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WAVE COMPETION IN THE FLOW BETWEEN A ROTATING AND A STATIONARY DISK

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ABSTRACT

This experimental work is devoted to the study of the dynamics of two systems of waves that appear in the flow between a rotating and a stationary parallel coaxial disk. Using visualization and Ultrasonic Doppler Anemometry, both a circular and a spiral system of waves are observed. Transition to turbulence seems to be driven by the non linear interactions between these two systems of waves.

1. Introduction

The study of the stability of flows between a rotating and a stationary disk is attractive because these flows produce various scenarios of transition to turbulence, when the angular velocity of the rotating disk is increased or when the aspect ratio h / R (where h is the axial distance between the disks and R their radius) is changed. This diversity was first recognized by Daily et al. [1] who distinguished mainly two types of transition which depend on the basic velocity profiles.When the disk boundary layers are merged at small aspect ratio, a first instability occurs and gives rise to different regular systems of waves extented over the whole depth of the gap (see San'kov et al. [2] and Sirivat [3]). Then, the next stages of the transition lead to the formation of turbulent spots and solitary waves (see [2]). For larger aspect ratios, the primary instability occurs on Batchelor type profiles where the two boundary layers are separated by an inviscid rotating core. The present study concerns this large aspect ratio instabilities, where the transition is quite different from before and envolves non linear interactions of systems of waves.

2. Experimental details

2.1 Apparatus

The experimental apparatus (see Figure 1) consists of a horizontal rotating disk (radius $R = 140\,mm$) set in a water-filled cylindrical housing with a sliding fit. The angular velocity of the disk Ω can be continuously varied in the range $0 - 4\pi\ rd/s$. The stationary disk is the top of the housing. The height of the rotating disk inside the housing is adjustable in such a way that the axial distance between the two disks h can be continuously varied up to $20\,mm$. The control parameters of the flow are the aspect ratio h/R, the Ekman number $Ek^{-1} = \Omega.h^2/\nu$ (where ν is the kinematic viscosity of the working fluid) and the local Reynolds number $Re(r) = \Omega.r^2/\nu$ where r is the local radius.

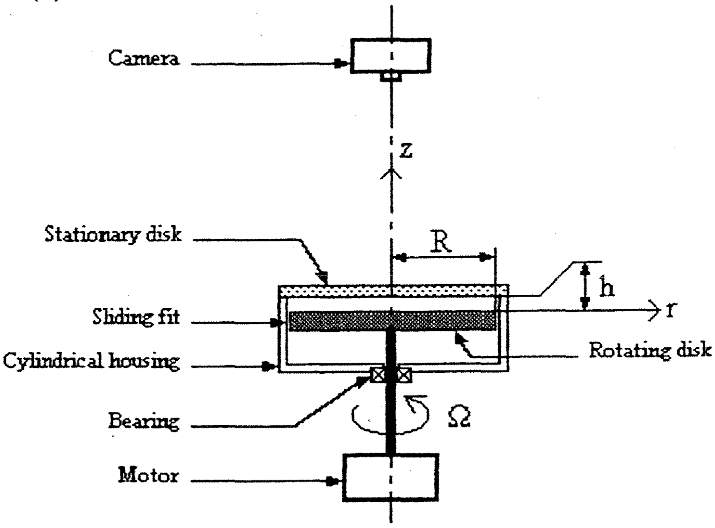

Figure 1: Experimental apparatus

2.2 Flow visualization and UDA techniques

A visualization technique is used to observe the different patterns of the flow. Visualization is performed with a small amount of anisotropic particles (flakes) added to the working fluid. These particles have a high reflective index and they tend to align themselves along stream surfaces, thus becoming visible under appropriate lighting conditions (for further details see Savas [4]). The images are captured with a CCD camera (see Fig. 1.) and recorded. Then, they are digitized and processed on a micro-computer through a standard library of image processing and graphics functions. In particular, a video line can be extracted at the video frequency ($25\,s^{-1}$). Then, these lines are gathered in a space-time diagram representing the dynamics of the waves.

The velocity field is characterized using an Ultrasonic Doppler Anemometer [5]. UDA is a device for measuring a velocity component of a fluid flow at various points along the ultrasound beam axis. A single transducer emits ultrasonic bursts, of frequency f_e, and receives the echoes, of frequency f_r, reflected by the microparticles in suspension in the fluid flow. The velocity component V in the ultrasound beam direction is derived from the Doppler frequency $f_d = f_e - f_r$ with the relation $V = c.f_d / 2.f_e$ (where c is the speed of ultrasound in the working fluid). The distance x from the particle to the transducer is obtained from the time delay τ between the emission and the reception of the bursts with $x = c.\tau / 2$. Measuring f_d at various times τ_i after the emission of one burst, instantaneous velocity profiles $V(x_i)$ are obtained.

3. Results and discussion

Figure 2 presents a mean velocity profile measured by the ultrasound anemometer, when the probe is set at a fixed angle of 20° versus the vertical axis. The local Reynolds number corresponding to this plot, is equal to 930 and the measured velocity is the time averaged projection of the velocity onto the beam direction. We recognize the fixed and the rotating boundary layers which are separated by the traditionnal inviscid core of the Batchelor's profile.

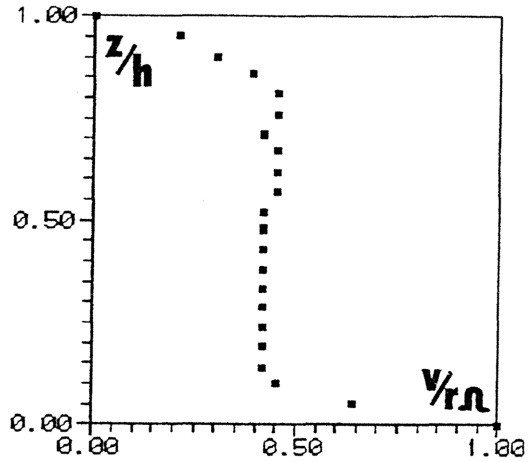

Figure 2: The Batchelor velocity profile of the rotating disk flow. Ek^{-1}=48, Re=930.

When increasing the rotating velocity to a certain threshold depending on the aspect ratio, a first instability arises and forms concentric circular waves which travel and grow from the border of the disk towards its center. At a slightly higher velocity, another system of spiral waves appears on the external half of the disk. Therefore, these two systems exist together and are located respectively at the center of the disk for the circular waves and at the periphery for the spirals. Figure 3 shows this complexe wave pattern.

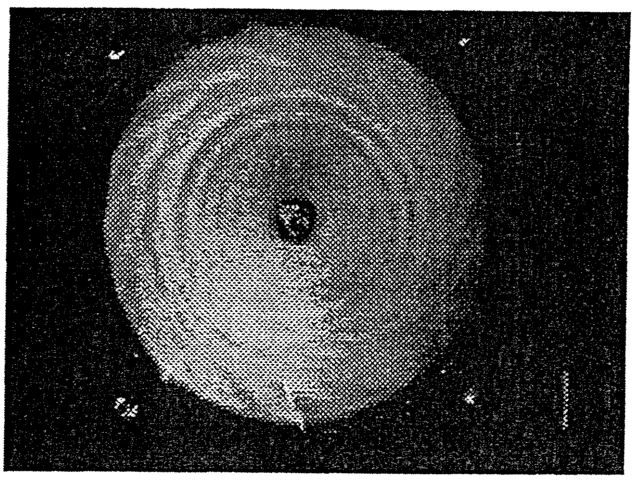

Figure 3: Visualization of the systems of waves. Ek^{-1}=48.

In order to study the spatio-temporal features of these waves, space time diagrams are built from the video image analysis presented before and from ultrasound anemometry. for this purpose, the ultrasound transducer is set in a groove machined in the sidewall in the radial direction. Thus the radial velocity profiles of the rotating flow is captured and analyzed. Figure 4 presents together a space time diagram built from (a) visualization and (b) anemometry.

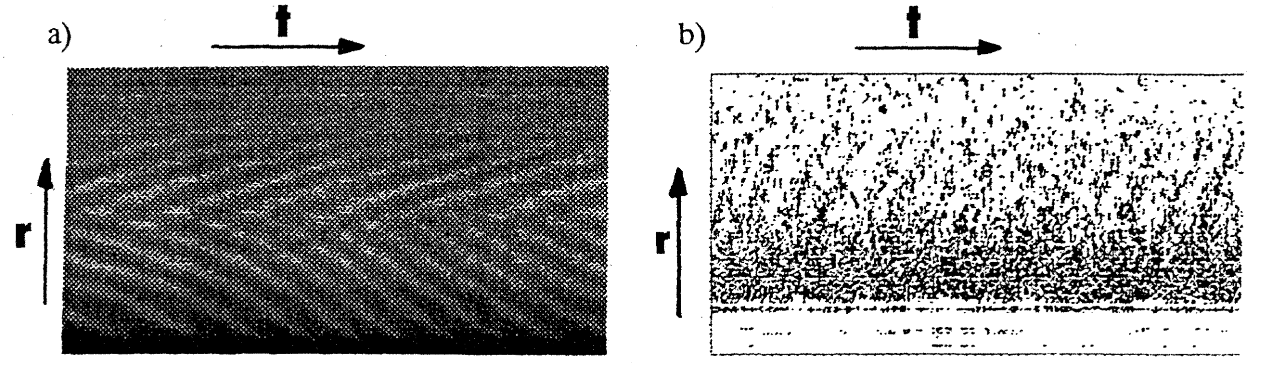

Figure 4: Space time diagrams built from a) visualization $Ek^{-1}=38$, b) ultrasound anemometry $Ek^{-1}=53$.

Fourier analysis of these diagrams shows that in the interaction region, new frequencies corresponding to linear combinations of the circular and spiral wave frequencies, are generated. This is the signature of non linear interactions between the wave systems. When increasing the rotating velocity, more and more complex wave patterns such as figure 5 appear and lead to turbulence.

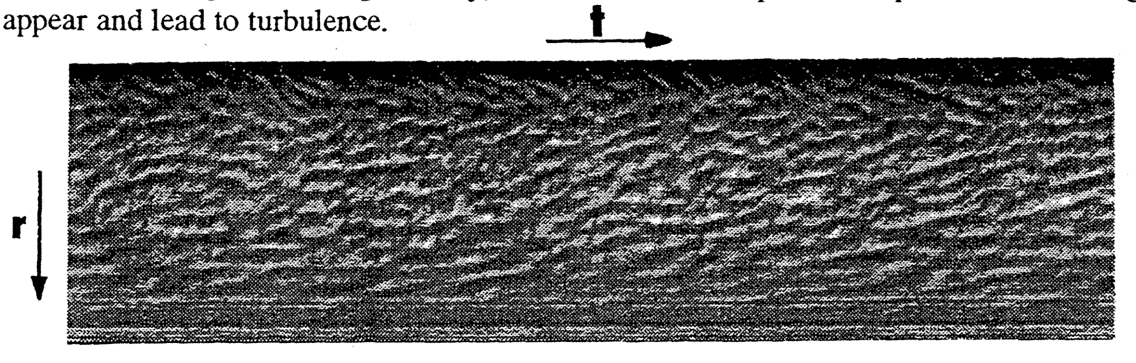

Figure 5: Space time diagrams built from visualization, $Ek^{-1}=63$.

4. References

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