Swirl Boundary Layer at the Inlet of a Rotating Pipe

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Abstract

When a fluid enters a rotating circular pipe, eq. the inlet of a turbo machine, an angular momentum or swirl boundary layer establishes at the wall which interacts with the axial momentum boundary layer. In the pipe center, i.e. outside the swirl boundary layer, the fluid is free of swirl and accelerated due to the displacement boundary layer. Only within the swirl boundary layer the flow has a circumferential velocity component. Below a critical flow number, i.e. the ratio of averaged axial velocity to circumferential velocity of the pipe, there is a flow separation known as part load recirculation in the turbo machinery context.

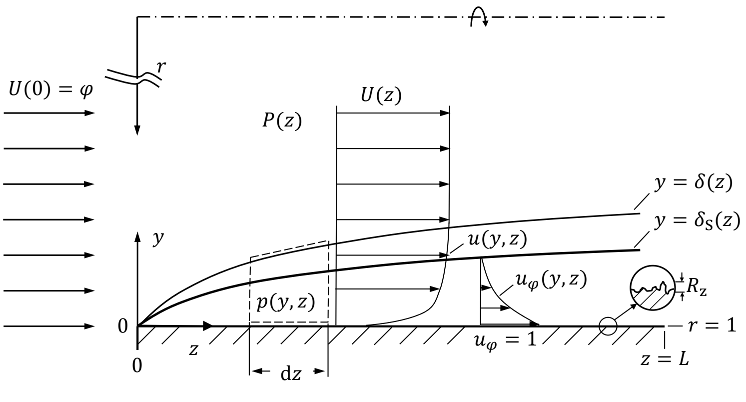

Figure 1: Inlet of a rotating pipe.

We extend the boundary layer theory by a swirl boundary layer interacting with the axial momentum boundary layer, see Figure 1. For this we use the conversation of momentum, the conversation of angular momentum and the continuity equation. The pressure inside the swirl boundary layer, so on for a part of the axial boundary layer, is no longer independent of the radial coordinate as it is usually assumed by boundary layer theory. We solve the extended boundary layer equations by Pohlhausen's method. The solution of the generalized von Kármán's momentum equation is a power low taking Reynolds, and flow number into account. For small flow numbers the axial momentum boundary layer thickness increases due to swirl. We validate the solution of the swirl boundary layer by experiments.