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Cranfield Aerospace

Total pressure distortion measurements in S-duct aero-engine intakes

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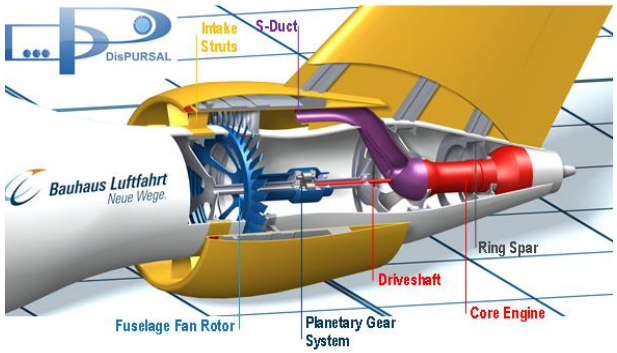
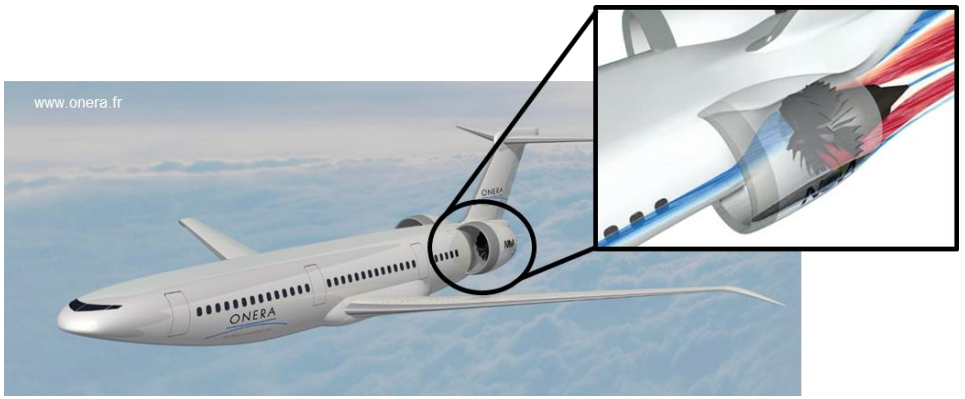
Agenda

- Introduction
- Experimental facility and measurement methods
- Time averaged total pressure and swirl
- Unsteady pressure measurements
- Spectra and cross-correlation
- Conclusions and overview

Research rationale

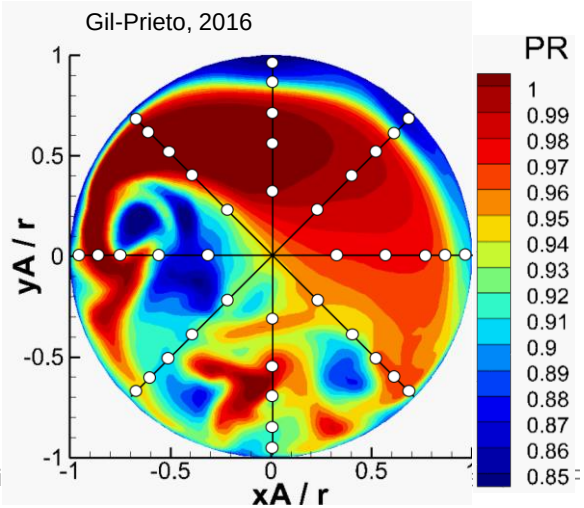


http://www.bauhaus-luftfahrt.net



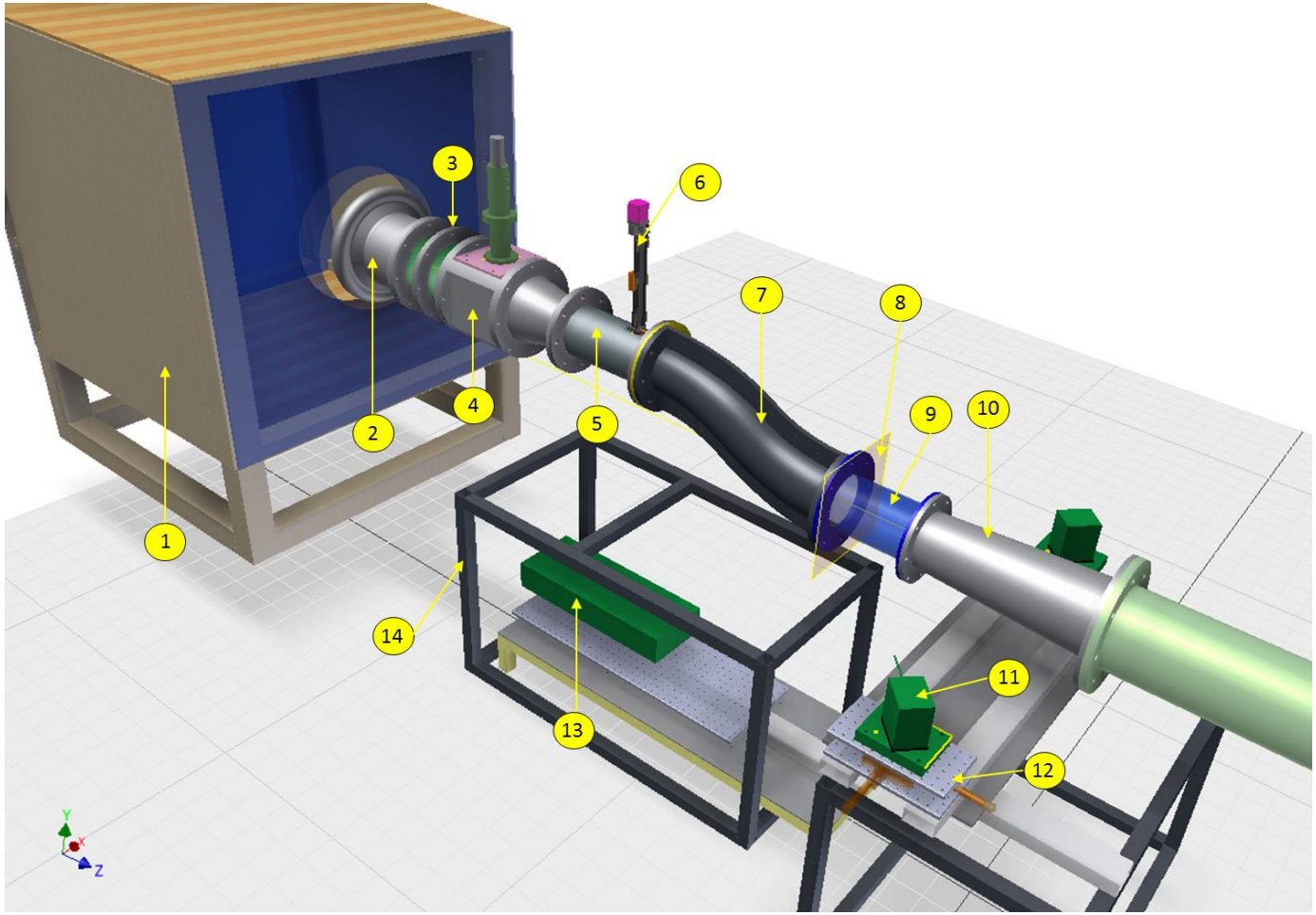
Tanguy, 2017

Gil-Prieto, 2016



- Future civil embedded and semi-embedded propulsion systems
- Boundary Layer Ingestion.
- Distributed, electric or hybrid electric.
- **Common aspect:** unsteady aerodynamics.
- 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: Pressure working section position

10: Suction system

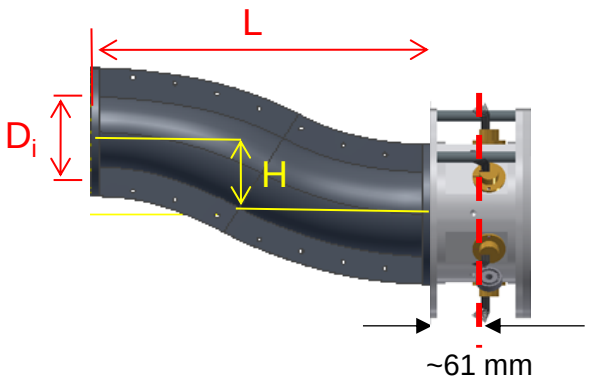
11: PIV camera

12: Camera traverse system

13: Laser

14: Support system

S-duct configurations



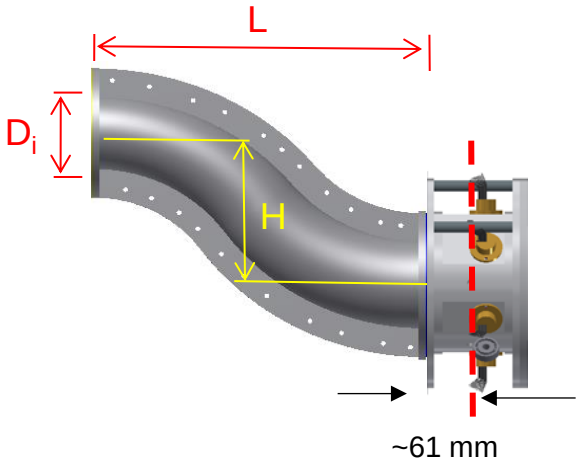
D_i = 121.6 mm

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

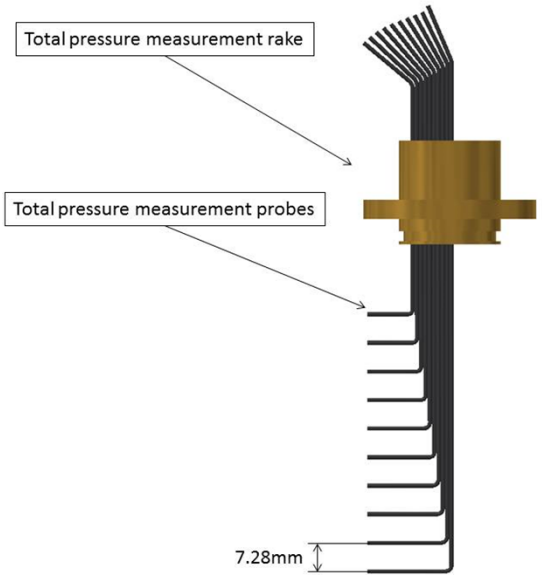
A_{out} / A_{in} = 1.52

H / D_i = 2.44

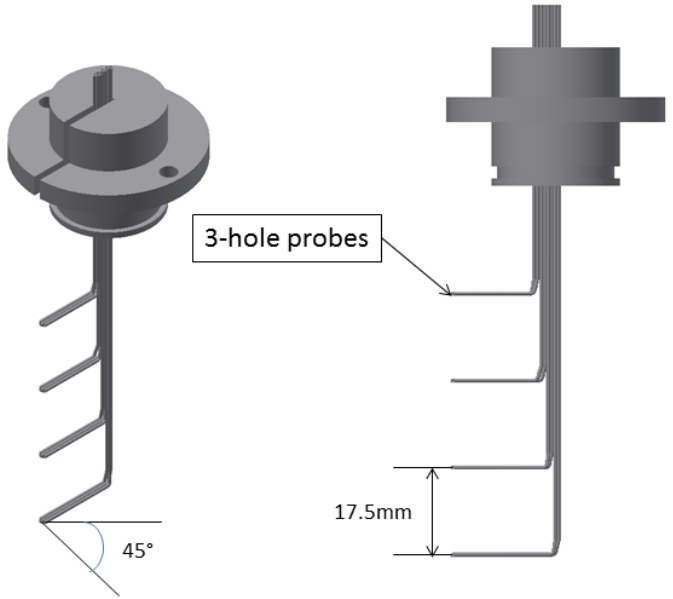
L / D_i = 4.95

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

Total pressure and swirl measurement rakes

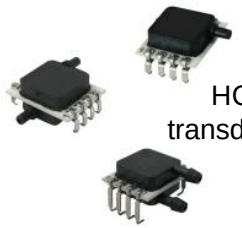


- Gauge 19 steel hypodermic tube.
- 10 probes per rake.
- 6 rakes – 60 probes.
- Equi-spaced at 60°.
- 20 radial measurement points per rake.



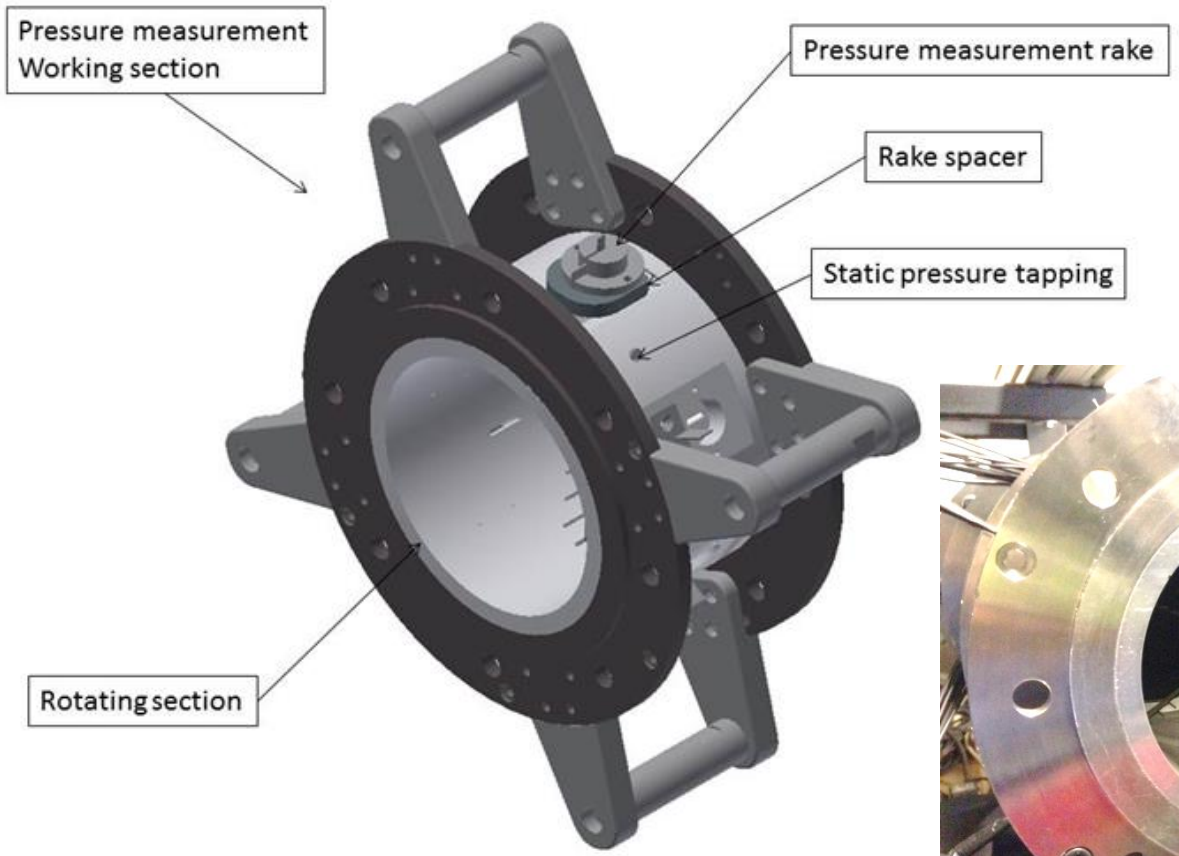
- Gauge 21 steel hypodermic tube.
- x4 3-hole L-shape probes per rake.
- 6 rakes – 24 probes.
- Equi-spaced at 60°.
- 24 radial measurement points per rake.

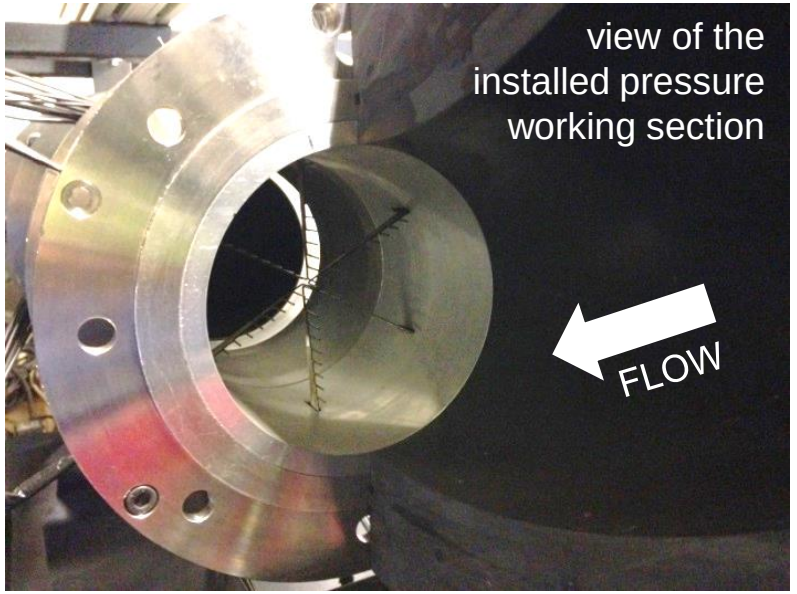
- Amplified transducers HCEM500 by First sensor.
- Up to 1000 samples per second.
- Uncertainties of $\delta P_{0,ref}$ and $\delta\langle\overline{P_0}_{\mathrm{AIP}}\rangle$ - 226.9 Pa and 107.5 Pa
- Pressure recovery uncertainty 0.0029 for $M^*_{ref} = 0.27$ and 0.0028 for $M^*_{ref} = 0.6$



HCEM500 amplified transducers by First sensor

Pressure working section

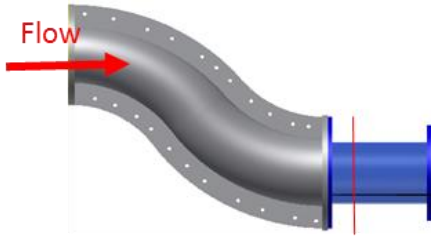




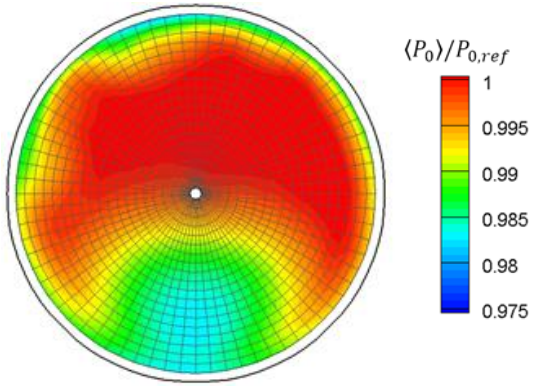
- 5° azimuthal resolution – 12 positions for 360°.
- 1440 measurement points for total pressure survey.
- 1728 measurement points for swirl survey.
- Adjustable rotation step – up to 1° resolution capability.

AIP time averaged total pressure

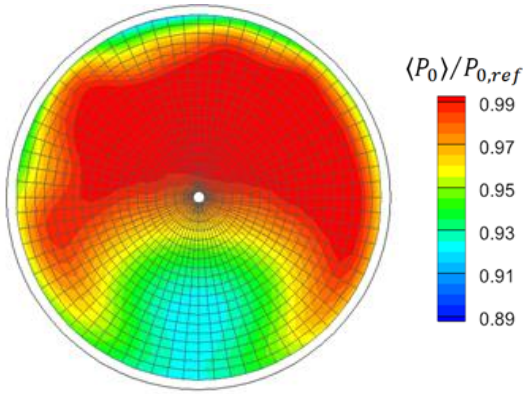
Low offset duct



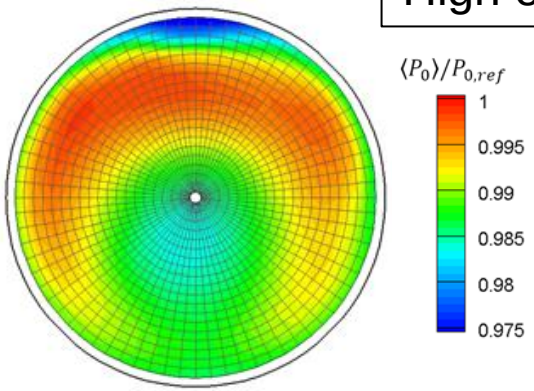
Mach 0.27

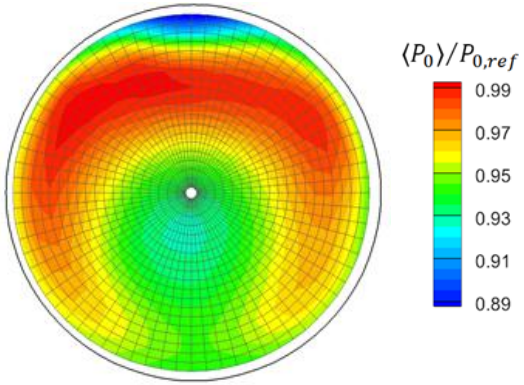


Mach 0.60



High offset duct





AIP total pressure distortion descriptors

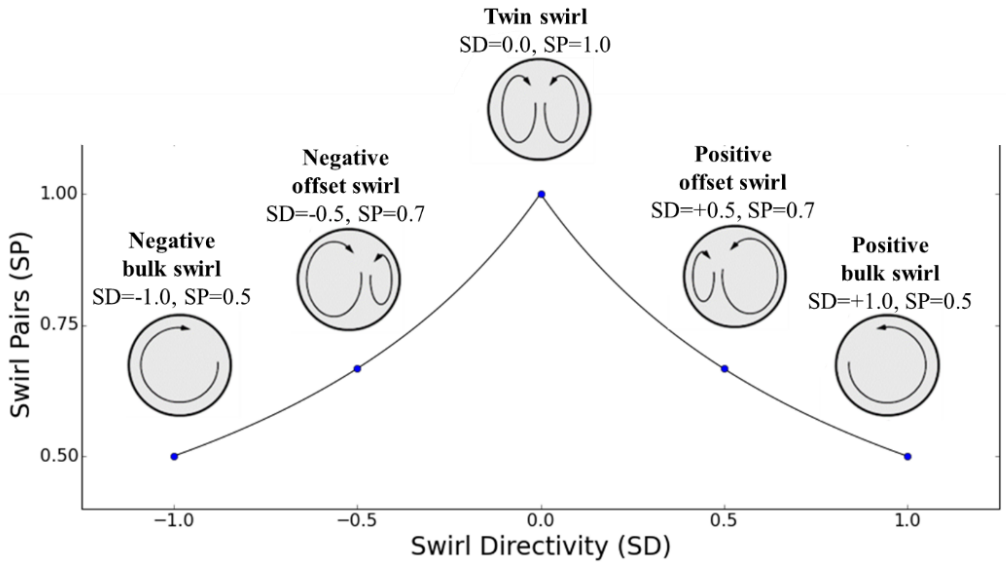
Type	Configuration	Inlet Mach	Resolution (rakes x rings)	mean PR	mean DC60	mean CDI	mean RDI
Total Pressure	High offset	0.27 0.60	72 x 20	0.990 0.958	0.164 0.186	0.013 0.058	0.005 0.025
	Low offset	0.27 0.60	72 x 20	0.994 0.969	0.187 0.209	0.013 0.058	0.006 0.0027

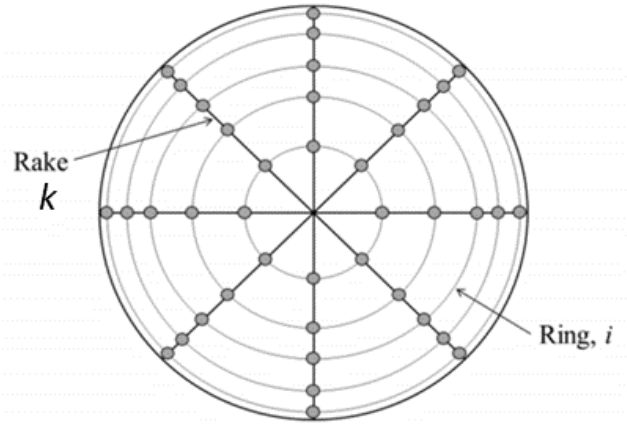
- Main loss region has approximately the same peak loss magnitude for both configurations.
- Total pressure loss dependent on inlet Mach and S-duct offset.
- DC60 and CDI also dependent on inlet Mach and S-duct offset.
- Modest impact of offset in RDI. Dependent on inlet Mach.

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

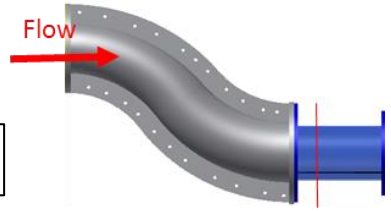




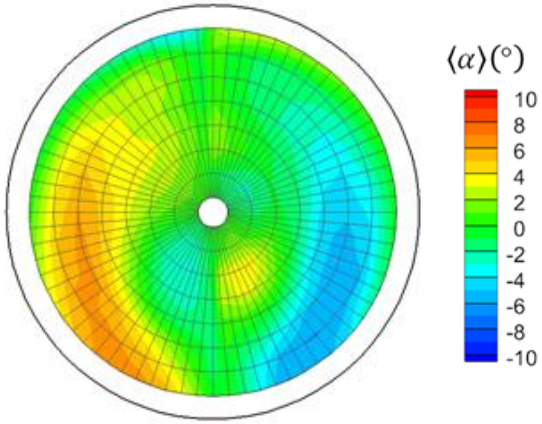
$$SS^{+}_{i,k} = \frac{1}{\theta^{+}_{i,k}} \int_{\theta^{+}_{i,k}} \alpha(\theta)_i \, d\theta \qquad SS^{-}_{i,k} = \frac{1}{\theta^{-}_{i,k}} \int_{\theta^{-}_{i,k}} \alpha(\theta)_i \, d\theta$$

(SAE, 2007)

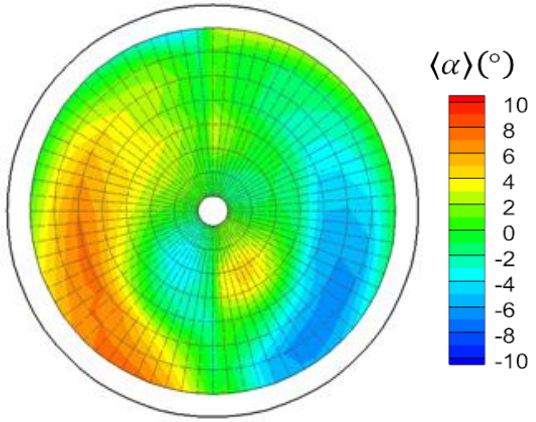
AIP pressure based swirl angle and distortion descriptors



Low offset duct - Mach 0.27

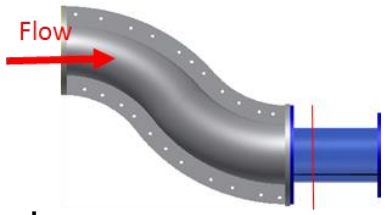


Low offset duct - Mach 0.60



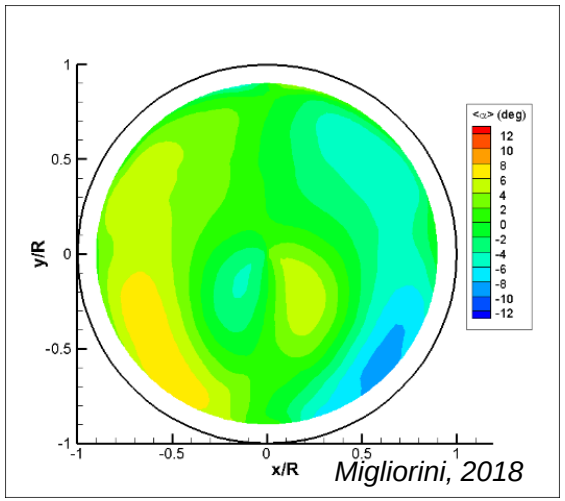
Type	S-duct	Inlet Mach	Resolution (rakes x rings)	mean SI	mean SD	mean SP
Pressure based Swirl	High offset	0.27 0.60	72 x 8	2.52 2.82	0.08 0.11	1.09 1.07
	Low offset	0.27 0.60	72 x 8	2.29 2.39	-0.02 -0.17	0.91 1.01

PIV and pressure based swirl angles



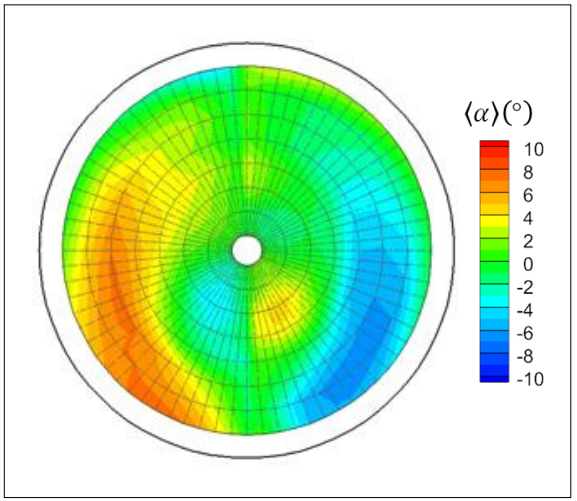
Low offset duct - Mach 0.60

PIV derived swirl angle



Migliorini, 2018

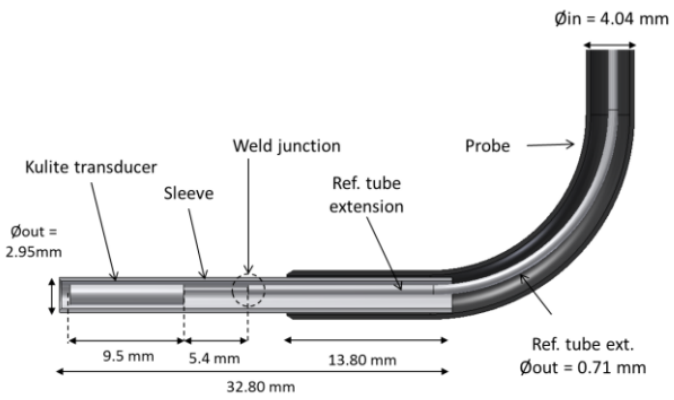
Pressure derived swirl angle

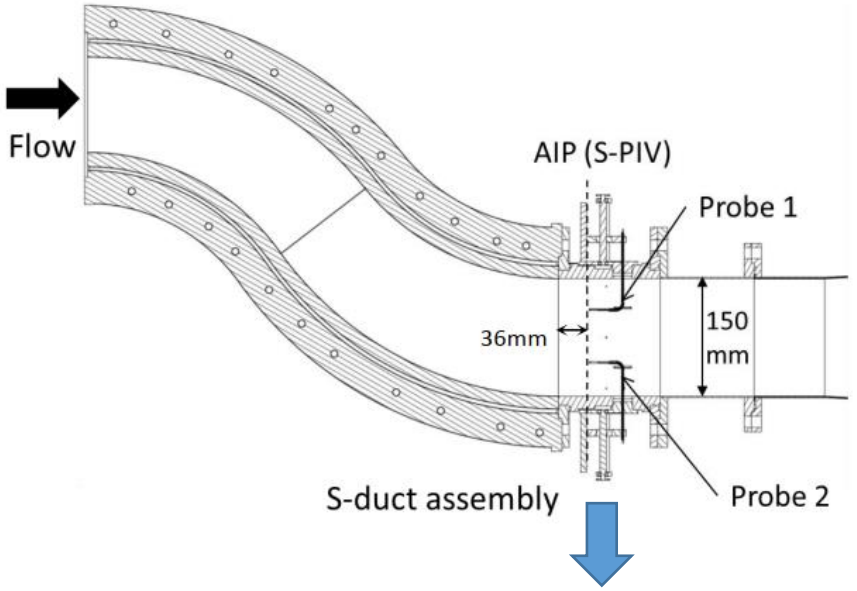


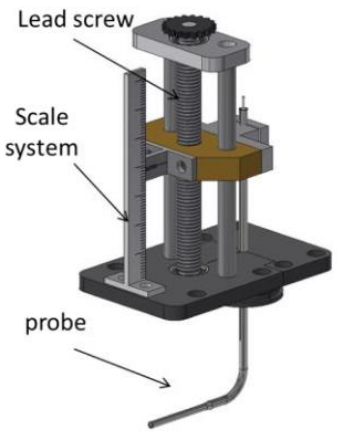
- Pressure based swirl angles in agreement with PIV results.
- Previous work has demonstrated the potential to reconstruct AIP total pressure profiles and descriptors from PIV results (Zachos et. al., 2016).
- Potential benefit to engine operability campaign timescales.

Unsteady pressure measurements

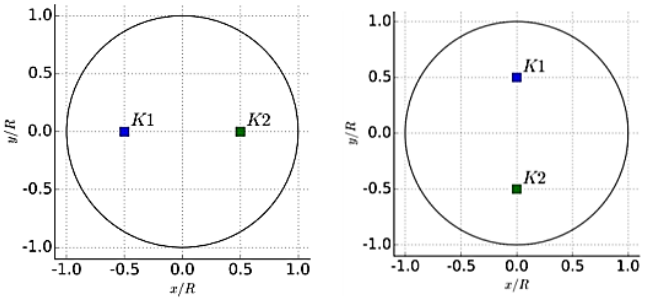
Instrumentation specification and setup





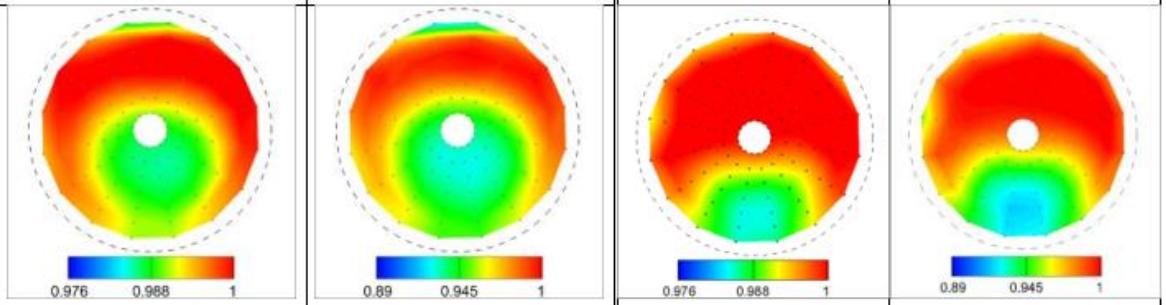
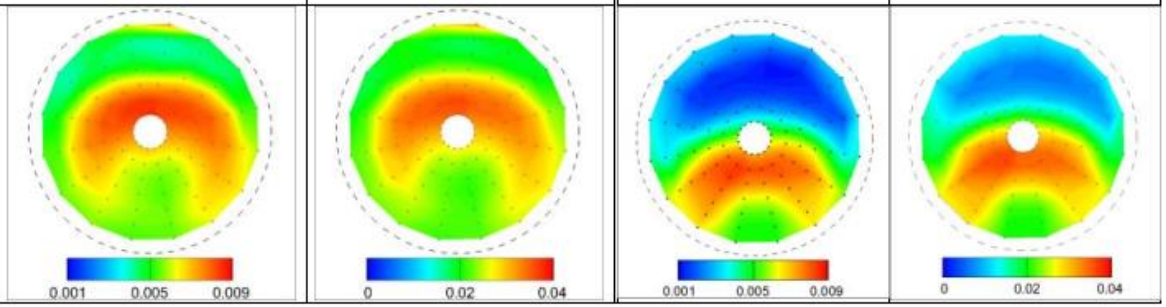


- x2 KULITE ultra-miniature XCS-062
- 5 psid – 0.1% full-scale accuracy
- 2.95 mm probe tip diameter
- Axial measurement plane at 0.24D_{out}
- Cross-correlation at the AIP



Unsteady pressure measurements

Mean and unsteady AIP distributions

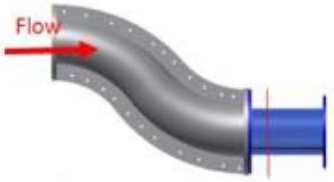
	High-offset (H_o/L=0.493)		Low-offset (H_o/L=0.268)	
	$M_{in} = 0.27$	$M_{in} = 0.60$	$M_{in} = 0.27$	$M_{in} = 0.60$
$\frac{p0}{p0_{ref}}$				
$\frac{\sigma(p0)}{p0_{ref}}$				

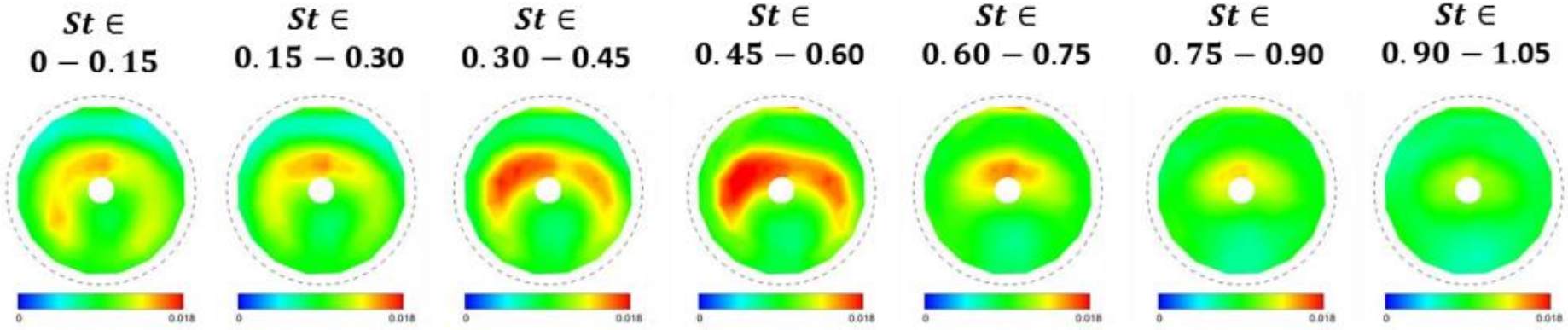
Unsteady pressure measurements

Banded spectra

$M_{in} = 0.60$

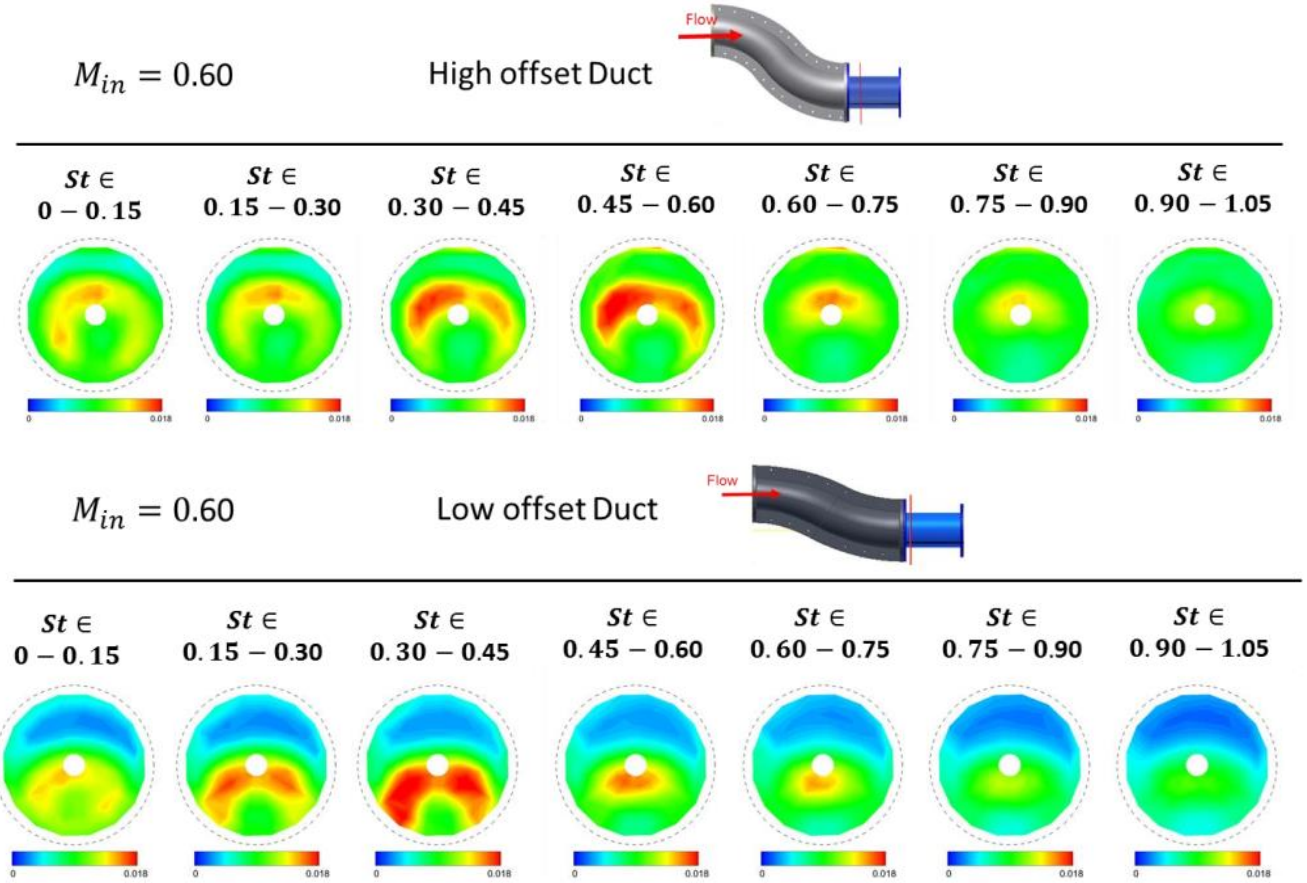
High offset Duct





Unsteady pressure measurements

Banded spectra



Unsteady pressure measurements

Multi-point lateral cross correlation

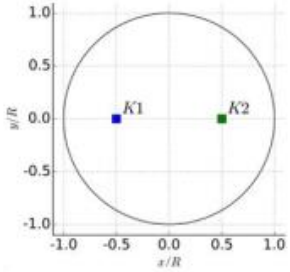
High offset

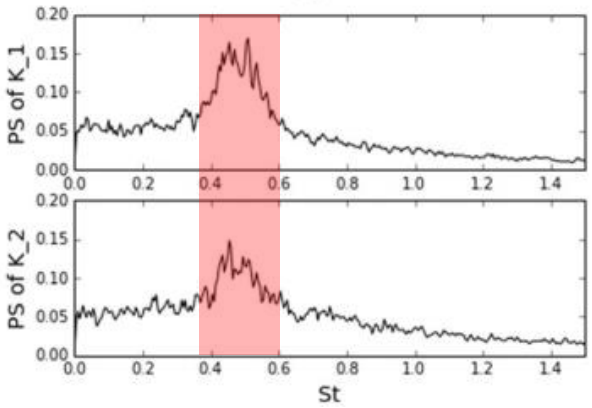
Ho/L=0.49

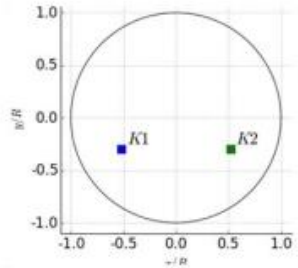
$M_{inlet} = 0.60$

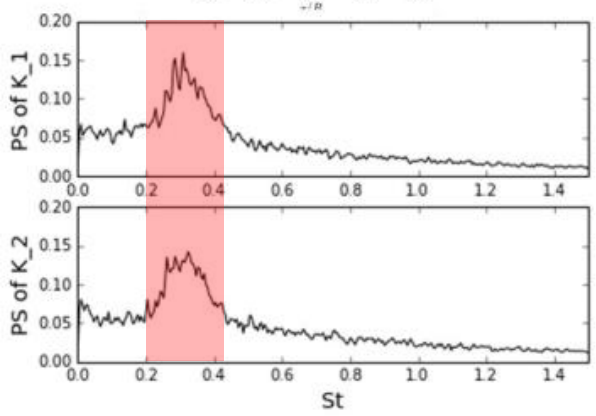
Low offset

Ho/L=0.26









Conclusions

- Flexible configuration for AIP total pressure and pressure based swirl survey.
- Unsteady pressure systems enables AIP spectral analyses and cross-correlations.
- Results provided conventional pressure distortion metrics and total pressure distributions which are overall in agreement with the established literature.
- Identification of flow switching modes via AIP unsteady pressure measurements.

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