Flow in sudden enlargement square duct with multiple normal jets

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ABSTRACT:-

A turbulent non-symmetrical and multiple normal jets through flow in sudden enlargement square duct is studied experimentally. The geometry of the enlargement is a duct with an area ratio of (AR= 5.09) . The effect of jets location , number of jets , inlet Reynolds number as well as the injection ratio on the pressure recovery coefficient are investigated .The inlet Reynolds number (Re_{in}), injection flow rate ratio ($\overline{Q}$) and the dimensionless downstream distance ($\overline{X}$) are chosen to cover the following range.

$5.3 \times 10^4 \leq Re_{in} \leq 10.7 \times 10^4$, $0.0 \leq \overline{Q} \leq 0.478$ and $0.64 \leq \overline{X} \leq 1.75$.

The experimental results show that, sleight change of the injection ratio, inlet Reynolds number or number of jets has an important effect on pressure recovery coefficient , interaction between main and injected flow and also the recirculation zone size .Furthermore, an increase of the distance between the jets location leads to an increase of the recirculation zone.

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1- Introduction :-

The important of multiple jets issuing into a cross flow is its wide application in many engineering problems such as: gas turbine combustors, film cooling of turbine blades and mixing flow in chemical industry .

Many experimental works has been conducted for the interaction between jets and flowing fluids. For example, Kind, et. al. [1] studied the interaction between two opposing plan turbulent wall jets . They concluded that for a pair of dimensional colliding wall jets, the location of stagnation region correspond roughly to the position of the maximum total pressure in the individual wall jet layer. Moss, et. al. [2] investigated the regions of separated flow associated with three simple sharp- edged two dimensional geometries, a rear-facing step, a front facing step and a rectangular block .Their measurements indicated that the region of re-circulating flow ending with re-attachment 5 – 6 step heights downstream and being followed by relaxation towards the boundary layer profile. Kadotani, et. al. [3] , Chandrsuda, et. al. [4] and Crabb, et. al. [5] studied row of jets introduced by pipes inclined at 35^o to the surface at various injection ratios . Prabhulal , et. al [6] studied the behavior of flow pattern and turbulent characteristics for two dimensional flow through large sudden expansion rectangular ducts with expansion ratios of 2 and 3 . Their results show that if the expansion ratio increases the reattachment lengths decrease for the short stail region and increase for the long stail region . In addition for larger expansion ratios , the flow pattern and flow characteristics through ducts are found to be of mirror images from each other. Barata , et . al . [7] studied the flow behavior from the impingement of a single axis-symmetric jet against a wall after penetrating a confined cross flowing stream . They concluded that the impinging jet penetrates strongly through the cross flow and although slightly bent with the stagnation point . Pietrzyk , et. al. [8] studied the hydrodynamics of a row of inclined jets issuing into a cross flow . Their results indicated that the existence of a separation region at the hole from which the jet issues , causing high level of turbulence and relatively uniform mean profile as well. Liou , et . al. [9] studied experimentally and theoretically the effect of the three- dimensional jet-jet impingement flow in a closed – end cylindrical duct with two – 60^o side inlets . El-mayit , et. al. [10 and 11] investigated the effect of injection ratio and the location of single and two – normal symmetrical jets on the pressure recovery coefficient for the flow through sudden enlargement square duct . Their results showed that in the case of two normal symmetrical jets , the size of the recirculation zone formed behind the jets increases by increasing the injection ratio , decreasing the inlet Reynolds number and shifting the jets position in the upstream direction . In the case of single normal jets , the experimental study indicated that at a certain value of injection ratio , the peak value of pressure at the jets zone increases and shifts in the downstream direction by moving the jets location in the same direction .

The current work is devoted to study the effect of multiple normal jets on the main flow through sudden expansion duct. The effect of injection ratios and the positions of jets on the pressure recovery coefficient were studied experimentally for low and high Reynolds numbers . This work include three cases of normal jets two – non symmetrical jets , three jets and four symmetrical jets .

2- Experimental Apparatus and Measuring Devices :-

The apparatus used in the present study is shown diagrammatically in figure (1). Experiments are carried out in a closed circular loop where the test section is a horizontal square duct ($101.6 \times 101.6\ mm^2$) and 1600 mm length . The test section is divided into two parts, one of length 300 mm as shown in Fig.(2) and the other with length 1300 mm . The six symmetrical jets with diameter (19 mm) are horizontally located on the centerline of two vertical sides of the first part of the test section as shown in Fig. (2) .Every two jets are opposite to each other , these sides are called the jets sides . Fig. (2) shows the location and arrangement of the normal jets on the jets side . The normal jets are located on the jets side where the centerline of every two jets is perpendicular to the centerline of the main inlet pipe. In addition the centerlines of the two parts of the test section and the inlet main pipe are the same . In order to overcome the non-uniformity of the flow caused by the valves , an entry pipe of 10 inlet diameter length is used before the test section to ensure fully developed flow at the entrance of the square duct . The test section has circular entry diameter (50.8 mm) . The tested square duct is provided with wall static pressure tapings along the three sides of the duct . The first and second sides of the first parts of the test section are facing to the jets ,while the third is in bottom side . The tap holes of the static pressure of one mm in diameter were carefully drilled to the test section surface . To measure the reference static pressure , one tap located at a distance of one diameter of the inlet main pipe ahead of the square duct is used . A multi – tubes differential manometers with carbon tetrachloride CCL_4 are used for measuring the pressure distribution along the three sides of the square duct . The pressure recovery coefficient , C_p is defined as : $C_p = 2\ (p - p_{in})/\ \rho\ U^2_{in}$, where p is the static pressure at any distance along the test section , P_{in} is the inlet static pressure ,U_{in} is the inlet average velocity and ρ is the fluid density . The volume flow rates (Q_{main} and Q_{inj}) are measured by two orifice meters calibrated by means of the collecting tank method. The errors in measuring head are found to be about ± 5 % while in measuring flow rates around ± 2.5% .

3- Experimental Results and Discussion :-

The effect of inlet Reynolds number (Re_{in}), injection ratio ($\overline{Q}$) , number of jets as well as the jets location ($\overline{X}$) on the pressure recovery coefficient (C_p) are investigated in this work . $\overline{X}$ is defined as dimensionless distance ($\overline{X}$ = x/b) , wher x is measured from the step of the sudden expansion and b is the height of the square duct . This paper includes three different cases of normal jets . The first case is for the two – non symmetrical jets , the second and third ones are for the three and four symmetrical jets . The experimental work has been carried out for injection ratios which varies from 0.0 to 0.415 , the inlet Reynolds number which varies from 5.3×10^4 to $10.7\ 10^4$ at three different locations of the jets. The static pressures are measured at three sides of the test section in the first two cases (two – non-symmetrical normal jets and three normal jets) . while for the case of four normal symmetrical , the static pressures are measured at two sides only , one is the jets side and the other is the bottom side as shown in Fig. (2) .

3-1: Effect of injection ratio ($\overline{Q}$) on the Pressure recovery coefficient (C_p):-

The measurements are taken for the three cases as mentioned above . Moreover , the effect of the injection ratio on the pressure recovery coefficient is performed with two inlet Reynolds number at three location for the jets as well . Figs. (3 to 8) show the results for the first case (two non-symmetrical jets). The three locations of the two non – symmetrical jets are taken as ($\overline{X}$= 0.64 – 1.20 , 0.64 – 1.75 and 1.20 – 1.75) .The locations of the three jets on the test section are chosen to be ($\overline{X}_1$ = 0.64 , $\overline{X}_2$ =1.20 and $\overline{X}_3$ = 1.75) as shown in Fig. (2). For four normal symmetrical jets the location of the jets are located at ($\overline{X}$= 0.64 – 1.20 , 0.64 – 1.75 and 1.20 – 1.75) . Figs. (3 and 4) represent the relation between the pressure recovery coefficient and the dimensionless downstream distance , $\overline{X}$ at different values of injection ratios at the first position of the jets ($\overline{X}$=0.64 – 1.20) for Re_{in} = 10.7×10^4 and 5.3×10^4 , respectively . The pressure recovery coefficient at the three sides of the test section is shown is Figs. (3 and 4) (a , b and c) , respectively . The results in Fig. (3-a) at the injection ratio, $\overline{Q} \leq 0.152$ show that ; the pressure recovery coefficient increases rapidly to a peak value in the region which formed behind the 1st jet . This is due to the effect of the fraction of the 1st jet kinetic energy which converted to static pressure . The peak value of C_p at this zone increases with an increase of the injection ratio because of increasing the radial component of the kinetic energy of the 1st jet . The peak value of C_p is followed by a minimum value at $\overline{Q}> 0.152$. This result is due to the recirculation zone formed behind the jets . The minimum value of C_p increases by increasing the injection ratio and causes a decrease of this minimum value of C_p . Behind the minimum value of C_p , the pressure increases again to a second peak value due to an increase of the flow area . Behind this zone the pressure decreases again due to the interaction of the recirculation zones formed behind the step and the jets , then increases gradually up to reach the reattachment point . At $\overline{Q} < 0.152$, there is no peak value of C_p behind the 1^{st} jet. This is due to the low value of injection ratio which leads to that the mean flow overcome the jets flow .

The distribution of C_p against $\overline{X}$ at different injection ratio in the second and bottom sides of the test section is shown in Fig. (3) b and c , respectively. The general trend of these figures are similar to that in Fig. (3-a) , unless the 1^{st} peak value of C_p occurs behind the 2^{nd} jet as shown in Fig.(3-b) and its value decreases because the 2^{nd} jet is in the high pressure zone compared to the 1^{st} jet . By comparing Figs. (3-a and 3-c) , it is noted that the 1^{st} peak values of C_p at the upper side wall (a) for $\overline{Q} = 0.197$ is greater than that for the bottom side (c) . The reason behind that may be related to the fraction of the kinetic energy in the direction of the bottom side which is smaller than that its value in the 1^{st} side direction . Moreover , by comparing Fig.(4) with Fig (3) it can be noticed that the mutual effect of main and injected flow on the pressure recovery coefficient is pronounced . These remarks can be summarised as follows : at small inlet Reynolds number ($Re_{in} = 5.3 \times 10^4$) , the peak values of C_p formed behind the whole jets are increased as shown in Fig. (4) (a & b), respectively . The peak value of C_p formed behind the 1^{st} jet in the bottom side decreases by increasing the injection ratio from zero to $\overline{Q} = 0.306$. For $\overline{Q} > 0.306$, the peak value of C_p moved down and take some negative values with the same order of magnitudes for $\overline{Q} < 0.306$. The interportation of these phenomenon may be explained as; the strength of the jets flow has predominant effect more than for the main flows . Therefore , this kind of flow pattern gives increase the ability of jets flow to diffuses everywhere and in turn ,, increase the peak value of C_p as shown in Fig.(4) a and b . Moreover, the jet flow act as an obstacles in the mean flow and , in turn, the mean flow moves adjacent to the bottom wall, and its peak values of C_p decreases as shown in Fig.(4-c).

Figs. (5 to 8) present the pressure recovery coefficient C_p versus the downstream distance at the second and the third location of the jets ($\overline{X}$ = 0.64 -1.75 and $\overline{X}$ = 1.20 – 1.75) at different flow Parameters . These parameters are $\overline{Q}$=0.0, 0.11, 0.152, 0.197 and 0.237 and Reynolds number , $Re_{in} = 10.7 \times 10^4$ and 5.3×10^4 · By Comparing the results of C_p at the first location of the jet, Fig.(3) ; 2nd location of the jet, Fig. (5) ; and the third location of the jets, Fig. (7) at fixed $Re_{in} = 10.7 \times 10^4$: it is concluded that , the recirculation zones , that formed from the interaction between the jets and mean flow and the step of the test section as well, are found to be in the front of the first jet . In contract , these irrotational zones are formed behind the second and third jets . Moreover , the amplitude of the peak values are affected strongly by the variation of the jets locations in the downstream directions . Similarly , the same trend for $Re_{in}= 5.3 \times 10^4$ is observed and computed in Figs. (4 , 6 and 8) . The Second set of the results are carried out for the three nonsymmetrical jets . Here again the effect of the injection ratios and the inlet Reynolds number on the pressure recovery coefficient are investigated .

Figs. (9 and 10) show the distribution of C_p along the duct at $\overline{Q}$= 0.0, 0.22, 0.306, 0.396 and 0.478 and two inlet Reynolds number ($Re_{in}=5.3\times10^4$ and 10.7×10^4). These results are recorded at the three levels of measurements . Level (a) refers to the upper side , level(b) refers to the opposite side of position (a) , while level (c) represent the bottom side of the rectangular test section as shown in Fig. (9-d) . Fig. (9-a) represents the results of C_p at level (a) . It is noted that , there are two peak values of C_p , one is found to be close to 1st jet and near to the entrance, $\overline{X}$ = 1.8 , while the second peak value is found to be away the jet zone effect , $\overline{X}$ = 5. By increasing distance downstream , C_p values decreases and always converge to be flatted for away from the jet effect . It is also noted that , C_p values increases with increasing the injection ratios . The first peak of C_p is formed behind the second jet , while the 2nd peak if formed behind the third jet . Fig. (9-b) represents the results of C_p at the level (b) . There are significantly change of the results at the level (b) than that at the level (a) , since there are two injection jet at level (b) comparing to a single jet at level (a). As a results , there are four peak values found to be at the level (b) , Fig. (9-b) . The 1st one is formed close to second jet , the second peak value is found to be behind the third jet while the third peak value of C_p is due to the interaction between the recirculation zones formed behind the step and the jets and the fourth peak value of C_p is the reattachment point. Fig.(9-c) represent C_p results at the bottom level (c) . It is noted that there are three peak values of C_p found within the disturbed zone (near jets) . The magnitudes of these peaks are smaller than that with level (a) and (b) , since the bottom location is not sensitive to the interaction between the jet flow and the mean flow . Generally , C_p values increases as the injection ratio increases . Similarly there are qualitatively trend of C_p distribution by increasing the inlet Reynolds number from 5.3×10^4 to 10.7×10^4 as shown in Fig. (10) . The peak values of C_p change significantly as the Reynolds number increases .

The measured pressure recovery coefficient for the case of four symmetrical normal jets at different injection ratio for two inlet Reynolds number at three locations of the jets ($\bar{X}$ = 0.64 - 1.20 , 0.64 – 1.75 and 1.20–1.75) for the two sides of the test section are shown in Figs. (11 , 12 and 13) , respectively . Fig. (11) a and b shows the distribution of C_p along the duct for different injection ratio at two inlet Reynolds number , Re_{in}= 10.7×10^4 and 5.3×10^4 , respectively , for the side wall at the 1st location of the jets ($\bar{X}$ = 0.64 – 1.20) . In addition to that the distribution of C_p along the bottom wall side is shown in Fig. (11) c and d . The trend of the curves in Fig. (11 - a) can be explained as follows : the pressure recovery coefficient (C_p) increases to a certain value of $\bar{X}$ due to an increase of flow area . Then remains constant to a certain value of $\bar{X}$. This still period of C_p is due to the impact of the four jets with the main flow . The value of C_p increases again to reach the reattachment point . By increasing the injection ratio , the pressure behind the jets decreases due to the acceleration of the flow which causes an increase of the hydraulic losses . It is also observed that the C_p formed behind the step in the case of injected flow is higher than that in the case of no injection . This is due to an increase of axial momentum component . By comparing the results of Fig. (10) a with b , it can be seen that the general trend of these curves are the same . The difference is the presence of the peak value of C_p at $\overline{Q}$= 0.396 which achieved behind the jets . This is due to a decrease of inlet Reynolds number which causes the jets flow overcome the main flow at this injection ratio . From Fig. (10 - c) it can be concluded that there are two peak values of C_p , the 1st peak is formed behind the jets and the second is at the reattachment point . The 1st peak value of C_p is flowed by a minimum value of C_p due to the interaction between the recirculation zone which formed behind the jets and the step . It can be observed also that by increasing the injection ratio , the peak value of C_p decreases and disappeared at the higher values of injection ratio . When the inlet Reynolds number decreases , the peak values of C_p appear only at the higher values of injection ratio as shown in Fig. (11 - d) . The peak values of C_p formed behind the 1st jets is due to the interaction between the main injected flow ratios .

The distribution of C_p against dimensionless downstream distance, $\overline{X}$ at the 2nd and the 3rd locations of the jets for the two inlet Reynolds number at the jets and bottom sides are shown in Figs. (12 and 13) , respectively . From these figures it can be seen that the general trend of curves as in Fig. (11) .The main differences can be summarize as : the recirculation zone formed behind the step increases by shifting the jets location in the downstream direction as shown in Fig. (12). This leads to a decrease of the pressure behind the step.

3-2: Effect of the jets location ($\overline{X}$)on the pressure recovery coefficient;(C_p)

Effect of the two-non symmetrical normal jets location on the pressure recovery coefficient , (C_p) at the three sides of the test section at $\overline{Q}$= 0.237 and Re_{in} = 10.7 x 10^4 are shown in figure 14 (a, b and c) . The jets location on the test section were taken as follows . The 1st position of the jets is $\overline{X}$ = 0.64 – 0.64 (this case represents the two normal symmetrical jets), while the 2nd position of the jets is $\overline{X}$ = 0.64 – 1.20 and the 3rd position of the jets is $\overline{X}$ = 0.64 – 1.75 as shown in Fig. (14-d) . From Fig.(14) , it can be seen that, the recirculation zone between the two jets increases by shifting the 2nd jet in the downstream direction as shown in Fig. (14- a). It can be observed also that the peak value of C_p which facing to the 2nd jet increases and shifts in the downstream direction with the moving of the 2nd jet in the same direction as shown in Fig. (14-b) . From this figure it can be seen that, the minimum values of C_p decrease by shifting the 2nd jet in the downstream direction . This is due to an increase of the recirculation zone. From Fig. (14-c), it can be observed that the peak values of C_p formed behind the 1st jet decrease by shifting the jets to a distance of $\overline{X}$ up to 2.8 . By shifting the jets over this value , the peak value of C_p increase again .These results are due to the size of the recirculation zone formed between the two jets.

The distribution of C_p for the three sides of the test section at the three position of the two-normal non symmetrical jets for $\overline{Q} = 0.396$ and $Re_{in} = 5.3 \times 10^4$ are shown in Fig.(15) a , b and c . By comparing Fig. (15) with Fig. (14) , it can be noticed that the peak values of C_p at the sides facing to the jets increase by decreasing the inlet Reynolds number. This can be explained as : due to the interaction between the main and jets flow , the jets flow overcome the main flow by decreasing the inlet Reynolds number. At the bottom side, the peak value of C_p converted to a minimum value and this value decreases in the case of the 3rd location of the jets as shown in Fig. (15 - c) . This is due to the constant of streamlines near the bottom wall. In the case of two symmetrical jets, there is a peak value. This is due to the impact of the two-symmetrical jets which causes that fraction of the kinetic energy of the jets in the bottom side converted to a pressure. In the case of two non-symmetrical normal jets, there is no impact of the two jets . At small inlet Reynolds number, $Re_{in} = 5.3 \times 10^4$, the jet flow overcome the main flow and represents an obstacles for it . Hence, the streamlines of flow concentrated at the bottom sides of the test section . The result is a decrease of pressure in the jets zone .

Fig. (16) shows the distribution of pressure recovery coefficient, $C_p$along the duct at the three different locations of the four symmetrical normal jets.(**$\overline{X}$=0.64–1.20,0.64–1.75 and 1.20–1.75)** at the jets side (I) . Fig. (16) a and b represents the distribution of C_p for Re_{in} = 10.7 × 10^4 at two injection ratios, $\overline{Q}$ = 0.11 and 0.197, respectively.The distribution of C_p at the bottom side for the same conditions are shown in Fig. (16) c and d . From Fig. (16) , it can be seen that the recirculation region laying in the zone between the step and the location of the jets increases by shifting the jets position .This leads to a decrease of C_p in this zone due to the effect of the interaction between the two recirculation zones formed behind the step and before the position of the jets. After this zone, the values of C_p depend on the summation of the pressure resultant from the two recirculation zones formed behind the step and behind the jets. It can seen also that the minimum value of C_p in the zone between the step and the jets decreases by increasing the injection ratio as shown in Fig. (16) a and b.

The effect of four symmetrical normal jets location on C_p at the jets and bottom sides of the test section for Re_{in}= 5.3 × 10^4 is plotted in Fig. (17). The distribution of C_p at the jets side for two values of injection ratios, $\overline{Q}$= 0.22 and o.396 are shown in Fig. (17) a and b , respectively, while Fig. (17) c and d shows the distribution of C_p at the bottom sides for the same two values of injection ratios . By comparing Fig. (17) with Fig. (16), it can be observed generally that at $\overline{Q}$= 0.396 the peak value of C_p at the side jets appeared after the jets zone as shown in Fig. (17-b) . At the bottom side at $\overline{Q}$= 0.396 there is a peak value of C_p appears behind the 1^{st} two jets as shown in Fig. (17 - c). This peak value of C_p decreases by increasing the distance between the jets position . This is due to an increase of the recirculation zone formed between the jets . The peak value of C_p shifts in the downstream direction by moving the two 1^{st} jets in the same direction . This can be explained as : along the downstream direction , the kinetic energy of the main flow decreases . At low inlet Reynolds , Re_{in}=5.3 × 10^4 , the jet flow is represented as an obstacles to the main flow . The degree of the obstruction increases by shifting the 1^{st} two jets location in the downstream direction . From Figs. (16 and 17) it can be seen that , the jets location have great effect on the recirculation zone formed behind the step. The recirculation zone is extended in the downstream direction as the jets position is shifted in the same direction . This leads to a good mixing and improvement of the injection chamber characteristic .

4-Conclusion :-

From the previous discussion of the effect of injection ratio , injection location as well as inlet Reynolds number on the pressure recovery coefficient through flow in sudden enlargement square duct , it can be concluded generally that ;

1- The interaction between recirculation zone formed behind the step and behind the jets zones are affected strongly with the inlet Reynolds number, injection ratios and number of normal jets .

2- The peak and minimum values of pressure recovery coefficient owing to the jets at the three sides of the test section depend strongly on the locations of the jets , injection ratios as well as the inlet Reynolds number .

3- By increasing the injection ratios , the peak values of pressure recovery coefficient increase and decrease along the downstream direction .

4- Increasing the inlet Reynolds number leads to disappear of the peak values of pressure recovery coefficient resulting from the jets due to the high kinetic energy of the main flow which overcome the jets kinetic energy .

5- The peak values of pressure recovery coefficient decreases and shifts in the down stream direction with increasing the inlet Reynolds numbers as a result of the interaction between the jets and main flows .

6- The characteristic curves of pressure recovery coefficient in the case of four-symmetrical normal jets distinguish with the presence of still period along the dimensionless downstream distance due to the impact of the four jets with the main flow .

7- In the case of two – non symmetrical normal jets , shifting the 2nd jet in the downstream direction leads to an increase of the recirculation formed between the two jets . Also , the peak value of C_p facing to the 2nd jet increases in the downstream direction by moving this jet in the same direction , while the minimum value of C_p decreases by shifting the 2nd jet in the down stream direction .

8- The recirculation region in the zone between the step and the location of the four- symmetrical normal jets increases by shifting the jets position .

9- The jets location have a great effect on the recirculation zone formed behind the step . The recirculation zone is extended in the downstream direction as the jets position is shifted in the same direction . This leads to good mixing of flow and consequently , an improvement for the injection chamber characteristic .

Nomenclature :-

b	: height of the square test section	mm
C_p	: pressure recovery coefficient, $C_p = 2\,(p - p_{in}) / \rho\, U^2_{in}$	--
D	: inlet main diameter pipe ,	mm
p	: wall static pressure ,	N/m^2
p_{in}	: wall inlet static pressure ,	N/m^2
$\overline{Q}$	: injection flow rate ratio = (Q_{inj} / Q_{main}) ,	----
Q_{inj}	: injected flow rate,	$m^3/sec.$
Q_{main}	: main flow rate,	$m^3/sec.$
R_{ein}	:inlet Reynolds number = $\frac{U_{in} D}{\nu}$	----
U_{in}	:inlet average velocity,	m/sec.
$\overline{X}$	: dimensionless downstream distance , ($\overline{X}$ =x/b)	----
x	: downstream distance measured from the step of the test section .	mm

Greek symbols :

ρ	: fluid density	kg/m^3
ν	: kinematic viscosity ,	$m^2/sec.$

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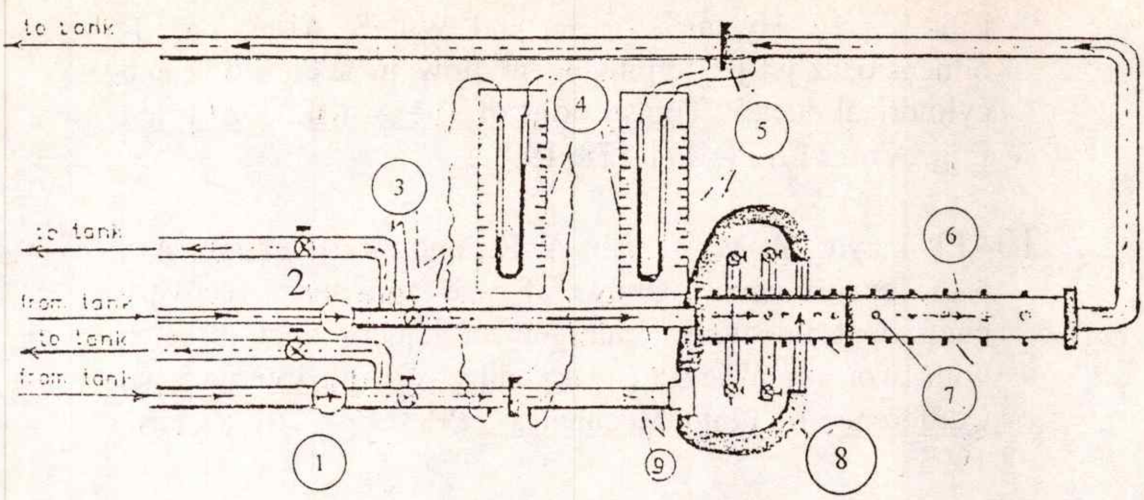


1- Injection pump
2- Main pump
3- Valves
4- U- tube manometers
5- Orifice meters
6- Square duct
7- Tapping points
8- Jet pipes
9- inlet pipe

Fig.(1) : Schematic Arrangement of the experimental set – up

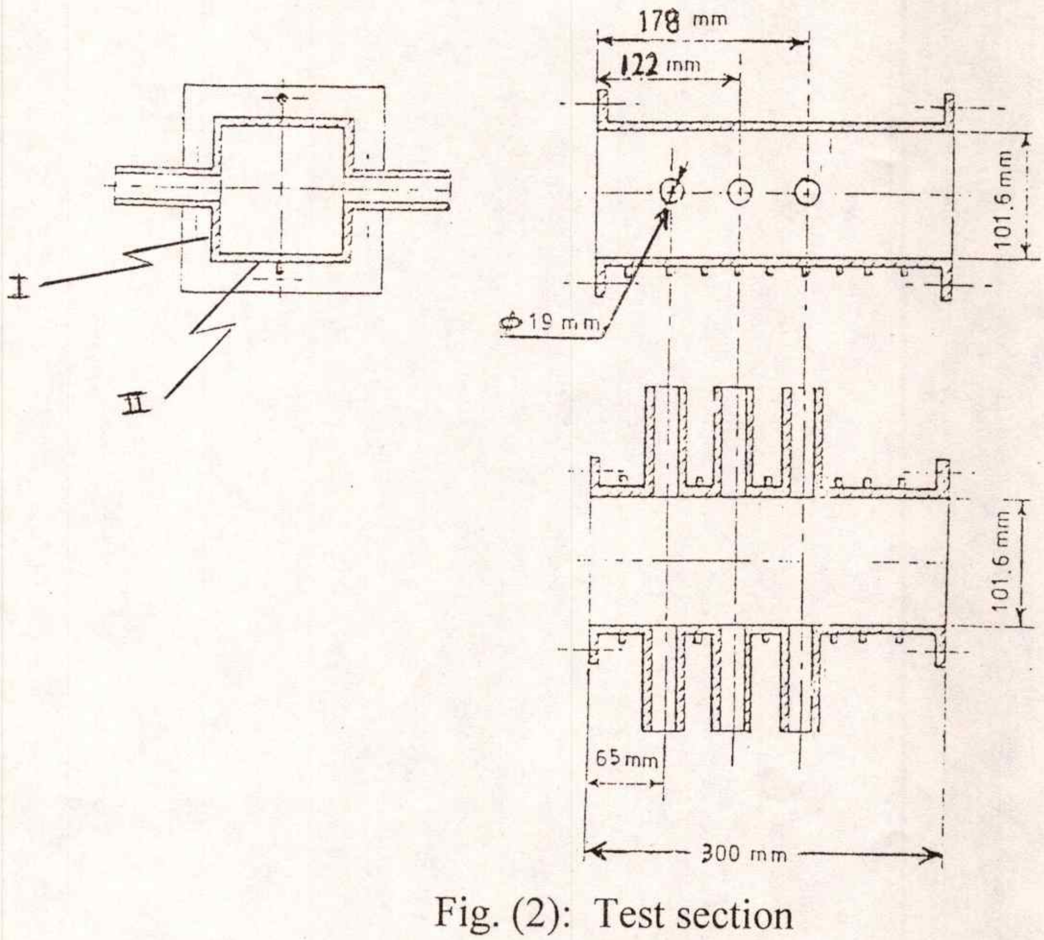
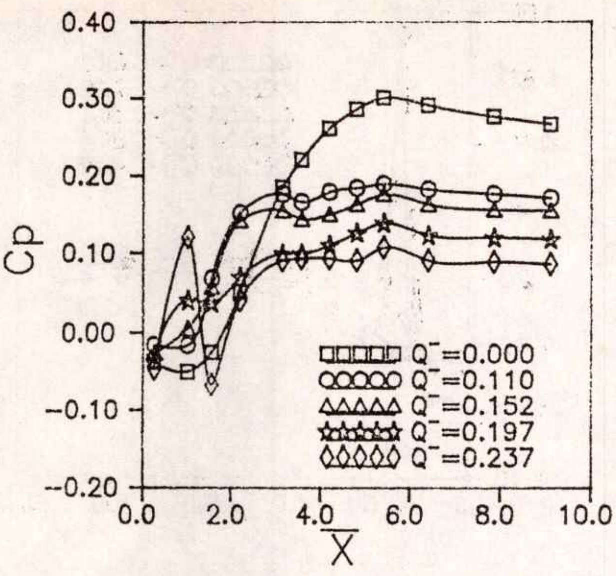
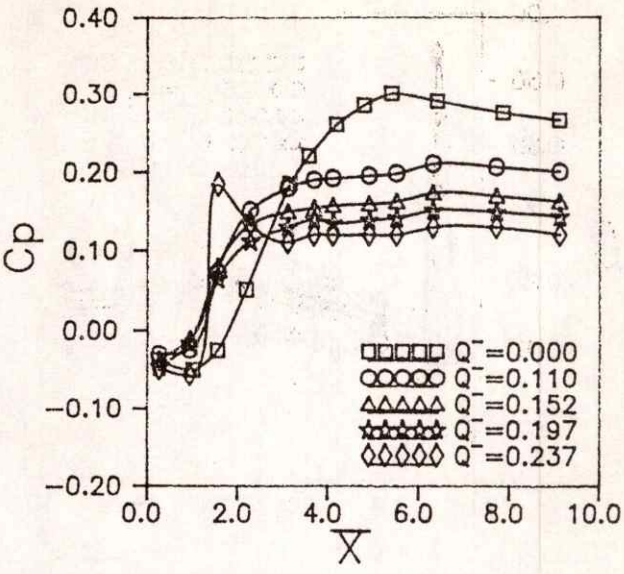


Fig. (2): Test section

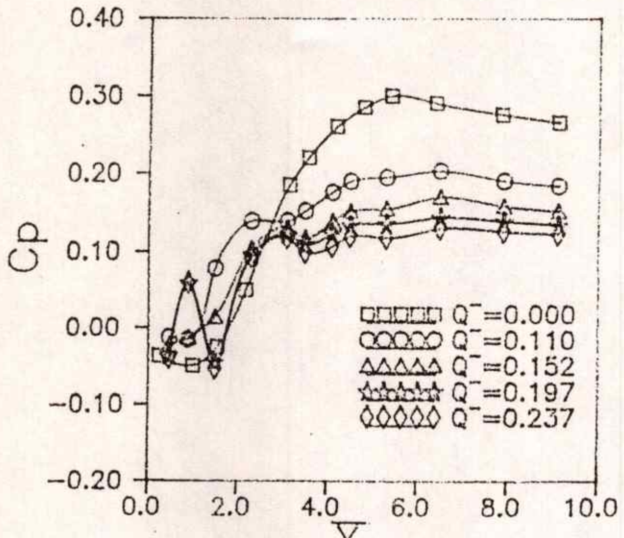
(1) Jets side and (II) bottom side



(a)



(b)



(c)

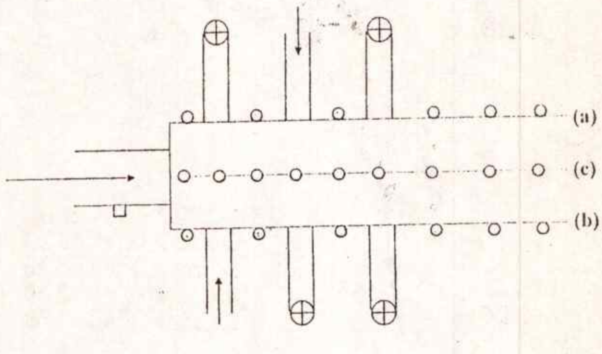
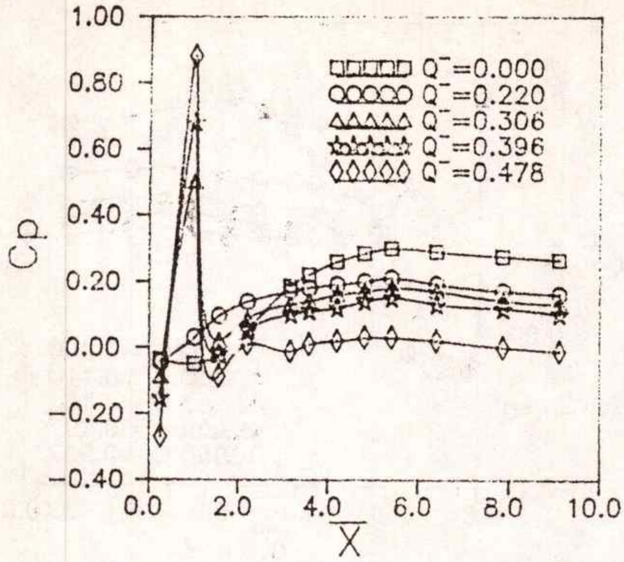
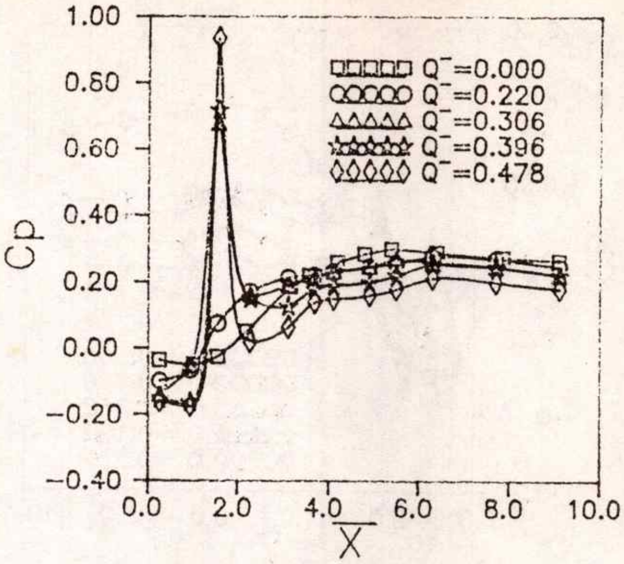


Fig. (3): Effect of the injection ratio ($\overline{Q}$) for two – non symmetrical normal jets on the pressure recovery coefficient (Cp) at the first location of the jets ($\overline{X}$ =0.64–1.20) for $Re_{in} = 10.7 \times 10^4$



(a)



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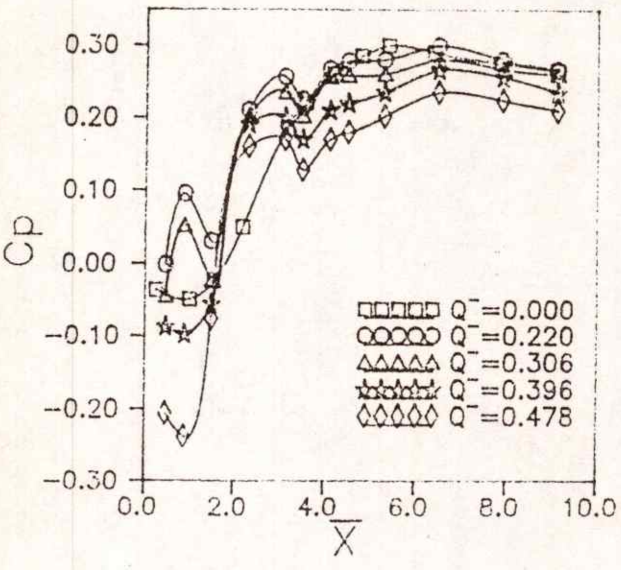


(c)

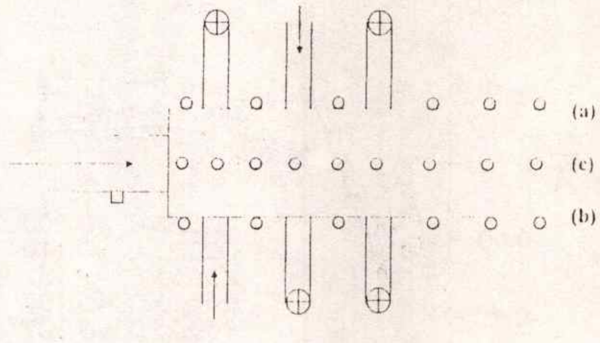
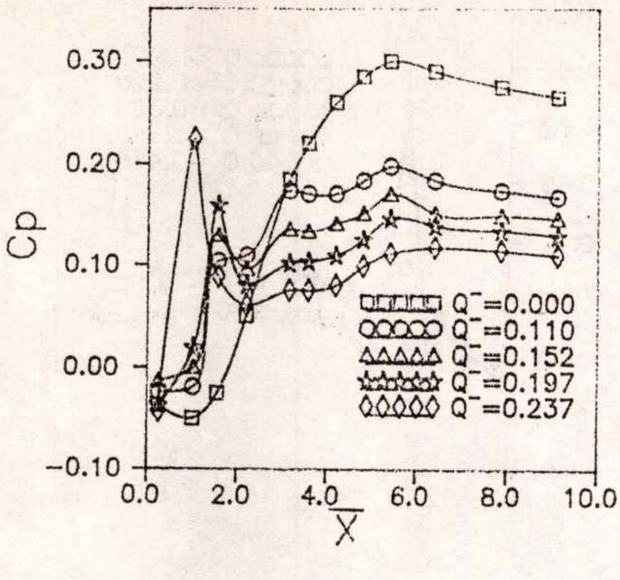
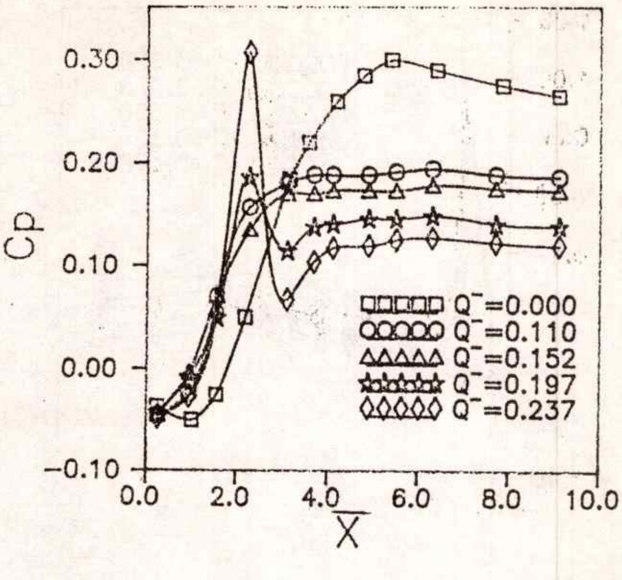


Fig. (4) : Effect of the injection ratio ($\overline{Q}$) for two – non symmetrical normal jets , on the pressure recovery coefficient (Cp) at the first location of the jets ($\overline{X}$ =0.64–1.20) for $Re_{in} = 5.3 \times 10^4$



(a)



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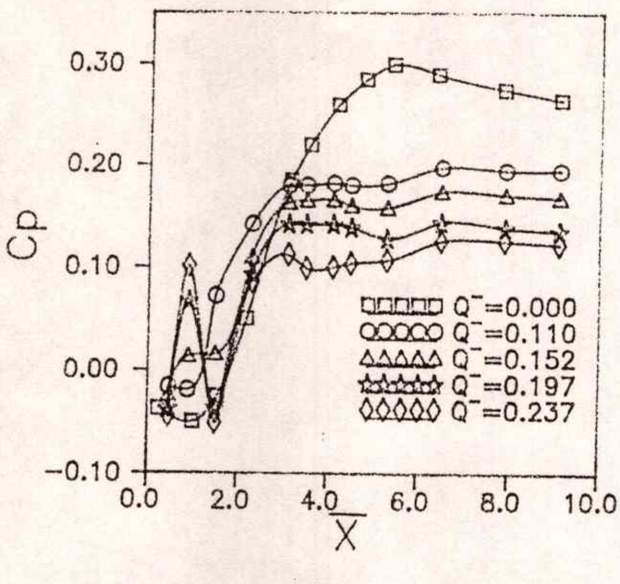
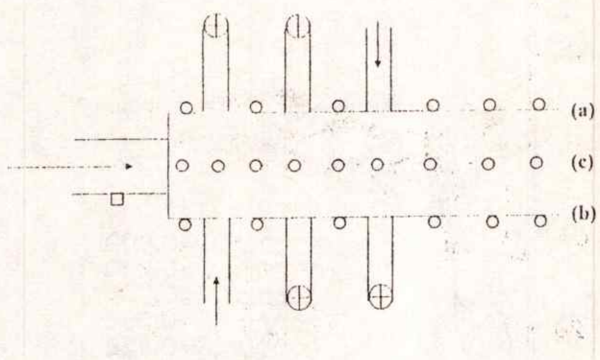
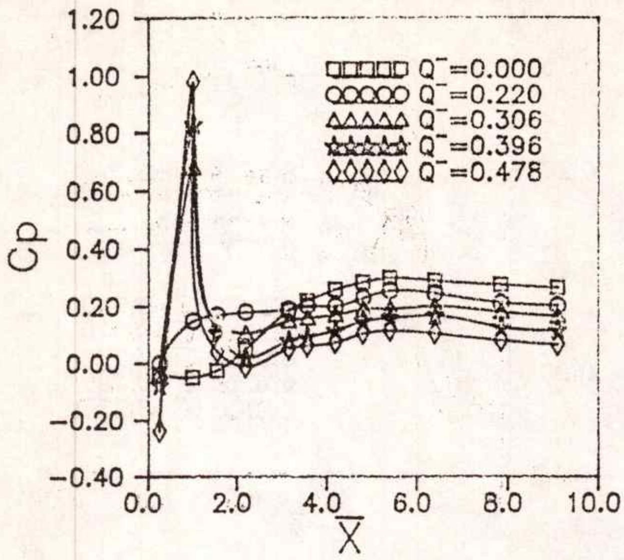


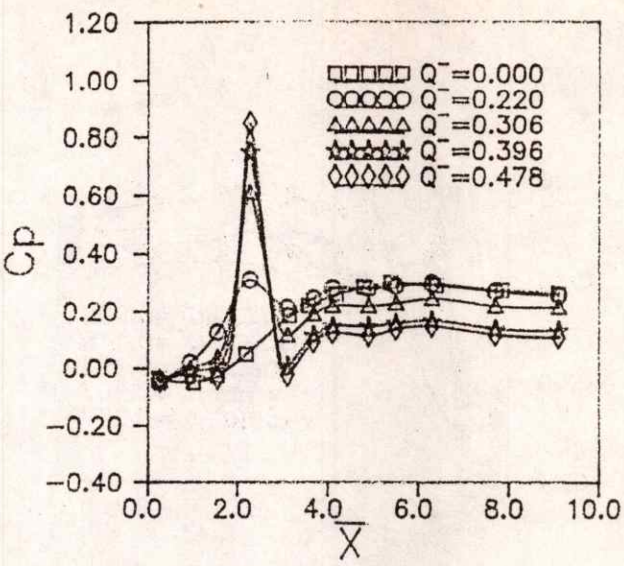


(c)

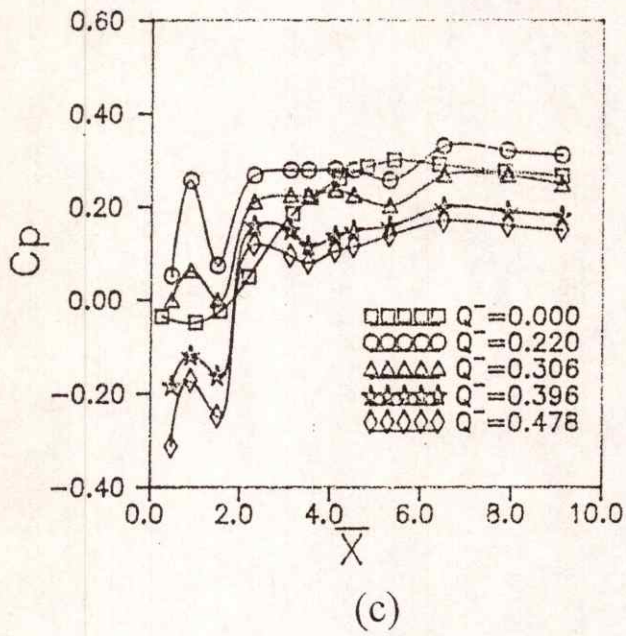
Fig. (5) : Effect of the injection ratio ($\overline{Q}$) for two – non symmetrical normal jets on the pressure recovery coefficient (Cp) at the second location of the jets($\overline{X}$ =0.64–1.75) for Re_{in}=10.7 × 10^4



(a)



(b)



(c)

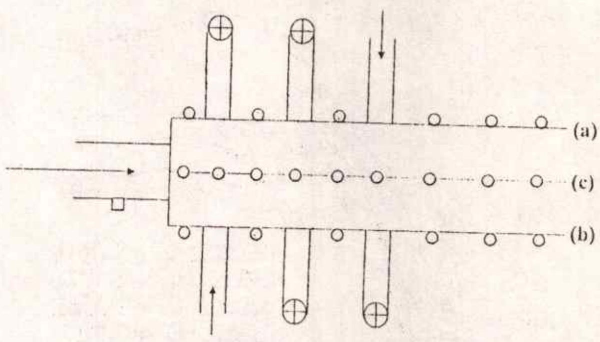
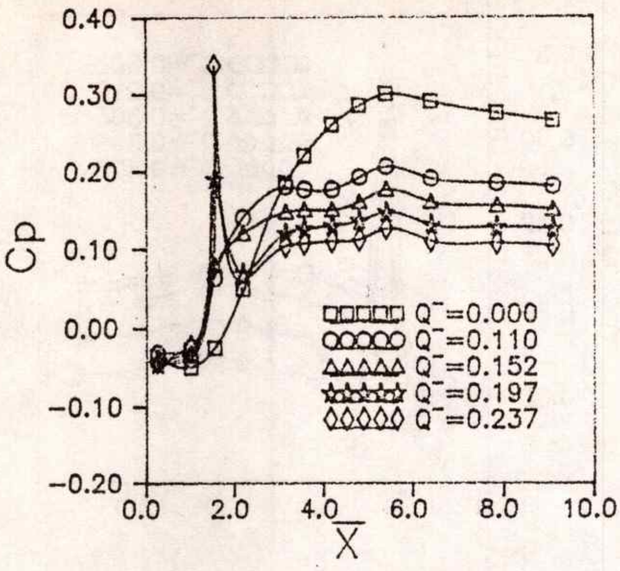
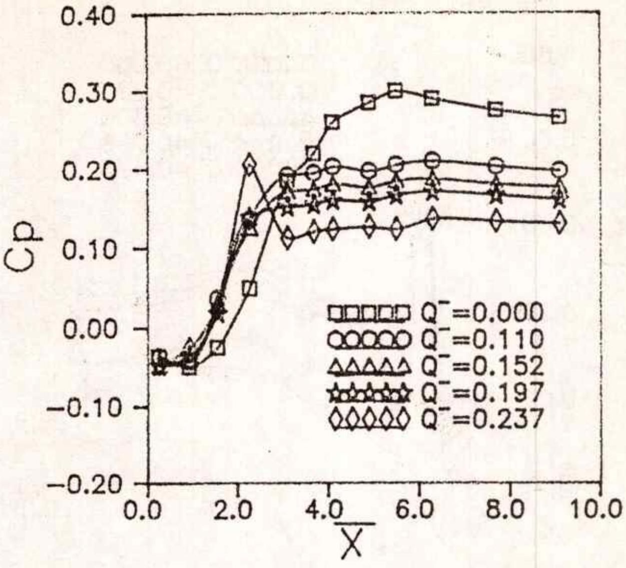


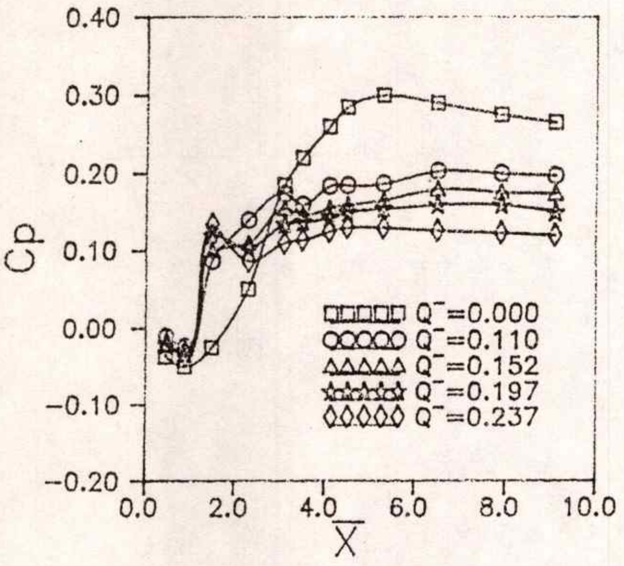
Fig. (6) : Effect of the injection ratio ($\overline{Q}$) for two – non symmetrical normal jets on the pressure recovery coefficient (Cp) at the second location of the jets ($\overline{X}$=0.64–1.75) for Re_{in}= 5.3 × 10^4



(a)



(b)



(c)

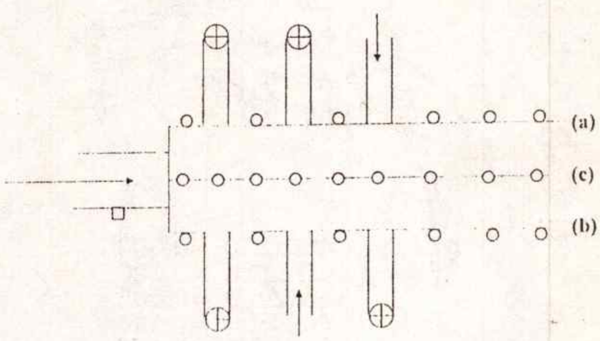
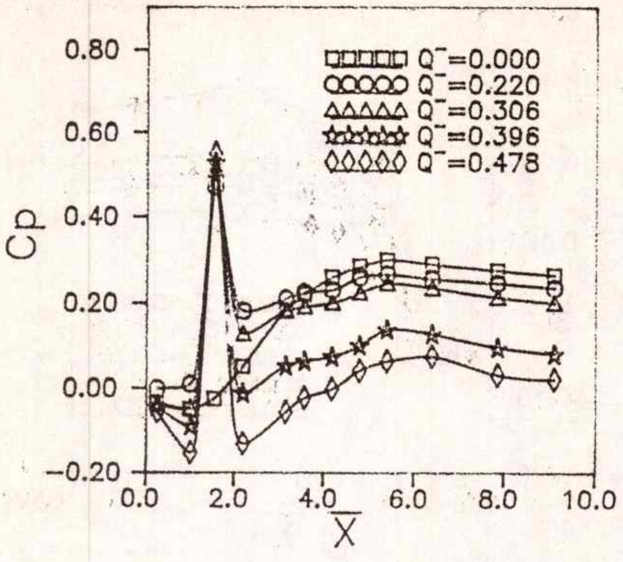
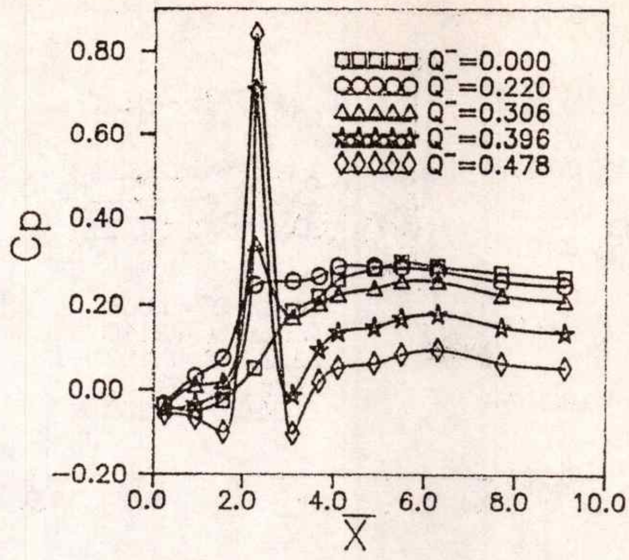


Fig. (7) : Effect of the injection ratio ($\overline{Q}$) for two – non symmetrical normal jets on the pressure recovery coefficient (Cp) at the third location of the jets ($\overline{X}$ =1.20–1.75) for Re_{in} = 10.7 × 10^4



(a)



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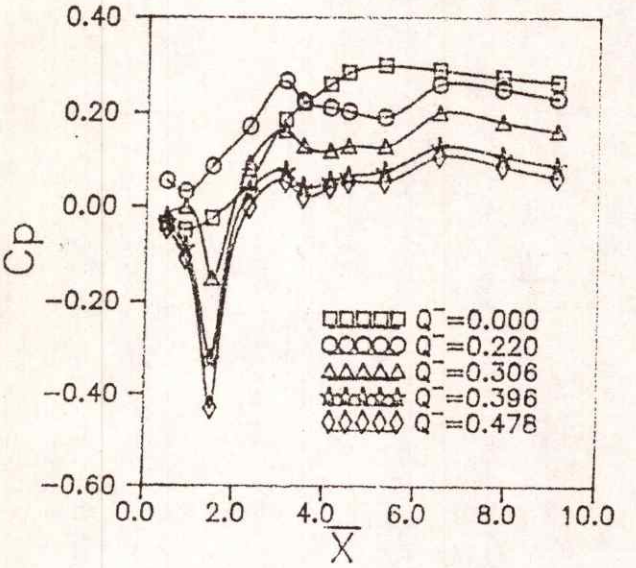
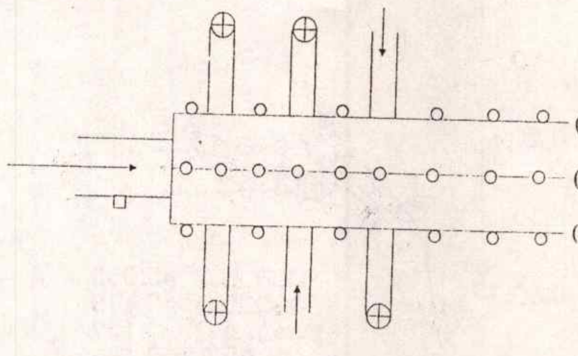
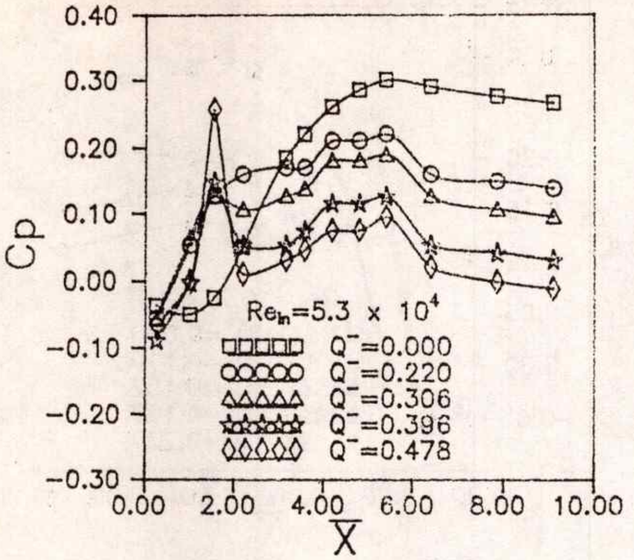


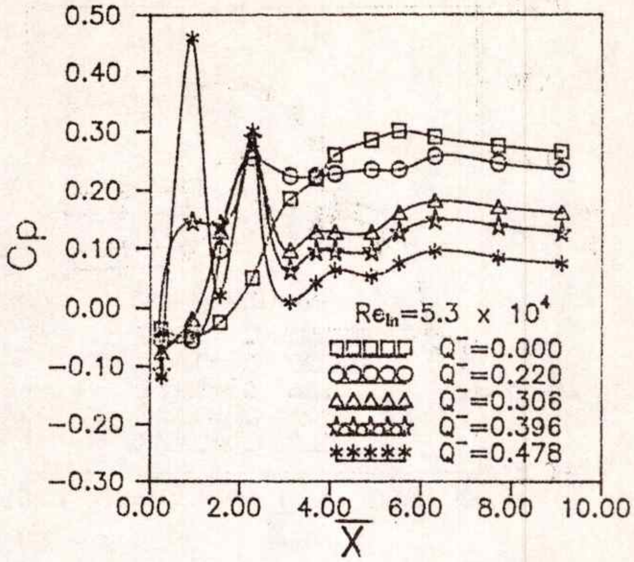


(c)

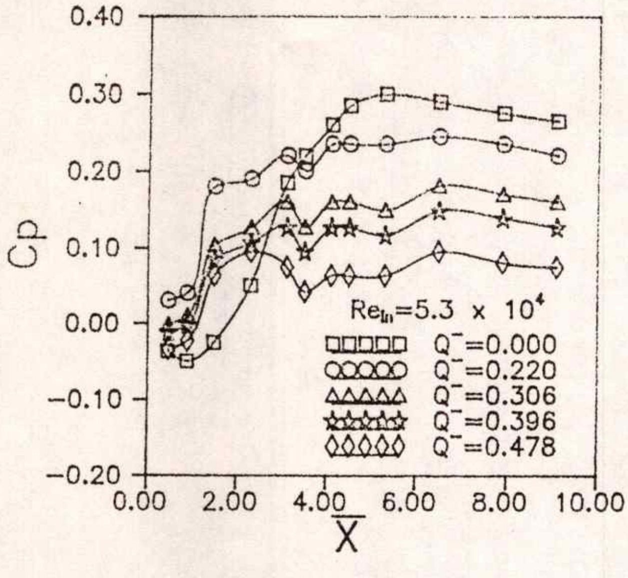
Fig. (8) : Effect of the injection ratio ($\overline{Q}$) for two – non symmetrical normal jets on the pressure recovery coefficient Cp at the third location of the jets ($\overline{X}$ =1.20–1.75) for $Re_{in} = 5.3 \times 10^4$



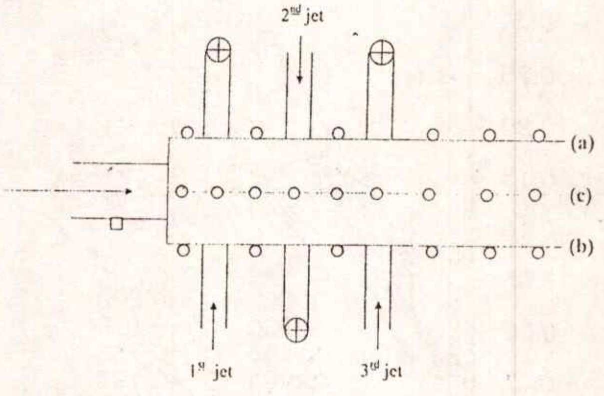
(a)



(b)

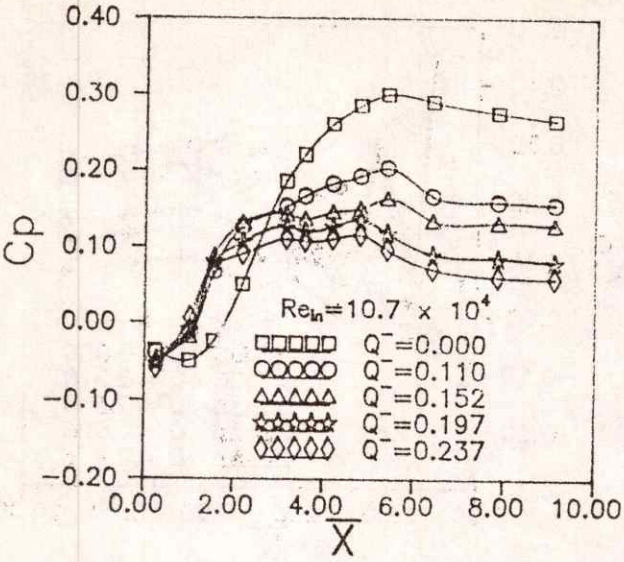


(c)

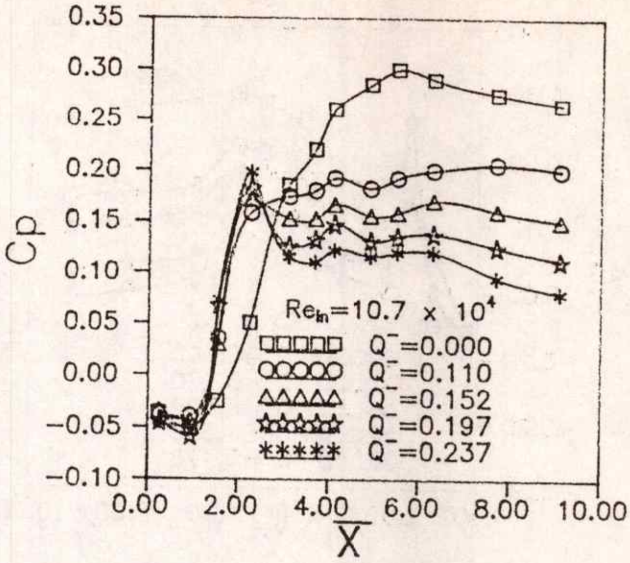


(d)

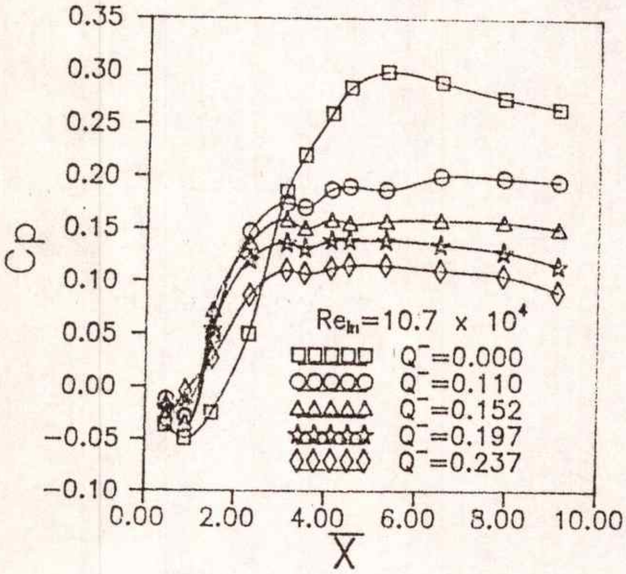
Fig. (9) : Effect of the injection ratio ($\overline{Q}$) for three –normal jets on the pressure recovery coefficient (Cp) at $Re_{in}= 5.3 \times 10^4$



(a)



(b)



(c)

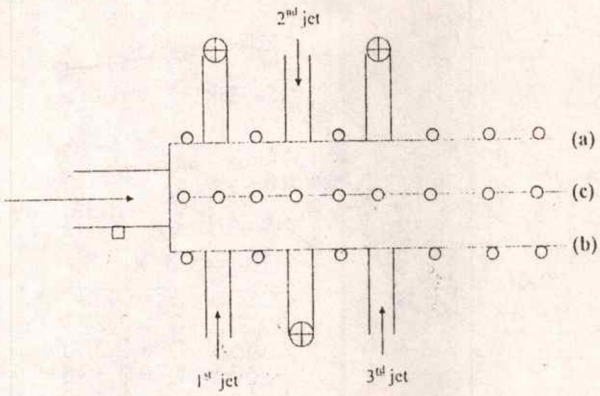


Fig. (10) : Effect of the injection ratio ($\overline{Q}$) for three –normal jets on the pressure recovery coefficient (Cp) at $Re_{in} = 10.7 \times 10^4$

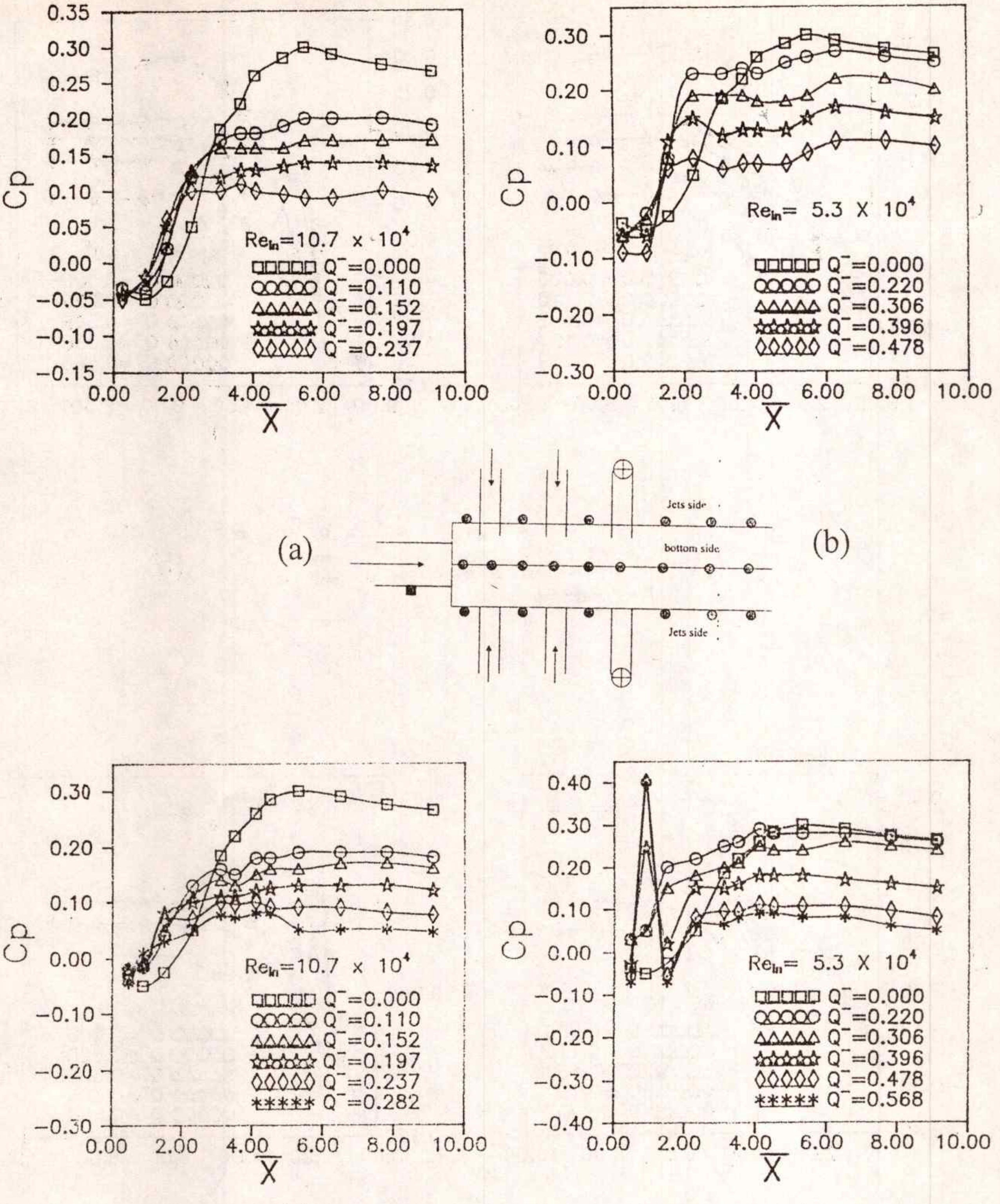


Fig. (11) : Effect of the injection ratio ($\overline{Q}$)on the pressure recovery coefficient (Cp) at the first location of the four – normal symmetrical jets ($\overline{X}$=0.64–1.20)

(a and b) for the side facing to the jets

(c and d) for the bottom side

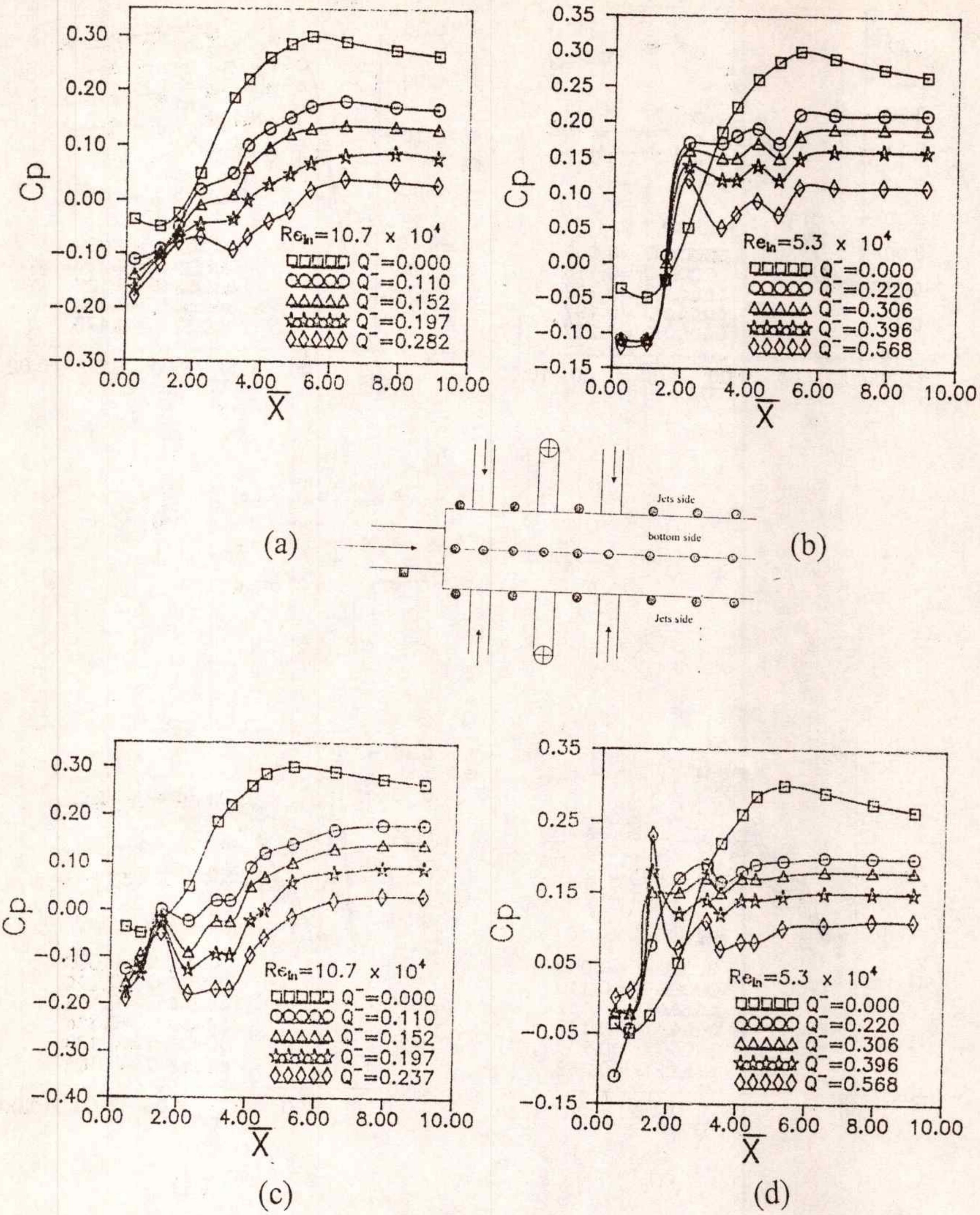


Fig. (12) : Effect of the injection ratio ($\overline{Q}$) on the pressure recovery coefficient (Cp) at the second location of the four – normal symmetrical jets ($\overline{X}$ =0.64–1.75)

(a and b) for the side facing to the jets

(c and d) for the bottom side

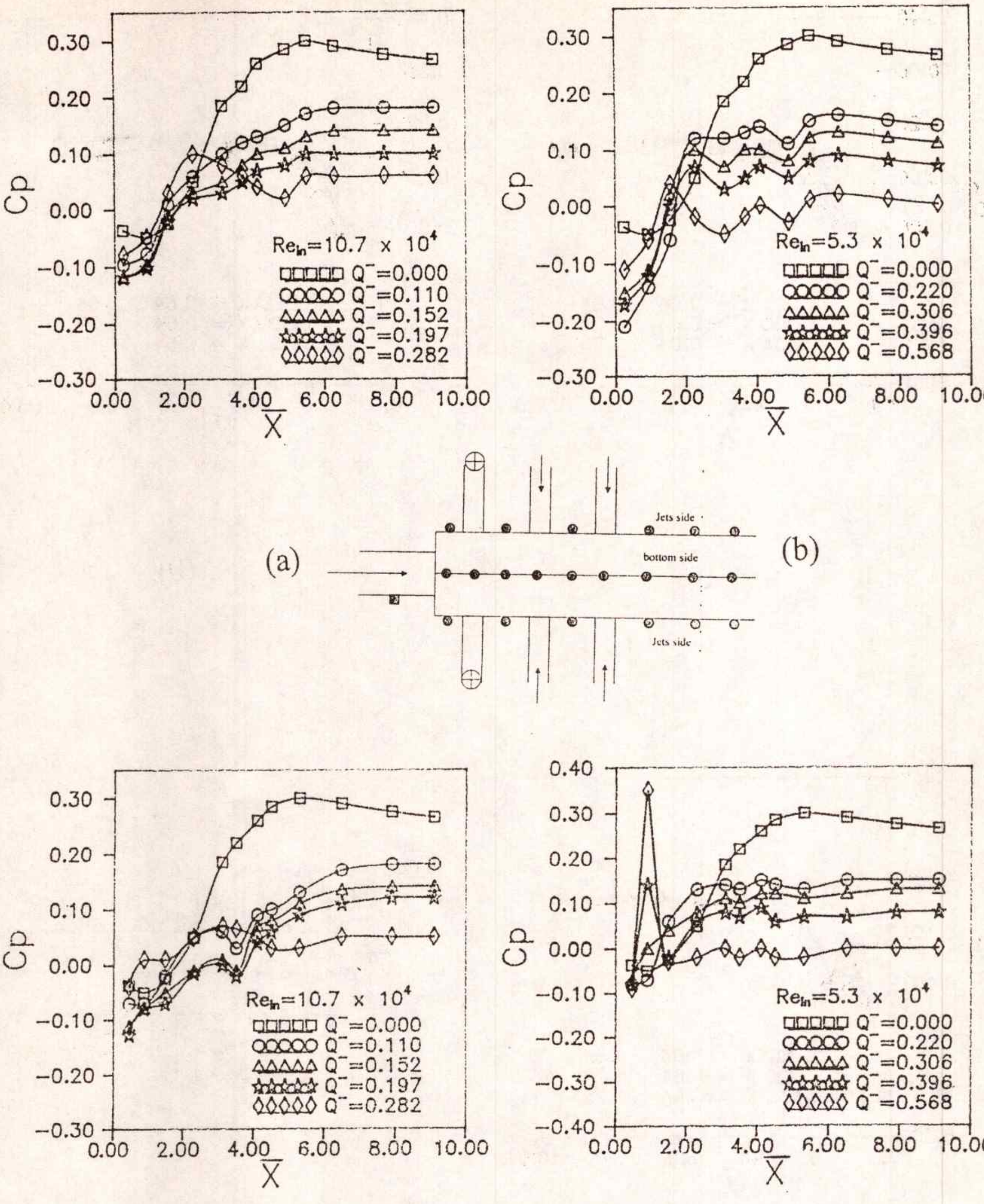
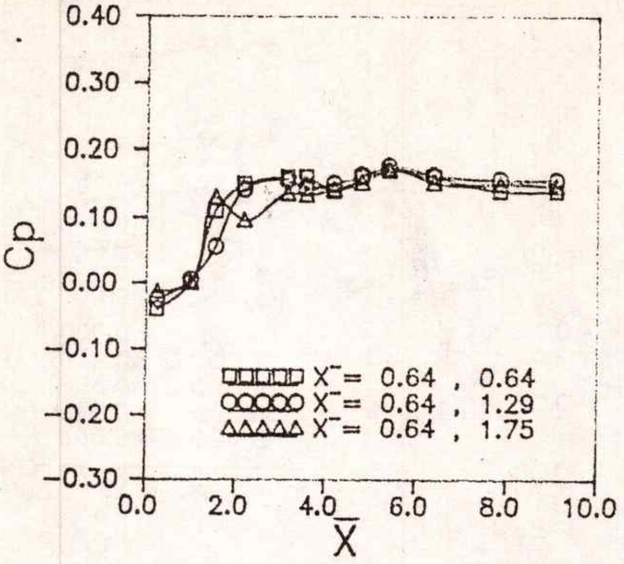


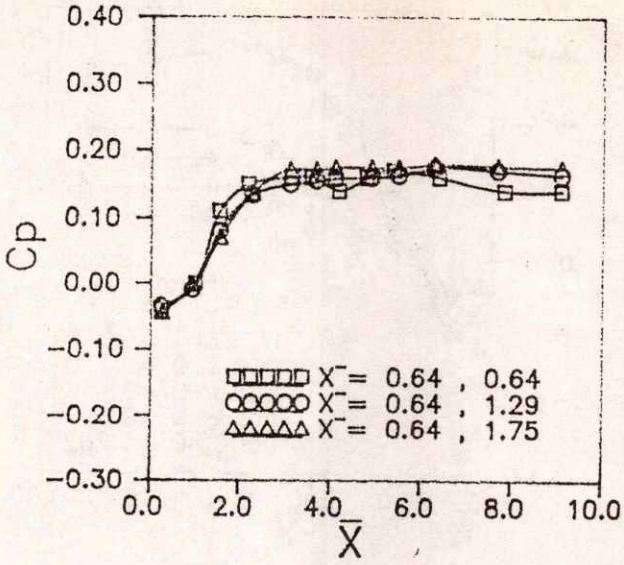
Fig. (13) : Effect of the injection ratio ($\overline{Q}$)on the pressure recovery coefficient (Cp) at the third location of the four – normal symmetrical jets ($\overline{X}$=1.20–1.75)

(a and b) for the side facing to the jets

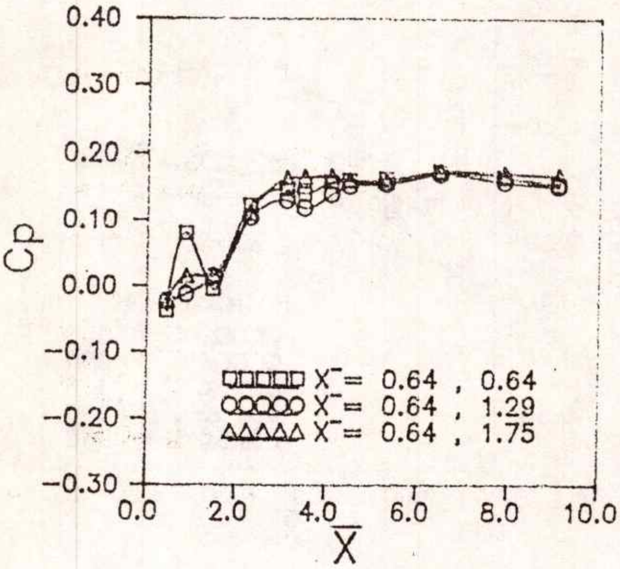
(c and d) for the bottom side



(a)



(b)



(c)

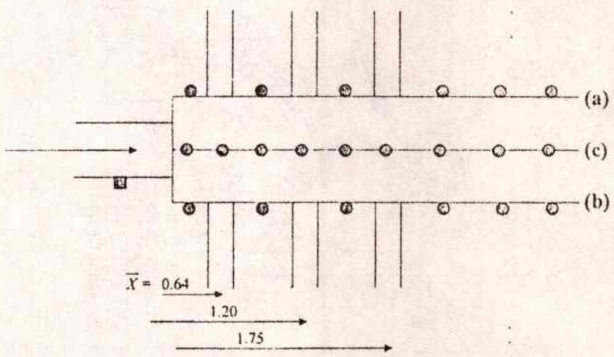
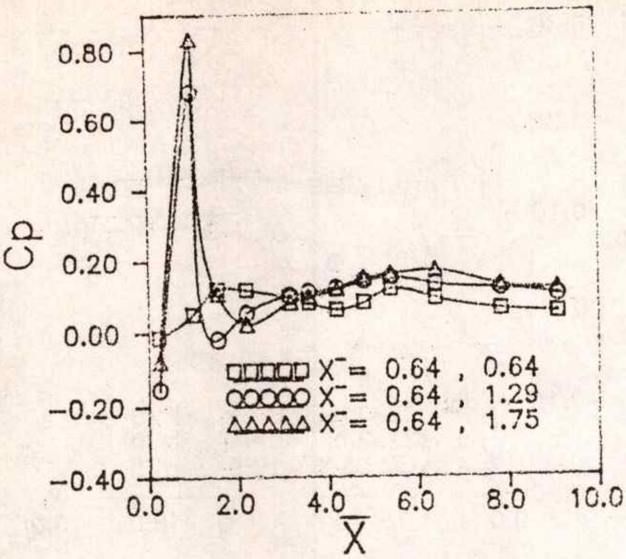
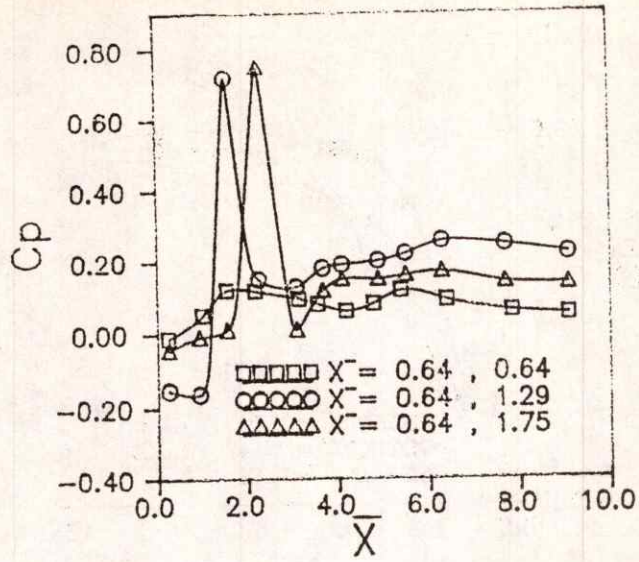


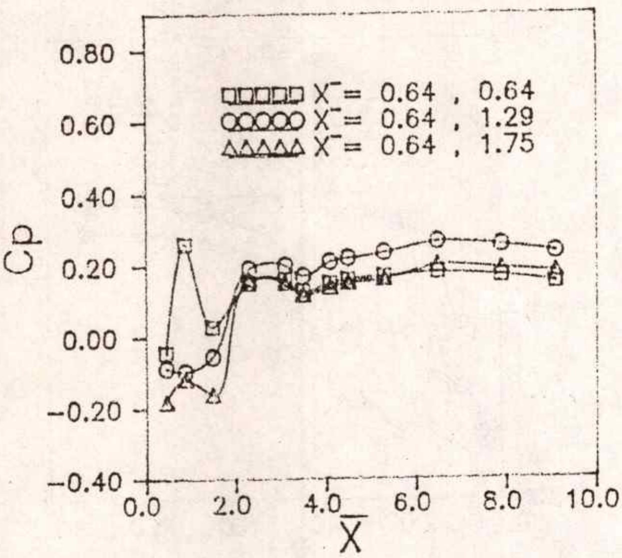
Fig. (14) : Effect of the two – non symmetrical jets location , $\overline{X}$ on the pressure recovery coefficient (Cp) at $\overline{Q}$ =0.237&Re_{in}=10.7× 10^4 ($\overline{X}$ =0.64–1.20 , 0.64 – 1.75 and $\overline{X}$ = 1.20 – 1.75)



(a)



(b)



(c)

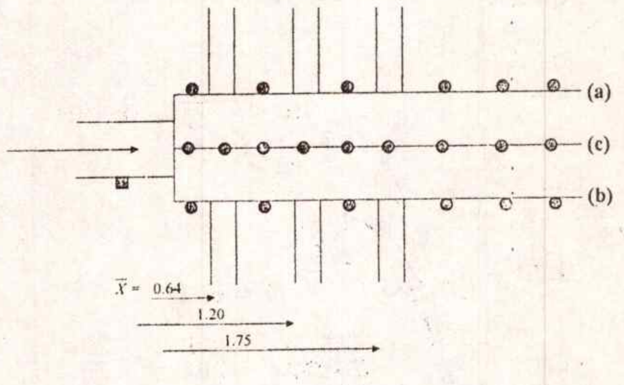


Fig. (15) : Effect of the two – non symmetrical jets location , $\overline{X}$ on the pressure recovery coefficient (Cp) at $\overline{Q}$ =0.396 & Re_{in}= 5.3×10^4 ($\overline{X}$ =0.64–1.20 , 0.64 – 1.75 and $\overline{X}$ = 1.20 – 1.75)

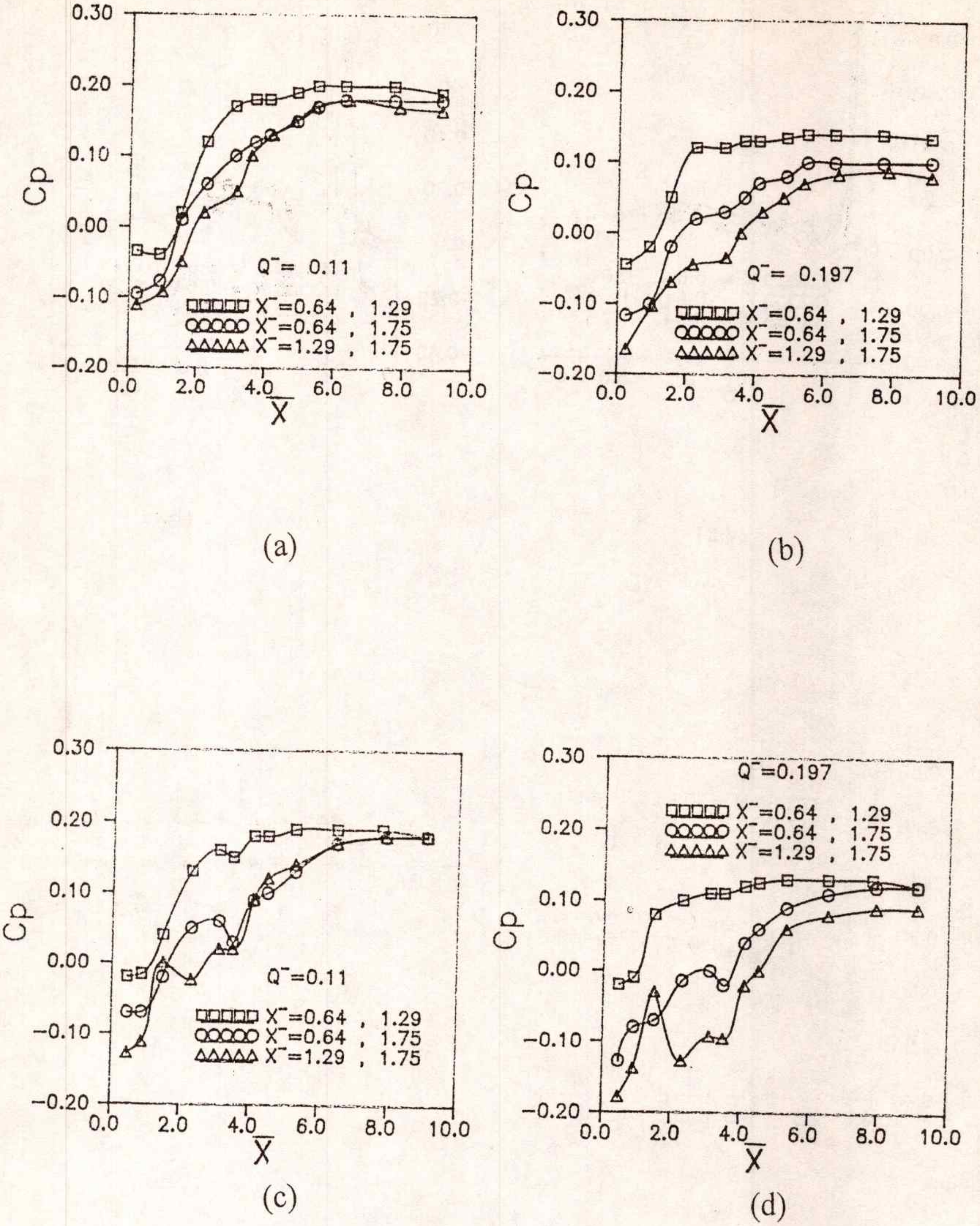


Fig. (16) : Effect of the four – symmetrical normal jets location , $\bar{X}$ on the pressure recovery coefficient (Cp) at $Re_{in} = 10.7\times 10^{4}$
(a and b) for the side facing to the jets
(c and d) for the bottom side
($\bar{X}$ =0.64–1.20 , 0.64 – 1.75 and $\bar{X}$ = 1.20 – 1.75)

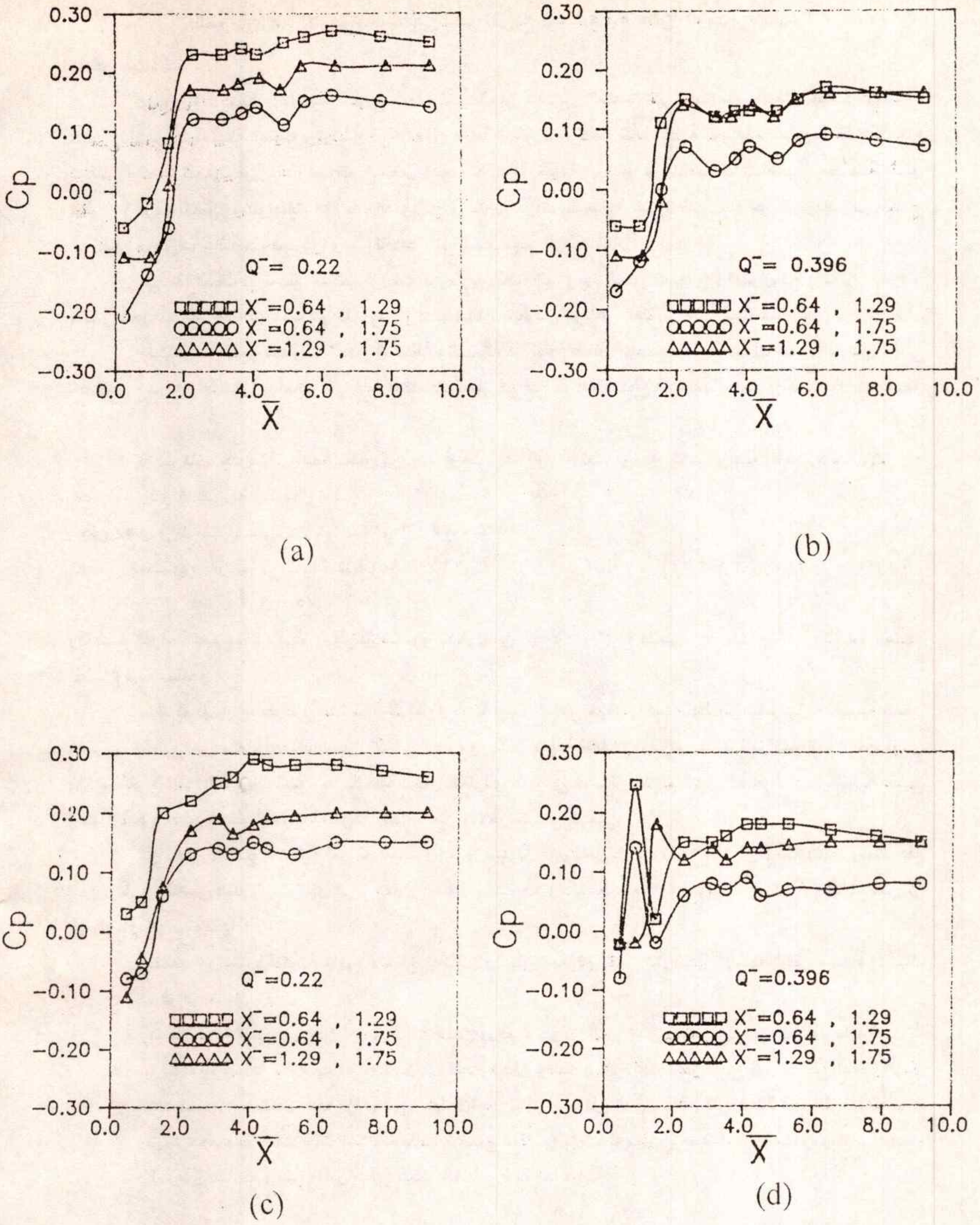


Fig. (17) : Effect of the four – symmetrical normal jets location , $\overline{X}$ on
the pressure recovery coefficient (Cp) at $Re_{in} = 5.3\times 10^{4}$
(a and b) for the side facing to the jets
(c and d) for the bottom side
($\overline{X}$ =0.64–1.20 , 0.64 – 1.75 and $\overline{X}$ = 1.20 – 1.75)

" السريان فى الأتساع المفاجئ لممر مربع المقطع مع حقن عمودى متعدد "

ملخص البحث :

يتناول هذا البحث بالدراسة التجريبية بيان تأثير الحقن العمودى المتعدد على خصائص السريان خلال الأتساع المفاجئ للممرات المربعة المقطع والمتمثل فى معامل الضغط المسترجع وكذلك حجم منطقة الدوامات المتكونة خلف الأتساع المفاجئ وكذلك خلف الحقن . هذا الموضوع مجال البحث له أهمية حيوية فى كثير من التطبيقات الهندسية المختلفة مثل الأفران وغرف الاحتراق للتربينات الغازية والصواريخ وكذلك العمليات الكيميائية التى تتطلب خلط جيد للمكونات التى تحتاج الى طاقة اضطراب عالية فى السريان والتى تساعد على الخلط الجيد للوسط العامل .

فى هذا البحث تم تخليق مناطق دوامات عن طريق ثلاث أنواع من الحقن العمودى والمتمثل فى (الحقن العمودى الثنائى الغير متماثل – الحقن العمودى الثلاثى – وكذلك الحقن العمودى الرباعى المتماثل على اتجاه السريان) .

تمت دراسة تأثير متغيرات الحقن المختلفة والمتمثلة فى نسبة الحقن موضع الحقن وكذلك عدد الحقن على خصائص السريان الأضطرابى لمائل غير قابل للإنضغاط المار فى قناة مربعة المقطع ذات اتساع مفاجئ عند أرقام رينولدز متعددة .

فى هذا البحث كانت حدود تغير نسبة الحقن من صفر وحتى ٤٧٨و٠ وتمت دراسة ثلاث مواضع للحقن كانت كالأتي :-

الحقن العمودى الثنائى الغير متماثل : (٦٤و – ٢٠و١ ، ٦٤و – ٧٥و١ ، ٢٠و١ – ٧٥و١)

الحقن العمودى الثلاثـــى :(٦٤و ، ٢٠و١ ، ٧٥و١)

الحقن العمودى الرباعى المتماثل: (٦٤و – ٦٤و ، ٢٠و١ – ٢٠و١) ، (٦٤و – ٦٤و ، ٧٥و١ – ٧٥و١) ، (٢٠و١ – ٢٠و١ ، ٧٥و١ – ٧٥و١)

وقد تمت الدراسة لقيم متعددة لرقم الرينولدز منسوباً للدخول من ٣و ٥ × ١٠ ^٤^ وحتى ٧و١٠ × ١٠ ^٤^ وكانت نسبة الأتساع فى المساحة (٥) .

وقد تم قياس الضغوط الأستاتيكية على طول ثلاث أوجه للمقطع المختبر عمد الخط المنصف لها ، بالنسبة للحقن العمودى الثنائى الغير متماثل وكذلك للحقن الثلاثى العمودى اثنان منهما متقابلان ومركب عليهما مواضع الحقن العمودى والثالث هو السطح السفلى للمقطع. أما بالنسبة للحقن العمودى الرباعى المتماثل فقد تم قياس الضغوط الأستاتيكية على وُجهين فقط للمقطع المختبر أحداهما المركب عليه الحقن والأخر السطح السفلى.

من تحليل النتائج المعملية التى تم الحصول عليها لمعرفة بيان تأثير كل من نسبة الحقن وموضع الحقن وكذلك عدد الحقن على خصائص السريان المتمثل في (معامل الضغط المسترجع وكذلك حجم منطقة الدوامات المتكونة) فقد تم التوصل الى النتائج الهامة ومنها :-

٥- منطقة لدوامات المتكونة خلفى الأتساع المفاجئ والحقن العمودى تتأثر تأثراً كبيراً بنسبة الحقن وعدده وكذلك برقم الرينولدز .

٦- هناك تأثير عكسى قوى بين كل من نسبة الحقن ورقم الرينولدز الأمر الذى ينعكس على منطقة الدوامات المتكونة

٧- تزداد حجم منطقة الدوامات المتكونة بزيادة نسبة الحقن وكذلك بزيادة عدد الحقن على طول المقطع المختبر تزداد عدد الدوامات المتكونة مما يؤدى الى زيادة الاضطراب فى السريان الذى يساعد على الخلط الجيد للوسط العامل .

٨- تزداد حجم منطقة الدوامات المتكونة خلف الأتساع المفاجئ بزيادة ترحيل مواضع الحقن العمودى فى اتجاه السريان مما يؤدى الى الأسراع فى عملية الخلط وزيادة كفاءته .