11th Australasian Fluid Mechanics Conference
University of Tasmania, Hobart, Australia
14-18 December 1992

A DETAILED STUDY ON THE FORMATION OF VENTURI EFFECT

A.A. WAHAB[1] and R.A. SAWYER[2]

[1]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai, Johor, MALAYSIA

[2]Dept of Aeronautical & Mechanical Engineering, University of Salford, UNITED KINGDOM

ABSTRACT

Detailed study on the formation of venturi effect in between buildings has been conducted in a simulated atmospheric boundary layer of suburban type in the 2.12m x 1.53m Salford University environmental wind tunnel. Four different venturi shapes ("V", "J", "Y" and "K") have been tested. The range of effective wind incidence angles for the occurrence of venturi effect, α_{ven} , and the variation of comfort parameter with systematic increase in venturi height have been determined. Also, the phenomenon of venturi effect occuring through the 360° wind direction in between Newton and Cockcroft Building has been varified. The experimental study and results are summarised and discussed in this paper.

NOTATION

D	Distance between two buildings, (m)
H, Ht	Building height, (m)
I	Turbulence intensity or local turbulence intensity
I_r	Turbulence intensity at the reference point
K	Ratio of the local to the reference velocities
L	Length of building, (m)
U	Wind velocity or wind speed or air velocity, (m/s)
U_r	Velocity at reference point, (m/s)
α_{ven}	Range of wind incidence angles for the occurrance of venturi effect, (deg.)
θ	Venturi included angle
ψ	Comfort parameter at pedestrian level

INTRODUCTION

Gandemer J (1975) described that for venturi effect to occur the venturi included angle must be ≤ 90°, the venturi neck (throat) must be ≤ 3 times the height and the total length of the buildings forming the venturi must be ≥ 100 metres. No information has been given on the wind direction or the range of wind incidence angles that can cause the venturi effect. Also the information given on the variation of comfort parameter with venturi height was limited and too general. Thus, an experimental study has been conducted to obtain these valuable details. In this study two "V" venturi configurations were used, both of the same total arms length (355m) and width (11.25m) but of different heights (ie 12m and 17.5m).

Wahab A.B.A (1992) reported that during his wind tunnel tests on the 1:250 Salford University Campus model venturi effect has been visualised to occur throughout the 360° wind directions in the area between Newton and Cockcroft Buildings (ie at location 18 of Figure 1). In order to understand this phenomenon wind tunnel tests have been conducted on another 3 different venturi shapes (ie the "J", "Y" and "K" shapes). The K-shape venturi resembles the venturi configuration forms by the Newton and Cockcroft Buildings. The experimental study and results are presented and discussed in this paper.

EXPERIMENTAL DETAILS

The experimental study reported in this paper has been conducted in a simulated atmospheric boundary layer of suburban type in the University of Salford 2.12m x 1.53m environmental wind tunnel. Prior to this study, surface oil film tests have been conducted on a V shape venturi to check for the suitable separation between buildings (venturi throat) that could exhibit effective venturi effect. These were done at 3 different venturi included angles (30°, 45° and 60°) and with its throat varies from 0.25 to 3 times of its height, ie in the range specified by Gandemer J [1975]. The throat of 0.5 time the venturi height was found to be the most outstanding one and has been used throughout the experimental study.

Range Of Effective Wind Incidence Angles

Surface oil film tests have been conducted on the V-shape venturi shown in Figure 2. By taking the line of symmetry of the V-shape venturi as the starting and reference wind direction, surface oil film tests were conducted for every 10° increment in wind incidence angle until there was no sign of the presence of the effect being detected. The test on the last 10° increment was then repeated by using a smaller increment of 2.5° each time. The last wind incidence angle that indicated no presence of the effect was noted as the right limiting wind incidence angle. The above steps were then repeated, but this time with the decrement in wind incidence angle, to get the left limiting wind incidence angle. The range of effective wind incidence angles was taken as starting from the left and ending at the right limiting angles. These tests were conducted at 3 different venturi included angles (30°, 45° and 60°).

Variation Of Comfort Parameters With Height

Tests were conducted on two similar V-shape venturi of heights 12 and 17.5 metres respectively as shown in Figure 2. The 12 and 17.5 metre height venturis represented two ranges of building heights, ie the Ht<15 and 15<Ht<25 metres respectively. Both the V-shape venturis were tested at 30°, 45° and 60° included angles. The wind velocities and turbulence intensities at pedestrian level for all the cases were measured by using a precalibrated DISA 55A01 constant temperature hot-wire anemometer. All measurements were taken at the centres of the venturi throats. These values were then converted into comfort parameters, ψ, using the relationship of

$$\psi = \{ [K(1+I)] / [1+I_r] \} \quad ......(1)$$

The 360° Venturi Effect Phenomenon

Flow visualisation tests, similar to those employed in finding α_{ven} have been conducted on the "J", "Y" and "K" venturi shapes (See Figure 2) with each shape having three values of included angle: 30°, 45° and 60°.

Results and Discussions

i). The limiting wind incidence angles for 30, 45 and 60 degree venturi included angles were found to be -88 and 88 degrees, -95 and 95 degrees, and -103 and 103 degrees respectively. If these limiting angles were substracted by half of their respective venturi included angles, then we obtained:

Included Angles	Result.Left Limit.Angles	Result.Right Limit.Angles
30°	$-88 + 15 = -73^\circ$	$88 - 15 = 73^\circ$
45°	$-95 + 22.5 = -72.5^\circ$	$95 - 22.5 = 72.5^\circ$
60°	$-103 + 30 = 73^\circ$	$103 - 30 = 73^\circ$

Thus, it could be seen that for venturi effect to occur the wind incidence angle must be in the range of $-73-\theta/2 < \alpha_{ven} < 73+\theta/2$ degrees.

ii). The comfort parameters measured are as follow:

Height Ranges	Comfort Parameters: Venturi Included Angle 30°	45°	60°
< 15 metres (12 metres)	1.0	1.0	1.0
15<Ht<25metres (17.5 metres)	1.1	1.1	1.1

Table I. Measured Comfort Parameters

Table I shows that:- a). the comfort parameter did not depend on the venturi included angles, b). at the height range of < 15 metres, there could hardly seen any difference between flow conditions at freestream and at the venturi affected area, and c). the comfort parameters were seen to built up when the venturi height became greater than 15 metres and at 17.5 metre height the comfort parameter measured was around 1.1 which would be taken to present the comfort parameter for the height range of 15 < height < 25 metres.

iii). From Figure 3 the ranges of wind incidence angles for venturi effect to occur in the J and Y-shape venturis are found to be $(-65-\psi/2)^\circ \leq \alpha_{ven} \leq (97.5+\psi/2)^\circ$ and $(-72.5 -\psi/2)^\circ \leq \alpha_{ven} \leq (72.5+\psi/2)^\circ$ respectively. The range of incidence angles for the Y-shape venturi is similar to the one for the V-shape. For the J-shape venturi, its right limiting angle is larger than its left one and a little bigger than the one for V-shape venturi. This is due to the longer left arm deflecting winds from a bigger wind direction into the J-shape venturi itself.

iv). The maximum ranges of effective wind incidence angles (ie when $\theta = 90^\circ$) for the J and Y-shape venturis whould be $-110^\circ \leq \alpha_{ven} \leq 142.5^\circ$ and $-117.5^\circ \leq \alpha_{ven} \leq 117.5^\circ$ respectively. Thus the total wind incidence angles responsible for the formation of venturi effect in the J and Y-shape venturis will be 252.5° and 235° respectively. These indicate that venturi effect does not take place for the whole 360° wind directions.

v). Figure 3 shows also that in the K-shape venturi, the venturi effect has occurred starting from -75° and ending at $+75^\circ$ of the inner walls of the upper and lower halves of building A respectively. Then total wind incidence angles responsible for the formation of venturi effect in the K-shape venturi will be $(2 \times 73) + 180 = 326^\circ$. Since the K-shape venturi was made to resemble the venturi formed by the Newton and Peel Buildings, then the venturi effect being visualised to occur throughout the 16 compass point wind directions in between the two said buildings was not a mistake but rather a reality.

vi). The occurrence of venturi effect for a total of 326° wind incidence angles in the K-shape venturi could be explained as follow:-

a). Consider the K-shape venturi as consisting of two separate V-shape venturis, ie one on top of the other, and take the top and bottom venturi included angles to be 60 and 30 degrees respectively. Then the total wind incidence angles responsible for the formation of venturi effect in the top and bottom venturis will be (2x73)+60 and (2x73)+30 degrees respectively.

b). Draw these two total effective wind incidence angles onto their respective venturi configurations. Some overlapping between the two total effective wind incidence angles do occur as shown Figure 4. It is clearly seen that the right limiting wind direction for the top venturi (arrows AA to XX) falls into the range of effective wind incidence angles of the bottom. Similarly, the left limiting wind incidence angle of the bottom venturi (arrows BB to YY) also falls into the range of effective wind incidence angles of the top. These imply that when the venturi effect in the top becomes weak and lastly diminished, the venturi effect in the bottom becomes strong and stronger and vice versa. Thus venturi effect in K-shape venturi occurs starting from the top left limiting angle to the right and up to the bottom right limiting angle. Then the total range of wind incidence angles for any K-shape venturi will always be 326°.

ii). From (vi) above, it could be deduced that for X-shape venturi, the venturi effects will occur throughout the 360° wind directions.

CONCLUSIONS

i). The ranges of wind incidence angles for venturi effect to occur in the V, J and Y-shape venturis are found to be $(-73-\psi/2)^\circ \leq \alpha_{ven} \leq (73+\psi/2)^\circ$, $(-65-\psi/2)^\circ \leq \alpha_{ven} \leq (97.5+\psi/2)^\circ$ and $(-72.5-\psi/2)^\circ \leq \alpha_{ven} \leq (72.5+\psi/2)^\circ$ respectively. Thus in general the range of effective wind incidence angles for venturi effect will be taken as $(-73-\psi/2)^\circ \leq \alpha_{ven} \leq (73+\psi/2)^\circ$.

ii). In the K and X-shape venturis, the total range of wind incidence angles have been found to be 326° and 360° respectively. It is concluded that venturi effect does occur throughout the 360° wind directions in between the Newton and Cockcroft Buildings.

iii). The variations of comfort parameters with venturi heights are as follow:

Height Ranges	Comfort Parameters
Ht < 15 metres	ψ < 1.0*
15 < Ht < 25 m	ψ may reach 1.1*
25 < Ht < 30 m	ψ may reach 1.3#
30 < Ht < 50 m	1.3 < ψ < 1.6#

* Experimental values
\# Values from Gandemer J. [1975]

Table II. Variation of Comfort Parameters with Heights

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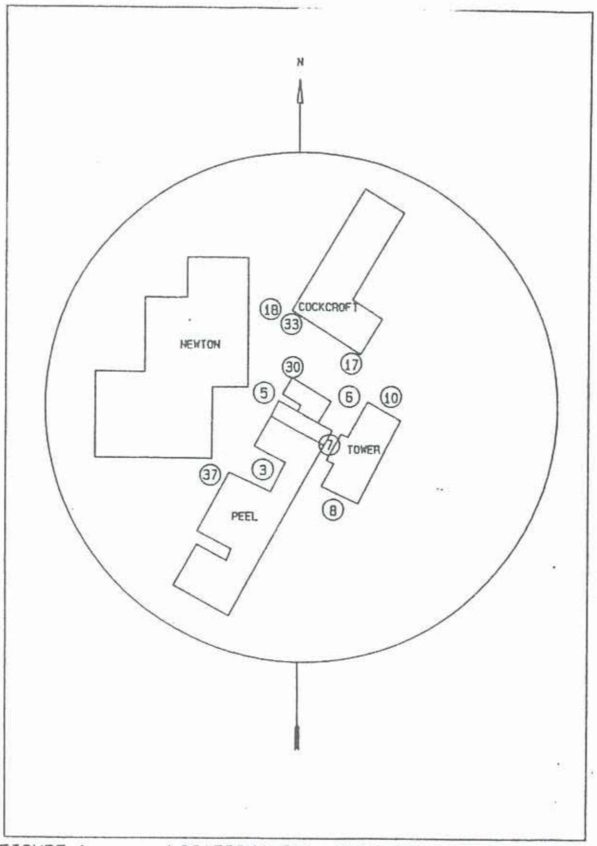

FIGURE 1 LOCATIONS FOR MEASURING AIR VELOCITIES AND TURBULENT INTENSITIES

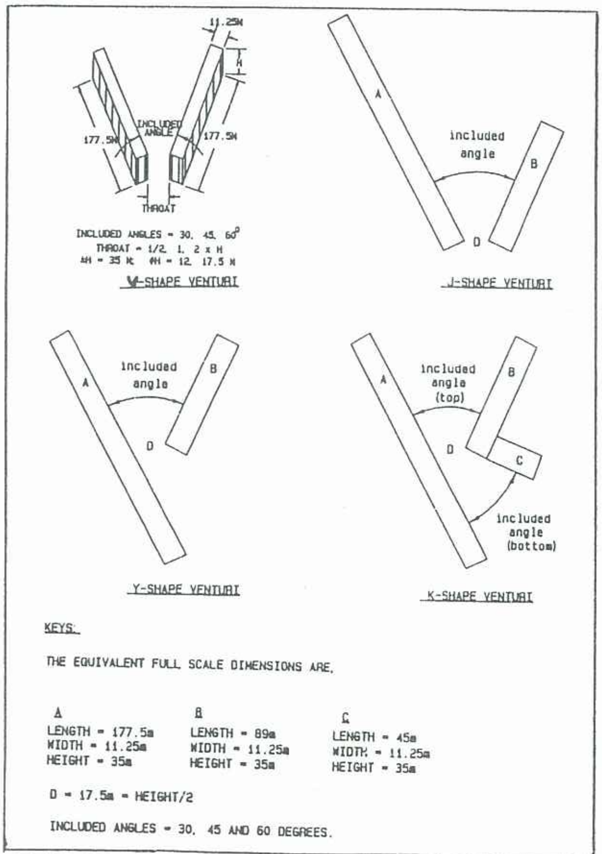

FIGURE 2 VENTURI CONFIGURATIONS

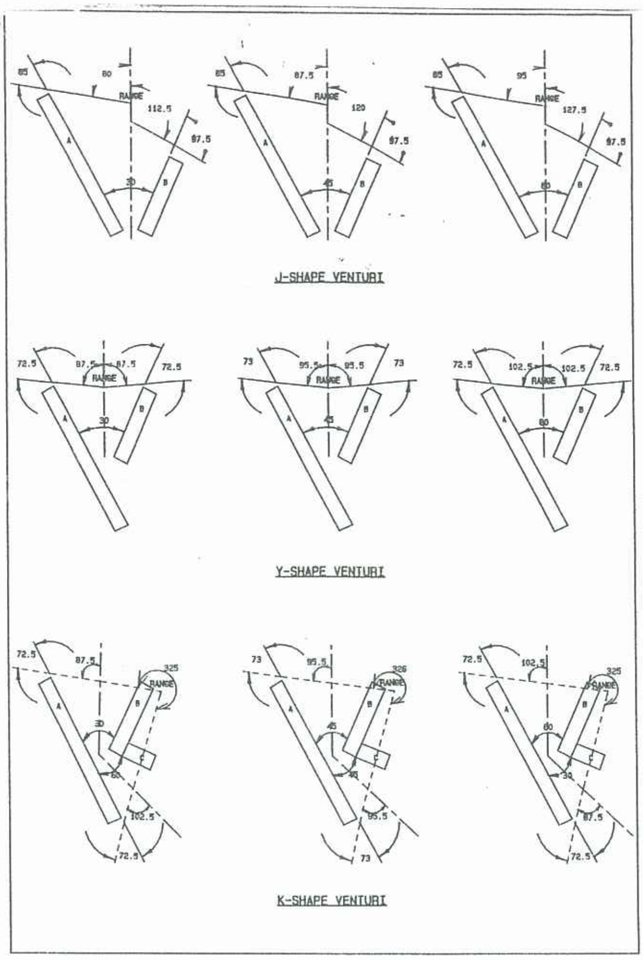

FIGURE 3 RANGES OF WIND INCIDENCE ANGLES FOR THE J, Y AND K-SHAPE VENTURI CONFIGURATIONS

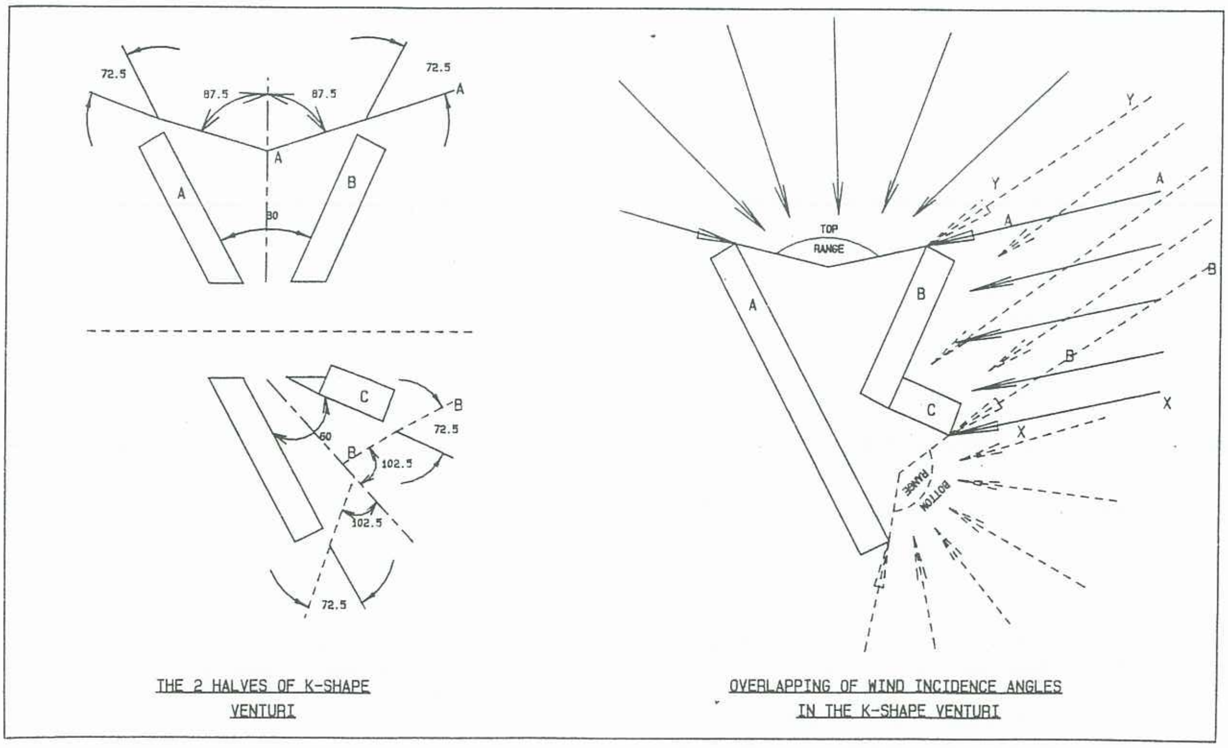

FIGURE 4 VENTURI EFFECT IN THE K-SHAPE VENTURI CONFIGURATION