Effects of Bottom Slope on the Flow Noise of Cavity

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ABSTRACT

Based on a rectangle cavity with a length depth ratio L/D=2, the incompressible large eddy simulation technique, coupled with the FW-H acoustic equation, is used to investigate the influence on the oscillating characteristics and hydrodynamic noise of an incompressible cavity shear layer by introducing a sloped bottom with different tilt angle. PIV measurements performed in a circulating water channel verify the effectiveness of the flow field simulation. It is demonstrated that bottom slope has evident effect on cavity’s oscillation mode, oscillation frequency and sound pressure level rather than noise directivity.

KEY WORDS: Cavity; incompressible flow; oscillation mode; large eddy simulation; hydrodynamic noise; acoustic analogy

INTRODUCTION

Cavity is a classical model for researching flow instability and flow-acoustic interaction. On the surface of underwater vessel, the cutouts and drain holes which destroy the geometric continuity are common sources of hydrodynamic noise and increased drag. In order to sustain a good overall performance of underwater vessels, it is important to understand unsteady flow phenomena, particularly flow induced oscillation and acoustic characteristics of cavity.

Cavity flow is concerned with many nonlinear physical processes such as flow separation near the leading edge, instability of shear layer, generation and development of vortex and interaction between turbulent boundary layer and pressure wave. Since the early experimental work of Krishnamurty (1955) and Roshko (1955), it is known that if certain conditions are satisfied, the flow past an open cavity is known to give rise to self-excited oscillations. Rockwell and Naudascher (1978) divided the oscillation into three forms, fluid-dynamic, fluid-resonant, and fluid-elastic categories. Fluid-dynamic oscillations are attributable to instability of the cavity shear layer and are enhanced through a feedback mechanism. Fluid-resonant oscillations are governed by resonance conditions associated with compressibility or freefluid wave phenomena. Fluid-elastic oscillations are primarily controlled by the elastic displacements of a solid boundary. Rossiter (1966) described cavity oscillation as a feedback cycle of flow-acoustic resonance and developed a semi-empirical formula to predict the resonant frequencies. However, for a given set of incoming flow and geometric conditions, Rossiter formula cannot predict the amplitude of oscillation modes and the interactions between the presented modes. So the later researchers continued studying the oscillation with experiments and simulations.

The geometric parameters of a 3-D rectangle cavity include length L, depth D and width W. Based on length to width ratio, Block (1976) first made a classification between cavities where the acoustic field is two-(L/W<1) and three-dimensional (L/W>1). The effect of a cavity’s width on resonance was also been studied by Ahuja and Mendoza (1995). It is concluded that if L/W<1 is satisfied, the cavity width is not important. Colonius et al. (1999) carried out a 2-D simulation shown a good approximation. Sarohia (1977) divided cavities into shallow cavity (L/D<1) and deep cavity (L/D>1). Oscillations of a shallow cavity are dominated by instability of shear layer. At low Mach numbers, oscillation of a rigid cavity is induced by fluid dynamic interaction between the shear layer and the cavity flow. Gharib and Roshko (1987) found an intermittent switching between the two modes, “self-sustained oscillations” (also named “shear layer oscillation mode”) and “wake mode”. It is found that above a critical value of the cavity width-to-depth ratio there is an abrupt and large increase of drag due to the onset of the “wake mode” of instability. With respect to shear layer oscillation mode, results of experimental study (Chatellier et al., 2004) at low Mach number (up to 0.1) indicated that the oscillation process is governed by convective waves, with no definite influence of convected vertical structures. However, the experimental evidence for “wake mode” is limited at low-speed axisymmetric cavity (Gharib and Roshko, 1987). Suponitsky (2005) summed the reason as a finite width in experimental studies inducing a three-dimensionality which is an inevitable feature of the turbulent flow.

Apart from rectangle cavities, some other studies are concerned with non-rectangular cavities. An experimental work was performed by Kuo and Huang (2001) to study the influence on the oscillating