air movements around buildings

(an investigation study)

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Thesis

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ABSTRACT
(Türkçe)

Bu araştırma, binalar etrafındaki hava akımlarını inceleyerek mimaride uygulanabilecek bazı pratik sonuçlara gitmeyi hedef almıştır.

Çalışmanın metodu, rüzgâr tünelinde, duman deneyimleri ile hava akımının görünümünü sağlayarak aynı veya farklı yükseklikte 2 bina arasındaki akımı incelemektir. Dört ana grup etrafında 60 adet deneyim yapılmıştır. Her deneyimde bina yükseklikleri aralarındaki mesafe ve hız değişmektedir. Sonuç deneyim sırasında çekilen filmi inceleyip, analiz etmekle elde edilmeğe çalışılmış, doğrudan gözlem yapılamamıştır.

İnceleme binalara etki eden hava akımının biçimlerini, jet akışı, akım ayırımı, akım yoğunluğu, cisimlerin arka akımı (akım içi izleri), girdaplar, yanal akımları, ortalı girdaplar, aşağı yalama ve yüzeysel akım gibi gruplar altında almıştır.

Çalışmadaki hata miktarı ölçüsel olarak saptanamadığı gibi, tamamlayıcı tam ölçekte (gerçek) de destekleyici çalışmalar yapılmamıştır. Sadece daha önce benzer çalışmaların sonuçları ile karşılaştırılmış çelişkili sonuçlar alınmadığı, fakat benzer sonuçlara ulaşıldığı görülmüştür.

Çalışmanın sonunda gelecek araştırmacılara da daha iyi deney şartları altında nümerik ölçmelerle araştırmalarını desteklemeleri tavsiye edilmiştir.

ABSTRACT
(English)

This investigation had been done to study air flow patterns around buildings in order to obtain some practical results for usage in architecture.

The method of the study was observation of flow visualization (by smoke tests) over the buildings, in a wind tunnel. There were 60 cases of experiments mainly in 4 groups with 2 buildings, having different heights and distances between them under three different velocities. The conclusion had been tried to be achieved by examining and analysing the film of the experiments.

The analysis had dealt about types of flows around buildings; separation of flow, jet flow, intensity, wake of the bodies, vortices, horse shoe vortices, side flows, downwash and surface flow.

Since tha cost of error was unknown and complementary, full scale experiments have not been studied, the efficiency of studies could be checked only by the previous experiments which show similar results.

At the end of the study, it has been adviced that, the further studies should be done in more better conditions of experiments with parallel studies of numerical measurements.

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introduction
part I

I. 1. INTRODUCTION

Nowadays, overdiversification of knowledge and science is the result of increase of the rate of accumulation of knowledge and opportunity to know more with their demand near by them. Architecture, as becoming more science or technique than art is also in the situation of others.

Architecture, as a physical reflection of social organisations in the media of nature is becoming more and more scientific parallel to other disciplines where in one section men deal with the social and functional aspectsof architecture, and in the other section they deal with more physical aspects of it by means of new technological knowledge and devices. Within this context, wind, as a natural force affecting the forming of shells, has a place of its own.

From very early times, wind effects on buildings and their surroundings are well known. The famous historian "Vitrivius discussed the effects of towns in the I.C.B.C."[1] We can see other examples mostly in anonymous architecture

(1) 'A Discussion on Architectural Acrodynamics' National Physical Laboratory, London, 1971. p.335

where chimneys, openings and the location of the buildings are placed and designed according to local winds.

It is apparent that wind loads on all building shapes are as complex in description as the shapes themselves. This complexity is considerably reduced if the designer is familiar with the characteristics of flow around bodies (buildings, structures, etc.) and can use this knowledge in his designing process. The prime object of this thesis study is a trial of searching this knowledge by means of some experiments in wind tunnel.

It is well expected that this thesis study must be perceived as a trial of an approach to an experiment within this scope, which is done by a Master student who knows her discrepancy within this subject, as being an architect, and the study done at one of the universities of Turkey, M.E.T.U., (See App.A.). Although it has been tried to achieve autocriticism of various aspects of this study within this report, other criticisms will be well appreciated.

I. 1.2. Air Movements Affecting The Architectural Environment.

Wind has mainly two basic characters, one, being a force inducer, the other, a movement inducer to an environment. Today, building owners, architects and engineers are becoming more interested in these environmental problems they create along with their buildings. In general, we can classify these effects resulting as advantages and disadvantages. If we briefly state:

I. 1.2.1. Disadvantages of Wind Effects:

- They are causes of structural failures (force effect)
  - lifting roofs
  - dragging surface claddings
  - destruction of suspansion bridges (because of oscillation)
  - other destruction of structures - damping, dynamic loading, impact loading, fatigue, etc.
  - damage to plants and trees.
- They make the physical qualities of the environment worse
  - assisting the penetration of water in surfaces
  - assisting snow accumulation[2]
  - warn of surfaces by dusts and other grainy materials
  - assisting to lose off heat of buildings
  - spreading the dust, smoke and odor
  - lifting dresses at pedestrian levels, interrupting activities[3]
  - making troubles to bicycle riders[4] and other drivers
  - from leaky windows or attachments to buildings such as signs and sun control devices noise come with the effect of wind[5]

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(2) ARONIN, 'Climate and Architecture' Elsevier Pub.Comp. N.S.A., 1968, p.179.

(3) Architectural Science Review, March 1972,Vol.15,No.1 'Wind Effects Around Buildings',p.9.

(4) 'A Discussion on Architectural Aerodynamics' National laboratory,London,1971, pp.493.

- spraying from nearby mountains or sea
- drying out of planting beds
- buffeting of vehicles on adjacent elevated roadways[6]
- assisting the accumulation of air pollution at special places
- increasing the effect of air pollution on buildings, as a dirt source, as a carrier of chemical particles damage
- others

I.1.2.2. Advantages of Wind Effects:

Although it seems that disadvantages of wind is much, there are some advantages also.

- it ventilates
- evaporates moisture and dries surfaces
- cools
- it has a comfort element of climatic conditions[7]
- it warms by preventing cold air sinking at night[8]
- it is a source of power

I.1.2.3. Environment Shapes the Wind :

While wind effects its environment, the environment assists the formation of the wind itself by:

- changing of heat
- topography and plantation upon it
- shape and relative location of buildings
- material differences
- others

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(5) Architectural Science Review, March 1972, Vol.15, No.1, ''Wind Effects Around Buildings', p.9

(6) ARONIN, 'Climate and Architecture', Elsevier Pub.Comp. N.S.A., 1968, p.179.

So, we can say there is a counter action or sometimes interrelation between air movement and its architectural surrounding. There is a gap of knowledge in this special aspect, and this is felt when there is a need to design urban centers and other big complexes. The problems are the same in all countries and may be more in Turkey as a developing country. Better understanding of behaviour of air movement could be obtained only by full scale experiments or model experiments in wind tunnels. Therefore, there is a need to study this subject.

I. 2. THE SCOPE OF THE STUDY

This is a Master Thesis Study which must be normally completed in one year. The study is divided mainly into two parts.. At the first part, where architectural research - ARCH.501 - study had been completed, is a research work as a base for the main thesis study. So, the goal of ARCH.501 study is to set the conditions, boundaries and dimensions of the thesis work, while, at the other part, the thesis study - ARCH.605 - is a kind of investigation of the field by some experiments. But because of the nature of the scientific study, there are some feedbacks - in this case, more detailed research of the field had been done. So, the sharp border of ARCH. 501 (Research) and ARCH.605 (Thesis) study is diminished and became a complete study.

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(7)'A Discussion on Architectural Aerodynamics' National Physical Laboratory, London, 1971, pp.493.

(8) ARONIN, 'Climate and Architecture' Elsevier Pub.Comp. N.S.A., 1968, p.179.

I. 2.1. The ARCH.501 Study.(Architectural Research)

At the beginning of the study, the name was 'Smoke Distribution Among Groups of Buildings and Characters of Wind'. Within the aim of this research, air movements, aerodynamics and their relation to buildings, and wind-tunnels and their characteristics and conditions of the wind tunnel has been studied, in order to complete the thesis study. At the end of this study, group of experiments and the aim of ARCH. 605 study have been set down. If results of the research study is briefly reviewed, we shall see following points:

- Results related to the Wind Tunnel:[9]

  - Up to certain revolution of the propeller(2200-2400RPM) the velocity in the tunnel increases as a function of straight line but after, small increase of RPM causes much more increase in velocity.
  - Velocity within the tunnel is not homogeneous all over the section
  - Maximum velocity, which has been observed in all velocities, is, at the bottom of the tunnel
  - And the velocity is distributed assymmetrically. The logical cause seems to be the shutter of the tunnel that has been played during the measuring.
  - These measurements are obtained with 5% accuracy.

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(9) ARCH. 501 Study - Winds and Structures. p.37.

- The experiment groups - goals and objectives[10]

Goal : Some experiments in the wind tunnel to give some criteria of control of air pollution and climatic situation to the designer.

Objectives : Experiments in the wind-tunnel will be done, by the observation of smoke distribution among groups of buildings and observing the variation of air movements with respect to the change in distance height of the buildings and the velocity.

Conditions of the experiments:

- Models will be three dimensional (Fig.1)
- Distribution of smoke will be observed horizontally and vertically.
- Experiments will be done at 3 different velocities of (1300, 2000, 2800 RPM)
- Since the Reynolds simulation formula cannot be applicable, the minimum blockage of the tunnel surfaces effecting the dimensioning of the models, then, the scale of the buildings are 1/100
- Model represents one street of the city with 6 buildings in two rows, and height of those are 30cms representing 10 storey building
- Heights will be changed from 30 to 5 and the distance between two rows from 25cm to 5 cm alternatively
- Model will be located in 3 different places as if wind is blowing from 3 different directions (Fig.1).

(10) ARCH. 501 Study - Winds and Structures, p.46

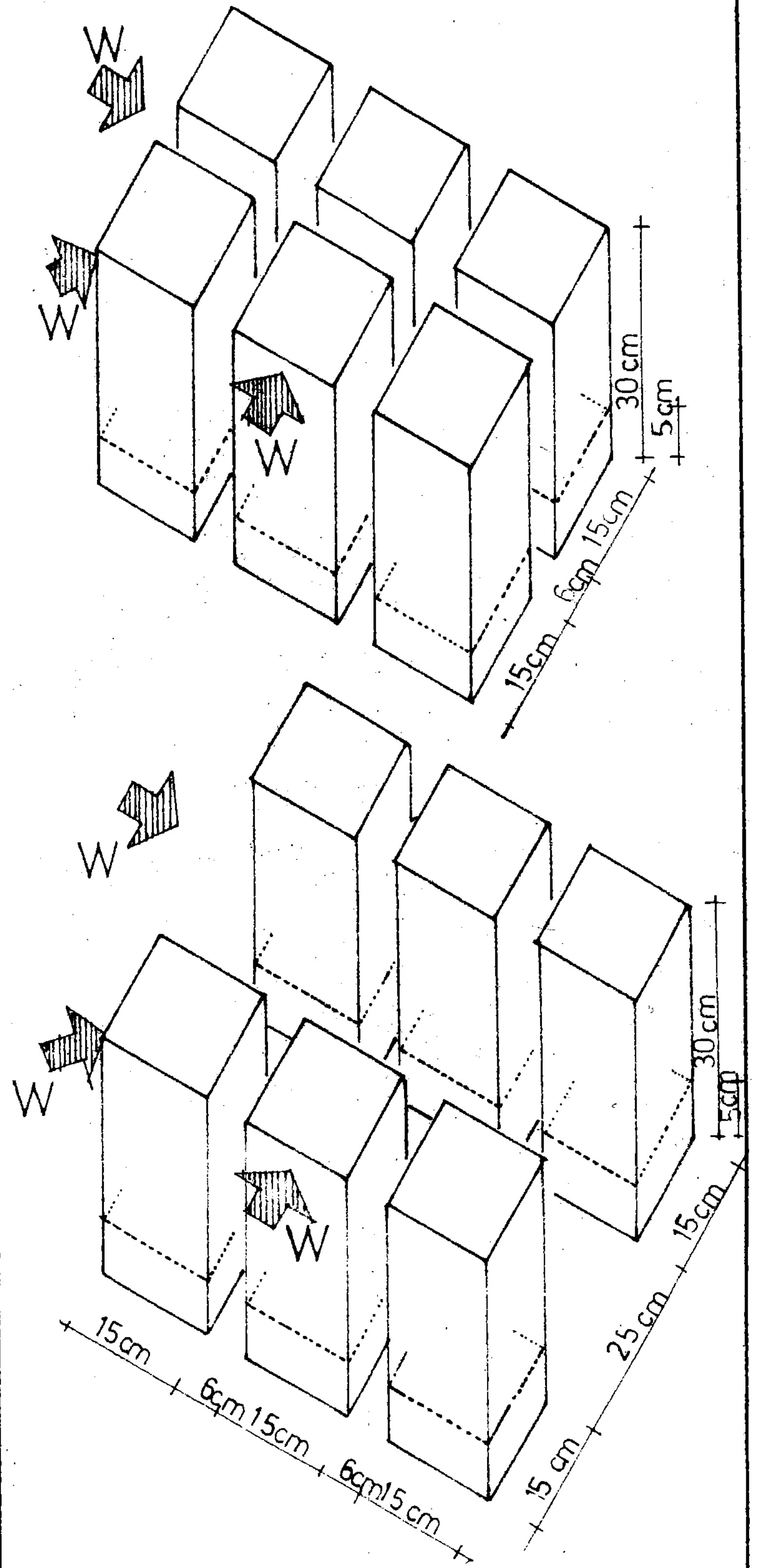

fig:1

Experiment groups suggested in Arch.501 study.(1/100 of full scale)

- The smoke pipe has holes of 1 mm diameters and 1 cm spacing between them, in order to let the smoke as streaks.

I. 2.2. Development of The Study - The Thesis Study.

At the beginning of the study, the check of velocities and their representation of reality had been done and seen that if Reynolds number is useless (See PART II.) then the Freude number could be useful and this resulted in very small velocities. The other problem was to obtain smoke and visualization of air movement. These studies and trials had changed the model and diminished its sizes to 20 cm by 10 x 10 cms, and the number of models, from 6 to 2 then, again, the scale of the model to 30x20x10cms, and velocities being dropped about 1200 RPM maximum, and instead of pipe, smoke had been spouted off hose. Then, at the end, the groups of experiments, their situations and the scale of the simulation had been changed. The story is told in detail in appendix A.

At the end, the goal has not been changed much, but the objectives and tools has been changed.

The New Goal : To obtain the effect of the triple velocity, height and distance on the wind-environment relationship which are important for city planners and urban architects as main variables of design.

The New Objectives : Wind tunnel experiments by flow visualization technique. This is a qualitative objective rather than quantitative. So, as a result in conclusion formulas and functional graphics cannot be offered except some sketches of flow patterns and their interpretations.

The new experiment conditions will be discussed in detail in PART III.

Ackoff discussed the research in six phases:

"1. Formulating the problem
2. Constructing the model
3. Testing the model
4. Deriving a solution from the model
5. Testing and controlling the solution
6. Implementing the solution" [11]

In this research of experiments, since the goal has been put in this way, and there is no opportunity to control the solutions by full scale experiments or measurements, the last two steps have not been done within the content of this study.

aerodynamics & buildings part II

II. 1. AERODYNAMICS AND BUILDINGS

II. 1.1. Wind.

Wind, as an environment described by Aronin, 'The sun heats the earth, warming it up to certain spots more than in others, the different temperature give use to unequal pressures, variations in pressure induce winds'.[12]

Air, with its molecular structure, has some physical characteristics. The molecular adhesive force is much more than cohesive forces in itself and because of this molecular adhesivity, there becomes a force between air layers which is called viscous forces. It is accepted incompressible under normal conditions. The movement of molecule increases with the increase in temperature and, experiments show that the movement of the particle is different than the movement of the layer of air.[13] In the condition of continuous flow, the amount of fluid passes through the same section in a specific time interval is constant.[14]

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(12) ARONIN, 'Climate and Architecture', Elsevier Pub.Comp. N.S.A., 1968, p.179.

(13)'Flow Visualization''National Committee for Fluid Mechanics Films, 1969.

(14) AKSAN, M., 'Uçuş Mekaniği' İTÜ Yayınları, İst.1955, p.19.

II. 1.2. Some Concepts About Air Movements and Aerodynamics.

II. 1.2.1. Types of Flow.[15]

Laminar Flow - All the fluid particles proceed along paths in it, and there is no transverse component of velocity gradient in laminar flow.(Fig.5) Laminar flow is associated with low velocities and viscous sluggish fluids.

Turbulent Flow - The progression of the fluid particles is irregular and there is seemingly haphazard interchange of position. Individual particles are subject to fluctuating transverse velocities so that, the motion is eddying and sinuous rather than rectilinear. Turbulent motion is almost at random, it must be studied by taking statistical averages. The velocity profiles will depend slightly on the Reynolds number, like the profiles in a turbulent boundary layer.

Rotational Flow - If each particle has an angular velocity about its own mass centre, it would be considered rotational.

Irrotational Flow - The velocity adjacent to the straight boundary must be uniform in case of flow in a circular path, it may be shown that irrotational flow will only pertain by providing the velocity inversely proportional to the radius.

(15) WEBBER, N.B. 'Fluid Mechanics for Civil Engineers', Great Britain, 1965, pp. 26-29.

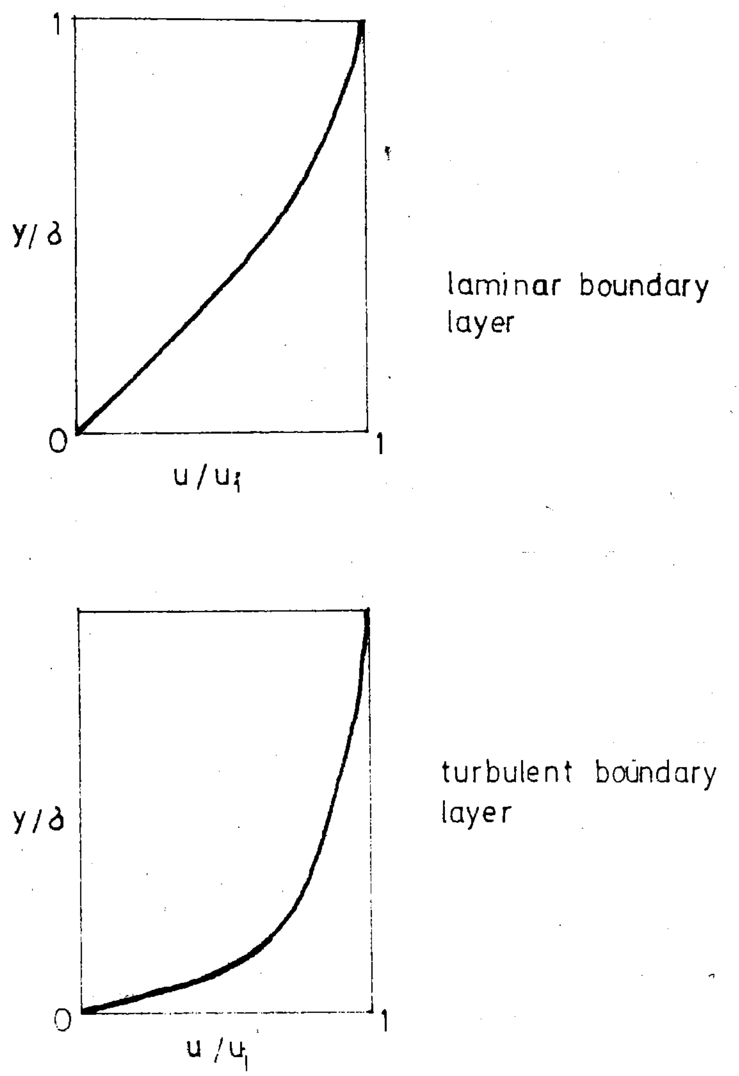

fig: 5
Boundary layer velocity profiles at law Mach numbers with no longitiudunal pressure gradient.

<u>Steady Flow</u> - It is said that, it exists when the conditions at any point are constant with respect to time. Turbulent flow will never be truly steady.

<u>Unsteady Flow</u> - When conditions vary with respect to time.

<u>Uniform Flow</u> - When there is no variation in the magnitude and direction of the velocity vector from one point to another along the path of flow. Both the area of the flow and the velocity must be the same at every cross-section.

<u>Non-Uniform Flow</u> - Occurs when the velocity vector varies with location, a typical example being flow between converging and diverging boundaries.

<u>Perfect Flow</u> - Flow without viscosity, namely, outside the boundary layer.

II. 1.2.2. Characteristics of Flow.

<u>Boundary Layer</u> - The layer of air from the surface of the body to the absence of viscosity within the fluid,(air).[16] The depth of boundary layer depends on the roughness of the surface.

In atmosphere, it varies 300 m. in open country, to 500 m., over large towns.[17]

Static pressure within the boundary layer is constant at a given streamwise position and equal to the static pressure just outside the layer. Boundary layer velocity profiles (at low Mach numbers) with no longitudinal pressure gradient is different in laminar flow and turbulent flow. (Fig.5).

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(16) AKSAN,M. 'Uçuş Mekaniği',İTÜ Yay.,İst.1955, p.26

Vortex (Fig.6.) - Circulation of air movement. It is generally knowntthat they are generated along lines and surfaces where discontinuities of the flow field occur.[18] There are several types of vortices:

a. Vortices having a conical form and generated along sharp edges.

b. Vortices generated at the edge of a region of separation by a lateral flow component.

c. Vortices in the secondary flow, generated along the boundary between the main and secondary flows.

For steady wind conditions, these vortices do not present a dangerous situation, but with gusting where the direction and intensity of the wind is constantly changing, pressure pulsation may appear with sufficient amplitude. "However great variety of architectural treatments create possibilities for the appearance of vortices which cause pressure pulsations of various frequencies and amplitudes. Under certain conditions, these vortices may produce pulsations efficient to break windows and cause fatigue failure in metal panels, and in winds of long duration to cause discomfort to the occupants."[19]

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(17) Building Research Station Current Papers, Experimental Techniques for Wind Tunnel Tests on Model Buildings. April 1972, p. 1.

(18) Wind Effects on Buildings and Structures, International Research Seminar, Canada, 1967, p.460

(19) Ibid, p. 463.

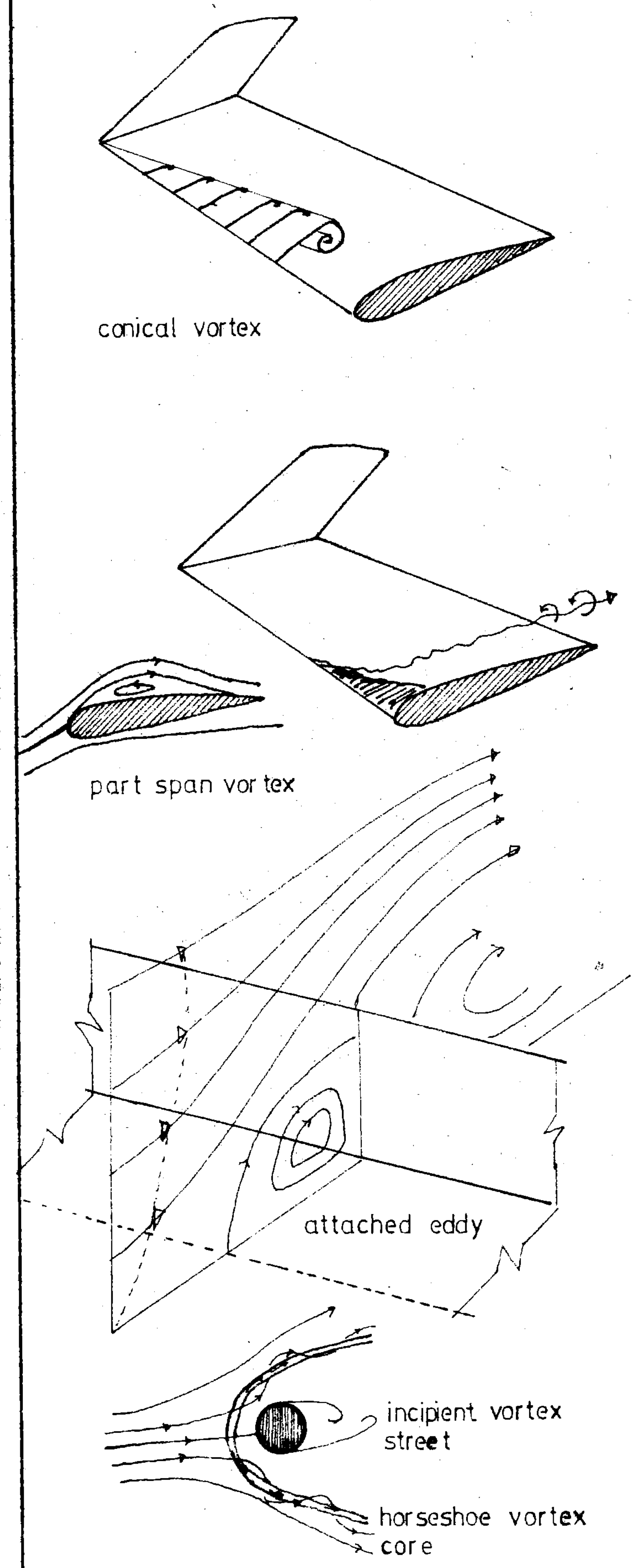

fig: 6
Types of vortices

Eddy - Eddies are steady edge vortices which can be generated along the feather edges of roofs having elementary forms and modern forms such as the hyperbolic paraboloid.

A stable eddy with a horizontal axis forms along the front of the wall at the base. This eddy is roughly circular and the size depends primarily on the curvature of the velocity profile.[20] Turbulent eddy viscosity varies strongly with height, stability and direction.

Wake (Fig.2.) - The flow normally separates at the sharp front edges and the separated flow is united at the rear. This region is called wake of the body. The shear along the edge of the wake induces a return flow in the centre, speeds within the wake are thus generally lower than those outside. This is a three-dimensional formation, so it is hard to investigate its real behaviour.

There are some characteristics of wake region:

- Velocities much smaller than the mean flow, and hence almost uniform pressure on the body surfaces.
- Gentle flow upstream along the surfaces.
- A negative pressure compared to the ambient.'[21]

Stagnation Point (Fig.4.) - It is the point where flow has zero velocity as if stopped.

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(20) Wind Effects on Buildings and Structures, London 1965, p.207.
(21) Ibid, p.200.

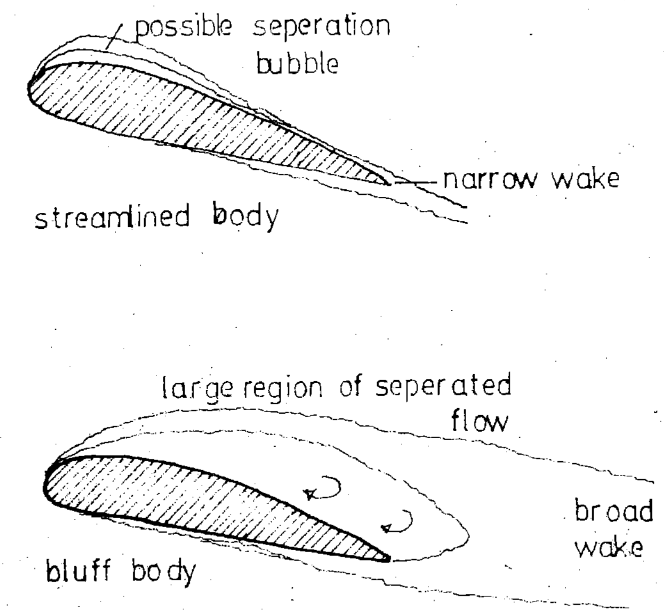

fig:2

Wakes

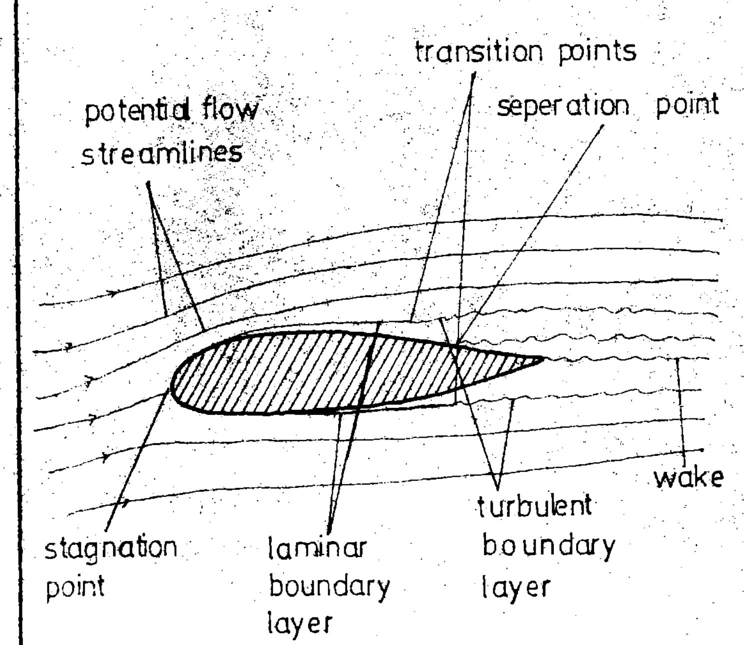

fig:4

Some flow characteristics

Separation (Fig.3.) - The line on which the boundary layer leaves the surface is called the separation line. "It coincides very nearly, with the line at which the viscous shear stress at the surface, becomes zero and behind this line the fluid nearest the surface moves slowly forward with respect to the body."[22]

In general, the location of separation depends on the shape and size of the body, the orientation and velocity of the wind, but for bodies with sharp edges namely for most of the buildings, the separation line is fixed along the edges.

"Separated turbulent flows are quite strongly unsteady sometimes randomly and sometimes in quasi-periodic sense leading to a [illegible] wake. This is just a particularly [illegible] of the fact that separated flows interact with the main quasi-inviscid flow."[23]

Jet Flow - This is a uniform flow which does not separate and turn into vortex formation throughout its path.

II. 1.2.3. Some Other Concepts From Aerodynamics.

Bluff Body - Bodies where boundary layers are well separated from the surface before they reach near the body, forming a thick wake, are called bluff.[24]

(22) Bradshaw, P., 'Experimental Fluid Mechanics', London 1964, p.24.
(23) Bradshaw, P., 'An Introduction to Turbulence and its measurement', Germany, 1971, p.78.
(24) 'A discussion on Architectural Aerodynamics', National Physical Laboratory, London, 1971, p.395.

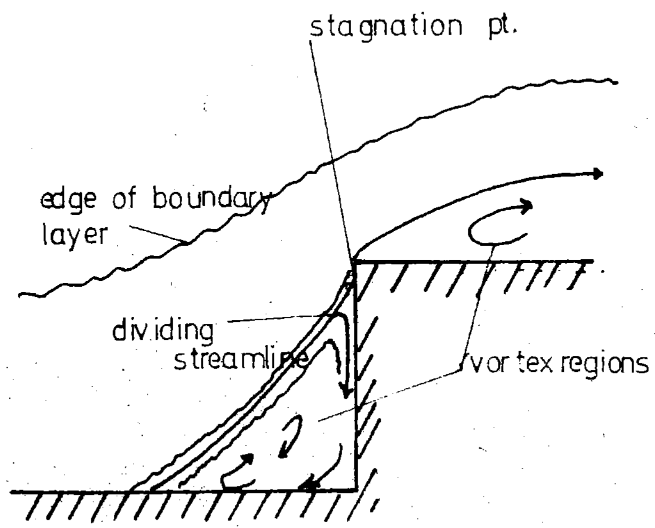

fig:3

Seperation point ahead of step

The separating shear layers are unstable and roll up to form discrete vortices. Generally all buildings are aerodynamically bluff.

Aerofoil - These are the bodies which assist the occurence of the buoayancy forces and lift forces.and the wings of the aeroplanes, some surface treatment and sun control elements of buildings, eaves, balconies, etc.

Velocity Gradient - Velocity profile which is changing from the surface to up gradually.

Coriolis Force - This is the force effecting the velocity gradient of natural wind because of rotational motion of earth.

II. 1.2.4. Concepts of Interpretation of Flow Patterns.

Path Line - This is the locus of points traversed by a given fluid particle during some specified time interval; the pathline is the particle's actual path during this interval.[25]

Timeline or Filament Line - A set of fluid particles that form a line at an instant [illegible]. Thus we make a timeline visible by [illegible] bubbles. At later times both the shape and location of the timeline will generally have been altered.

Streak Line - The locus of particles which have passed through a prescribed point during a specified time interval.

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(25) Flow Visualization.

Streamlines - These are imaginary lines traced out by successive fluid particles throuhout the flow stream.[26] The streamline concept is essentially mathematical in nature. A field of streamlines and individual streamlines can be found in various ways from streaklines, pathlines and timelines.

A smoke test gives an information of filament lines (timelines) which we can derive streamlines from interpretation of it.

"In unsteady flows, the pathline, streakline and streamline generally differ from each other. In unsteady flows the instantaneous streamlines can be determined from a short time exposure or a multiple exposure."[27]

II. 1.2.5. Some Theoratical Concepts of Aerodynamics.

Aerodynamic forces arising from relative motion between a body and the surrounding air are dependent not only on the size and shape of the body and the magnitude of the relative velocity, but also upon the density, compressibility, and viscosity of the air. It has been shown that air density is dependent upon temperature and pressure, while viscosity and speed of sound are dependent only on temperature.

Any movement of fluid has the equation of motion which was divided mathematically and verified experimentally, while deriving this equation, some of the parameters were

(26) WEBBER,N.B. 'Fluid Mechanics for Civil Engineers' Great Britain, 1965., p.29

(27) Flow Visualization. The film.

not considered because of their negligable quantity.[28] This equation of a motion basicly is the application of low of motion (F = m.a). Total forces within the system (Viscous forces, forces due to turbulence, pressure gradient force) are equal to inertia forces of the system. Each part of the formula represents one of the characteristics of the fluid motion. These parts are derived into some non-dimensionalized equations. These are the similarity criteria describing fluid's dynamic and static behaviour and with appropriate conditions determine the flow.

The Rossby Number ($R_o = \frac{U}{L\Omega}$) : This dimensionless equation is the ratio of advective or local acceleration to Corriolis acceleration. Corriolis acceleration, due to earth rotates are negligible if the study is dealt with less than 15 kms.[29]

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(28) The Equation of a motion of a fluid is:

$$\frac{\delta U_i}{\delta t} + \frac{U_j \partial U_i}{\partial x_j} + 2 \varepsilon_{ijk} U_k \Omega_j = - \frac{1}{\rho_o} \frac{\partial \delta P}{\partial x_i} + \frac{g}{T_o} \delta T \delta_{3i} + \frac{\nu \partial^2 U_i}{\partial x_k \partial x_k}$$

Where:

- U - Mean velocity inside the boundary layer; m/sec or cm/sec.
- L - Typical length; m or cm.
- Ω - Angular velocity of the earth.
- U_i - Instantaneous velocity; m/sec or cm/sec.
- δ_p - Deviation of pressure; kg/m^2 or gr/cm^2.
- δ_t - Deviation of temperature; degrees of centigrate
- T_o - Temperature (function of height); °C gr/cm^3
- ρ_o - Density (constant for incompressible flow); gr/cm^3
- ν - Kinematic viscosity; m^2/sec.or cm^2/sec.
- k - Thermal diffusivity, [illegible]/cm-sec.
- ε_{ijk} - Alternating tensor.
- δ_{ij} - Kronecher's delta.
- a - Velocity of sound; 340 m/sec.

The Reynolds Number ($R_e = \frac{UL}{\nu}$) : The ratio of inertial to viscous forces give another dimensionless equation. The effect of viscosity is important in establishing the physical limitations of model studies and interpreting the results of certain types of prototype studies. The Reynolds number is of interest where surface resistance and form resistance are of an appreciable magnitude.

"The discussion of the Reynolds number criteriaon normally centers around sharp edged geometry, where it is usually stated that the mean flow pattern will not be much affected by changing the Reynolds number"[30] With increasing Reynolds number, the transition to turbulent flow in the shear layer, downstream of the body, moves upstream and turbulence is then, supposed on the pattern of vortices.

(28 continued)

The assumption of deriving these equations:

1. The atmosphere is composed of a perfect gas of constant composition.
2. The deviation of pressure, temperature, and density are small when compared with natural values.
3. The density is independent of the fluctuating pressure (small Mach number)
4. Variations of and k is negligible.
5. The generation of heat through viscous stresses are negligible.
6. There are no sources of any kind.

(These informations are from the paper "Similarity Criteria for the application of physical models" and the book, "Handbook of Applied Hydraulics".)

It has been found from early experiments, "vortex wake with periodic shedding might not be present at high Reynolds number."[31] "In Laminar flow viscous effect has an important role while in turbulent flow it has not an important role"[32] In high Reynolds number the flow becames turbulent.

The Prandtl and Schmidt Numbers -"Prandtl number is the ratio of the momentum diffusivity, (Kinematic Viscosity) to the thermal diffusivity. The Schmidt number is the ratio of the momentum diffusivity to mass diffusivity."[33] They are both fluid properties and not flow properties. Thus, these are nearly the same both in prototype and model if the medium is air.

The Peclet Number ($Pe = \frac{UL}{k}$) It represents the ratio of inertial forces to thermal diffusivity.

"The Peclet Number and Reynolds - Schmidt product may be neglected as modeling criteria if the flow exhibits Reynolds number's independence."[34] Which means Reynolds number is high enough to produce turbulent flow in model.

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(29) SNYDER, P.W., 'Similarity Criteria For the Applic.of Physical Models For the Study of Air Pollution Meteorology', Paris, 1971; p.9.

(30) Ibid, p.19.

(31) 'A Discussion on Architectural Aerodynamics,' The Royal Society, London, 1971, p.426.

(32) 'Modelling Criteria in Hydraulics', Lecture notes, by Assoc.Prof. Cahit Çıray.

(33) SNYDER, P.W., 'Similarity Criteria For The Application Of Physical Models For The Study of Air Pollution Meteorology', Paris, 1971, p.23.

The Froude Number ($F_r = \frac{U}{\sqrt{gL}}$) : This is the ratio of inertial forces to buoyancy forces (in other words gravitational forces). The most basic, model - prototype relationships are those in which the gravity forces are dominant in the model. A large value of Froude Number implies that buoyancy forces are small when compared with inertial forces.

"Froude Number is likely to be the most important individual parameter to be matched when the model is to stimulate atmospheric diffusion."[35]

In order to match small Froude Numbers of the prototype in a model with a typical scale reduction in it, it is necessary to decrease the mean flow speed. To match the Reynolds Number between the model and prototype requires the mean flow speed to be increased. This conflict is resolved by matching the Froude Number while ensuring that a Reynolds number independent flow is established.

Strouhal Number ($S = \frac{F_r H}{U_i}$): This gives the characteristics of the structure. "For a particular structure, the vortices in each row form at a frequency F_r, proportional to the incident wind speed U_i, and inversely proportional to the lateral dimension H."[36] so that a characteristic number the Strouhal Number is associated with each structural shape. All cross sections have characteristics of Strouhal Numbers which is generally vary with the response of the section to the wind and with the Reynolds Number.

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(34) Ibid, p.25

(35) Ibid,

(36) 'A Discussion on Architectural Aerodynamics', The Royal Society, London, 1971, p. 395.

Mach Number ($M=\frac{u}{a}$): This ratio of velocity of flow to the velocity of sound gives some critical values such that, over these values, the fluid must be accepted to be compressible.

II. 2. PREVIOUS STUDIES

The first wind tunnel wasbuilt in 1897 to test windmills. From then on, many investigations had been done in tunnels. Many of the investigations were related to aerodynamics, because of the nearly developing vehicles the aeroplanes. Few researchers, especially after thirties, dealt with building aerodynamics. Because of the urgent characteristics of pressure problems on buildings, most of the investigations were done about aerodynamics of structures, namely the pressures (wind loads) on the structures and their response to these pressures. Vortex formation and pressure fluctuations of buildings were investigated by experiments. These researches and experiments were done either by model simulation or by full scale experiments. And the flow pattern and wind environment around buildings are recent concerns of those studies. Of course, the development of experiment techniques and theories of simulation made this conocern possible.

II.2.1 Studies those are similar to ours are mostly dealing with the airflow pattern around a building in a very detailed way. Some of them are:

- Airflow around groups of buildings,
- Effect of tall buildings on the environment,

- General effects of buildings on the environment,
- Change of boundary layer and velocity gradient, due to diffusion of urban pattern,
- Airflow around raised buildings and passageways, and the like. These studies were done under different velocities and different directions of flow. (See App.B).

II. 2.2. Investigation Techniques of Wind.

The model studies and simulation of the wind environments are experimented in wind-tunnels and fluid channels (usually water). These studies are concentrated generally on two kinds of data:

- The velocities, pressures and other numerical characteristics [illegible]
- Visualization of flow is tried to be achieved.

Many of the research works agree on, investigations should be done in both kinds, because the interpretation of the study could only be possible with these parallel studies.

Flow visualization technique has always been an important problem, with the question it brought with, how it simulates and how it can be interpreted, to a research worker.

Bradshaw, in his book 'Experimental Fluid Mechanics, 1964' explains up-to-date flow visualization techniques:

- Tufts (Tufted nylon yarn which is spun, is used to examine the external flow).

- Smoke (There are several means, but, since "many of the compounds are suggested for flow visualization in general, are toxic and therefore unsuitable though on several occasions this has only been realized indirectly after prolonged use without ill effects"[37], usually fluid paraffin spray is used).
- The Hele-Shaw Analogy (Visualization is obtained by using dye-filaments in a Hele-Shaw apparatus).
- Oil Films ([illegible] can be examined).
- China Clay ([illegible] evaporation technique using to investigate [illegible]).
- Shadow Gr[illegible] light is used).
- Schlieren [illegible] is used).
- Interf[illegible] light sources).

Other [illegible] developed recently. Hydrogen bubbles [illegible] in water tunnels and the new method, durable bubbles filled with helium[39] are used in wind tunnels. All of these are used with special devices and apparatus and the problem arising with introducing it into the stream is without disturbing [illegible] the flow or the tunnel operators.

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(37) BRADSHAW, P., '[illegible] Mechanics', 1964, p.149.

([illegible]) Flow Visual[illegible] - A Film.

([illegible]) Air Flow in Wind [illegible], Machine Design, v. 15, 1971, p.[illegible].

the experiments
part III

III. 1. BOUNDARIES OF THE EXPERIMENT

III. 1.1. Testing Conditions.

In section I.2.1., goals and objectives had stated e.g. briefly: by means of smoke test in a wind tunnel flow around buildings will be visualized and examined. Available testing conditions naturally have some importance on experimentation and simulation. In Appendix A, the change and better conditions of testing equipment is explained step by step.

III. 1.1.1. The Wind Tunnel.

Available wind tunnel is an open circuit one, with a test section by 07 x 80 x 110 cms (Fig.7). Overall length of the tunnel is 7.30 m. It is out of wood and the surfaces were finished and painted.

It is in a closed space and the fresh and free air can only be obtained from windows of adjacent rooms, where freely circulating air is necessary for this type of tunnel. Therefore during the working of the tunnel there is air movement with the same speed around.

The speed variation of the tunnel is ranging from 0.1 m/sec to 20 m/sec. The revolution can be changed by the varyaç of 25 ampers.

Without any equipment in the tunnel, velocity gradient performance of it is parallel to those of Building Research Station (Fig.8.)

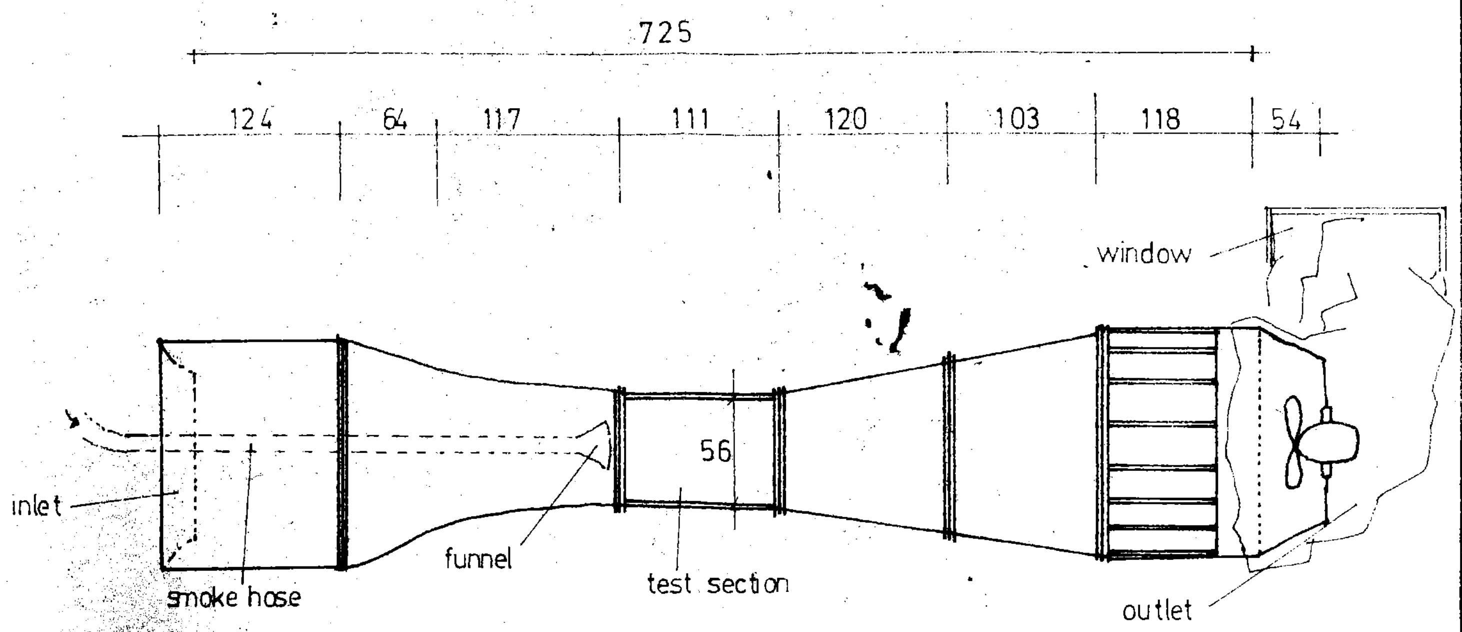
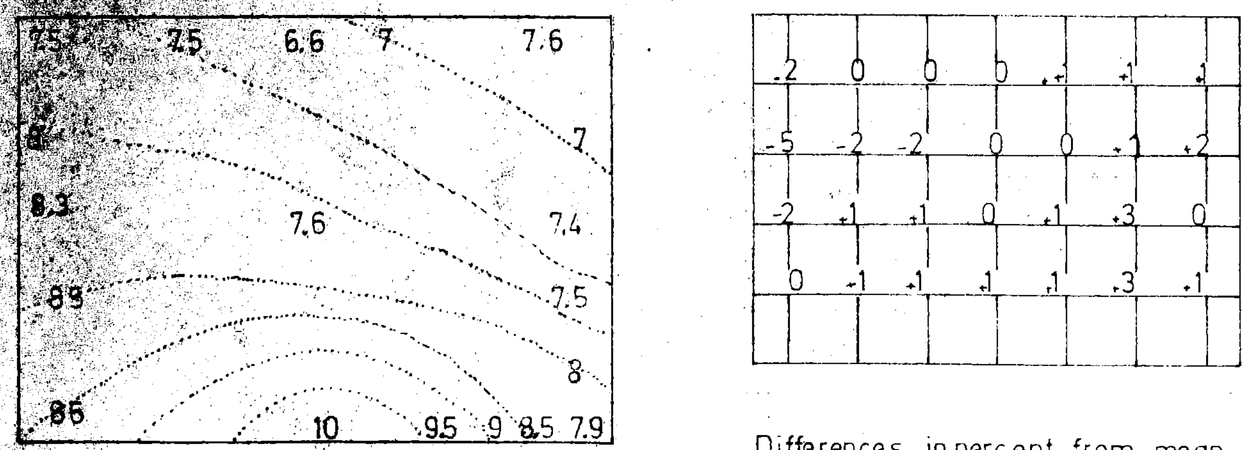


fig:7

Available wind tunnel



Velocity distribution, m/s

(the tunnel available in M.E.T.U.)

Differences in percent from mean speed 16.4 ft/s (5.0m/s)

(the tunnel available at Building Research Station)

fig:8

Velocity gradient of the wind tunnels

There are some equipments during testing so that the flow within the tunnel which can never be laminar.

III. 1.1.2. The Models.

The models are wooden boxes with painted fine surfaces. there are two boxes representing two buildings. their dimensions are, 10cm width, with 30cm depth and two alternating heights, 20cm and 10cm. Model is placed on a wooden plate by 40 x 80cms, raised about 10 cm from the tunnel ground. Since the length scale is 1/150, the models represent a slabtype buildings of 45m width, 15m depth and 30m height.

III. 1.1.3. The Smoke.

Ordinary military smoke screen is used. It is fired from outside the tunnel room and brought into the tunnel by means of a hose of 7cm diameter. There is a funnel at the tunnel end. It is interesting that, without this funnel smoke does not come out, although the fan runs with its ultimate speed.

The flow from the hose is not uniform and laminar, and the concentration or diffusivity of smoke in itself is not uniform. The colour of the smoke is very light grey.

Chemical compounds with their ratio in the composite in the smoke screen are shown below:

<u>White Smoke Composite</u>

Hegzachloretan	52 %
Zinc Powder	30 %
Zinc Oxide	13 %

Chalk Powder	2.5 %
Strontium Nitrate	2.5 %
	100.0 %

Thermit Composite

Red ferroxide	75 %
Aluminium Powder	25 %
	100 %

Matchead Composite

Potantium Chlorade	60 %
Antimuan Sulphur	30 %
Sodium Oxilade	7 %
Sulphur	2 %
Glue	1 %
	100 %

III. 1.1.4. The [illegible]

Model is [illegible] tunnel, by two sunguns of 1000 [illegible] lights from top 250 Watt each. In [illegible] image from black and white film, colours have been chosen accordingly. (See App.A). The test section of the tunnel and the plate under the model are painted matt black and the models are matt red, in order to prevent shining, so that, white-grey smoke can easily be observed. The 16 mm Kodak Camera is [illegible] for taking the film. The distance between [illegible] the camera is about 75 cms.

III. 1.2. Simulation.

The above conditions set the main boundaries of the simulation characteristics. Our problem is the simulation of the wind environment around the slab type apartment blocks with different distances, heights and velocities of the flow.

The first problem of modelling is how to reduce dimensions. There are many dimensionless equations which should be matched both in prototype and model for simulation. The length scale is the main parameter of this modelling. In section II. 1.2.5., the similarity of equations has been briefly discussed. Within those equations, some of them are affected by fluid characteristics. (Schmidt, Prandtl, Rossby), and some others show the flow characteristics (Reynolds and Froude). Over critical Mach Number (0.7) fluid becomes compressible, so that, its physical properties are changed.

In our tunnel, [illegible] circulated, therefore, the physical properties [illegible] change in the tunnel, such as density, [illegible] gravitational force are the same.

Maximum velocity of the flow in our tunnel is about 20 m/s. Velocity of sound is 340 m/s. So, Mach equation is :

$$M = \frac{V}{a} \qquad M = \frac{20}{340} = 0.06$$

Since $0.06 \ll 0.7$, the circulated [illegible] will never be compressible.

The Reynolds and the Froude Numbers are the main equations giving relations between prototype and model, concerning flow characteristics.

Reynolds Number indicates the effects of viscous forces. In turbulent flow, viscous forces are less effective, so, the

Reynolds Number has less importance if the flow is turbulent.[40] And, it is learned from experiments that, flow in our tunnel is turbulent.[41] Then, Froude Number is the main similarity formula we have.

In the research study, the length scale has been established as 1/100, but to reduce the tunnel blockage on the flow the length scale is reduced to 1/150. (See App. A). And the model cannot be very small to see better the details of smoke filament as suggested.

The normal wind of 5 m/s speed (Beaufort Number 3)[42] has slight disturbance of effects on environment. Up to 15 m/s, speed (Beauford scale: 7), these disturbances increase and small damages occur, after this value towards 30 m/s, (Beaufort scale: 12, hurricane), strong structural and landscape damages occur.

Then, velocities of the prototype is selected as 30 m/s, 18 m/s and 6 m/s, but accurate velocities could not be obtained by operating the scale of varyac. Then, the approximate velocities which are determined by 16, 8, 6 grades of varyac are used. Under 0.6 m/s, the smoke is diffused all over the tunnel, such that, any observation could not be possible.

So, 16, 12 and 8 grades of varyac is used, which represents 32 m/s, 16 m/s, 9 m/s, according to Froude similarity respectively. These are the three velocities of the experiment.

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(40) See Section II.1.2.5. for further information.

(41) Streamlines could not be obtained during the experiments (See App.A., for further information) which shows the flow is turbulent.

Since the observation has been done only on qualitative basis, these changes of velocities from first selection, have no importance, because, the experiments would not give numerical values to plot curves, but the tendencies.

Froude Number is:

$$F_r = \frac{V}{gL}$$

'V' is the mean velocity, m/s ; 'L' is the characteristic length, m; gravitational acceleration 'g' is 980 gr/s ; and suffices 'm' and 'p' represent model and prototype respectively.

$$\frac{Vm}{\sqrt{gLm}} = \frac{Vp}{\sqrt{gLp}} \qquad \text{we know: } g_m = g_p$$

Therefore,

$$\frac{V_m^2}{V_p^2} = \frac{L_m}{L_p} \; ; \quad \frac{L_m}{L_p} \text{ gives the length scale which is } 1/150$$

$$V_{m_1}^2 = \frac{1}{150} \times 32^2 \quad \ldots\ldots\ldots \quad V_{m_1} = 2.6 \text{ m/s}$$

$$V_{m_2}^2 = \frac{1}{150} \times 16^2 \quad \ldots\ldots\ldots \quad Vm_2 = 1.28 \text{ m/s}$$

$$V_{m_3}^2 = \frac{1}{150} \times 9^2 \quad \ldots\ldots\ldots \quad Vm_3 = 0.74 \text{ m/s}$$

To see the contradictory effect of Reynolds Number:

$$R_e = \frac{VL}{V}$$

V = kinematic viscosity, for air 0.1 m/s

$$V_mL_m = V_pL_p \qquad V_m = V_p \frac{L_p}{L_m}$$

$$V_{m_1} = V_{p_1} \frac{L_p}{L_m} \qquad V_{m_1} = 32 \cdot \frac{150}{1} \qquad \underline{\underline{V_{m_1} - 480 \text{ m/s}}} \text{ (!)}$$

If we apply the model velocities from the Froude Number and compare it to prototype, we will see the possibility of being mistaken by expecting similar attitudes from the prototype, concerning the Reynolds Number.

$$R_{e_{m1}} = 260 \text{ cm/s} \times 20 \text{ cm/s} = \underline{\underline{5200}}$$

$$R_{e_{p1}} = 3200 \text{ cm/s} \times 3000 \text{ cm/s} = \underline{\underline{9.600.000}}$$

$$R_{e_{p1}} \ggg R_{e_{m1}}$$

III. 1.3. Feasibility of Testing Conditions and Simulation.

Snyder, in his report, stated that the Froude similarity can be used safely only if the flow is independent of Reynolds. According to some research workers, having sharp corners in the model is sufficient for the Reynolds Number's independence, but Snyder proclaims:

"The flow was independent of the Reynolds Number effects if the ratio of length of the cavity region to the building height was the same in both model and prototype."[43]

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(42) Beaufort Numbers are Meteorological scale of wind which is set according to its effects. f.e. Beaufort number '0' indicates calm air, smoke rises vertically and speed of wind is less than 0.3 m/s, '11' indicates storm, very rarely experienced, causes widespread damage, its speed is about 26-29 m/s. (ARONIN, J., 'Climate and Architecture,' p.177).

(43) SYNDER,P.W., 'Similarity Criteria for the Application of Physical Models for the Study of Air Pollution Meteorology' Paris, 1971, p.20.

In our experiments, the models have sharp corners and the cavity region length to the building height ratio (the case of one building placed at windward side of the plate - Case A 1a) is approximately 3.5 to 4. So, we expect this ratio in prototype to make sure the use of the conclusions of the experiments.

III. 1.3.1. Assumptions.

There are some assumptions which are accepted before the beginning of the experiment. Some of them are theoratical where the others are practical.

- The flow is independent of the Reynolds number,
- Boundary layer conditions are assumed to be less important to simulate,
- Fluctuating of the velocity of the wind is neglected,
- Natural velocity gradient is less important to simulate,
- Since the simulated length scale is much smaller than 15 km., Coriolis force is neglected.
- Effect of urban environment is neglected. Such as temperature rise in urban areas and surface roughness of the environment,
- Oscillation of the wind which causes change of the direction of the wind is neglected,
- It is assumed that the flow is uniform and irrotational within the tunnel,
- Temperature and pressure changes due to altitude of the testing place are negligible.

III. 1.3.2. Errors.

The term error describes a discrepancy between the actual result and the true value of what one sets out to measure in the laboratory.

There are several sources of error in measurement which may contribute to it separately or in combination.

- Errors Due to the Observer:

The experiments have not been observed directly but through the medium of the motion picture. So, there may be some errors due to the properties of the camera, the film and the photographic conditions. Any error from one of those causes some disturbances on the image brightness which may result in wrong interpretation of the images. Since there is a lack of practice in the usage of photography for scientific purposes, sharp images are hardly obtained except in few of the films - particle section and cases of 'BB'.

During the interpretation (or reobservation), a slide of grid pattern is overprojected on the projected film and some ratios dealing with the air movement have been tried to be achieved. This study shows that the displacement of the camera for each experiment causes some errors. This error is made uneffected by taking the ratios in each case of the experiment within itself.

Since the camera is placed very closely to the tunnel, perspective distortion has occured which results in fussy images of the smoke.

- Errors Due to the Instruments Used:

The instruments, the tunnel, varyac, etc., may themselves cause some errors. The improvement has been tried to achieve as much as possible, because, this is the way of reducing observational error.

"A model situated within an enclosed working section will tend to be overestimated because extraneous suction effects are introduced into the wake (termed 'wake' or tunnel blockage'), due to the proximity of the tunnel walls... it is describlé to limit the size of model so that less than 10-5 % of the area of the working section of the wind tunnel is occupied by the model."[44]

$57 \times 80 = 4560\ cm^2$, $20 \times 30 = 600\ cm^2$, $600:4560 = 0.13$ $= 13\ \%$ **means** 3% of error.

- **Interference effects** on flow due to the instruments **within the tunnel:**
  - **In order to canalize the smoke into the tunnel, the hose had been suspended in the tunnel although the** interference and disturbance effects on flow **are** expected.
  - The fånnel had been put at the end of the hose for **the same** reason and expectance.
  - The **raised** plate had been put with the suggestions that it would not disturb the flow because of its similarity **to** a **streamlined body,** but at the end, it

(44) **Proceedings of the** Conference Held **at** the National Physical Laboratory, **'Wind** Effects **on** Bldgs., and Structures', London, 1965, Vol. I., p. 297.

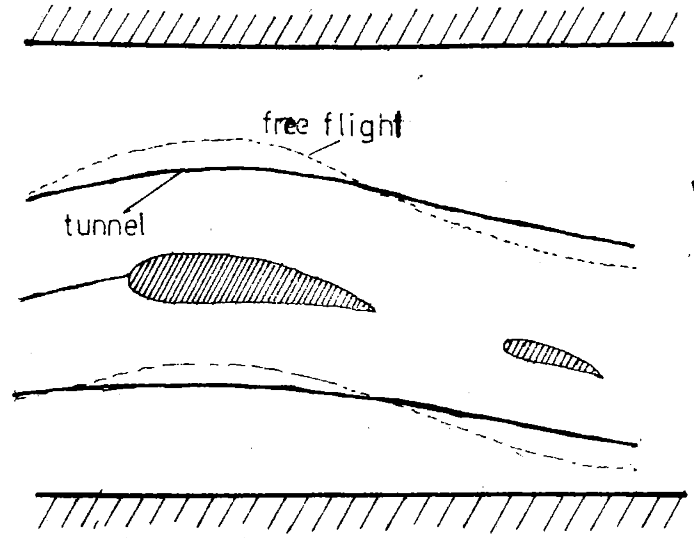

fig: 9

Tunnel wall blockage-Effect of tunnel constraints in reducing streamline deflection and curvature.

is observed that the flow is separated as if it is a bluff body.

- The sungun which had been placed at windward side of the tunnel may have some interference effect because of its wake but it is suggested that this is negligible because of its distance (about 2m) to the models.
- The shutter of the tunnel causes 5 % of error on the velocity of the flow which was concluded in the research (ARCH.501) study. And it was observed that if the shutter is open, smoke would not come through the hose, which shows its interference effect on the flow.

- Errors Due to the Environment:

Some of these errors are assumed to be negligible at the beginning of the study, such as the change of temperature, and pressure due to the climatic conditions.

Since the room where the tunnel has been placed is small, there may be velocity fluctuations within the tunnel because of the outside flow.

- Errors Due to the thing observed:

- The movement has happened in the tunnel in three dimensions, but the observation was manipulated as if it was two dimensional.(no top observation had been done because of impossibilities).
- Smoke has been diffused all over the section easily, especially at low speeds. Models have the length of approximately one third of the tunnel width. So,smoke passing through the sides prevents clear observation.

III. 1.3.3. The Cost of Error.

The measurement of the cost of error of interference effects are impossible in these experiments, and also the error due to the camera cannot be estimated easily.

As Bradshaw and many other research workers agreed on that, the flow pictures may or must need considerable experience to be interpreted. So, the error due to the lack of this practice is of course, unmeasurable.

"The figure generally quoted for the best occurency required of the experiments in fluid mechanics is 1%(!), but this is to be regarded as a target rather than a necessity, but in some cases, this raises to 20 % - 10 %".[45]

In this research study, the cost of error cannot be found which seems unnecessary at least to the observer, because of the main aim is, to simulate flow patterns of the prototype. Since flow has an interference effect within itself, even a small deviation of flow, results in entirely different flow pattern.

So, checking of the results with full scale experiments is necessary.

Comparison between similar studies and this, study may give some ideas of the feasibility of results which will be discussed in following sections.

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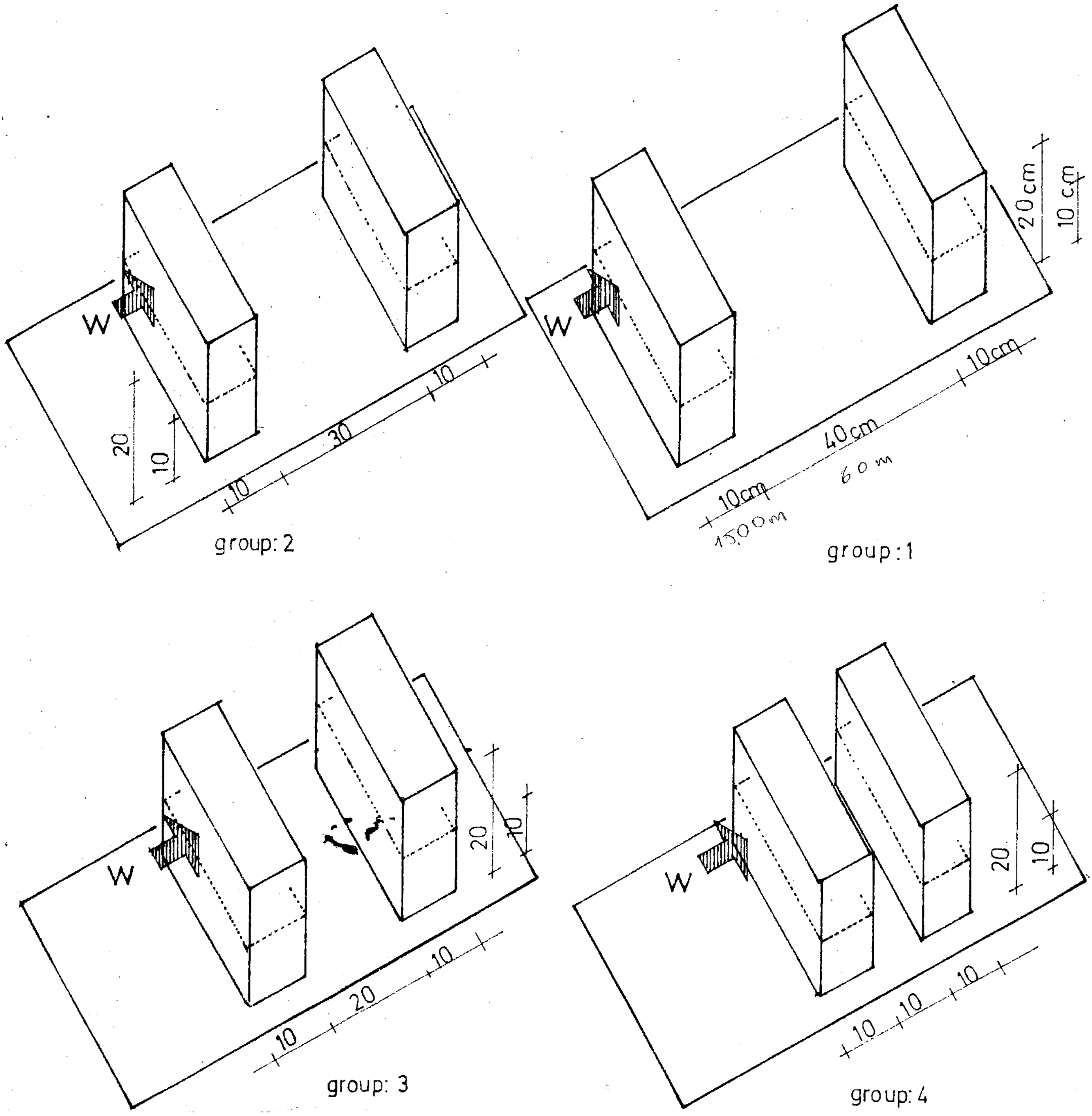
(45) BRADSHAW, P., 'Experimental Fluid Mechanics', Pergamon Press, London, 1964, p. 168.



Experiments

Experiment groups with alternating heights in 3 different velocities.

III. 2. THE EXPERIMENTS

III. 2.1. The Notation of The Experiments.

Some abbreviations are used to identify each case of the experiments, namely they are given the call numbers. (See Chart I.).

The capital letters 'A' and 'B' denote the heights of the buildings 20 cm and 10 cm respectively. If one letter is noted, this means, one building is tested, and if there are two letters, first letter denotes the one at windward side, where the other, leeward.

The figures '1', '2', '3' and '4' give four different distances between two buildings.

1 = 40 cm., 2 = 30 cm., 3 = 20 cm., 4 = 10 cm.

If there is only one building '1' represents the windward end, '2', the middle and '3', the leeward end of the plate.

Small letters, 'a', 'b' and 'c' represent the velocities in m/s.

a = 2.6 m/s, b = 1.28 m/s, c = 0.74 m/s.

Examples:

a: The investigation of research conditions beforehand at the velocity of 2.6 m/s.

AB2c: There are two buildings, the one at the windward side is 20cm, where the other is 10 cm in height and the distance between them is 20cm. The testing velocity is 0.74 m/s.

BB4a: The two buildings, having the same hight, 10cm with the distance between them, 10cm are tested at the velocity of 2.6 m/s.

III. 2.2. The Interpretation.

III. 2.2.1. Efficiency of Experiments.

In this research study, all the experiments which have been aimed, have been completed. The experiments were done in groups whilst the time was conditioned by the smoke bomb. One box lasted about eight or ten minutes when the smoke was ceased, the intensity of smoke decreased, so that visualization was very poor. And, if the fan ran at slow speeds longer than a minute, the smoke dissipated all over the section, therefore, the vision of the models were disappeared, under the smoke. The efficiency of each case of experiments therefore, were not the same, namely, some were poor for interpretation. Especially the cases 'AA4c', 'BB2a','BB2c', 'BA4c' were poor to interpret, and the cases 'BA4' and 'BA3' could not be relied on, since the interference effect of the plate with the funnel. Because of the shortage of financial support, these cases of the experiments have not been repeated again.

III. 2.2.2. Observation of Experiments.

The interpretation needs some experience in this field of work, so, in this part, only the observations will be tried to be outlined in groups. (See Charts I, II, III.)

The flow was unsteady, turbulent and accepted as uniform. The observation from the film has been tried to be evaluated by some means of measuring (projecting the grid upon the film) and the flow was examined in accordance with the types of it. This typology has been done mainly for a purpose to give an opportunity of interpreting them for architectural purposes. Charts I and II are graphical representations of the experimental cases and Chart III shows the matrices of the results of these experiments.

III. 2.2.3. The Analysis of Experiments.

In this section, interpretation of the flow is going to be evaluated in groups of flow as jet flow, separation of flow, intensity of flow, wake of the buildings, vortices, swirling side vortices, side flows, downwash and surface flow in accordance with the change in velocity of flow, height of the buildings and distance between them.

- Jet Flow and Separation:

Since jet flow is the current of an air which flows without any change in it, any disturbance of it will be resulted in its separation. So, the separation in this part is related with the separation of flow due to any cause, so differs from the concept of separation in aerodynamics.

• Velocity has two effects on jet flow, one of them is, with the decrease in velocity, the thickness of the jet flow is getting spoiled and fanned. The other effect is, separation occurs early in low velocities. (As a result of the first effect). The place of stagnation point falls from 1/5 - 6 to 1/3 ÷ 1/2 of building height as decreasing the velocity.

• Distance shows its effect on the intensity of flow over the faces of the buildings. In distances '1' or '2' (40 and 30 cm, respectively) separation occurs before reaching the second building. And, in the positions of the distances of 20 and 10 cms, separation occurs just over the second building.

• The height of the frontal building has an influence on the place of separation; if the building is high, the separation occurs because of the striking of the flow on building and the continuation of jet flows will not separate later, in the distances '4', '3' and '2'.

Separation after the second building occurs at high velocities, especially in the cases of 'AA' and 'AB'.

- Wake and Intensity of Flow,

Almost in all cases the intensity of smoke is getting higher from the front of the first building to the back of the second, while getting more and more homogeneous and movingless.

• Length of the wake changes with velocity and height of the building. In the cases of 'a', 'b' and 'c', without any building the wake of the model plate is decreasing from 1/2nd, 1/3rd and 1/4th of the plate length respectively. And, also the wake of the buildings decrease from 3 1/2 times to 2 1/2 of the building height.

Intensity of flow changes also with velocity. Change of distance and height assists the formation of this intensity with the change of wakes of the bodies. In the cases of without building intensity of flow decreases as velocity decreases. In other cases, if the velocity is high, flow can drag residued smoke and with its energy, it can turn around the complex and no concentration of smoke occurs.

• While buildings are getting closer, the smoke between them is getting movingless and may be seemed as if stopped. Especially in 'AA'3' andd'AA 4' cases, the half of the space between buildings are filled with residued smoke which seems uniform, non-moving and less intense than the vortex upon it. Distance between the buildings shows its effect on wake, so that the flow within the wake changes and unusual vortices occur. (Compare A1 and AA1, AB1, BA1 cases from Chart I and II).

• If the buildings are higher than the distance between them, then, the intensity of flow (which moves less) is high. This stagnation of flow may happen due to the wake of the buildings. For example, in 'AB' case, the second building is in intense smoke area, if the distances are '2', '3', or '4'. But in 'BA' case, since the windward building is shorter, the flow between them is much more active than 'AB' cases.

- Vortices :

There are many kinds of vortices (See Section II.1.2.2.). Swirling vortices, horseshoe and "W" shaped vortices,[46] which

(46) This type of vortice has not been come accross with in literature, so, the call name of it is not common.

is the distorted form of a horseshoe vortice. (Fig.10). Vortices occur at the down front corner of the buildings (eddies), at the top of the buildings and between the buildings.

. Without any building in high velocities, vortices can be seen due to the wake of the plate, while velocity decreases their forms are getting obscure.

In all cases there occurs vortex in between two buildings and in accordance with the decrease in velocity vortices begin to happen away from the buildings and their relative velocity (relative to mean velocity) decreases. At the same time, in the highest velocity vortexes are not regular and round but, rather distorted and usually in semicircular forms. Generally, circular vortexes are formed in similar way but under different situations of the buildings.

. The interference effect of the plate with funnel can mislead the evaluation of vortices. If the windward building is close to the edge of the plate (Cases '4'), the front eddy will not occur. While the buildings are getting closer, the front eddy occurs. (shows the interference effect of the plate). In front of the second building eddy may occur only if the cases are 'BA' or 'BB' namely the frontal building is short, where the distances are 40 or 30 cms.

If the distances between the buildings are 40 and 30 cms, there may occur, vortices in between the buildings. And

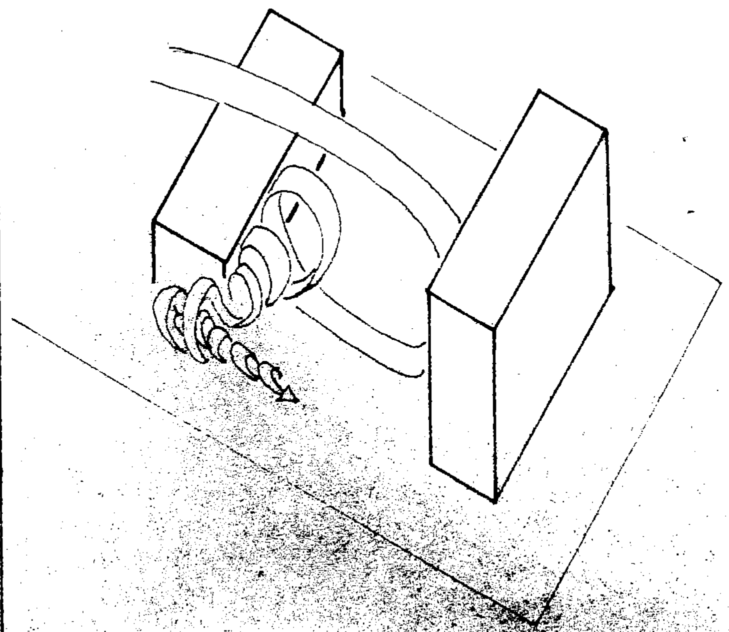


fig: 10

'W' type of vortex (actually symmetric)

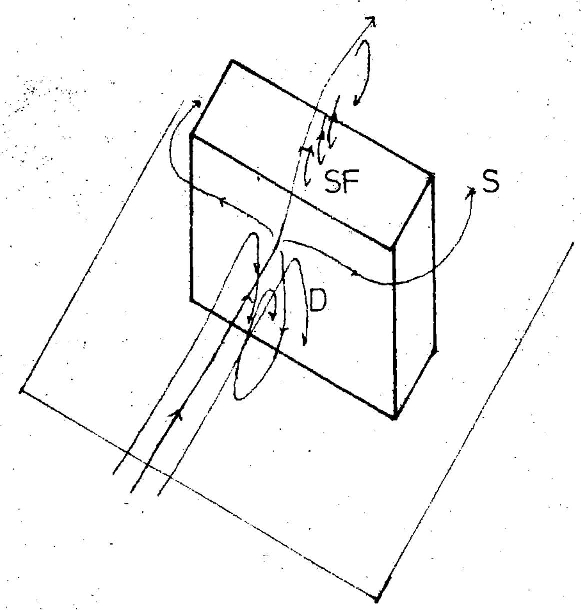


fig:11

S - side flow

fig:12

SF - surface flow
D - downwash

in some cases, ('AA1' and 'AA2' and 'BB1', 'BB2', 'BB3'), the small vortices swirl at the upper section between the buildings as if there is a cushion underneath them. In between the buildings with their distances of '1' and '2', two types of vortices occur at the same time. A horseshoe vortex at downstream part and a normal vortex or in some cases "W" type of vortex in upstream part (behind the 1st building) occur. This may easily happen if the second building is high.

The circular vortex can be formed if the distances and heights of the buildings are equal.

With getting closer to the buildings, the place of the vortex slides towards upstream, to the back of the first building.

. Vortexes have been resulted from obstruction of flow by surfaces as we have mentioned, so as an obstruction height of the buildings effect the formation of vortices. (See Chart II)

- Horse shoe vortices and "W" type vortices:

. Horse shoe vortex happens usually at high velocities and they are the out product of front vortices or eddies.

"W" type vortex can only happen in 'a' and 'b' speed where the only exception is 'BB 3c' case.

Side flow, due to the separation of jet flow on surfaces seems not so dependent on velocities (Fig.11)

. Horse shoe vortices usually happen in the front part where the height is 20 cm.

Side flow may occur when the 1st building is high (20 cm) and the distance is 20 cm or less.

. Distance seems not important alone, but if the distance is so close (cases '4' - 10cm) then, the vortex may not occur at the lower section of the spaces between buildings. The upper side vortices do not develop in horse shoe vortices.

. Especially at 'BA' cases (due to height) when the distances are '40' and '30' cms, the horse shoe vortex changes its form, first flow towards upstream at the sides of first building, then, to downstream. And, only in the case of 'AB4c' there is a horse shoe vortex between the buildings.

- Downwash and Surface Flow :

Surface flow mainly happens in two ways; one is the surface wash, and the other is the facial source of smoke. In surface wash case, flow licks the surface and flowing parallel to it, because of the boundary layer. Surface source is a visual awarance that, as if the surface, as a whole generates the flow, usually perpendicular to the surface itself. This may be the result of thick boundary layer and the drag flow.

• With the decrease in velocity, probability of occurance of surface flow increases. In all 'c' speeds surface generator type happens. Because of the boundary layer conditions or viscosity of flow, in lower speeds, separation cannot occur easily so that flow spreads all over the surface, which explains the downwash flow also.

• If the distance between the buildings are two times the height of first building, or more,surface flow between the buildings can occur. If the space is closer, this surface flow turns out to be a vortex.

• In cases of 'BA' (first building is low), downwash upon the windward face of the second building occurs. In 'AA' and 'AB' cases (first building is high), downwash occurs at the first building's face which shows downwash of the surfaces mainly depend on their heights.

Nearly in all cases, the top of the buildings act as a smoke source, it may happen due to the suction in the wake.

In cases of 'BB1' smoke has so resídued between the buildings that, the vortices swirl upon them as if there is an air cushion.

III. 2.3. Interpretation for Architectural Purposes.

These interpretations with the guidance of charts can be used for design purposes. Of course, the applicability of them depends on their reliability, which are feasible to an extent. (See section III. 1.3.2.). In previous sections, effects of wind on environment have been briefly discussed. In the following section, how th interpretation of experiments can be applicable to architecture will be briefly discussed.

Since we cannot change the velocity, the only parameters that we can handle to counter with the unwanted effect of the wind are dimensions and shape of the buildings. In previous studies, (App.B), the area of the building face has been found as an important parameter, shapes of the buildings have also been studied.

'Jet Flow' is mainly effected by velocity at first, which means in low speeds, the residue of smoke from chimneys would be more and by introducing some obstacles to this smoky flow, the distribution and spread of pollutions will be more.

'Wakes' with their uneven flow distribution and relative negative pressure in them, may cause some structural problems. As it is known, the velocity of flow within the wake region is slower than the boundaries of it. So, by changing height and the distance of the buildings, we can organize the proposed complex according to the purpose we have. And, related to the characteristics of wake region, at hot humid sea shores, for example, where we need breeze, the distance between two buildings must be more than 2 to 3 times of the height of the windward building.

If the distances between buildings are narrower than their heights at least, there will be residued and stagnated air between them with half of their height.

At the back of the second building, under the zone of more concentrated smoke, if its height is 20cm (or 30 m in reality) there is the possibility of a result of downwash.

Vortices are more active parts of the flows. They lift papers, dusts, suits and disturb hair and cause some damages to flowers, etc., around. Height of the building is important parameter for formation of vortices, a parallel conclusion to previous results. Since they are unsteady, they may have a gust effect (impact force) on structures also.

Sideflow occurs where the jet flow separates at the upper portion of the building and in high velocities with the aid of suction due to the wake. For side flow, it seems, a condition that, flow shouldbalmost be parallel to floor, so, on the bodies in wake region, this side flow cannot occur.

The "M" type vortex may be the effect of the wake of the first building, but it does not occur in all cases. The cases 'BA 1b', all 'BA 2' cases, 'BB 2b', 'BB 2c', all 'BA 4' and 'BA 3' cases which show the effect of the height of the first building, the top view would be more meaning-ful to interpret the situation.

If the building height is more (A), flow, which strikes the building, flows down on the surfaces and causes strong eddies at the bottom of the building. This downwash causes some defects on the faces of the buildings so that, surface treatments are important factors of design on tall buildings.

Surface flow or surface source effect of flow occurs only in wakes, in negative pressure. This may show the possible suction areas on the surfaces. If the vortex in the wake cannot be formed, the flow is distributed over the surface and the surface seems as if it generates smoke. So, architectural control must be decided upon the material of the surface or the treatment of it accordingly.

Many other conclusions may be obtained from these results of experiments under the condition of getting familiar to interpret them with deep knowledge of the effects of different kinds of flows on buildings.

IV. CONCLUSION

The study have been completed under an inadequate situation, as insufficiency of knowledge, equipment, finance, labour, and to an extent, time. At least, this is an introductory trial to the field, with the evaluation of the results, evaluation of the study would have an importance.

• What could have been done for more reliable experiments?

• The feasibility [illegible] of the tests have been discussed [illegible] sections and concluded that [illegible] So, to check the results, [illegible] but supportive experiments [illegible] should deal with only one or [illegible] detail. Supportive studies should be [illegible] velocity [illegible] measure- [illegible] accurate [illegible], existing [illegible] of the [illegible]

[illegible] apparatus should [illegible] of smoke is [illegible]; the inlet and outlet of tunnel design should be changed in order to get rid of the hazardous effect of smoke and in the other part, hoses and funnels with the test section should be designed such that, the flow within the tunnel should not be affected by them.

• In order to introduce the boundary layer and turbulative conditions corrugated paper or small cubes of woods should be separated all over the floor of the tunnel.

• And for better filming, the illuminating conditions should be changed such that, all the light sources will illuminate the model from top. The distance between the tunnel and the camera should be increased, (means need for a new space for the tunnel) in order to prevent false interpretation.

• <u>What could be the [illegible]?</u>

First of all, the difficulties should be altered, which have been discussed in 'appendix A' before beginning to a new study.

And, as a continuation of this study, investigation on 'AA' cases [illegible] and without a funnel and [illegible] convenient apparatus)would be adviced, and [illegible] should be supported by complementary [illegible] on velocity distribution (a new anemometer of special size for this purpose is necessary) and, at the end, the study should be verified by full scale measurements or experiments.

So far, as a conclusion of this investigation study, similar works should be supported financially and technically by proper institutions. Otherwise, completeness and excellency of results can never be achieved, where they would probably be turned out to an unprofitable work.

appendices

APPENDIX A.

The Story of The Research Study :

The aim of this study was to complete a Master Thesis work by experimenting flow around building groups in a wind tunnel to fulfil the requirements of the Faculty of Architecture of M.E.T.U., which was supposed to be completed in one semester. But, this study has been completed in three and a half semesters with full time study at the school. So, there were some disadvantages of explaining the causes of this retardation for future workers who will be dealing with parallel studies and researches. And, through this review, the improvements of testing conditions and change of model groups will be briefly discussed.

• According to the objectives of this thesis study which was decided in ARCH. 501 research study, the first step was to build models and to obtain smoke for visualization of flow.

- We know that paraffin was used in such studies which is liquid, and misted in the air. But, one liter of it was about 1000 T.L., and imported from U.S.A.,.This liquid, with the spray machine was under the control of the Government Theaters (Devlet Tiyatroları). And it was said the paraffin must be ordered because it was not available at that time.

- So, we had to try new methods to obtain concentrated smoke. From the Department of Chemistry of our university, some apparatus for mixing HCl and NH_3 was adviced.(Fig.A.1.) The apparatus was prepared but observed that the smoke was not so concentrated and it could be hazardous to health.

- Then, new mixtures had been tried to obtain smoke such as cellulosic varnish composed with sand or sawdust, or cotton. The initial tests outside, seemed hopeful, but they could not get through the pipe in the tunnel and their colour was dark grey which was hard to see.

- After these trials, it was suggested that the smoke screen could be useful, but it was hard to find any at the market, after some conversations with the competents, sample of special size smoke box was obtained. After its control test, it seemed that it could be useful and 50 of them were ordered, (1/2 kg.,special size where the ordinaries are 2 kg.) sufficient for the completence of the study.

. Our Models were prepared, smoke and the smoke apparatus - which was suggested to give streamlines - 2 pipes with 1 inch diameter and 4 mm., holes on them with 1 cm. distance, were ready. We expected the smoke passing through holes must be formed in lines, but an astonishing observation, any trace of smoke within the tunnel could have not been seen. So, where was the mistake? The hoses bringing smoke to the tunnel were shortened but there was no use.

The velocity was so fast that we could not slow it by rheostats. We had then, in order to decrease the velocity, after some difficulties whilst obtaining it from the Department of Electrical Engineering, we used varyac. This gave us some hope since we could see some traces of smoke within the tunnel. The velocity could vary from 0.1 m/s to 19 m/s, which gave us opportunity to use the Froude similarity easily.

. Then, the problem was to obtain images as pictures. Another difficulty appeared, the traces of smoke had not been seen on photographs, a problem of photography.

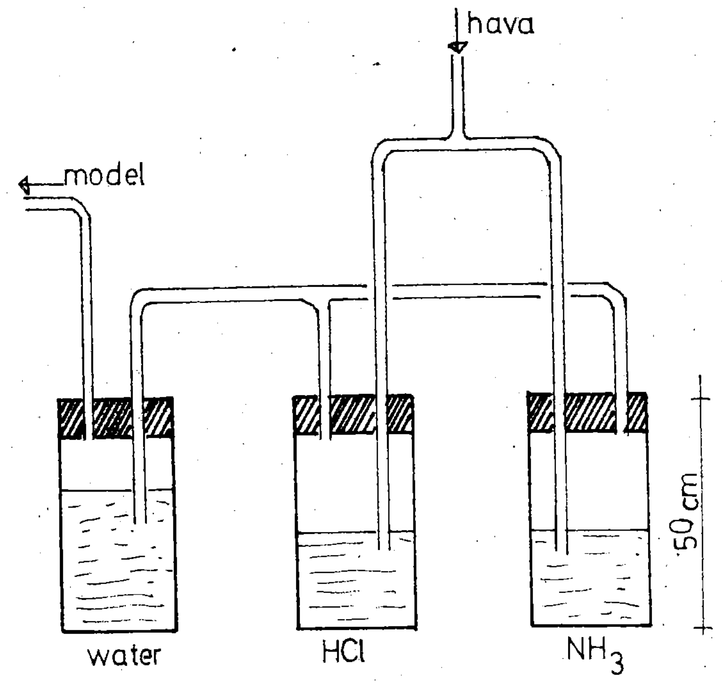


fig: A1

A smoke apparatus (which has been tried)

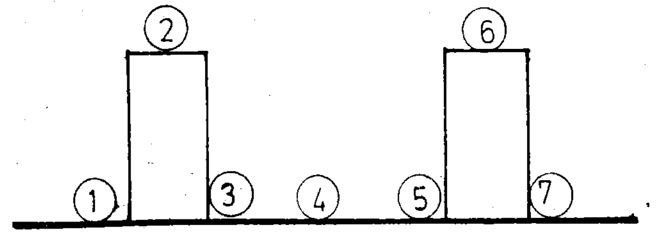


fig:A2

Places of anemometre readings

The transparent walls of the test section were plexiglass and they were changed with the ordinary glass for better vision. Another problem was reflection of the glass, in order to get rid of this problem, the back wall of the test section had been covered with black cloth. The illumination was obtained from two spotlights of 250 watt each, which were placed at the top of the test section. Again, there was no trace of success.

Then, yellow filter and blue background,then, other , filters and different distances of spotlights have been tested but no better results were achieved. These trials showed us there must be strong light source to illuminate models, and sunguns have been provided from the Department of Civil Engineering. (These tools and machines could be obtained by the special permission of that department upon the request of the Faculty of Architecture, which was a procedure of bureaucracy).

. These trials did not give the expected result,so, the problem had been turned again on smoke. The smoke bombs were very powerful as a source so, the problem was to get the smoke within the tunnel.

Holes on the pipe were then widened, which resulted with some hope. Half length of the pipes could give smoke, but it was not as streaks that we expected but as screen.

Then, the flow within the tunnel have been studied theoratically and simulation formulas have been checked again which gave the opportunity of interpreting the situation. If flow in the tunnel is laminar, then, smoke must come out as streaks, but if the flow in the tunnel is turbulent, smoke could not follow any path but form as screen, which was the situation of our tunnel. This gave the Reynolds Number independence. (See Sections III.1.2. and III. 1.3.).

. After those trials and errors, the models were illuminated from above with spotlights and from inside of the tunnel at both sides with sunguns. And, it was decided that the air movement could not be figured out by photographing but possibly by the motion picture, after several qualities of films and techniques of photography have been trialed. The best contest of the image was obtained from red coloured models on black background. (Painted with matt dyes).

Each trial had taken several days with the preparation and testing of it, so that the work could not go on easily. And, I should mention here that, at each trial, other technicians and workers have been needed besides the real research worker, the author.

. The motion picture did not show any miracle as we expected, but, gave some helpful critics. The smoke must be much more condensed and pressured or any other smoke apparatus must be designed. Since it was thought that the pressure might destroy the real effect of velocity within the tunnel, other methods of visualization have been tried.

. Visualization, by small pieces of papers (confettis of telex strips) were tested. But it was extremely difficult to control and set the simulation of flow with these pieces, because, they might represent equal sizes of air particles(as if to say), if their weights were equal to each other, which actually was not. Several meters of film had been taken which was interesting. In order to obtain better diffusion of these paper particles, the scale of the model was reduced, (from 1/100 to 1/150) which did not give any successful result.

- Then, we turned back to smoke again. Another apparatus was designed and then, smoke was brought with the 7cm diameter hose from outside through the bell mouth of the tunnel, to the test section. In order to obtain greater diameter of smoke flow, a funnel had been put at the end of the hose. The condensation of smoke in the tunnel was too successful that, the model could hardly be observed because of the diffusion of smoke.

The models should be changed so that the representative of tower type buildings turn out to be slabtype. Because the flow in front of the model with the behind of it had interference effect on vision of real flow, the new models with new experimentation groups had been set. (See I.2.1.2)

. Such concentration of smoke brought other problems. Breathing under such conditions could be hazardous, and was very discomfortable (cough and fever at throat was felt) Competents said hagzachloretan with zinc powder could be dangerous if the study was carried out over 5 minutes in closed spaces.

In order to decrease the smoke concentration within the room, the outlet of the tunnel was connected with the free air by a nylon outlet. Although such precautions had been taken, smoke was distributed all over the room and the canteen, (which was adjacent to the test room). So, the door of the test room had to be closed. This brought much more condensed smoke in the room and another precaution was held, a fan was mounted at one of the closed windows. But discomfortable effects did not change the danger of it. Then, we (the research worker and some people who helped her) had to use gas masks. Whilst providing those masks, we had to face with another chain of bureaucracy.

. In order to get better visualization of flow, instead of largening the funnel, the model was lifted about 10 cm., from the tunnel ground, because the largening of the funnel might have been resulted in destruction of clear vision. Then, the results on films were very successful. It had been observed during the study that, the smoke from the hose could not penetrate when the funnel had been taken or the shutter of the tunnel (the upper wall of the test section) was open. Of course, better conditions could be obtained which were dependent on the parameters, money, time, technology, technical knowledge and labour. So, all experiments have been carried out under these conditions, and so, completed.

• In order to assist the conclusions, some numerical investigations had been tried out. Anemometer measures of the velocities at seven places of each case of the experiments (Fig. A.2.), but since our anemometer was very big cube of 5cm for this purpose, the obtained measurements were not to be trusted. The measurements might have been much more different from those of the real ones and while interpretation, this was regarded as such.

CONCLUSION

This research study has been completed under very difficult circumstances. These difficulties will be mentioned here, in order to give some ideas to the future research workers in the Faculty of Architecture.

• The first problem was the lack of knowledge in this field as being an architect. Throughout the work, this new field has been discovered from place to place. For this study, I made some communications with persons from other disciplines, civil engineers, mechanical engineers, chemicists and film and photographical technicians. So far, such a work, a team work was necessary.

• Another problem was the available technology. This depended on the technological level of Turkey. There were several kinds of smoke apparatus sold in the market abroad.

• This technological advantage might be altered by buying and ordering those from abroad if financial sources were sufficient. A student, with her or his conditions, could not afford this money, and it has been very difficult to get the financial aid from the university. The university authorities, at least might agree on the idea that these studies would be necessary and useful!

• The student, with her or his economic situation are still dependent on their families and must complete the work as quick as possible, and since it has been announced that the master thesis study should normally be completed in one year, the students are in a position of hurry, because of psychological reasons, of course, this hurry effects on the study very much.

. Similar research studies need some assistance as labour at least. For example, during this study, three people worked for each experiment. Sometimes this number increased to five or six persons. This problem of labour might be solved by a group work of thesis students.

APPENDIX B.

Other Similar Studies.

The study of air flow around buildings and building groups have been done by various groups from various countries. In the following few pages, some of those studies and their results will be briefly mentioned in order to give an idea of such work.

. In one of the studies,[50] aerodynamic behaviour of bodies in the wakes of other bodies have been investigated through pressure measurements and smoke tests. Buildings were square tower type, and their distance were constant. The incident angle of the wind was changing. It has shown that a small change of wind incidence (10°) increases the force coefficient of the rear blocks a lot. Another study for similar purpose[51] showed that, as the wind angle approached 0°, i.e.,wind, parallel with the wall, regions of suction developed at angles of 10° or less, the whole wall was under suction. This change of coefficients and other results can be stated precisely, since the interpretation from using both, testing methods (measurements and visualization) give this opportunity.

The effect of single buildings and structures have been studied by J.C.R. Hunt.[52] Calculations stated that

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(50) Philosophical Transactions of the Royal Society of London, A Discussion on Architectural Aerodynamics, The Royal Society, London, 1971, p.437.

(51) SEXTON, D.E., Building Aerodynamics, Building Research Station, London, 1968, p.17.

the flow at either sides of the wake was very turbulent, turbulent flow was composed of steady and fluctuating flow. On the boundaries of the wake, fluctuating component raised up to 40% of steady component. It was observed that upstream of an obstacle in a shear flow on the ground, a vortex had been found which created a downwash at the front face of the body. This can be explained as the 'piling' up of vortex lines, swept in by the incident flow. And, the author explained that the effects of shear in the incident flow on the separation at the sides or at the top of the building were still not known, and the effect on the roof vortices was equally uncertain. The addition of turbulence to the incident flof affected both the steady and the fluctuating velocity near the building. One of the basic effects of turbulence on steady flow was to force the wake to start nearer the rear of the building. The other effect was to thicken the shear layers.

Both, the magnitude and the distribution of the pressures were greatly influenced by the shear and turbulent properties. of natural wind, and also by the proximity of neighbouring buildings.[53]

These results have been checked by theoratical calculations and aerodynamic theories and also by full scale experiments.

The experiments of Cook (1970)[54] at Bristol University were aimed at finding out how the intensity and scale of turbulence affect the flow at the sides and in the wake of a rectangular block with a square section and a height, three times the side. The results have shown how increasing the scale of the turbulence intensity and, the scale of the turbulence destroyed the vortex shedding.

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(52) Philosophical Transactions of the Royal Society of London, A Discussion on Architectural Aerodynamics. The Royal Society, London, 1971, p.458.

(53) Ibid, p.362.

. An early experiment from thirties was done by Jensen[55] who examined the flow behind artificial screens in nature and similar screens in the wind tunnel and found that the shelter in nature was much shorter than that in the tunnel. The reason was stated that the natural wind was more turbulent than in the tunnel. And, the other reason which was not stated at that report might be the tunnel blocage upon the flow.

Another research was done for examining air pollution problems. Smoke came out from a tall stack of a factory at different velocities upon the groups of buildings and was seen that flow could not reach the surfaces of buildings if flow is low but getting higher than the velocity, the effect of smoke on buildings increased.[56]

Baines searched for an experiment , how flow about a building in a built-up area differed from that about a similar building in open level country.[57] Flow pattern around a typical sky-scraper of square plan of height/ breadth ratio of 8, and also a long, low building have been observed. (Fig. B.1.).

. In the Department of Environment of Building Research Station,many investigations were tried. These researches which were similar to ours showed interesting results concerning architecture.

They used wind speed ratio (R), representing the ratio of wind speed at pedestrian height, near a building to free wind speed at the same height with no building around. By using this ratio, they could compare the flow around buildings and interpret them accordingly. When the wind

(54) Proceedings of the Conference held at the National Physical Laboratory, Wind Effects on Buildings and Structures, London, 1965, p. 463.

(55) Proceedings of the Intr. Research Seminar held at the [illegible] Research Council of Canada, Wind Effects on [illegible] Ottawa, 1967,Vol.I,pp.1-21 [illegible], 4th Dec. 1968.

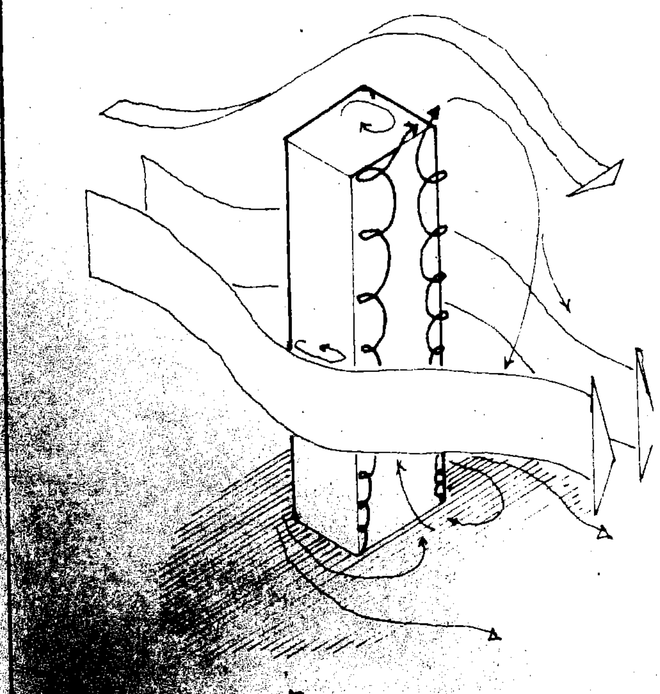

fig: B1

Basic airflow around a tower type building.

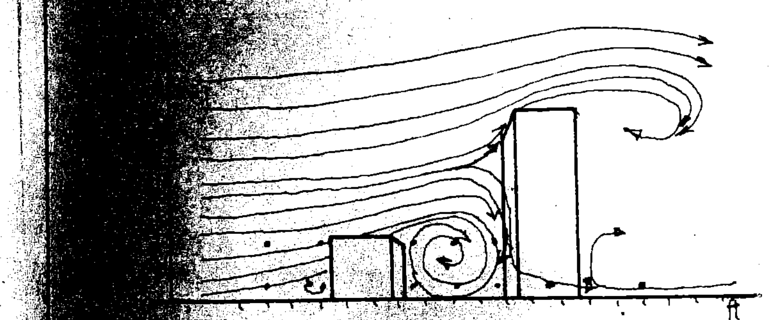

fig:B2 Flow and velocity distribution

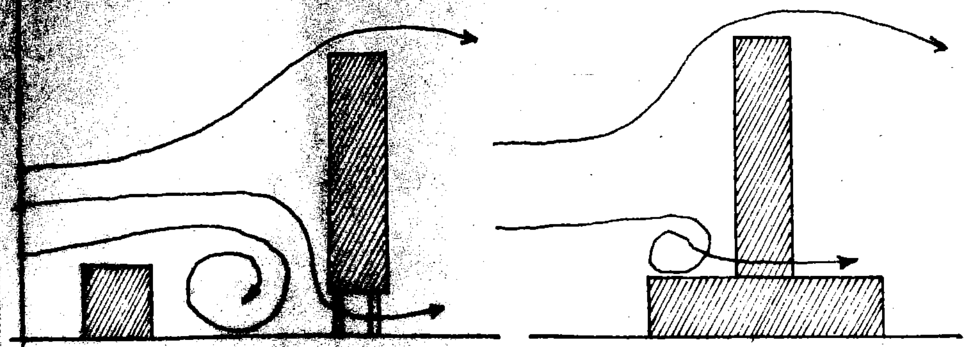

fig:B3

Airflow around raised buildings.

flew over raws of low buildings as in the older parts of a town, pedestrian areas were generally sheltered with wind speed ratios, R, in the region of 0.5 to 0.7.

In Fig. B.2., the wind divides at about 2/3 to 3/4 of the building height. Above this division, the air flows up the face of the building and over the roof. Below, the wind descends to form a vortex in the space in front of the tall building, and sweeps around the windward corners. This produces high wind speeds in regions A and B, where R may be as high as 1.5 and 2.0 respectively. And, other experiments deal with the buildings raised upon piers and it is seen that the velocity under such places are very high. (Fig. B.3.).

Effects of velocity distribution on wind loads and flow pattern on buildings have been studied by W.D. Baines.[58] Pressure distribution has been measured in a wind tunnel and changes in the flow pattern due to the velocity distribution have been observed and correlated with the pressure distribution. Only in the front surfaces, distinct phenomena were observed. An intense downward flow carrying high energy air to ground level exist on tall buildings, and on low structures a region of reversed flow occured at ground level, resulting in an attached eddy.

. Some other test results show the great variety of architectural treatments create possibilities of the appearance of vortices which cause pressure pulsations of various frequencies and amplitudes. Under certain conditions, these vortices may produce pulsations, sufficient to break windows, and cause fatigue failure in mental work panels, and in winds of long duration to cause discomfort to the occupants.

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(57) SEXTON, D.E., Building Aerodynamics, Building Research Station, London, 1968, p.17.

(58) Proceedings of the Conference held at the National Physical Laboratory, Wind Effects on Buildings and Structures, London, 1965, p.198.

Another group of studies dealt with the effect of the slope of the roofs. For example, it was found that the wind around the roof slope of 20^{o} had no effect of pressure and suction.[60] And, Aronin stated that: 'Le Corbusier has thus probably accomplished more than one purpose when he provided gardens on top of the roofs of his dwellings, the layer of the air trapped in the blades of grass and other plant cover undoubtedly reduced the wind chill effect on that horizontal plane'.[61]

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(59) Philosophical Transactions of the Royal Society of London, A Discussion on Architectural Aerodynamics, The Royal Society, London, 1971, p.463.

(60) ARONIN, J., Climate on Architecture, Reinhold Pub., U.S.A., 1963. p.205.

(61) Ibid, p.186.

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CHART II
1a vel: 2.6 m/s dist: 40 cm
1b vel: 1.28 m/s dist: 40 cm
1c vel: 0.74 m/s dist: 40 cm
2a vel: 2.6 m/s dist: 30 cm
2b vel: 1.28 m/s dist: 30 cm
2c vel: 0.74 m/s dist: 30 cm
3a vel: 2.6 m/s dist: 20 cm
3b vel: 1.28 m/s dist: 20 cm
3c vel: 0.74 m/s dist: 20 cm
4a vel: 2.7 m/s dist: 10 cm
4b vel: 1.28 m/s dist: 10 cm
4c
AA h_1: 20 cm h_2: 20 cm
BA h_1: 10 cm h_2: 20 cm
AB h_1: 20 cm h_2: 10 cm
BB h_1: 10 cm h_2: 10 cm


CHART
I
1a
1b
1c
2a
2b
2c
3a
3b
3c
without model
A
h:20cm
4/9 l
l
a
1/3 l
l
b
1/4 l
l
c
A1a
A1b
A1c
A2 a
A2b
A2c
A3a
A3b
A3c