Flow and Pressure Field Characteristics around Pyramidal Buildings

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Abstract
An experimental investigation of the flow and pressure characteristics around pyramidal buildings is presented. The experiments were conducted in an atmospheric boundary layer wind tunnel. The velocities of the flow around the pyramids and the pressure distribution on the pyramid surfaces were measured using 2D Laser Doppler Anemometry (LDA) and standard pressure tapping technique, respectively. Eight different pyramids with varying base angles were investigated. The mean and fluctuating characteristics of the flow and pressure field around pyramids surfaces are described. The basic flow characteristics that distinguishes pyramids from rectangular buildings are also discussed in this study. The influence of two parameters, base angle and wind direction, was investigated. The results show that base angle and wind direction characteristically influence the flow and pressure field around pyramids yielding differences in integral flow describing quantities and in wind loads on the structure.

Keywords
Pyramid, wind tunnel, recirculation zones, flow characteristics, pressure characteristics.

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I. Introduction

Pyramid comes from the Greek word “Pyre” which means fire, and from which the words Pyramis and Pyramids are derived. The meaning of the word Pyramis is obscure and it may relate to the shape of a pyramid. The word Pyramids has been translated as "Fire in the Middle" [14]. For millennia, the shape of the four-side pyramid has been the subject of pondering for the curious-minded. Many historical buildings or monuments have been built in the shape of a pyramid. The Cheops pyramid in Egypt, which has been built thousands of years ago, is famous as one of the Seven Wonders of the World. Nevertheless, today, no one can give an exhaustive account of the reasons why a tomb was constructed as such a giant regularly shaped monument. How was it built? What techniques did the builders use and what kinds of instruments did they apply?

The mystery and the attractiveness of pyramidal shape have made pyramidal buildings undergoing a renaissance in today’s architectural design. Buildings as a whole for various purposes such as residences, hotels, multifunctional halls, offices, museums, halls as well as building components like roofs (Fig. 1), or entrance halls are constructed in pyramidal shape.

From the aerodynamic engineering point of view, the pyramidal building has its own interesting characteristics. The pyramidal geometry shows specific fluid mechanical properties when compared to rectangular, sharp-edged configurations mainly due to the vertical wall taper, which has an important implication to environmental and industrial aerodynamics. Although the surface flow for the pyramidal building and the rectangular one bear some similarity [8, 21], the pattern on the leeward face indicates that the mean flow structure of the recirculation wakes is very different. Fig. 2 shows sketches of flow structures around bluff body, which are compiled from the previous studies [1,16,22,24], where some basic differences of the flow structure around rectangular and pyramidal building are shown. Fig. 2(a) shows qualitatively the flow structure in the 2-D centre plane. It shows clearly that the size and length of the recirculation zone decreases significantly for pyramidal buildings when compared to other rectangular structures. It can be inferred from Fig. 2(b) that the flow around a pyramid gives as well rise to a discrete horseshoe vortex system. However, the vortex systems attached to the pyramids are not
so uniform as systems of rectangular bodies. The wall taper induces e.g. conical forms of vortices on the side surface and on the back surface. The diameter of these vortices depends on the local rotating velocity (driven by the flow velocity around the edge) and on the local pressure at height z. Thus, the aerodynamic loading of the structures is rather specific.

The technical layout of pyramids with respect to wind load assumptions is usually not listed in standard tables. The Building Research Establishment (BRE), e.g., gives design values of the pressure coefficient (c_p) at different wind directions for the case of pyramid base angle ζ=45° [9], which is the angle of surface declination of the pyramid. Unfortunately, this report does not cover investigations of pyramidal buildings for other base angles. Also, these facts underline the need of systematic experimental investigations of pyramidal buildings.

Ruck & Roth [24,26] carried out experimental investigations which involved 2 types of pyramids. However, more than two variations are required to produce a comprehensive understanding of flow and pressure characteristics around pyramidal buildings. Recently, an aerodynamic study on a pyramid with small base angle has been performed by Ikhwan and Ruck [16]. The results showed that for normal (shallow to medium in steepness) pyramids the base angle and wind direction are the dominating influencing factors for the flow and pressure field characteristics.

Abuomar et. al. [1] investigated steep pyramids with three different base angles (ζ=45°, 60°, and 67.5°). Whereas the study by Ikhwan and Ruck showed a strong dependency of base angle, the Abuomar study showed that the flow (i.e. separation and reattachment zone) and pressure characteristics do hardly not depend on the base angle for steep pyramids.

In the present study, eight pyramids with different base angles ζ = 20° (pyramid P20), 30° (pyramid P30), 40° (pyramid P40), 45° (pyramid P45), 50° (pyramid P50), 55° (pyramid P55), 60° (pyramid P60) and 70° (pyramid P70) were investigated. All pyramids have the same square base (l x l = 200 mm x 200 mm) and show sharp edges. The experiments were carried out in a closed-loop 29 m long atmospheric boundary layer wind tunnel at the Laboratory of Building- and Environmental Aerodynamics, Institute for Hydromechan-
ics, University of Karlsruhe. This study describes mean and turbulent characteristics of the flow around pyramids and of the pressure field on the pyramid surfaces with varying base angle $\zeta$ and wind direction $\alpha$.

II. Experimental Set-up

The actual measuring section of the wind tunnel is 8 m long and has a 1.5 m octagonal cross-section, capable of creating boundary layers with a height of 0.5 m. The wind velocity in the measuring section can be varied within a range of $0 - 45$ m/s.

The atmospheric boundary layer flow was developed along a 2.6 m section of roughness elements combined with two types of vortex generators 65 cm and 50 cm high, see Fig. 3. The free stream velocity was fixed at $u_\infty = 5$ m/s at $z = 0.5$ m height and the corresponding Reynolds number (Re) based on the pyramid height (h) varied from 12,000 to 90,000.

Simulation of the Atmospheric Boundary Layer Flow

A proper simulation of the atmospheric boundary layer in a wind tunnel was described by many researchers [3,4,12,19]. The similarity of wind profile is an essential requirement as pointed out already in 1932 by Flachbart [12], who performed systematic drag and pressure coefficient measurements in uniform and in boundary layer flow.

The wind conditions in the tunnel should be simulated as similar as possible to the conditions in nature. These characteristics include the variation of the mean wind velocity with height, the variation of turbulence intensities and integral scales with height, the spectra and cross-spectra of turbulence in the along-wind, across-wind, and vertical directions [28].

Fig. 4 shows the mean wind speed profile at two positions (upstream and downstream) of the test section in the wind tunnel. The profile indicated as ‘upstream flow’ is measured at 2.6 m after the roughness elements, which is the starting point of the measuring section (see Fig. 3). The end point is located 0.8 m downstream from the starting point and the measured profile there is indicated in Fig. 4 as ‘downstream flow’. The velocity profiles are well fitted with $\alpha = 0.26$ using the exponential velocity law (Eq. (1))
where \( u_z \) and \( z_{\text{ref}} \) represent the velocity at height \( z = 0.5 \) m and the reference height of 0.10 m, respectively, and \( d \) is the displacement thickness (0 m). According to Plate [23] and others the profile exponent can be categorized due to the dominating surface roughness (e.g. suburban or industrial area and city centres). In nature, the actual roughness of the ground surface is not always homogeneous but may consist of various elements such as soils, concretes, water surface, forests, buildings, etc. As can be seen in Eq. (2) the flow profile can also be expressed by a logarithmic law, where the roughness effects are represented by a parameter \( z_0 \). Fortunately, this parameter \( z_0 \) has been determined in many studies for various types of surface properties [2,7,18,20,27].

\[
\frac{u_z}{u_*} = \frac{1}{k} \ln \left( \frac{z - d}{z_0} \right)
\]

where \( k \) is the von Karmán constant with a value of 0.4 and \( u_* \) is the friction velocity. The experimental set-up used delivered \( u_* = 0.422 \) m/s and a roughness length of \( z_0 = 2.49 \) mm (Fig. 5), which corresponds with a model scale of 1: 200 to \( z_0=0.50 \) m in nature. Roth [25] stated that a boundary layer over an urban canopy can be subdivided into two layers, the inertial sublayer (IS) and the roughness sublayer (RS). The depth of RS is still subject to debate but it is in the range of 2 to 5 times the average building height. Inside RS turbulent fluxes and all other boundary layer properties are assumed to be influenced by individual elements. Which means the turbulent fluxes are neither spatially homogeneous nor is the logarithmic law fully applicable. Therefore, as shown in Fig. 5, the value below 30 mm can be neglected. According to EUROCODE 1: ENV 1991-2-4 [11], the roughness length generated in this study (\( z_0 = 0.5 \) m) can be categorized between wind flow over suburbs (0.3 m) and city centre areas (1 m).
The turbulence intensities in the longitudinal and vertical directions are defined as in Eq. (3) and (4).

\[ I_u(z) = \frac{\sigma_u(z)}{u(z)} \]  

(3)

\[ I_w(z) = \frac{\sigma_w(z)}{u(z)} \]  

(4)

where \( \sigma_u \) and \( \sigma_w \) are the standard deviations of the longitudinal and vertical velocities, respectively. From the proportionality between the standard deviations of the individual velocity fluctuations and the velocity friction \( u^* \), and after subsequent substitution, turbulence intensities can be expressed as below [18,23].

\[ I_u(z) = \frac{1}{\ln \left( \frac{z - d_0}{z_0} \right)} \]  

(5)

\[ I_w(z) = \frac{0.5}{\ln \left( \frac{z - d_0}{z_0} \right)} \]  

(6)

The vertical profiles of the turbulence intensities of the simulated boundary layer are presented in Fig. 6. Below 20% of the boundary layer height \( z \), the longitudinal turbulence intensity \( I_u(z) \) is a bit higher than the theoretical profile (Eq. (5) and (6)) [23] for a roughness length of \( z_0 = 0.50 \) m. However, it fits well for a roughness length of \( z_0 = 1.00 \) m, which is categorized as a flow above city centre area [11]. For the vertical turbulence intensity profile, the simulated values are up to about 30% higher than those given by the theoretical profile.

Taylor (1920) introduced the concept of correlation measurements and for the transition from spatial to temporal spectra, the so-called Taylor hypothesis is used. This concept showed that turbulence scales could be determined from [17]:

\[ L_{ux} = \frac{u}{\sigma^2_u} \int_{0}^{\infty} R_{uu}(\tau)d(\tau) \]  

(7)
where \( L_{ux} \) is the length scale of turbulence and \( R_{uu}(\tau) \) is the temporal autocorrelation-function. Usually, the autocorrelation function is integrated in time up to its first zero crossing yielding an area proportional to the degree of correlation. A rectangular area of similar size can be deduced, defining a turbulent length scale. Thus, this integral length scale is a measure for the length of longitudinal vortices. According to EUROCODE 1 [11], \( L_{ux} \) increases with height and above 300 m \( L_{ux} \) remains constant or is independent of the surface roughness. Fig. 7 shows the simulated turbulent length scale compared with the values given in EUROCODE 1 for flows above urban areas. The overall trend shows a good agreement except in the region above 300 m where the \( L_{ux} \) values in the model are found to be a bit smaller than in the nature. One possible explanation is the fact that the upper part of the wind tunnel acts as a boundary which inhibits the growth of the eddies and thus restrain the size of the developing vortex. In 1995, Plate [23] also categorized different \( L_{ux} \) values for different areas. The values of \( L_{ux} \) above suburbs and city centres compared to the simulated flow of this study are shown in Table 1. Looking at the constraints of the wind tunnel and the comparison, the simulated flow is still acceptable to be categorized as a flow between suburban and city centre area.

Additional theoretical work by Taylor in 1938 provided a relationship between power spectral and the correlation coefficient [10]. In practice, the measurements of spatial correlation and spectra in wave number space are difficult to perform. Likewise, measurements of the covariances as spatial averages are equally difficult. Taylor’s hypothesis, otherwise known as the frozen turbulence hypothesis, states that if the turbulent intensity is low and the turbulence is approximately stationary and homogenous, then the turbulent field is unchanged over the atmospheric boundary layer time scales of interest and advected with the mean wind [13].

The spectral distributions of the fluctuations of velocity are given in the form of logarithmic frequency spectra and they are usually obtained by using a Fast-Fourier Transform. The one dimensional spectral density is represented by \( S_{uu}(f) \) and is given by
\[ \sigma_u^2 = \int_0^\infty S_{uu}(f)df \quad (8) \]

The Karmàn`s function for the spectral distribution gives the form [7]

\[ \frac{f \cdot S_{uu}(f)}{\sigma_u^2} = 4 \cdot \frac{f \cdot L_{ux}}{u} \left[ 1 + 70.8 \left( \frac{f \cdot L_{ux}}{u} \right)^{2/3} \right]^{5/6} \quad (9) \]

Fig. 8 shows the power spectral density distributions of the longitudinal velocity fluctuation of the simulated flow at the height of \( z = 45 \) and 50 cm. The power spectra measured are well fitted with the von Karmàn spectrum. After reaching a maximum, the power spectrum declines with a gradient of \( f^{-2/3} \). However, due to a finite measuring resolution, the power spectral density distribution of the simulated flow is increasing again – a typical shortcoming of the measuring technique used. Nevertheless, the comparisons show that the simulated atmospheric flow in the wind tunnel is kinematically similar to the nature conditions.

**Measurements**

Longitudinal and vertical velocities were measured with the aid of a 2D Laser Doppler Anemometer (2D-LDA), working in forward light scattering mode using blue (488.0 nm) and green (514.5 nm) light from a 4 watts argon-ion laser. The scattered light signals were detected by photomultipliers and filtered from 300 KHz to 1 MHz. These filtered signals were processed using two counter-based signal processor TSI model IFA 550, which measures the time required for 11 cycles of each Doppler burst. 1,2-propanadiol droplets were generated with an evaporation-/condensation-type particle generator, producing seeding particles of 1.5 µm mean diameter, see [26].

The pressure distribution on the pyramid surfaces were measured using the standard pressure tapping technique. Pressure taps with 1.5 mm diameter were distributed systematically on one half of a pyramid surface. The pyramid versions investigated had different numbers of pressure taps ranging from 46 to 59 due to different sizes in surface area.
The pressure taps were connected to the pressure transducers with vinyl tubes via metal connectors to a scanivalve unit. Usually, the connectors and tubes cause a certain pressure loss, which limits the frequency response of the pressure measuring system. However, in the frequency range encountered here, this systematic error was negligible. The scanivalve unit switched the tubes connected to the transducers i.e. the measurements were carried out one after another in a temporally stable boundary layer flow.

Dimensionless mean pressure coefficients ($c_p$) and root-mean-square (rms) values were deduced from a continuous sampling at about 1000 samples per second per tap over a period of 30 s. The pressure coefficients ($c_p$) were calculated by dividing the differential pressures (surface pressure $p_{surface}$ minus the static reference pressure $p_{stat}$) by the dynamic pressure at the reference height of 275.4 mm, which is the height of pyramid P70 (see Fig. 3). The pressure coefficient $c_p$, is expressed as

$$c_p = \frac{\Delta p}{q} = \frac{p_{surface} - p_{stat}}{(\rho/2)u_{ref}^2}$$  \hspace{1cm} (10)

where $\rho$ is the air density. The static reference pressure was measured at $y=0.75$ m, a location where the free stream turbulence intensity was low and no interaction of the flow with the model itself was observed [21].

III. Experimental Results and Discussion

Flow Characteristics

All flow fields were investigated with a wind direction of $\alpha' = 0^\circ$ (normal to the windward surface). The flow fields were measured ranging from 1 x l upstream to 2 x l downstream (l: length of the pyramid) of the pyramid and within a height from $z=0$ to $z=1.5 \times h_{70}$ (height of P70).

Velocity vector fields at the centre line cross-section ($y/l = 0$) are shown in Fig. 9. From the plots given, the formation of recirculation zones in the lee of the pyramids can be observed. For pyramid P20, no recirculation zone is found (Fig. 9 (a)) but the pattern shows that the velocities in the lee are decreasing also (see [16]).
A small recirculation zone can be observed in the lee of pyramid P30 (Fig. 9 (b) and 10). This recirculation zone is attached to the backward facing pyramid surface. For pyramid with base angle $> 45^\circ$ (Fig. 9 (c) – (g)), the recirculation zone can be clearer visualized. The size of the recirculation zone increases together with the base angle. The vector plot of the flow velocity reveals in this zone a large-scale fluid rotation. This large scale vortex is considered to be very stable in comparison to recirculation bubbles behind rectangular bluff bodies where the flapping of the shear layer intermittently causes the recirculation bubble to be convected downstream [1]. Moreover, the recirculation zone in the lee of a pyramid is much shorter in length than that of a rectangular bluff body of similar height. As a consequence, the rotating mass must be smaller. Due to a smaller gradient between ambient pressure and back pressure of the pyramid, also the rotating velocity within the recirculation is decreased. It was observed that the overall vortex system of pyramids is more stable than those of rectangular bluff bodies. The latter might come from the two very stable side vortices on the side walls and of the two very stable vortices at the corners of the backside of the pyramid. All of these vortices are found to have varying size and rotating velocity with height.

The recirculation zone is characterized by the reattachment length in the wake of the pyramid. The reattachment length is regarded as the most important parameter characterizing separated and reattaching flows [14]. The reattachment point is defined as the point where the zero streamline hits the ground again. The reattachment length $x_r$ is measured from the leeward surface of the pyramid (at bottom position) to this point and is normalized with the pyramid length $l$ in our case (see Fig. 10(b)). As mentioned in section 1, Abuomar [1] concluded that for steep pyramids the reattachment lengths in the lee of pyramids depend only on the angle of wind directions and is rather insensitive to pyramid base angle variations. In our study, the results show for shallow to medium steep pyramids that there is a dependency, see Fig. 11. As can be seen at the centre plane, the reattachment lengths are influenced by the steepness of the pyramids. As the base angle increase, the length $x_r$ also increase. It is remarkable that the differences in reattachment lengths for steep pyramids are not as big as for shallow pyramids. Base angle variations with shallow or medium steep pyramids result in significant differences in the
flow and pressure field around. A significant change in the size of the recirculation zone seems to happen between base angles of 45° and 50°, see Fig. 11. This base angle range can be assumed as the transition between base angle sensitive and insensitive configurations. This seems to be the reason why experimenters have sometimes categorized pyramids as “shallow” and “steep”.

Evans in 1957 [15] introduced an equation to calculate the reattachment length for rectangular buildings. The geometry of the buildings were characterized by length (l), height (h) and width (w), see Fig. 10(a). The equation can be applied for buildings with l/h < 2, and later, in 1979, Hosker [15] introduced another equation for l/h > 2. Both equations are:

Evans (l/h<2) : $$\frac{x_r}{h} = \frac{l}{h} + \frac{A \cdot (w/h)}{1.0 + B \cdot (w/h)}$$

where, 
$$A = -2.0 + 3.7 \cdot (l/h)^{-1/3}$$
$$B = -0.15 + 0.305 \cdot (l/h)^{-1/3}$$

Hosker (l/h>2) : $$\frac{x_r}{h} = \frac{1.75 \cdot (w/h)}{1.0 + 0.25 \cdot (w/h)}$$ (12)

Fig. 12 shows the comparison of reattachment lengths between pyramidal and rectangular buildings. The rectangular building has a square base which length (l) equal to width (w). The figure shows that the reattachment lengths at all planes in the wake of the pyramids are significantly smaller when compared to rectangular buildings. Considering centre plane data reveals that there is a logarithmic dependency between h/l and x_r/l.

Apparently, for the plane at y/l=0.25, a significant change in reattachment length happens at the ratio of h/l = 0.5 (i.e. l/h =2), which is similar to the ratio described by Evans and Hosker and used to differentiate Eq. (11) and (12) for rectangular building.

The fluid phenomena around pyramid structures are of interest not only in building aerodynamics or in architecture, but also in other technical fields and processes, where the mixing or heat transfer above technical surfaces covered with arrays of small pyramids can be increased significantly.
One of the interesting quantities that characterize a flow is the turbulence intensity, which reflects e.g. turbulent mixing processes. Fig. 13 and 14 show the level of turbulence intensities in longitudinal and vertical direction at the centre plane of the pyramids, respectively. The figures show clearly how the turbulence intensities increases as the base angle increases. Maximum fluctuations occur near the tip in the lee of the pyramids. For the shallow pyramid P20, it seems that the pyramid does not significantly increase the turbulence intensity. This is due to the fact that for this configuration, the pyramid height is relatively small compared to the height of the roughness elements. The pyramid-induced turbulent distortion does not overrule the roughness-induced turbulence in this case.

**Pressure Characteristics**

Pressure measurements were carried out with a velocity of 12 m/s in order to obtain measurable and reliable pressure differences. Thirteen different wind directions (\(\alpha'\)) ranging from 0° to 180° with 15° increments for each pyramid were investigated. The pressure characteristics on the pyramid surfaces can be visualized as shown in Fig. 15. This figure shows the effect of base angle variation at a wind direction 0°.

The \(c_p\) mean distributions indicate that the maximum pressure, which occurs on the windward surface A, increases with increasing base angle. For pyramid P20, the \(c_p\)-maximum is 0.16 and it is increasing to 0.76 as the base angle reaches 70°. The same behaviour was found for maximum suction (i.e. \(c_p\)-minimum), which occurs on the upstream edge of side B and D. In 1993, Tieleman studied pressure on surface-mounted prisms [30]. His study concludes that the magnitude of \(c_p\) decreases with increasing turbulence intensity. This behaviour also applies for surface C. As can be seen in Fig. 13 and 14, the turbulence intensities in the wake of the pyramids are increasing as the base angle increases, and the increase of turbulence intensities causes the \(c_p\)-value to decrease at surface C. However this behaviour does not apply for pyramid P20 because of the reasons mentioned before. The measured pressure distributions show that a base angle variation exerts a significant influence on the resulting wind load of a pyramidal building.
Moreover, the variation of the base angle also changes the locations of maxima and minima pressure on the pyramid surfaces as can be seen in Fig. 16. For shallow pyramids maximum $c_p$-values were found on the windward side A at the bottom and the maximum suction is measured on the side surfaces B and D at the upstream edges near the top. As can be seen in Fig. 16. The locations of maximum pressure and of suction (minimum pressure) are shifted when the base angle of the pyramid increases. The maximum pressure is shifting up toward the centre of the windward side A of the pyramid whereas the maximum suction on the side surfaces B and D is moving down towards the base line.

For the steep pyramid P70 the maximum $c_p$-value is found at 53 % of the total pyramid height, and the maximum suction is measured near the baseline of the side surfaces. These locations and values are relatively similar compared to the locations and values of maximum pressure and suction on pyramids from previous studies [1, 24, 26].

The variation of pyramid base angle also affects the distribution of pressure fluctuations, which in this study are indicated as root mean square values ($c_p$-rms). The distribution of pressure fluctuations on the surface of the pyramids are coincident with the positions of the visualized vortex structures around the pyramids. The maximum fluctuation on the surface of the pyramid at wind direction 0° are found at the side surfaces B and D at the upstream edge, see Fig. 17. These are the locations where the flow generates vertical vortex systems. The maximum fluctuations on the side surfaces B and D increase when the base angle increases and the area of these maximum fluctuations move down towards the base line.

The next parameter of interest is the wind direction. Fig. 18 indicates the maximum and minimum pressure coefficient on the selected pyramid surface A as a function of incident wind direction (irrespective of the location of the extreme values in the surface). Obviously, a maximum pressure on this selected surface A is associated with the 0° wind direction, and the symmetric geometry of the pyramid creates mirror effects to other surfaces. For the $c_p$-maximum, similar trends are observed for almost every pyramid except pyramid P20. For wind directions beyond 90°, only suction can be found on the A
surface of the pyramids. The minimum pressure (maximum suction) occurs when the wind blows from directions between 60°-120°.

As can be seen in Fig. 19, the wind direction affects, of course, the (maximum) fluctuations on surface A. A trend can be seen that the steeper a pyramid the higher the fluctuations in pressure. This trend holds up to a wind direction of about 90°.

IV. Conclusions

This study presents experimental results of flow and pressure characteristics around pyramids with sharp edges and square bases. Time mean results and fluctuating quantities are given for eight different pyramid geometries.

It was found for pyramidal structures that a variation of base angle and/or wind direction alters significantly and specifically the velocity and pressure field and should be considered when such structures have to be designed. Base angle and wind direction obviously will affect the characteristics of wind loading for such structures. It could be shown, that the location of maximum and minimum pressure on the pyramid surfaces can be shifted by changing one of these parameters. Furthermore, the data reveal that changes in flow field are more pronounced for base angle variations of shallow or medium steep pyramids than of steep pyramids.

Acknowledgement

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(a) 2D flow structure

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Figure 3. Experimental set-up
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<th>City centre area*</th>
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<tr>
<td>Lu_x (d_0 + 10m)</td>
<td>65 – 85 m</td>
<td>48 – 60 m</td>
<td>78 m</td>
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<td>Lu_x (d_0 + 30m)</td>
<td>130 – 360 m</td>
<td>100 – 190 m</td>
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* Plate [23]