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Experimental Study of the Flow in a Linear Cascade of Axial Compressor Blades

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ABSTRACT

This article presents an experimental study of the performance of the boundary layer in the meridional line, measured on different planes of the suction and pressure surface of the blade. Besides the tip leakage of the blade, with tip clearances of 0% and 1% of the blade span were measured. The experiment was carried out in a linear cascade of 5 axial compressor blades. With blade chord of 0.2 m and blade span of 0.4 m, placed into the suction test section of a low speed wind tunnel, with a Reynold`s number of 3.62 x 10^5. It were tested two conditions, corresponding at inlet angle of 29.44º y 34.44º. The measurements were made with hot wire anemometry, with the general purpose probe 55P11and the boundary layer probe 55P15, besides static pressure tappings in the wall. From the experiments were obtained the velocity vectors and pressure contour in one dimension, that show the performance of the boundary layer and downstream flow in the meriodional region of the blade, so the vortex of the tip leakage

Keywords: *Blade of axial compressor; Boundary layer; Tip leakage; Flow linear cascade.*

1. INTRODUCTION

The flow in the region of the southern line and the top of the blade is very complex, due to the interaction of several such viscous phenomena as layer limit of the blade and flows of loss in the top. This flow is responsible for a significant portion of losses and reduction of load of blades of compressors, turbines and bombs. In case of compressors, it produces blockade of the step of flow and distorts the distribution of the angle of current flow below of the rotor [1]. The losses that they increase with these phenomena are the source of major inefficiency in the rotor and of the increase of noise. In case of the blades that it agrees to the compressor it is preferable that the Layer Limit is as small as possible, so that there is a major effective area in the step of flow without it is disturbed, causing a major alignment in the lines of current [2].

In the environment of real compressors, measurements detailed in blades of stator they show layers limits to laminate extended on 30-50 % of the rope of the blade. To numbers of Reynolds of 0.8x106, a separation to laminate with turbulent transition is visible in the side of sucking, which does not disappear when the turbulence of the free current is increased to 3 % [3]. On the other hand, in the majority of the rotors of the turbo machinery, the space between the blade and the wall of the casing induces a flow of escape across the space. This flow also happens in stages of the stator with the space close to the rotor. The dissipation and miscellany of the flow of escape and whirlpool introduce aerodynamic losses and inefficiency. The distribution of losses indicates that the flow of escape includes close to 16 18 % of the height of the blade, from the top [4]. Also, the flow close to the surface of the top, diverges from the half of the profile of the blade and produces a whirlpool of separation of the top in the entry of the spread. This whirlpool increases in size and forces along the rope, and due to the area of contraction in the spread, the fluid moving across the spread, one accelerates [5]. One of the principal skills in the development of design of compressors is the study of cascades across wind tunnels, since it allows realizing a detailed study of the mechanism of loss in these areas [6]. For this reason, a cascade of blades will settle, in the wind tunnel of the Laboratory of Thermal Engineering and Applied Hydraulics, to realize a series of experiments and to determine the characteristics of flow and losses related in the southern line and top of the blade.

2. THEORETICAL FOUNDATIONS

The flows in turbomachinery are the most complex found in the practice of fluid dynamics and are always three-dimensional, viscous and unstable [7]. For example, the secondary flow increases are due to the viscous boundary layer, but in the analysis of their effects are treated as non-viscous. Some three-dimensional not viscous effects are due to:

1. Compressibility, radial density and pressure gradients.
2. Radial change in thickness and geometry of the blade.
3. Presence of finite walls of shafts and casings, shaft area change, curvature and rotation.
4. Working entering or leaving that varies radially.
5. Presence of two-phase flow, and refrigerant injection.
6. Leakage flow due to the clearing at the tip and axial spaces.
7. Regions of mixed flow.
8. Secondary flow caused by input velocity gradients, stagnation pressure and angle of rotation.

Studies by Prandtl showed that a in a body immersed in a fluid in motion all the frictional energy losses occur in a thin layer adjacent to the surface in contact with the fluid. This layer is known as boundary layer. The flow outside the boundary layer can be considered as lacking in viscosity. As small errors in the alignment of the blades results in a boundary layer separation earlier than expected causing the thickness increases very quickly resulting in widespread inefficiencies due to aerodynamic effects. Moreover, the stage blades rotate near the stationary outer wall, or casing seal. Furthermore, the flow condition when pass the crown of blades creates a pressure difference between pressure and suction sides of blade, which induces a leakage flow through the spacing or clearance between the blade tip and seal. A vortex is generated between the jet and the main flow and is wound with its induced velocity to form a “tip leakage vortex”, as shown in Figure 1. Although the effects of other flows are appreciable, the flow of tip plays an important role in the flow phenomenon in this region, where raises an important part of the losses.

3. SELECTION AND DESIGN OF THE CASCADE

The blade that was used is a stator vane of the compressor´s first stage of Ruston gas turbine. The compressor blade was digitalized by optical means, to obtain the coordinates and have the exact correspondence between the actual blade and model. This we obtained the coordinates of the middle section of the blade. Once the coordinates are obtained we proceeded to build the aluminum blade for experimentation, through CNC. It was took the plane that places to 43 mm from the base of the blade. This profile is scaled to 7 times the actual size for the installation blade. The blades have a chord of 199.94 mm, a height of 400 mm and thickness is 25.03 mm. So the parameters for the cascade of 5 blades are shown in Table 1.

4. EXPERIMENTAL DEVELOPMENT

The wind tunnel that is used which is of the suction type is located in the LABINTHAP. The test section for the experiment was modified to obtain the different configurations of the blades cascades. At the bottom section, the acrylic is formed by a circular cross section to the rotation of the cascade, that section has 5 holes for the rotatory base of the blade.

To achieve the different spacings on the tip of the blade, the module has an intermedium wall of acrylic, with 121 holes for static pressure taps arranged in an array of 11 x 11. To measure the effect of leakage flow on the tip were measured the velocity and turbulence profiles downstream, as the static pressures on the intermedium wall. The conditions to measure are spacings of 0 and 1 of de blade height (0 and 4 mm of spacing), and angles of entry flow of 29.44 ° and 34.44 °. For the boundary layer, the measurement planes are composed of two sets of planes. The first series consists of the entry plane located at a blade chord of the attack edge; downstream five planes are located at 1, 1.25, 1.5, 1.75 and 2 cords of the attack edge of the blade. The second set of measurement planes is composed by the measurement planes of boundary layer, distributed along the suction side and pressure. These planes are located with a distribution of 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% of the blade string starting at the attack edge. In the case of the tip it was choosed to measure five transversal planes downstream of the central blade of the cascade, that is, at 1.125c, 1.25C, 1.5c, 1.75cy 2c, in corresponding to the measuring transversal planes 1, 2 , 3, 4 and 5, respectively, shown in Figure 2. Each transversal measurement aligned with the cascade angle, covered about 90 mm transversely of the flow channel of the pressure side, and 110 mm for the suction side, taking measurements every 0.008 m. For the two cases of spacing, in addition to the transversal measurements it was measured in 2 planes. Considering the blade height of 0.4 m, the foreground is located at 0.97625% of the height (z = 0.97625) from the base, the second at z = 0.96125.

5. INSTRUMENTS

Hot wire Anemometer brand Dantec model 90C10. General purpose probe 55P11 for velocity and turbulence up and downstream from blade cascade. Boundary layer probe 55P15. For velocity and turbulence mapping it was use positional system brand Dantec model 41T50, measurement range x = 0.590 m, y = 0.590 m y z = 0.690 m, resolution 12.5 mm (x, y) and 6.25 mm (z). "L" Pitot tube, brand Airflow, 8 mm diameter, ellipsoidal pointer, one orifice for total pressure and 7 orifices at 25mm each for static pressure, connected to two inclined manometers brand Airflow type 4.

For total pressure it was used manometer from 0 to 2.5 kPa, for static pressure it was used manometer from 0 to 5.0 kPa. For static pressure it was used an intermediate acrylic wall with 1.75 mm orifices, where put 1.5875 mm external diameter brass tubes (0.8763 mm internal diameter) perpendicular to wall. These tubes connected through plastic hoses to a specially constructed differential manometer. Differential Manometer scale from 0 to 250 mm H_2O, with 121 independent U probes (one end open to atmospheric pressure).

6. RESULTS

Figures 3-4 show velocity profiles of boundary layer suction side and downstream flow in meridian zone of the blade for 29.44° and 34.4^0 respectively. For 29.44^0 the maximum thick of boundary layer suction side is $\delta 11 = 5.799$ mm, in pressure side $\delta 11 = 10.564$ mm, with separation at 77% (suction side) and less than 20% (pressure side) of the chord with a downstream flow of 0.025m (15% of the step). For 34.44^0 the maximum thick of boundary layer suction side is $\delta 11 = 9.096$ mm, in pressure side $\delta 10\text{-}11 = 7.83$ mm, with separation at 58.14% (suction side) and 27.94% (pressure side) of the chord. With a downstream flow similar to previous condition. The no-symmetry profile of the downstream flow 1c for 29.44^0 is because of the boundary layer of the pressure side, while downstream flow for 34.44^0 the deviation is in opposite direction because the biggest thickness of the boundary layer is in suction side. The difference of suction side separation point of 58% at 34.44^o, in relation with 77% at 29.44^o, is because the difference between the blade outlet angle and the flow in the wind tunnel. For the pressure side, separation point is longer at 34.44^0 because the difference between blade inlet angle and the flow in the wind tunnel is smaller.

Figures 5-6 show the difference in turbulence level and boundary layer separation point giving higher turbulence level in pressure side than the suction side. For inlet point figures 6 and 7 show static pressure coefficient behavior at the wall. In Fig 6a it can be observed that vortex tip leakage for 29.44^0 do not match with next blade. But wall influence is bigger as shown in 6b, where leakages stand from 30% to 81% chord, extending downstream. Fig 7a shows for 34.44^0 an increase vortex because de incidence angle, an almost no influence in the others blades. Fig 7b vortex is moved toward inlet point, standing almost half chord. For 29.44^0 wall influence is up to z= 0.96125. Fig 8c show vortex thickness gets 23mm between 1.5c and 1.75c and dissipates in fig 8d. For 34.44^0 fig. 9a shows a bigger wall influence z=0.97625. or 1% space, fig 9c and d, vortex moves greatly toward suction side, getting influence of bigger thickness in every plane up to 40 mm.

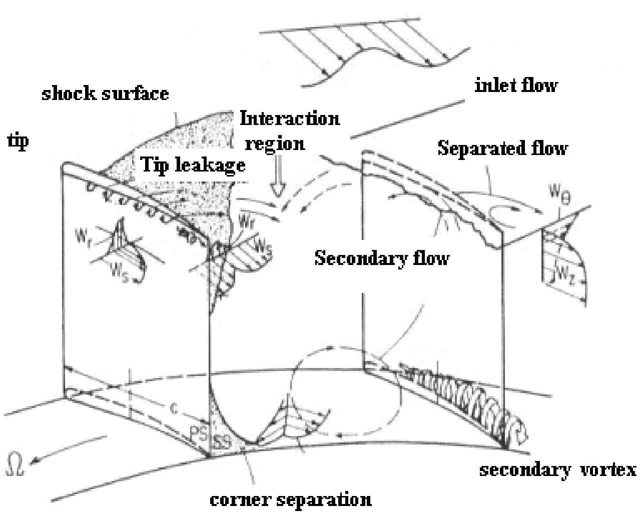


Fig. 1 Compressor blade three-dimensional flow

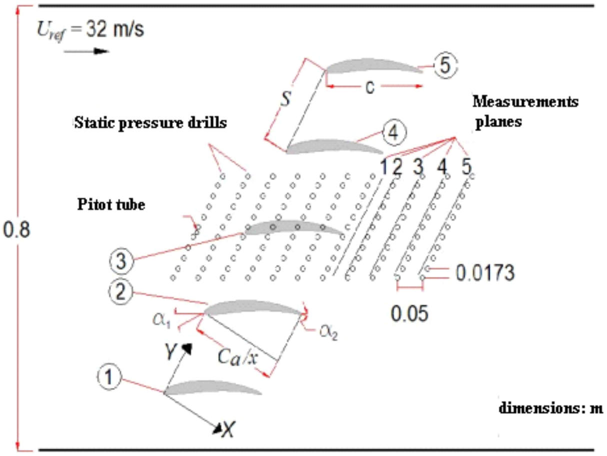


Fig. 2 Measurements planes

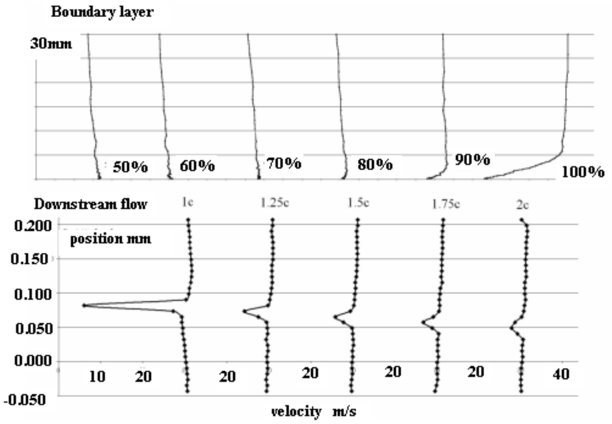


Fig. 3 Velocity profile, boundary layer and downstream, 29.44^0

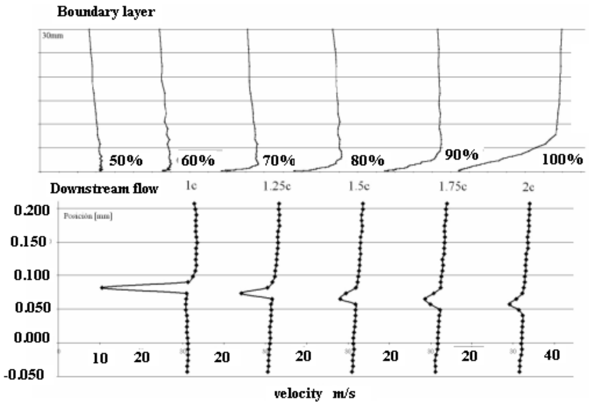


Fig. 4 Velocity profile, boundary layer and downstream, 34.44^0

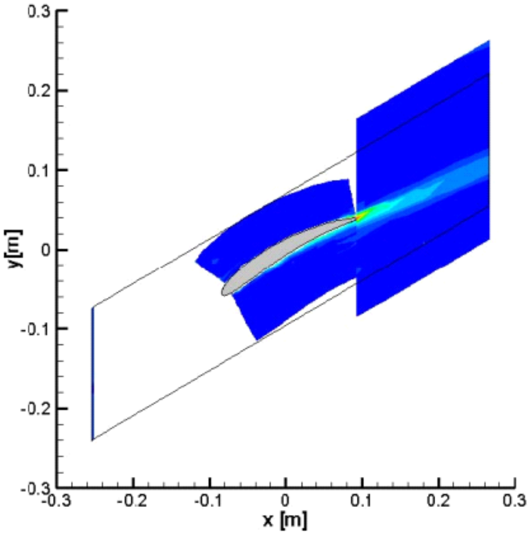


Fig.5 Turbulence pattern 29.44^0

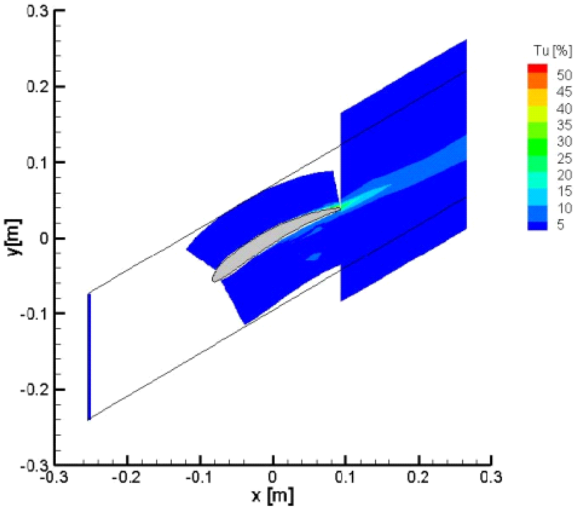
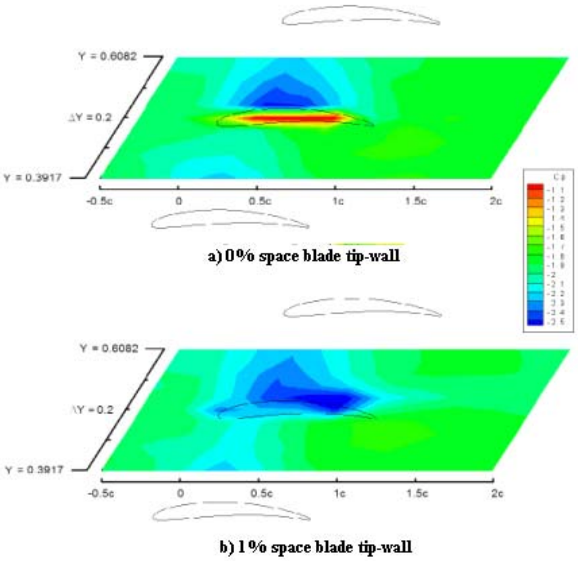


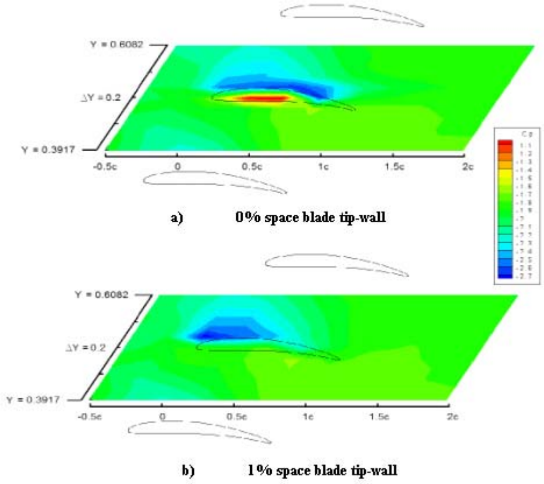
Fig. 6 Turbulence pattern 34.44^0



a) 0% space blade tip-wall

b) 1% space blade tip-wall

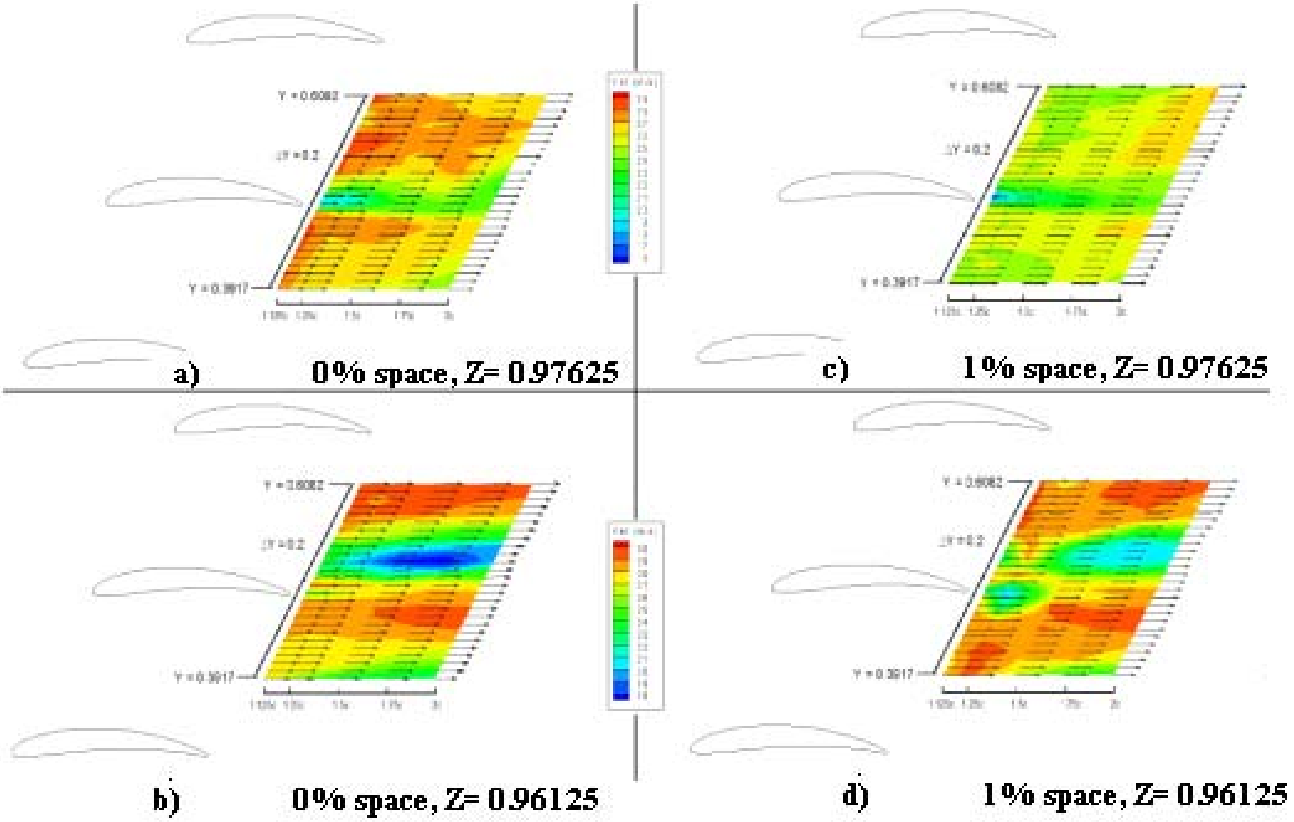
Fig.7 Static pressure coefficient behavior 29.44^0



a) 0% space blade tip-wall

b) 1% space blade tip-wall

Fig. 8 Static pressure coefficient behavior 34.44^0



a) 0% space, Z= 0.97625

c) 1% space, Z= 0.97625

b) 0% space, Z= 0.96125

d) 1% space, Z= 0.96125

Fig.9 Velocity Behavior 29.44^0

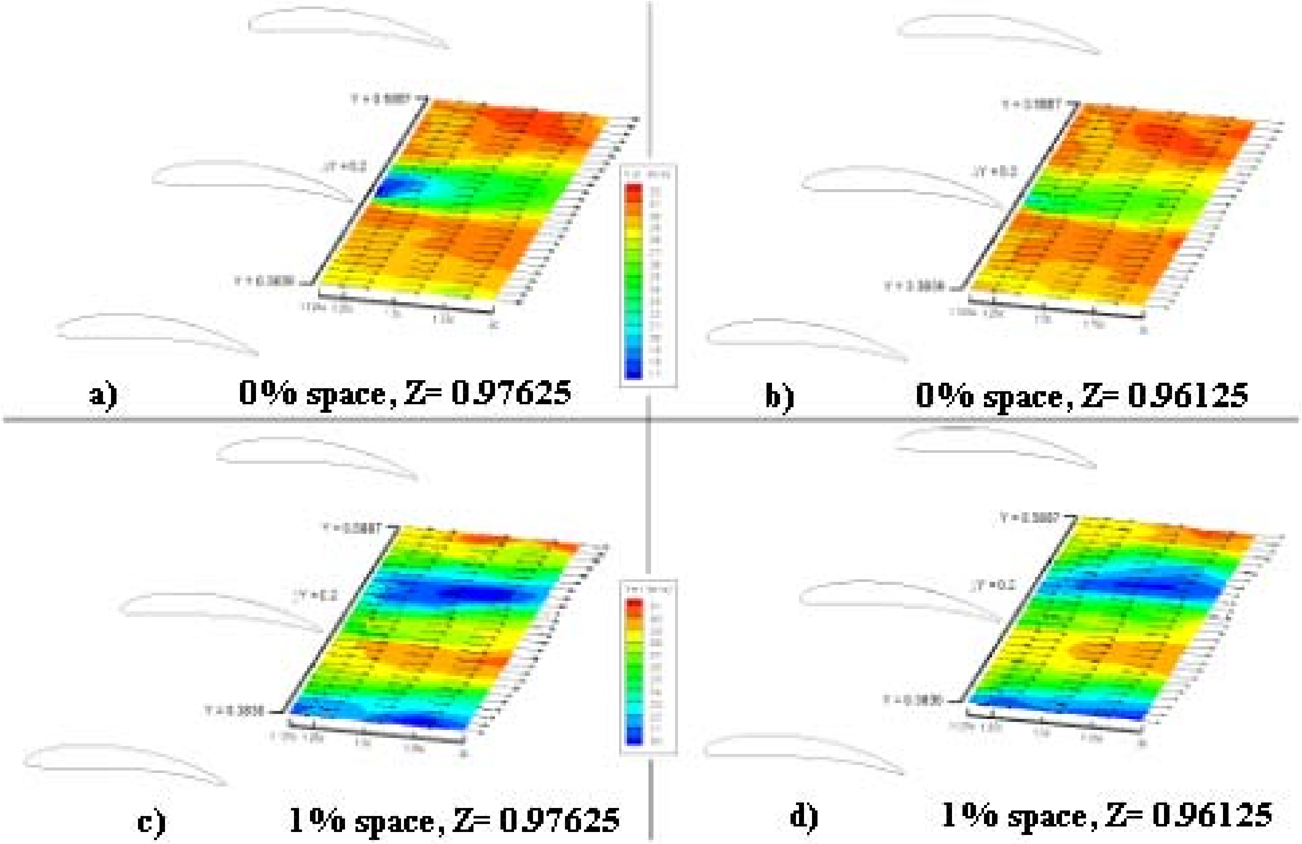


Fig.10 Velocity Behavior 34.44^0

Table 1 Cascade parameters.

Scale factor	7
Chord length	20 cm
Step	16.66 cm
Chord / step	1.2
Blade Length / chord	2
Re	3.62×10^5
Inlet outlet blade angle	15^0
Blade Position angle	29.58979^0
U ref	32.4 m/s
flow middle Inlet angle	29.449^0
Incidence angle	0.14079^0

CONCLUSIONS

Measurements made in blade meridian region show importance of alignment between flow and blade inlet angle. For 29.44^0 conditions, a thickness of 5.79 mm at separation point at 77% chord was observed. For 34.44^0 conditions, at suction side, a maximum thickness of 9.09 mm at separation point at 58% chord was observed; this gets influence in the distance of downstream flow affected for the high turbulence level caused by boundary layer. Which is for 29.44^0 conditions, bigger of 50% chord, downstream from blade outlet point? For 34.44^0 conditions, this length is 25% chord. Vortex tip leakage is figure out through pressure and velocity mapping, vortex formation length for 29.44^0 condition, 30% chord, and vortex thickness 40mm. This shows losses tip region, between blade tip and wall.

APPENDIX: NOMENCLATURE

C = Rope
S= Spend between blades
U_∞ = Speed of entry of the flow (m/s)
α = Angle of entry and exit of the blade
β = Angle of entry and exit of the flow
1 = Blade of number
δ = thickness of limit layer (mm)

x = Axial direction
y = Tangential direction
z= Blade height (m)
Re = Reynolds number
Tu = Turbulence intensity (%)

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