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FLOW CHARACTERISTICS DOWNSTREAM OF A TURBINE BLADE CASCADE

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Abstract

The paper presents an experimental investigation of flow downstream of a fixed blade at different stagnation pressure ratios. The experiments were performed on a straight blade cascade with an aspect ratio $\bar{l}$=1.0 and $\bar{t}$=0.7. The flow was explored by means of three-hole probe in three axial planes downstream of the blade cascade. Measurements of wall pressure on the suction and pressure sides of the blade were made and the pressure loss coefficient was calculated. The flow losses as well as the flow direction along the blade pitch were found to change due to the alteration of the stagnation pressure ratio. The experimental results were compared with theoretical analysis and a considerable agreement was found between them.

Introduction

The development of efficient turbomachinery blading has always been associated with systematic testing of blade profile in cascade wind tunnel. Over the last ten years, numerous method for predicting the flow characteristics in cascade has largely changed. The function of cascade testing is to verify the numerical method rather than developing new blade section.

Many investigators studied theoretically and experimentally the influence of various parameters, such as blade chord, blade height, surface roughness etc., on the flow characteristics through and behind the blade passage. Mobarak, [1], investigated experimentally the effect of blade tip clearance on the flow losses downstream of a linear turbine cascade. The experimental study shows that the distribution of loss behind the cascade give an idea of the wake mixing. Hirayama, [2], reviewed the theoretical and experimental methods for studing the flow through turbine blade rows. He also, developed a new method of analyzing the secondary flow. He suggested that more information about the turbulence structure of blade boundary layers, the mixing process in the downstream of blade rows and the effect of leading edge vortices are necessary. The flow characteristics after the turbine cascade was studied experimentally and theoretically by Volvson and Epifanov,[3]. They found that the theoretical results of velocity profiles agree with experimental results when neglecting the higher order terms in the analysis behind the blades. The effect of inlet flow angle on total losses in turbine cascades was investigated by Deish, [4], using pitot tube and visual methods. His results show that there is a change in position and dimensions of the stagnation zone from the inlet to the cascade end. So, the overall losses of kinetic energy change intensively with inlet flow angle.

Alam el-din, [5], studied theoretically the effect of channel geometry on flow characteristics through turbine cascade. The results show that the geometry of blade has a more significant influence on the flow field along the suction side than on the pressure side. Mobarak and et al,[6], studied the influence of blade aspect ratio and exit Mach number on the total loss coefficient and cascade efficiency. The effect of leading edge shape on the overall loss in a large-scale linear cascade of turbine blades was studied by Moore and Ransmayer, [7].

This paper presents the influence of the stagnation pressure ratio on the pressure distribution on both blade surfaces and on the overall loss coefficient produced by a turbine blade cascade at different axial distances downstream of the cascade. The stagnation pressure ratio was varied from 1.05 to 1.09. Measurements of exit flow angle are also provided.

Description of the experimental set-up

The experiments on the turbine blade cascade have been conducted in an open wind tunnel constructed in the Gas Dynamic Laboratory Fig.(1). Processing from upstream to downstream, it can be seen that air flows from the compressor through an air drier and accumulates in a pressure tank. Then, the air passes through a pipe to the divergent section which is connected to the circular wind tunnel. The air in the circular part passes through a honeycomb, flow straightner before, being accelerated in the cascade.

The blade cascade used in this work was formed from seven similar blades distributed equi-distance from each other and bounded by two prespex flat plates, Fig.(2). The two central blades were made plastic and the other blades were made aluminum with smooth finished surfaces. The main geometrical parameters of the blade (N-90°-15°) are , C= 51 mm, h = 51 mm, t = 36 mm; [8], see Fig.(3). To measure the pressure distribution on the suction and pressure sides of the blade, eleven holes on each side at the mid height of the plastic blades were drilled as shown in Fig.(4). All holes are of 1.0 mm diameter and are connected by rubber tubes through the selector mechanism Fig. (5) to a U-tub manometer.

Selector mechanism was used to measure the pressure at different points on profile of testing blades. This mechanism consists of a hollow cylinder which has 22 holes along its length. The total pressure at the upstream blades cascade was measured by a Pitot-tube. The total pressure at the down stream blade cascade and the flow direction were measured by a 3-hole probe. To control and adjust the position of the three-hole probe along the test section, a three dimensional traverse mechanism was used.

Results and Discussion

The outlet flow from the cascade was measured at three axial planes downstream of the blade trailing edge ($\bar{z}$ = 0.098, 0.196, 0.294). Contours of blade loss are plotted in Figs.(6,7,8), over the blade pitch at the different three planes. All the spaces are made dimensionless by the blade chord. The cascade loss is calculated by

$$\zeta = 1 - \frac{1 - \left(\frac{P_2}{P_{o2}}\right)^{\frac{k-1}{k}}}{1 - \left(\frac{P_2}{P_{o1}}\right)^{\frac{k-1}{k}}}$$

Where P_{o1} and P_{o2} are measured using pitot tube and P_2 is the atmospheric pressure.

Fluid with high total pressure losses in the passage vortex is convicted towards the middle of the passage. The value of the total pressure losses in the core of this fluid changes between plane of $\bar{z}$=0.098 (ζ=4.96%) and plane of $\bar{z}$=0.294 (ζ=6.5). Fluid with high loss region near the pressure side of blade appears at plane 1 ($\bar{z}$=0.098) with a peak value of ζ=15.88 %. However this peak value reduces to 13.2 % at plane 2 ($\bar{z}$=0.196) and to 11.9% at plane 3 ($\bar{z}$=0.294) due to change of flow area and flow mixing. Between the high loss region and the low loss region there is a region which does not exhibit very high losses. The local value of ζ decays from about ζ=7.27 % at plane 1 to 7.1% at plane 2 and 7.0 at plane 3 for $\bar{p}$ = 1.05.

Figures (8,9,10) depict the effect of stagnation pressure on the contours of total pressure loss at plane 3. From these figures it can be noted that increasing $\bar{p}$ tends to decrease the lower value of ζ from ζ=6.5% at $\bar{p}$=1.05 to 5.63 % at $\bar{p}$= 1.09. The total pressure losses in the passage convicte towards the suction side with increasing $\bar{p}$. Fluid with high losses region near pressure side decreases with increasing $\bar{p}$. The level of ζ in the region between the mid blade pitch region and near pressure side region changes slightly with different values of $\bar{p}$.

The loss distribution over the blade pitch at $\bar{z}$=0.294 and at mid of the blade height is shown in Fig.(11).

The distribution of this loss is nonuniform over the blade pitch due to the blade wakes caused by the boundary layer. The position of the maximum value of the cascade loss is close to pressure side of the blade and it moves toward the suction side of blade with increasing $\bar{p}$.The cascade loss decreases near the suction side of blade and takes a minimum at a certain value of $\bar{t}$ and then it rises sharply to reach a maximum near the pressure side of the adjacent blade as shown in Fig.(11).

The distribution of pressure over the blade profile is shown in Fig.(12). The coefficient of pressure is given by

$$C_p = \frac{P_i - P_2}{P_{o2} - P_2}$$

The diagram is drawn with C_p on the y-axis and axial distance/axial chord on the x-axis. The diagram shows that, on the pressure surface, the pressure coefficient is positive and negative on the suction side in the range of $\bar{X}$ from 0.3 to 0.9 and it is positive in the beginning of the blade surface. Also, it can be seen from this figure that the pressure coefficient on the pressure side rises until it reaches its maximum value at $\bar{X} \simeq 0.5$. After this point C_p decreases to reach the trailing edge of blade. The pressure coefficient on the suction side falls uniformly from the leading edge of blade to $\bar{X} \simeq 0.4$. After this point the pressure coefficient rises to a certain value of $\bar{X}$ depends on the stagnation pressure ratio as shown in Fig.(12). From the above analysis it is clear that inside the blade passage there is a non-uniform distribution of pressure on both blade surfaces and at any section of blading normal to the streamline, the pressure increases in the direction from suction to pressure surfaces.

Fig.(13) indicates the exit flow angle from a cascade. It is observed in the diagram that the exit flow angle is not deflected uniformly and it is maximum near the trailing edge. The wake flow and boundary layer which are formed on both blade sides, considerably affect the exit flow angle. The exit flow angle increases with increasing the stagnation pressure. This effect may be due to increasing the wake flows at the trailing edge.

Comparison between theoretical and experimental results

A comparison between theoretical and experimental results is shown in Fig.(14). The theortical results were calculated using the channel method,[9,10]. In the theoretical analysis, the flow is assumed to be irrotational, isentropic and free of shocks. Therefore, the difference between the experimental and theoretical results is due to the above assumptions. But, the trend of both results is almost the same.

Conclusions

The conclusions that can be drawn from this study are:

i) The peak value of pressure loss coefficient diminishes from trailing edge of blade towards the downstream direction.

ii) The level of pressure coefficient decreases with the increase in distance from the cascade.

iii) The pressure loss coefficient and exit flow angle have non-uniform distributions over blade pitch due to the blade wakes caused by the flow boundary layer.

Nomenclature

C : Chord
h : Blade height
p_i : Pressure on the blade surface
P_{o1} : Total pressure at inlet
P_{o2} : Total pressure at exit
α_1^* : Inlet blade angle
α_2^* : Exit blade angle
α_2 : Exit flow angle
ζ : Pressure loss coefficient
$\bar{l} = h/c$: Aspect ratio
$\bar{t} = t/c$: Pitch ratio
ss : Suction side
ps : Pressure side
t : pitch
Z : Axial direction
2 : Exit condition
$\bar{p}$: p_{o1}/p_2
$\bar{X} = x/c$
$\bar{Y} = y/c$
$\bar{z} = z/c$
L.E.: Leeding Edge
T.E.: Trailing Edge

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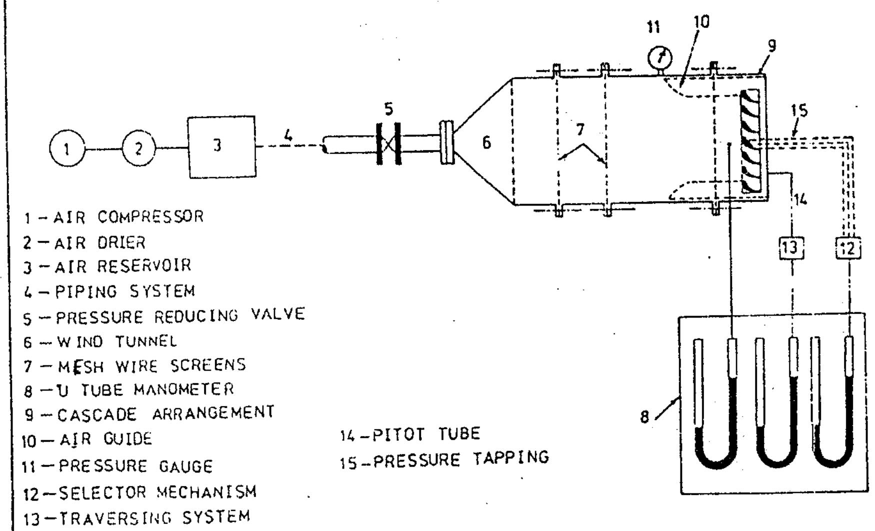

Fig.(1) Schematic layout of the experimental set up

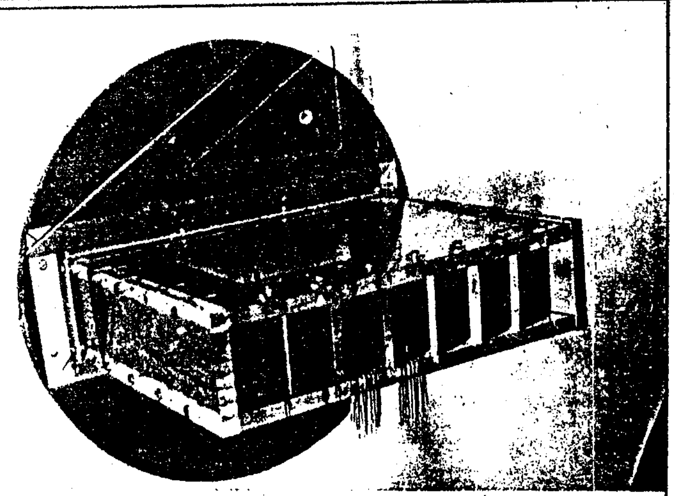

Fig.(2) The blade cascade

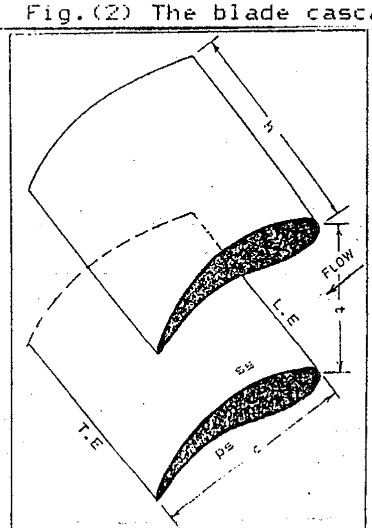

Fig.(3) Blade geometry

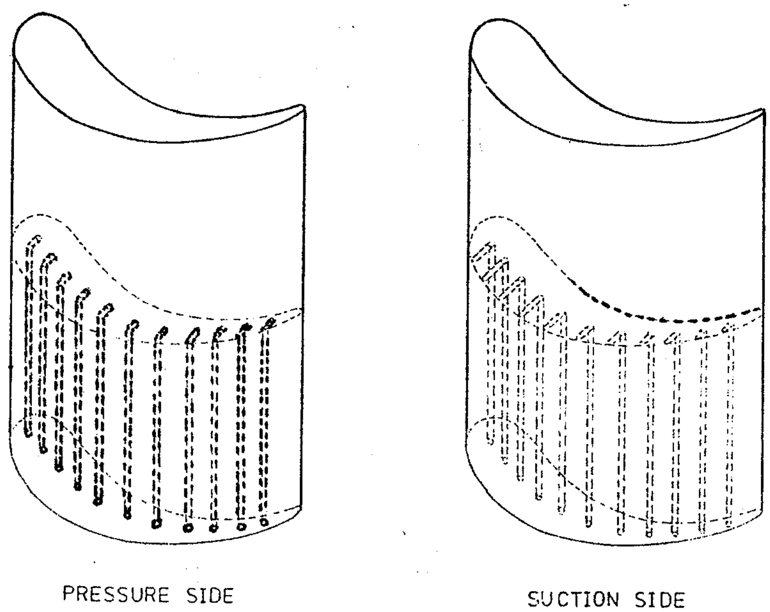

Fig. (4) Static pressure taps on the suction and pressure side

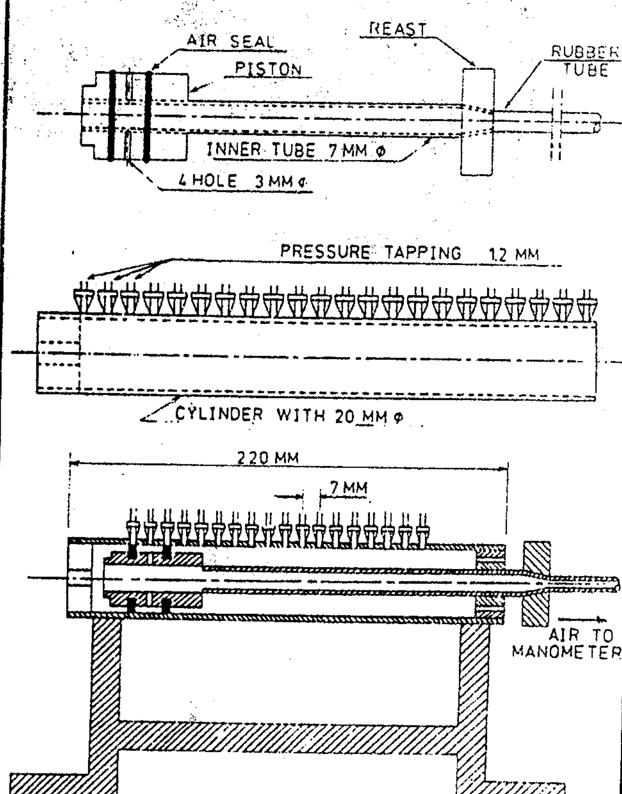

Fig. 5 Selector mechanism

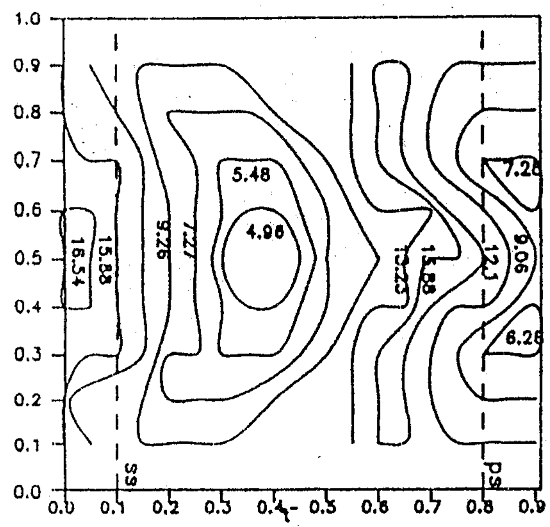

Fig. (6) Contours of total loss at z^{-}=0.098 and P^{-}= 1.05.

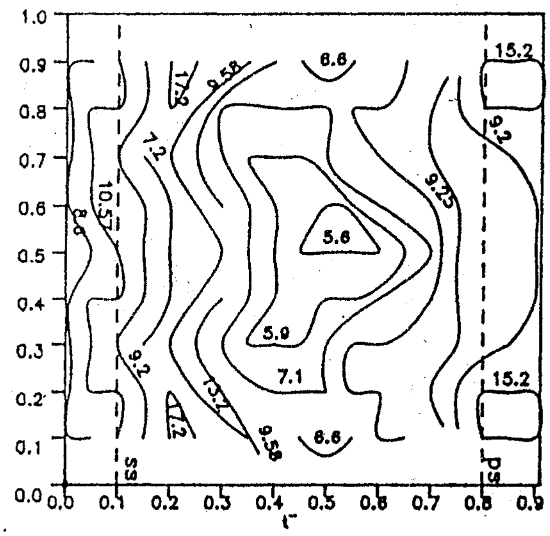

Fig. (7) Contours of total loss at z^{-}=0.196 and P^{-}= 1.05.

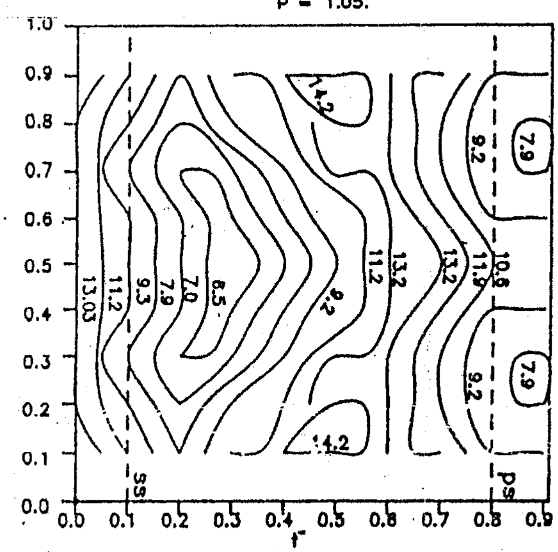

Fig. (8) Contours of total loss at z^{-}=0.294 and P^{-}= 1.05.

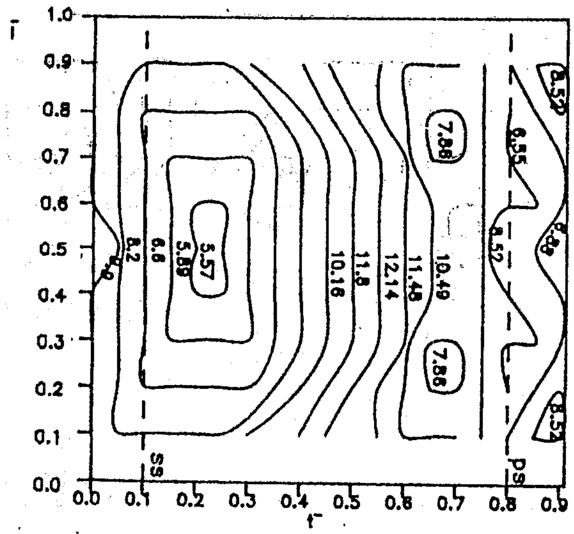

Fig. (9) Contours of total loss at z⁻=0.294 and P⁻= 1.07.

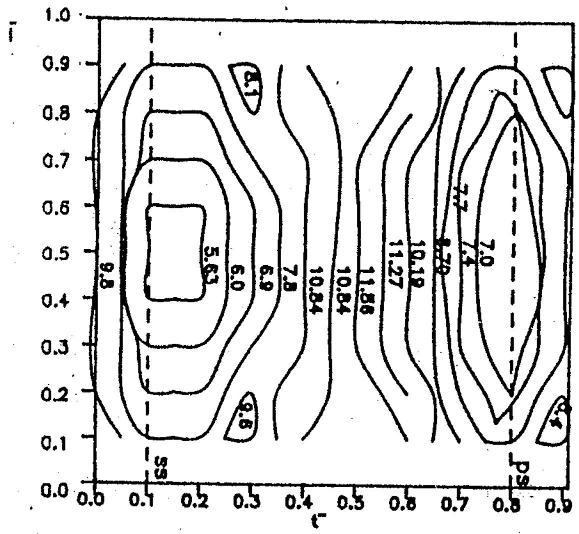

Fig. (10) Contours of total loss at z⁻=0.294 and P⁻= 1.09.

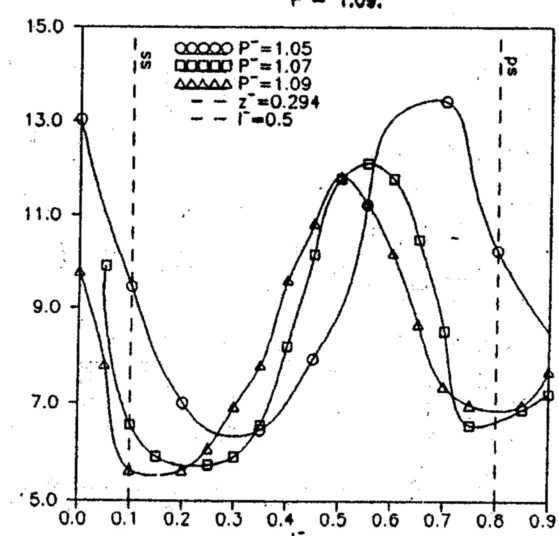

Fig. (11)Effect of the inlet stagnation pressure on the total loss at exit of cascade.

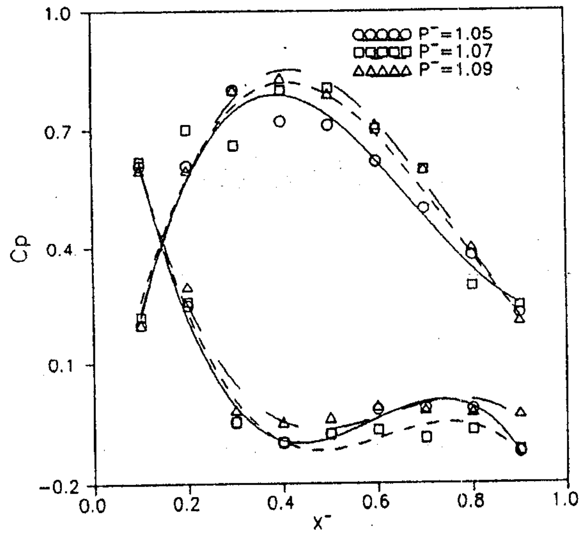

Fig.(12)Pressure distribution on the blade surfaces

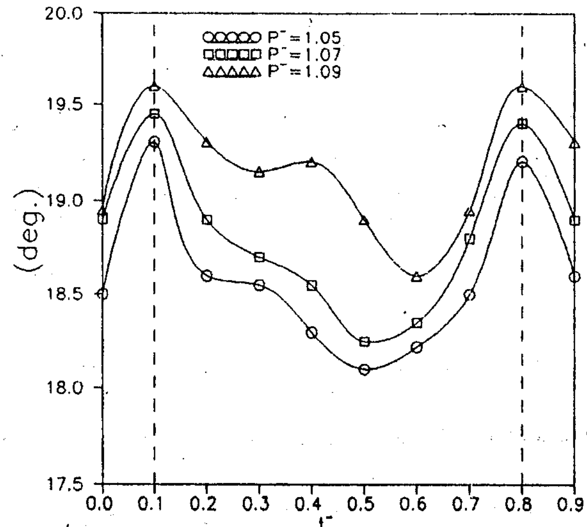

Fig.(13) Variation of the flow exit angles over the blade pitch at z^{-}=0.098.

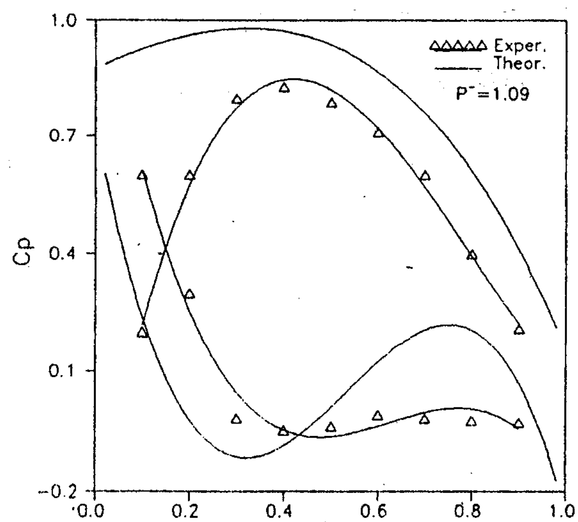

Fig.(14) Comparison between the theoretical and experimental work.

ملخص البحث

خصائص السريان خلف كاسكيد ريش التربينات

تناول البحث دراسة معمليه لخصائص السريان خلف ريش التربينات الثابته وذلك عند قيم مختلفه لنسبة الضغط الكلى .

ولإجراء هذه التجارب تم تصميم جهاز معملى حيث اجريت التجارب على كاسكيد من النوع المستقيم يحتوى على ٧ ريش من النوع الثابت وتم عمل ثقوب على جانب الضغط والسحب للريشتين المتوسطتين وذلك لقياس توزيع الضغط على بروفيل الريش ، حيث كان الطول النسبى والخطوه النسبيه للريش ١ & ٧ر.

تم قياس النتائج المعمليه وذلك باستخدام انبوب بيتوت ذو الثلاث فتحات وقد تم تثبيتها على ميكانيزم وذلك لإمكانية قياس الضغط على امتداد الخطوه وكذلك على امتداد طول الريش ، تم حساب معامل مفاقيد الضغط وكذلك زاوية خروج السريان على امتداد الخطوه وايضا تم حساب مفاقيد الكاسكيد وقد قورنت النتائج العمليه بالنتائج النظريه حيث وجد تقارب بينهما .