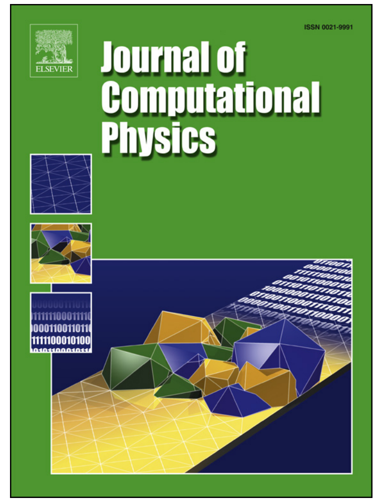
Accepted Manuscript



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PII: S0021-9991(16)00141-8
DOI: http://dx.doi.org/10.1016/j.jcp.2016.02.069
Reference: YJCPH 6450

To appear in: *Journal of Computational Physics*

Received date: 12 August 2015
Revised date: 28 November 2015
Accepted date: 29 February 2016

A Method for Analysis of Stability of Flows in Ribbed Annuli

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Abstract

A spectrally-accurate algorithm for the linear stability analysis of pressure-gradient-driven flows in corrugated annuli is presented. The algorithm is suitable to analyze three-dimensional disturbances in the form of spiral travelling waves as well as in the form of streamwise vortices. A separate algorithm for the analysis of axisymmetric disturbances is presented. The discretization method relies on Fourier expansions in the streamwise and circumferential directions and on Chebyshev expansions in the radial direction. The Immersed Boundary Conditions (IBC) method is used to enforce the physical boundary conditions at the corrugated walls. Numerous tests confirm the spectral accuracy of the results. The performance of the algorithm is consistent with the theoretical predictions.

Keywords: Linear stability analysis, immersed boundary conditions method, flows in annuli.

1. Introduction

Pressure-driven flow in an annulus is widely encountered in applications, e.g. flow in tubular heat exchangers, plastic extrusion operations, movement of drilling mud in oil and gas wells, etc. The character of this flow has profound effects on the efficiency of the relevant devices and, especially, on the pressure losses. Since friction is the dominant source of drag, one is interested in the development of techniques resulting in the reduction of viscous shear. It is well known that laminar flow generates less friction than turbulent flow and, thus, it is crucial to determine conditions which prevent the onset of the laminar-turbulent transition. Conditions leading to the loss of stability of the laminar flow can be determined using the linear stability theory which was used for the first time by Mott & Joseph [1]. More recent results can be found in [2]-[5].

Ideal annular flow can rarely be found in practice as the surface finish of the conduit depends on the manufacturing process used. This surface degrades during the lifetime of any particular device due to fouling, corrosion, erosion and similar processes. It is of interest to determine the effects of such surface modifications on the stability characteristics of the flow. Surface modification could also been introduced intentionally with the goal of increasing mixing. This can be done by selecting surface topographies which are able to destabilize the flow with respect to the streamwise vortices as such structures increase the radial mixing by an order of magnitudes [6]. The development of passive mixing-enhancing techniques which rely on flow instabilities is of particular interest in the design of more efficient heat exchangers as they are expected to produce much smaller pressure losses compared with those generated by currently available vortex generators [7].

Core-annular flow (CAF) formed by the parallel movement of two immiscible fluids is another example of annular flow in potentially corrugated passages [8]-[9]. Reducing the required pumping power in heavy oil extraction [10]-[12] drives the interest in such flows and forms the basis of the lubricated pipelining technique. In this approach a low-viscosity liquid is injected into the pipe to wet the wall to reduce the shear stress that the oil flowing through the core region is exposed to [12]. The stability of such flows has been studied both numerically and experimentally [12]-[14].