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The linear instability of the stratified plane Poiseuille flow

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In the non stratified case, plane Poiseuille flow is known to be linearly unstable for Reynolds numbers larger than 5572. Above this value, two dimensional waves - known as Tollmien-Schlichting waves - are viscously unstable and can propagate in the flow.We present here the stability analysis of a plane Poiseuille flow which is stably stratified in density along the vertical direction, i.e. orthogonal to the horizontal shear. Density stratification is ubiquitous in nature and we may think here to water flows in submarine canyons, to winds in valleys or to laminar flows in rivers or canals where stratification can be due to temperature or salinity gradients. Our study is based on laboratory experiments, on a linear stability analysis and on direct numerical simulations. This study follows recent investigations of instabilities in stratified rotating or non rotating shear flows: the stratorotational instability [1,2], the stratified boundary layer instability [3] or the stratified Plane Couette flow instability [4] where it is shown that these instabilities belong to a class of instabilities caused by the resonant interaction of Doppler shifted internal gravity waves. A particularity of the present case is that for the Poiseuille flow, Tollmien-Schlichting waves can also interact and possibly resonate with non viscous gravity waves. The experiments are realized in an annular channel having an inner diameter of 1.4 m and a rectangular vertical section of 85 x 200 mm^2. This channel is filled up to a level of 130 mm (position of the free surface) with salt stratified water using the classical double bucket technique. The free surface fluid is then entrained by the side and bottom walls of the canal when this one is set into slow rotation. However, a barrier, placed radially inside the channel, blocks the fluid, prohibiting solid body rotation and resulting in a nearly parabolic horizontal velocity profile. Visualizations and PIV measurements show the appearance of a stationary (versus the laboratory frame) braided pattern of waves above a given threshold that depends on the Reynolds and Froude numbers ($Re_c \sim 2000, Fr_c \sim 0.5$). The comparison with the theoretical threshold and the critical wavenumbers calculated by linear analysis is excellent. Finally, direct numerical simulations permit to complete the description of this instability that can be interpreted as a resonant interaction of boundary trapped waves.

References

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