Numerical Study of a Fluidic Precessing Jet Flow

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Contents

Abstract

This thesis reports the structure of turbulent, unsteady, fluidic precessing jet (FPJ) flow within a suddenly expanding axisymmetric chamber and the mode switching phenomenon using finite volume Computational Fluid Dynamics (CFD) method. The reliability of these CFD methods in predicting both the velocity field and the scalar field has also been assessed. Although a number of experimental studies were reported, due to the challenges of measuring all relevant parameters in the flow-field simultaneously, the understanding of the structure of the FPJ flow is still incomplete. Moreover, the FPJ flow is bi-stable and it switches occasionally between the Precessing Jet (PJ) and the Axial Jet (AJ) modes, which is undesirable. However, the mode switching phenomenon has not been investigated yet. Computational Fluid Dynamics was chosen to address these research gaps. Since no systematic numerical study on the FPJ flow has been reported in literature, the reliability of CFD method in predicting this flow remains unknown. Increasing the understanding of the structure, the mode switching phenomenon and the feasibility of CFD models in predicting the FPJ flow will contribute to the development of industrially relevant design tools, which is the overall objective of this thesis.

The first aim of this research is to comprehensively assess the reliability of two-equation Unsteady Reynolds Averaged Navier-Stokes (URANS) models in predicting the velocity field of the FPJ flow. Five two-equation URANS models, namely the standard k-ε model, the modified k-ε (1.3) model, the modified k-ε (1.6) model, the Re-Normalisation Group (RNG) k-ε model and the Shear Stress Transport (SST) model, were employed to simulate the complex FPJ flow. The predicted phase-averaged velocity field within and in the emerging region of the nozzle, energy of total fluctuation and precession frequency of the FPJ flow were compared against the measured data. Both the RNG k-ε model the modified k-ε (1.6) model failed to predict the precession motion. All main features of the FPJ flow that observed from previous visualization studies were predicted with both the standard k-ε model and the SST model. Furthermore, reasonable quantitative agreement against the experimental result was achieved with both the standard k-ε model and the SST model, although the spreading

and velocity decay rate of the phase-averaged jet within the nozzle were under-predicted.

Secondly, the scalar field of the FPJ flow was simulated with both a two-equation URANS model and a Hybrid Large Eddy Simulation (LES) approach. Under the current numerical configurations, the jet downstream from the nozzle exit was predicted to be mainly distributed in the region near to the wall of the external confining cylinder with both the two approaches, while the measured jet was preferentially concentrated near to the centreline region. This may due to the over-predicted deflection angle of the emerging jet and the under-predicted mixing rate. In addition, the distribution range of the Probability Distribution Function (pdf) of the centreline concentration in the far field was predicted to be narrower than the measured jet. Although the results calculated with the Hybrid-LES approach agrees better with the measured data than that calculated with the SST model, it still did not reproduce the external scalar field of the FPJ flow well. This implies that the simulation of the scalar field of the FPJ flow is significantly more sensitive than is the velocity field.

The third aim of this work is to provide further details of the flow structure and develop a topological model of the FPJ flow, based on the critical point method, previous experimental observations and the numerical results of the CFD model. The unsteady SST model was chosen because it exhibited good qualitative agreement with the experimental result, which is essential for the critical point method. The predicted flow pattern at the surface of both the nozzle and the centre-body were compared against those deduced previously. The flow streamlines, velocity and vorticity cross-sectional contours within the FPJ nozzle were presented to provide further flow details for the development of the vortex skeleton. A vortex skeleton of the FPJ flow within and in the emerging field of the nozzle with six main vortex cores is identified for the first time. All the six vortex cores are deduced to be responsible collectively for the continuous precession.

The fourth aim of this study is to investigate the switching phenomenon and the change of flow structure during the mode switching process using the unsteady SST model. Three methods were employed to trigger the flow to switch from the AJ to the PJ modes, namely imposing a continuous axial perturbation onto part of the inflow, imposing a continuous swirling component to the inlet flow and adopting a slightly asymmetric initial flow field. Some asymmetry was found to be necessary to trigger the mode switching, while the switch time is inversely proportional to the extent of asymmetry. It was also found that the direction and frequency of the precession are both dependent on the direction and intensity of the imposed inlet swirling, respectively, which is consistent with previous experimental observations. The change to the vortex skeleton of the FPJ flow during the mode switching process is reported for the first time.

Statement of Originality

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