SPATIO-TEMPORAL ANALYSIS OF SWIRLING JETS UNDERGOING VORTEX BREAKDOWN

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Introduction

The unsteady processes of a swirling jet undergoing vortex breakdown has been examined experimentally using time resolved stereoscopic PIV. The experimental setup has been designed, build and prepared at the HFI, Technical University Berlin. It generates a turbulent swirling jet swirling air jet at levels of swirl high enough for Vortex Breakdown to occur. The facility and its performance is described in [1] in details.
The Bi-Orthogonal Decomposition (BOD) method has been chosen for the data analysis, e.g. the Proper Orthogonal Decomposition has been applied both in space and time. The BOD method enables to decompose the time varying velocity field into energetic modes in space (toposes) and in time (chronoses) (for more details see e.g. [2]).
In the experiments, the Reynolds number based on the nozzle diameter and bulk velocity was Re ~ 20000. The measurement technique provides the three components of the instantaneous velocity field in the jet streamwise measurement plane. Frequency of acquisition was 500 Hz, one record of 1636 instant vector fields represents about 3.2 s in experiment.

Results

Our record consists of three phases. First is the starting state a level of swirl below the onset of Vortex Breakdown, second is the transitional phase where vortex breakdown occurs and third is the final state with a stationary breakdown located at the nozzle exit.

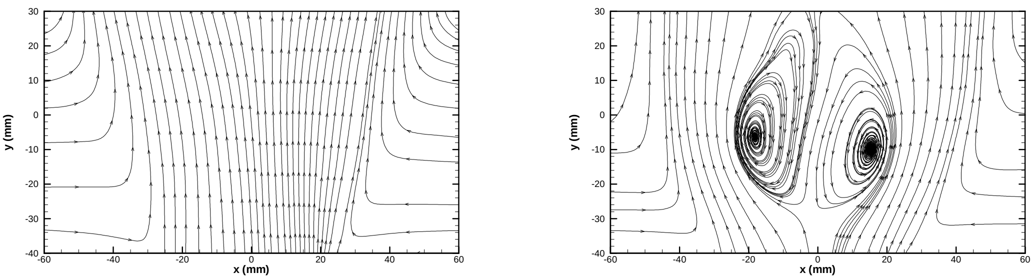

Fig. 1 - Mean starting (left) and final (right) states structure

Typical flow patterns are displayed in Fig. 1. The transitional part is given by the phenomenon physics, while lengths of the starting and final states are arbitrary. In this context, time averaged flow quantities have no physical justification. Therefore, we decided to analyze full records including both mean and fluctuating components.
The BOD analysis of the dataset provides 1636 modes ordered by descending kinetic energy. The total energy evolution in time is shown in Fig. 2. The beginning of the transition at 1.5 s and the end at 2.5 s can be identified.
The chronoses show clearly that only the first five modes exhibit different behavior in the three flow states (no breakdown, transient, breakdown), the remaining modes are qualitatively state

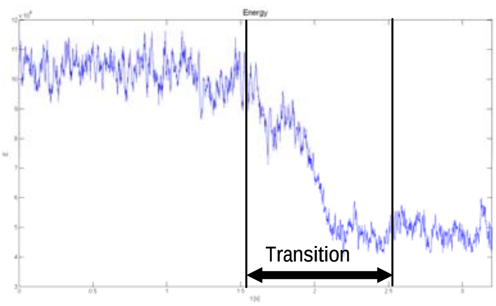

Fig. 2 - Total energy evolution in time

independent. The state-sensitive modes contain about 89% of the total kinetic energy; among them shift and oscillation modes are identified. Modes 1 to 3 exhibit strong changes during the transient state and more or less constant levels at the stationary states (before/after transient) - see Fig. 4 (mode 2 show the same structure as mode 1). These modes could be considered as shift type, they describe the transition of mean flow between the stationary states depicted in Fig.1. The 4th and 5th mode span the basis for an oscillating mode, as they both show an oscillating signal, with the same amplitude and 1/4 period phase shift. They exhibit chaotic low intensity fluctuation during the first state and quasi-periodical behavior in the final state - see Fig. 5. These oscillation modes are related to the precision of vortex breakdown.

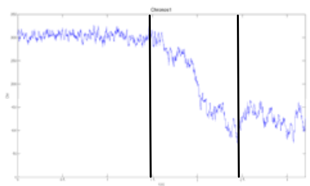

Fig. 3 - Chronos 1

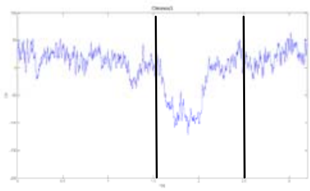

Fig. 4 - Chronos 3

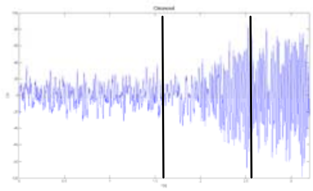

Fig. 5 - Chronos 4

Conclusions

The BOD method is convenient for discretization and studying of non-stationary processes in space and time. In case of a swirling jet transient, there are only a few relevant (high energy) modes that characterize differences between the two states of the dynamical system. The remaining, less relevant (low energy) modes are included in both states equally, they are contributions of higher harmonics and stochastic turbulent fluctuations.

Acknowledgement

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References

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