# ME PhD Thesis Defense

## Torque Transport, Mean Velocity Profiles and Turbulent Statistics of a Wide-Gap Taylor-Couette Flow

Akhilesh M. Prabhu, IISc

### ABSTRACT

Wall-bounded turbulent flows that possess finite curvature of the mean flow streamlines are known to be starkly different from their plane counterparts. One of the primary distinguishing features of such flows is the existence of a distinct mechanism of instability (centrifugal instability) that is altogether absent in planar flows. This fact is seen to have direct consequences with regards to flow dynamics and coherent structures and begs further inquiry into the underlying physics. With this as the primary motivation, we have chosen a wide-gap Taylor-Couette (TC) configuration with rotating inner cylinder and a fixed outer cylinder as a model problem to isolate and study the effects of flow curvature. Direct numerical simulation (DNS) of the incompressible Navier-Stokes equations in cylindrical polar co-ordinates has been employed for obtaining high-resolution spatio-temporal data of the flow field. The radius ratio and the aspect ratio chosen for the simulations are 0.1 and 5.5 respectively. The first part of the study deals with the implementation of an efficient multi-core algorithm using an influence matrix based domain decomposition technique. Using this code, we proceed to study the centrifugal instability that occurs around an impulsively rotated cylinder in an otherwise quiescent fluid. We find that the critical wavelength and the critical boundary layer thickness at the onset of the instability scales with Reynolds number with an exponent of 2/3. A critical Taylor number defined using the Reynolds number and gap-width is found to achieve a constant value at large Reynolds numbers. This result is analogous to the one obtained by Taylor wherein the critical Taylor number for small-gap approximation is ~1708, independent of the Reynolds number.

The investigation proceeds to a systematic study of the statistically stationary flow in the annulus of the wide-gap TC configuration described above. Both axisymmetric and fully three-dimensional simulations are performed to obtain the mean and turbulent statistics for (Ta/Ta_{c}) in the range 50-5*10^4.(Ta_{c} is the critical Taylor number for the onset of the first instability). A striking feature of the flow is the presence of significant asymmetry in the flow dynamics at the two walls as evidenced by both the global torque fluctuations and the spatio-temporally averaged velocity profiles. It is found that the mean azimuthal velocity profiles near the inner and outer walls plotted in wall co-ordinates significantly deviate from the classical log-law profile. Guided by the fact that for curved flows a finite production of energy exists for the radial r.m.s velocity component, we seek an alternate velocity scale (to friction velocity) which is in many respects similar to the Deardorf10f scale commonly used in free convection. Starting from Karmans' law of the wall and assuming the profiles far from the wall to be independent of fluid viscosity, we obtain the 'free convection' scaling in the inertial regime. A similar result was obtained by Claussen whose argument was based on Monin-Obhukov similarity theory as applied to circular Couette flow. Surprisingly, the profiles of mean angular momentum near the inner wall for both the axisymmetric and fully 3D simulations display this scaling, while the profiles near the outer wall do not; a fact that further elucidates the asymmetry of the flow dynamics at the two walls. The mean temperature profile of convective turbulence is found to have a similar variation in the inertial regime, a fact that hints at similarity between buoyancy driven and curved wall-bounded turbulent flow. Further, we explore the scaling of the time averaged torque with Reynolds number and find that the torque non-dimensionalized by the laminar torque (a ratio analogous to the Nusselt number of free convection) scales with Taylor number with an exponent of 0.21. The exponent obtained here is significantly smaller than 0.33, the exponent predicted by marginal stability theory (MST) of Marcus which although is applicable only for small gap-widths. We propose that the torque scaling obtained is directly related to the boundary layer dynamics, with the boundary layer thickness determined by centrifugal instability. Next, we discuss some salient flow features both with regards to the time-averaged and the instantaneous flow. Instantaneous flow fields are investigated to identify some plausible coherent structures in the flow that may be responsible for the torque transport. Lambda2 criterion as proposed by Jeong & Hussain is used for this purpose and its contours at a particular value show the presence of stream-wise oriented vortices that resemble those predicted by G\"{o}rtler to be the dominant structures in a centrifugally unstable boundary layer.

### ABOUT THE SPEAKER

Obtained Mechanical Engineering degree from B.M.S College of Engineering, Bangalore. Joined the department of Mechanical Engineering IISc for PhD under the guidance of Prof. Jaywant H. Arakeri and Prof. R. K. Shukla.

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