Delayed-Detached Eddy Simulation for Optical Path Control on Backward Step Flow

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Abstract: A feedback flow control is designed to reduce the aero-optical distortions behind a backward facing step. Delayed-Detached Eddy Simulation based on Spalart-Allmaras turbulent model is developed to simulate the unsteady density variations caused by the shear layer. A database from simulations of both an unforced baseline flow and open-loop forced flows is built using Proper Orthogonal Decomposition. Artificial Neural Network and Auto-Regressive eXogenous model is used to build a reduced order model of the flow field. The ANN-ARX model is appled to the simulation under closed loop control. Results from the closed-loop simulation show that aero-optical distortions can be reduced.

Keywords: Delayed-Detached Eddy Simulation , Backward Facing Step, Feedback Flow Control, Reduced Order Model, Optical Path Difference

1 Introduction

Unsteady density fluctuations in the surrounding flow field of an aero-optical system can severely affect its performance. These unsteady density fluctuations caused by separating shear layer affect the refractive index and in turn, distortions are imposed on the optical beam. Separating shear layer found on turbulent flow over a backward facing step has been a common example of aero-optical studies [1, 2]. In this study, a suction-blowing feedback flow control device is numerically implemented on a backward facing step in order to reduce the aero-optical distortions.

2 Numerical Method

A preconditioned three-dimensional Navier-Stokes equations solver, KFLOW, using the Spalart-Allmaras turbulent model based DDES method has been developed to simulate the unsteady turbulent flow over a 3-D backward facing step. In this study, a centralized fifth-order accurate upwind scheme is used for the invicid fluxes and a fourth-order accurate central scheme for the viscous fluxes. The flow solver is verified by a parametric study with grid convergence. The numerical simulation is validated with Driver & Seegmiller's experimental results [3]. As shown in Figure 1, instantaneous vorticity contour displays small vortices structures breaking up from the shear layer. Wall pressure coefficients and skin friction coefficients are compared with the experimental data along with the flow natural frequency obtained from frequency analysis. In order to build flow database a number of numerical simulations are performed with actuating amplitude and frequency for open-loop sinusoidal suction-blowing.

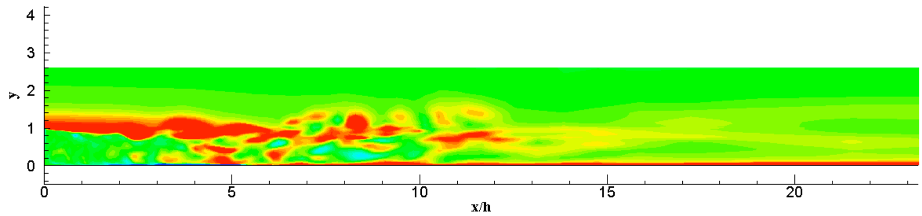

Figure 1: Vorticity contour behind a 3-D backward facing step.

Proper Orthogonal Decomposition (POD) is used to analyze the database and to obtain POD time coefficients, which are needed to build Reduced Order Model (ROM) based on Artificial Neural Network and Auto-Regressive eXogenous (ANN-ARX) model. A feedback algorithm to control the suction-blowing velocity as the output is applied to the ANN-ARX model to investigate the effects of the designed controller. Only the first 2 POD modes are applied to the ANN-ARX model for testing the possibility of reduction of aero-optical distortions.

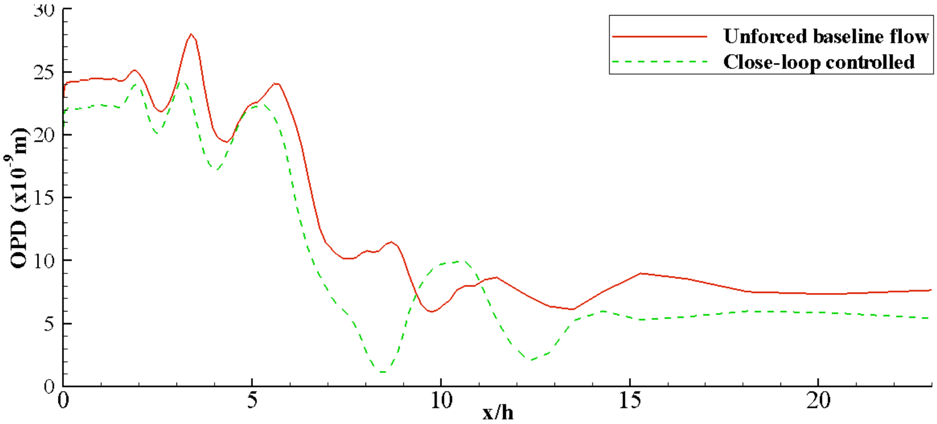

Figure 2 shows Optical Path Difference comparision between uncontrolled baseline flow and closed-loop controlled flow at an arbitrary time. The results shows that the designed controller, despite of using only the first 2 modes, is able to reduce the aero-optical distortions.

3 Conclusion and Future Work

The test result from the designed feedback flow controller proves the possibility of reducing optical distortions caused by the separating shear layer over the backward facing step. Density fluctuations were obtained from Delayed-DES computations and POD-based reduced order model was constructed by training the neural network. In the final paper, the number of modes used will be increased in an attempt to further reduce the optical distortions. The numerical schemes and control strategy will be discussed in detail. The results of the feedback flow control will be validated again by CFD computations using the resulting control output.

References

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