The Role of Centerbody Wake on the Precessing Vortex Core Dynamics of a Swirl Nozzle

Arnab Mukherjee, Nishanth Muthichur, Chaitali More,

Saarthak Gupta and Santosh Hemchandra

Department of Aerospace Engineering

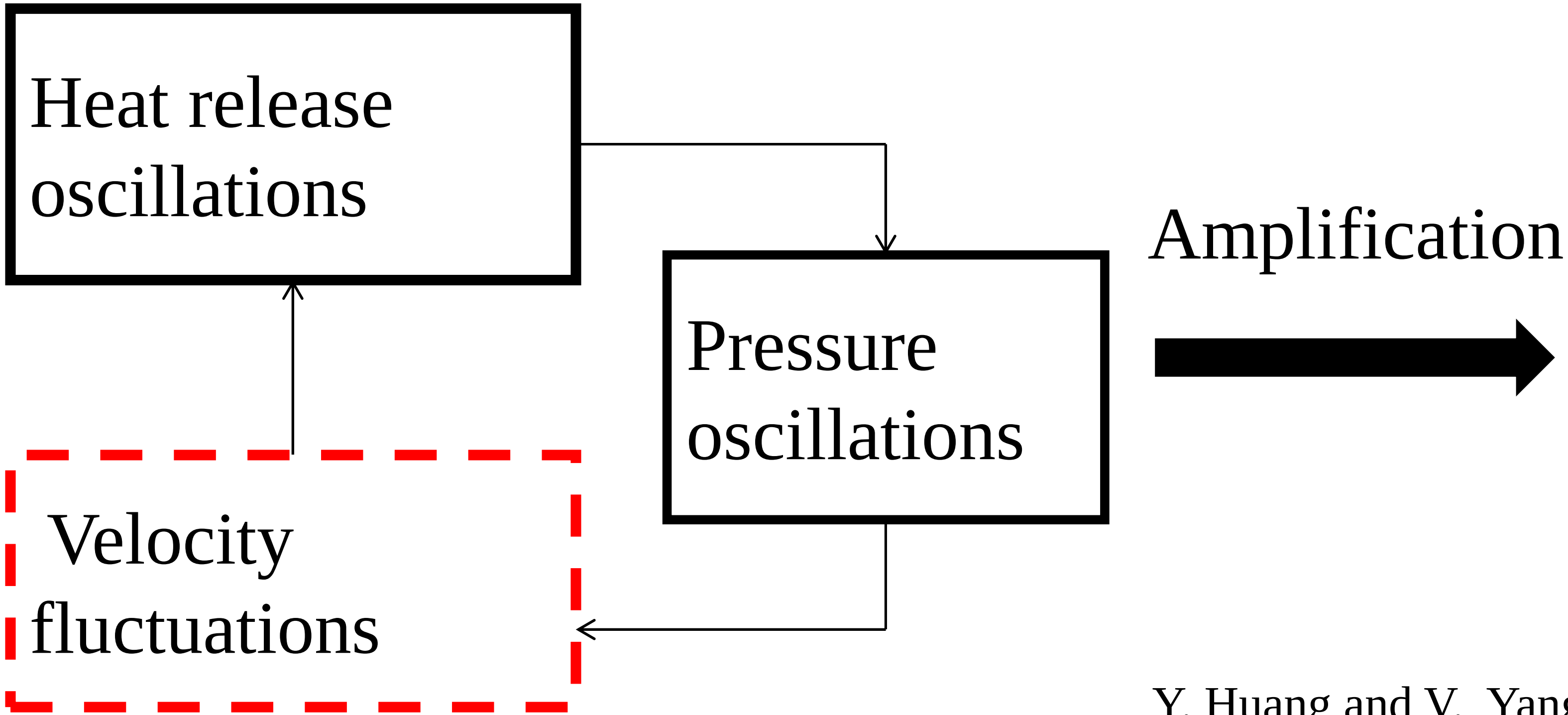
Indian Institute of Science, Bangalore

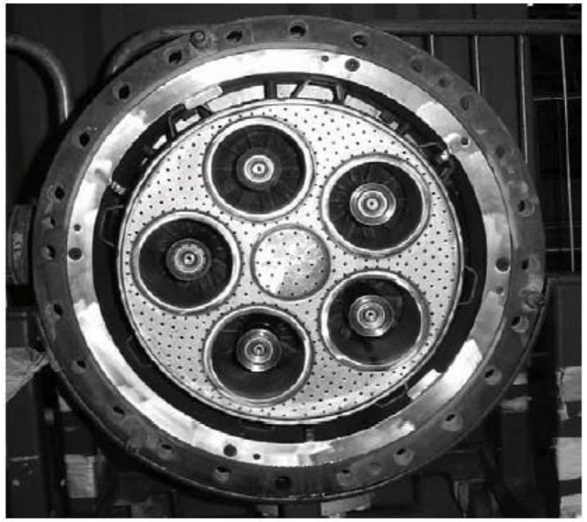
Overview

- Motivation
- Flow Configuration
- Theoretical and Computational work
- Results
- Conclusion

Motivation

- Combustion instability in Lean-Premixed combustors

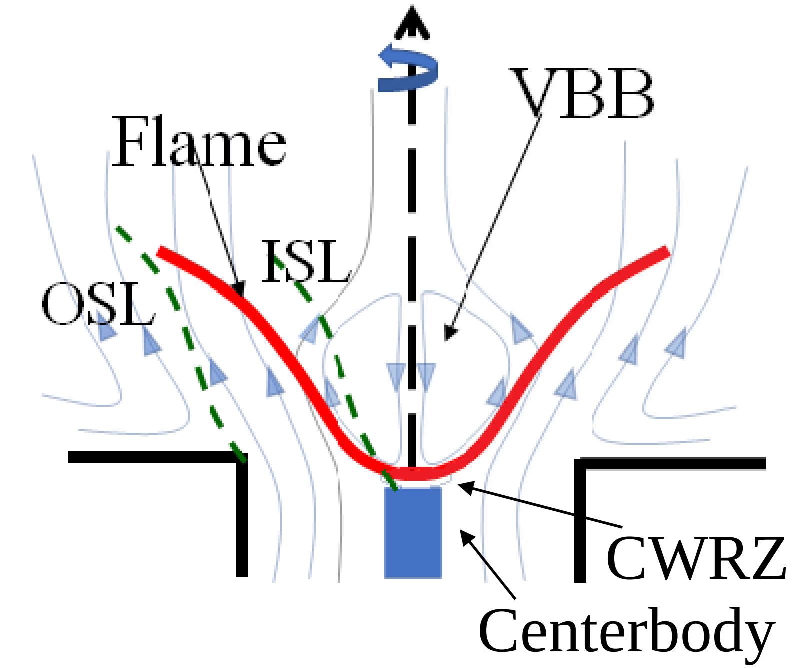




Y. Huang and V. Yang,
Prog. in energy. and comb. Sci. (35) 2009, 293-364

Single nozzle swirl flow field

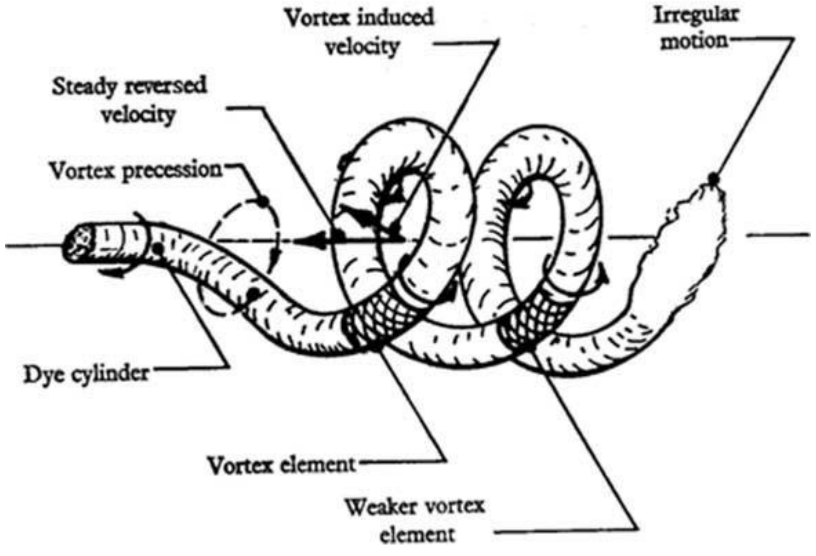
- Centerbody wake recirculation zone (CWRZ) downstream of the centerbody
- Strong shear layers between vortex breakdown bubble (VBB) and annular flow



Manoharan et al, ASME GT2015 -42985

Precessing vortex core (PVC)

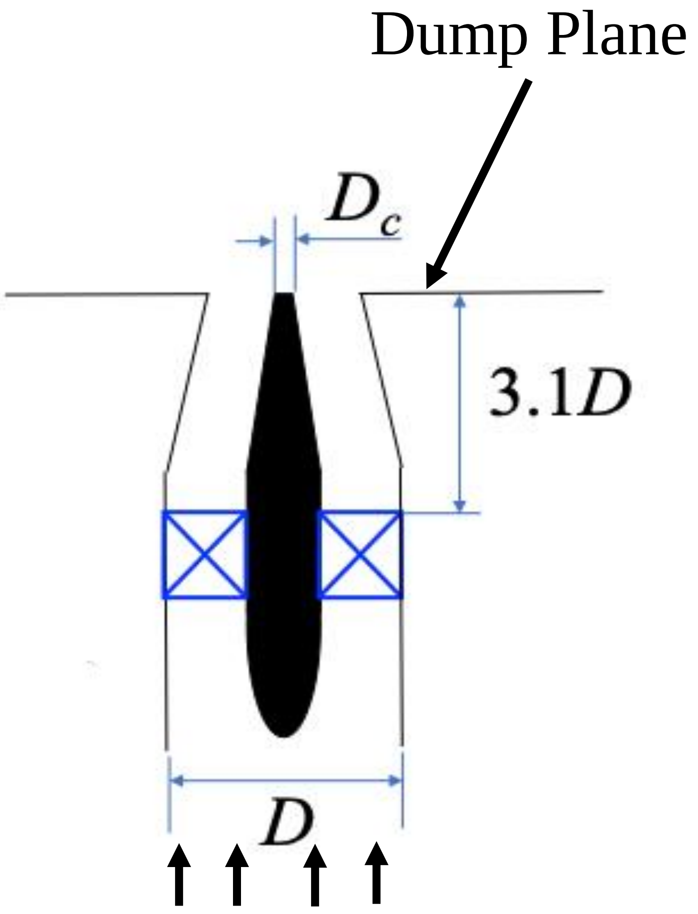
- Neutrally stable hydrodynamic mode
- Helical vortex structure



N.Syred 2006

Configurations Investigated

Name	U_0 (m/s)	Re = U_0D/ν	D_c	N (in million)
LES50	50	48,677	**10mm**	71
LES85A	85	82,751	**10mm**	90
LES85B	85	82,751	**5mm**	87

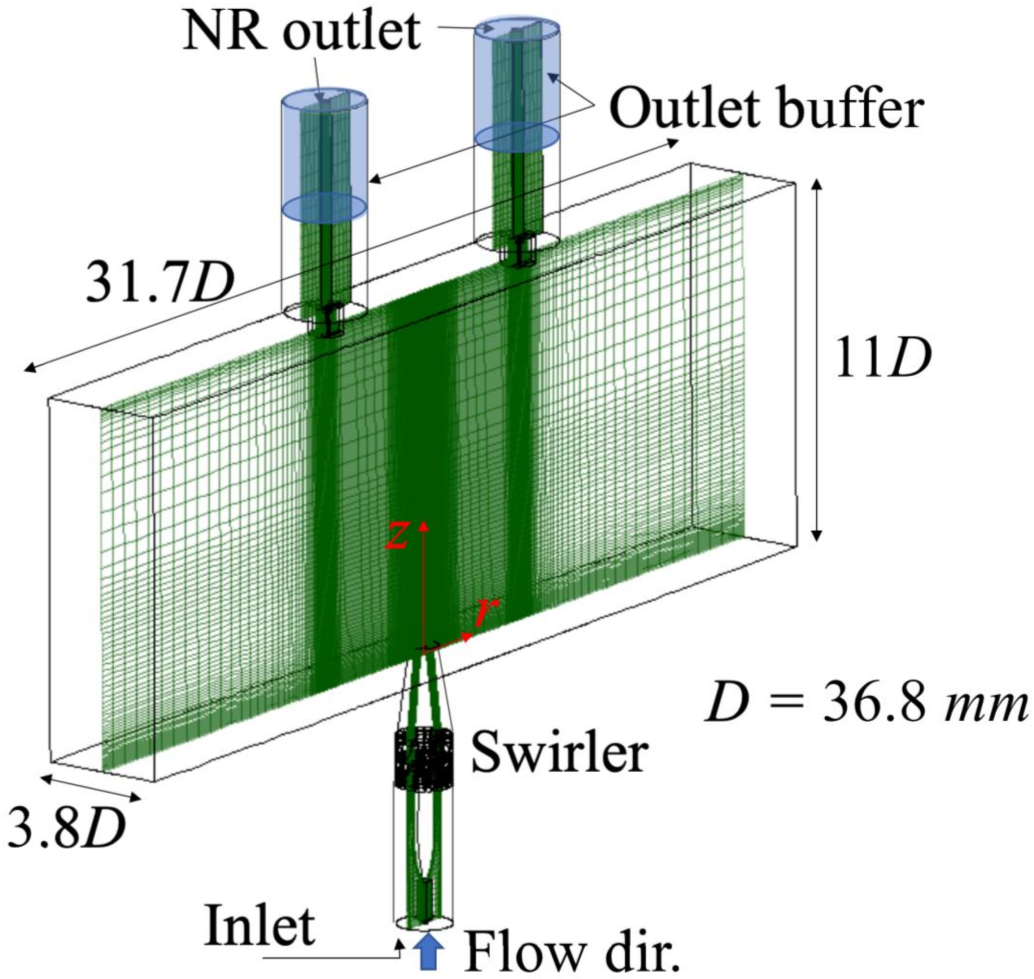


Swirler Schematic

- Steady top hat axial velocity profile at inlet
- Length scale = D, Velocity scale = U_0 (area averaged bulk flow velocity)

Large Eddy Simulations

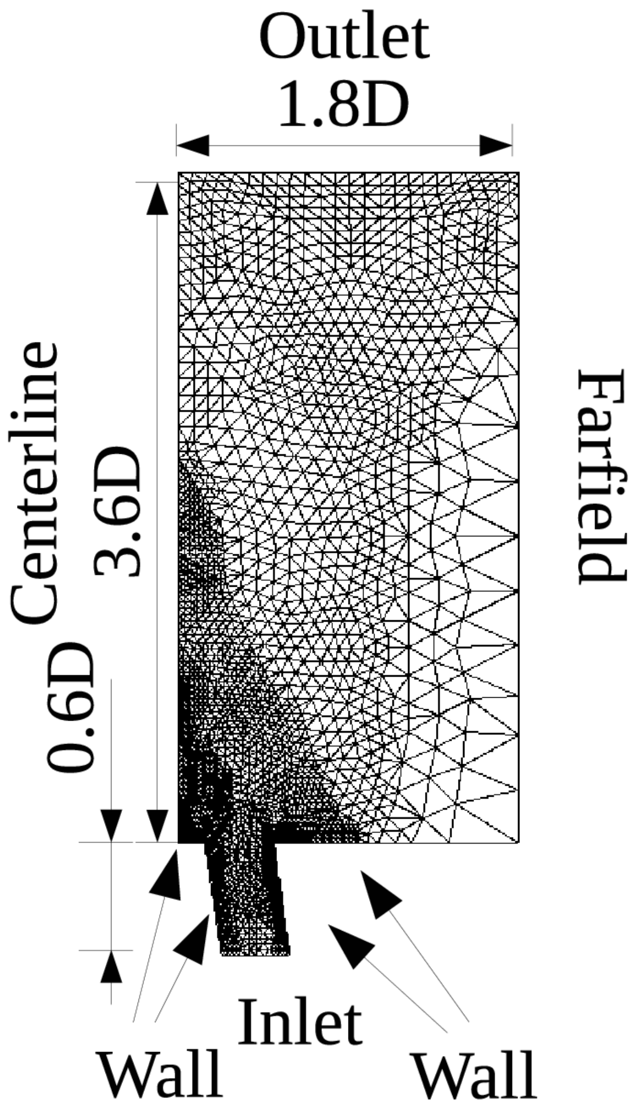
- Explicit filtering LES method
- Spatial derivatives: 8th order central difference scheme
- Time advancement: 3rd order Runge-Kutta scheme.
- Overset mesh method



Schematic of LES computational domain geometry

Linear Stability : Formulation

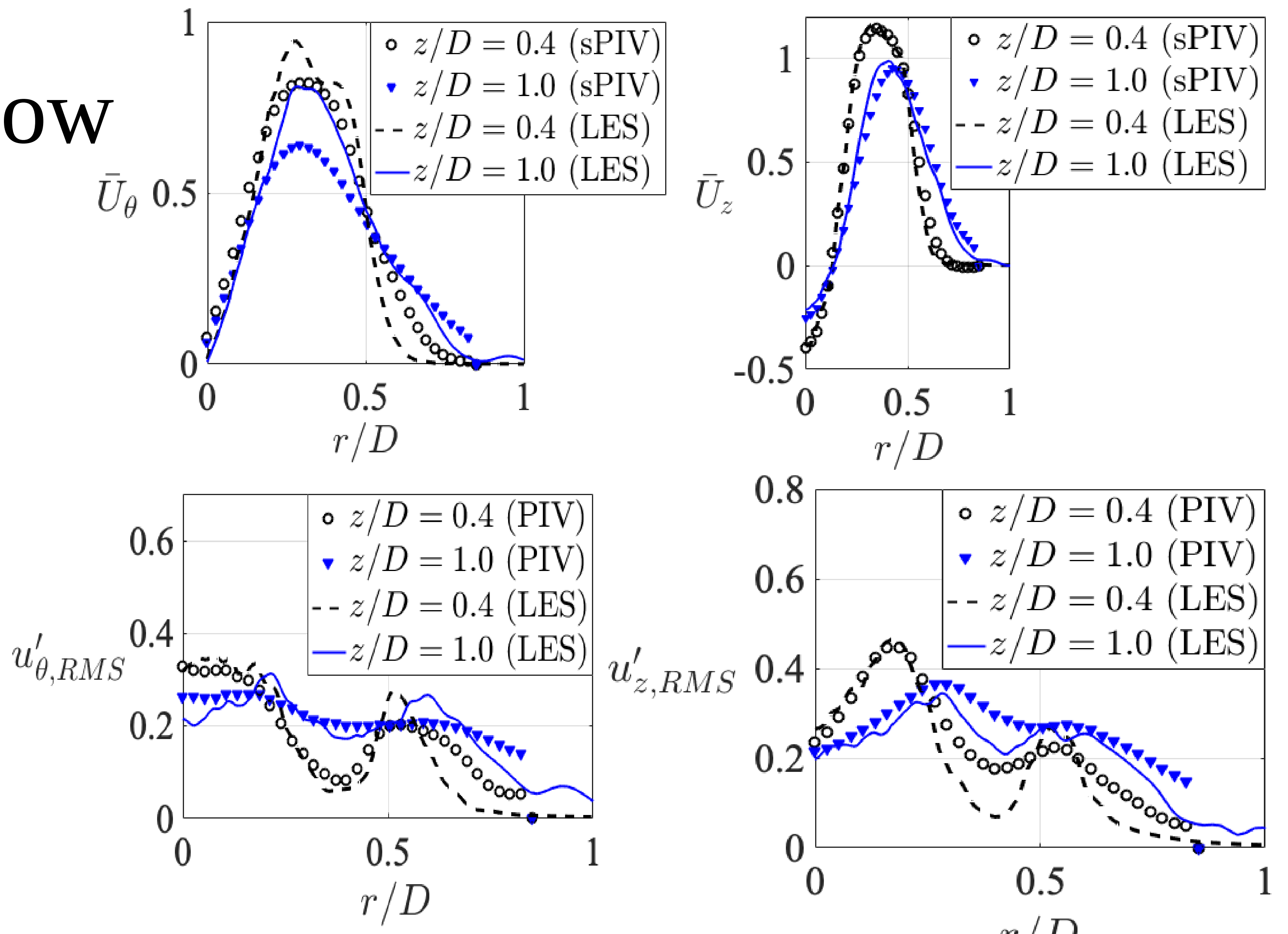
- Linearized Navier-Stokes equations
  - $q = Q + q' + q''$
  - $q' = q_m(r,z)\exp[i(m\theta - \omega t)]$
  - $-i\omega\mathcal{B}q_m = \mathcal{L}_m(Q)q_m$
- Boundary Conditions
  - Walls: $u_r = u_\theta = u_z = 0$
  - Farfield: $u_r = u_\theta = u_z = p = 0$
  - Centerline: $u_z = p = 0,\ u_r + imu_\theta = 0,\ du_r/dr = 0$ (ref: Batchelor, JFM 1962)
  - Inlet: $u_r = u_\theta = u_z = 0$
  - Outlet: $du_r/dz = du_\theta/dz = du_z/dz = 0$
- Finite Element discretization based on triangular elements (FreeFEM++)
  - Velocities – P1bubble
  - Pressure – P1



Schematic of axi-symmetric domain used for hydrodynamic stability analysis

Results - Baseflow

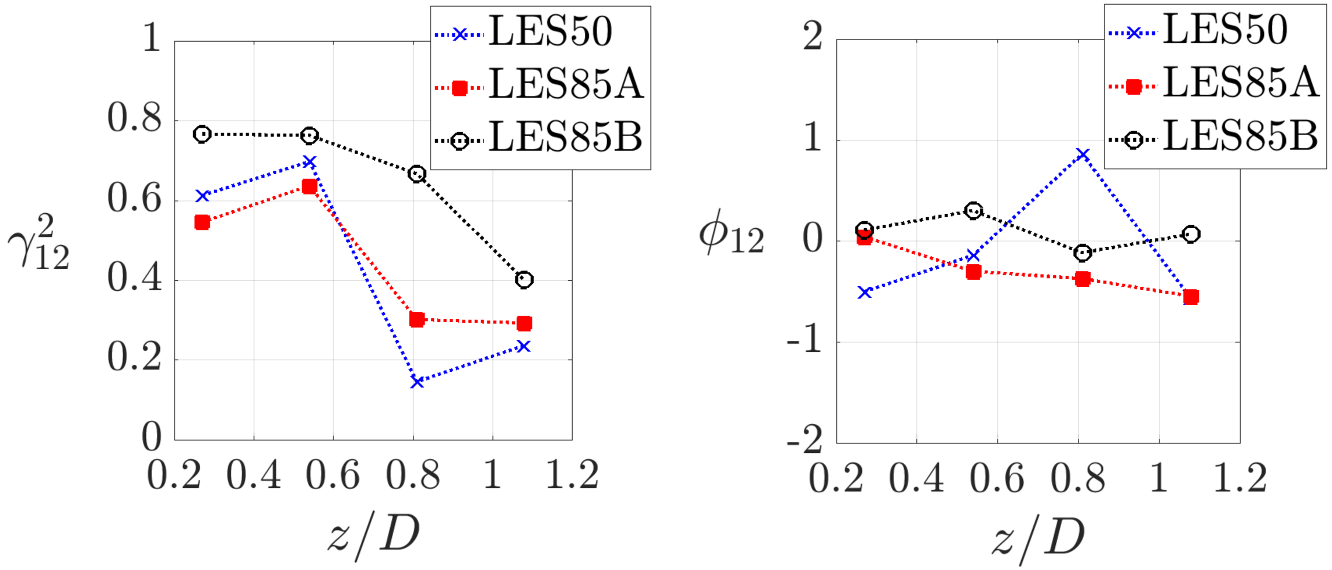
- Validation of LES from experimental results
- Mean azimuthal velocity peak value different
- Rms velocities – location of peaks are accurately captured
- LES method – flow dynamics properly captured



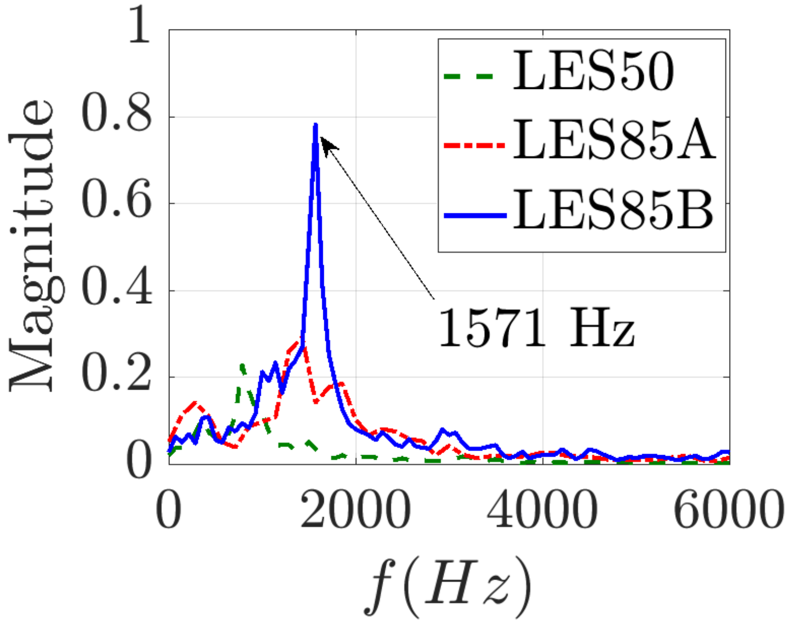
Comparison of radial profiles of time-averaged fields (LES50 and SPIV)

Results - Time Series Analysis

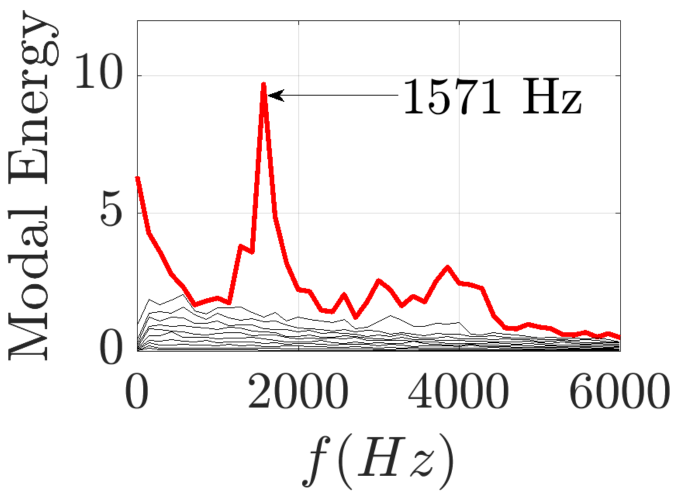
- LES85B – PSD peak, High cross coherence, zero phase (helical)
- LES85B – most energetic mode – strong oscillation at 1571Hz



Mean squared coherence and phase of the cross-spectrum between points radially positioned at r/D = +0.32,-0.32



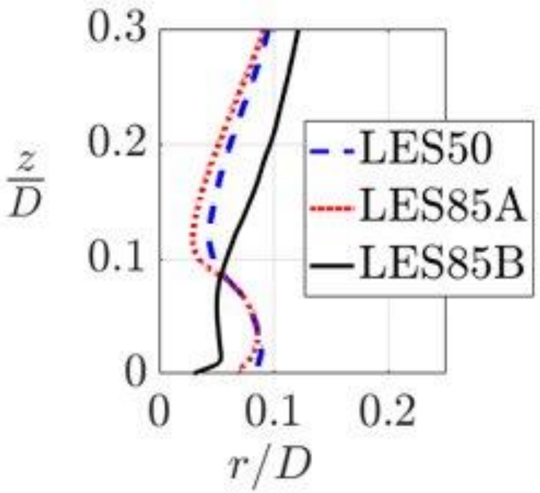
PSD at r/D = 0, z/D = 0.81



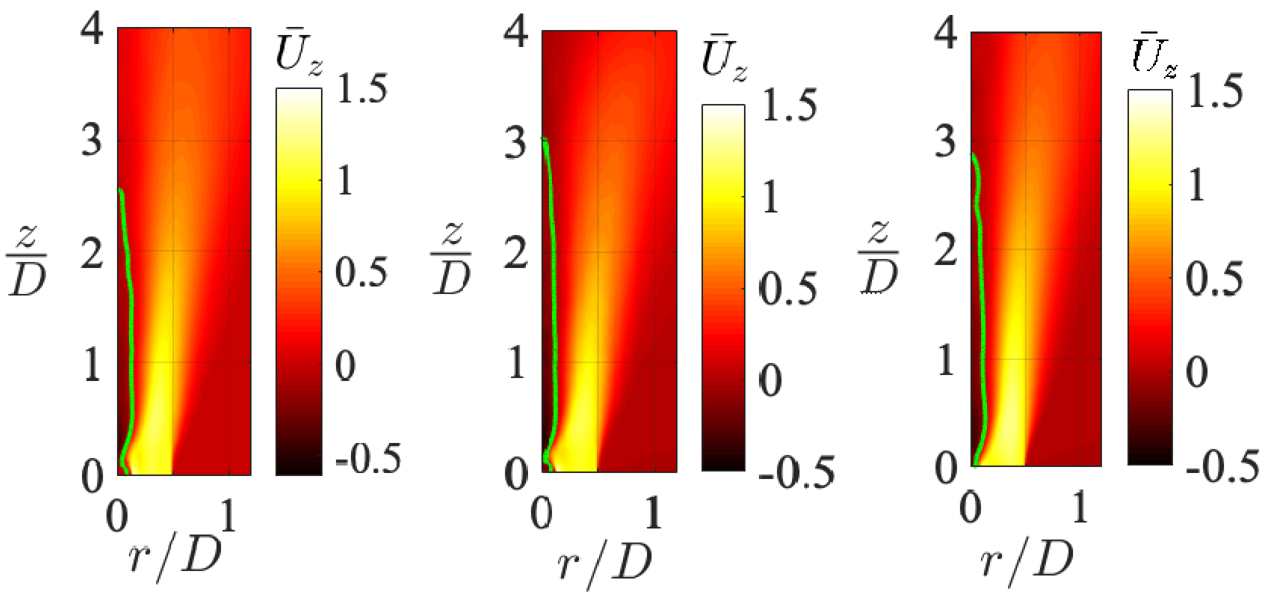
Modal energy spectrum from SPOD (LES85B)

Results - Linear Stability Analysis

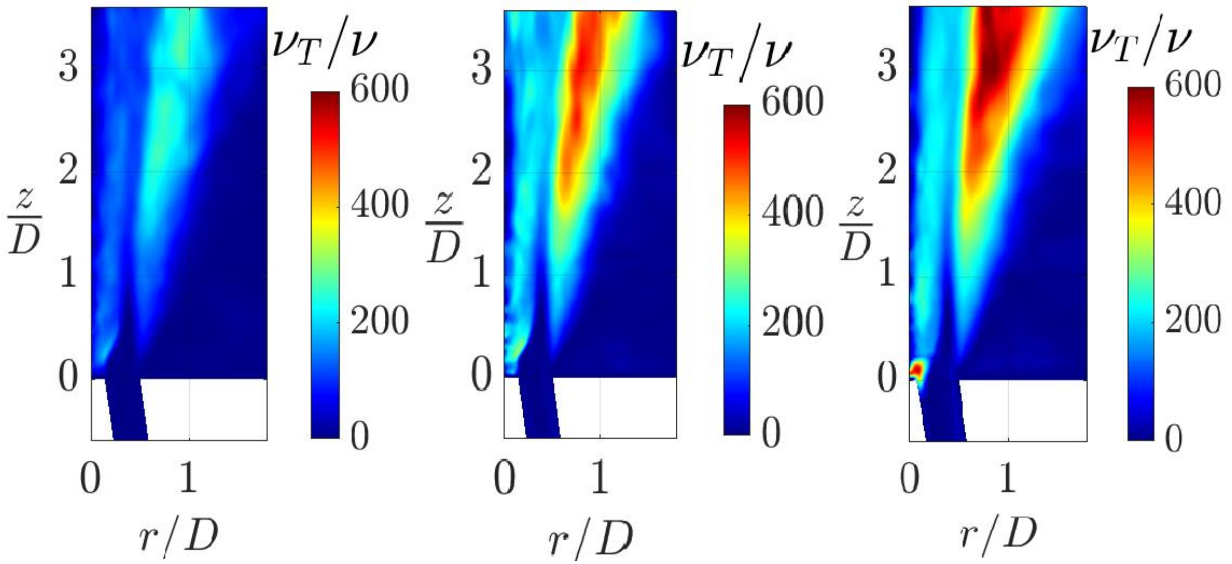
- Zero axial velocity contour – VBB and CWRZ region
- LES50 and LES85A – overlapping contours
- LES85B – clear demarcation not observable



Time-averaged zero axial velocity contours



Time-averaged axial velocity for LES50, LES85A and LES85B

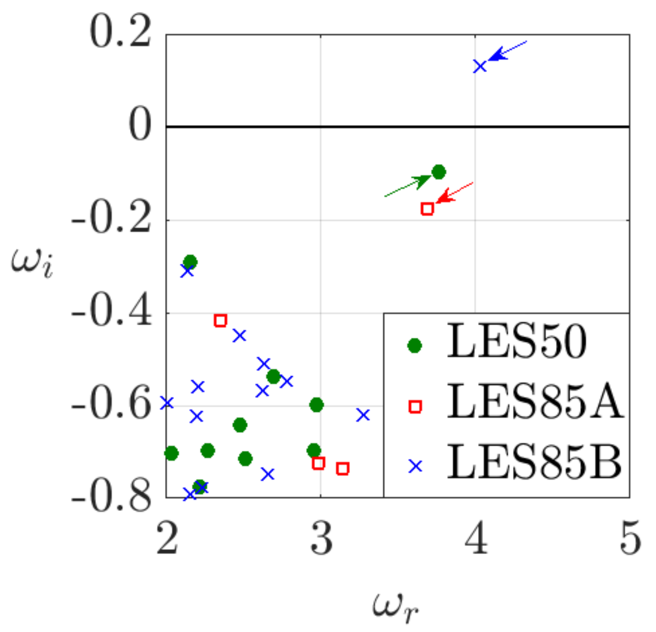


Eddy Viscosity fields for LES50, LES85A and LES85B

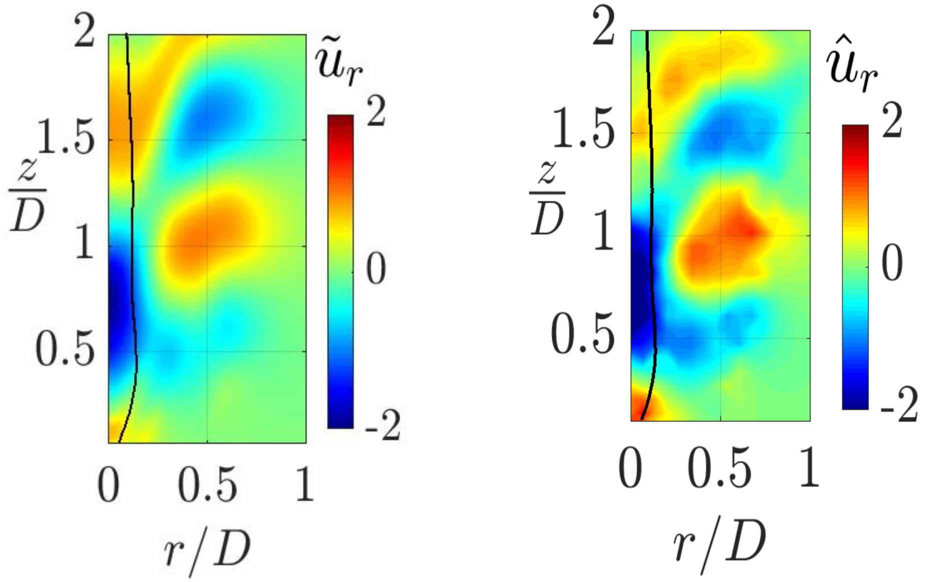
Results - Linear Stability Analysis

Case	ω	f_{LSA}(Hz)	f_{SPOD}(Hz)
LES50	3.8 + i(-0.09)	822	No Precession
LES85A	3.7 + i(-0.17)	1367	No Precession
LES85B	4.0 + i(+0.13)	1477	1571

- LES85B – marginally unstable mode
- Centerline radial oscillation – VBB precession

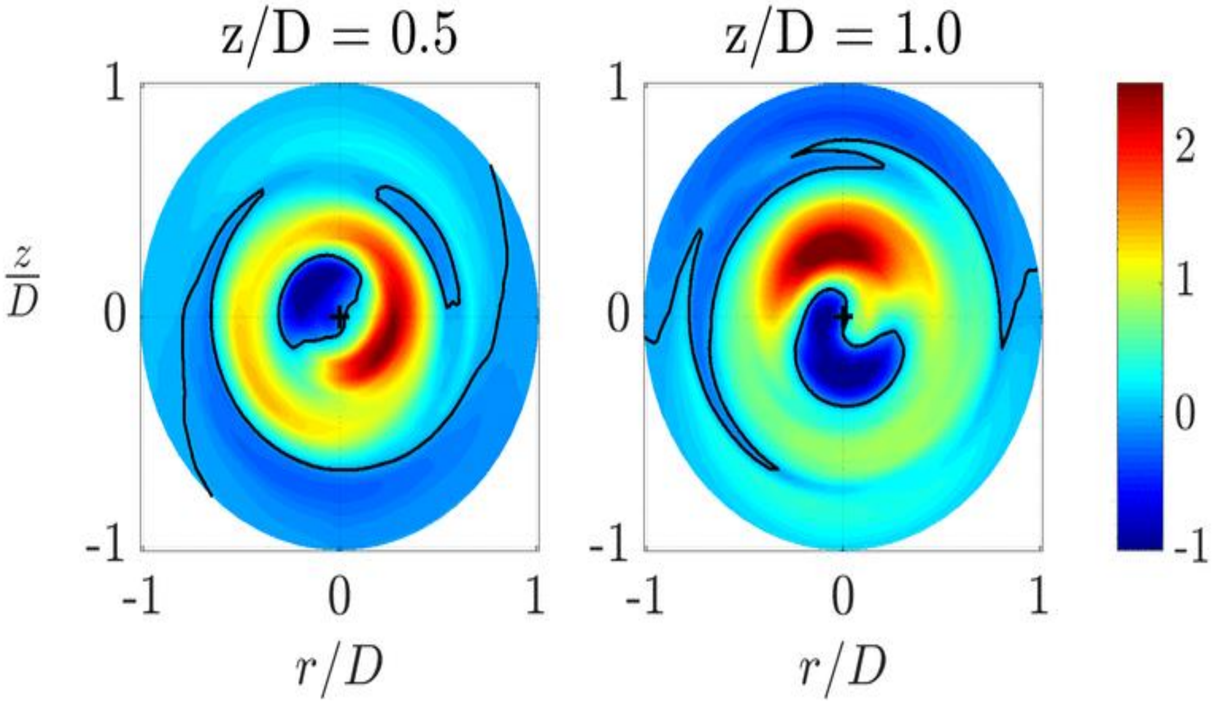


Eigenspectrum of helical (m=1) modes

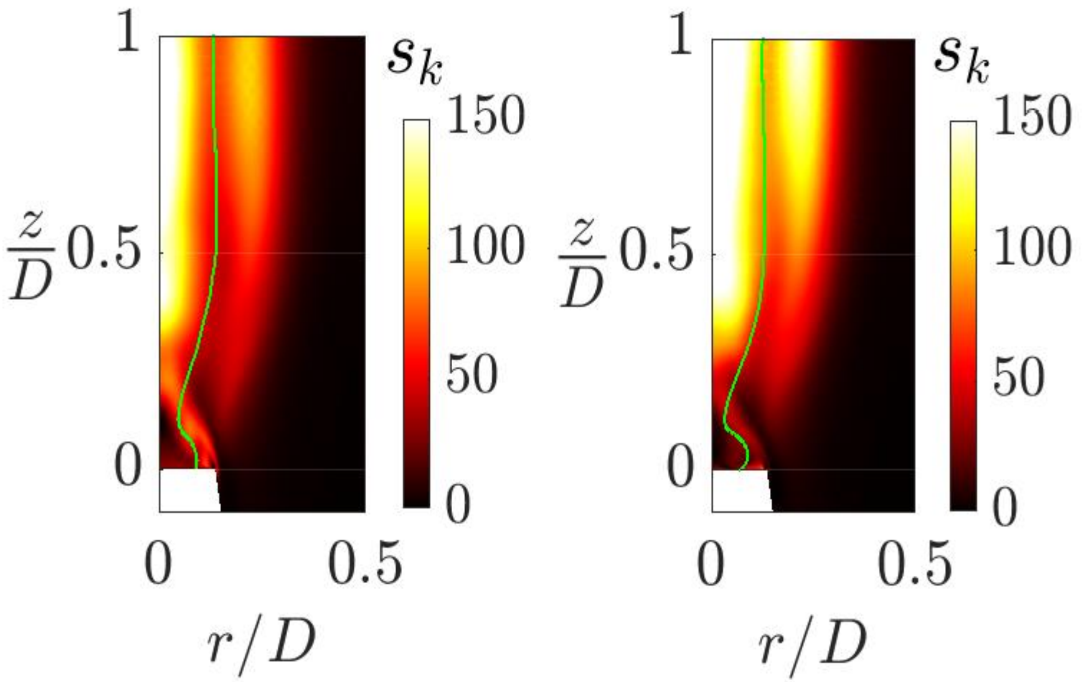


Results - Linear Stability Analysis

- Structural sensitivity noticeable near the neck.
- Halving inner diameter – halves CWRZ length – VBB precession



VBB precession mode (LES85B)



Structural Sensitivity Plots for LES50 and LES85A

Conclusions

- LSA solver has great agreement with time series analysis. The solver is fast and takes 30 minutes at most on an average laptop to run.

- Halving D_c reduces the length of CWRZ resulting in VBB and CWRZ being separated – possibly being the cause of VBB precession.

- Centerbody could effectively be used to turn on or turn off the PVC instability.