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[Extended Abstract]

Swirl Boundary Layer at the Inlet of a Rotating Circular Cone

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Introduction

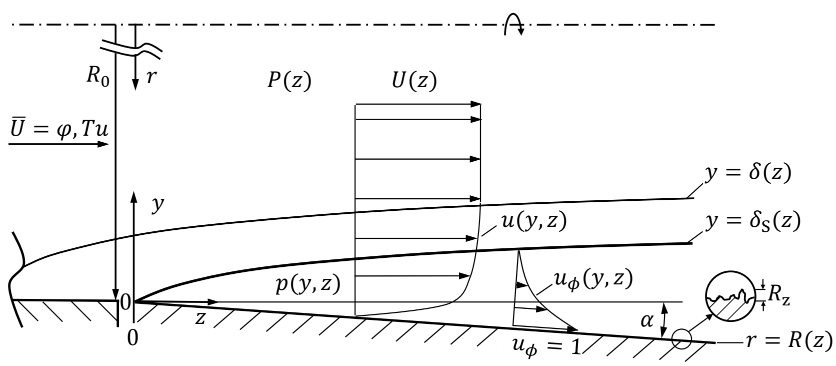

Figure 1. Flow at the inlet of a rotating circular cone.

When a fluid enters a rotating pipe a swirl boundary layer with thickness of δ_S appears at the wall and interacts with the axial momentum boundary layer with thickness of δ. The swirl is produced by the wall shear stress and not due to kinematic reasons as by a turbomachine. In the center of the pipe the fluid is swirl-free and is accelerated due to axial boundary layer growth, see figure 1. Below a critical flow number $\varphi := \bar{\tilde{U}}/(\tilde{\Omega}\tilde{R}_0) < \varphi_c$, with average axial velocity $\bar{\tilde{U}}$, circumferential velocity of the pipe $\tilde{\Omega}\tilde{R}_0$ and pipe radius at the inlet $\tilde{R}_0 = \tilde{R}(\tilde{z} = 0)$, there is flow separation, known in the turbomachinery context as part load recirculation.

Previous work analyses the flow at the inlet of a rotating cylinder ($\tilde{R} = \tilde{R}_0$). For a systematic approach to a turbomachine, the influence of an accelerated and deaccelerated flow on the evolution of the swirl and on the flow separation is to analyse. The function of a pump is to increase the pressure and this is schematic fulfilled by a diffuser and the turbine's function is to decrease the pressure, i.e., a nozzle. The radius of the rotating pipe changes constantly depending on the axial coordinate, yielding a rotating circular cone, to accelerate or deaccelerate the flow. The swirl boundary layer thickness depends on the Reynolds number $Re := 2\tilde{R}_0^2\tilde{\Omega}/\tilde{\nu}$ with the kinematic viscosity $\tilde{\nu}$ and the flow number. The influence of the apex angle α on the swirl boundary layer thickness, the swirl velocity profile and the turbulence intensity $Tu_\phi := \sqrt{\overline{\tilde{u}_\phi'^2}}/(\tilde{\Omega}\tilde{R}(\tilde{z}))$ is the main task of this paper.

1. Methods

Numerical, experimental and analytical investigations analysis the development of the swirl boundary layer and flow separation at the inlet of a rotating cylinder depending on the inlet conditions [1–4]. There, the centrifugal force interacts with the axial momentum and the swirl boundary layer thickness follows a power law

$$\delta_{\mathrm{S}} \sim Re^{-0.48\pm0.05}\varphi^{-0.44\pm0.05}z^{0.44\pm0.05} \tag{1}$$

for regime I. This relation is more or less independent of the inlet condition of the rotating cylinder, e.g., laminar or turbulent flow [3,4]. For $(Re,\varphi,z) > (Re,\varphi,z)_{\mathrm{t}}$ equation 1 is not longer valid and a second turbulent regime of the swirl boundary layer occurs with a new self-similar swirl velocity profile [2]. The flow is axiomatic described using the integral method of the boundary layer theory and the familiar von Kármán momentum equation is generalized taking the centrifugal force into account. The solution is validated by experiments and the influence of roughness is shown [1,3]. With Stratford's method [5] a point of incipient separation is derived analytically and validated by experiments [1].

There are some investigation on swirl decay and vortex breakdown at the inlet of a rotating circular cone [6,7]. Hence, up to now the influence of the apex angle on the evolution of swirl is unknown. Therefore, this paper uses a free stream channel with a radius of $\tilde{R}_0 = 25$ mm with air to investigate the evolution of swirl depending on the apex angle by Laser Doppler Anemometry. The rotating circular cone has a length of $5\tilde{R}_0$, is exchangeable and positive and negative apex angles $\alpha = -1.83\dots1.61°$ are used. The apex angles are chosen in such a range that flow separation is avoided when the circular cone does not rotate. Finally, this investigation improves the physical knowledge and understanding of swirl evolution and part load recirculation. The gained knowledge is employable for the design of a turbomachine, especially a shrouded turbomachine and flow channels of secondary air flow of a gasturbine.

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