AN EXPERIMENTAL VERIFICATION OF THE EFFECT OF BOUNDARY LAYER SUCTION ON THE DIFFERENT ANGLE DIFFUSERS

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ABSTRACT

The work described in this research is concerned mainly with the experimental verification of the effect of boundary layer suction on the diffuser performance having three different divergence angles. The test facility has been designed so as to permit different values of suction velocities (0, 0.386, 4.88 and 6.365 m/sec). The static pressure and total pressure were measured by pitot – static tube and inclined manometer. The application of boundary layer suction was found to increase the pressure recovery and hence increase the diffusion efficiency. An improvement in pressure recovery was found to be more significant for diffuser having divergence angle (15^o).The maximum percentage improvement in pressure recovery obtained is (34.7 %). The study of B.L control through its suction leads to better understanding of the flow geometrical design and parameters.

KEY WORDS

Boundary Layer, Suction, Diffuser Performance, Pressure Recovery.

NOMENCLATURES

The following symbols are used though out in this paper, others she be defined as and when appear in the text

Symb.	Quantity	Symb.	Quantity
AR	Area ratio (exit area / inlet area).	x	distance along the diffuser axis , cm
B	Blockage factor	y	distance from diffuser wall perpendicular to flow direction
b	Width of diffuser inlet section	u	Velocity in the boundary layer m/s
C_p (x)	Local pressure – recovery coefficient.	U	Velocity in the free stream m/s .
C_p	Pressure – recovery coefficient .	V	Suction velocity , m/s .
C_{PA}	ideal pressure – recovery coefficient	W	passage width , m/s .
H	Shape factor.	**Greek symbols**	
C_{PA}	Ideal pressure – recovery coefficient.	η	Diffuser efficiency .
h	Manometer reading mm water gauge	δ^*	Displacement thickness.
m	orifice area ratio , mass flow rate kg/sec	θ	Momentum thickness .
N	axial length of the diffuser , cm .	2ϕ	Divergence angle of the diffusion.
P	Pressure, N/m^2	α	Kinetic energy correction factor.
Pd	dynamic head	**Subscripts**	
Q	Volume flow rate m^3 / s .	1	Inlet
W	Passage width, m/s .	2	Outlet
		S	Separation point

INTRODUCTION

Diffusers need careful design considerations so as to achieve the desired pressure recovery over the shortest possible length. This requirement has led to the development of a family of wide-angle diffusers. Flow through wide-angle diffuser is characterized by intensive flow disturbances, which result in considerable loss of energy due to separation[1].

Flow in diverging ducts or diffusers with static pressure rise in the flow direction are not only of great practical importance, but also provide specific study of displacement interactions and/or with shear interaction. The central problems of diffuser design are prediction and prevention of flow separation [2].

The phenomenon of diffusion is a *Fundamental* fluid dynamical problem and requires detailed consideration and attempt made to design it from the mechanical point of view.

The assessment of the performance of diffuser is generally directed towards the achievement of a given reduction of velocity or the increase in pressure, stable flow conditions at outlet and an acceptable internal energy loss[3].

In real flows, boundary layers are formed adjacent to the solid boundaries, which, with diffusion thicken rapidly because of the adverse pressure gradient and viscosity makes the correspondence between the decrease of velocity and increase of static pressure quite complex[4].

The diffuser is one of the basic components of a turbomachinary or a fluid transport system. Further, owing extension to geometric limitation of the internal flow system particularly true of aircraft application.

This research is related to the experimental study of the two – dimensional straight walled wide-angle diffusers and the possibilities of increasing its pressure recovery by application of boundary layer suction technique. It is intended to study the effect of suction flow rate relative to that of the main flow in the diffuser performance such as pressure recovery and velocity distribution. The study has been conducted on three different diffuser configurations with constant area ratio.

A good design for the optimum performance of diffuser which is one of the basic components of many applications such as those of turbomachinary and fluid transport system necessitates proper understanding of the geometric and flow parameters. The knowledge helps the diffuser analyst to prevent flow separation from the wall and thus achieving the maximum possible retrieval of static pressure[5].

Boundary Layer Control

Flow separation is accepted to be the breakaway or the breakdown of boundary layer flow from a solid surface. Whether caused by a severe adverse pressure gradient or a geometrical aberration, separation is accompanied by thickening of the rotational flow next to wall and significant values of the velocity component that is normal to the surface [6]. This flow-interaction causes energy losses (i.e. loss of lift, drag increase, pressure recovery losses), rendering the device uneconomical, or exert unsteady forces on bodies, causing them to vibrate (flow induced vibration). To improve the performance of man-made flow systems due to separation, engineers have been preoccupied by controlling its location (altering or voiding flow separation). Successful separation control in aerodynamics benefits technological applications such as VSTOL(Vertical Take Off and Landing), bird-like flight, diffuser, stall in turbomachinery.

The approaches for separation control can be broken down into four categories [7]:

1. tangential blowing (in all its various forms, include leading-edge slats, slotted flaps, and moving wall) to directly energize the low-momentum region at the wall. 2. wall suction to remove the low-momentum region.
3. vortex generators to enhance the convective transport of free stream momentum to the wall. It is and, a relatively a new approach.
4. forced excitation just upstream of separation (e.g., see Refs. 3-6).

The first two approaches are extremely effective in controlling separation, essentially eliminating the separation. However, this degree of control requires the complexity of internal piping from a source of pressure (or vacuum), and the parasitic cost to generate this pressure (or vacuum) source. Because of these disadvantages, suction and blowing are infrequently used (except on slotted wings achieved with variable geometry). The third approach, vortex generators, has been frequently applied due to simplicity of these generators. However their effectiveness is limited because of parasitic drag (controlling extreme separation requires large vortex generators which have high parasitic drag). In addition,

The fourth approach, so-called “dynamic forcing” takes advantage of the natural instability of the separated shear layer to perturbations. By periodically exciting a leading-edge airfoil separation with, for example, a small vibrating flap or an oscillating slot flow, the shear layer roll up of vorticity is modulated creating large scale, phase-locked coherent vortex structures over the downstream surface. At a preferred range of frequencies which depends on free stream velocity and airfoil chord that nominally introduces 2-3.

Coherent structures over the surface, a large increase in flow turning has been observed. It has been speculated that the mechanism is advancement of the shear layer reattachment via the convection of free stream [8]. A relatively new flow control device that has been demonstrated in computation and laboratory tests for virtual shape control is the so-called “synthetic jet”. For example, applications are given by Glezer et al for thrust vectoring, bluff body and lift control and Hassan10 for lift control. The synthetic jet consists of an orifice (or neck) driven by an acoustic source in a cavity They approached this problem using the initial porous diffuser section from the inlet illustrated in Figure (1).

During the process of optimizing the overall external contour, we masked off a portion of the porous material using a silicone sealant to simulate the effect of adding a solid plenum sheath. Figure (2) shows the results. With no masking a suction flow rate of 41% of the entrance flow was required to achieve completely laminar flow. A small amount of masking reduced the suction requirement to 36%. Further masking gradually increased the suction W.R. Seebaugh ATM-9713408 required to achieve laminar flow. They concluded that we could block off a length of the outside of the porous diffuser about equal to the inlet diameter before significantly increasing the suction flow required to achieve completely laminar flow in the inlet. This result, which is incorporated.

THEORETICAL BACKGROUND

The application of suction was first tired by L. Prandtl [1] and was later widely used in the design of aircraft wings. The ability to control the boundary layer resulted in to an increase in diffuser effectiveness and a decrease in total pressure loss.

Boundary layer suction also has been recommended by Horny and Wilbeur. They were followed by Ackret and Furuya et al[9]. The ability of controlling the boundary layer resulted into an increase in diffuser effectiveness and a decrease in total pressure loss.

Boundary layer separation is a major problem which constraints/limits the design of most devices involving flow. Hence, there is a strong desire for a flow separation control technique that is not only

Effective at reducing or eliminating separation, but does so with small parasitic drag, energy consumption, and simple installation. Not surprisingly, there has been a tremendous amount of research and development into the control of boundary layer separation

The governing equation of the flow field is the Bernoulli's equation which is for real flow is :-

$$\frac{P_1}{\gamma}+\rho_1\frac{ui^2}{2g}+Z_1=\frac{P_2}{\gamma}+\rho_2\frac{u_2^2}{2g}+Z_2+H+L \qquad \ldots\ldots\ldots\ldots\ldots(1)$$

Where

$Z_1 = Z_2$ = static heads.

H…… external work = 0.

L….. loss head due to friction etc.

From this equation and after some arrangement we can get the performance parameters.

The most widely used parameters is the pressure coefficient (Cp) which may be defined as :-

$$C_p=\frac{P_1-P_2}{\frac{1}{2}\rho U_1^2} \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

The diffuser efficiency is defined as the ratio of actual static pressure rise to that ideally obtained by neglecting any pressure loss when ever in the diffuser.

$$\eta = \frac{C_p}{C_{pi}}$$

Where Cpi – is the ideal pressure coefficient

$$\eta = \frac{P_1 - P_2}{\frac{1}{2}\rho u_i \alpha \left(1 - \left(\frac{1}{AR}\right)^2\right)} \qquad \text{.. ....(3)}$$

In Boundary layer calculation, the main parameters are displacement thickness, momentum thickness shape factor.

The displacement thickness may be given as follows:

$$\delta^* = \int_0^\infty \left(1 - \frac{u}{U}\right) dy \qquad \text{...................(4)}$$

While the momentum thickness that reveals the amount of defect in momentum: -

$$\theta = \int_0^\infty \frac{u}{U}\left(1 - \frac{u}{U}\right) dy \qquad \text{...................(5)}$$

A parameter which is defined as the ratio of the boundary layer displacement thickness to momentum thickness; is called shape factor

$$\mathbf{H} = \frac{\delta^*}{\theta} \qquad \text{……………….(6)}$$

The blockage factor is defined as the ratio of the boundary layer displacement thickness to the passage width, i. e.

$$\mathbf{B} = \frac{2\delta^*}{\mathbf{W}} \qquad \text{……………..(7)}$$

It was found that the onset of separation in the diffuser depends upon the local blockage factor.

APPARATUS AND INSTRUMENTATIONS

The apparatus consisted as shown in Figure (3&4), of the blower section assembly that consists of an electric motor with a 3-phases induction motor of 7.5 HP, the blower is of a centrifugal type.

A flexible joint made of nylon strap is used to connect the blower output pipe and transition section to prevent vibration transmission. To connect two different pipes cross section, a transition section was used.

To prevent some swirl and non- uniformity, wire mash screens were provided. A duct made of wood lined with Formica (plastic laminate) with wall thickness of 15 mm and 4 meters long and cross section of (305x152.5mm).

The tested diffusers followed the main duct. The pattern was made of 12-mm thick plywood for the top and bottom wall, while the side walls were made of a trapezoidal section of glass sheet of 3-mm thickness. Three diffusers were constructed with different divergence angles.

These diffusers were connected from outside on the top and the bottom walls with jackets for providing suction.

Suction holes were drilled on the top and the bottom walls of the diffusers. A blower of centrifugal type sucks the air; it is driven by a single-phase electric motor of 0.5 hp. A voltage regulator regulated the speed. The suction flow rate was measured by introducing an orifice plate made according to British Standard (BS 1042/1966).

The static tube, manometer, and pitot-static tubes were used for the pressure and velocity measurement respectively.

DISCUSSION OF EXPERIMENTAL RESULTS

The objective of this experimental aspect of the present investigation was to obtain detailed performance data for three two-dimensional straight walled wide-angle diffusers with and without suction of the boundary layer[10]. The Experimental data was used to estimate the diffuser two – performance parameters such as pressure – recovery, efficiency, blockage factor and shape factor.

Inefficiencies of diffusion is mainly due to the growth of boundary layer under adverse pressure gradient. A large number of parameters are likely to influence the performance. These parameters fall into geometry and fluid dynamic constraints.

The influence of the suction velocity on the thickness of the boundary layer is shown in Fig.(5). It shows that the boundary layer thickness decrease with increased suction velocity. This leads to a good diffuser performance.

Fig.(6) shows the influence of the suction velocity on the pressure recovery for diffuser 2. It shows that as the suction velocity increases, the pressure recovery factor increases too.

The variation of momentum thickness along the diffuser axis is shown in fig.(7). Higher values of suction velocities lead to lower momentum thickness and hence lower losses in energy.

Variation of blockage factor with the diffuser axis for different suction velocities is presented in Fig.(8). Higher values of suction velocity lead to lower blockage due to lower boundary layer thickness.

Fig.(9) shows the variation of the shape factor along the axis of the diffuser for different suction velocities.

Large diffusion leads to lower diffuser efficiency. Fig.(10) shown the variation of diffuser efficiency along the diffuser for different suction velocity. Higher efficiency corresponds to lower diverged diffusers.

Boundary layer profile is presented in Fig.(11) for different diverged angles.

CONCLUSIONS AND RECOMMENDATIONS

The performance of the diffuser was found not to depend on the geometrical parameter alone, as the divergence angle increases, the pressure recovery decreases. It is also increased with the application of suction; and becomes less significant with high suction so did the diffusion efficiency.

The performance parameter which were of prime interest were those concerned with the following:

The static pressure rise, which reflects the ability of diffuser to convert kinetic energy into pressure energy.

The total pressure loss that is directly related to the efficiency of the diffusion.

The exit flow distribution which critically affects the operation of a unit discharge are as important as the amount of velocity reduction or the quantum of station pressure rise . The development of the velocity profiles was such that the shape factor of the boundary layer increased along the flow direction, and the shape factor decreased with suction and that decreases was more significant of the large diverged diffusers.

The optimum flow rate could be increased about 4% of the main flow. It would be useful to design other diffuser configurations and to study the effect of turbulence .A theoretical investigation necessary to be carried out to correlate the experimental findings. For best understanding the macro – phenomena, a visual study of the flow might be performed.

The study of the second component of velocity perpendicular to the direction of the flow is recommended.

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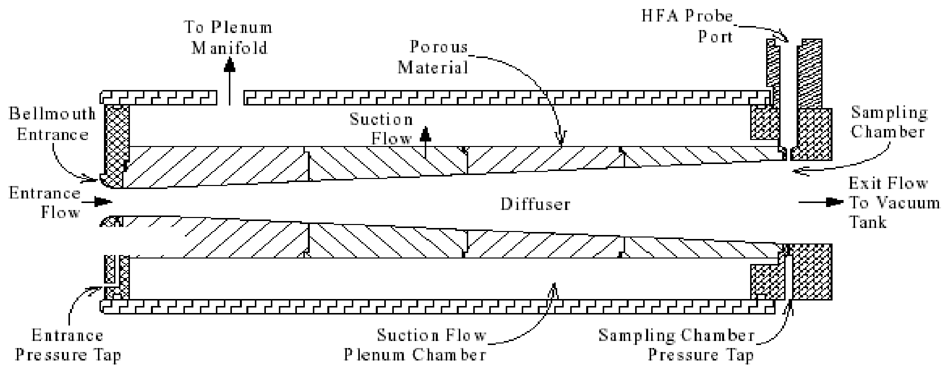


Figure (1) Schematic of the laboratory high-volume low-turbulence inlet

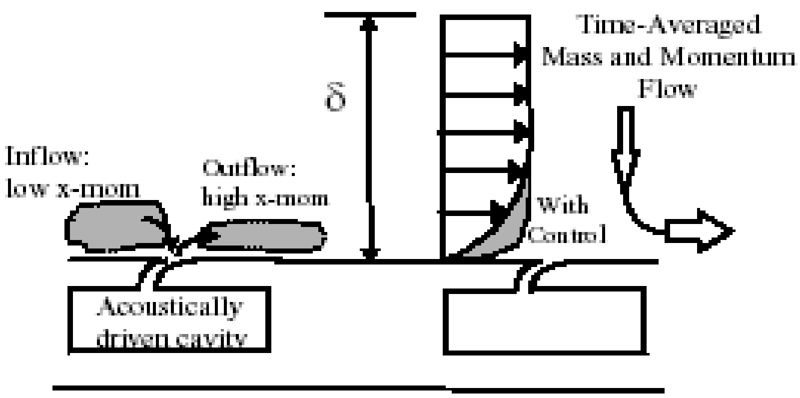
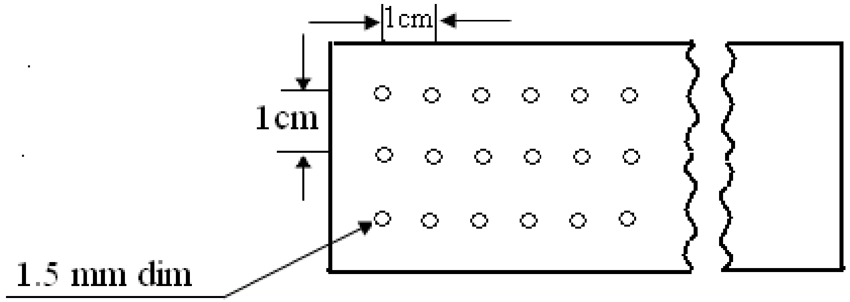
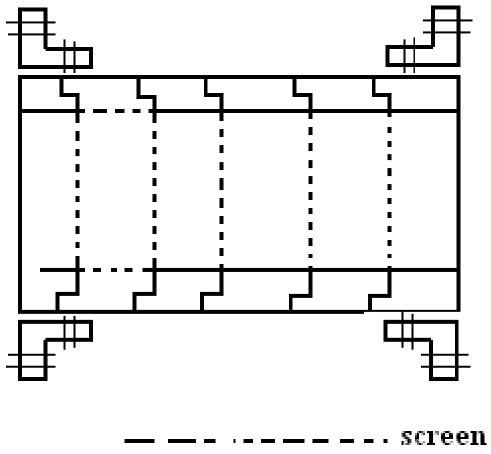


Figure (2) Directed Synthetic Jet Concept



Part of Diffuser wall showing suction holes



Screen Section

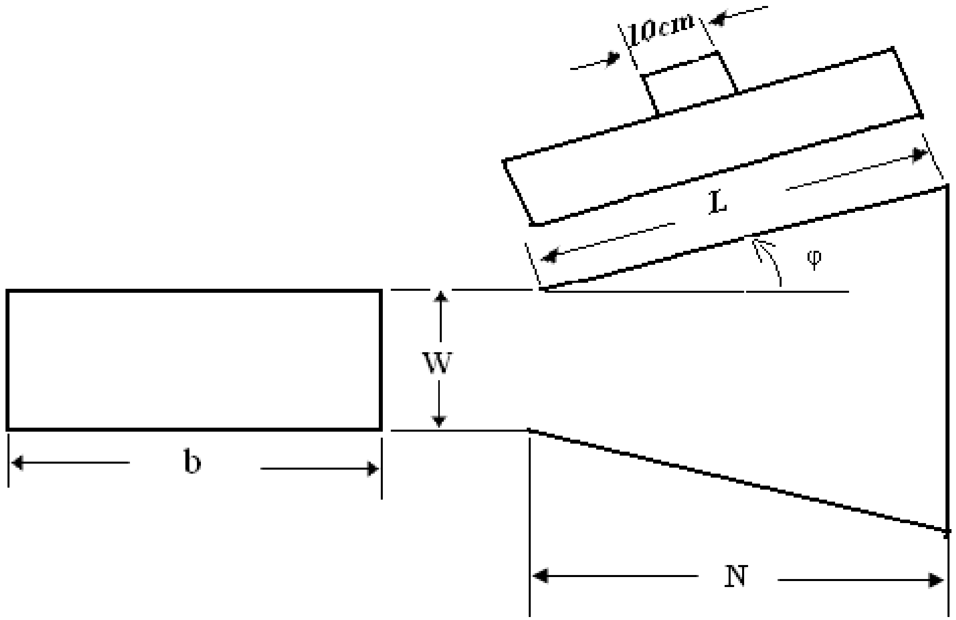


Figure (3) boundary layer suction arrangement

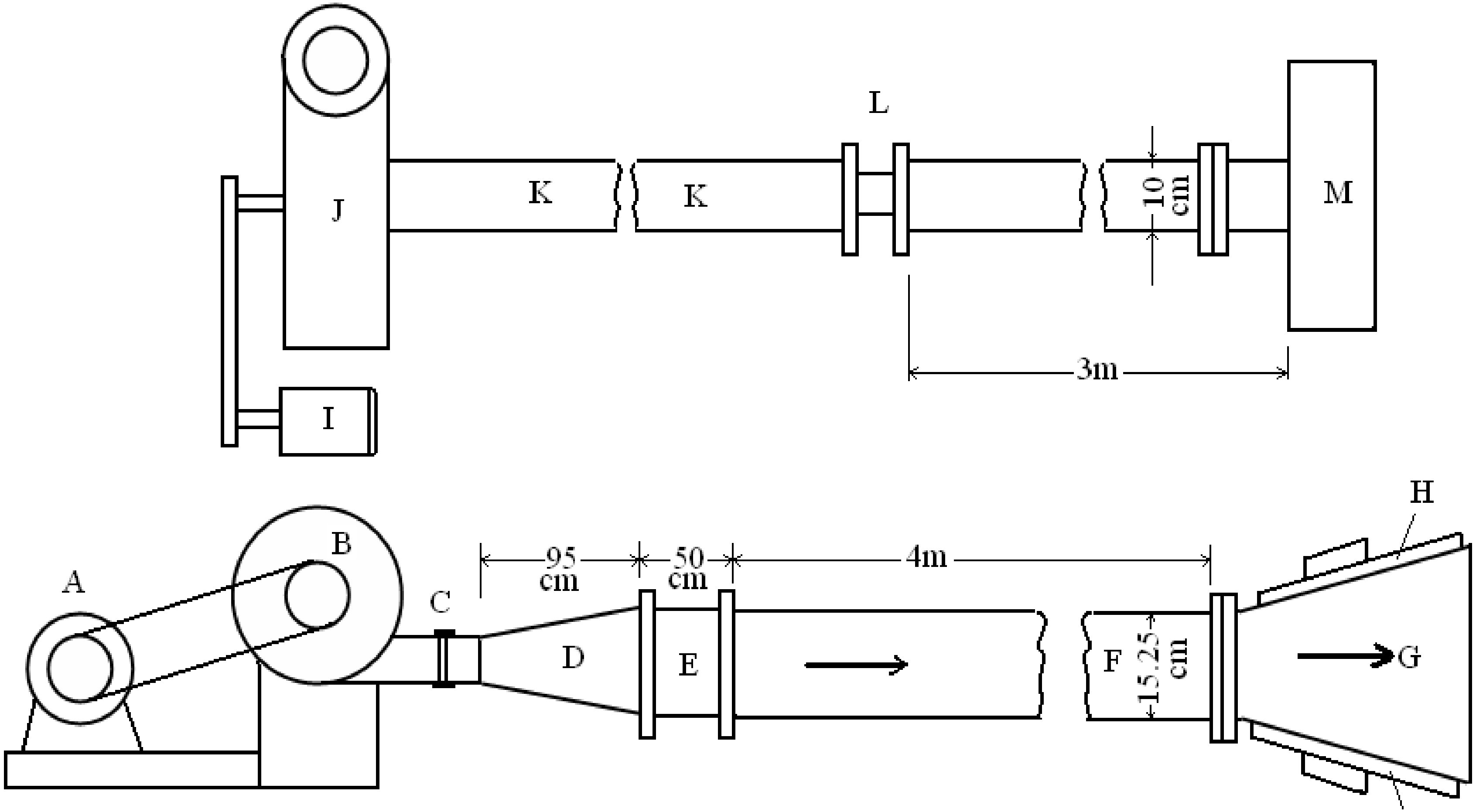


Figure (4) Wind tunnel specifications

I- Electric motor tapping
E- Screen section
I – Motor to derive the suction power
M – Orifice plate and pressure
II- Centrifugal Blower
F- Wooden Duct
J – Suction blower
N – T joint
Flexible joint
G – Test diffuser
K – Suction duct

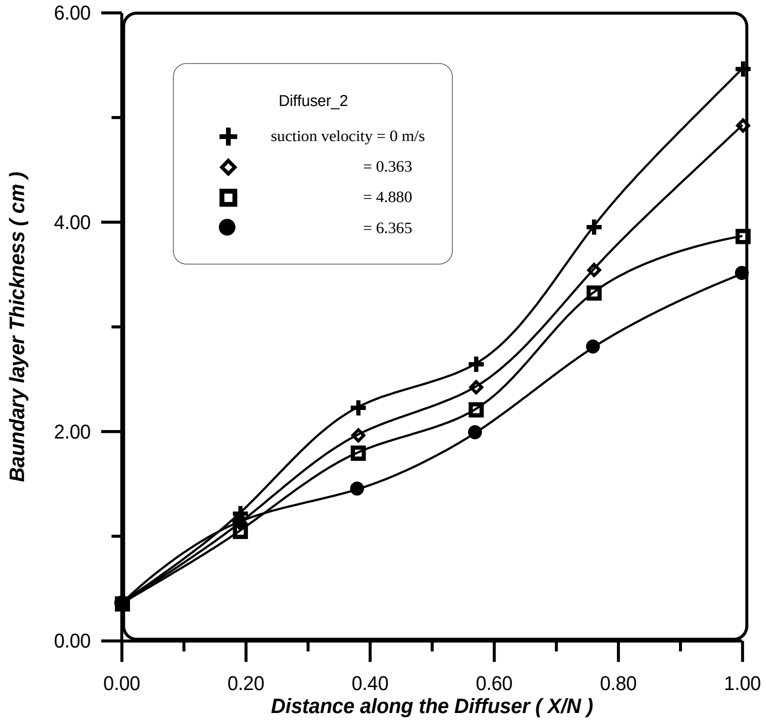


Figure (5) Variation of BL Thickness with Diffuser Length

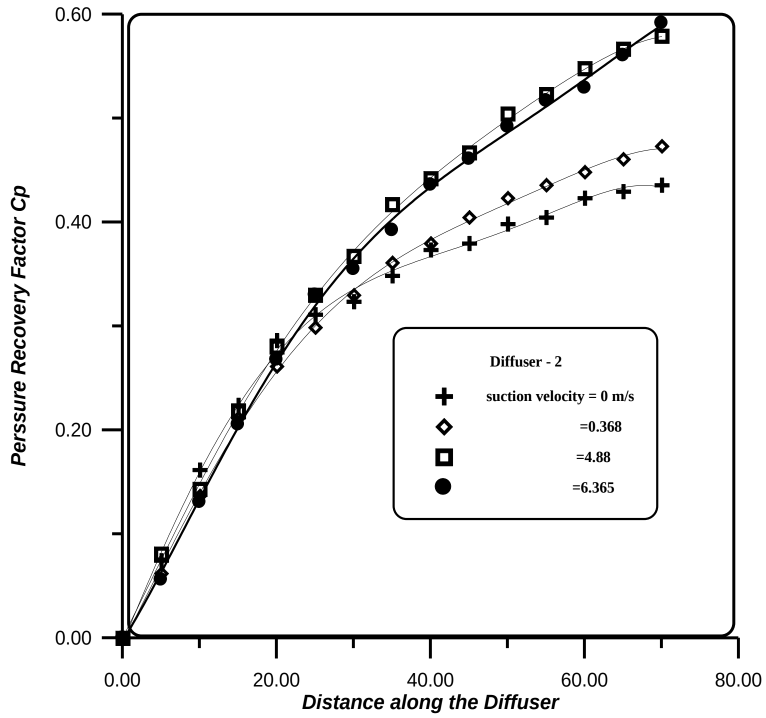


Figure (6) Variation of Pressure recovery with (X/N) for Different Suctions

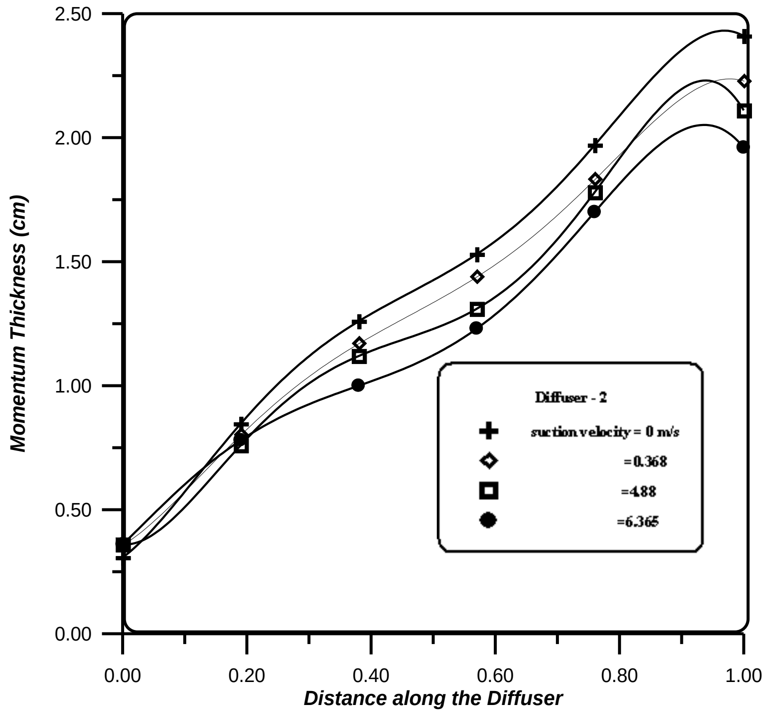


Figure (7) Variation of Momentum Thickness with (X/ N)

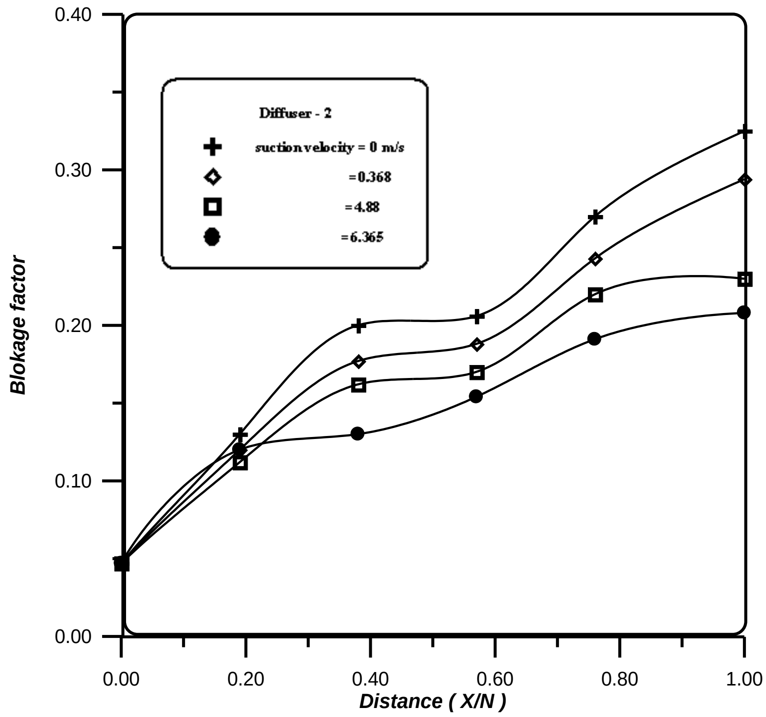


Figure (8) Blockage ratio with distance (X/N)

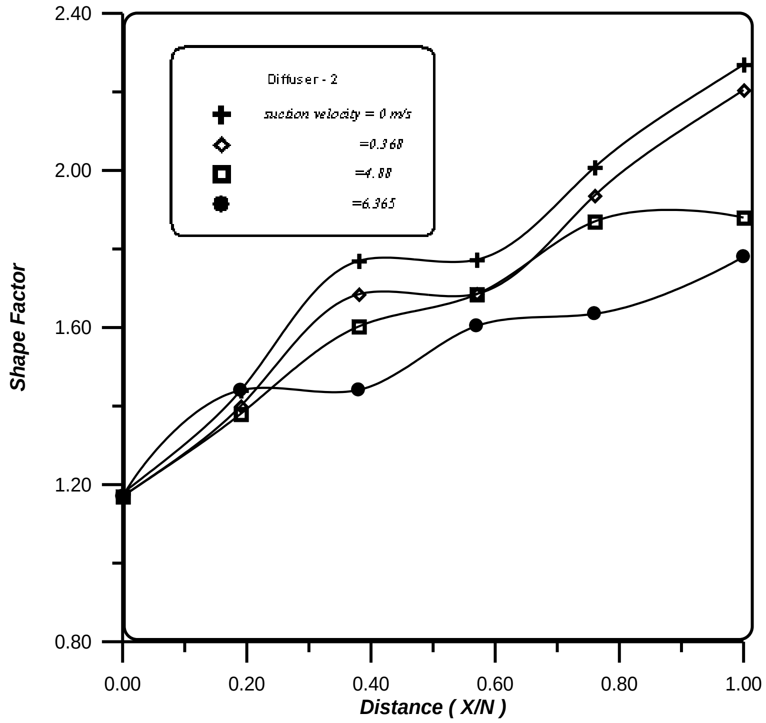


Figure (9) Variation of Shape factor with Distance (X/N)

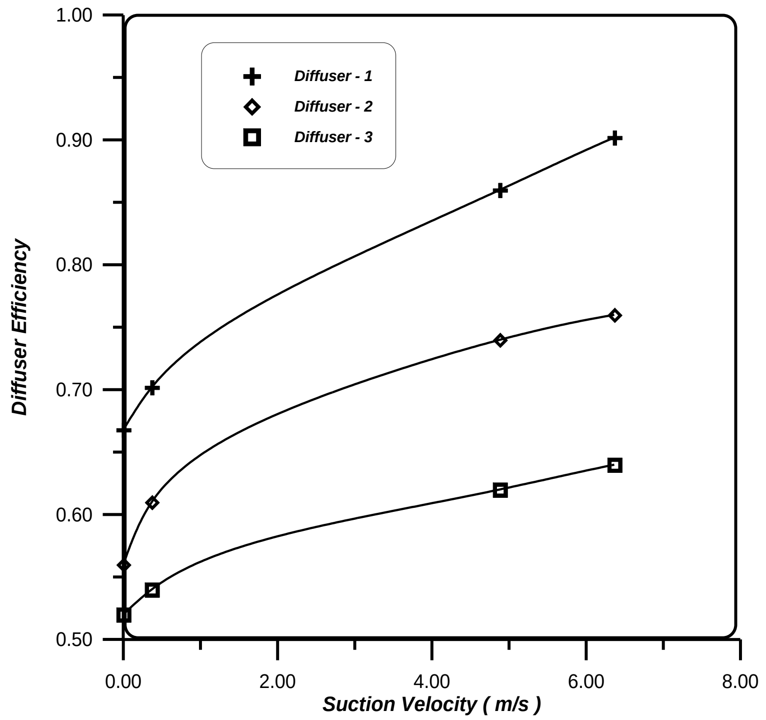


Figure (10) Effect of the Suction Velocity on the efficiency of the diffuser

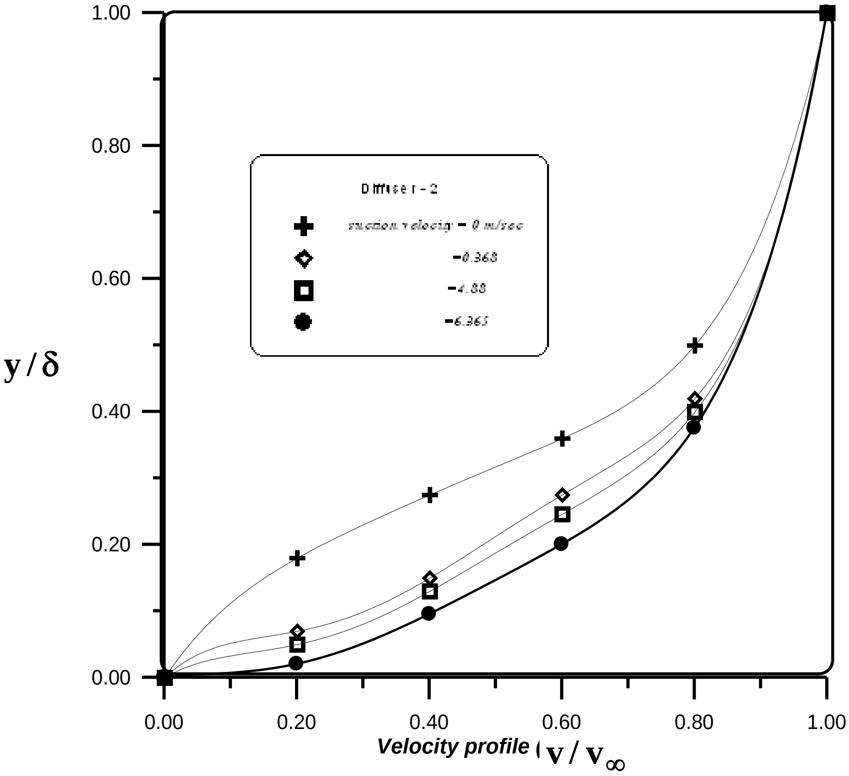


Figure (11) Velocity Profile Through the Baundary Layer

دراسة عملية لبيان تأثير سحب الطبقة المتاخمة على أداء الناشرات بزوايا انفراج مختلفة

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الخلاصة

يتضمن هذا البحث دراسة تجريبية لمعرفة تأثير مص الطبقة المتاخمة من الجدار على أداء الناشر . تم إجراء التجارب على ثلاث أنواع من الناشر اعتمادا على زاوية الانفراج. ناشر ذو زاوية انفراج (° 10 ،° 15 ،° 20). عملت ترتيبات إجراء التجربة بحيث تسمح لعدة سرع للمص وهي (0 ,0.386 ,4.88 ,6.365)m/sec . وقد تم قياس السرعة بواسطة أنبوب التصدي والضغط بواسطة مانوميتر كحول مائل.

أثبتت النتائج عمليا إن مبدأ مص الطبقة المتاخمة يؤدي إلى زيادة معامل زيادة الضغط وبالتالي زيادة الكفاءة للناشر بتخليصه من الطبقات المنفصلة. كذلك إن مص الطبقة المتاخمة كان أكثر تأثيرا في حالة الناشر ذي الانفراج (15^o) وان أكثر نسبة تحسين لاستعادة الضغط كانت(34.7%). أضف إلى ذلك إن إجراء هذه الدراسة يؤدي إلى الفهم الجيد للسيطرة على الطبقة المتاخمة من خلال إحدى تقنياتها.

الكلمات الدالة

الطبقة المتاخمة، السحب، أداء الناشر، استرداد الضغط.