The onset of fully turbulent pipe flow

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Transitional turbulence in pipe flow is composed of localized puffs whereas space-filling fully turbulent flow only becomes sustained at larger Reynolds numbers. In the present computational study we introduce a body forcing that flattens the mean streamwise velocity profile, a method recently used to suppress and even eradicate turbulence in simulations and experiments [1] [2]. Using the forcing amplitude as a control parameter, we are able to observe the onset of space-filling turbulence over a wide range of Reynold numbers ($Re = \mathcal{O}(10^3) - \mathcal{O}(10^4)$) and determine the minimum energetic requirements for fully turbulent flow to become sustained. Interestingly, and despite strongly differing forcing amplitudes, the 'minimal' velocity profiles are found to collapse in inner units and equally collapse with the unforced case at the puff-slug transition point. Such condition is linked to a critical level of input energy that needs to be supplied to the system in order to drive the fully turbulent flow. The minimum requirements determined above are then compared to other canonical shear flows such plane Couette and plane Poiseuille flows.

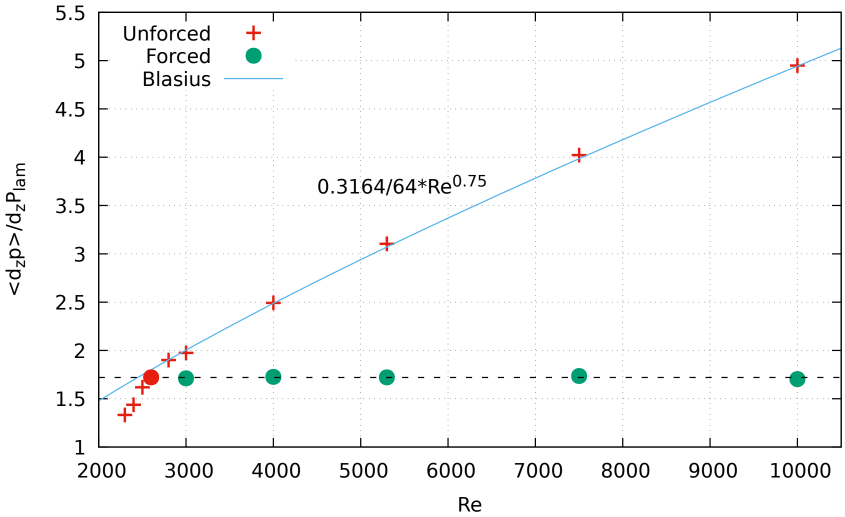

Figure 1: Input energy from the driving pressure gradient as a function of the Reynolds number in pipe flow. The unforced simulations follow the Blasius relationship, while the forced cases at the onset of fully turbulent flow lie on a constant line.

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