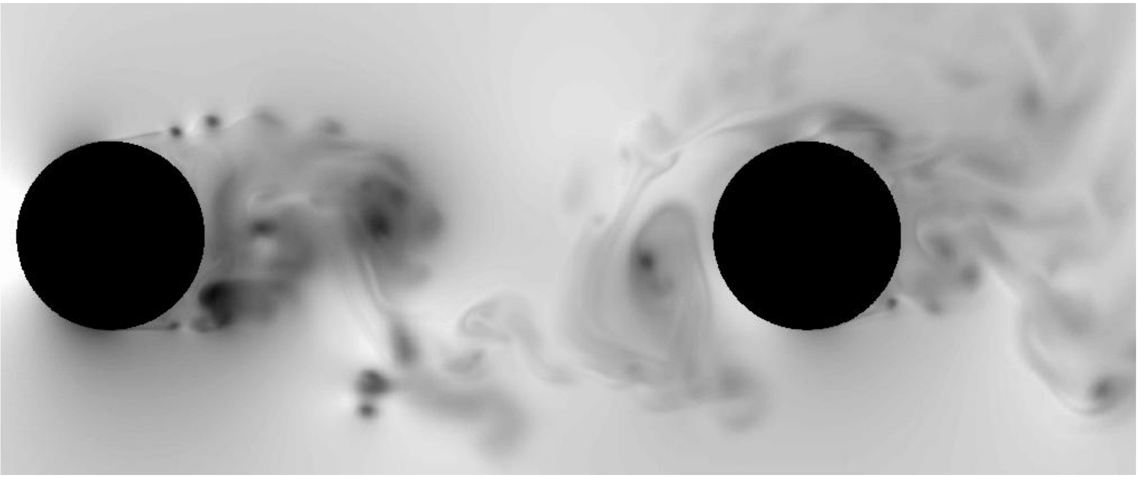
Tandem Cylinder Benchmark Problem

Experiment Description and Results



Dan H. Neuhart

Flow Physics and Control Branch

David P. Lockard, Meelan Choudhari,

and Mehdi Khorrami

Computational AeroSciences Branch

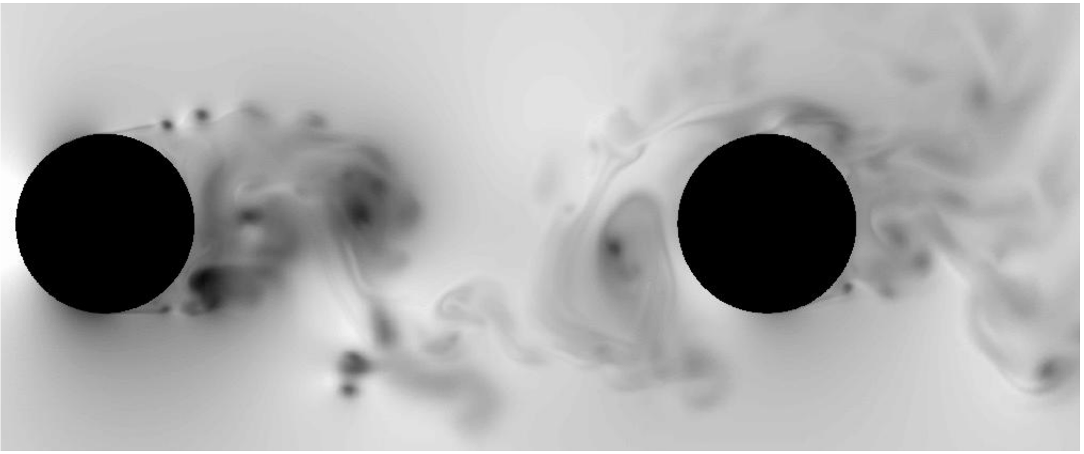
NASA Langley Research Center

Workshop on Benchmark problems for Airframe Noise Computations (BANC) – I, June 10-11, 2010

This talk describes the tandem cylinder experiments

Motivation

Physics

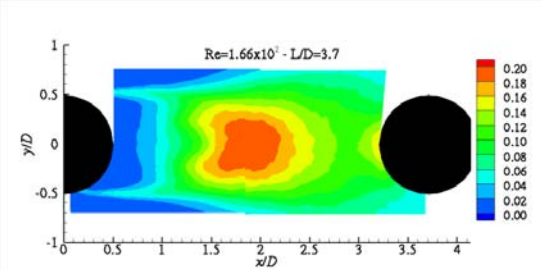


Experiments

Facilities : - Basic Aerodynamic Research Tunnel (BART)

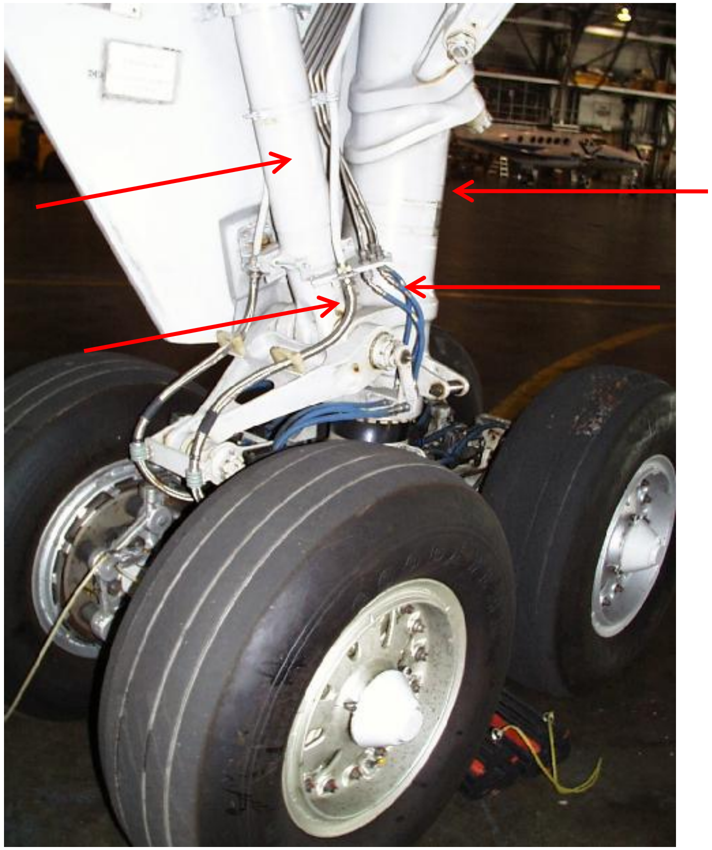
- Quiet Flow Facility (QFF)

Data

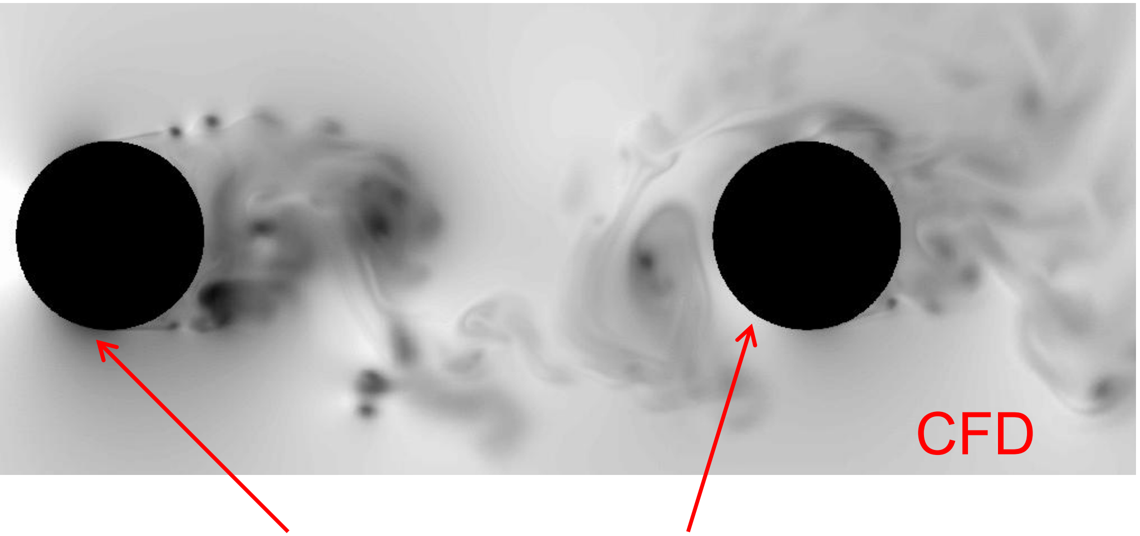


Why Study Inline Tandem Cylinders?

- Exhibit physics similar to flow around airframe components such as the landing gear
  - Boundary layer growth
  - Instabilities
  - Vortex rollup and shedding
  - Wake propagation
  - Wake impingement
- Simple geometry
  - Can isolate effects
  - Grid generation less difficult

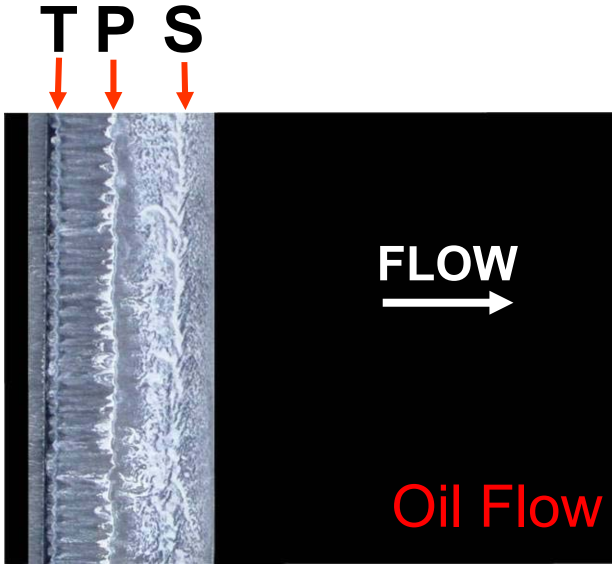


Physics – it was desired to provide post-critical ($Re_D > 4.0 \times 10^5$) flow characteristics



- Turbulent boundary layers

- Separation point determines trajectory of shear layer



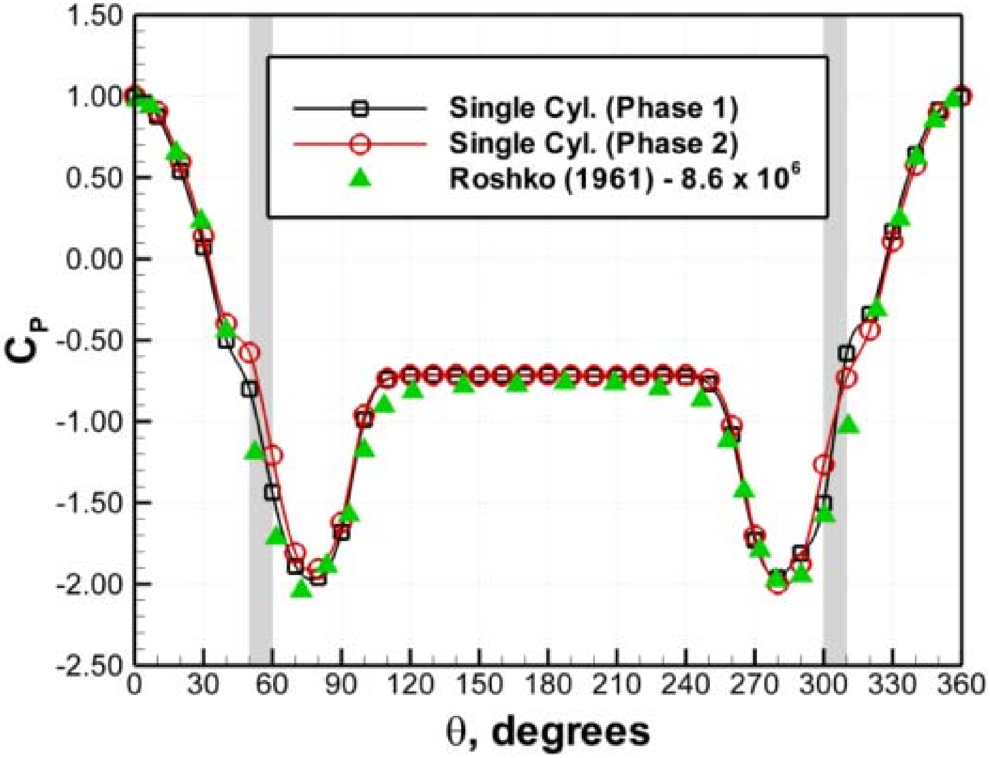
Trip

Primary separation

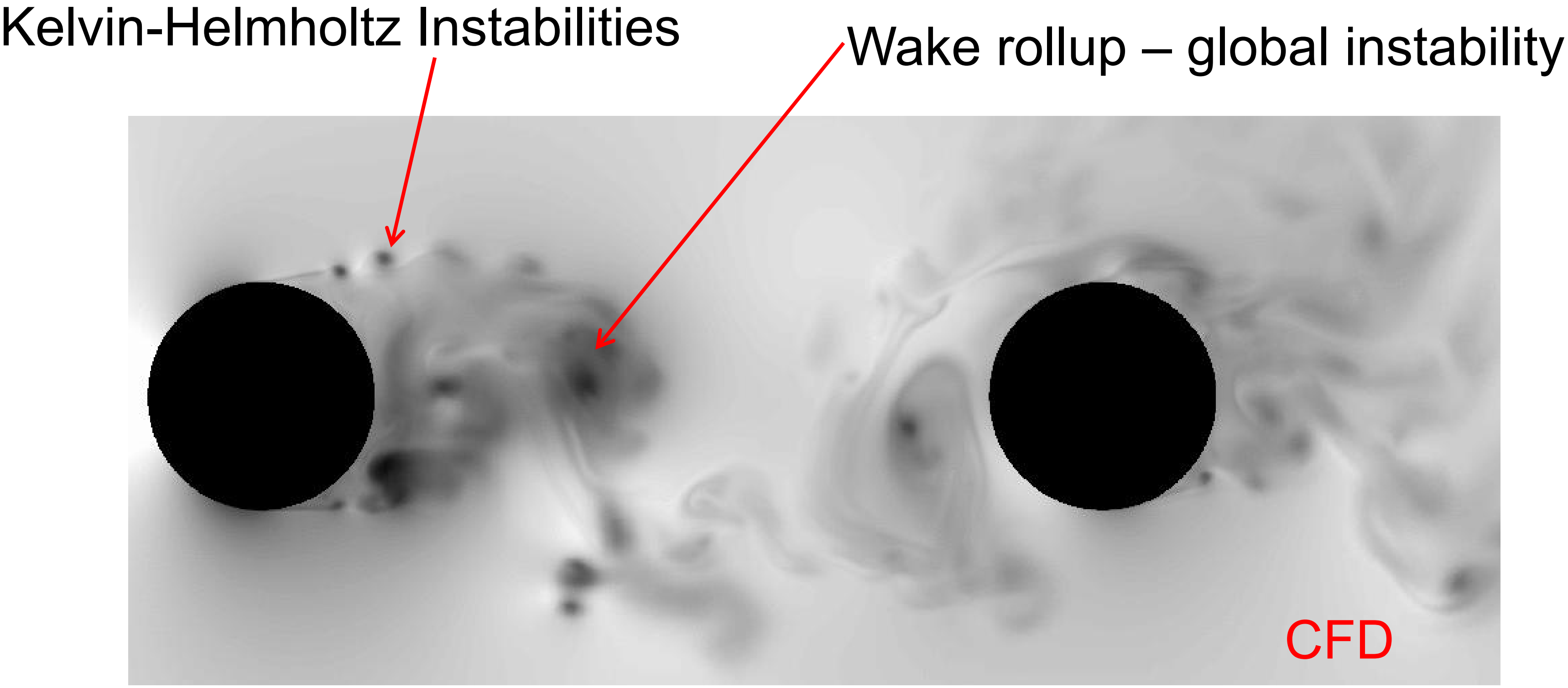
Secondary separation

Physics - the BL trip was used to provide post-critical ($Re_D > 4.0 \times 10^5$) flow characteristics

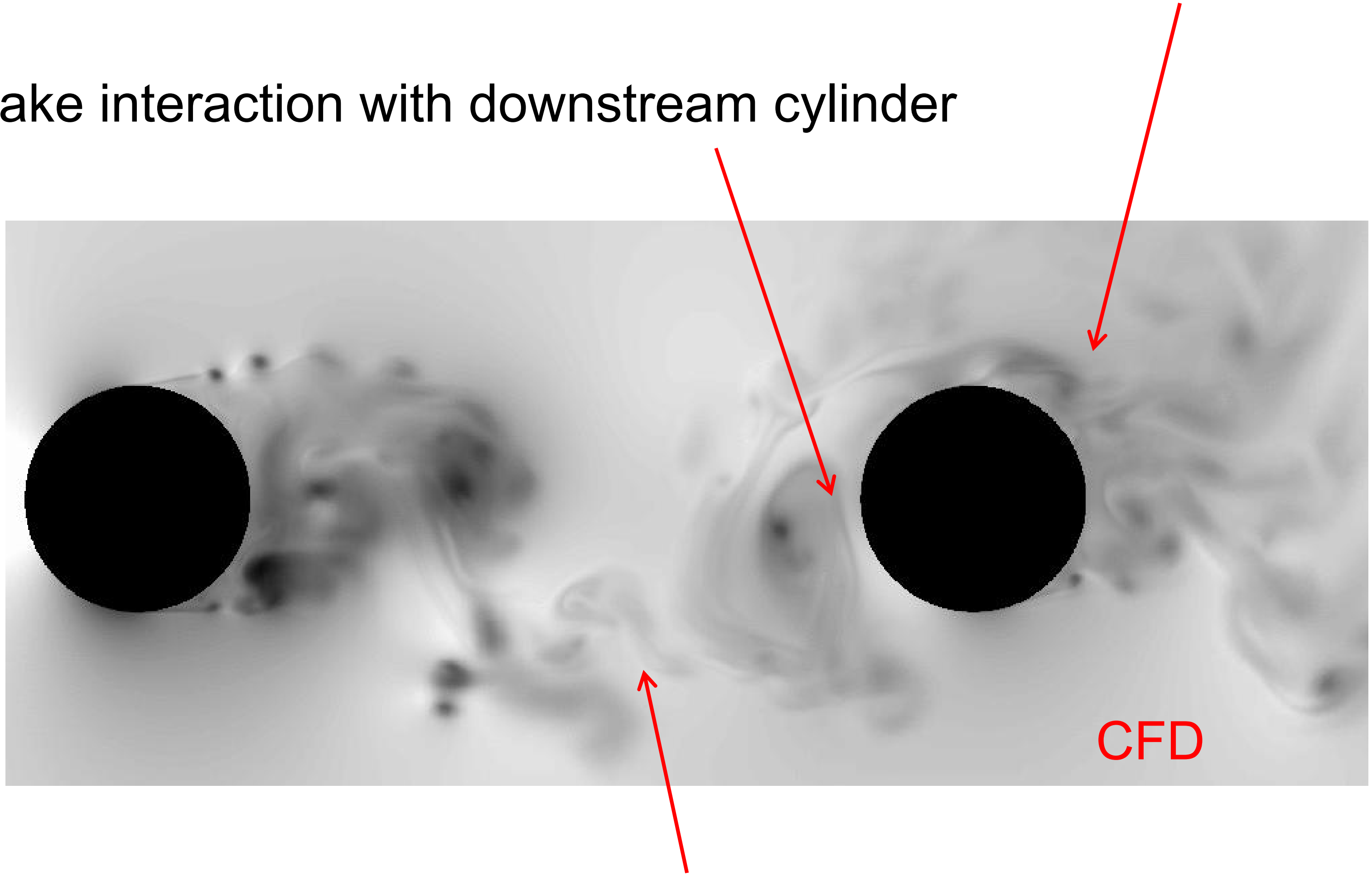
- Character very different from laminar case and Cp distribution very similar to data at Re=8.6X10^6



Physics – the shear flow exhibits instabilities



Physics – the shed wake from the upstream cylinder interacts with the downstream cylinder



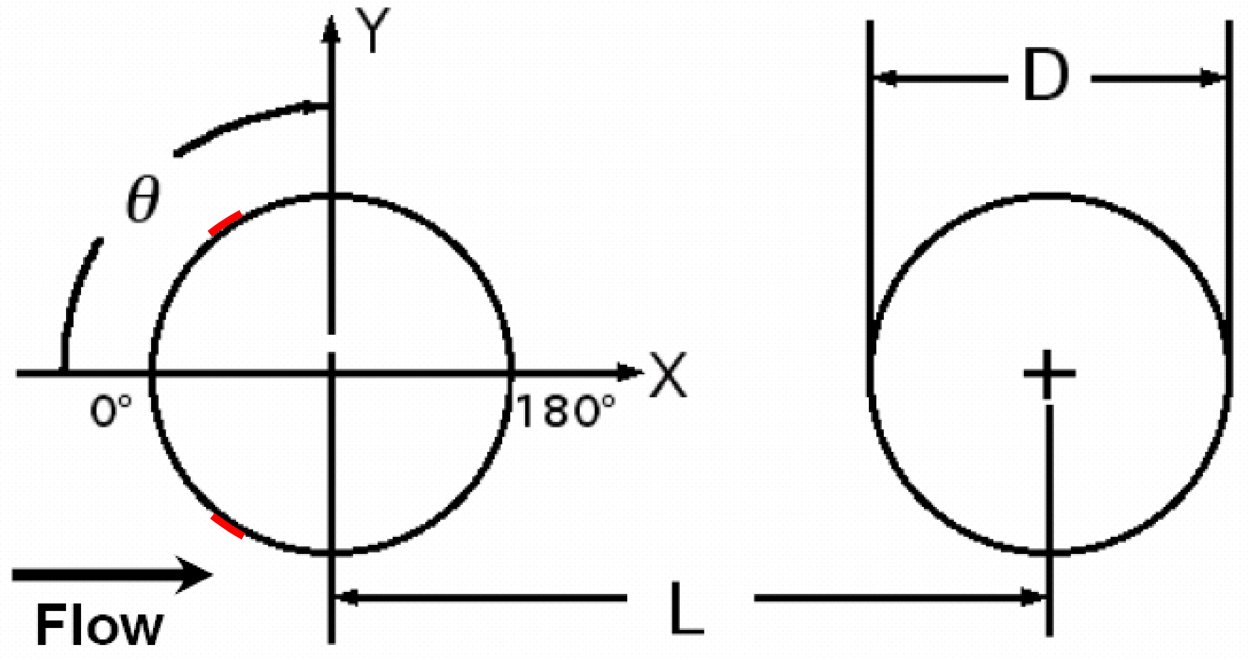
Shedding from downstream cylinder

Wake interaction with downstream cylinder

CFD

Advection (transport) of the wake

The geometrical details of the tandem cylinder models are…….



- D=2.25 in (0.05715 m), L = 3.7 D
- Trip between 50 – 60 deg on upstream cylinder
- Span of 12.4 D

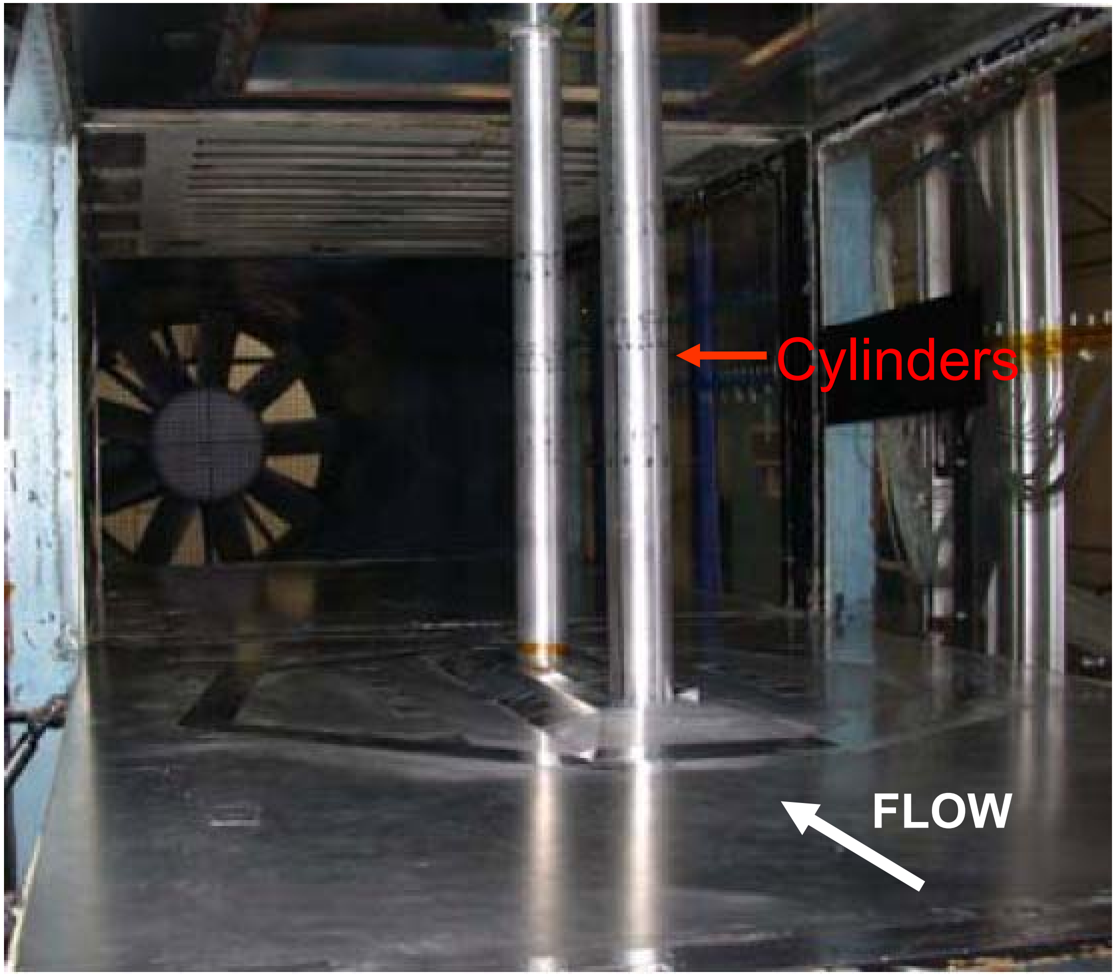
The tandem cylinders were tested in the BART facility, in three separate entries

Measurements:

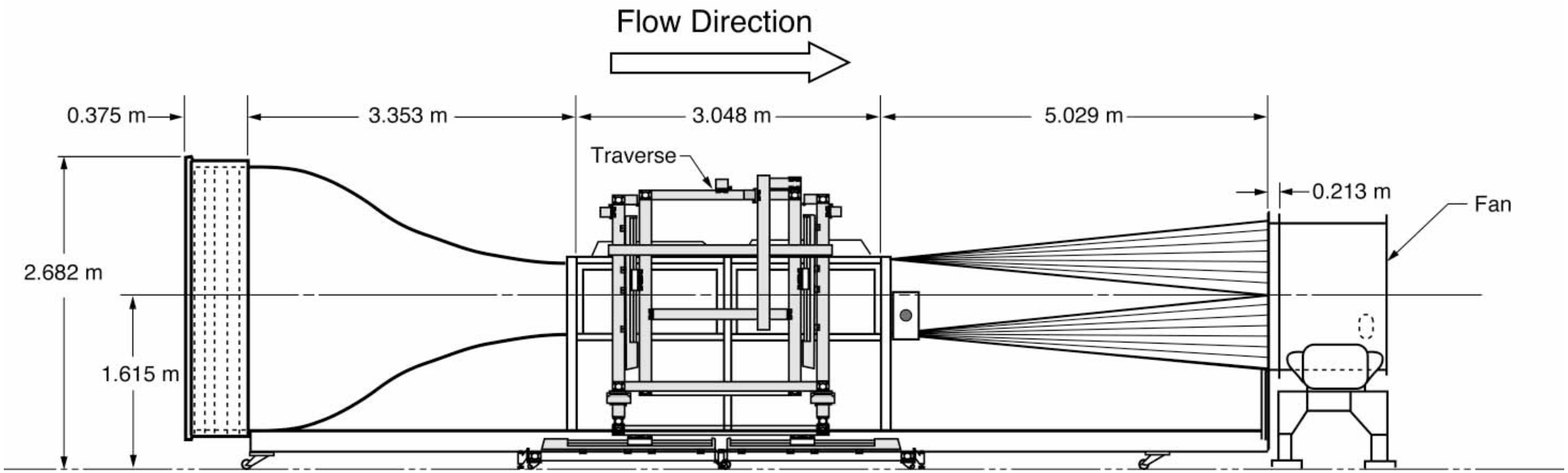
- Steady and unsteady surface pressure
- Flow field (PIV)

Test results are documented in….

AIAA 2005-2812
AIAA 2006-3202
AIAA 2006-3203
AIAA 2007-3450
AIAA 2009-3275



The Basic Aerodynamics Research Tunnel (BART)



BART Specifications

- Test section: 0.711m x 1.016m x 3.028m

Test Condtions

•Velocity: 44 m/s

•Re_D: 1.66×10^5

•Mach No: 0.128

•Turbulence Intensity: 0.067%

The tandem cylinders were also tested in the Quiet Flow Facility

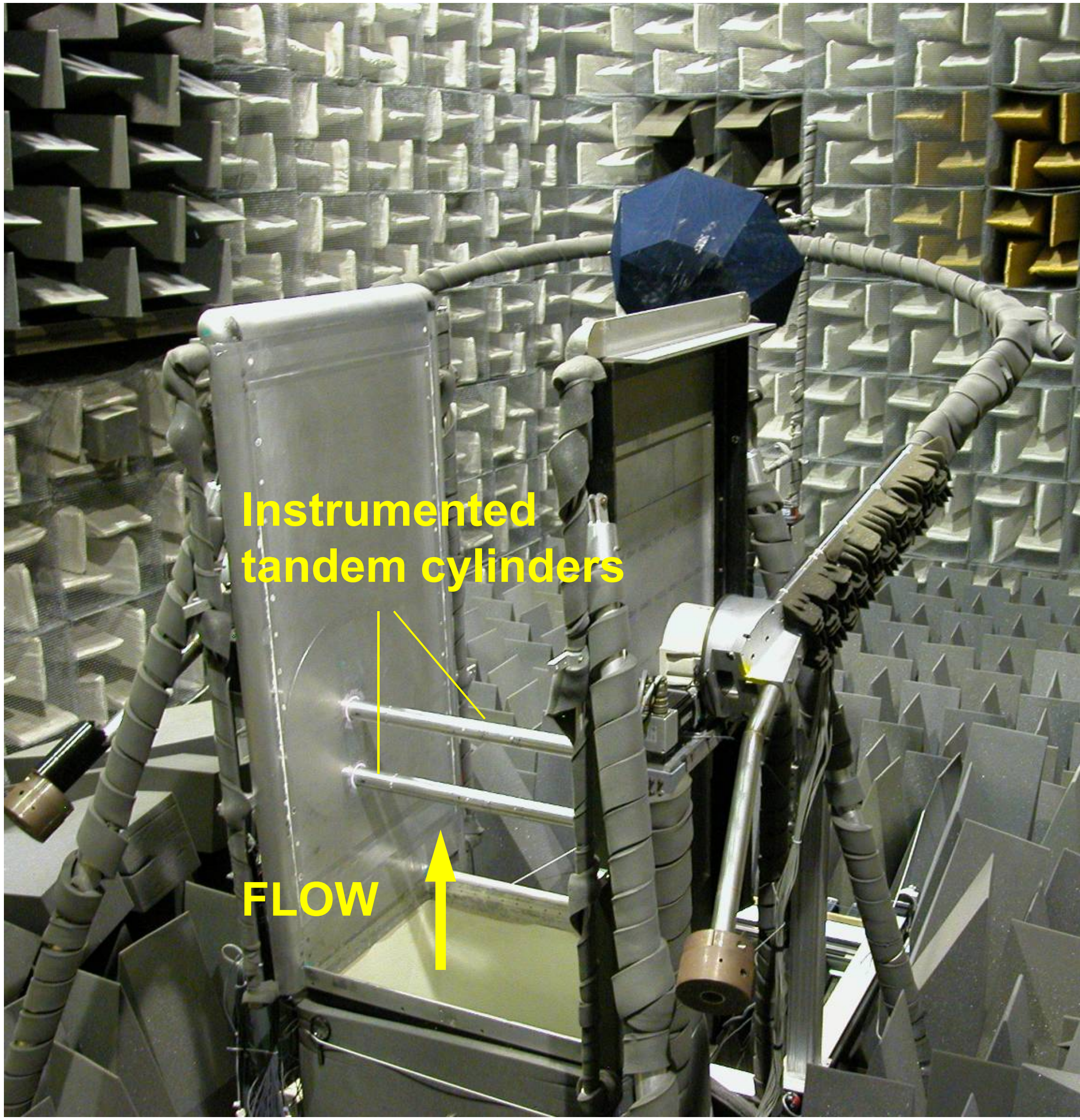
Measurements:

- Steady and unsteady surface pressure
- Acoustic (out of flow microphones)

Test results are documented in….

AIAA 2007-3450

AIAA 2008-2862

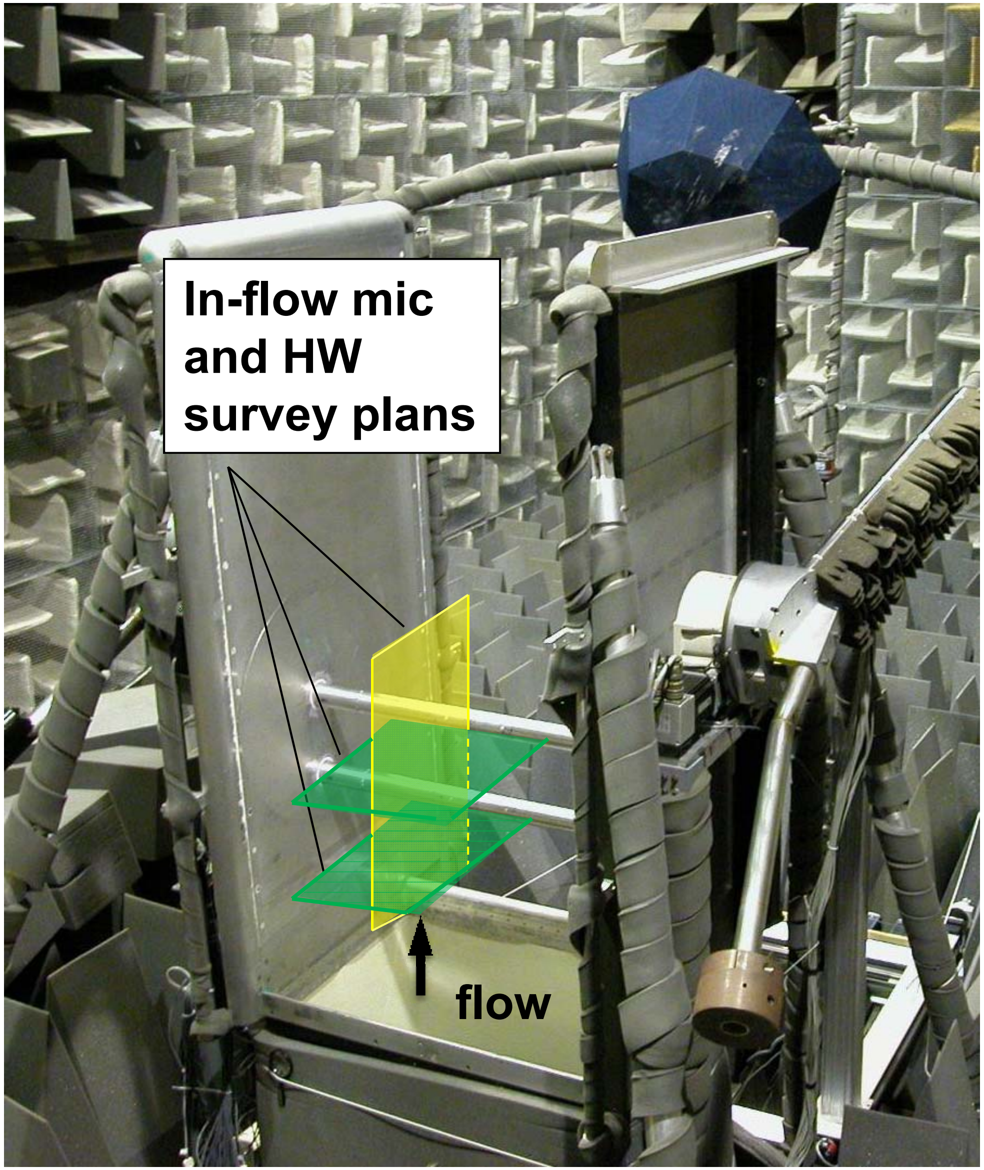


Additional Details from QFF Tandem Cylinder Test

- Cross-wires and in-flow microphone surveys to relate acoustic near field to unsteady surface pressure.

- Noise directivity measurements.

- Results likely available in Fall 2011.



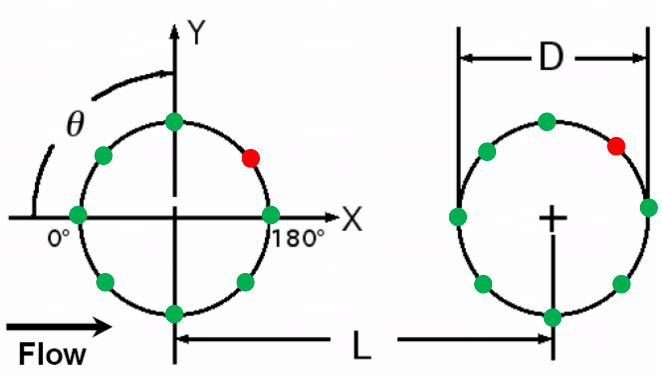
The experimental data shown will consist of steady and unsteady surface pressure and PIV

Steady surface pressure - central circumferential ring with 10 deg spacing

Unsteady surface pressure

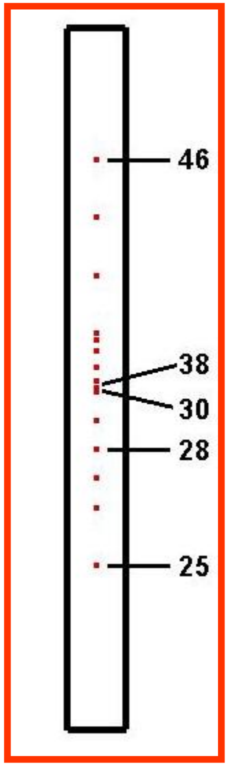
Circumferential ring (45 deg spacing)

5 deg cylinder rotations around centroids



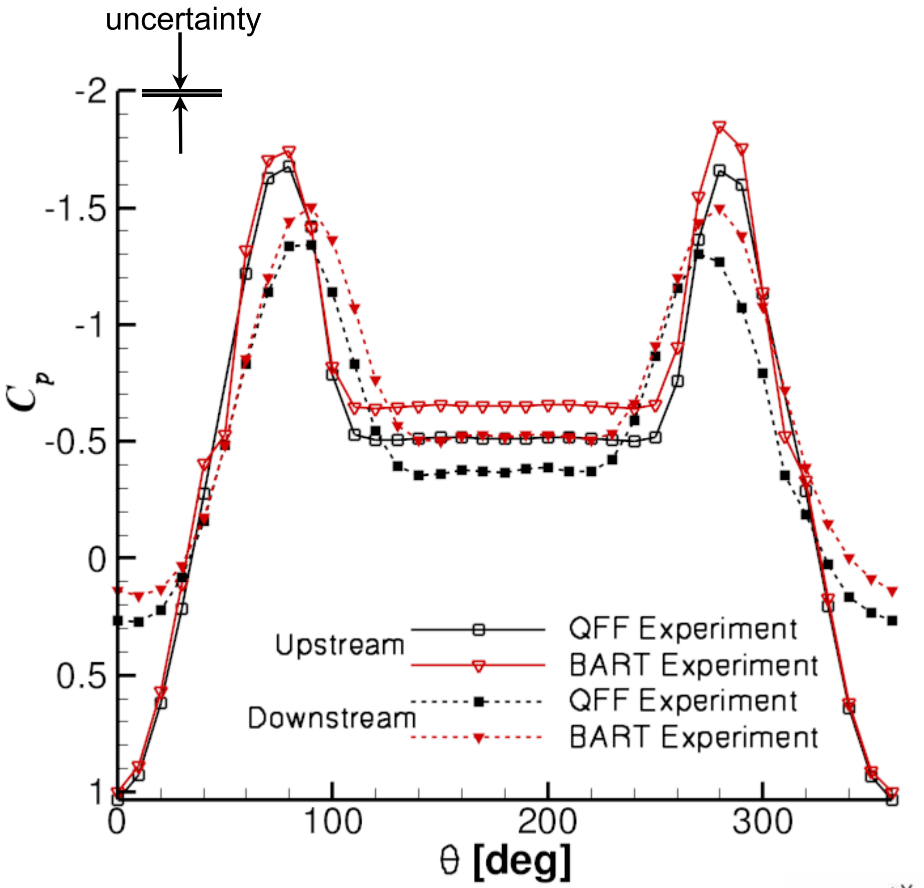
Spanwise row for

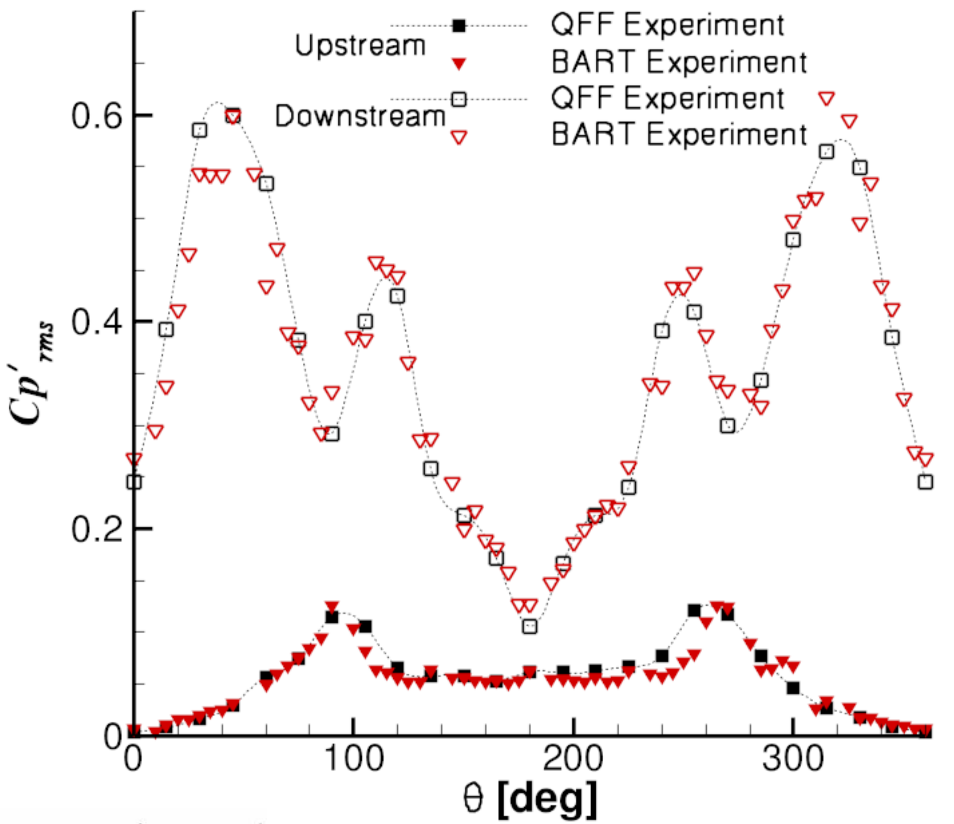
correlation and coherence



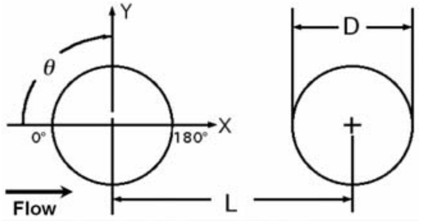
PIV – mean U velocity and TKE between cylinders and in wake

Distributions of steady and unsteady surface pressure - unsteady pressure shows detail





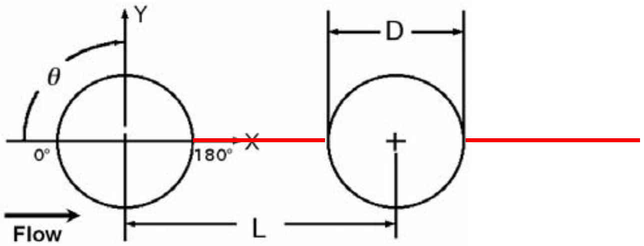
Steady

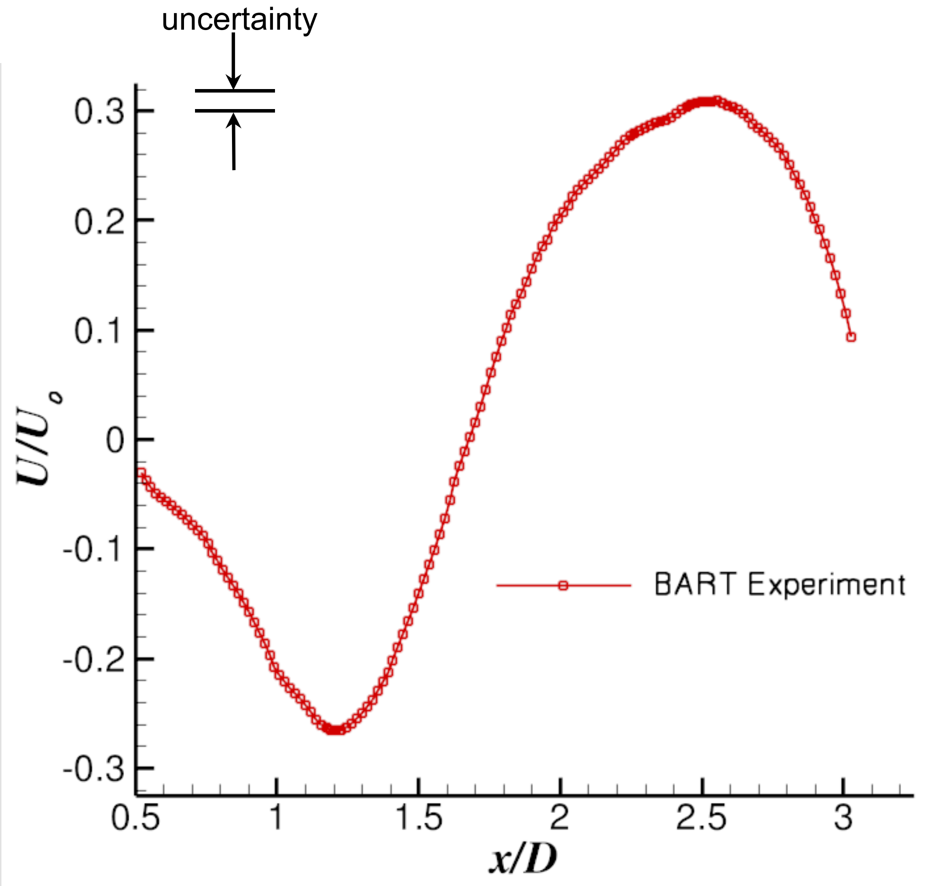


Unsteady

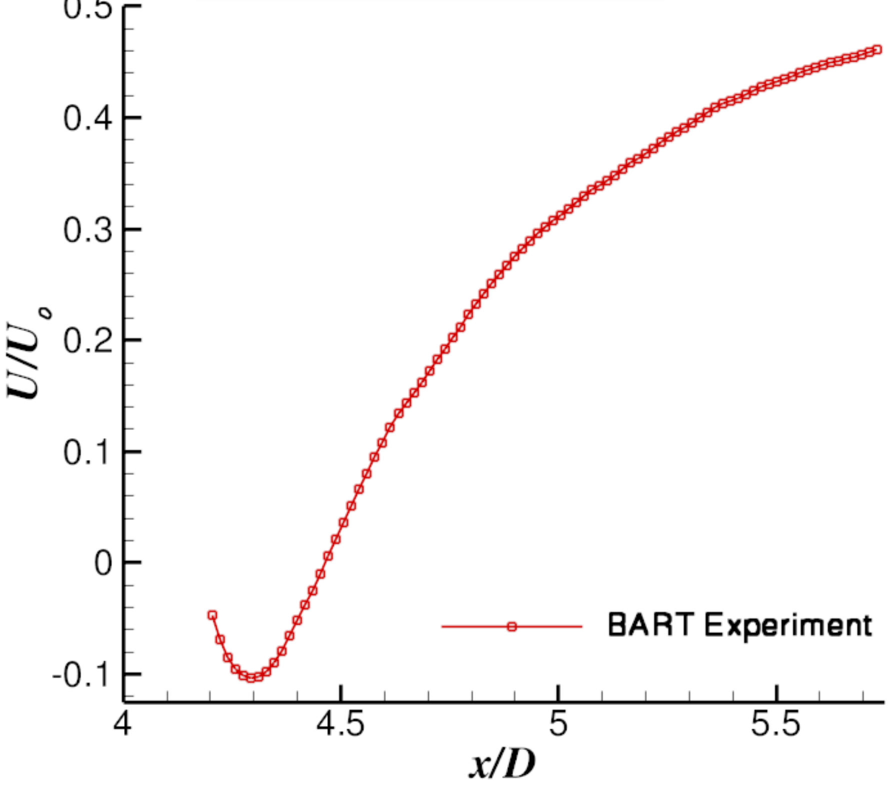
The distribution of mean U velocity from PIV shows how U changes between and behind cyl.

- Along $y/D=0$





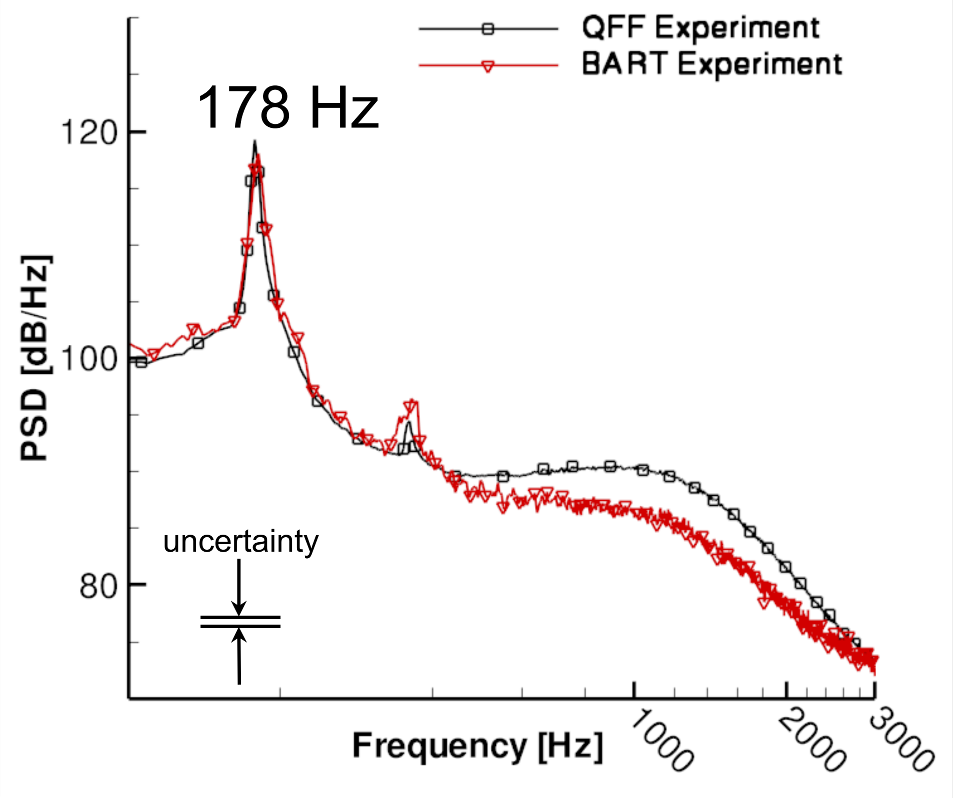
Gap Region



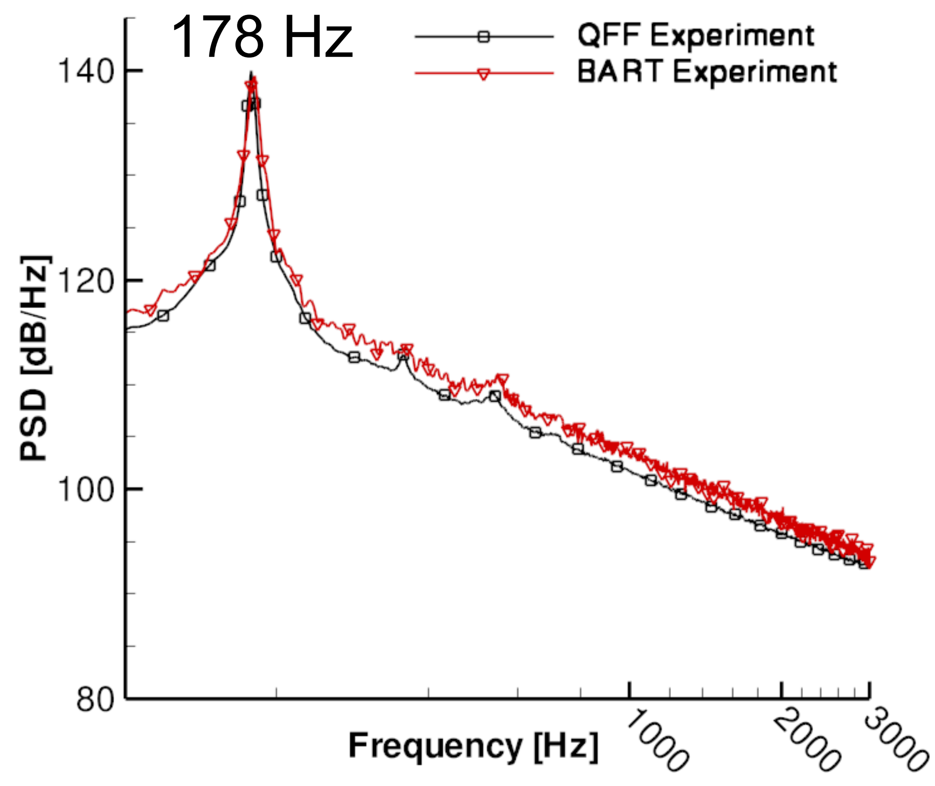
Aft of Downstream Cylinder

Surface pressure spectra are shown for the separation and re-attachment locations

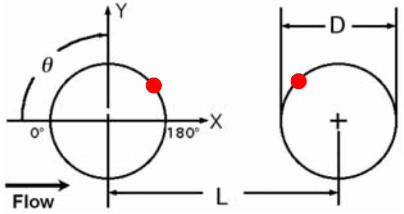
- Power Spectral Density



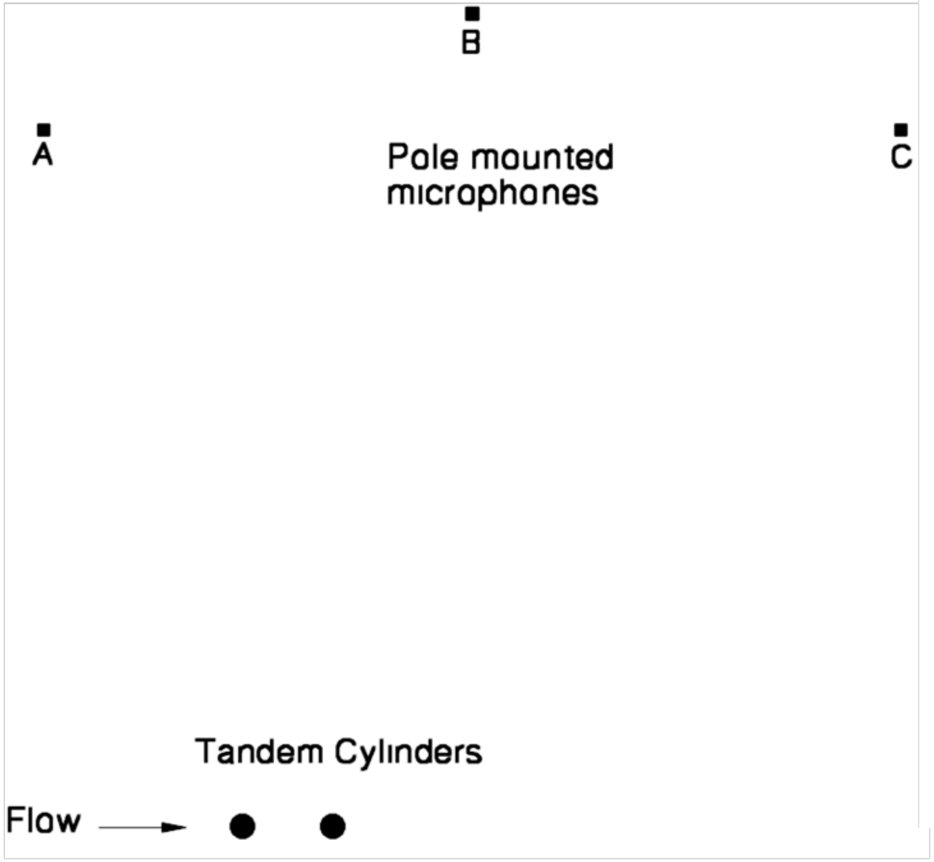
Upstream, $\theta = 135^{o}$

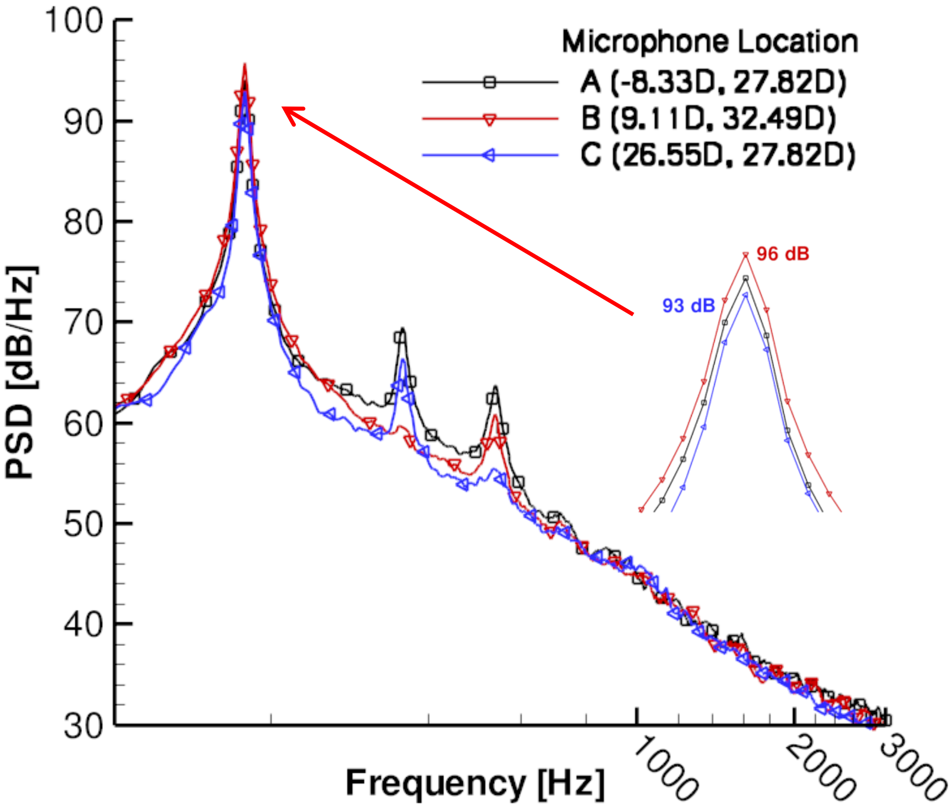


Downstream, $\theta = 45^{o}$



Acoustic Radiation

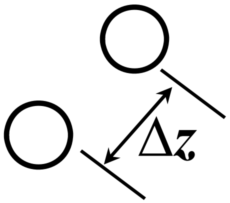


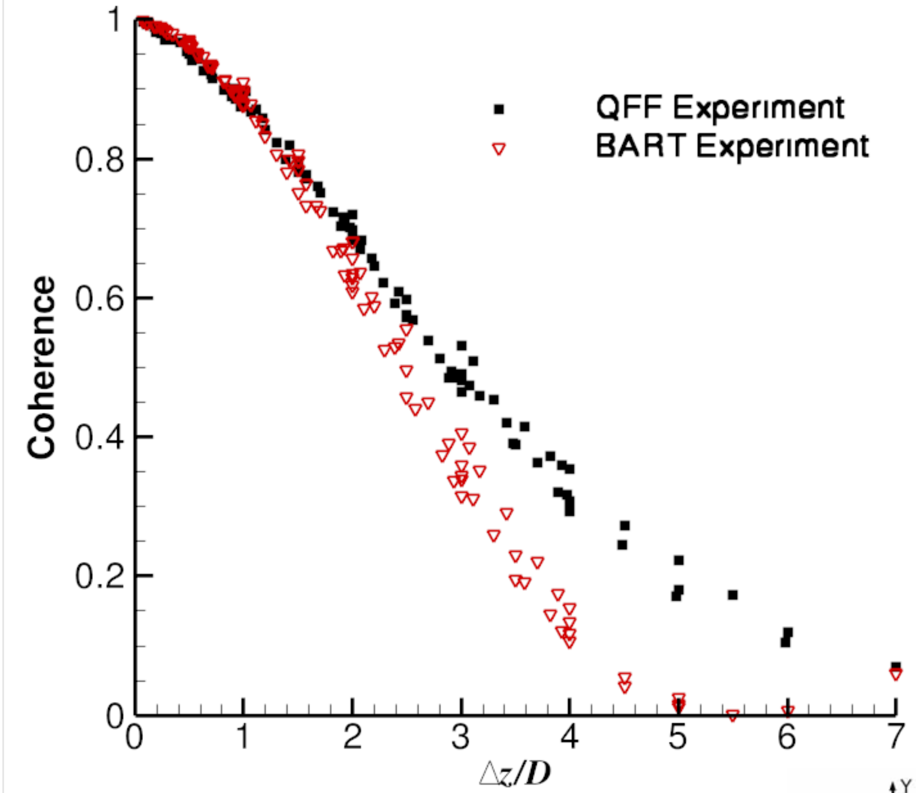


- Significant peaks at harmonics

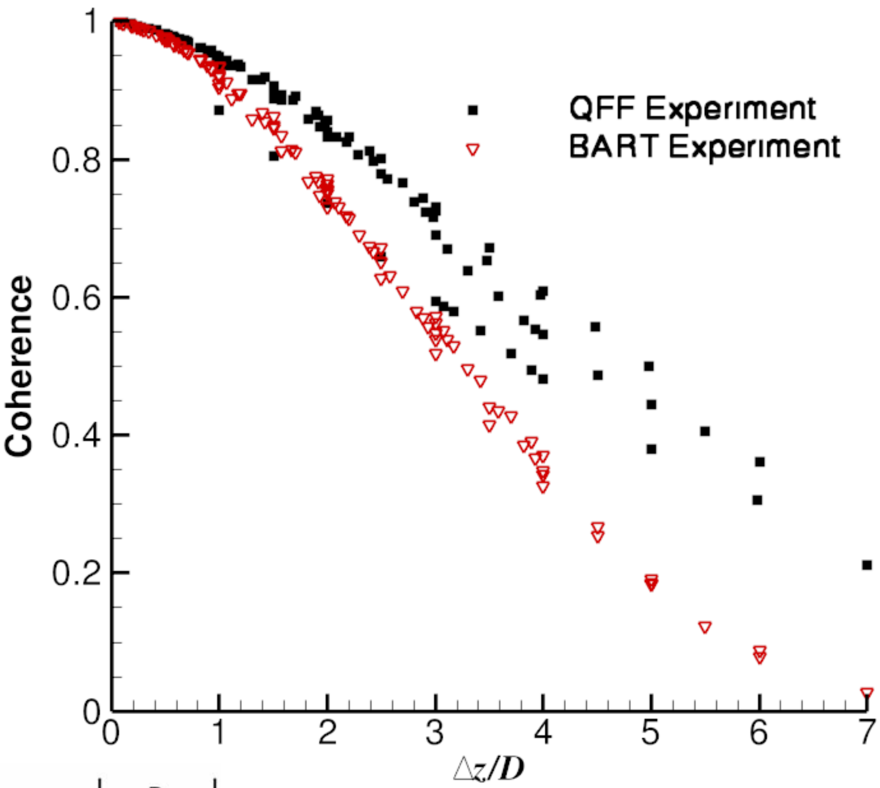
The coherence of surface pressures indicates spanwise uniformity at the primary shedding freq.

- Spanwise row of sensors at θ=135 deg
- Coherence at shedding frequency = 178 Hz

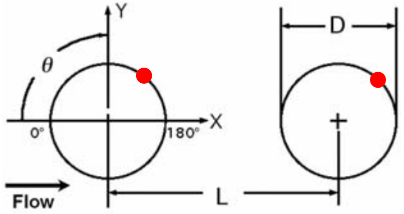




Upstream

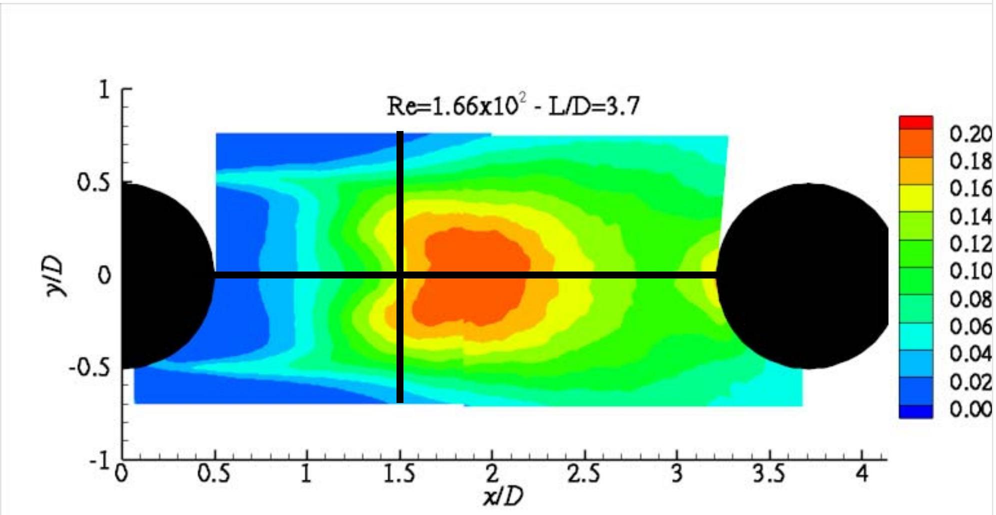


Downstream

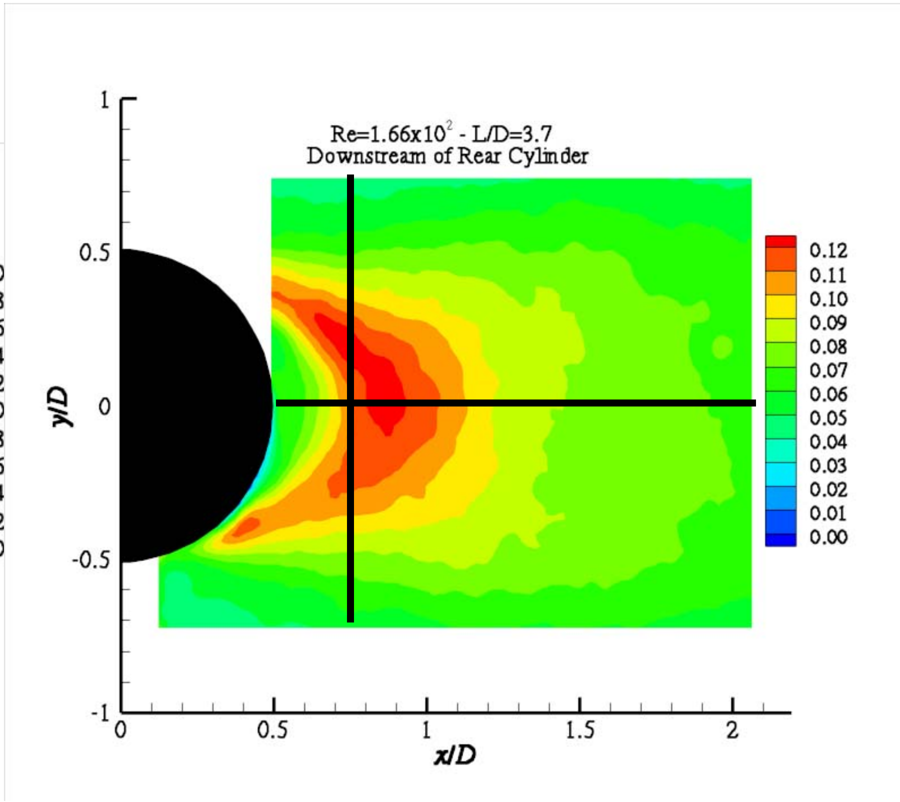


Contours of 2D TKE from PIV reveal energy levels between and behind the cylinders

- $1/2\ (\overline{u'\,u'} + \overline{v'\,v'} + \cancel{\overline{w'\,w'}})/)/U_o^2$



Gap Region



Aft of Downstream Cylinder

The estimated experimental uncertainties are……

- Steady Cp ~ 0.02
- PIV[*]: Umean ~ 0.02-0.03 (normalized)
- PIV: TKE ~ 4%
- PIV: Vorticity ~ 1.25 (normalized)
- PSD ~ 0.9 dB
- Cp'_{rms} ~ 5-11%
- Coherence ~ 0-0.25
- R_{pp} ~ 2-6%
- D, Δz ~ 0.005” (0.127mm)

[*] the uncertainty in PIV quantities is based on the system velocity resolution, which relates to the minimum displacement (velocity) the system can measure.

Final Comments

- Tandem Cylinders
  - Simple geometry, complicated physics
  - ease/difficulty of performing the tests
    - Instrumentation – in-situ calibration
    - Model changes
      - Clocking=>moving transition strips
    - Data acquisition and processing
  - what (if anything) would make the dataset better
    - BL measurement

Background Slides

References

- Jenkins, L. N., Khorrami, M. R. , Choudhari, M. M., and McGinley, C. B., “Characterization Of Unsteady Flow Structures Around Tandem Cylinders For Component Interaction Studies In Airframe Noise,” AIAA-2005-2812 (2005).
- Jenkins, L. N., Neuhart, D. H., McGinley, C. B., Khorrami, M. R. , and Choudhari, M. M., “Measurements Of Unsteady Wake Interference Between Tandem Cylinders”, AIAA-2006-3202 (2006).
- Neuhart, D. H., Jenkins, L. N., Choudhari, M. M., Khorrami, M. R. , “Measurements of the Flowfield Interaction Between Tandem Cylinders,” AIAA Paper 2009-3275, Miami, May 11-13 (2009).
- Lockard, D. P., Khorrami, M. R., Choudhari, M. M., Hutcheson, F. V., Brooks, T. F., and Stead, D. J., “Tandem Cylinder Noise Predictions,” AIAA Paper 2007-3450, (2007).
- Lockard, D. P., Choudhari, D. P., Khorammi, M. R., Neuhart, D. H., M. M., Hutcheson, F. V., and Brooks, T. F.,”Aeroacoustic Simulations of Tandem Cylinders with Subcritical Spacing,” AIAA-2008-2862 (2008).

References (continued)

- Hutcheson, F. V. and Brooks, T. F., “Noise radiation from Single and Multiple Rod Configurations,” AIAA–2006-2629 (2006).
- Khorrami, M. R., Lockard, D. P., Choudhari, M. M., Jenkins, L. N., Neuhart, D. H., and McGinley, C. B., “Simulations Of Bluff Body Flow Interaction For Noise Source Modeling,” (2006).

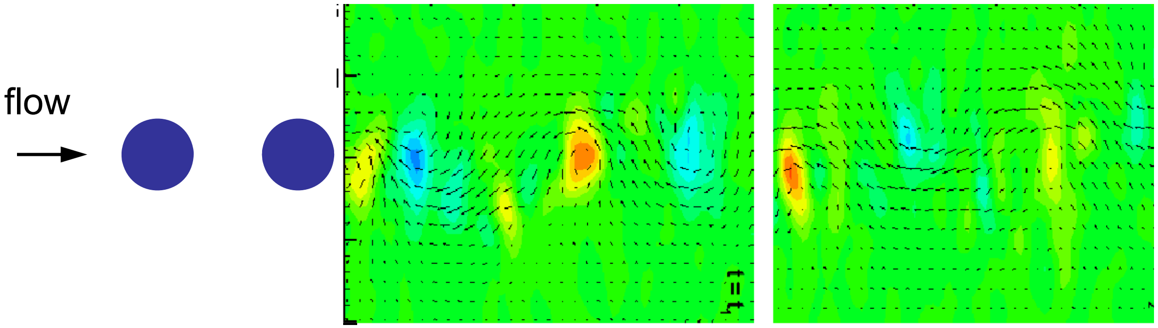
- Hutcheson, F. V. and Brooks, T. F., “Noise radiation from Single and Multiple Rod Configurations,” AIAA–2006-2629 (2006).

- Coleman, H.W., and Steele, W.G., Experimentation and Uncertainty Analysis for Engineers, John Wiley & Sons, 1999.
- Bendat, J.S. and Piersol, A.G., Random Data, John Wiley & Sons, 2000.

Other QFF Tandem Cylinder Data

Rods diameter D=1”;

L/D= 1, 2, 3 and 4.5

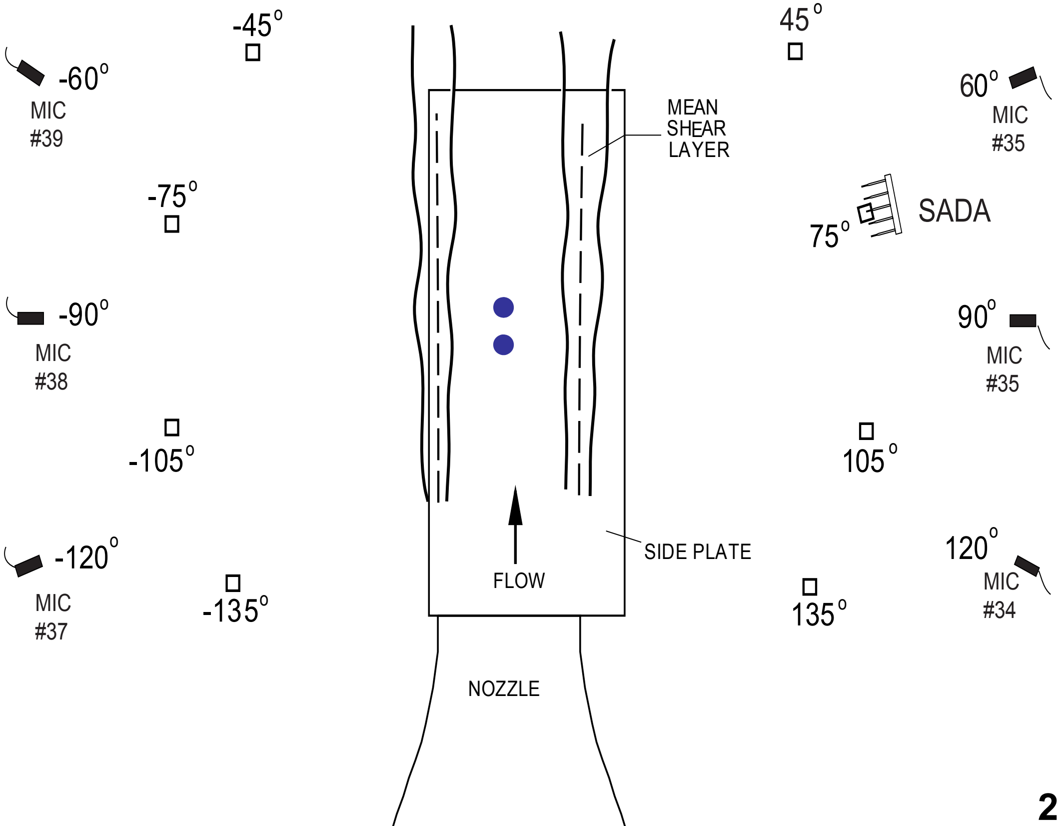


- PIV and acoustic measurements.

- Results presented in:

  AIAA 2006-2629

  NASA TM 2010-216209



The details of the 2-D PIV system are ……

- Lightsheet thickness – 2 mm
- Dual, 220 mJ, Nd-YAG lasers
- Digital camera frame rate – 5 Hz
- Sensor size – 1360X1036 pixels
- Measurement volume –

  - 1.0 mm^2 (50 mm lens, 24X24 interrogation window) (0.0175D)

  - 0.649 mm^2 (105 mm lens, 30X30 interrogation window) (0.0114D)
- 50% interrogation window overlap
- Flow seeded by commercial fog generator
- 1500 image pairs per configuration

The details of the dynamic data acquisition are……….

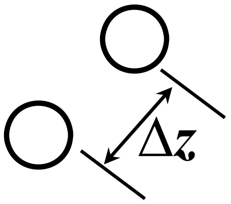
- Signal gain incorporated into sensitivity coefficients through in-situ calibration

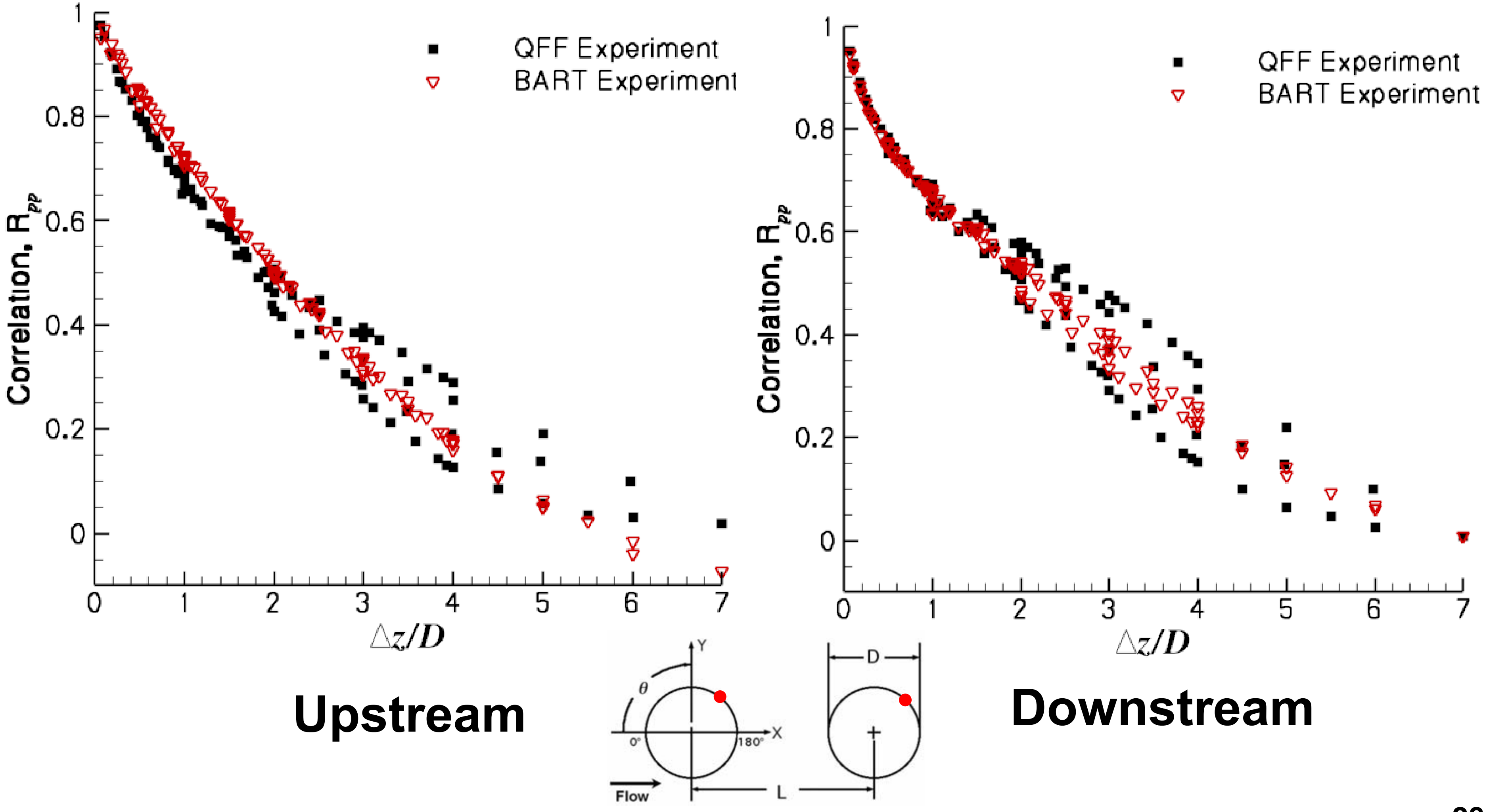
- AC-coupled data
- Sample rate: 25.6 kHz
- Blocksize: 8192
- Number of blocks acquired: 100
- Anti-alias filter in front of A/D: 10 kHz, elliptic
- AC coupling frequency: 1 Hz
- Range: set as needed for each channel

- DC-coupled data
- Sample rate: 50 Hz
- Number of samples acquired: 1600
- DC coupling frequency: 1 Hz

The correlation of surface pressures gives an indication of "correlation length"

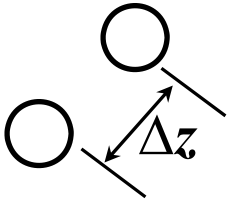
- Spanwise row of sensors at θ=135 deg

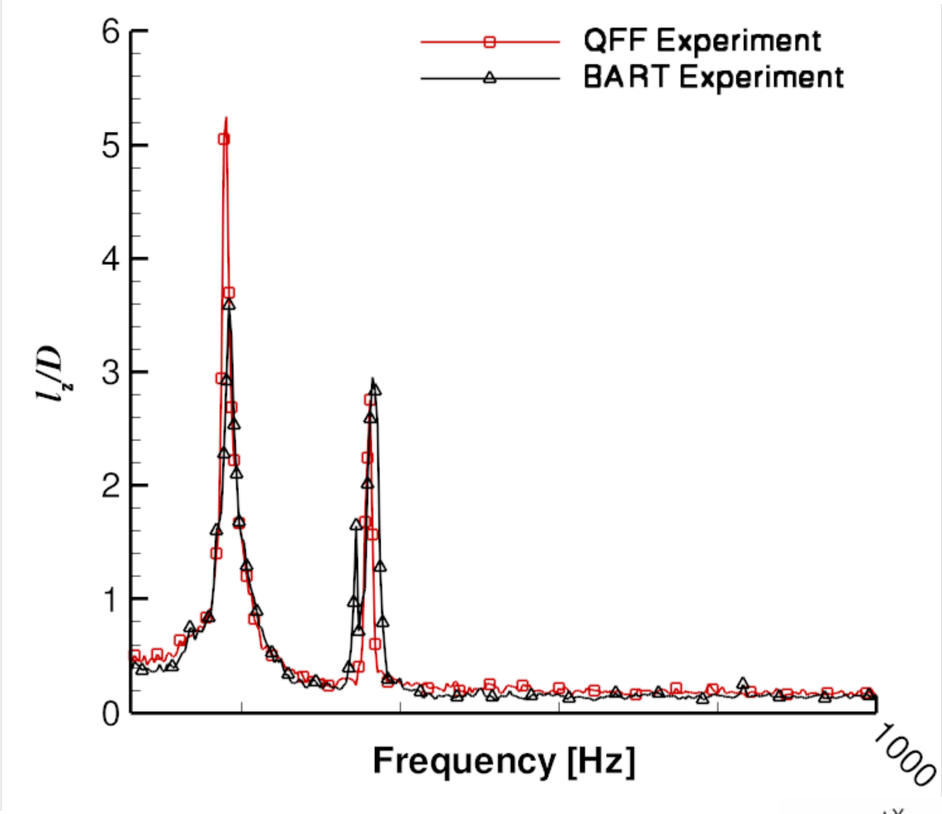




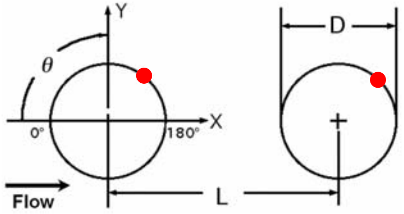
Fitting the surface pressure coherence to a Gaussian distribution yields a "coherence length"

- Coherence Length at θ=135° for a Gaussian fit
  - Coherence(Δz) = exp(-($\Delta z/l_z$)^2)

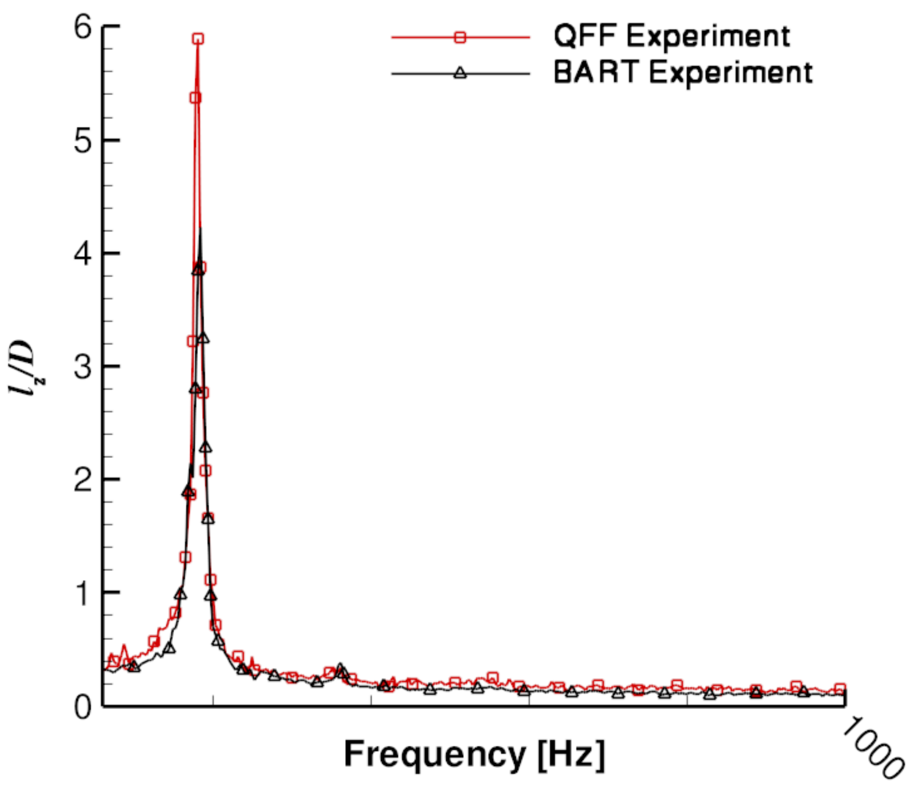




Upstream

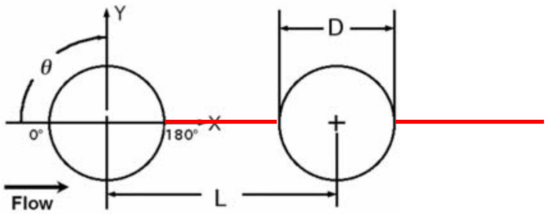


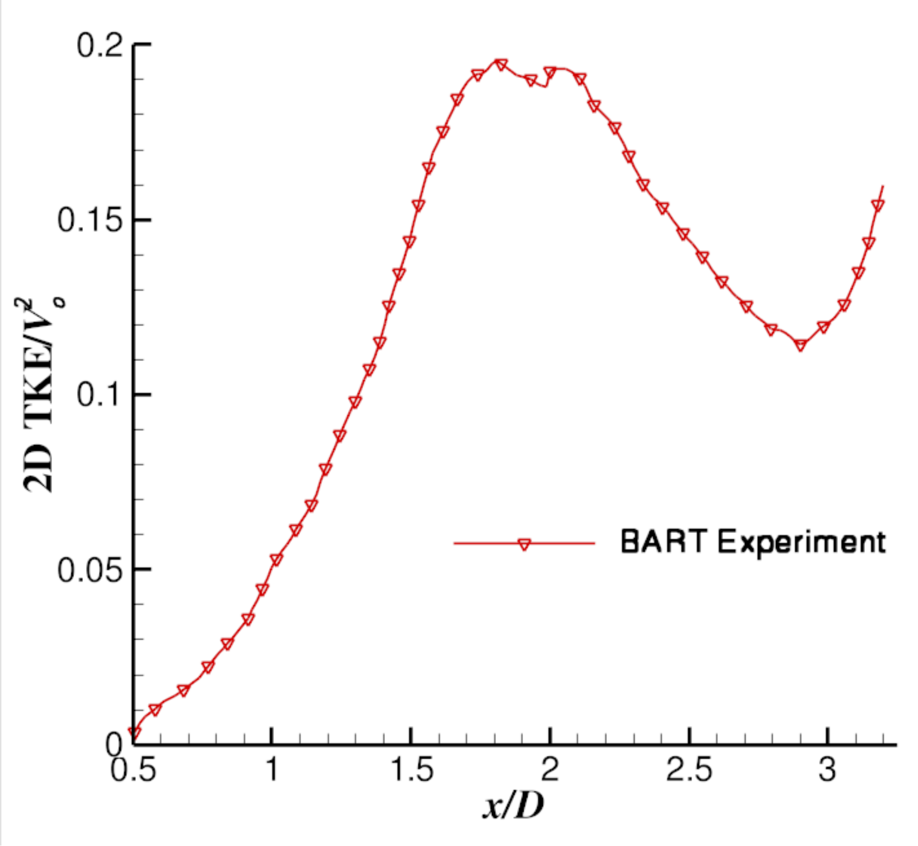
Downstream



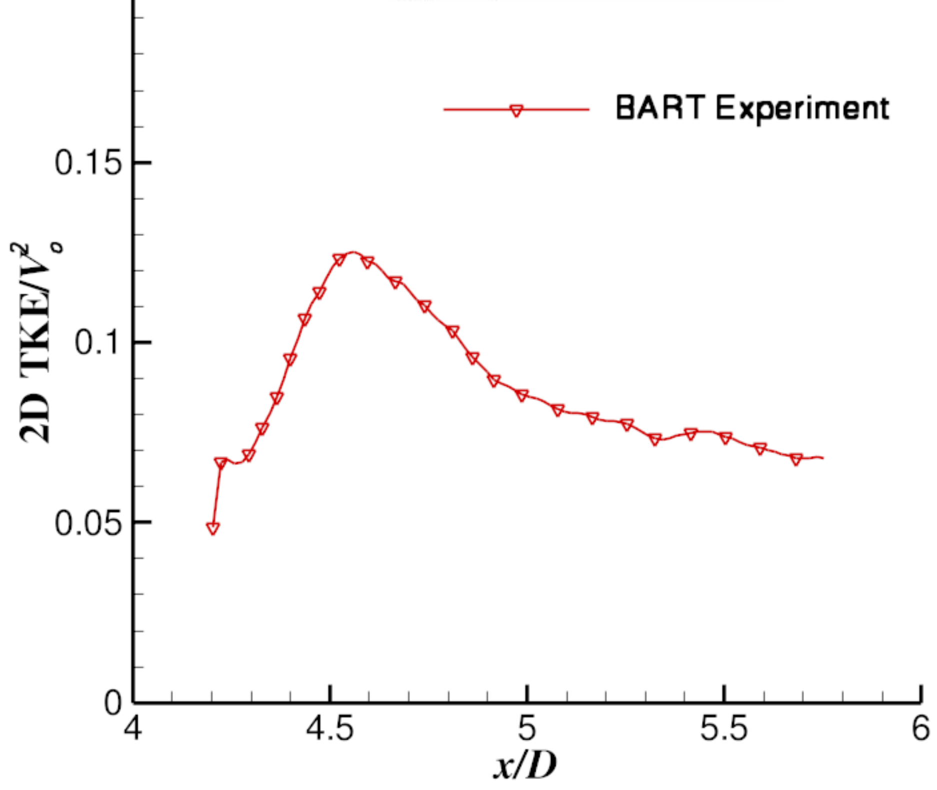
Cuts taken in PIV contours reveal horizontal dist. of 2D TKE between and behind the cylinders

- $1/2\ (\overline{u'u'} + \overline{v'v'} + \cancel{\overline{w'w'}})/)/U_o^2$ along $y/D=0$





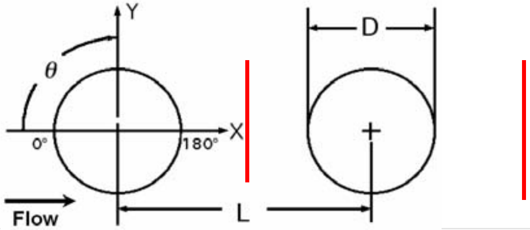
Gap Region

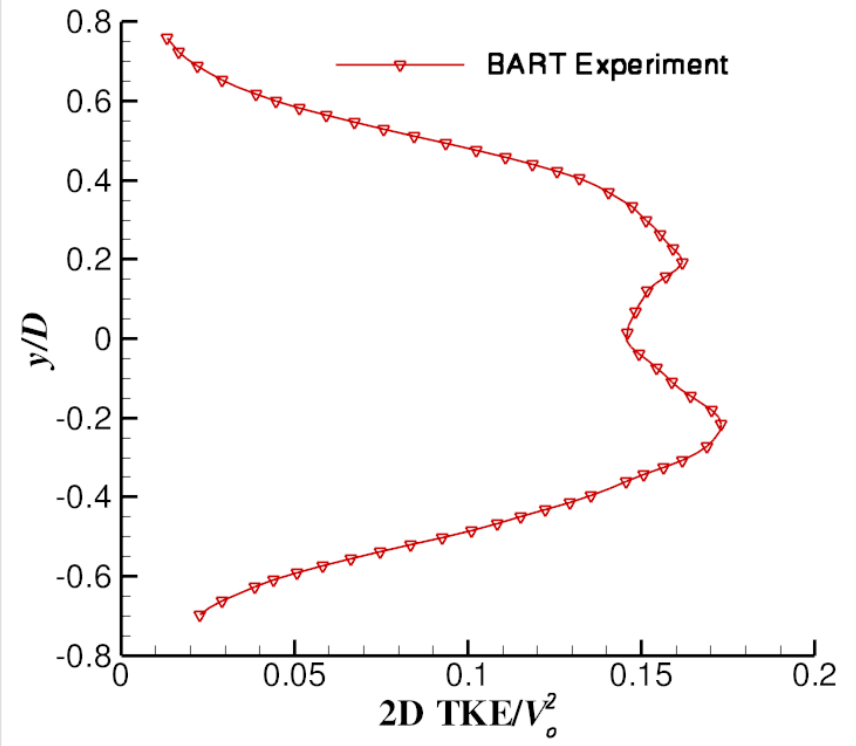


Aft of Downstream Cylinder

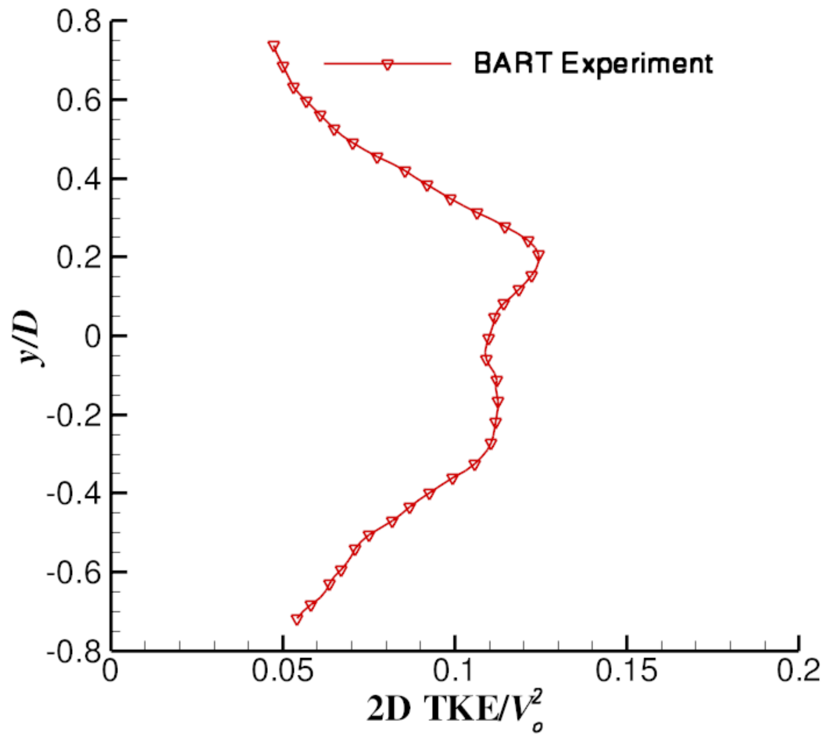
Cuts taken in PIV contours reveal vertical dist. of 2D TKE between and behind the cylinders

- $1/2\ (\overline{u'u'} + \overline{v'v'} + \cancel{\overline{w'w'}})/)/U_o^2$





Gap Region, *x/D*=1.5



Aft of Downstream Cylinder, *x/D*=4.45