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EFFECT OF THE EXTERNAL PARALLEL ACOUSTIC EXCITATION ON THE ADVERS PRESSURE GRADIENT (APG)

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ABSTRACT :

There was a needed for a technique to be able to enhance the flow properties by decreasing the velocity in (APG) Adverse Pressure Gradient and increasing the skin friction .The present work used a technique of the effect of external parallel acoustic excitation on the Adverse Pressure Gradient (APG) over a rough surface and smooth surface for a turbulent flow. This study was conducted at fully developed turbulent flow with a Reynolds number based on hydraulic diameter (8.3×10^4). The experimental ducts test carried out in wind tunnel manufactured from Perspex (250mmx250mm) and length of 690 mm . A Preston tube was used to measure the air flow velocity profile, pressure distribution and skin friction. The adverse pressure gradient was produced in unsymmetrical diffuser with three different diffuser angles (8, 11,and 15) degree. The external excitation was parallel to the flow , and the excitation frequency (150) Hz and SPL (95) dB were used in this study . The obtained results showed that the performance, and other flow characteristics of diffusers depend on the angle of diffuser and acoustic excitation, and indicated that the surface roughness enhanced the production of turbulence as well as the turbulence level when compared with the smooth-wall data. It is well known that both wall roughness and APG reduce the mean velocity close to the wall. The rough surface with the external parallel excitation effect are regarded as the key parameters to enhance the flow characteristics, this technique is able to decrease the velocity and increase the skin friction and to enhance the flow properties and thus improve the flow structure.

Kay words ; parallel external excitation , wind tunnel , at fully developed turbulent , flow velocity profile, pressure distribution ,skin friction .

تأثير الاثارة الخارجية الصوتية الموازية على انحدار الضغط العكسي

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الخلاصة :

ان الحاجة لتقنية قادرة على تعزيز خصائص الجريان في الناشر بتقليل السرعه وزيادة الاحتكاك القشري ، ادت الى استخدام تقنية الاثارة الصوتية الخارجية الموازية للتحقق من انحدار الضغط العكسي على سطح خشن واملس لجريان مضطرب كامل التطور ولعدد رينولدز (محسوب على اساس القطر الهيدروليكي لقناة الجريان) مقداره (8.3×10^4). المقطع العرضي لمنطقة الاختبار (250*250) ملم وبطول (690) ملم .اجريت الدراسه العمليه داخل قناة جريان للرياح مصنوعه من مادة البيرسبكس ابعادها(250*250) ملم وبطول (2400 ملم). كما تم تصنيع مجموعة زوايا لناشر غير متناظر(8°،11°،15°). حيث كان تردد الاثارة الخارجية الموازيه في هذه الدراسه مقداره (150)هرتز ومستوى الشدة (95) ديسيبل .اظهرت النتائج التي تم الحصول عليها ان الاداء وخصائص الناشر تعتمد على زاوية الناشر و الاثارة الصوتيه ،كما بينت النتائج ان خشونة السطح تساعد على تعزيز مستوى الاضطراب بالمقارنة مع بيانات السطح الاملس. ومن المعروف ان كلا من خشونة السطح وانحدار الضغط العكسي قلل من معدل السرعه قرب الجدار. كما بينت هذه الدراسه ان خشونة السطح مع الاثارة الصوتيه هي العوامل الرئيسية لتحسين خصائص الجريان داخل الناشر. حيث اثبتت هذه الدراسه ان استخدام هذه التقنيه يؤدي الى تقليل السرعه وزيادة الاحتكاك القشري وبالتالي تحسين خصائص التدفق .

الكلمات المفتاحية : اثارة خارجية صوتية موازية ، نفق هوائي ،جريان مضطرب كامل التطور ، سرعة الجريان، توزيع الضغط، احتكاك قشري.

NOMENCLATURE :

Latin Characters:

Character	Description	Units
SPL	Sound Pressure Level	dB
Re	Reynolds Number	---
U, V, W	Mean Velocity Components	m/sec
U_∞	Free-Stream Velocity	m/sec
U_c	Center velocity (max. velocity)	m/sec
$U\tau$	Friction Velocity	m/sec
u,v ,*w*	Cartesian Velocity Components	m/sec
x, y ,z	Cartesian Coordinate	---
Subscript		
Mod.	Model	---
Abbreviations		
APG	Adverse pressure gradient	---
VGs	vane-type vortex generators	---

INTRODUCTION :

Internal flow is typically flow inside channels or tubes. Closed channel flow is concerned with the flow of liquid or gases in closed conduits, such as in pipes, oil galleries, gas mains, water mains, oil pipelines, air-conditioning ducts etc. This type of flow often concerns mechanical engineering – since incorrect pipe sizes, or incorrect design, can lead to excessive pumping power or restricted flow rates. It is normally assumed that the fluid completely fills the tube or closed channel. The internal flow configuration represents a convenient geometry for heating and cooling fluids used in chemical processing, environmental control, and energy conversion technologies. An example includes flow in a pipe. Boundary layer separation can occur for internal flows. It can result from such causes such as a rapidly expanding duct of pipe. Separation occurs due to an adverse pressure gradient encountered as the flow expands, causing an extended region of separated flow. The point where the dividing streamline attaches to the wall again is called the reattachment point. As the flow goes farther downstream it eventually achieves an equilibrium state and has no reverse flow. A diffuser, as an element where the stream cross-section changes from inlet to outlet, either plane or axisymetrical, has a great importance in many practical engineering applications. The flow structure in the diffuser transforms into the velocity profile with stream separation (stall), which is defined where the value of shear stress on the wall is equal to zero, then after this, the cross section stream starts to separate from the channel wall **(see Fig. 1)**. The problem of stall is very old but very important. In the diffuser, several regime flows can exist, which depend on the geometry and Reynolds number, for the turbulent flow in the plane diffuser .[Mile and Cvetko 2003. The flow field exhibited different characteristic , and the momentum exchange is enhanced due to the introduction of the acoustic waves. One of the techniques is called the external acoustic excitation in which the sound is radiated onto the wall from a source outside the flow system. The technique of acoustic excitation was applied by Hsiao and Shyu [1991] who studied the influence of acoustic excitation upon flow passing over a circular cylinder in an open-type suction wind tunnel via hot-wire velocity measurements, static pressure measurements and smoke-wire visualization . The excitation produces the most effective influence on the flow when the excitation frequency equals the instability frequency of the separated shear layer, and when the forcing location is around the separation point. Marx et al. [2008] investigated experimentally the acoustic behavior of a liner in a rectangular channel with grazing flow. When increasing the velocity of the grazing flow, the transmission coefficient increases at resonance frequency. This amplification of the sound wave accompanied by an increased in the stationary pressure drop induced by the liner. This effect was attributed to a modification of the flow induced by the acoustic wave. Thus, the flow is measured using PIV imaging technique and a comparison of velocity maps with and without sound excitation was performed. It was shown that the convection of large flow structures accompanies the sound amplification phenomenon. Some evidence of a hydrodynamic instability was thus given.. Bodén and Zhou[2012] studied experimentally the acoustic properties of an orifice with bias flow under high sound level excitation. The test included no bias flow and two bias speeds for three different frequencies. It was seen that without bias flow there is a reasonably good agreement between the model results and measurements for the resistance , Zhou and Bodén [2013] investigated experimentally the acoustic properties of an orifice with bias flow under medium and high sound level excitation. Orifices with two different edge configurations were tested. The study included a wide range

of bias flow velocities, various acoustic excitation levels and different frequencies. The nonlinear acoustic scattering matrix was identified by a finely controlled two-source method. Stefan Weyna [2014] Investigation of acoustic waves in ducts is of practical interest for use in the control of noise in duct systems. The noise produced by laminar and turbulent flows in annular ducts is studied using experimental sound intensity measurement (SI), to test the acoustic energy transmission of duct modes.
The main purpose of this paper is to examine the effectiveness of the external parallel acoustic excitation technique on the performance of a diffuser at angles (8, 11,and 15) degree, with smooth and rough surfaces.

EXPERMENTAL METHOD.

The aim of the experimental investigation carried out in the present work is to determine the effect of external parallel acoustic excitation on the flow separation in the diffuser. To meet the experimental objectives, models of diffusers, source of excitation, wind tunnels and instrumentations are needed. The experimental apparatus will be described in the following sections.

Experimental Apparatus:

- Air Supply Equipment.
- Wind tunnel (Test rig)fig.(4).

Instrumentations of local flow:

- Pitot – tube .
- Preston tube .

Sound Excitation Cycle (Fig.2):

- Function Generator .
- Osllescope .
- Power Amplifier .
- Sound level meter .
- Speaker in an Air Box .

The experimental work was performed on three different geometrical diffusers models made of Perspex material. These Models were used in a subsonic wind tunnel for pressure measurements . To study the pressure distribution for three diffuser , three models (Mod.1= 8^o , Mod.2=11^o , Mod. 15^o) , see **Fig. 3**, were manufactured from Perspex material .each diffuser consist of two parallel side wall and from the top, it is divided for four sections : the first plane (170 mm long) , second (130 mm long), third (220 mm long),and the last plane represents the outlet section (300 mm long).. The experimental work employed in this study is to investigate the effect of external acoustic excitation on the APG . In all experiments, the inlet velocity at the test suction was (5 m/s) with Reynolds number ($8.3x10^4$) based on hydraulic diameter. The angle of diffuser was (8◦ ,11◦ ,15◦), the excitation frequency for each angle was constant (150 Hz) , and constant sound pressure level (95 dB). The experimental procedure can be summarized into two parts, the First is the work without external acoustic excitation while the second part is the work with external parallel acoustic excitation . The experimental work was performed on models (1 , 2 and 3) for the wind tunnel tests. The experiments were conducted to measure the velocity profiles., skin fiction coefficient (c_f) and pressure coefficient . At five planes along (x- axes of the channel length) (x=1.45, 1.62, 1.7, 1.84, 2.06) m .

RESULTS AND DISCUSSION :

Experimental Results.

The comparison of the surface velocity profile without excitation and with external excitation at frequencies (150) Hz for the external parallel acoustic excitation location for a turbulent, incompressible, steady and two-dimensional flow inside three different angles diffuser model is presented by as follows :

A-Distributions of the mean velocity profile with/without external acoustic excitation in outer coordinates .

The comparing view of mean-velocity profiles in the four plane of diffuser angle 8° under three effects . The values of U are normalized by the local maximum velocity, U/Uc, while the wall-normal distance (Y/Yc). **Fig.4** , shows the first plane (inlet plane) , which is compared in two cases , in **Fig. 4a,** the flow inside diffuser without effect of external excitation , comparing the velocity profile on the smooth surface (case 1) with respect to rough surface (case 2) , shows that the surface roughness and APG make the mean velocity profile 'less uniform' than that over a smooth surface(about 21.3%) . These results are the first indication in terms of the mean velocity. The roughness will increased the surface obstruction , thus leads to decrease the velocity in the surface. **Fig.4b**, indicate the effect of external parallel excitation on the surface in two cases (smooth and rough); the figures illustrated that the velocity in case (2) "is less uniformly" than (about 7.3%) that over (case 2) (a smooth surface). These results are the indication that the velocity in the case of external parallel excitation be less than the case without external excitation, because the waves emitted from speaker act as a curb lead to oscillation velocity and thus reduce it. **Figs.(5,6 and 7)** , manifest respectively, the second plane (x=1620 mm), third plane (x=1700 mm) , and forth plane (x=1840 mm) , which is compared with the three cases . The value of U/Uc decreases monotonically with streamwise distance over the entire range of measurement (1450 < x < 2060), irrespective of the surface condition. To quantify the local flow deceleration within each measurement plane, the velocity gradient, dU/dx was computed as follows: the streamwise mean velocity profiles across the channel, U(y), were extracted at several x-locations at intervals , and the local maximum value, Uc, for each profile was determined. In **Figs. (5a), (6a), and (7a)** , the flow inside diffuser without effect of external excitation ;comparing the velocity profile on the smooth surface (case 1) with respect to rough surface (case 2) depicts that the surface roughness makes the mean velocity profile 'less uniform' than that over a smooth surface . These results are the first indication that in terms of the mean velocity. The roughness will increased surface obstruction ,thus leads to decrease the velocity in the surface. Figures (5b), (6b), and (7b) indicate the effect of external parallel excitation on the surface in two cases (smooth and rough); the figures showed that the velocity in case (2) is “less uniformly” than that over (case 1) (a smooth surface). These results are the indication that the velocity in the case of external parallel excitation be less than the case without external excitation , because the waves emitted from speaker act as a curb lead to oscillation velocity and thus reduce it. Figures (8),(9),(10), and (11);show the velocity profile in diffuser angle(11◦) . These figures reveal respectively the first plane (x=1450 mm), second plane (x= 1620mm), third plane (x=1700 mm), and forth plane(x=1840 mm), which is compared with the three cases . The value of U/Uc decreases monotonically with stream wise distance over the entire range of measurement (1450 < x <2060) mm, irrespective of the surface condition. In **Figs. (8a),(9a),(10a), and (11a**); the flow in the APG region without the effect of external excitation , comparing the velocity profile on the smooth surface (case 1) with respect to rough surface (case 2) reveals that the surface roughness makes the mean velocity profile ‘less uniform’(about 23.3%,19.5%,11.35%,10.9%, respectively) than that over a smooth surface . These results are indication in terms of the mean velocity. The roughness will increase the surface obstruction , thus leads to decrease the velocity on the surface. **Figs. (8b), (9b), (10b) and (11b)** indicate the effect of parallel excitation on the surface in two cases (smooth and rough); the figures showed that the velocity in case (2) is “less uniformly”(about 22%, 9.4%, 8.4%, 5.9% respectively) than that over (case 1) (a smooth surface). These results are the indication that the velocity in the case of parallel excitation be less than the case without external excitation, because the waves emitted from speaker act as a curb lead to oscillation velocity and thus reduce it. Figures (12), (13), (14), and (15) depict the velocity profile in diffuser angle (15◦). These figures show respectively the first plane (x=1450 mm), second plane (x=1620 mm), third plane (x=1700 mm) and forth plane(x=1840 mm), which is compared with the three cases . The value of U/Uc decreases monotonically with streamwise distance over the entire range of measurement (1450 < x < 2060), irrespective of the surface condition. In **Figs. (12a),(13a),(14a), and (15a)** , the flow inside diffuser without effect of external excitation , comparing the velocity profile on the smooth surface (case 1) with respect to rough surface (case 2) reveals that the surface roughness makes the mean velocity profile ‘less uniform’(about 47%, 24.72% , 22.5%, 14.9% ,respectively) than that over a smooth surface . These results are indication in terms of the mean velocity. The roughness will increase the surface obstruction ,thus leads to decrease the velocity in the surface. **Figs. (12b), (13b), (14b) and (15b)** exhibit the effect of external parallel excitation on the surface in two cases (smooth and rough); the figures showed that the velocity in case (2) is “less uniformly” than that over (case 1) (a smooth surface) about (43.61%, 24% , 23% , 8.14% ,respectively) . These results are the indication that the velocity in the case of parallel excitation be less than the case without external excitation, because the waves emitted from speaker act as a curb lead to oscillation velocity and thus reduce it.

B- Pressure distribution.

The pressure distributions along the solid boundaries of the diffuser were measured to study the aerodynamic characteristics and the effects on the flow when it is excited externally by acoustic waves. The comparison of the surface pressure coefficients distributions without external excitation and with external parallel excitation at frequency (150) Hz and SPL(95 dB) is presented in **Figs. ((16), (17)) and (18)**). From **Figs.((16a), (17a) and (18a)**);and table (1), one note can the pressure distribution used throughout this investigation (smooth and rough) without the effect of external excitation . These figures depict that the pressure coefficient decrease with the velocity increase . The pressure distribution at diffuser angle (α=8◦) less than those for diffusers angles (α=11, α=15) degree. The **Figs.(16 b), (17 b) and (18b)** show is the effect of external parallel excitation . **Table 1** , reveals the comparison for these cases (at x=2.06 m).

C- Calculation of Skin Friction .

One of the main goals in boundary layer research is to determine the wall shear stress, the friction velocity u_τ, and corresponding skin friction coefficient, $\boldsymbol{C_f}$. The comparisons of the $\boldsymbol{C_f}$ values distributions without acoustic excitation and with external parallel acoustic excitation at frequency (150) Hz and constant SPL (95dB) is illustrated in **Figs. (19), (20) and (21**) . The comparisons of the c_f values for the smooth APG data and the rough APG data are clarified in these figures. From **Fig.(19a)** , the impact that roughness has on skin friction is clear. There is an increase in C_f due to roughness .The roughness increased about 25.6% . However, this increase is not consistent as the flow develops downstream, and as the boundary layer grows due to roughness and pressure gradient.

From **Figs.(20a), and (21a)** one can notice that the value of C_f decreases due to high angle of diffuser, the values of C_f are consistently larger over the rough surfaces than the smooth surface , the increasing in c_f about 16%, 57% ,respectively. The results showed an increase of C_f due to roughness . A considerable decrease in C_f due to the APG is seen, as would be expected, (**Figs. (19a), (20a), and (21a)**). From **Figs. (19b), (20b) and (21b))** present the comparison of the surface skin coefficients with the effect of external parallel excitation. It was note from these figures that the larger value of skin friction will result when using the external parallel acoustic excitation with a rough surface (about 59.2% ,62.8% ,73.9% at x= 2.06 m.

EXPERMENTAL CACULATIONS:

The velocity profile, skin friction coefficient ($\boldsymbol{c_f}$) and the pressure coefficient (c_p) are calculated by using the following formulas:

- **Velocity profile** = $\frac{\boldsymbol{U}}{\boldsymbol{Uc}}$ (1).

Velocity profile for inner scale:

For smooth :

$$\mathbf{U^+}= \frac{\boldsymbol{1}}{\boldsymbol{K}} \boldsymbol{lny^+ + B} \quad (2)$$

For rough:

$$\mathbf{U^+}= \frac{\boldsymbol{1}}{\boldsymbol{K}} \boldsymbol{lny^+ + B - \Delta U^+} \quad (3)$$

Where:

$\boldsymbol{U^+}$ = the inner normalized mean streamwise velocity . K = Von Karman Constant ≈0.41.

B = the smooth wall log law intercept ≈ 5 ., ΔU^+= the roughness function .

- **Skin friction coefficient** $\boldsymbol{(C_f) = \tau_w/(0.5\rho U^2 c)}$ (4)
- **Pressure coefficient** $\boldsymbol{(C_p) = (P_{local} - P_{in})/(0.5\rho U^2 c)}$ (5)

CONCLUSIONS.

1. The results showed that the velocity profile in the case of external parallel excitation be less than the case with no excitation .
2. The results exhibited an increase in skin friction c_f due to roughness and the external acoustic excitation, and it was observed from the result we note that the larger value of skin friction will observed(about 59.2% , 62.8% ,73.9%) .
3. The external parallel acoustic excitation leads to enhance the characteristics of diffusers for 150 Hz excitation frequency and SPL 95dB.

Table (1) Comparison of pressure coefficient for without excitation effect and with external parallel excitation effect .

Test		C_p values	
		Without excitation effect	With parallel excitation effect
8◦	Smooth	-1.63483	-0.8160
	Rough	-1.27943	-0.78259
11◦	Smooth	-0.14215904	-0.10662
	Rough	-0.120835184	-0.07463
15◦	Smooth	-0.146868	-0.09418036
	Rough	-0.13125278	-0.08174145

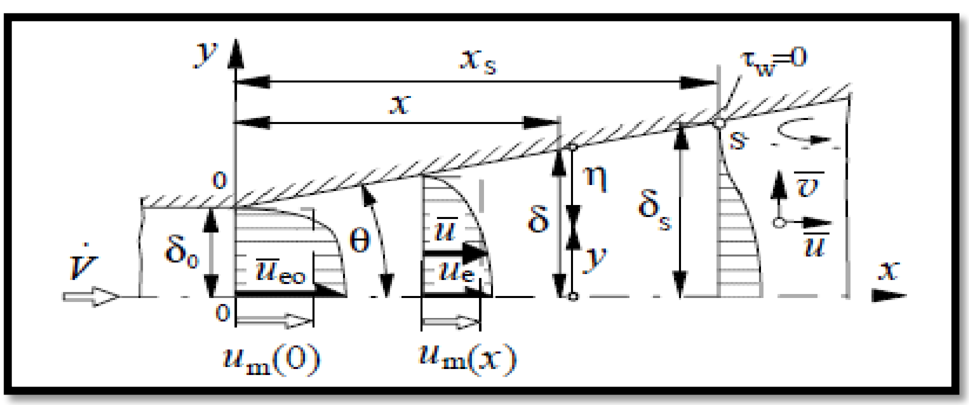

Fig. (1) Flow through a diffuser .[Mile and Cvetko 2003] .

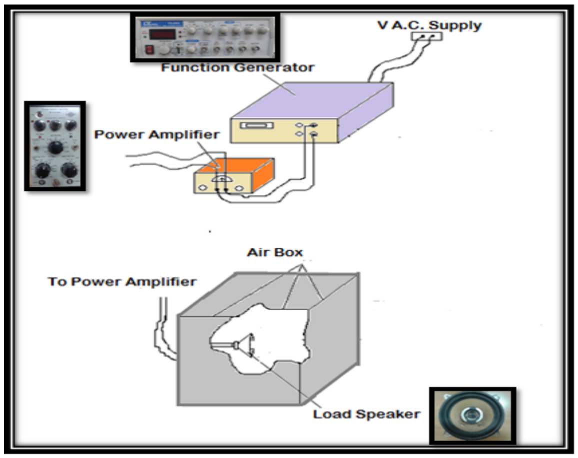

Fig.(2) Excitation cycle.

Fig. (3) Diffusers models employed in the present study.

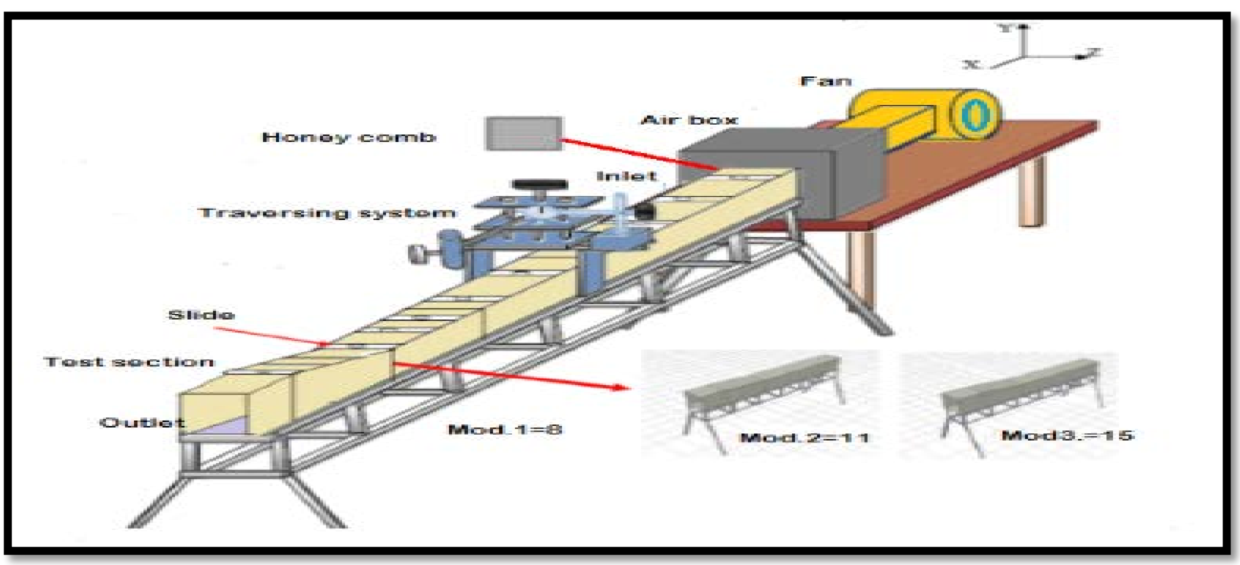

Fig.(4) The schematic of the air supply, honey comb, slides, traversing system, three diffuser angles and test rig.

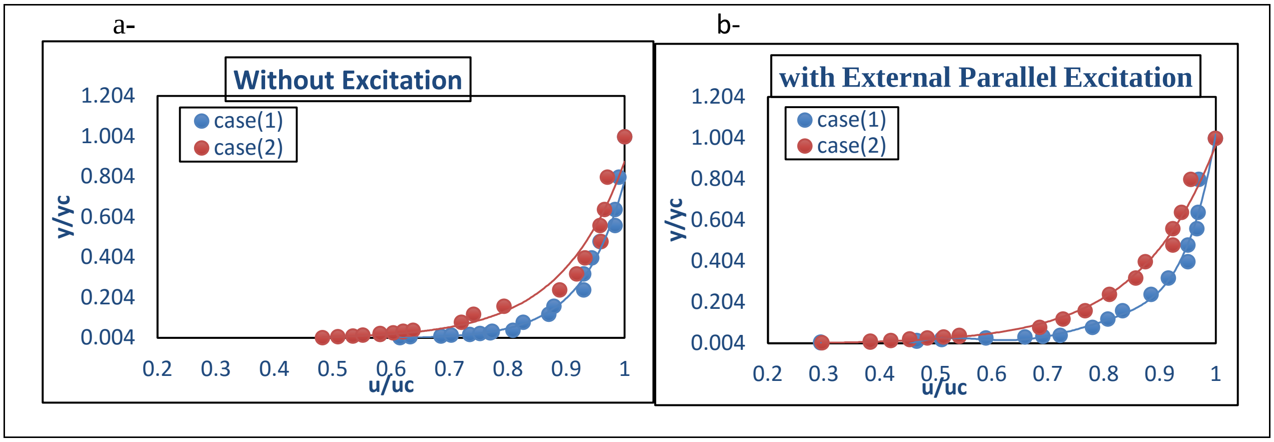

Fig. (5) Comparison of first plane (inlet plan) in diffuser(α=8◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

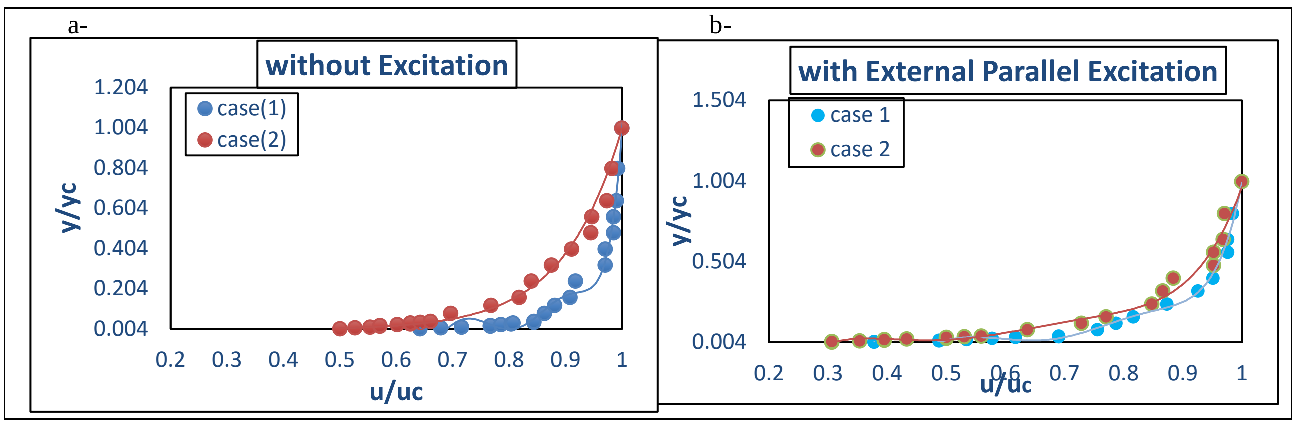

Fig. (6) Comparison of second plane in diffuser(α=8◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

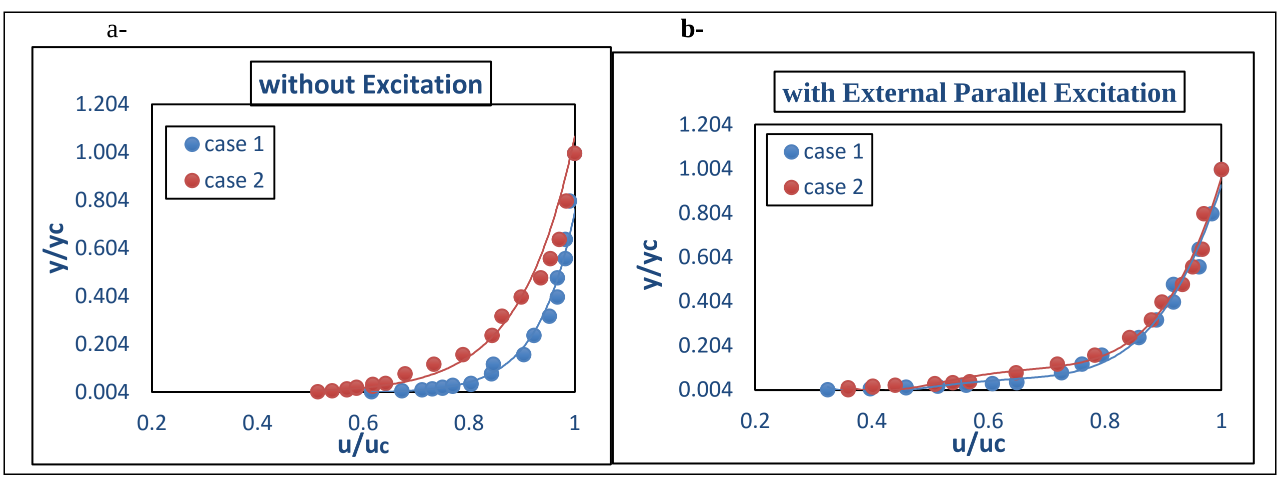

Fig. (7) Comparison of third plane in diffuser(α=8◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

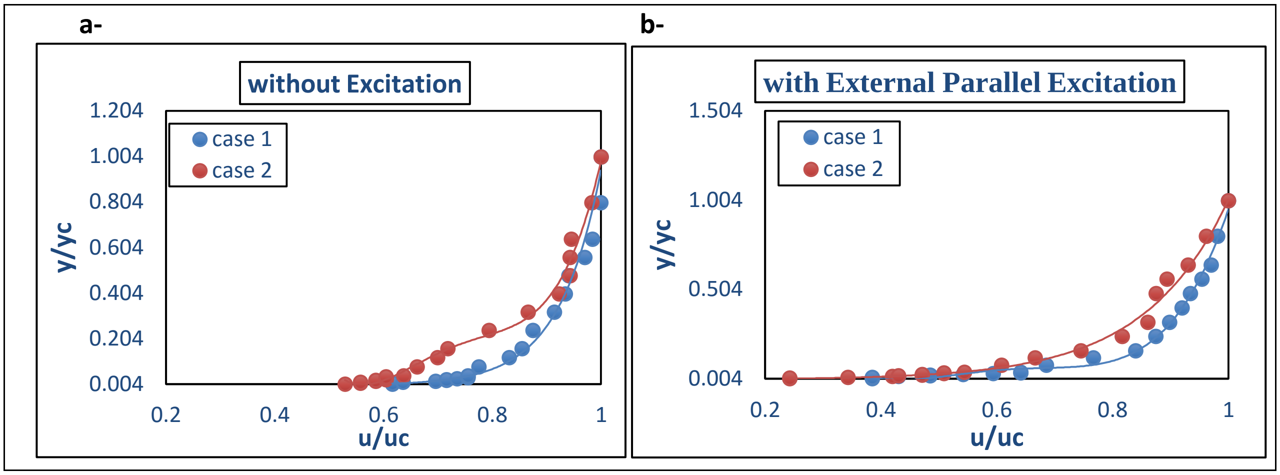

Fig. (8) Comparison of forth plane in diffuser(α=8◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

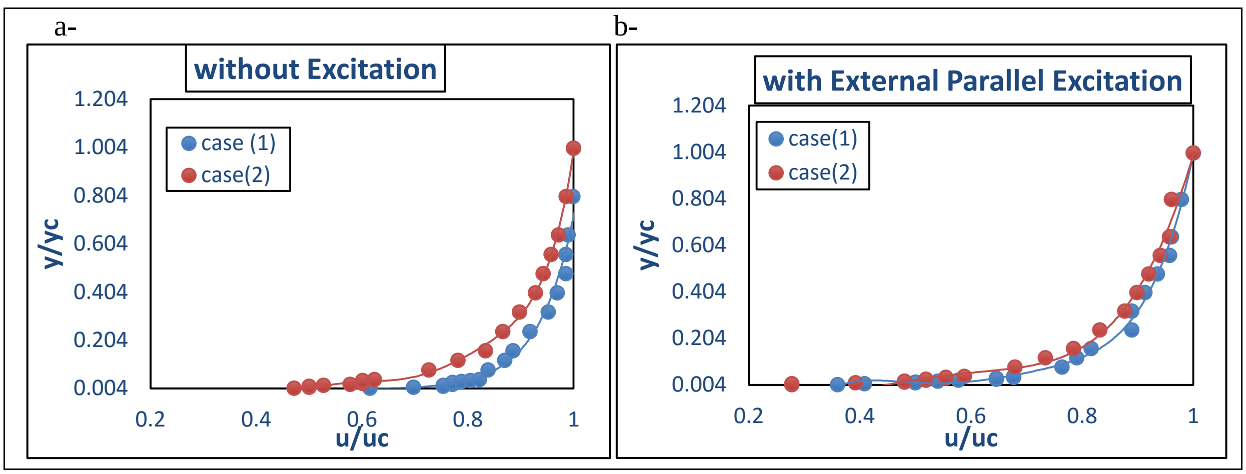

Fig. (9) Comparison of first plane in diffuser(α=11◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

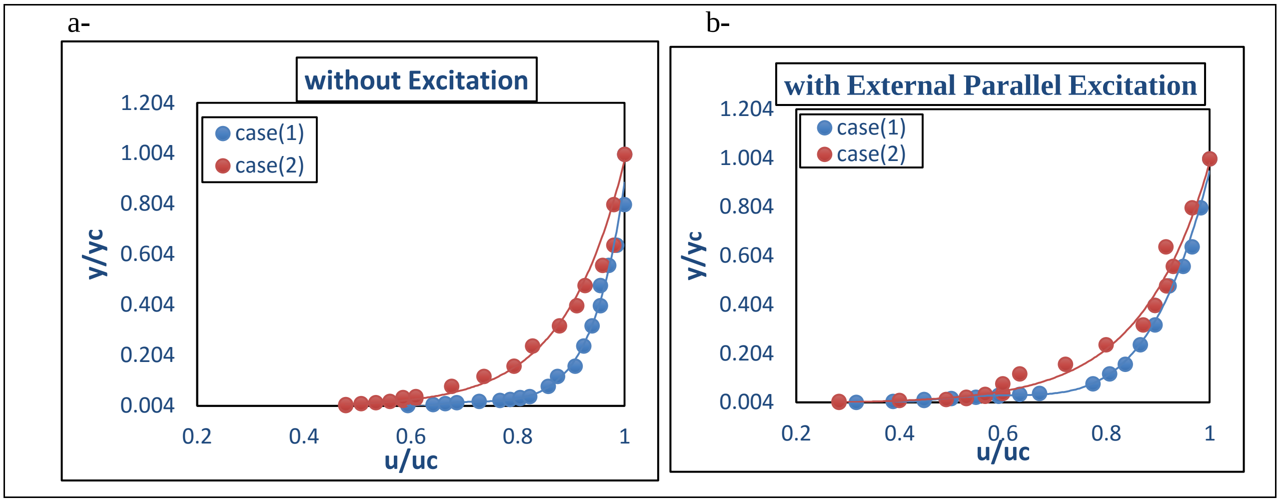

Fig. (10) Comparison of second plane in diffuser(α=11◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

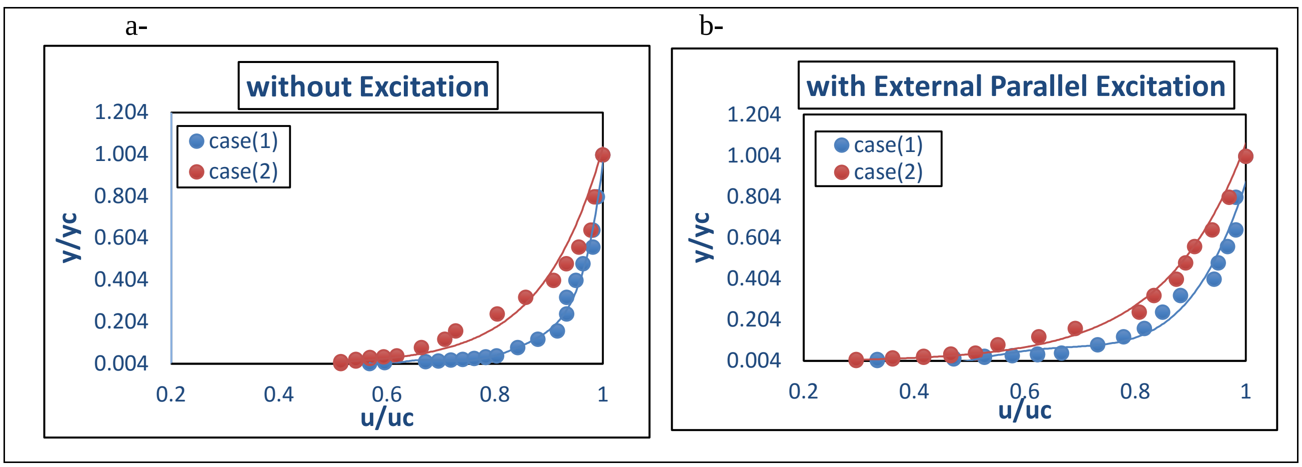

Fig. (11) Comparison of third plane in diffuser(α=11◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

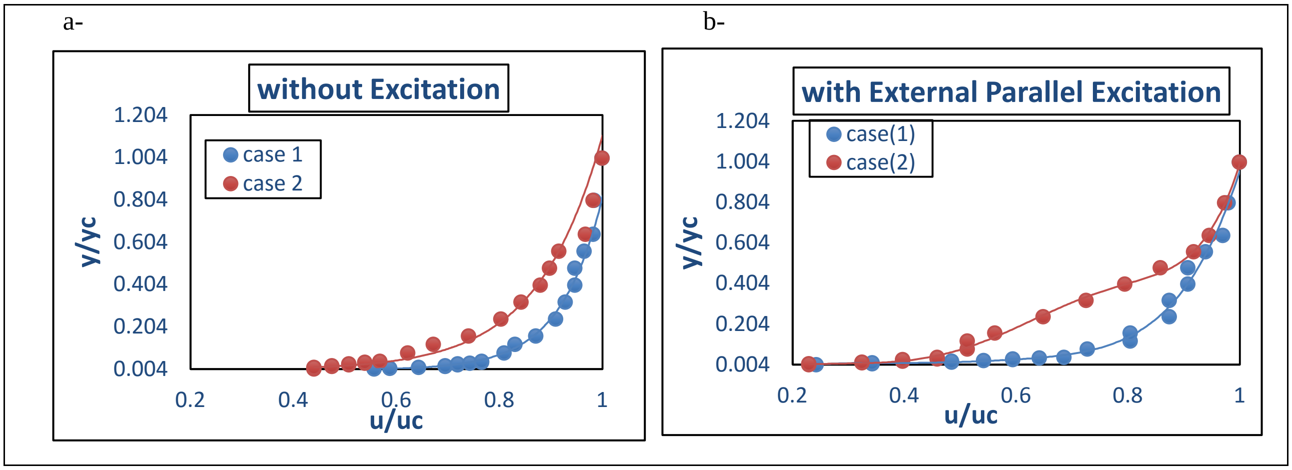

Fig. (12) Comparison of forth plane in diffuser(α=11◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

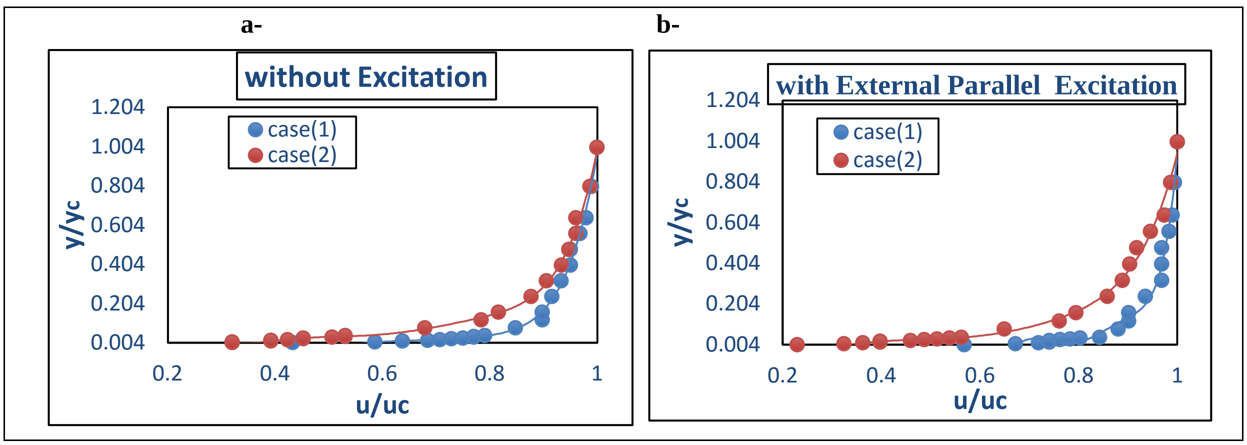

Fig. (13) Comparison of first plane in diffuser(α=15◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

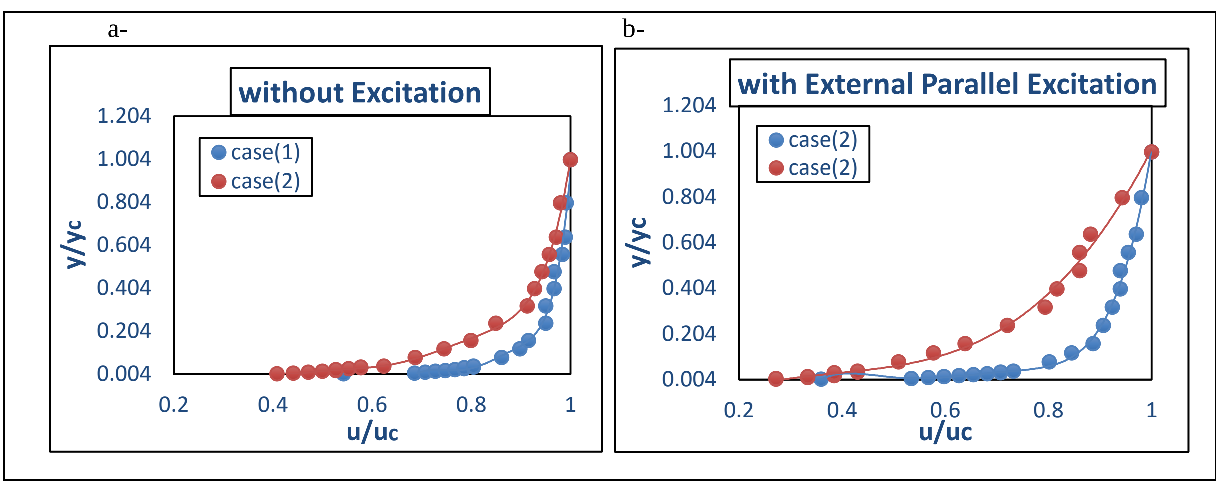

Fig. (14) Comparison of second plane in diffuser(α=15◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

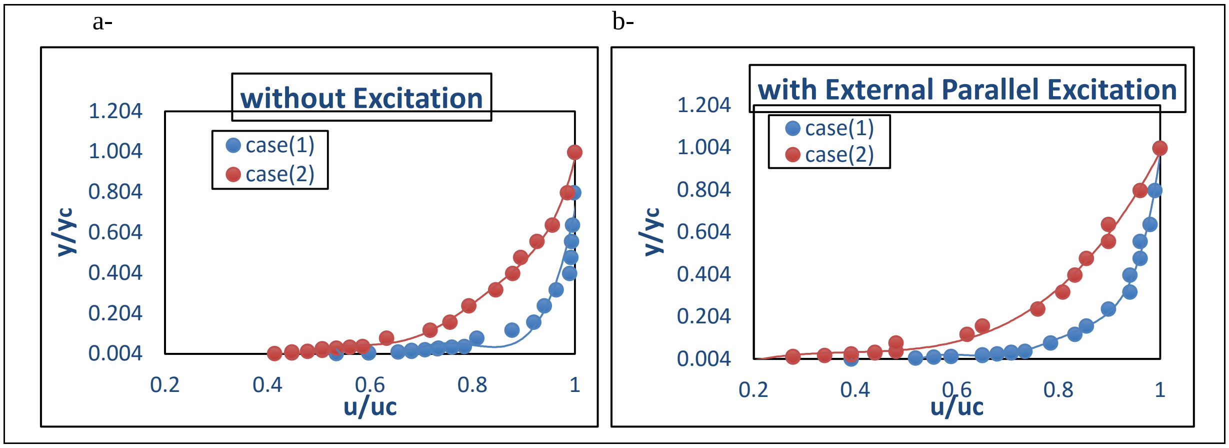

Fig. (15) Comparison of third plane in diffuser(α=15◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

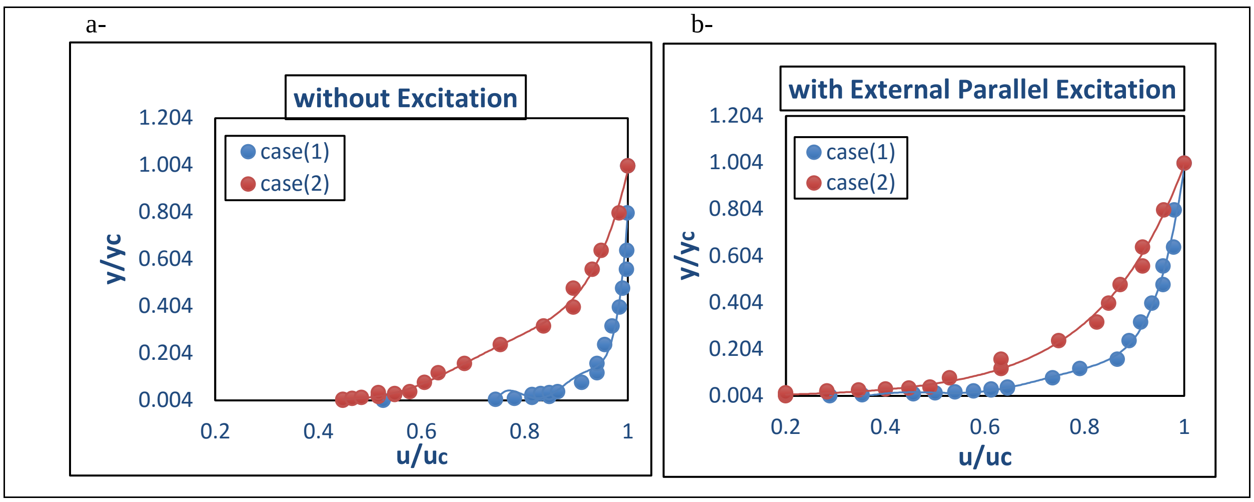

Fig. (16) Comparison of forth plane in diffuser(α=15◦) for two cases a-without excitation effect ; and b- with external parallel excitation effect .

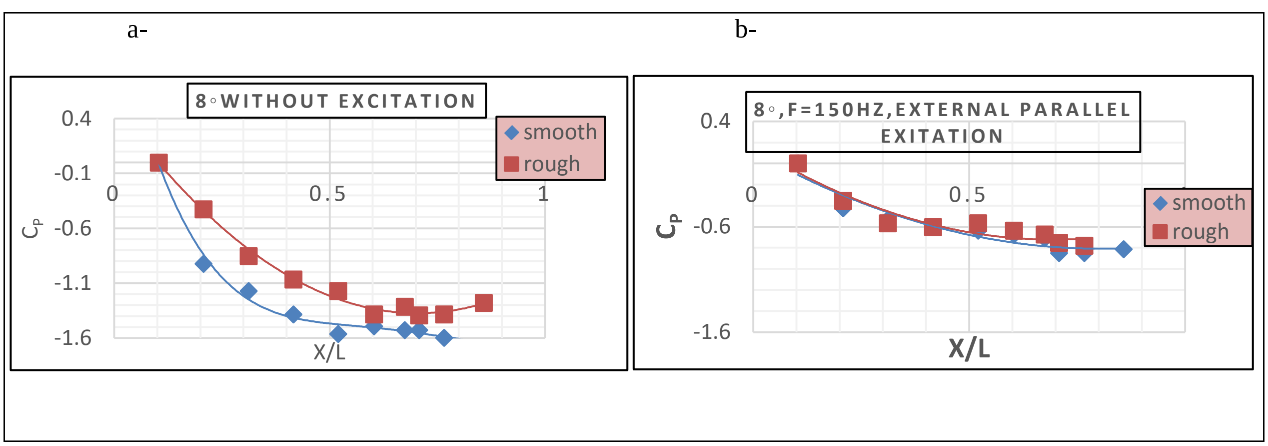

Fig. (17) Comparison of Pressure distribution, C_p, for smooth and rough surface in diffuser (8◦) ; a-without excitation effect ; and b-with external parallel excitation effect .

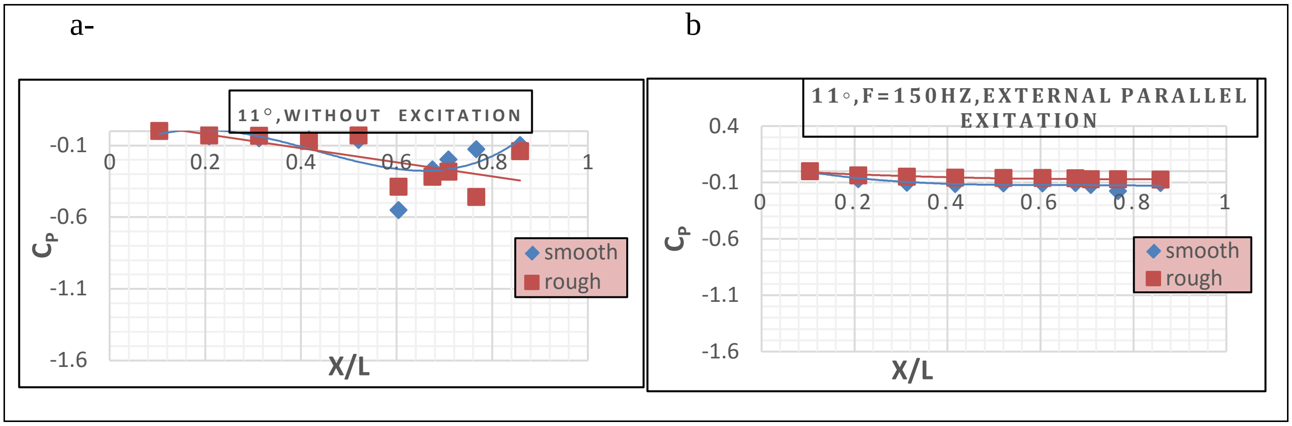

Fig. (18) Comparison of Pressure distribution, C_p, for smooth and rough surface in diffuser (11◦) ; a-without excitation effect ; and b-with external parallel excitation effect .

a- b-

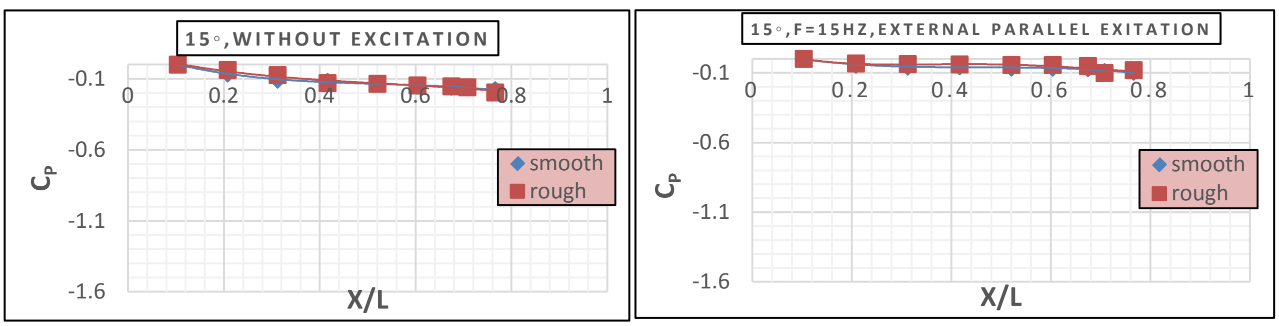

Fig. (19) Comparison of Pressure distribution, C_p, for smooth and rough surface in diffuser (15◦) ; a-without excitation effect ; and b-with external parallel excitation effect .

a- b-

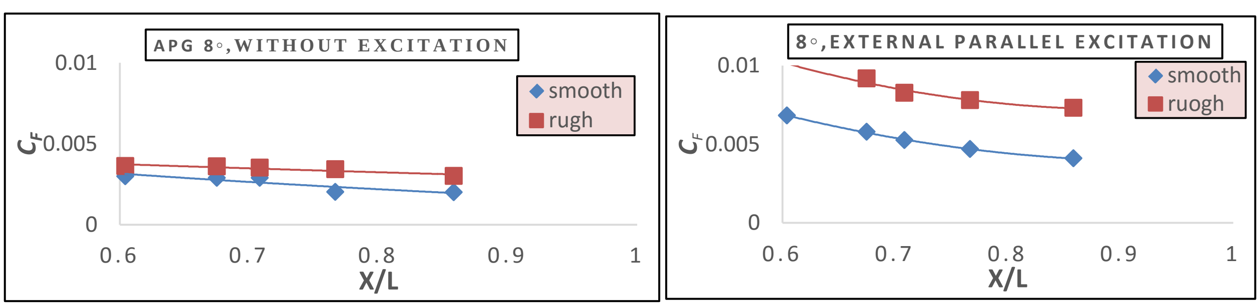

Fig. (20) Comparison of Skin friction coefficient, c_f, for smooth and rough surface in APG (8◦) ; a-without excitation effect ; and b-with external parallel excitation effect .

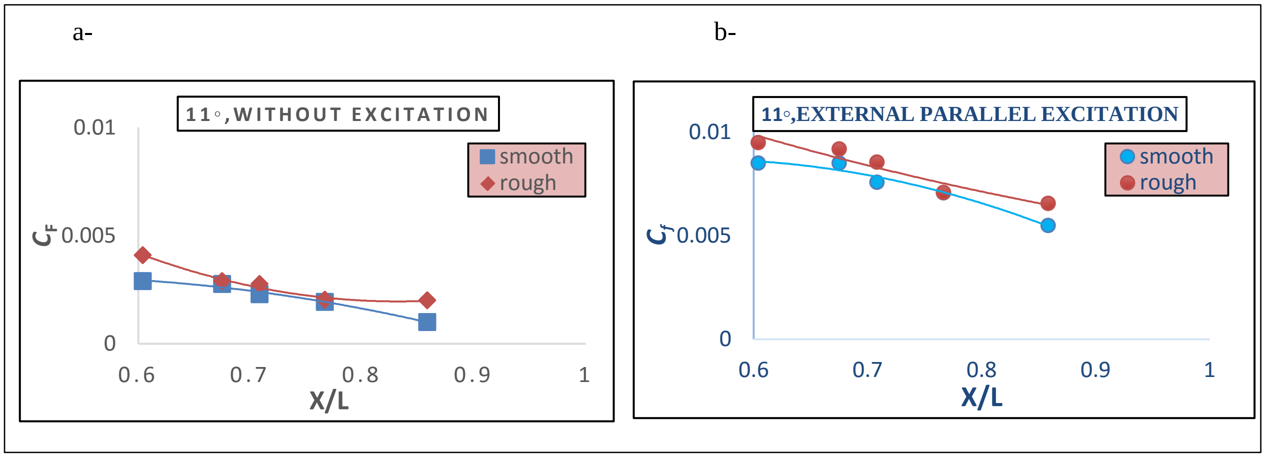

Fig. (21) Comparison of Skin friction coefficient, c_f, for smooth and rough surface in APG (11◦); a-without excitation effect; and b-with external parallel excitation effect.

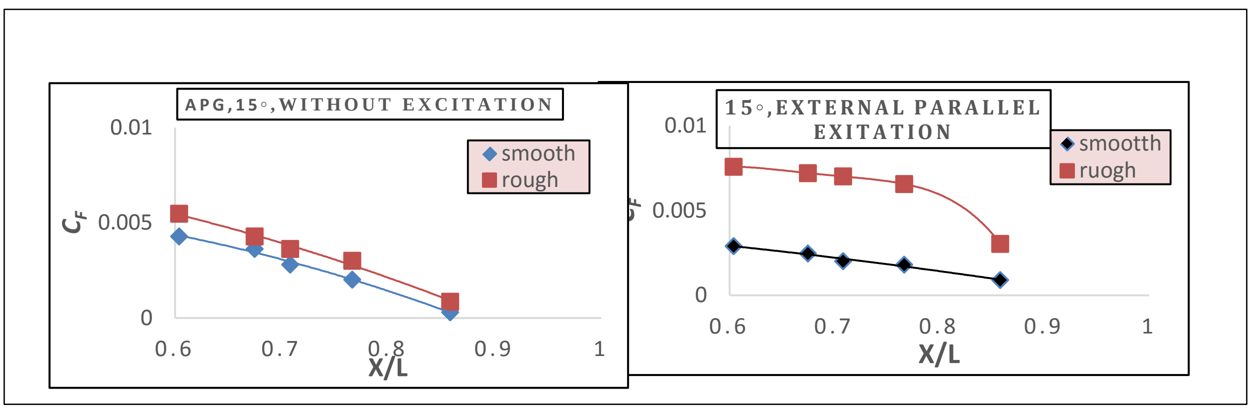

Fig. (22) Comparison of Skin friction coefficient, c_f, for smooth and rough surface in APG (15◦); a-without excitation effect; and b-with external parallel excitation effect .

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