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THE INFLUENCE OF THE VANE LEAN ON THE FLOW IN A TURBINE REAR STRUCTURE

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Abstract

For the first time, the effect of the vane lean on the flow through engine-realistic turbine rear structure (TRS) was investigated. Two different engine realistic configurations with zero lean and positive straight lean have been tested. The experiments were performed at engine representative Reynolds number and three different turbine loads based on a low-pressure turbine exit swirl angle. For each type of TRS, the data acquisition was done by means of pressure probes located upstream and downstream of outlet guide vanes (OGV). The OGV lean, with a positive lean angle, is shown to affect the flow in the TRS and lead to the pressure redistribution influencing pressure losses. The obtained experimental data are to be used for the validation of simulation results and aerodynamic optimization of TRS design in the future.

Keywords: Experimental, TRS, OGV, Lean

1. Introduction

The aviation industry has made great progress in reducing key emissions and making aircraft engines more fuel-efficient. However, the new ambitious goals of the aviation industry push manufacturers and designers to develop even more efficient aero-engines. The introduction of a geared turbofan engine was a breakthrough, allowing the aircraft manufacturer to increase the by-pass ratio (BPR) further while limiting the fan tip speed. Also created new challenges for designing individual components such as the turbine rear structure (TRS) in terms of aerodynamic performance. TRS serves a structural function by supporting a rear shaft bearing and connecting the engine core to the aircraft body. The outlet guide vanes (OGV) positioned between the outer, and inner TRS rings serve as structural connectors. The aerodynamic function of the TRS is to eliminate the swirl from the low-pressure turbine (LPT) and provide axial flow with minimum pressure losses. In geared engines with an increased off-design range for the TRS and more strict weight and length requirements, new demands on OGV design are imposed on aerodynamic efficiency.

Figure 1 illustrates the schematic flow in the LPT-TRS with LPT stator and rotor wakes, typical total pressure distributions at inlet and outlet, as well as OGV oil visualization with a highlighted zone of laminar-turbulent transition and hub corner separation (taken from Vikhorev et al. [1]). The TRS flow is affected by different parameters: the OGV geometry, the shape of the inner and outer casings, the incoming flow from the LPT, etc. For example, Selic et al. [2] investigated the effect of varying leakage flow on TRS losses. Deshpande et al. [3] performed numerical investigations and studied the effect of surface roughness on the aerodynamic performance of TRS. Simonassi et al. [4] and Zenz et al. [5] studied acoustically optimized and riblet-equipped vanes. Vikhorev et al. [6] studied the effect of vanes with increased thickness and shrouded bumps typical for the engine realistic TRS. Moreover, Vikhorev et al. [7, 8] experimentally investigated the state-of-the-art TRS with a shroud of a polygonal shape. They performed a detailed comparison with numerical results discussing the influence of different vane types in terms of pressure losses and turning performance.

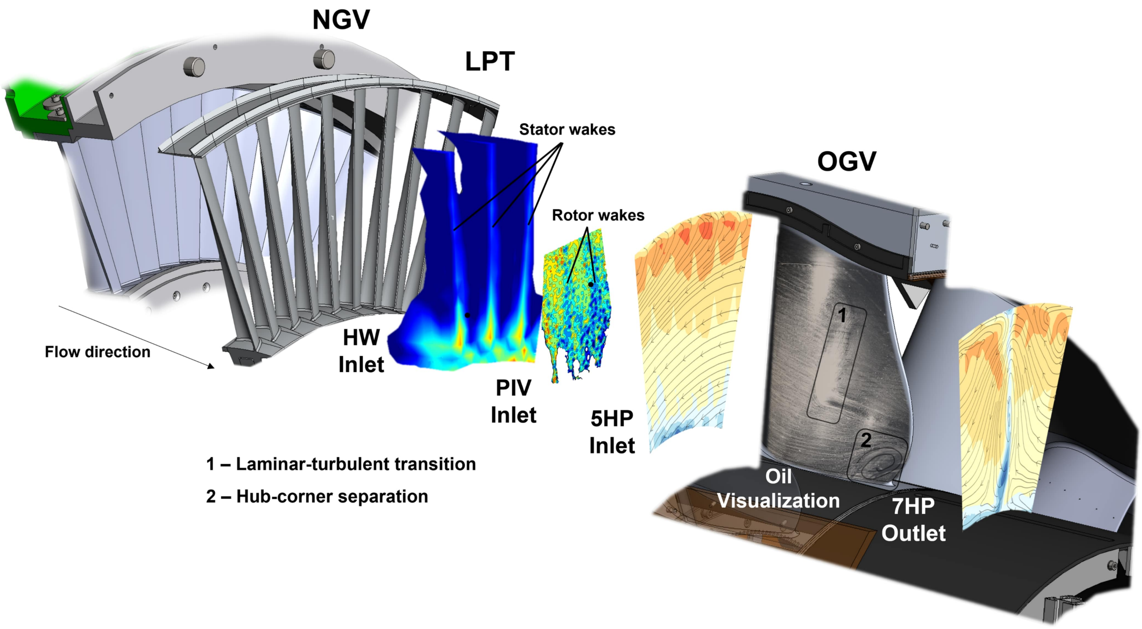

Figure 1 – Flow in LPT-TRS (from Vikhorev et al. [1]).

The lean angle of OGVs is an important geometric parameter related to the design of TRS. The lean is a circumferential displacement of the vane stacking line relative to the radial direction. Implementing lean in a TRS design is a requirement determined by other disciplines than aerodynamics to possibly improve the structural, thermal, and acoustic capabilities of the component. Several studies have discussed the influence of the lean on the flow in other than TRS turbomachinery components. For instance, Wang et al. [9, 10] have shown that the overall effect of the lean is the change of the radial pressure gradient in the hub region. For the radial vanes (with zero lean), the non-uniform swirl distribution along the blade height causes the radial pressure gradient that drives low-momentum fluid toward the hub. The accumulation of the low-momentum fluid may lead to the hub-corner separation and corresponding pressure losses [11, 12]. Positioning vanes with a positive lean angle of 20 degrees (so that the angle between the suction side of the vane and the hub is obtuse) minimizes the value of the radial pressure gradient, and the hub corner separation can be weakened or eliminated [13]. However, no studies describe the aerodynamics of leaned LPT OGVs and no studies for engine realistic leaned-vane TRS configurations such as those equipped with a bump or thickened vanes. Therefore, a more detailed investigation of the TRS with leaned engine realistic OGVs is needed to fully understand the influence of the OGV lean on the flow in the TRS.

2. Experimental setup

Experimental investigations were carried out in a closed-circuit low-speed large-scale LPT-OGV facility at Chalmers University of Technology, Sweden. The LPT stage consists of a stator stage with 60 nozzle guide vanes and a rotor stage with 72 blades and provides realistic inlet boundary conditions for the TRS section. In this work, two engine realistic configurations of TRS were experimentally investigated (Fig. 2), one with radial OGVs and one with leaned OGVs.

Each TRS configurations has regular, tube and mount sectors as in a real aero engine. The sectors are highlighted with different colours in Fig. 2. The tube sector is highlighted by blue, the mount sector by red, and the regular sectors by grey colour. The regular sectors contain so-called regular vanes. The tube sector comprises vanes with enlarged thickness compared to the regular vanes. The thicker vanes of the tube sector are required to provide space for the oil supply tubes. The mount sector consists of bump vanes with engine mount recess needed to reduce bending moments at the point of attachment of the TRS to the aircraft. The total number of OGVs for each configuration has been determined by the goal of minimal weight and required structural strength. For the leaned configuration (Fig. 2, right), the number of OGVs was increased to 18, and the chord and thickness of

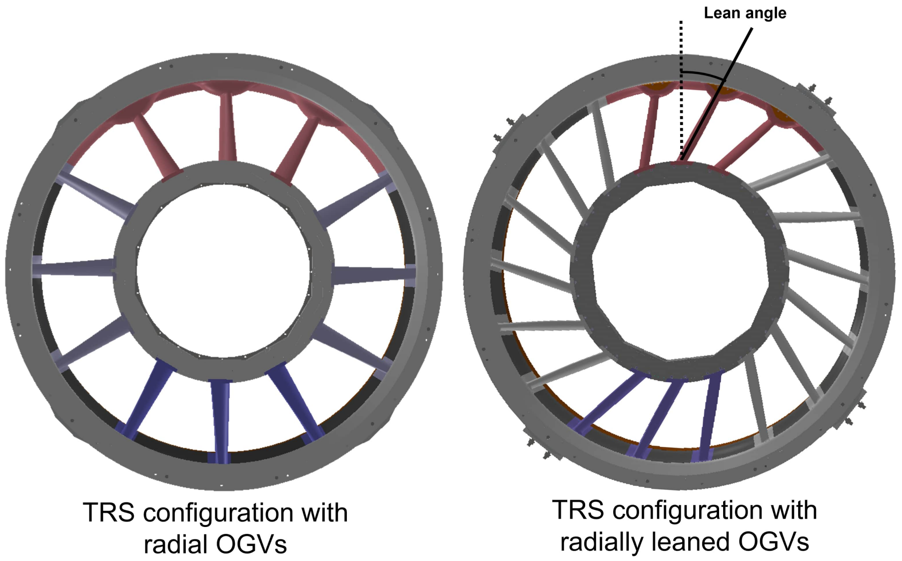

Figure 2 – Investigated TRS architectures. Left - configuration with radial OGVs and right - configuration with leaned OGVs.

OGVs were decreased. Thus, the solidity of both TRS configurations was the same. Note, however, increased length of leaned OGVs due to the lean angle. Both TRS architectures have been designed by GKN Aerospace Sweden for the experimental rig and are not related to any GKN Aerospace product characteristics.

Total pressure measurements were performed using pre-calibrated aero probes in two planes, one located upstream and one downstream (Fig. 3). The traversing systems used to position aero probes were fully automated and controlled by a PC. Inlet and outlet measurements were performed for a 30-degree sector located upstream and downstream of the OGVs.The azimuthal resolution was 0.6°, and the radial resolution was 9.7 mm. Acquisition of pressure data was performed using a 16-channel PSI-9116 system with a 500 Hz sampling rate and 2.5 seconds of sampling time. This data was time-averaged, and only average values were analysed. Tests were carried out under on-design and off-design conditions. The flow Reynolds number based on the inlet channel height was 350,000 and used for all three operation points, representative of three aero-engine operating conditions: sea-level takeoff, climb point, and cruise flight.

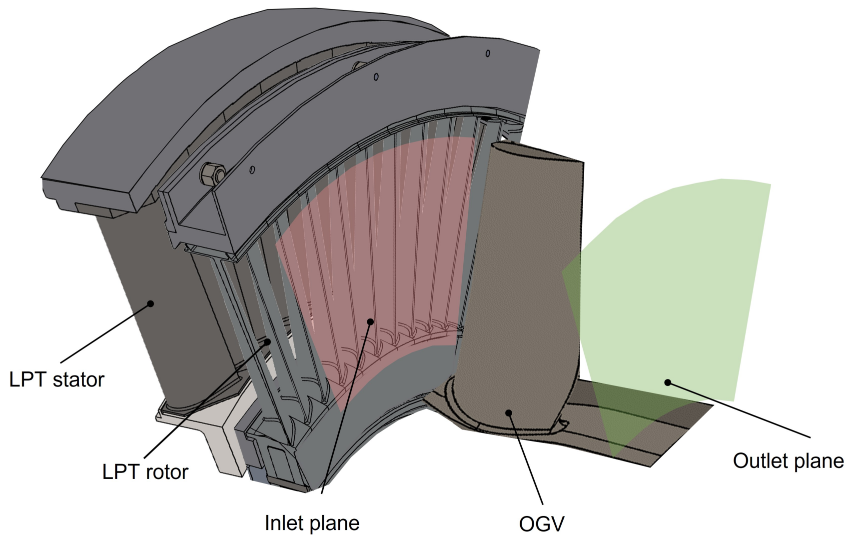

Figure 3 – The schematic of LPT and TRS with locations of inlet and outlet planes.

3. Results

The effect of the OGV lean is studied for the first time in an engine realistic TRS. The results of the experiments are compared to the previous data obtained by Vikhorev et al. [7].

Figure 4 presents a side-by-side comparison of the total pressure coefficient distributions obtained for a 30-degree sector located downstream of a regular, thick and bump vanes at on-design conditions. In each contour plot, the left part of the OGV wake corresponds to the pressure side (PS) and the right part to the suction side (SS). The outlet comparison between the on-design cases shows that the OGV lean substantially changes the distribution of losses in the wake region due to the pressure gradient redistribution compared to radial OGVs. One can observe increased losses in the hub region for the leaned configuration in the regular and bump sectors and decreased losses in the shroud region of the bump sector. The wake strength of the leaned OGVs is decreased due to a shorter chord length and reduced wetted surface; however, more wakes around the circumference exists as more vanes are required.

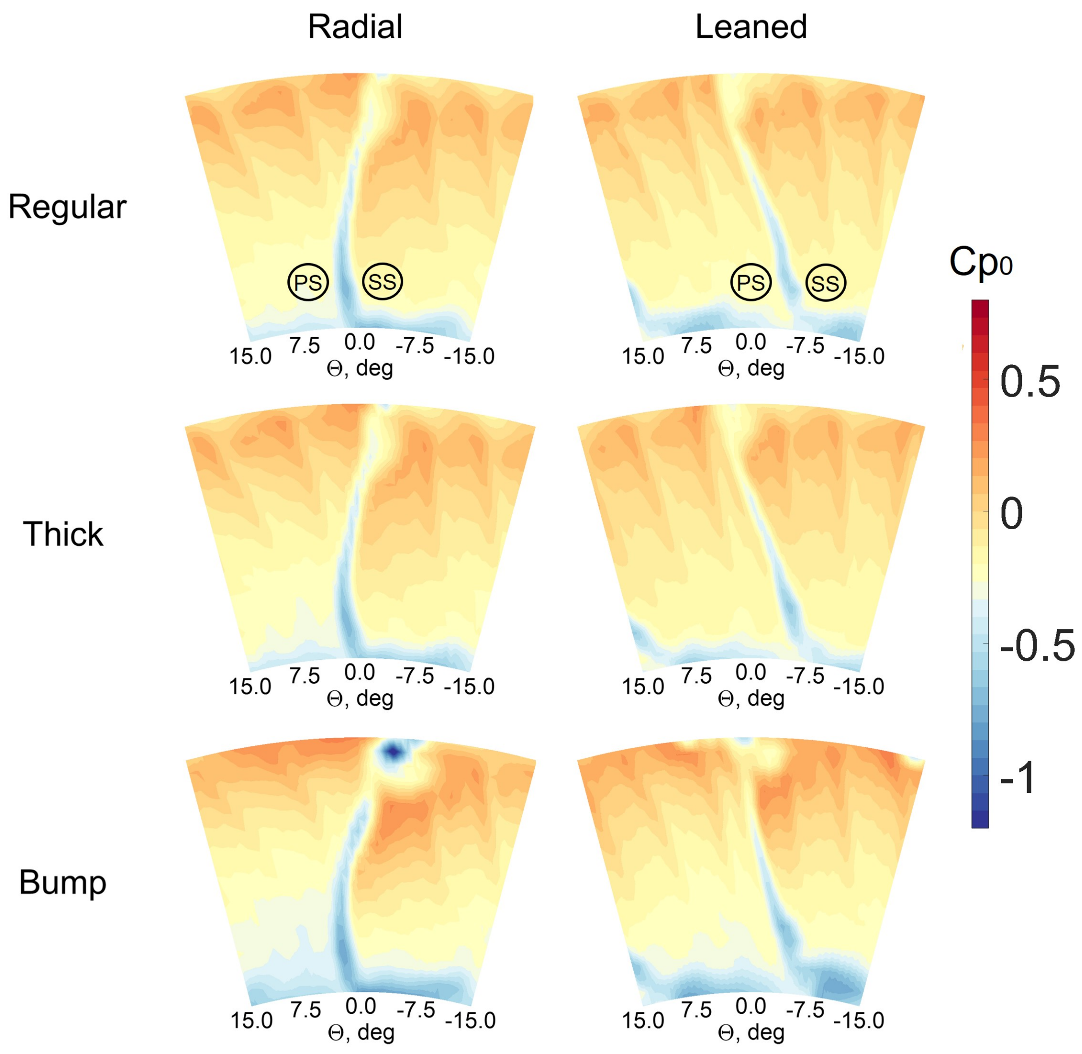

Figure 4 – Total pressure coefficient distributions at inlet and outlet planes for radial and leaned configurations of thick and bump vanes at on-design condition.

Typically, for a thicker OGV, the flow diffusion on the suction side increases, making the flow more sensitive to separation. However, the current designs of the thick vane does not lead to an additional flow separation for both configurations, which highlights successful aerodynamic designs. Remarkably, the leaned configuration of the thick vane leads to reduced losses in the hub region, which may be attributed to the changed pressure gradient.

The wake from the bump for the leaned configuration decreases despite a more aggressive bump aspect ratio and is attributed to the redistributed static pressure in the channel. The bump design for the leaned configuration shows good aerodynamic performance with a much weaker vortex in the shroud region. For the radial configuration, a strong shroud vortex is clearly seen (see [7] for further discussion). However, the negative effect of the lean in the bump sector is a notable increase of the total pressure losses near the hub.

Figure 5 shows a side-by-side comparison of the total pressure coefficient distributions at the off-design condition with decreased loading. One can observe a relatively large region with reduced total pressure located near the hub for all cases. The OGV lean leads to pressure redistribution due to the changed radial pressure gradient compared to the radial vanes. The thick leaned vane has larger losses in the vane wake and barely visible decreased pressure losses near the hub. Closer inspection of the total pressure distribution for the leaned bump vane indicates that the flow is not perfectly periodic. Marked with black solid line pressure loss region should be repeated for the bump sector with a spacing of 20 degrees; however, the left region of pressure losses is located closer than its expected location marked with a black dotted line.

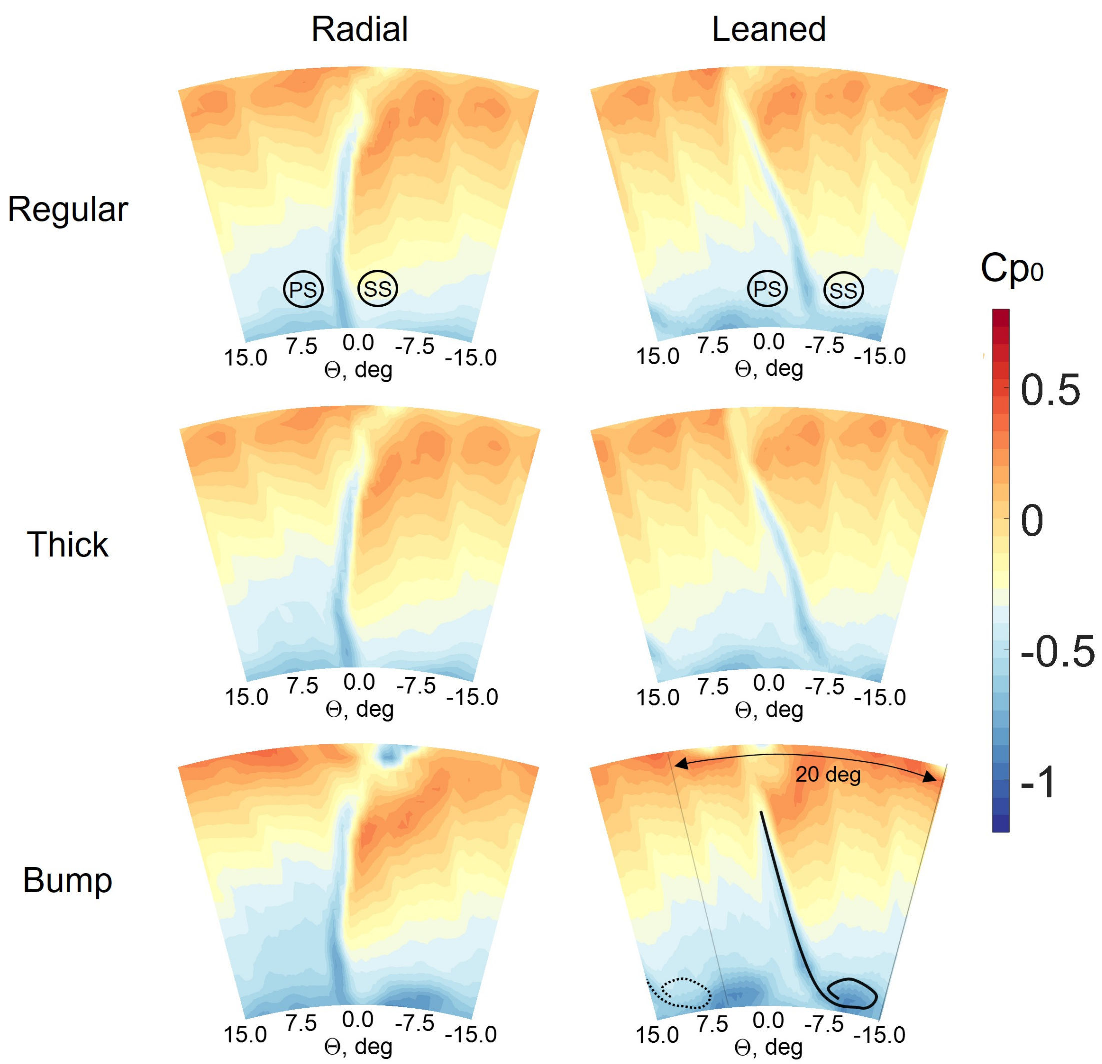

Figure 5 – Total pressure coefficient distributions at inlet and outlet planes for radial and leaned configurations of thick and bump vanes at off-design condition (low loading).

Figure 6 shows a comparison of the total pressure coefficient distributions at the off-design condition with increased loading. The losses from the vanes increase with increased loading due to the increased inlet swirl angle and more skewed swirl angle profile. The leaned OGV configurations show substantially decreased vane wakes partially due to the shorter OGV chord and partially due to the changes on the radial pressure gradient. The vane wake near the hub is decreased for the leaned configuration due to a more favourable streamwise pressure gradient on the vane suction side near the hub. As for the on-design case, the thick leaned sector has smaller losses in the hub region than the regular sector. The leaned bump sector has decreased losses near the shroud and increased losses near the hub.

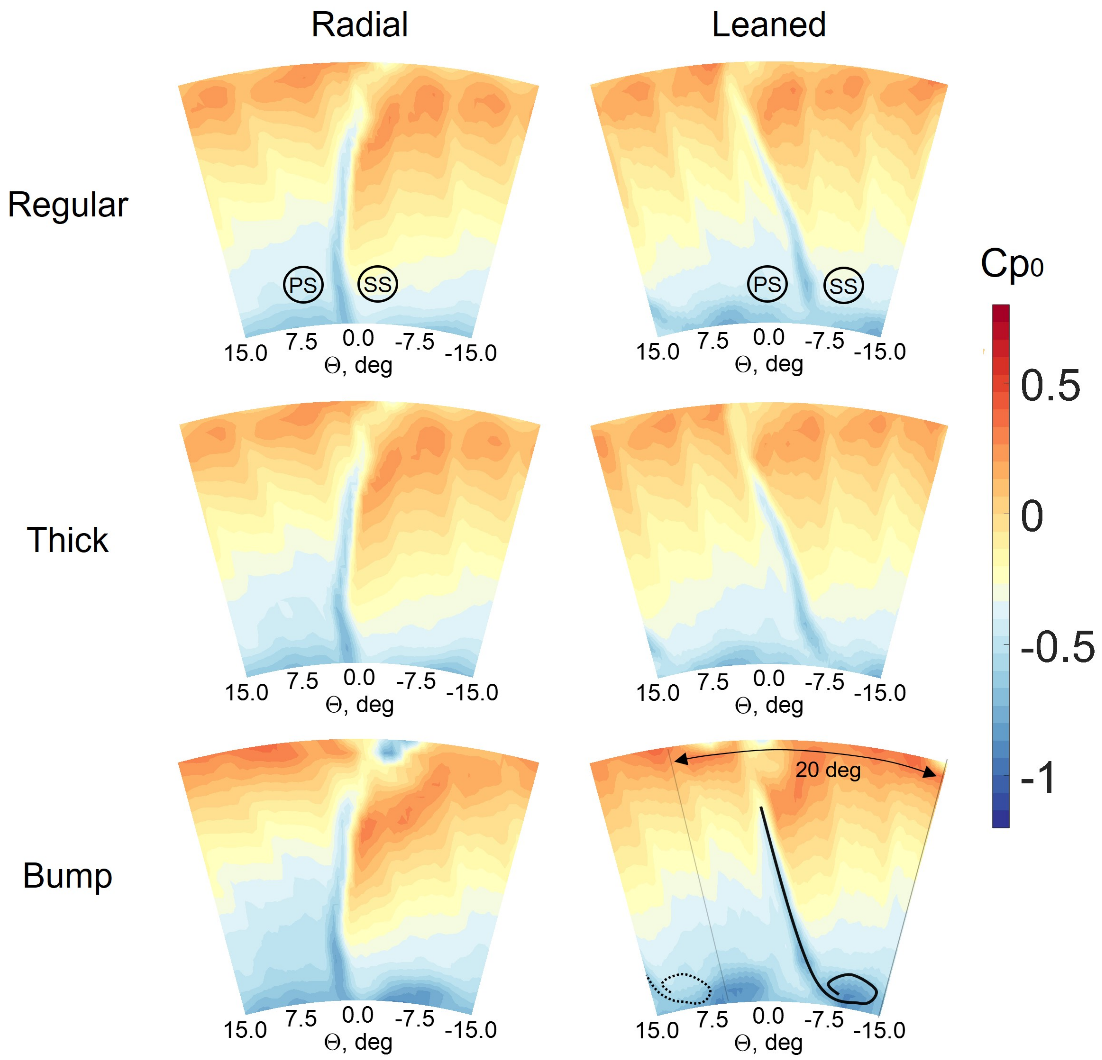

Figure 6 – Total pressure coefficient distributions at inlet and outlet planes for radial and leaned configurations of thick and bump vanes at off-design condition (high loading).

4. Conclusions

This paper presents a detailed comparison of the aerodynamics of two engine realistic TRS: one with radial OGVs and one with leaned OGVs. The measurements were performed for three operation points representing three aero-engine operating conditions. The OGV lean, with a positive lean angle, is shown to affect the flow in the TRS and lead to the redistribution of the total pressure due to the decreased radial pressure gradient and weakened flow diffusion on the vane suction side near the hub. As a result of this, the total pressure losses in the wake regions are reduced, especially for the higher loading cases. The OGV lean for the bump vane additionally leads to a substantial decrease in losses near the shroud and an increase near the hub.

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6. Copyright statement

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