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Boundary layer limit for laminar flow through a slowly rotating straight pipe: effect of rotation ratio

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ABSTRACT

We consider fully developed steady laminar flow through a pipe that is rotating slowly about a line perpendicular to its own axis. The solution is expanded by computer in powers of a single combined similarity parameter introduced by [1], $K = RR_r$, where R is a Reynolds number based on axial velocity and R_r is the Reynolds number based on rotational velocity. The solution is expanded by computer in powers of our similarity parameter number K and $d = R_r/R$ which is the rotating ratio. A major difference between results in [1] and those of other analyses is in the asymptotic behavior of the friction factor as the similarity parameter $K = RR_r$ and hence k increases. The prevailing opinion has been that the relationship goes as $f_r/f_s \sim k^{1/4}$, whereas [1] find that $f_r/f_s \sim k^{1/8}$ in this work we try to see whether the effect of the rotating ratio changes this relation or not.

The previous work on this problem divided into four categories: First theoretical analysis, perturbation theory by [2], [3], [4], and [1]. Second experiments for a rotating pipe were conducted by [5], [6],[7]. Third, the boundary layer analysis is done by [8], where they assumed that the boundary-layer thickness is constant with respect to the angular coordinate inasmuch as the Coriolis force due to the rotation acts in a fixed direction. Their assumption about angular independence of the thickness seems unreasonable, in reference [7] also a boundary-layer analysis was carried out. Their equations were solved via the Karman-Polhausen method of integration. But their model seems to be invalid in the vicinity of the innermost ring because at that point they predict infinite boundary-layer thickness. Fourth, as far as numerical work is concerned [9], [10], [11] have carried out computation and they all agreed with Ito's experiment.

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