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DRAFT: THE EFFECT OF VARIYING VISCOSITY IN TURBULENT CHANNEL FLOW

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ABSTRACT

In various applications in nuclear engineering and in particular in test reactors, heat removal is carried by single-phase axial flow. In these applications, we observe sharp changes in molecular viscosity while the density presents very limited changes. As a consequence, the Reynolds number increases often by 2-3 folds across the channel, with an inlet value often transitional. In these conditions, turbulence changes significantly across the length of the channel with redistribution and thinning of the boundary layers. This is different from acceleration as the effect of changes in density is negligible. We aim to characterize in detail this phenomenon.

In particular Nek5000, a spectral-element computational fluid dynamics (CFD) code, will be used to perform DNS of fluid flow in the transition regime for channel flow with varying viscosity. We set up a novel benchmark case: the channel is extended in the stream-wise direction up to 20pi. The viscosity is kept constant in the first 4pi region. This inlet region is used as a cyclic region to obtain a fully developed flow profile at the beginning of the ramping region. The ramping region (4pi -20pi) is defined as a transition region where the viscosity is linearly decreased along the channel. The flow is homogenous in the span-wise direction due to the periodic boundary conditions. Due to the cyclic and wall boundary conditions, the flow is non-homogenous in the stream-wise and wall-normal direction respectively.

In this study, specific focus is given to the investigation of turbulence properties and structures in the near-wall region along the flow direction. Detailed turbulence budgets are collected and investigated. As expected, the results show that variation in the Reynolds across a channel does not cause an immediate change in the size of turbulent structures in the ramp region and a delay is in fact observed. Moreover, the results from the present study are compared with a correlation available in the literature for the friction velocity and as a function of the Reynolds-number.

NOMENCLATURE

A You may include nomenclature here.

α There are two arguments for each entry of the nomemclature environment, the symbol and the definition.

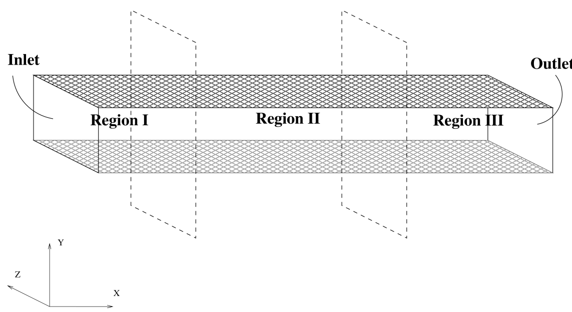
The spacing between abstract and the text heading is two line spaces. The primary text heading is boldface in all capitals, flushed left with the left margin. The spacing between the text and the heading is also two line spaces.

INTRODUCTION

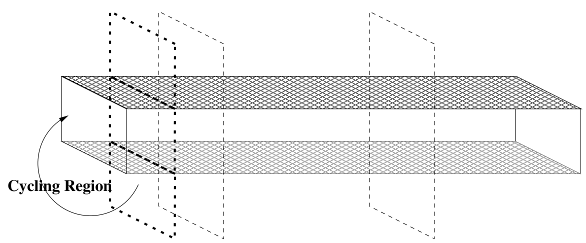
The turbulence channel simulated is shown in Fig. 1a. In this figure, regions I, II and III are defined by two planes crossing the channel. In this problem, the viscosity is a function of the streamwise distance, expressed here by the spatial variable x. This parameter has constants values of $1E-4$ Pa.s and $5E-5$ Pa.s along regions I and III respectively, while in region II it decreases with respect to the inverse of x.

For the present work, three cases varying the length of region

II are studied. Cases I, II and III have their region II begining at $x = 4\pi$ and the length of region II are respectively 16π, 8π and 4π. Fig. 2 shows the plot of the viscosity as a function of x for each one of these cases. For all cases the inleat flow in region I is considered to be fully developed with $Re_\tau = 550$, i.e., the same conditions as in [1], while a periodic condition is considered for the boundaries of the spamwise direction, i.e., z axis, and finally wall conditions are considered for the boudaries of the vertical direction, i.e., y axis.



(a) GEOMETRY OF THE TURBULENCE CHANNEL, THE CHANNEL IS DIVIDED INTO THREE DIFFERENT REGIONS.



(b) CYCLIC REGION IN THE INLET.

FIGURE 1: SCHEMATICS OF THE SIMULATIONS EMPLOYED.

METHODS

In order to resolve the finest turbulent scales, the calculations of this work has been developed through Direct Numerical Simulation (DNS). To do so, a spectral element code Nek5000 was employed, where this code has been developed in Argonne National aboratory (ANL) and it has been validated in references [2] and [3].

The solution of this method is given by trigonometric series, in each element a polynomial functions of up to the twelveth degree have been employed to discretize the velocity field. Fig. 3 shows an example of the grid from half of the channel's cross section. One should notice that the discretization presented by

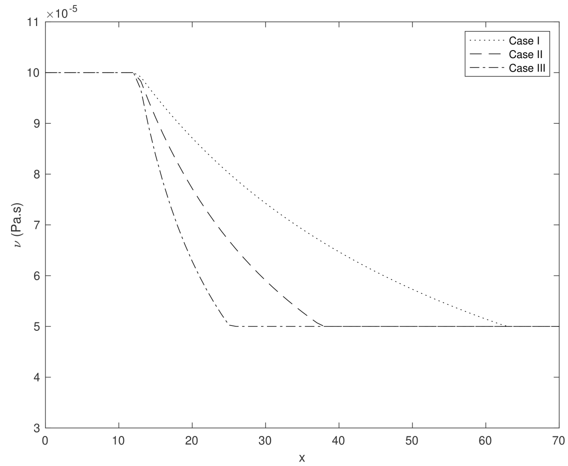


FIGURE 2: THE GRID EMPLOYED IN THE SIMULATION FROM HALF OF THE CHANNEL'S CROSS SECTION.

this particular area is identical through all model's domain and it is only presented half of the cross-section for better visualization of the frame.

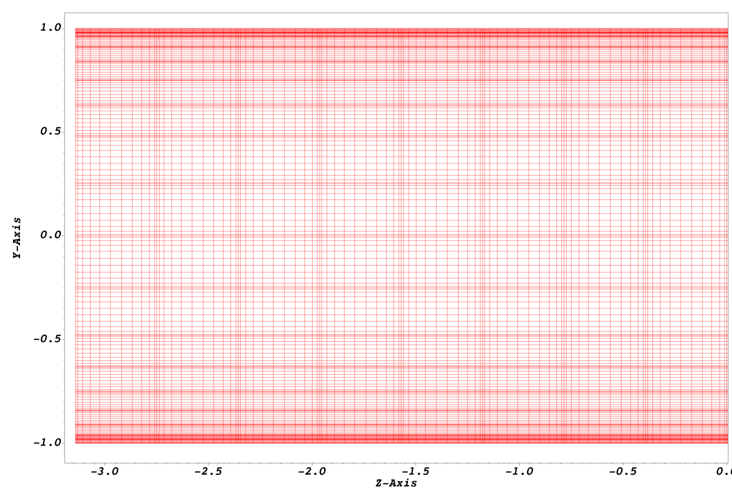


FIGURE 3: THE GRID EMPLOYED IN THE STREAMWISE-DIRECTION CROSS SECTION OF THE TUBULENCE CHANNEL.

DNS simulations are able to simulate the finest turbulent length scales without using any turbulent model. Since the present work is focused on studying the contribution of the smaller scales to the energy cascade, it is required to use DNS rather than Reynolds Average Navier-Stokes (RANS) or Large Eddy Simulations (LES), although there is a substantial growth of the computational cost.

Add some stuff about the mesh and polynomial order.

RESULTS

The results from the three cases considered in this work are presented in this section. First, the friction Reynolds number variation along the streamwise direction x of the channels are computed and compared with an expression for Re_τ as a function of the Reynolds number existed in Ref. [4]. This analysis shows the fact that the predicted shift in the friction Reynolds number due to a viscosity change imposed through region II is not immediate. Thereon, Reynolds stresses are collected and turbulent structures are investigated along the simulated channels.

Analysing the friction Reynolds number

Here goes nice things.

Reynolds stresses and turbulent structures

More good stuff.

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$$f(t) = \int_{0_+}^{t} F(t)dt + \frac{dg(t)}{dt} \tag{1}$$

FIGURES AND TABLES

All figures should be positioned at the top of the page where possible. All figures should be numbered consecutively and captioned; the caption uses all capital letters, and centered under the

Beautiful Figure

FIGURE 4: THE FIGURE CAPTION USES CAPITAL LETTERS.

TABLE 1: THE TABLE CAPTION USES CAPITAL LETTERS, TOO.

Example	Time	Cost
1	12.5	$1,000
2	24	$2,000

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ACKNOWLEDGMENT

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Appendix A: Head of First Appendix

Avoid Appendices if possible.

Appendix B: Head of Second Appendix

Subsection head in appendix

The equation counter is not reset in an appendix and the numbers will follow one continual sequence from the beginning of the article to the very end as shown in the following example.

$$a = b + c. \tag{2}$$