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Mode Analysis of Downstream Flow from Rotating Fan Using Double Proper Orthogonal Decomposition

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1. Introduction

Proper Orthogonal Decomposition (POD) can be used to determine dominant modes of complicated natural phenomena [1,2]. By examining the natural modes, the fundamental physics of a natural phenomenon can be understood effectively. However, for transient phenomena the dominant modes may change as time increases, therefore, POD is not an appropriate method to identify the modes. In this case, additional POD can be applied to obtain the information on the variance of the main modes. This is the double POD (DPOD) method [3,4]. In this study DPOD is applied to the downstream flow from a rotating fan during the start-up transient. Computational fluid dynamics was used to obtain the flow field data. The physical meaning of the eigenvalues, main and shift modes, and time coefficients are examined. The results can be applied to investigate the effect on the dynamics of structure located in the fan downstream flow.

2. Analysis of Fan Flow using DPOD

2.1 Double Proper Orthogonal Decomposition (DPOD)

The proper orthogonal decomposition (POD) decomposes the flow field data using spatial modes and temporal modes [1, 2]. For a periodically time-evolving flow field, POD can be written as shown in equation (1), and this is called SPOD (Short time POD) [3,4].

$$u^{(i)}(x,y,z,t) = \sum_{j=1}^{J} a_j^{(i)}(t)\emptyset_j^{(i)}(x,y,z) \qquad (1)$$

,where $u^{(i)}(x,y,z,t)$ is flow variable for $i-th$ cycle, $a_j^{(i)}(t)$ is the mode amplitude of the spatial mode $\emptyset_j^{(i)}(x,y,z)$.

For a transient case, *e.g.,* Reynolds number is varied over time, the mode amplitudes and spatial modes evolve. In this case Double POD can analyze the variation of main modes obtained by POD. If multiple bins of data set, are available DPOD can be performed as the following equation (2) [3,4].

$$\mathrm{u}(x,y,z,t) = \sum_{j=1}^{J}\sum_{i=1}^{I} a_{ij}(t)\emptyset_{ij}(x,y,z) \qquad (2)$$

,where $\emptyset_{i1}(x,y,z)$ is the mean flow mode and $\emptyset_{i1}, \emptyset_{i2}, \emptyset_{i3} \ldots, \emptyset_{iJ}$ are the shift modes, which allow the POD mode ensemble to adjust for changes in the spatial modes. The shift modes modify a given physical mode to match a new flow state due to transient condition or change of flow speed, etc.

2.2 Application of DPOD to downstream flow from a rotating fan with variable speed

Computational fluid dynamic analysis was performed to obtain the velocity field data from three-dimensional cylinder wake flow during start-up transient. Fig. 1 shows the CFD model. The pipe diameter is 0.2m and its length is assumed as 1 meter. The fan is installed at the center of the pipe. The fan rotates from rest to 60 rpm during 2 seconds. Fig.2 shows the data acquisition region to obtain the flow data such as velocity, pressure, etc.

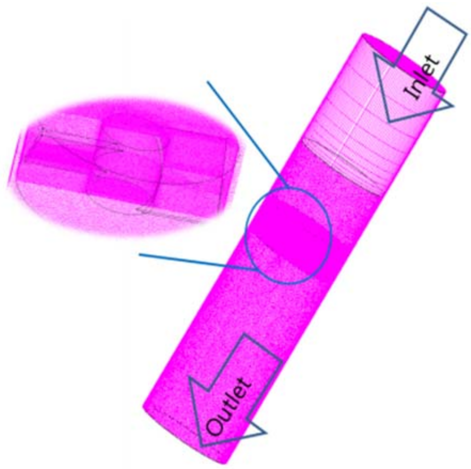

Fig. 1 CFD model of a fan inside a pipe

The flow data were extracted at 1,000 different points every 0.05 seconds during 10 seconds.

Eigenvalues for lower 10 modes are shown in Fig. 3. It is clearly shown that the lower modes have governing effects and the energy of shift modes are identified by DPOD.

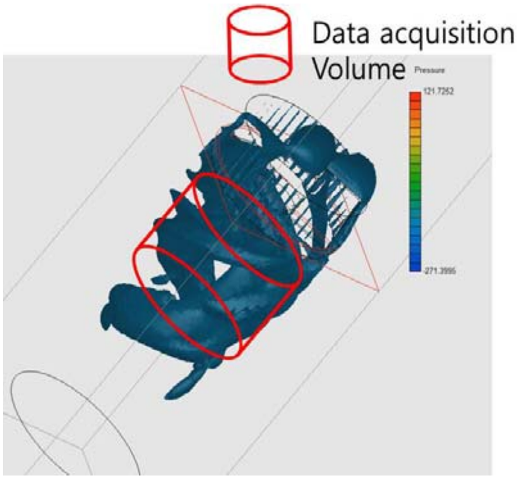

Fig 2 volume for data acquisition

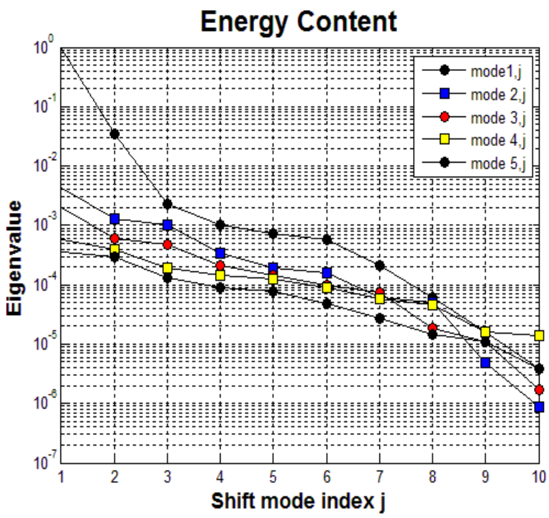

Fig 3 Eigenvalues of the DPOD Modes

Some examples of spatial modes from DPOD analysis are shown in Fig. 4 and their time coefficients are presented in Fig. 5.

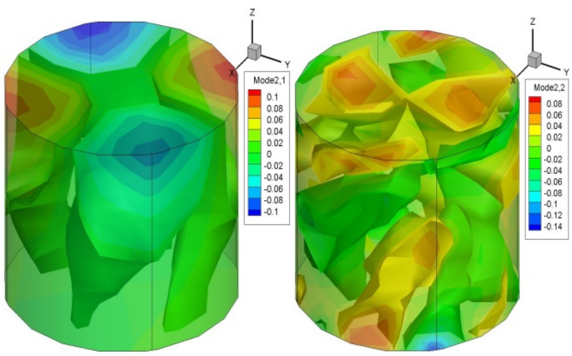

Fig 4 Spatial modes from DPOD analysis (2.1, 2.2)

Time coefficients of DPOD spatial modes give the information about which modes are governing the total

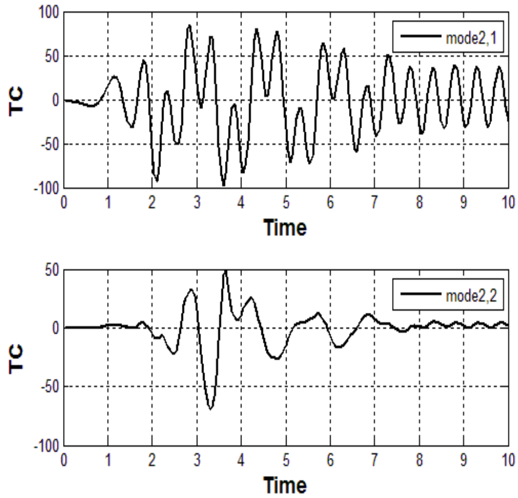

Fig 5 Time coefficients(2.1, 2.2)

flow field. In Fig. 5 during 2~7 second after start-up, the variation of mode 2 is prominent, and after 7 second the steady state is reached.

These DPOD modes can be used to reconstruct the original flow field, so that lower dimensional modeling of flow of high order is feasible.

3. Conclusions

A computer program for double proper orthogonal decomposition is developed, which analyzes complex natural phenomena such as transient flow field or oscillatory motions so that the fundamental modes can be identified. In this study three-dimensional transient flow field data from a rotating fan was analyzed using DPOD. The eigenvalues, spatial modes and time coefficients of physical modes and their shift modes were successfully obtained for potential application to the reconstruction of the flow filed for lower dimensional modeling.

ACKNOWLEDGEMENT

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