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Subcritical Instabilities of Astrophysical Interest in Couette-Taylor System

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Abstract

We report experimental results concerning subcritical instabilities in linearly stable rotation regimes in Couette-Taylor apparatus. The study was motivated by Astrophysical concerns about turbulent transport in differentially rotation flows. We explored linearly stable domains of rotation to seek for finite amplitude instabilities. We found a turbulent domain when the outer cylinder is rotating and the inner cylinder is at rest or slowly corotating. This is in agreement with previous experiments published by [1] and [2]. We also find turbulence between the linear stability curve and the solid body rotation. This is of primary interest for Astrophysical systems such as accretion disks.

Introduction

Most Astrophysical flows are experiencing differential rotation : in the Sun, the transition between the solid body rotating core and the convectively unstable outer layer shows high gradients of angular velocity ; In accretion theory, the disks are beleived to be in Keplerian rotation. The turbulent transport of angular momentum and the mixing of chemical species are fundamental for the evolution of these objects ([3-8]). For exemple, turbulence is believed to be a key player in planetary systems formation, because of its effect on dust concentration. Numerical modelling of Astrophysical systems is using numerous prescriptions for turbulent viscosity, based on dimensional arguments. Even though these models helped understanding the basic evolution and properties of stars or disks around stars, more physical prescriptions are necessary to developped more realistic models. This implies a better understanding of turbulence properties in differentially rotating flows.

Experimental Setup

The Couette-Taylor apparatus we use has the following geometry : the radius of the inner cylinder is Ri = 3.5cm, the outer one is Ro=5.0cm, and the useful length is h=38cm. The outer cylinder is aluminum made while the inner cylinder is in glass. The flow visualization is performed through the « fluorescent lighting » technic described [9]. Velocity field is measured using Laser Doppler Velocimetry. The whole apparatus temperature is maintained constant through controled temperature water flowing inside the inner cylinder and in a plexiglas cage around the outer cylinder.

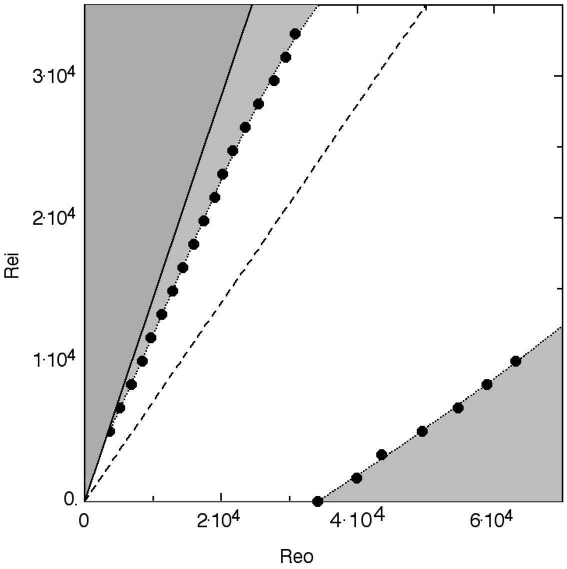

figure 1 : Stability diagram in (Rei,Reo) plan. Solid line is the linear stability curve ; dashed line is the solid body rotation ; light grey area shows the domain where turbulence is observed and filled dots represent the lower limit of turbulence in our system

Results

We define Ωi and Ωo the respective angular velocities of the inner and outer cylinder. Rei= Ωi.Ri.d/ν and Reo= Ωo.Ro.d/ν are the Reynolds numbers associated with each cylinder, where d is the width of the gap and ν is the cinematic viscosity of the fluid. Figure 1 shows the regimes for which turbulence is observed in our apparatus. The domain appearing in the lower right part of the (Rei,Reo) plan, shows evidences of subcritical transition to turbulence. It is less clear concerning the turbulence below the theoretical linear stability curve. More experiments in that case are presently run.

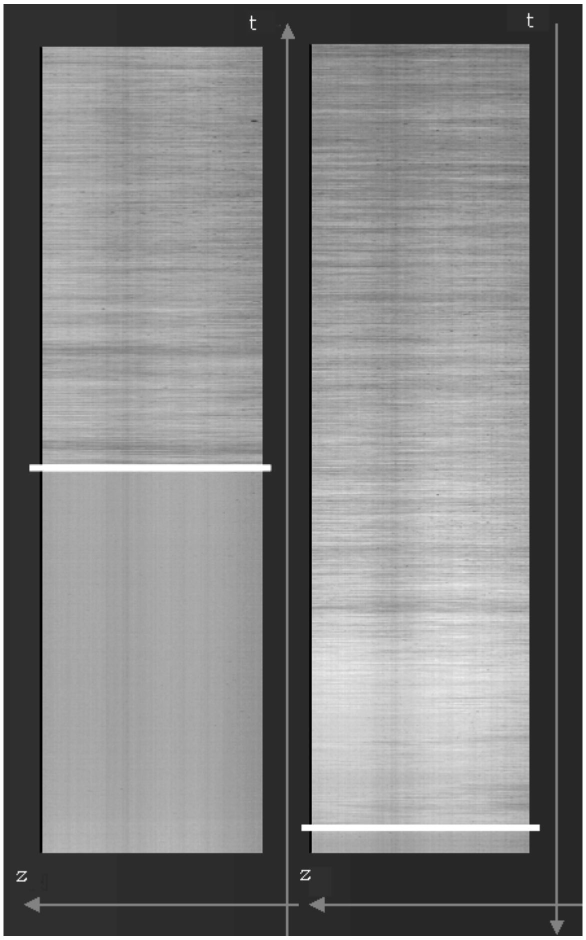

figure 2 : Spatio-temporal diagram for Rei=0 and 2.10^4<Reo<4.10^4 . Horizontal axis is the axial position in the flow, vertical axis is time (equivalent to Reynolds number). left : from laminar to turbulent flow ; right : from turbulent to laminar flow. White lines indicate the laminar-turbulent limit. The cylinder acceleration/decceleration was constant at the value of 0.01 Hz/s.

The first regime shows hysteretical behavior, turbulence being sustained at lower Reynolds when comming from an already turbulent regime compared to a path coming from laminar flow. Figure 2 shows spatio-temporal diagrams of two run following a laminar to turbulent path (left) and a turbulent to laminar one (right). Figure 3 is the temporal fluctuations of azimutal velocity measured at one third of the gap, for the same Reynolds number in a turbulent and in a laminar state.

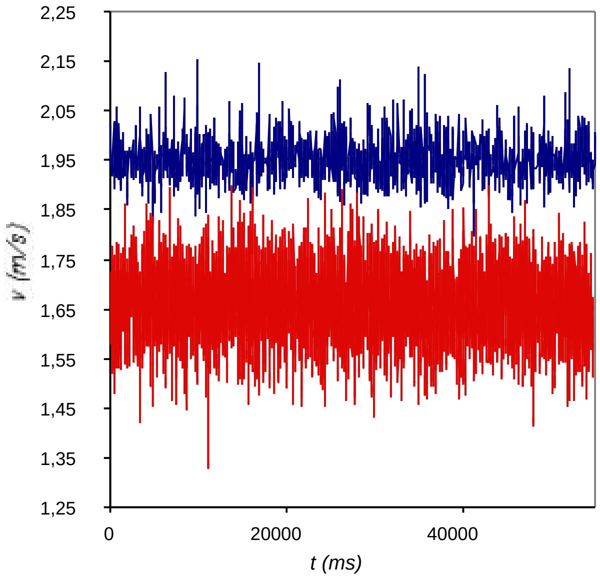

figure 3 : temporal fluctuation of azimutal velocity component at Re=21000 ; Upper signal : in a laminar state ; Lower signal : in a turbulent state.

A local stability analysis shows that the relevant control parameters should be

$$\frac{(r^3 \P_r W)^2}{\frac{n}{r} \P_r W r^2} = cst$$

between the linear stability and the solid body rotation, and

$$\frac{(r^3 \P_r W)^2}{2nW} = cst$$

below the solid body rotation. These parameters are actually constant in each one of the relevant experimental curves.

Conclusion

We report subcritical instabilities in rotation regimes relevant for Astrophysical problems. The mapping of those instabilities is important to differenciate in which Astrophysical objects differential rotation driven turbulence can be expected. The further study of turbulence properties should allow us to derive some prescriptions for turbulent transport that can be used in the modeling of stellar interiors and accretion disks.

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