Delayed Detached-Eddy Simulation of Tandem Cylinders

A. Garbaruk, M. Shur, M. Strelets

NTS, SPbSPU

P. R. Spalart

Boeing Commercial Airplanes

and

R. Balakrishnan

Argonne National Laboratory

Email: strelets@mail.rcom.ru

Outline

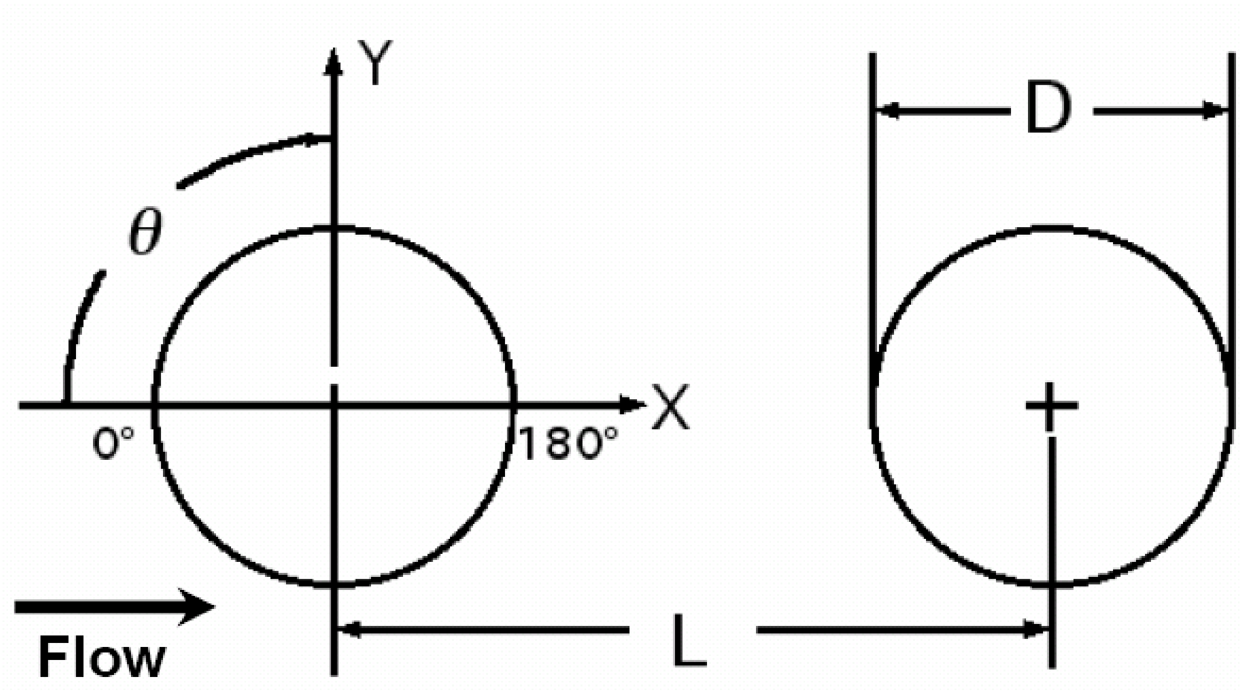
- Preliminary Comments
- Flow Conditions
- Simulation Approach and Numerical Method
- Grids
- Results
- Conclusions

Preliminary Comments

- The flow has been studied in a series of experiments performed at NASA Langley Research Center in Basic Aerodynamics Research Tunnel (**BART**)

- It is a prototype for interaction problems commonly encountered in airframe noise configurations (e.g., the oleo and hoses on a landing gear) and, as such, is a representative stepping stone to these, industrially relevant, flows
- Simulation can help testing a capability of different turbulence modeling approaches and numerical methods to reproduce such complex phenomena as
  - Separation of turbulent boundary layer
  - Free shear layer roll-up
  - Interaction of unsteady wake of the front cylinder with the downstream one
  - Unsteady massively separated flow in the wake of the rear cylinder, etc.
- Exactly for these reasons it has been selected as a representative test case by organizers of the 1st BANC Workshop hold in Stockholm in June 2010 and by the Consortium of the EU Project ATAAC

Flow Conditions in Experiments



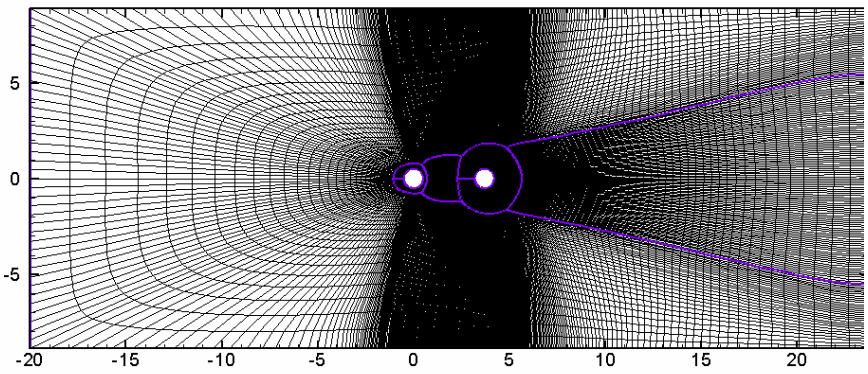
- Re = 166,000 based on D
  - Tripping of BL on both cylinders to ensure separation of turbulent boundary layer
- L=3.7D
- M=0.115

Simulation Approach and Numerical Method

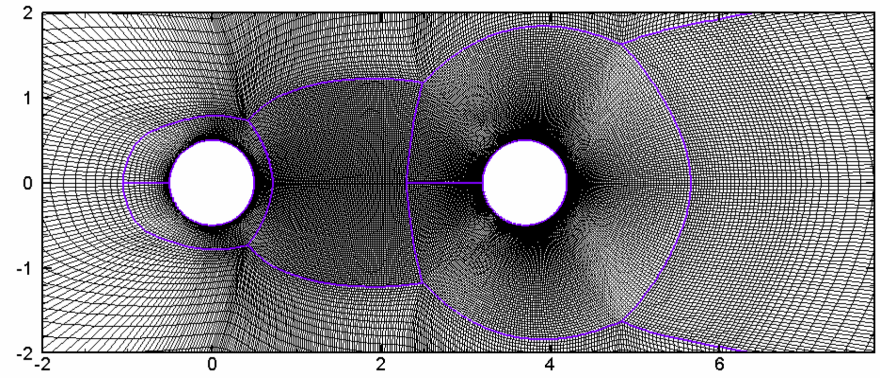
- Turbulence simulation approach
  - Incompressible Delayed DES (DDES) of Spalart *et al.* 2008
- Spatial and temporal discretizations
  - FV hybrid (weighted centered/upwind-biased) numerical scheme based on Rogers and Kwak flux-difference splitting method
    - 4^{th} centered / 5^{th} upwind-biased for inviscid fluxes;
    - 2^{nd} order centered for viscous fluxes;
    - 2^{nd} implicit time integration (3 layer scheme)
- Boundary Conditions
  - **Inflow:** uniform streamwise and zero lateral velocity components; eddy viscosity equal to molecular one (FT approach to transition control)
  - **Cylinders walls:** No-slip
  - **WT section side walls:** Free-slip
  - **Spanwise:** Periodic at two span sizes of the domain: **Lz=3D** and **16D**
  - **Outflow:** Specified pressure

Grid and Time-Step

- Block-structured overset grid of Chimera type
- Uniform grid in spanwise direction, Δz=0.02D
- Total grid count: 11 M for L_z=3D and 60 M for L_z=16D



Full domain

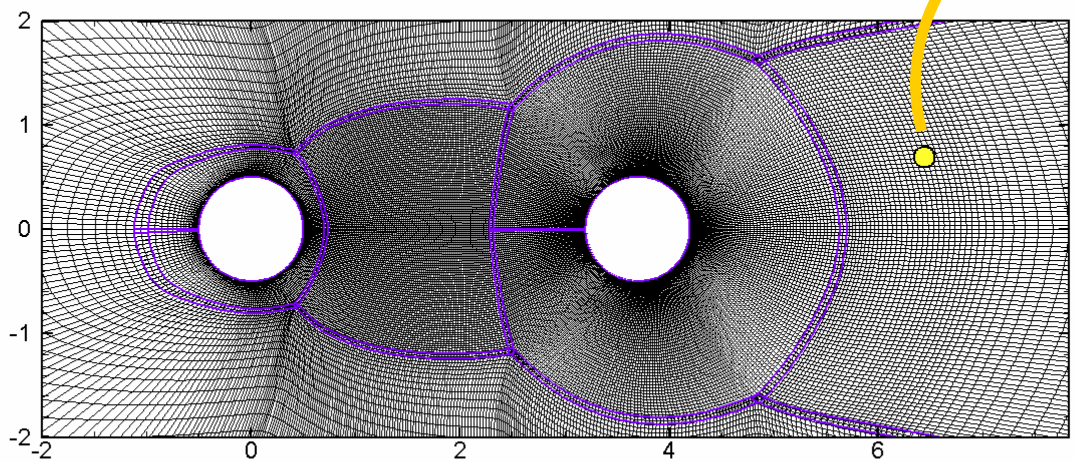


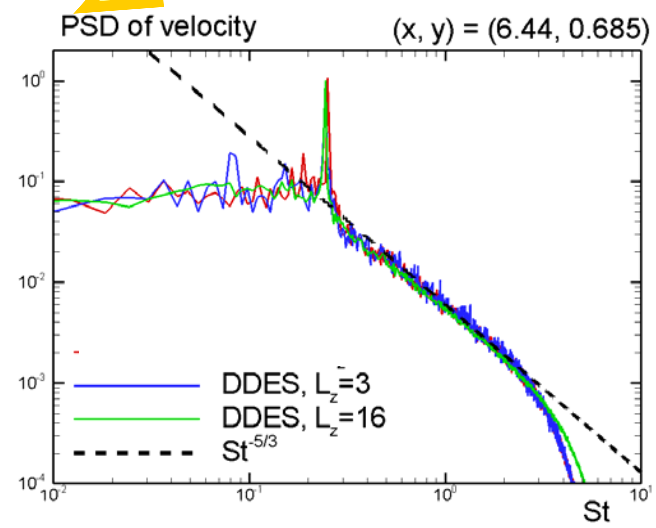
Zoomed fragment

- Time step
  - 0.02D / V_0 (2.6·10^{-5}s)
- Time Sample
  - 350 convective time units, D/V_0, with 300 units used for sampling

Internal Quality Checks

LES Quality

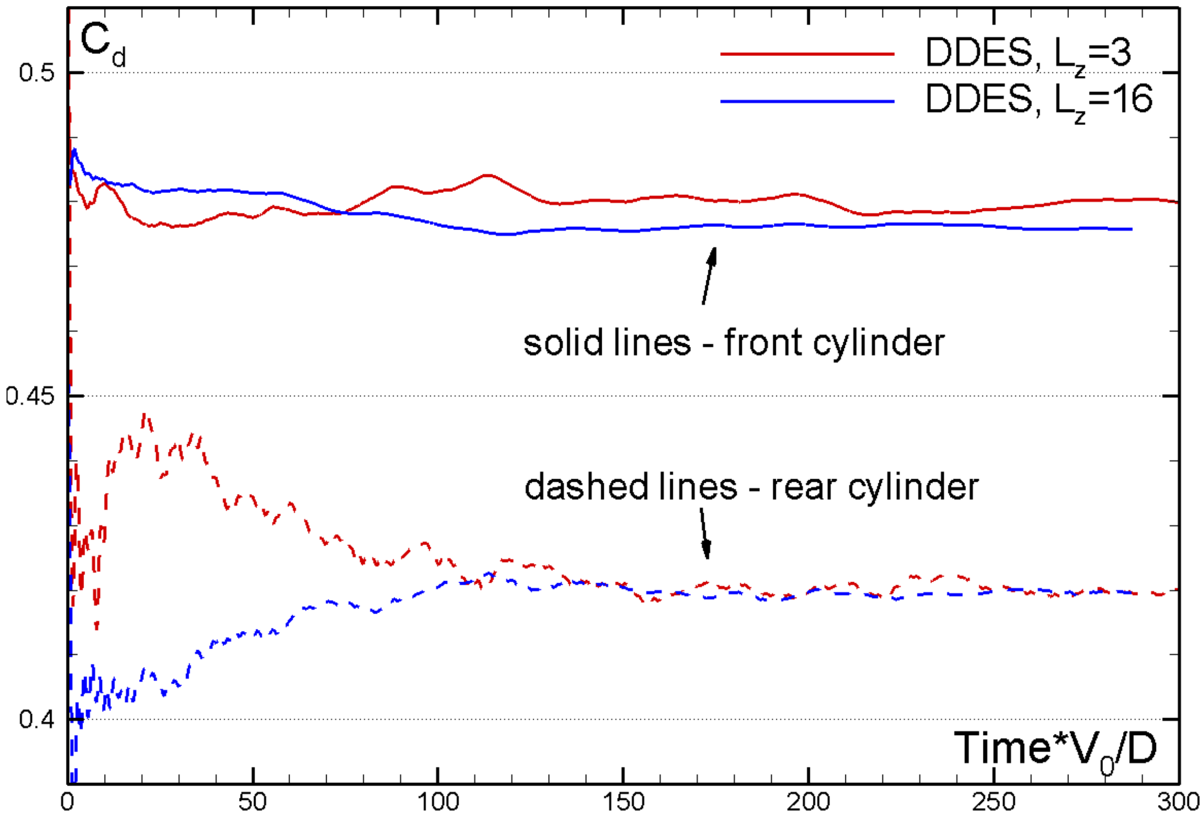




Power Spectral Density spectrum of velocity at the point in the wake of the the downstream cylinder

- Even in the relatively coarse grid region, extent of the inertial range of frequencies in the spectra is about a whole decade in both simulations
  - A proper three-dimensional energy cascade does exist
- Karman-street shedding peak near Strouhal number of 0.25, as is typical with turbulent separation and observed in the experiment

Sufficiency of Time Sample



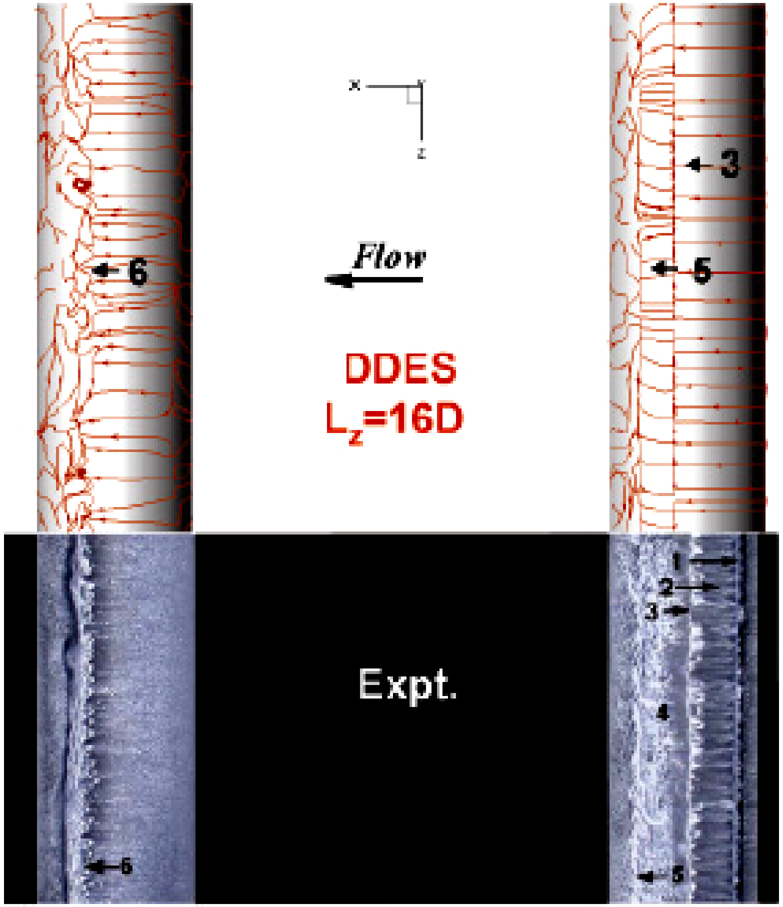
Running average of the integral drag coefficient

- After 300 convective time units the averaged drag is fairly stable

Results & Comparison with Experiment

Oil Flow

1- transition strip
2- streaks from streamwise vortices generated by transition strip
3- primary separation line
4- spanwise flow between 2 separation lines
5- secondary separation line
6- rear cylinder separation

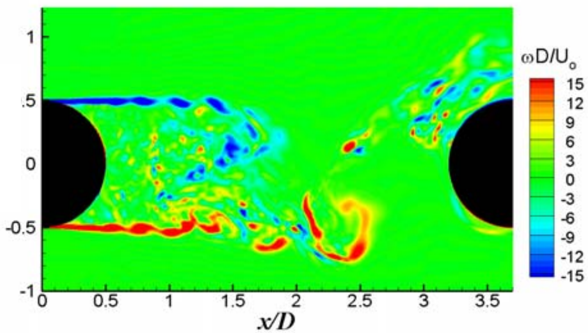


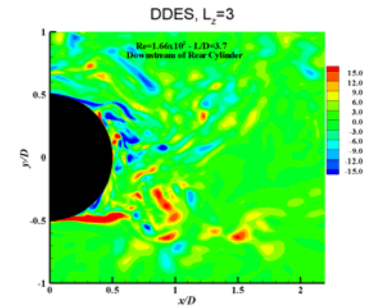
- Fairly good agreement on both primary and secondary separation on the front cylinder (3, 5) and separation on the rear cylinder (6)

Flow Visualization (instantaneous vorticity magnitude)

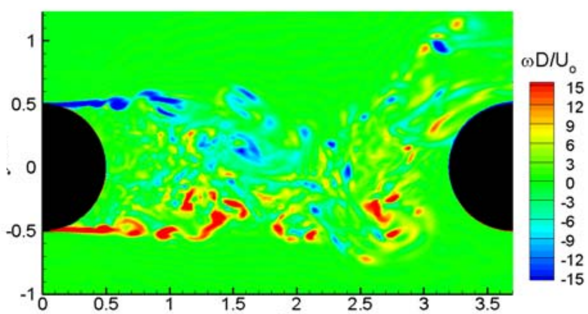
Gap region | **Aft of downstream cylinder**

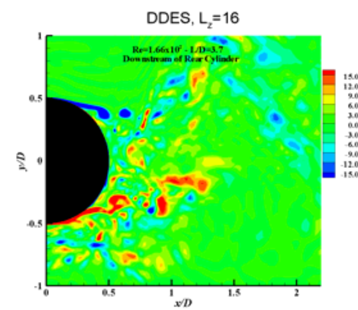
DDES Lz=3



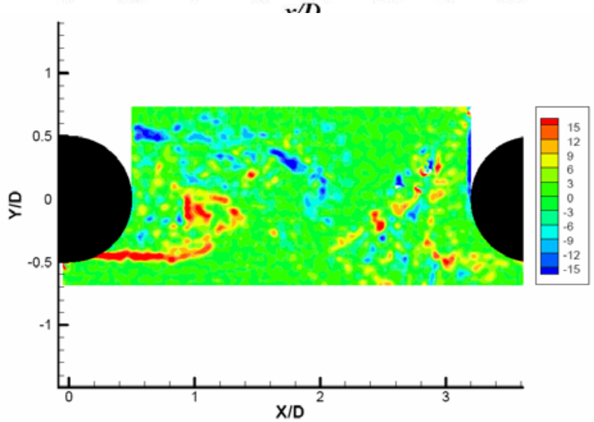


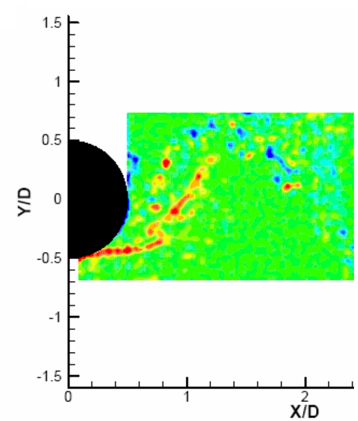
DDES Lz=16





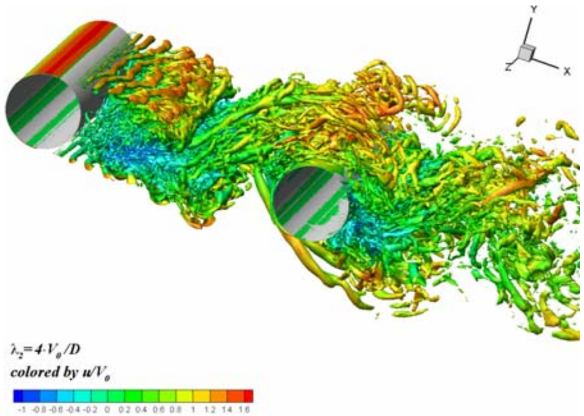
PIV



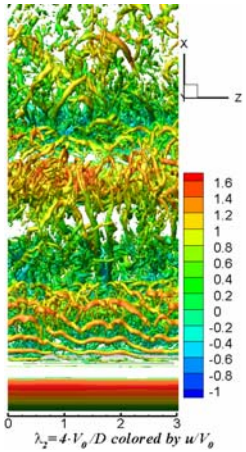


- Well resolved turbulent structures, qualitatively similar to PIV both in the gap between cylinders and in the near wake of the downstream cylinder

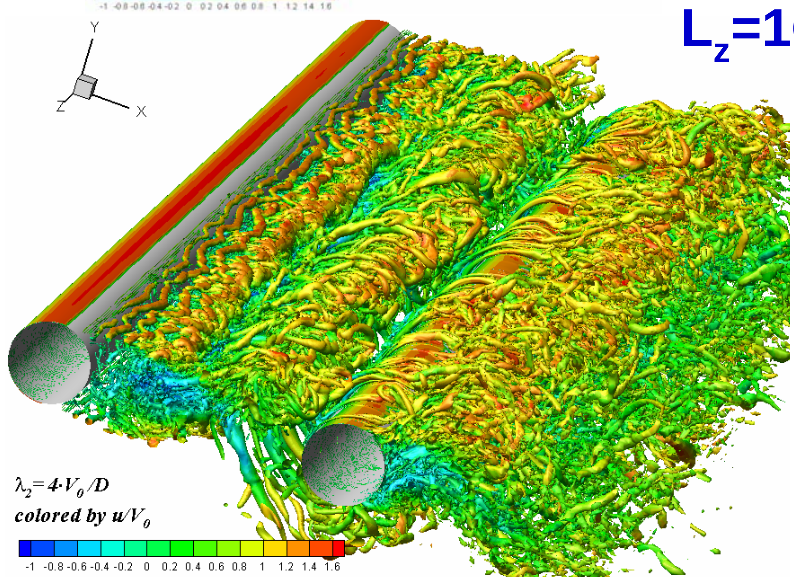
Flow Visualizations (λ_2 isorsurface)

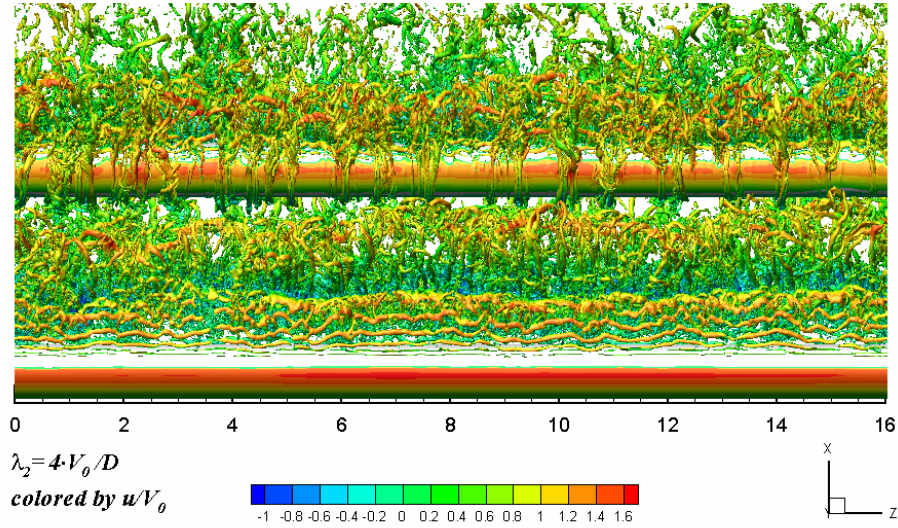


L_z=3D

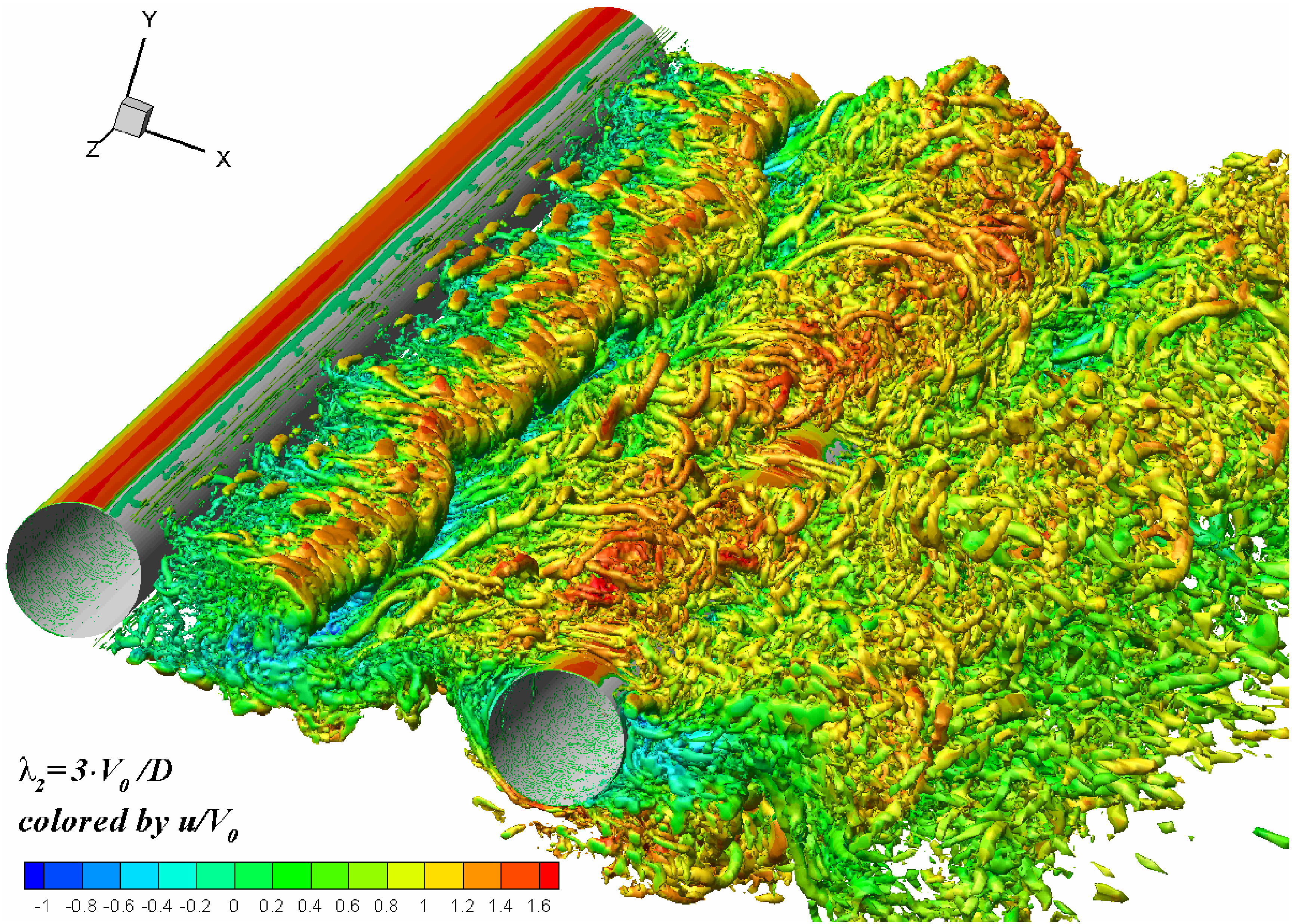


L_z=16D



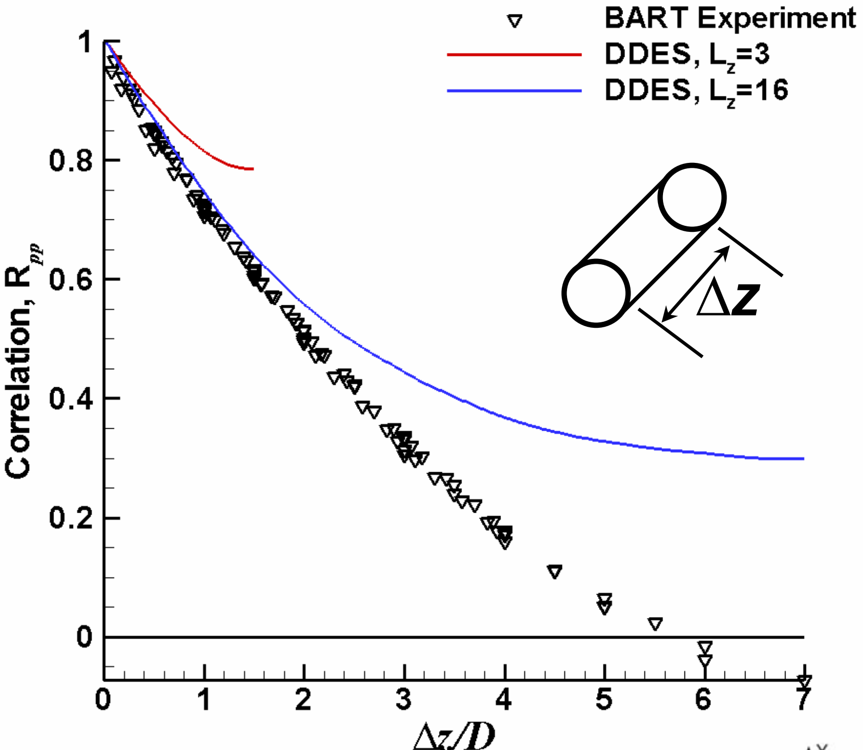


- The drift of the shedding phase versus *z* is small
  - Even at L_z=16D, imposing of periodic boundary conditions may be not fully justified

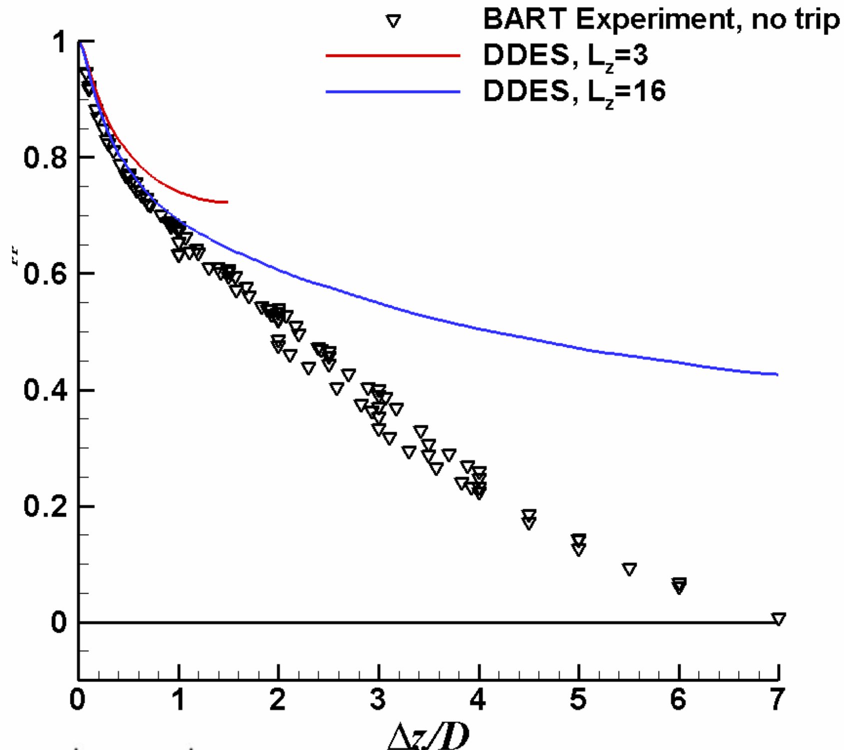


Y
Z
X
$\lambda_2 = 3 \cdot V_0 / D$
colored by u/V_0
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6

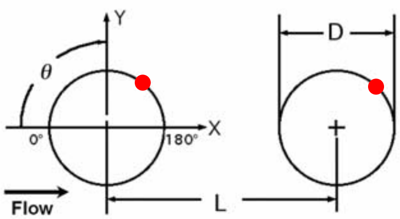
Surface Pressure Correlations at θ=135º



Upstream

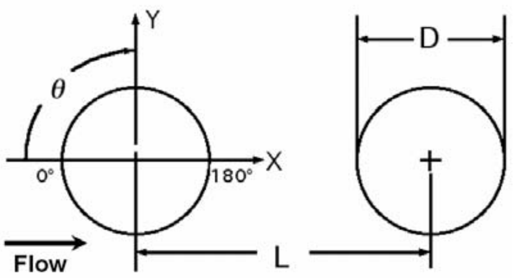


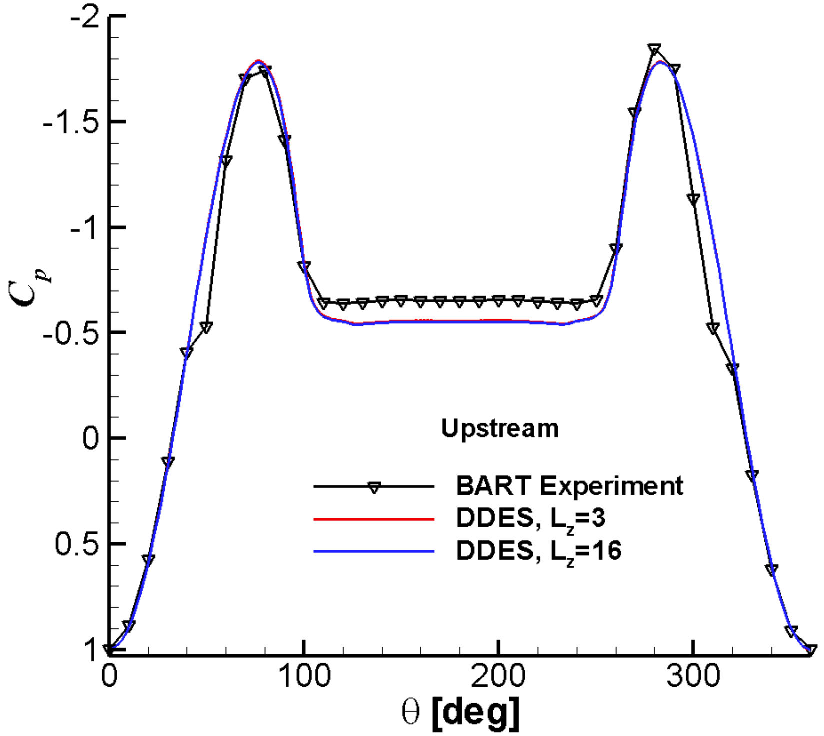
Downstream



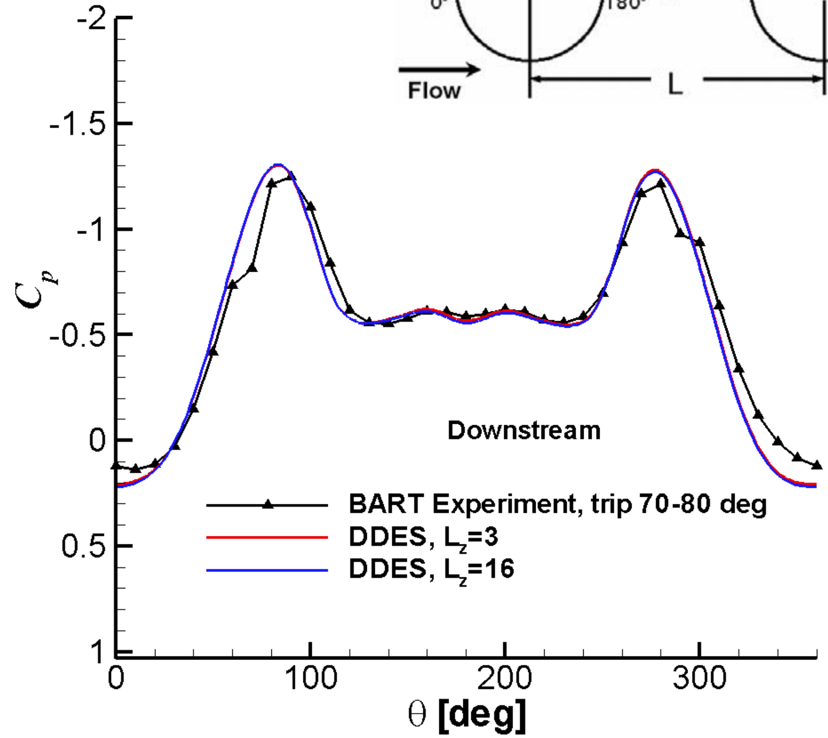
- Support above conclusion that even L_z=16D is not sufficient

Surface Pressure





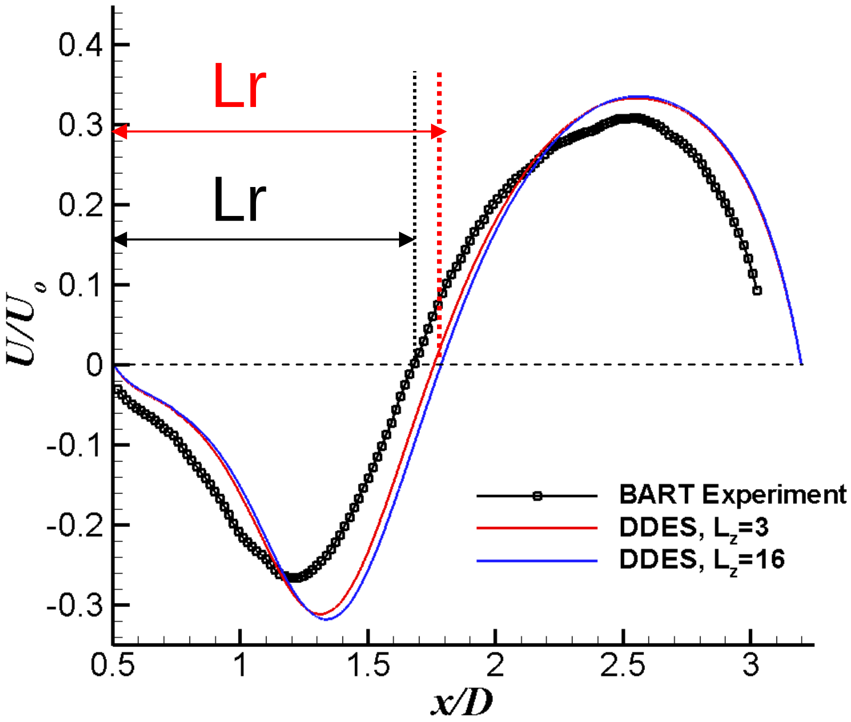
Upstream



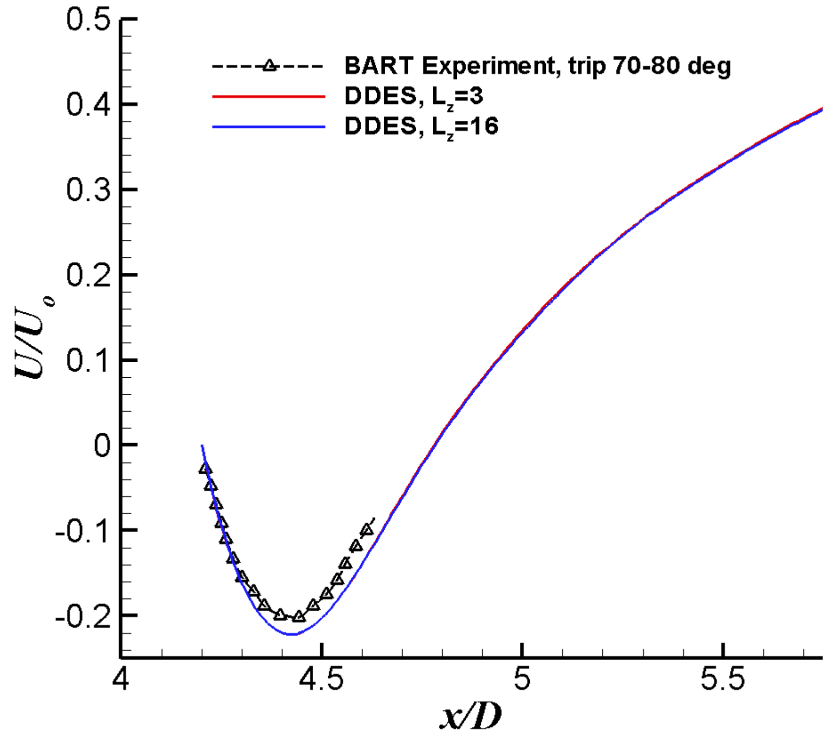
Downstream

- Fairly good agreement with the data
- Weak sensitivity of C_p to L_z

Centerline Mean Velocity



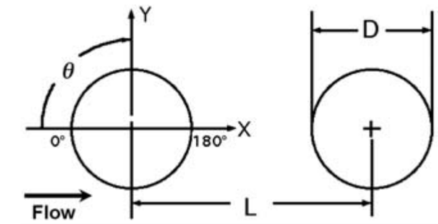
Gap Region



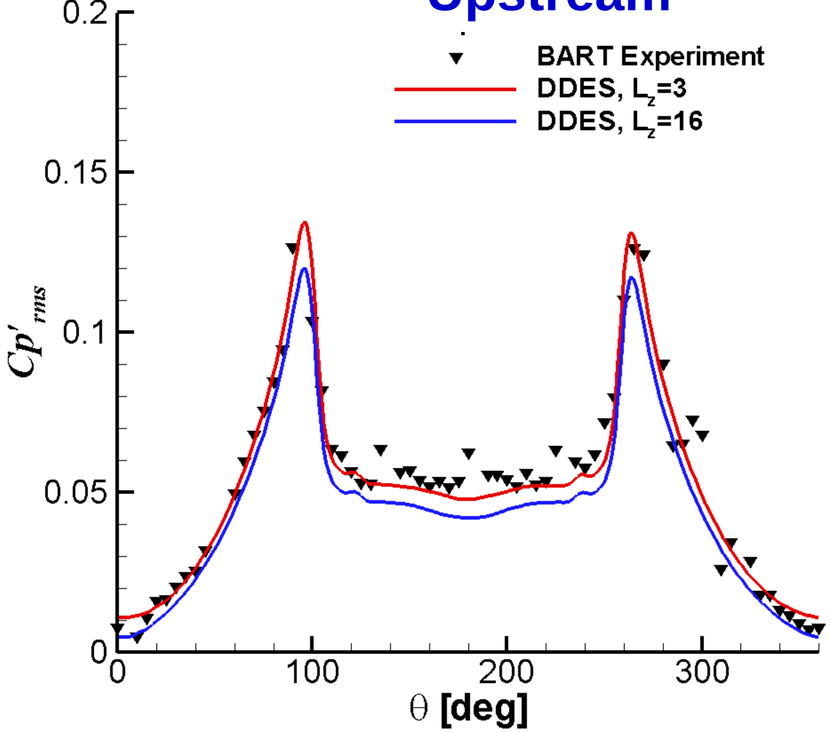
Aft of Downstream Cylinder

- Fairly good agreement with the data but some overestimation of the length of the recirculation zone any back flow intensity
- Marginal sensitivity to Lz

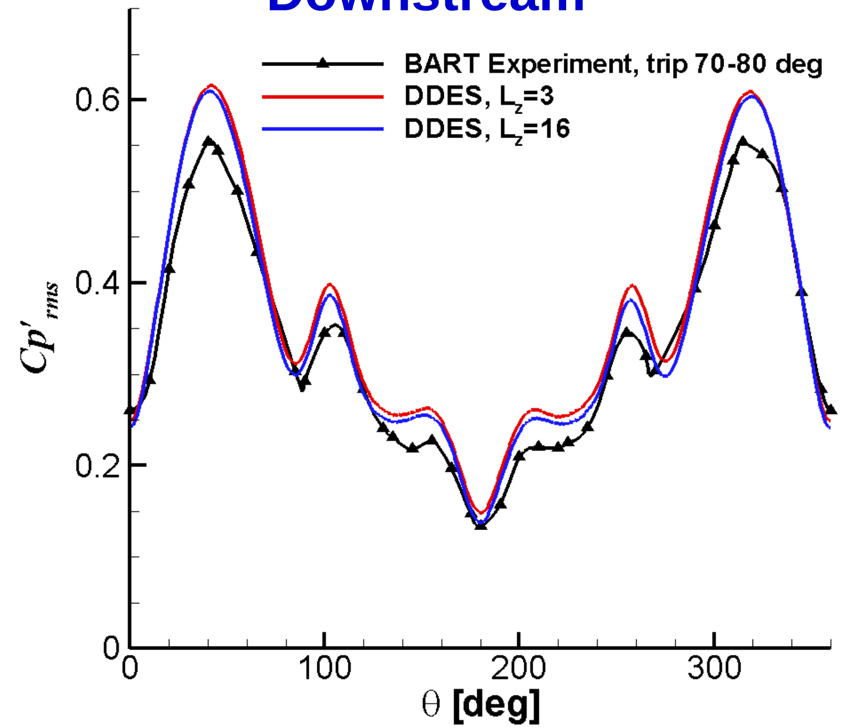
RMS of Surface Pressure Fluctuations



Upstream

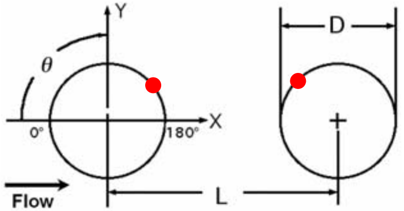


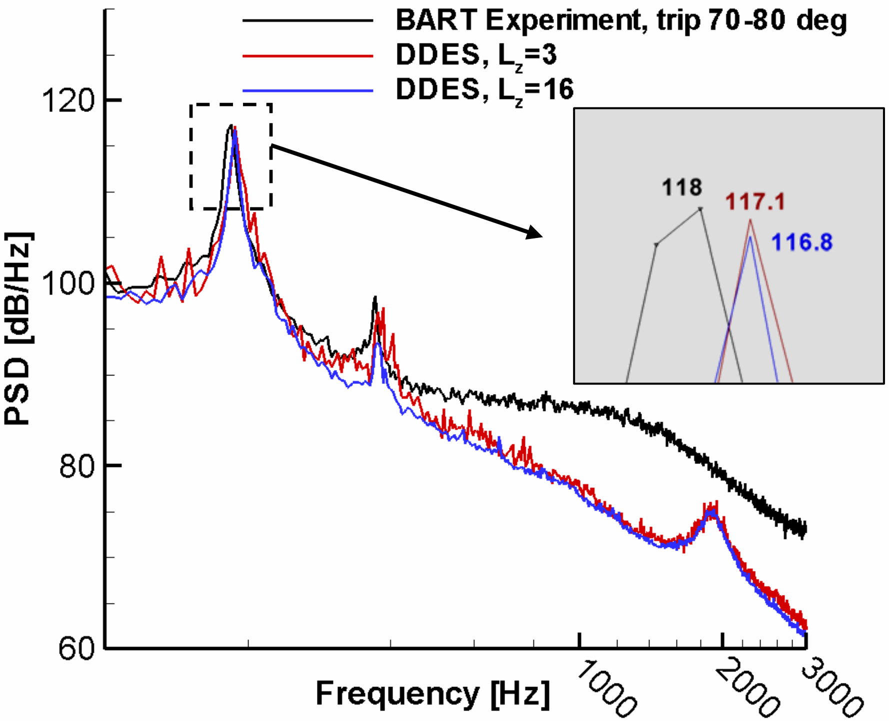
Downstream

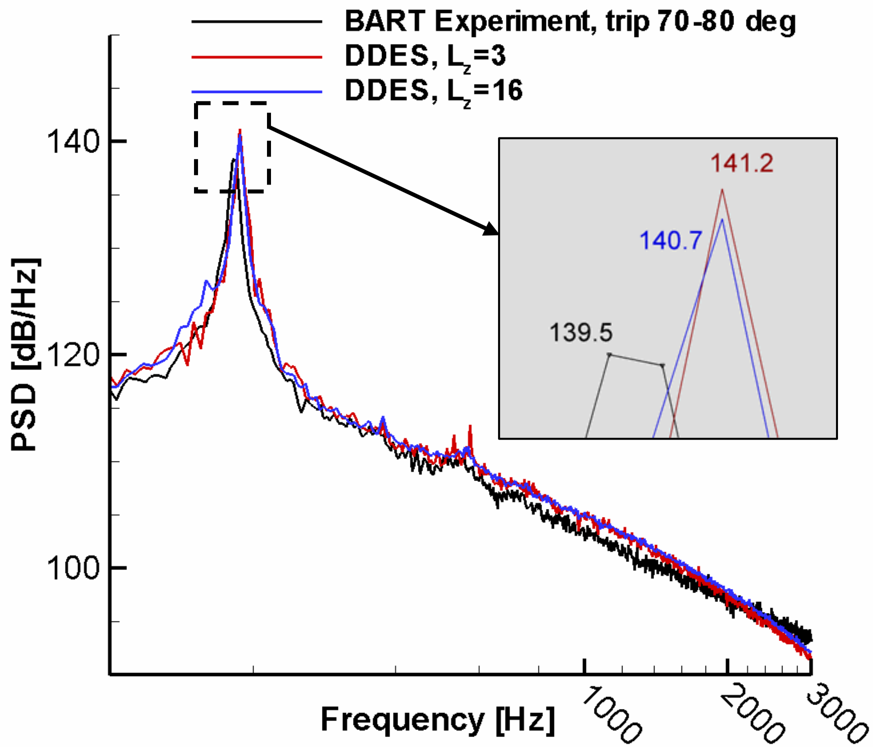


- The most important quantity in terms of the noise prediction
  - Good agreement with the data, although somewhat stronger (still not crucial) sensitivity of the upstream cylinder RMS to L_z

Surface Pressure PSD Spectra







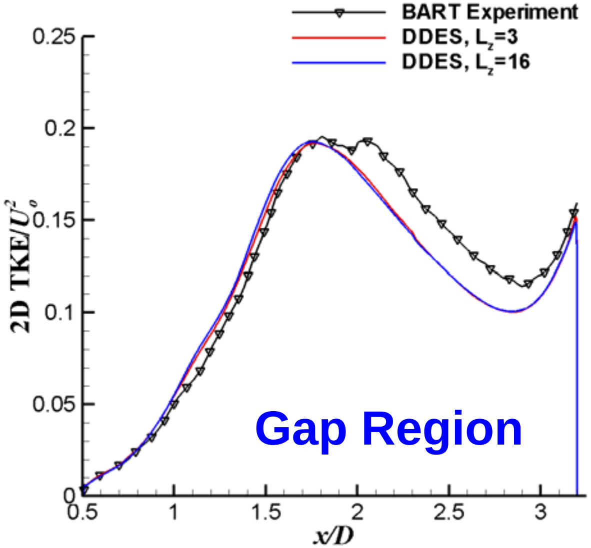
Upstream, θ = 135°

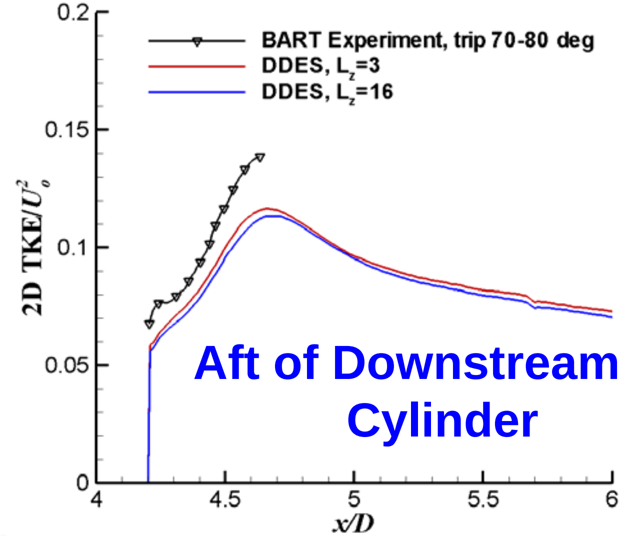
Downstream, θ = 45°

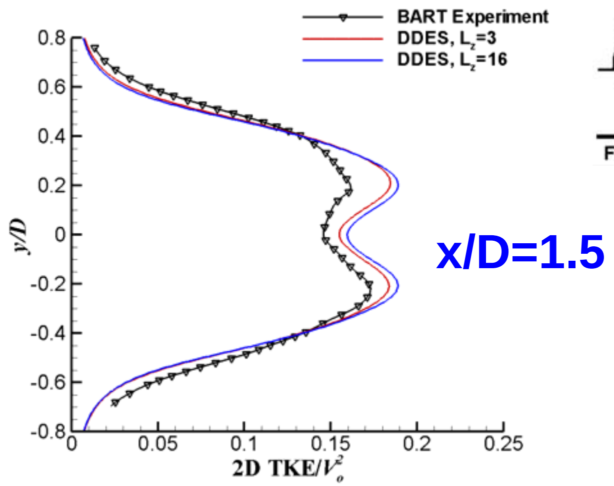
- Observed shedding frequency
  - 188 Hz for both DDES runs
  - 178 Hz in the experiment

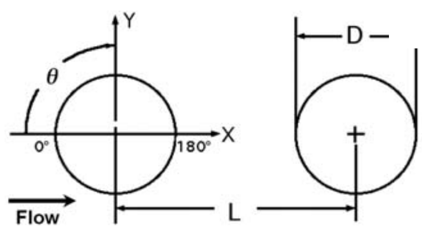
2D TKE Centerline Distributions and Profiles

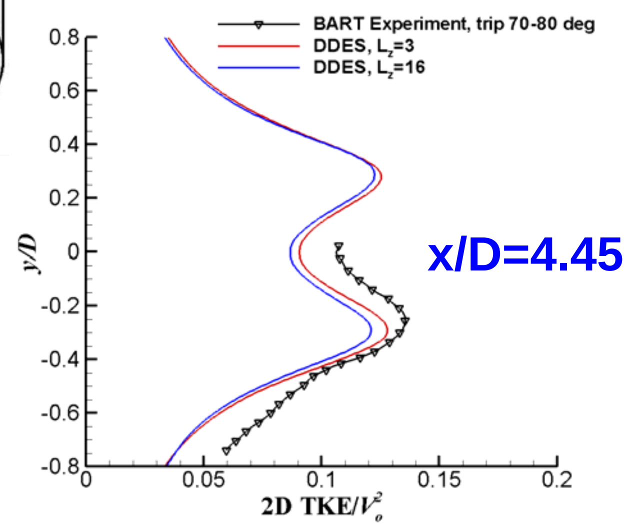
$$1/2\,(\overline{u'u'} + \overline{v'v'} \cancel{+ \overline{w'w'}})/V_o^2$$





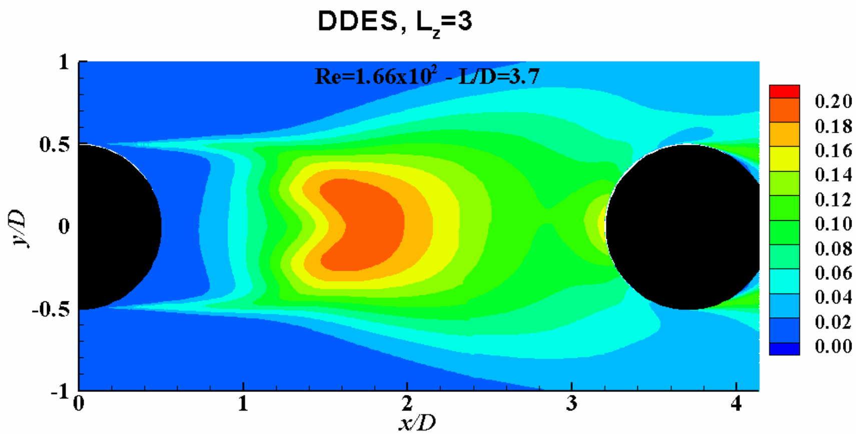


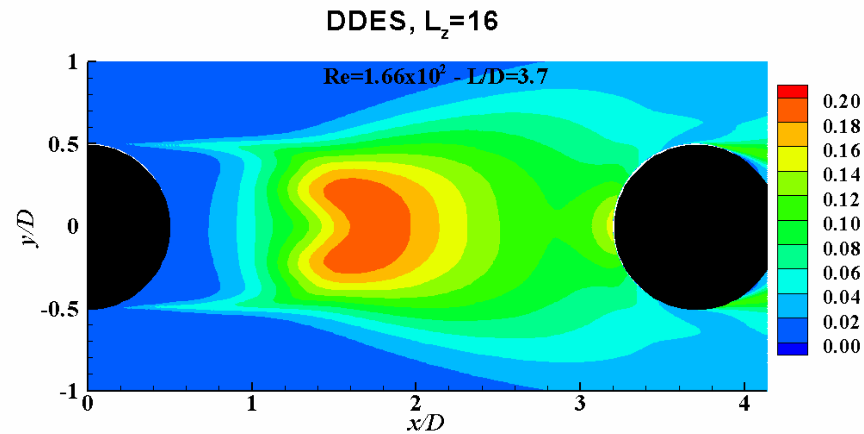




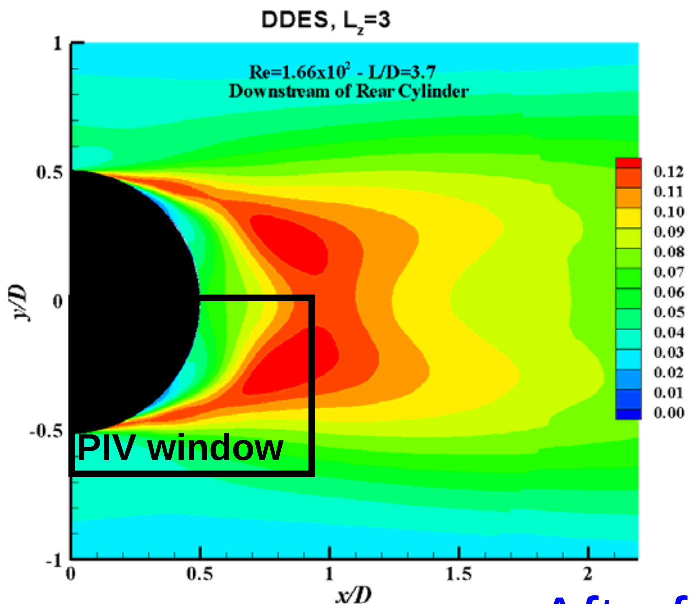
- Acceptable prediction of TKE in both simulations

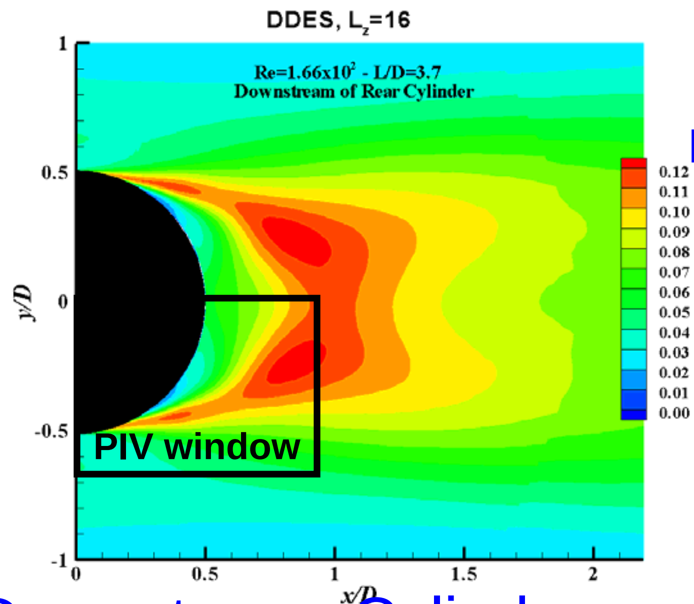
2D TKE in Symmetry Plane



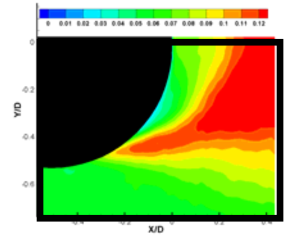


Gap Region





BART Experiment, trip 70-80 deg



PIV window

Aft of Downstream Cylinder

Conclusions and Outlook

- DDES is shown capable of providing a fairly accurate prediction of the flow
- In contrast to simulations of NASA, no significant effect of increase of the size of the domain in the spanwise direction from 3 up to 16D is observed
- Although grid and numerics used in the simulations seem to be “good enough”, a substantial grid-refinement should be yet performed

Acknowledgments

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