Low-frequency Unsteadiness in Backward-Facing Step Flows

Fatemeh Malmir, Jérôme Vétel

L^{A}DyF– Dept. of Mechanical Engineering – Polytechnique Montréal, Montréal, Québec, H3C 3A7, Canada

GPS Génie par la simulation
SBES Simulation - Based Engineering Science

LADyF Laboratoire de Dynamique des Fluides
POLYTECHNIQUE MONTRÉAL

1 Context

Flow separation is an undesirable phenomenon that may occur in engineering and environmental applications. Flow in separated regions is strongly unsteady and this unsteadiness causes flow-induced vibration, fatigue failure and acoustic noise. Therefore, the prediction and control of such phenomena are crucial for air, land, marine transport, and for energy production.

Backward-facing (BFS) flow is a representative separation flow model which is widely found in our daily life. The separated flow generated by an abrupt change in geometry is a suitable case to study unsteadiness. Shedding of vortices emanating from the separation point and low-frequency flapping motions are two main unsteadiness observed in BFS.

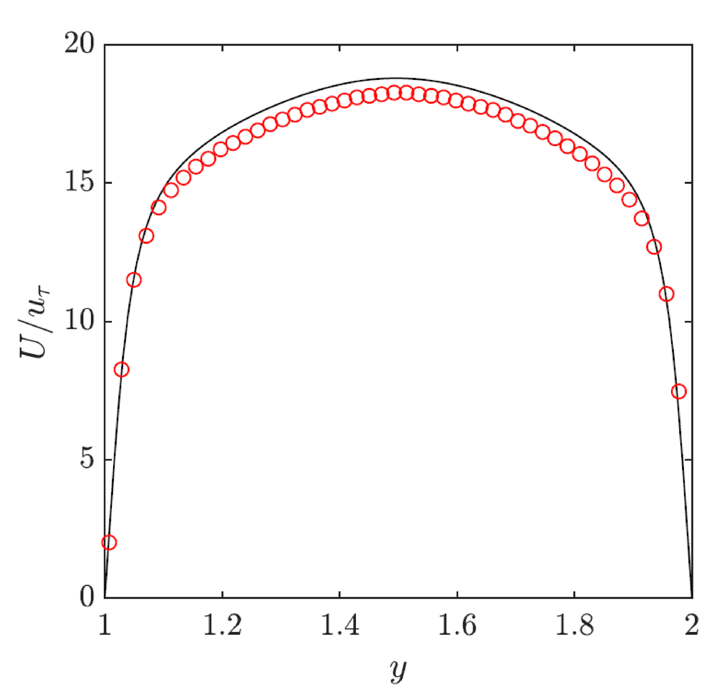
The main objective is to find the magnitude of low-frequency unsteadiness and its physical origin.

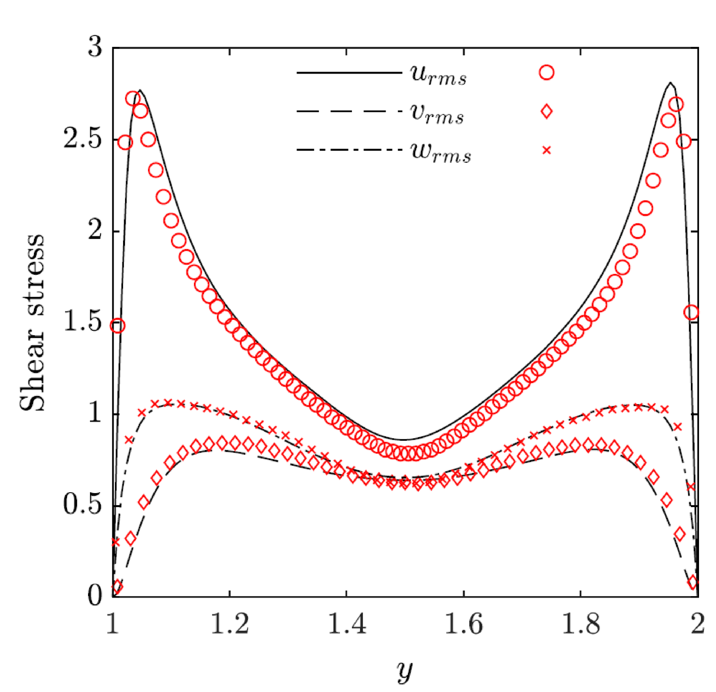
2 Methodology

- A massively-parallel open-source code **Xcompact3d** is applied to numerically simulate the flow[1].
- The **iLES** approach is chosen for solving Navier-Stokes equations.
- The **immersed boundary** method is used to generate geometry.
- The **recycling-rescaling** method is performed to define the turbulent inflow.

3 Validation

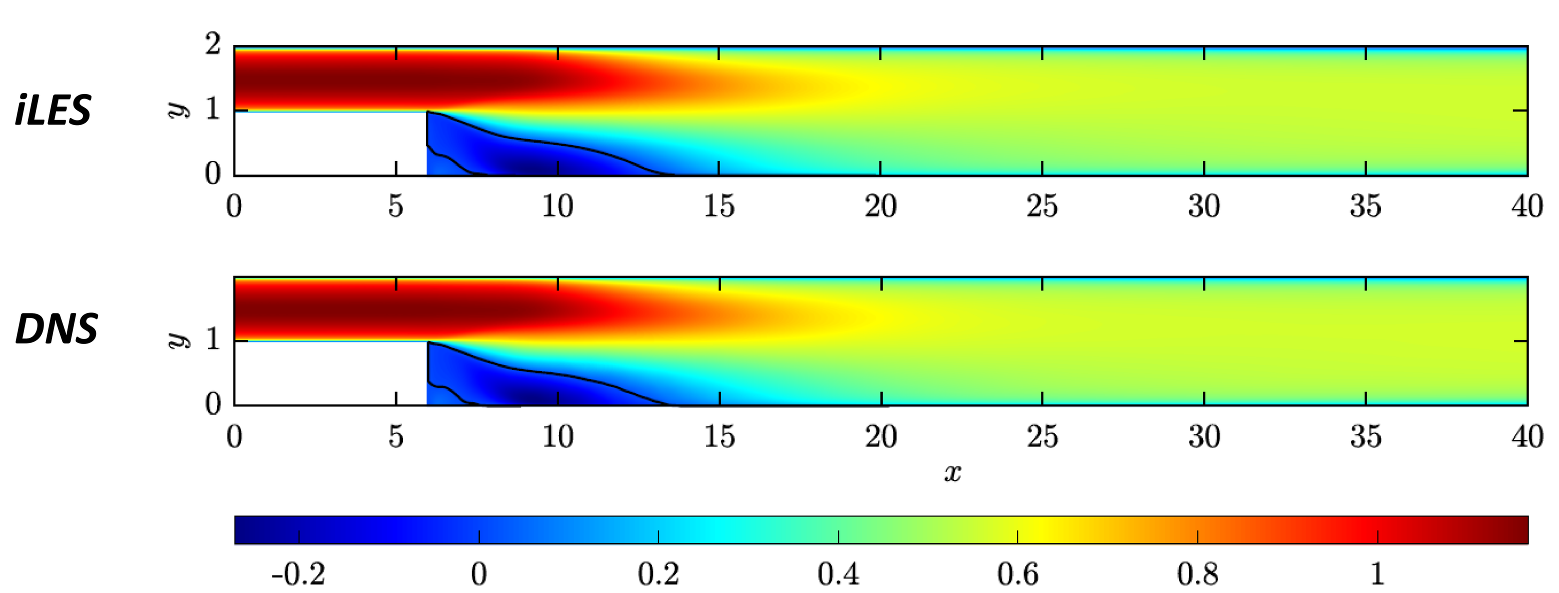
The inflow condition is validated with Barri *et al* (2010) work[2]:





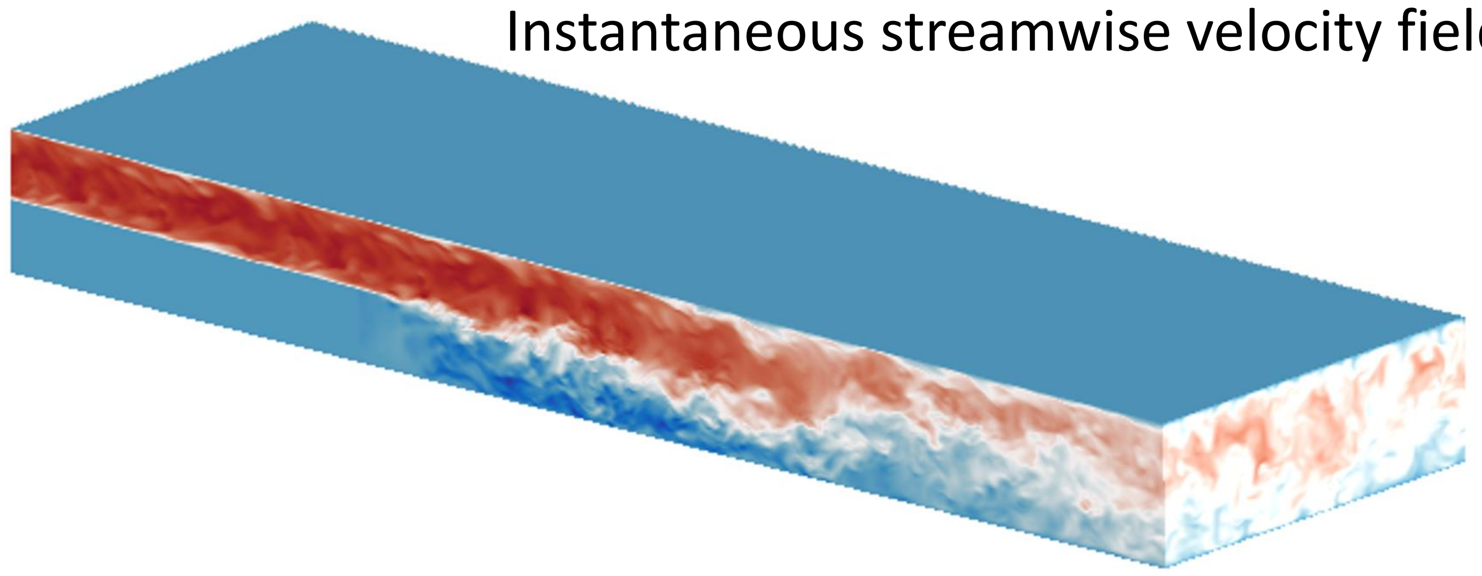
The iLES results are verified with DNS data. The comparison between the time- and spanwise-averaged of the streamwise velocity is in a good agreement.

	Mesh size	Time step	L_b
iLES	1025×257×128	0.0005	7.64
DNS	1601×601×432	0.0005	7.73

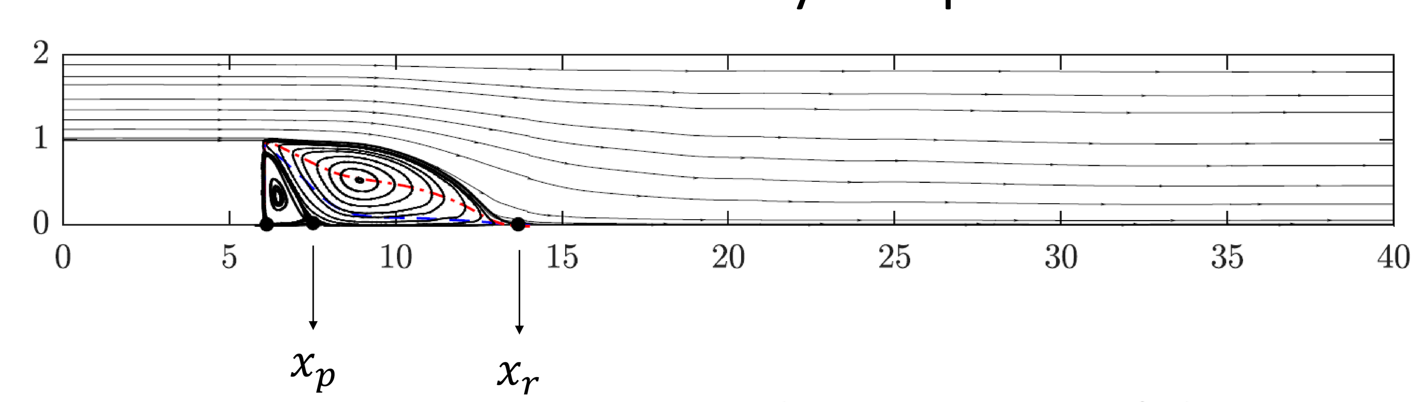


4 Results

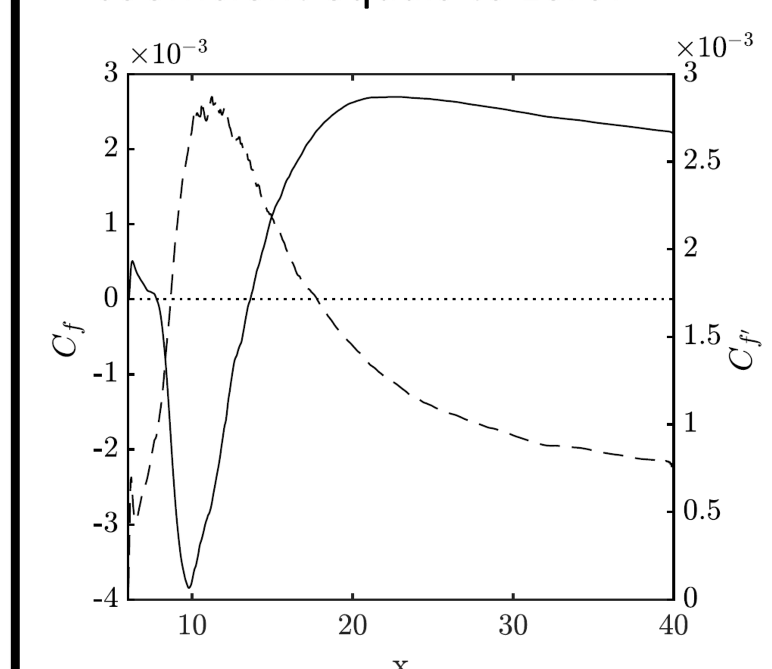
Instantaneous streamwise velocity field



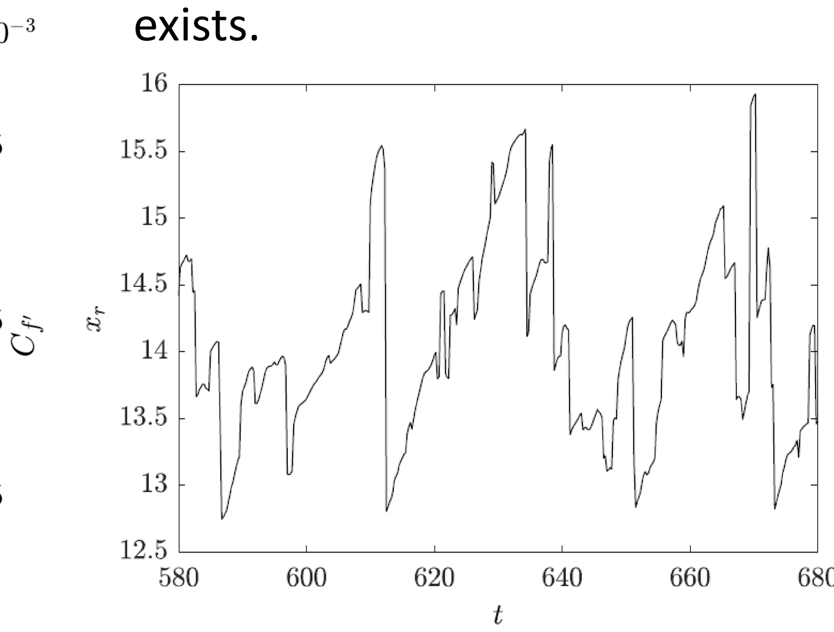
Streamlines of the mean velocity in k-plane:



The reattachment point x_r is where the mean skin friction coefficient equals to zero:

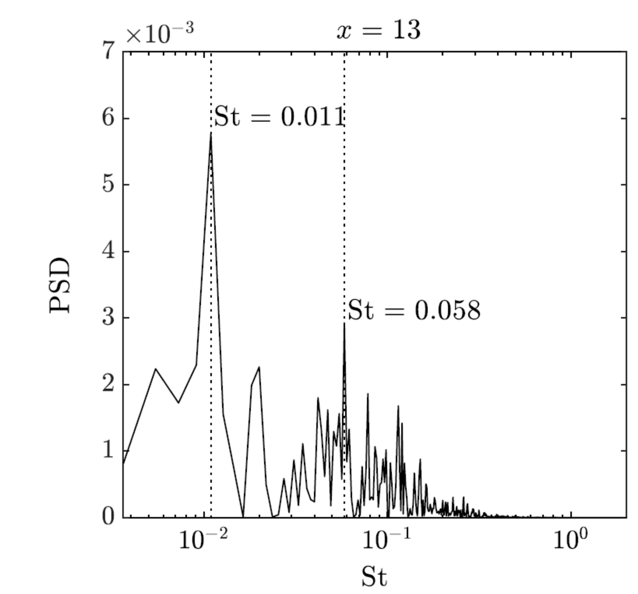


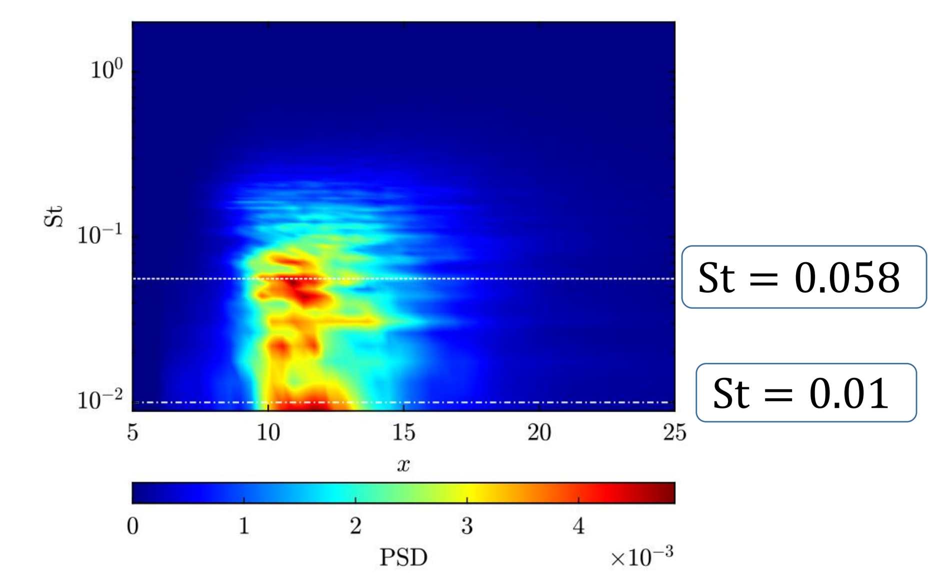
The time traces of the spanwise-averaged reattachment locations justify that a large unsteadiness exists.



Spectral Analysis:

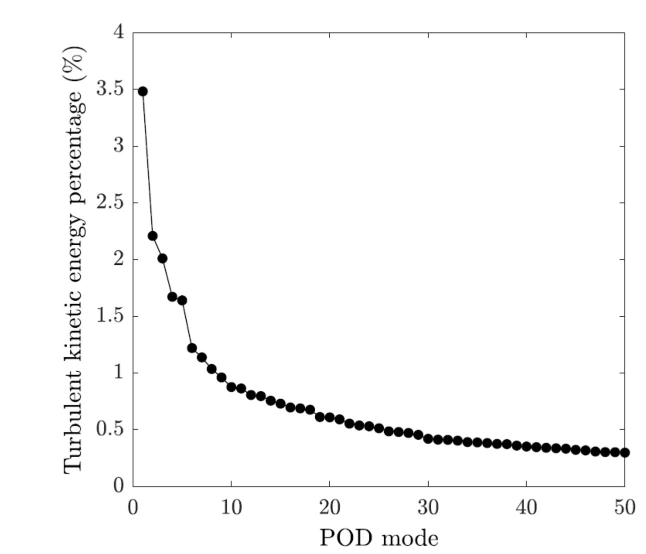
The power spectral density (PSD) of the bottom-wall pressure:

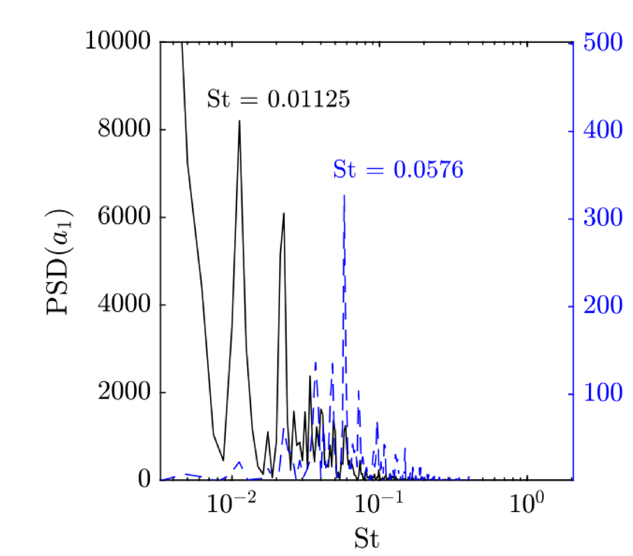


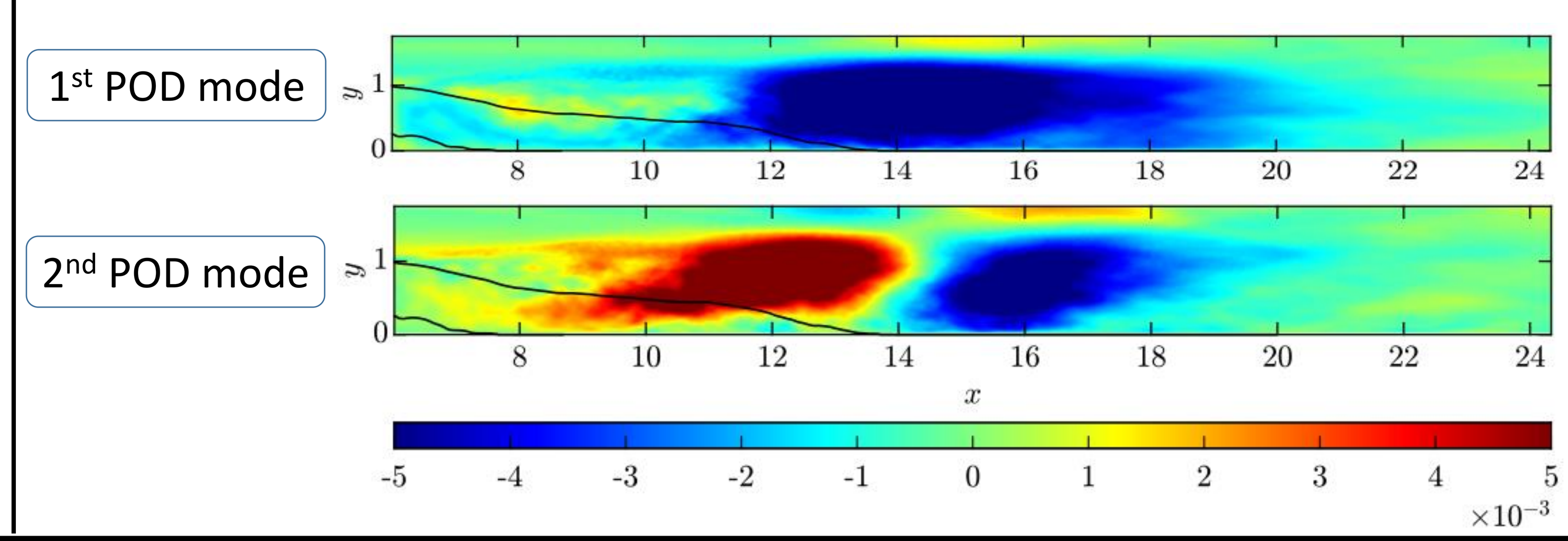


Modal Analysis (POD):

To capture coherent structures, POD analysis is done on the mid-kplane:







5 Conclusion

- The mean reattachment length of the main bubble is 7.6h.
- The motions of the spanwise-averaged reattachment length shows a quasi-periodic behavior which was previously observed in Le *et al* (1997) work[3].
- The spectral analysis on the pressure field and modal analysis on the velocity field indicates two dominant frequencies.
- A low-frequency at **St** $= \mathbf{0.01}$ is linked to **the shrinkage and enlargement of the separation bubble**.
- Another dominant frequency at **St** $= \mathbf{0.058}$ is attributed to the **shedding mode**.

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References

[1] S. Laizet and N. Li, "Incompact3d: A powerful tool to tackle turbulence problems with up to O(10^5) computational cores," Int. J. Numer. Methods Fluids, 2011
[2] M. Barri, G. El Khoury, H. Andersson and B. Pettersen, "DNS of backward-facing step flow with fully turbulent inflow," Int. J. Numer. Methods Fluids, 2010
[3] H. Le, P. Moin, J. Kim, "Direct numerical simulation of turbulent flow over a backward-facing step," J. Fluid Mech., 1997