FIRST AND SECOND CENTRIFUGAL SPANWISE INSTABILITIES IN AN OPEN CAVITY FLOW

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Summary Recent experimental and numerical investigations have shown that open cavity flows may develop, in addition to usual shear layer instabilities, inside centrifugal instabilities leading to well-organised spanwise rows of vortical structures. The present work is devoted to the study of those fully three-dimensional spanwise centrifugal structures. Although the primary instability is now rather well documented, such is not the case for the secondary instability. In this communication, modal approaches are used to determine the global modes against which the stationnary base flow may become unstable, and dynamic mode decomposition is applied to both experimental velocity fields, obtained by using Particle Image Velocimetry techniques, and numerical snapshots of the velocity field, in order to get the basic structures of the flow in the non-linearly saturated regime. By comparison of both global and dynamic modal analyses, the intrinsic features of the first instability can be investigated in close details, in the case of a square cavity. A description in time, space and frequency of the second instability, together with a discussion on the nature of the bifurcation (super or sub-critical), are further proposed.

INTRODUCTION

Cavity flows, belonging to the family of impinging flows, are known to develop strong self-sustained oscillations [1]. The shear layer is actually subjected to Kelvin-Helmholtz (KH) instabilities, that are basically two-dimensional modes, growing in the shear layer along the flow direction. As a consequence, the shear layer oscillations generate energetic well-defined peaks in the spectral signature of the flow [2]. However, power spectra also exhibit a wide range of low frequency modes, that are mainly associated with spanwise structures, in the flow inside the cavity. Part of this spanwise organization results from centrifugal instabilities that generate Taylor-Görtler-like structures [3]. Three-dimensional instabilities have been recently studied numerically by Brès & Colonius [4], who have shown that spanwise modes are able to destabilize the stationary base state, at lower Reynolds numbers than KH modes. Experimentally, we have observed the occurrence of a secondary (time-dependent) instability, developping on those primary spanwise centrifugal structures, whose features will be investigated in this contribution: homogeneous development in the spanwise direction or spatially localized patches of oscillation, super-critical sub-critical bifurcation, behavior over long time scales.

INTRINSIC FEATURES OF THE FIRST INSTABILITY

The three dimensional instability, described above, is responsible for the development Taylor-Görtler-like vortices. It manifests itself in the form of pairs of counter-rotating vortices, shaped as tori around the cavity main recirculation flow. Due to an Ekman pumping at the sidewalls, that primary instability can exhibit, in a limited range of parameters, a spanwise drift of the row of vortices toward the span-walls.

We have conducted both numerical and experimental analysis on our three-dimensional cavity flow. Numerically, a linear stability analysis of a 2D stationary base state, with respect to spanwise pertubations, provides a good prediction in terms of most unstable wavelengths. In order to emulate more closely the real flow, fully 3D direct numerical simulations, in the conditions of the experiment – Reynolds number, spanwise and inflow boundary conditions – has been performed, successfully reproducing the non-linearly saturated three-dimensonal flow (fig.1). Experimentally, we have been able to identify and to extract non-stationnary coherent structures, associated with the 3D flow organisation (fig.2a), by using dynamical mode decomposition (DMD) [5]. DMD is applied to velocity fields, obtained by PIV techniques, in a horizontal plane inside the cavity. Taylor-Görtler-like vortical structures, isolated in the experiment, as well as their dynamical features, are investigated and compared to DNS.

SECOND INSTABILITY

A parametric study has been realized, mainly based on flow visualization, that revealed, for different values of the control parameters, a new bifurcation towards a non-stationary phenomenon. In flow visualizations, that instability shows axial movement out of phase between two pair of Görtler-like vortices (fig. 2b). We want to characterize quantitatively this secondary instability. To that aim, we carried out PIV and LDV measurements. The objective is to extract dynamic modes, associated with this unsteady phenomenon, and characterize their features. The study is realized in a plane parallel to the background of the cavity and located 30% below the upstream cavity edge.

The Koopman decomposition has been used in order to obtain the frequency hallmark of the Taylor-Görtler vortices. It shows that we can synthetised, with only a few dynamic modes, the inside dynamic of the cavity and consequently track

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the spatial mode(s) associated with this secondary instability.

REMARKS

The secondary instability has neither been reported yet in numerical simulations, nor mentioned, to our best knowledge, in the literature. Up to now, it remains a direct observation from our experiment.

Taylor-Gortler vortices drift and oscillations are two non-stationary features of the flow dynamics beyond the secondary instability. Both combine to each other, in such a way that decomposition in dynamic modes may not be able to discriminate between them. As a consequence, it remains difficult to get an unambiguous characterization of the inside cavity dynamics in the frequency domain, as well as its spatial organization.

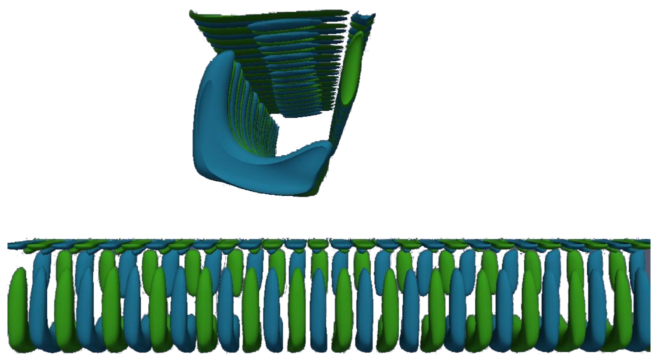

Figure 1. Helicity isosurfaces inside the cavity flow, that reveal the Taylor-Görtler-like structures (from periodic 3D DNS).

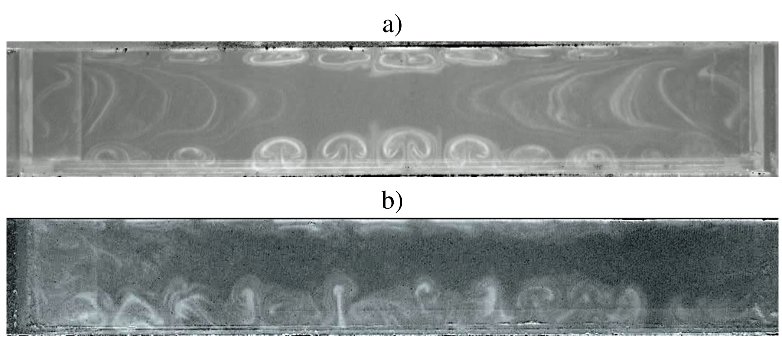

Figure 2. Top view of the Taylor-Görtler-like structures, in a horizontal plane inside the cavity, revealed by seeding the flow with smoke (from experiment), a) the first instability, b) the second instability.

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