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AN EXPERIMENTAL STUDY ON A FENCED TURBINE BLADE CASCADE

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ABSTRACT

An experimental investigation was conducted on a straight blade cascade with aspect ratio of unity to control the generation of secondary losses. Different geometries of fence fitted to the suction side were used. Circular and two dimensional cross sectional fences were tested. The results show that the presence of the circular geometry fence on the suction blade side decreases the secondary losses and as well the total losses. The effect of the two dimensional fence on the secondary losses is not pronounced as that of the circular geometry fence. However, it is found that the fitting of the two dimensional fence increased the secondary losses in the turbine blade cascade.

INTRODUCTION

Principal aerodynamic losses occurring in most of the turbomachines aries due to the growth of the boundary layer and its separation on the blade and passage surfaces. Others occur due to wasteful circulatory flows and the formation of shock waves. Non-uniform velocity profiles at the exit of the blade cascade lead to another type of loss referred to as the mixing loss. Successful aerodynamic design of a

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turbine depends mainly on the accurate estimation of the losses.

One of the major losses in the turbine cascade is known as the secondary loss. This loss occurs in the region of flow near the end walls owing to the presence of circulatory or cross flows. Such secondary flows develop due to the combined effect of blade curvature and annulus wall boundary layers, Ref. [1-4]. The pressure differentials across the flow near the end walls give rise to circulatory flows which are superimposed on the main flow through the blade passage. As a result of this, secondary vortices in the streamwise direction are generated at the root and tip of the blade [5,6]. The presence of these vortices in the main flow leads to an increase of the energy loss, thus increasing the possibility of an early separation of the boundary layer on the suction side. Control or minimization of these losses is a very important fact in the design of turbomachines. The magnitude of the energy loss due to secondary flow depends on the fraction of the passage height that affect the upstream boundary layer thickness, Ref. [5].

A research on the flow through turbine blade rows was reviewed by Hirayama [7]. Methods for controlling the secondary flow losses in turbomachines were discussed by Sabry et al [8]. These methods are classified to end wall contouring [9], cooling air injection into secondary flow region [10], bumped blades [11]. Recently, secondary flow and loss reduction in a turbine cascade can be controlled using end wall fences, Ref. [12,13]. It was found that the presence of end wall fences decreased the secondary flow losses in the turbine cascade. The previous investigations were conducted for moving blades with high aspect ratios.

This paper aims to study the effect of fence fitted to the suction side of a short blade on the secondary losses. Therefore, an experimental study was carried out on a short blade cascade with an aspect ratio of unity. Different geometries of fences are tested. In addition, the experiments are conducted at different inlet conditions.

EXPERIMENTAL APPARATUS AND MEASURING DEVICES

The experimental apparatus is shown in Fig.1. Dry air was supplied from two electrical compressors to the tested blade cascade through a cylindrical settling chamber and two mesh screens 20 mm apart to improve the flow uniformity at the cascade inlet. The cascade consists of seven blades fabricated according to Russian standardization [14]. The cascade dimensions are given in table 1.

Table 1 Geometry of blade cascade

Cascade parameters	dimensions
blade chord, b	500 mm
blade aspect ratio, $\bar{l}$	1
pitch/chord ratio, $\bar{t}$	0.7
inlet flow angle, α_o	90^o
outlet flow angle, α_1	15^o

Fences with different sections were fitted to the suction blade surface at 5 and 10 mm from the end wall as shown in Fig.2. The geometry and dimensions of tested fences are given in table 2.

Table 2 Geometry and dimensions of tested fences

Cicular fence, d	Two dimensional fence
F1 = 0.1625 mm	F5 = 1.125 x 1.125 mm^2
F2 = 0.24 mm	F6 = 2.25 x 2.25 mm^2
F3 = 0.605 mm	F7 = 1.25 x 2.25 mm^2
F4 = 1.005 mm	

The flow parameters downstream of the cascade was measured using a *three hole pressure probe. Pressure taps* were drilled normal to the suction and pressure surfaces for measuring the static pressure distribution; with the help of multi-tube water manometer.

The experiments were conducted for different inlet Mach number ranged from 0.1 to 0.4. The profile loss coefficient (τ_{pr}) was determined by measuring the total pressure along the pitch of the blade cascade and then was calculated using the formula given by Deish [14] :

$$\tau_{pr} = \varepsilon^{(k-1)/k} \frac{1 - \left[1 - (\Delta p_i / \Delta p_o) \ (1 - \varepsilon) \right]^{(k-1)/k}}{\left(1 - \varepsilon^{(k-1)/k}\right) \left[1 - (\Delta p_i / \Delta p_o) \ (1 - \varepsilon) \right]^{(k-1)/k}}$$

where $\Delta p_i = p_{o1} - p_{o2}$

$\Delta p_o = p_{o1} - p_2$

and $\varepsilon = p_2 / p_{o1}$

The cascade loss coefficient is obtained by plotting the average loss coefficient against the blade height of tested blade cascade. The gross of secondary losses are determined by subtracting the measured midspan averaged loss coefficient from the passage averaged loss coefficient.

RESULTS AND DISCUSSION

It has to note that the results show a representative section of the experimental measurements. Energy losses over the blade length are shown in Fig.3 and Fig.4 for different Mach numbers. In Fig.3, the fences are attached to the suction side at $\bar{x} = 0.1$ whereas in Fig.4, fences are fitted at $\bar{x} = 0.2$. It is seen that, the profile loss coefficient at the hub section of the fenced and unfenced blades is much higher than that at the mid-span of the blade. However, it is indicated that the profile loss coefficient decreased for the case of fenced blades. For example, at $M = 0.3$ and $\bar{x} = 0.1$, the profile loss coefficient decreases by about 18%. This shows that the fences have a significant effect on the generation of secondary flow. But the magnitude of the profile loss is changed as the fence geometry and location are changed. The existence of the circular fence tends to reduce the profile losses compared with the two dimensional fence. The diameter of circular fence and the attached location are also so important as shown in Fig.3b. It is found that the fenced blade (F4) reduced the losses compared with the other fenced blades. From Figs.3 and 4 one can see that the small diameter fence (F1) has a slightly effect on the profile loss coefficient compared with the large diameter fence (F4). This effect increases as the fence diameter increased for the limit of tested diameters. Figs.3 and 4 indicate also the effect of two dimensional fence on the profile loss coefficient. Two dimensional fence with different cross sectional area are tested, namely : F5, F6 and F7, and indicate the same result. As a sample of these results is presented in Figs.3 and 4, namely : the fence that denoted as (F5). Generally, it can be observed from these figurers that, the profile loss coefficient increased when the two dimensional fence is fitted on the suction side of the blade. The main reason in which the two dimensional fences show an increase in the profile loss can be explained as follows. A side wall may be induces vortices in the main flow. Moreover the presence of the side wall increases the separation possibility.

Fig.5 shows the variation of total and secondary losses with the inlet Mach number for different fenced blades. It is seen that the total and secondary losses decreased with increasing the Mach number for all fenced blades. This behavior is the same as that of unfenced blades. The unfenced blades give higher values of total and secondary losses. While, the reduction in the values of the total and secondary losses are affected by the fence geometry and position at which the fence is attached; as discussed previously. The fenced blades (F4) give smaller total and secondary losses than the other geometries. As discussed above, the generation of secondary flows is affected by the fence diameter and consequently the total losses are also affected.

Figure 6 illustrates the effect of Mach number on the secondary losses for F1 and F4 at $\bar{x} = 0.1$ and $\bar{x} = 0.2$. From this figure, it is seen that F1 gives higher secondary losses compared with those of F4.

The distribution of static pressure along the suction and pressure sides is given in Fig.7 for unfenced and fenced blades, namely (F4). The mean behavior with different magnitude is the same for both cases. This figure indicates that the pressure distribution along the pressure side unchanged while the suction side pressure distribution is increased. This leads to a decrease in the total loss and confirmed the previous results.

CONCLUSION

Experiments were made to control the generation of secondary flow in turbine blade cascade. Fences attached to the suction surface of the blade were tested. Fences with circular and two dimensional cross sectional area were examined. The presence of these fences were found to have a significant influence on the secondary losses. This influence depends on the geometry of fence and the position at which the fence is fitted. Circular fences fitted to the suction blade side decrease the secondary losses. On the other hand, the two dimensional fences increase the secondary losses in the turbine blade cascade.

NOMENCLATURE

b	: blade chord	t	: blade pitch
l	: blade height	α_o	: inlet flow angle
$\bar{l}$	: aspect ratio (l/b)	α_1	: outlet flow angle
M	: Mach number	ps	: pressure side
CF	: circular fenced blade	ss	: suction side
N	: normal blade	d	: diameter

p_2 : atmospheric pressure

p_{o1}: total pressure before the blade cascade

p_{o2}: total pressure after the blade cascade

$\bar{x}$: location of the attached fence (x/b)

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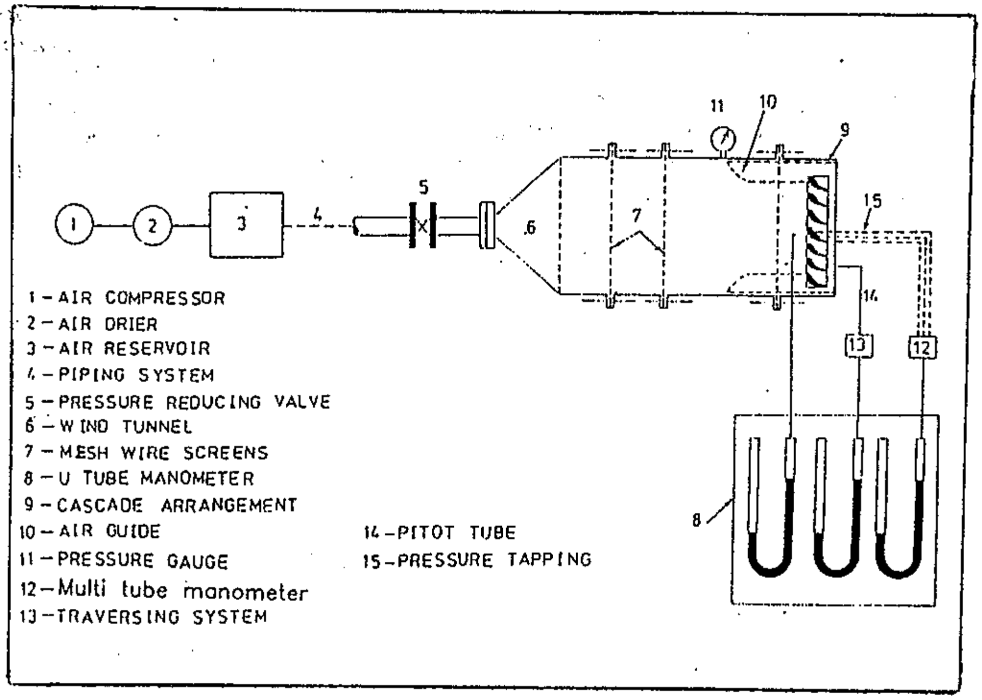


FIG(1) SHEMATIC LAYOUT OF THE EXPERIMENTAL APPARATUS

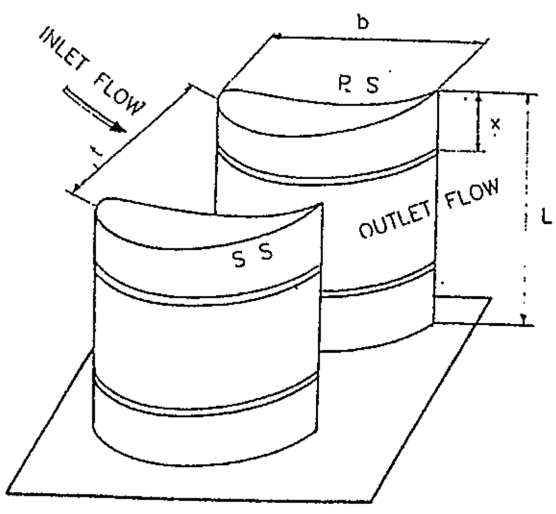
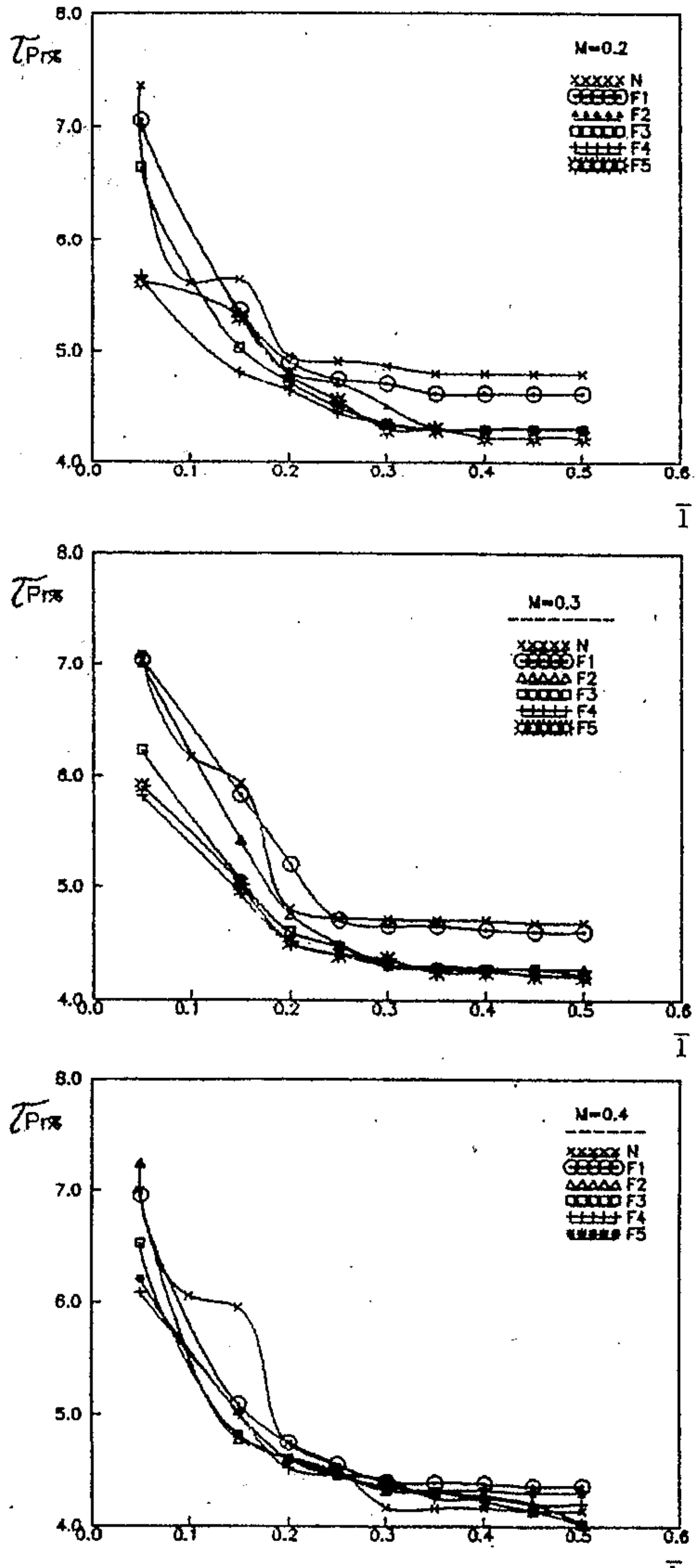
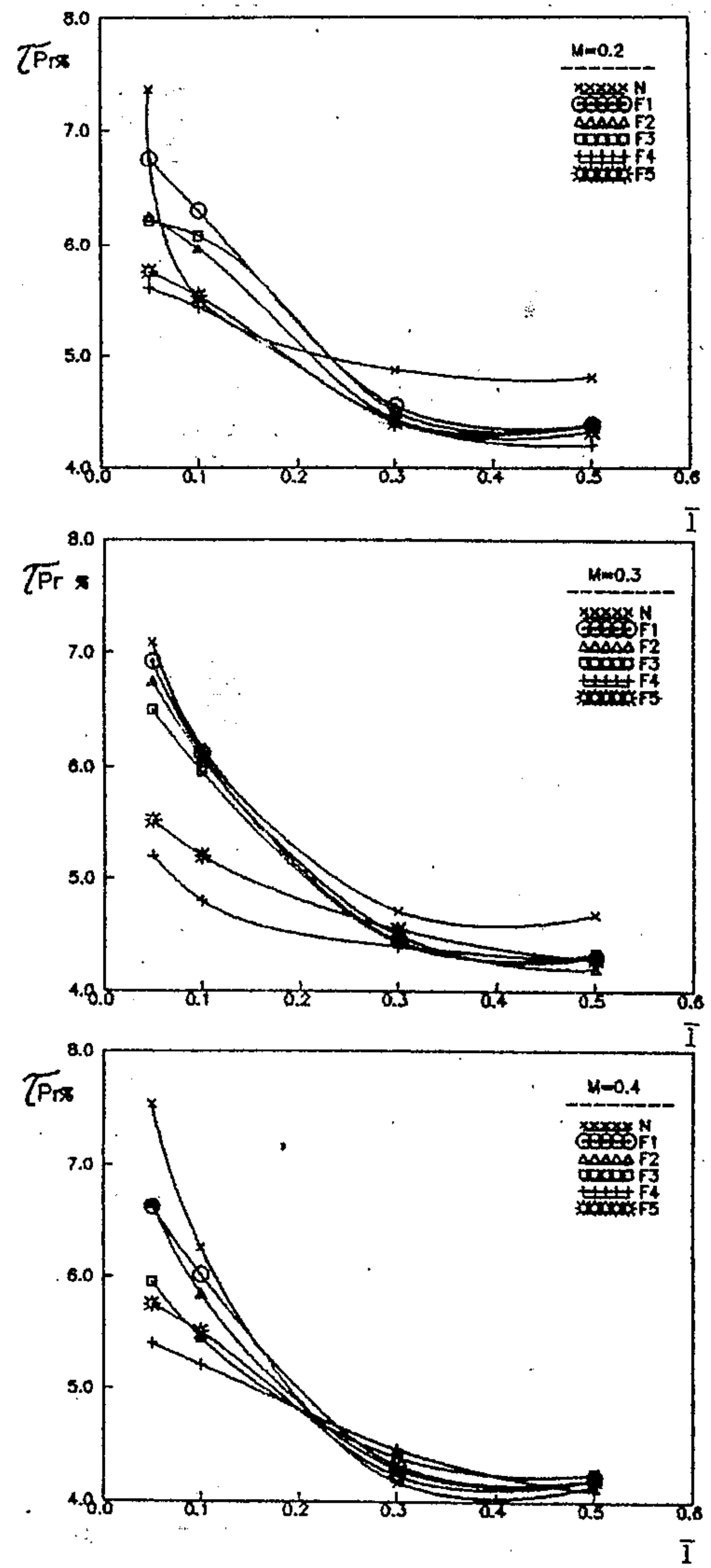


FIG (2) Installation of boundary layer fences



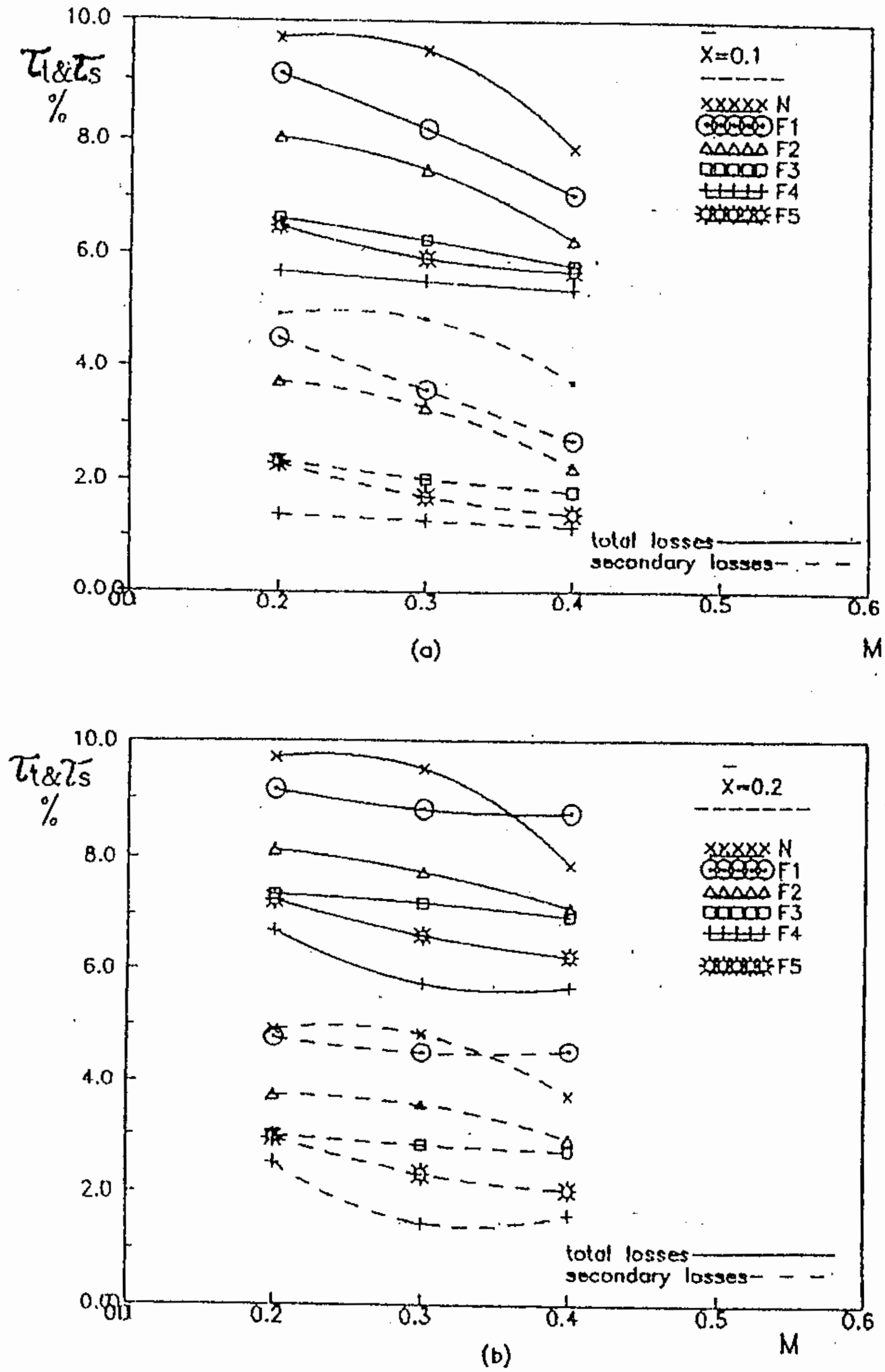
FIG(3) THE PROFILE LOSS COEFFICIENT ALONG THE BLADE HEIGHT

$(\bar{X}=0.1)$



FIG(4) THE PROFILE LOSS COEFFICIENT ALONG THE BLADE HEIGHT

($\bar{X}$=0.2)



FIG(5) Effect Of Mach number on the total and secondary losses

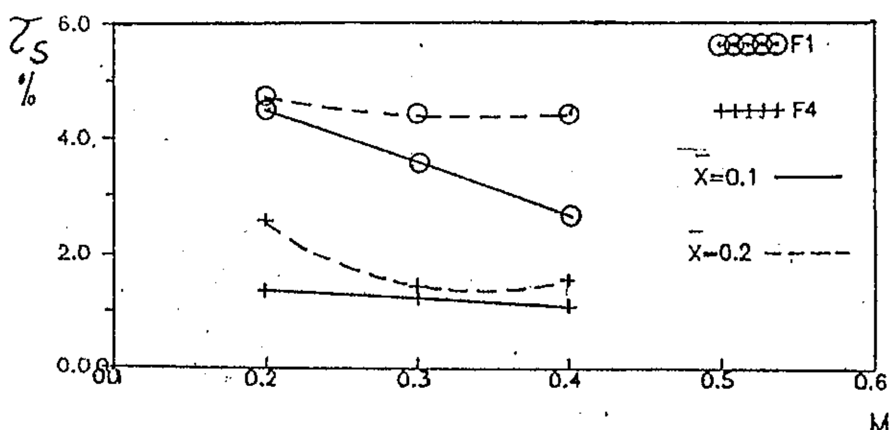
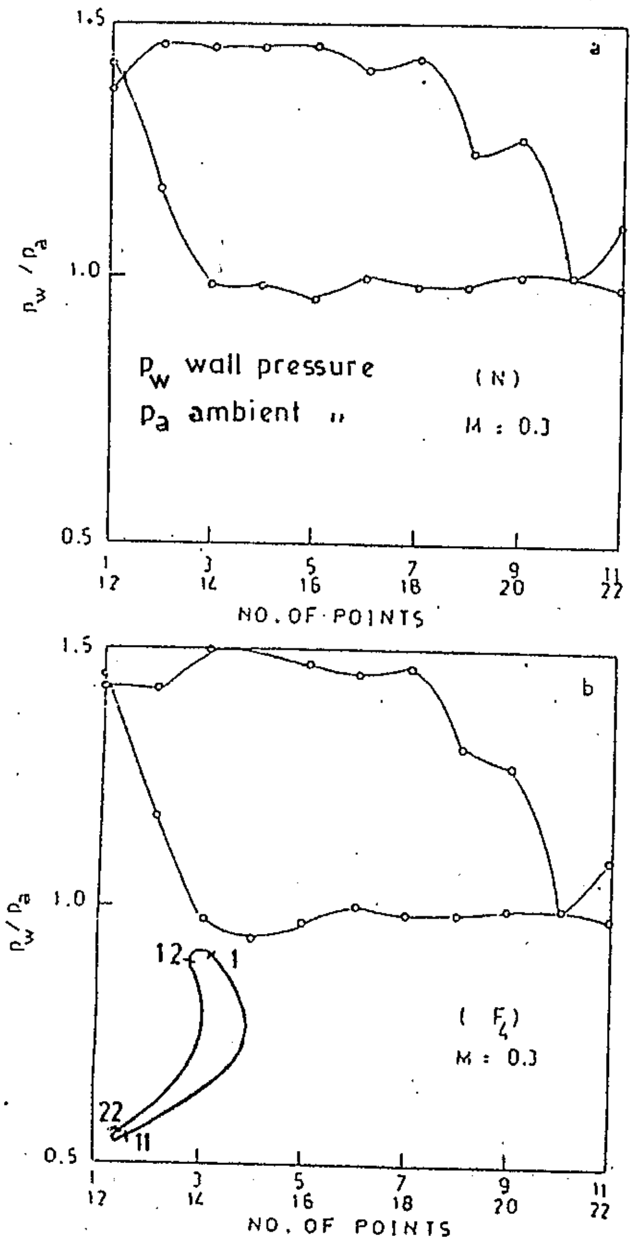


Fig. (6) Effect of Mach number on secondary losess



Fig(7) pressure distribution on the blade surface

عنوان البحث

" دراســة معمليـة على كاسـكيد ريش التربيـنات ذات العـوائق "

تناول البحث دراسـة معملية علـى كاسـكيد الريـش العـدل (**Straight Cascade**) وذلك بهدف التحكم فـى تولـد المفـاقيد الثانويـة وذلـك عنـد سـرعات أقـل مـن سـرعة الصوت (**Subsonic Flow**) .

ولإجراء هذه التجارب تم تصميم جهاز معملى وكاسكيد من النـوع العـدل مكـون مـن عدد ٧ ريش من النوع الثابت (**N 90 - 15**) . ولقد تم إستخدام عوائق **Fences**) (مثبتة على بروفيل الريش وذلك على جانب السحب . ولقد تم إسـتخدام نوعين من العوائق الأولى وهى ذات مساحة مقطع دائرى (**Circular Fence**) و قد تم إستخدام أربعة عوائق منهاً ذات أقطارمختلفة والثانية ذات مسـاحة مقطـع مستطيل **Two**) **Dimensional Fence** (وقد تم استخدام ثلاثة عوائق منها ذات مساحات مختلفـة. ولقـد أجريت التجارب المعملية والعوائق مثبتة على جانب السحب على بروفيل الريش مع إمكانية تغيير موضعها.

أجريت التجارب المعملية عند سرعات مختلفـة حيـث تـم حسـاب مفـاقيد البـروفيل) **Profile Loss Coefficient**) وذلك مـن خـلال معادلـة مسـتنتجة مـن معادلـة الطـاقـة للسريان الأيزونتروبى وتم ذلك عن طريق قياس الضغط الكلى قبل وبعد الريش وذلك على امتداد طول الخطوة وكذلك على امتداد طول الريش. وقد بينت النتائج أن معامل الفقد فى بروفيل الريش يبلغ أقصى قيمة له وذلك عند طرفى الريش بالقرب من جدار الكاسكيد (**End Wall**) ولقد أخذت النتائج على الريش العادية ثم على الريش المثبت عليها عوائق وقـد وجـد أيضـا مـن النتـائج أن إستخدام العوائـق ذات مسـاحة المقطـع الدائرى قد عملت فعلا على تقليل المفاقيد.

أيضا تم حساب معامل الفقد الكلى (**Total Losses**) وكذلك تم حساب المفاقيد الثانوية (**Secondary Losses**) وقـد وجـد مـن النتـائج أن العوائـق ذات مسـاحة المقطـع الدائرى قد عملت على تقليل المفاقيد الكلية وكذلك المفاقيد الثانوية وكان أفضـل عـائق مستخدم فى التجارب ذات قطر (1.005mm) . أما بالنسبة للنتائج المستنتجة للعوائـق ذات مسـاحة المقطـع المسـتطيل فقـد أعطـت مفـاقيد أعلـى مـن العوائـق ذات مسـاحة المقطع الدائرى وأيضا أعطت مفاقيد أعلى من مفاقيد بروفيل الريش العادى حيـث أن تلك العوائق عملت وكأنها حـائط آخرمثبـت علـى الريشـة وبالتـالى زاد سـمك الطبقـة المتاخمة مما نشأ عنه زيادة فى قيمة المفاقيد.