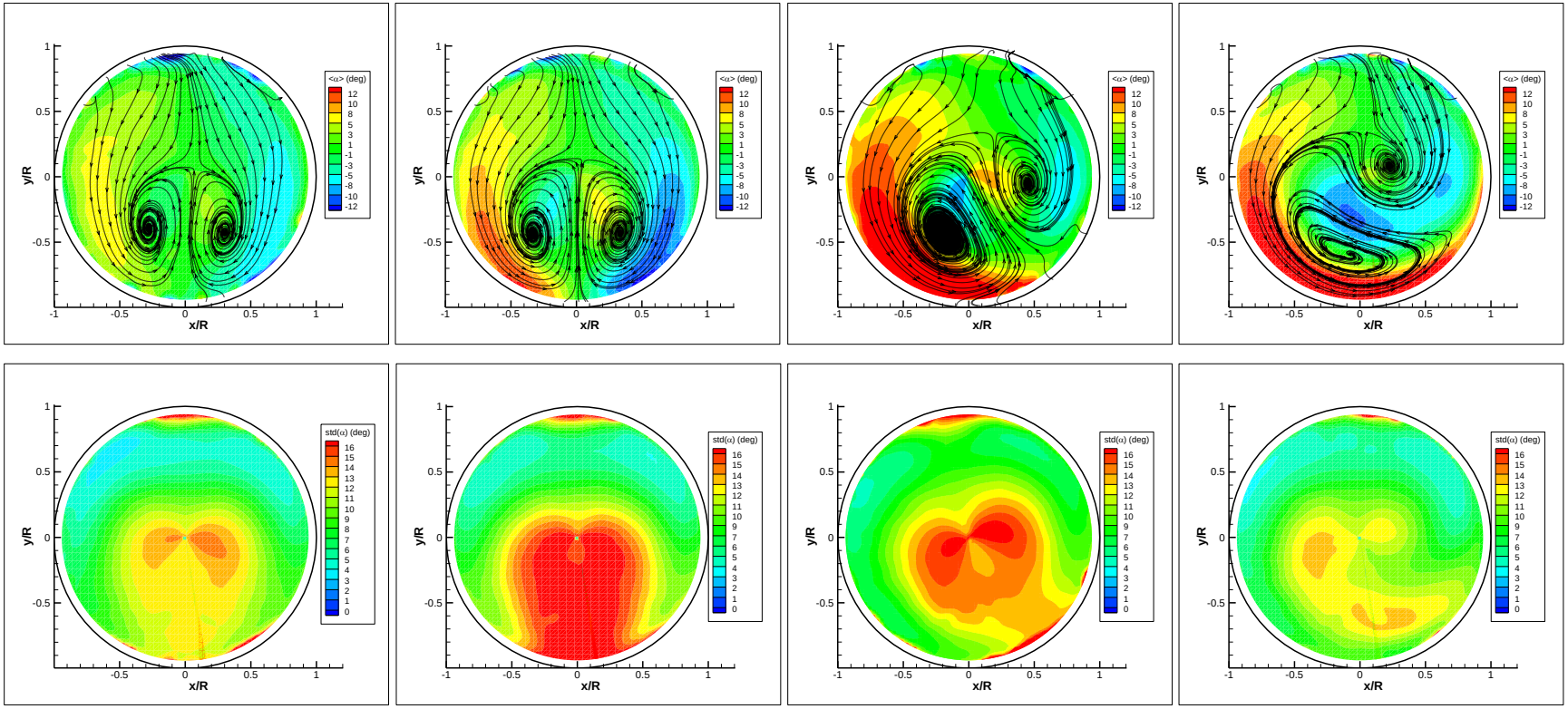
Time-resolved PIV – swirl angles

Swirl Angle



Time-averaged Swirl Angle

Standard Deviation

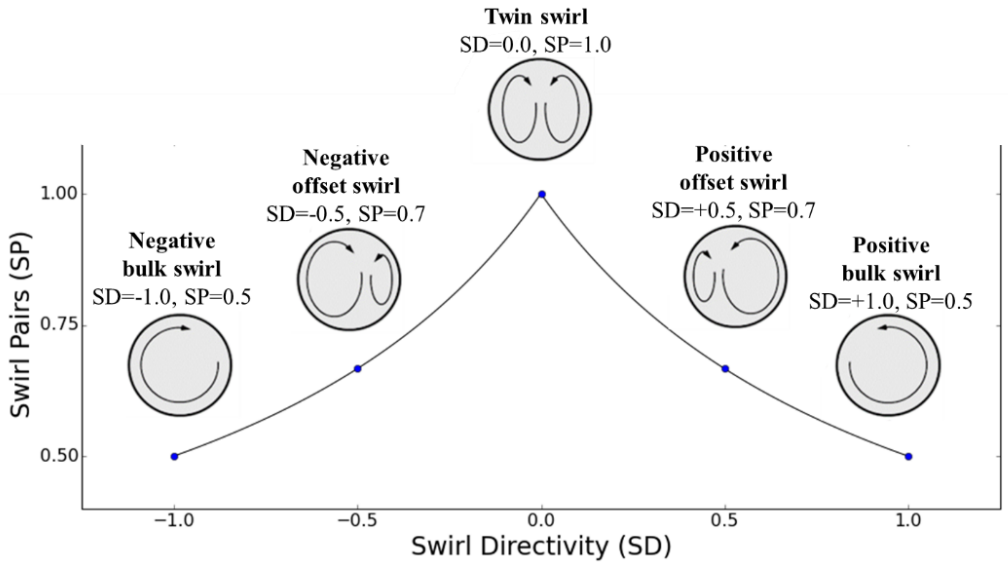


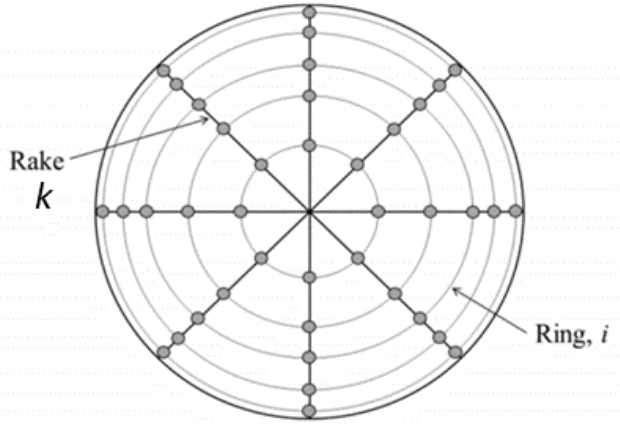
δ/D=0.04 - Clean | **δ/D=0.336, θ = 0º** | **δ/D=0.336, θ = 45º** | **δ/D=0.336, θ = 90º**

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

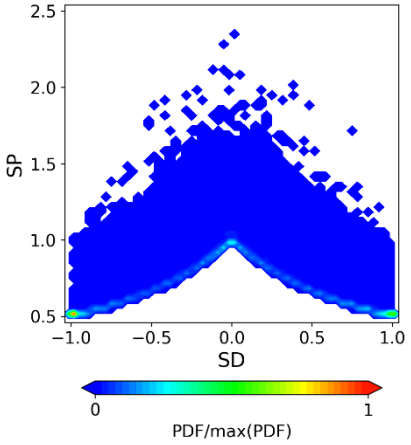




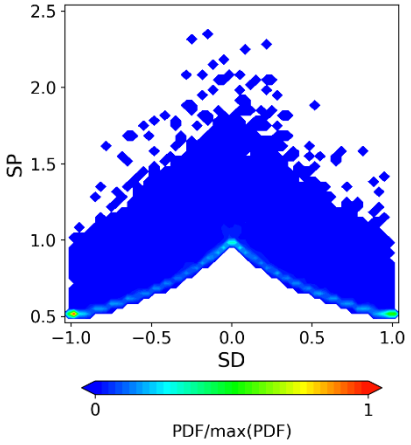
$$SS^{+}_{i,k} = \frac{1}{\theta^{+}_{i,k}} \int_{\theta^{+}_{i,k}} \alpha(\theta)_i \, d\theta \qquad SS^{-}_{i,k} = \frac{1}{\theta^{-}_{i,k}} \int_{\theta^{-}_{i,k}} \alpha(\theta)_i \, d\theta$$

(SAE, 2007)

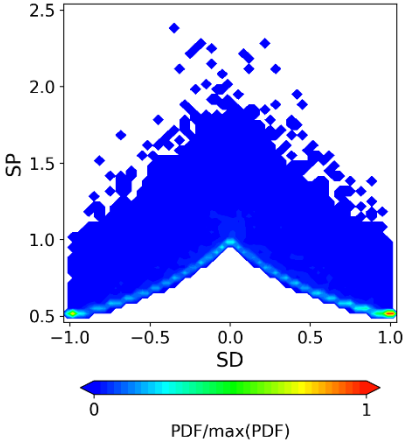
Time-resolved PIV – Swirl descriptors – Hub



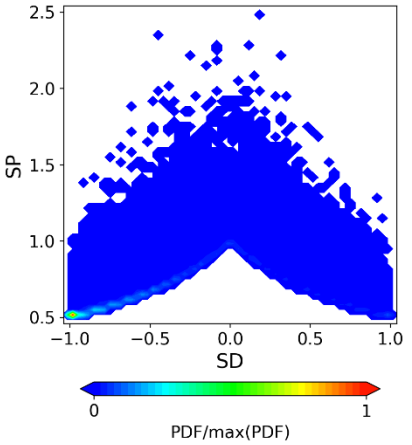
δ/D=0.04 - Clean



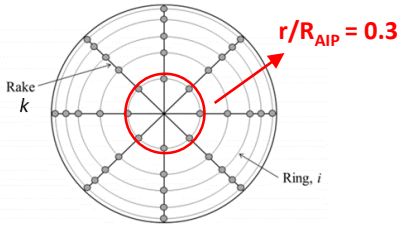
δ/D=0.336, θ = 0º

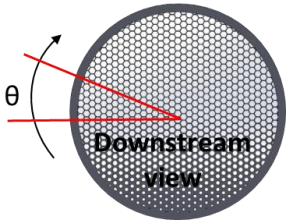


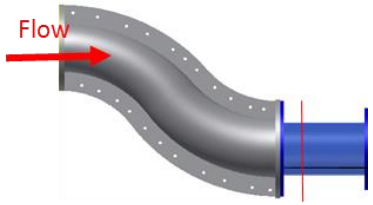
δ/D=0.336, θ = 45º

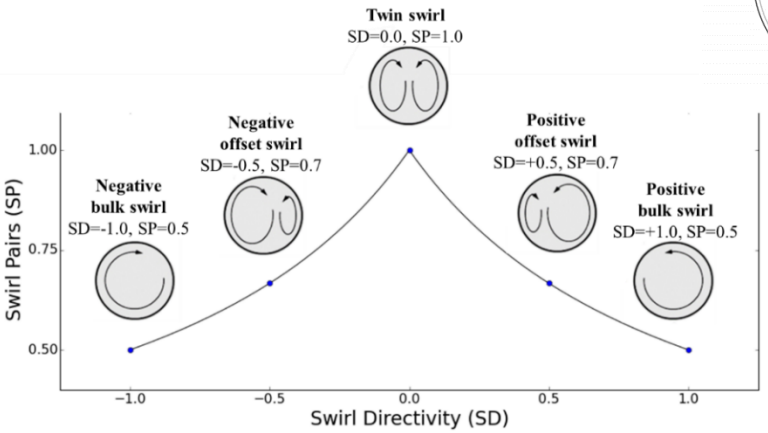


δ/D=0.336, θ = 90º



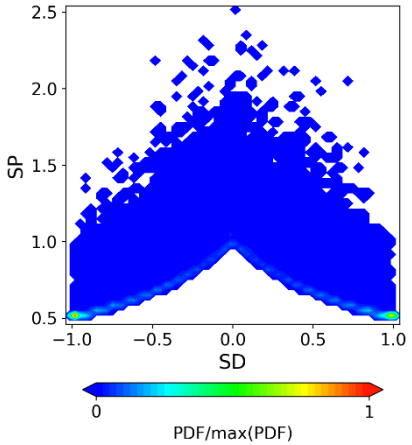




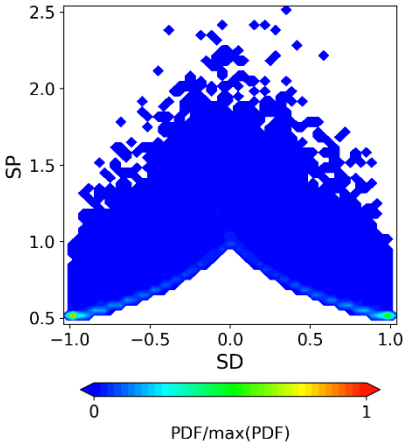


- No pattern variation between clean, 0 and 45 deg
- Negative bulk swirl locking for 90 deg case

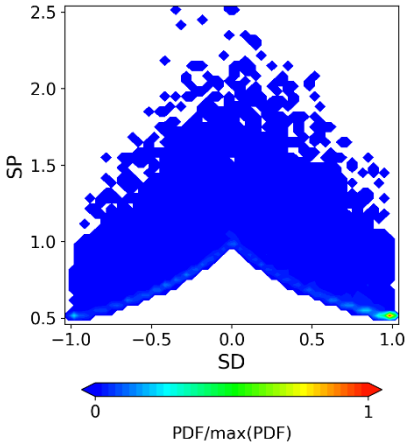
Time-resolved PIV – Swirl descriptors – Mid-span



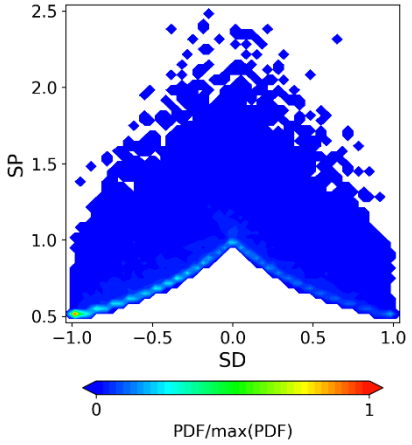
δ/D=0.04 - Clean



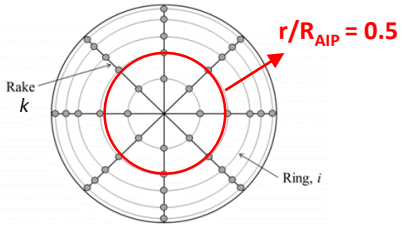
δ/D=0.336, θ = 0º

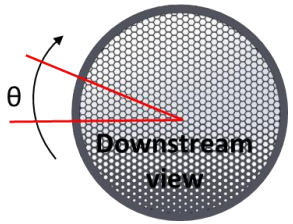


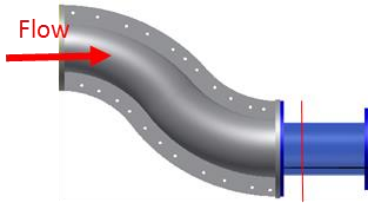
δ/D=0.336, θ = 45º

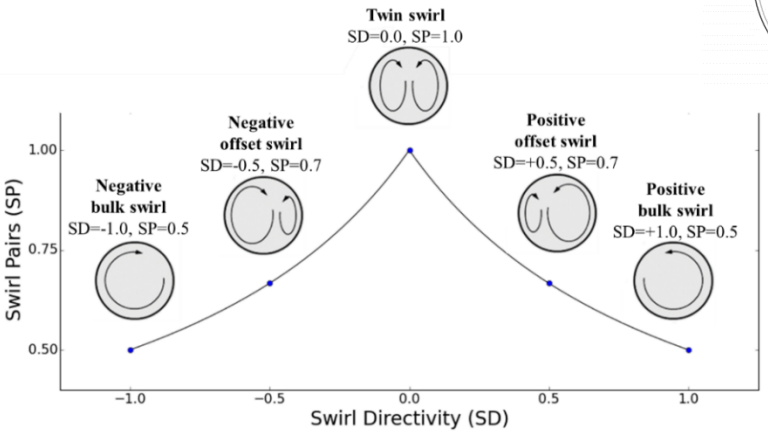


δ/D=0.336, θ = 90º



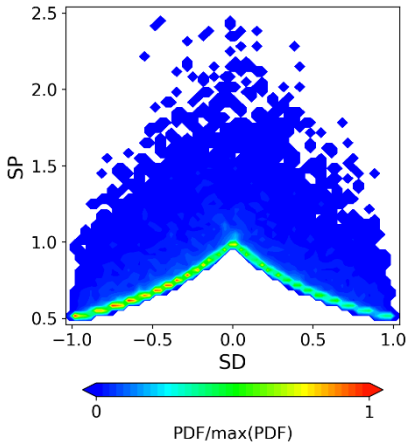




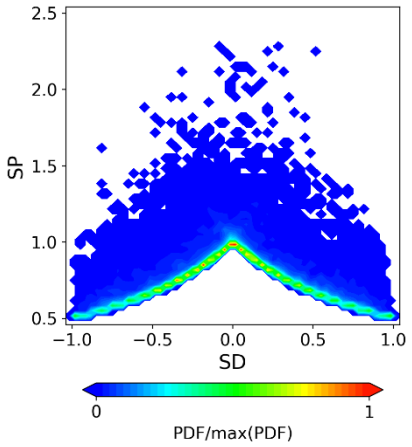


- No pattern variation between clean and 0 deg case
- Positive bulk swirl locking for 45 deg case
- Predominant negative bulk swirl for 90 deg case

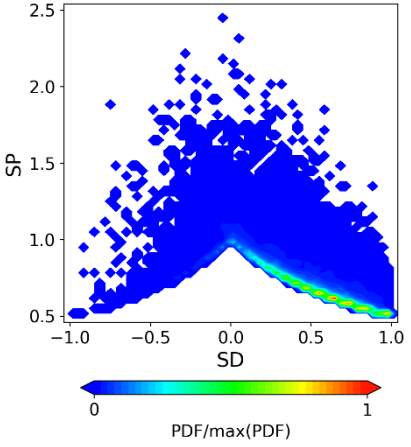
Time-resolved PIV – swirl descriptors – Tip



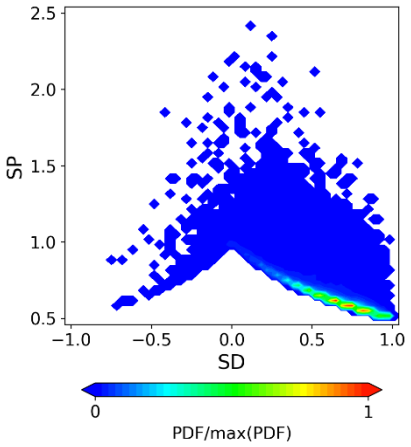
δ/D=0.04 - Clean



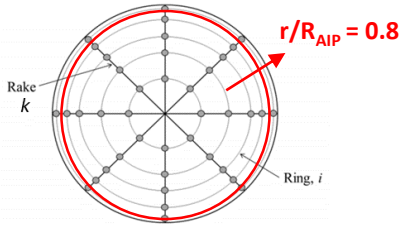
δ/D=0.336, θ = 0º

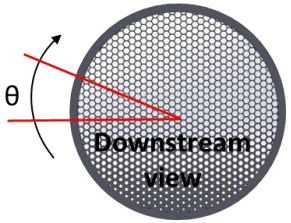


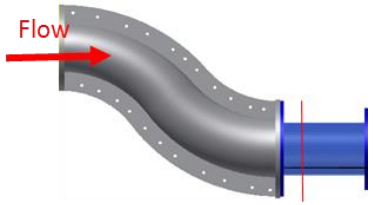
δ/D=0.336, θ = 45º

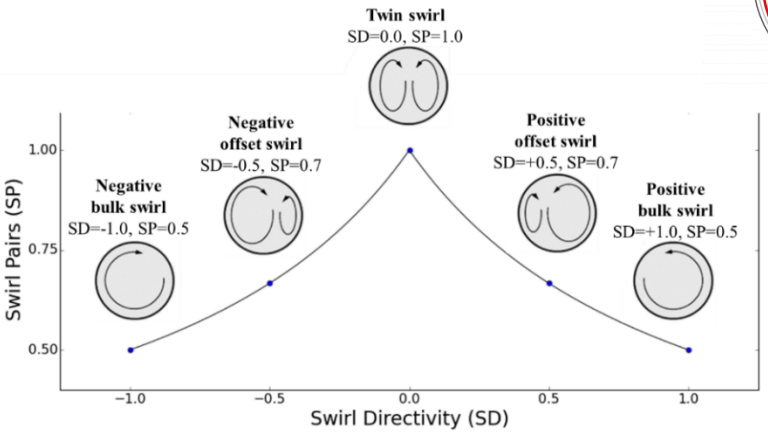


δ/D=0.336, θ = 90º



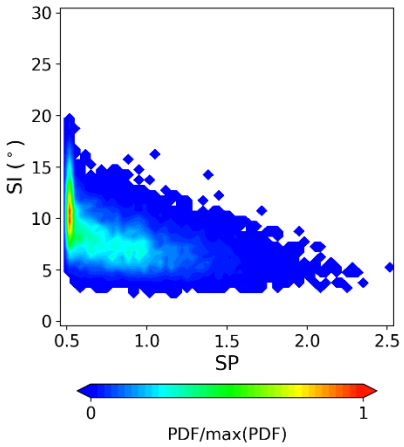




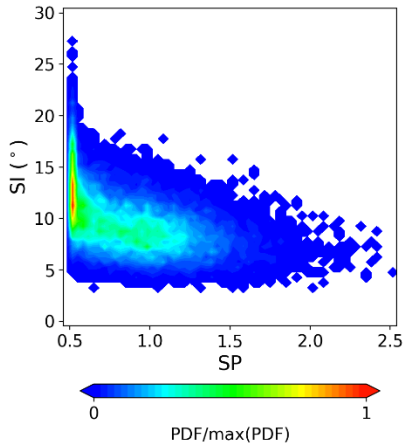


- Promotion of twin swirl events at 0 deg
- Shift to positive swirl developing at 45 deg
- Predominance of positive swirl at 90 deg

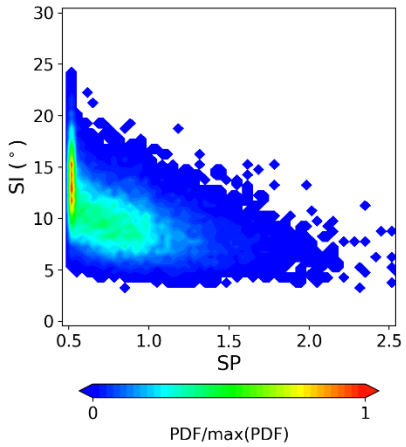
Time-resolved PIV – Swirl descriptors – Intensity



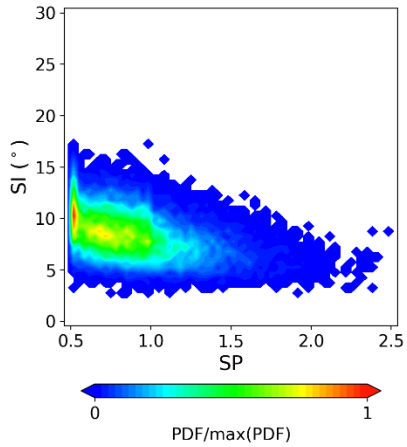
δ/D=0.04 - Clean



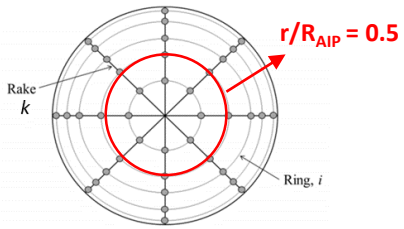
δ/D=0.336, θ = 0º

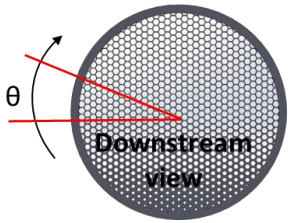


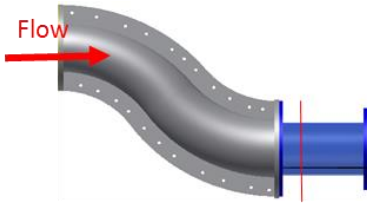
δ/D=0.336, θ = 45º



δ/D=0.336, θ = 90º







- **δ/D=0.336, θ = 0º** - swirl intensity peak values increased by 40%.
- **δ/D=0.336, θ = 90º** - narrow range – intensification of bulk swirl events.

Conclusions

- Inlet pressure profile generation via flow distortion screens.
- Inlet flow profile characteristics enable off-design intake operating points.
- Inlet δ/D has notable impact on AIP velocity unsteadiness.
- Increase of swirl angle range – identification of non-uniform blade loading areas.
- Distortion screen has different effect on tip-hub swirl angle topology.
- Increase of swirl intensity up to 40% in negative bulk swirl topology.

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