EXPERIMENTAL STUDY ON FLOW AROUND IMMERSED OBJECTS

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ABSTRACT

It is well known that when fluid flows around an object, the object will experience a force due to the interaction between the object and the fluid surrounding it. This study was conducted in an open channel using three different types of immersed objects (circular-shaped, rectangular-shaped, square-shaped) and was divided into two parts. The first part was on the investigation of wake length that results due to different immersed object shapes and fluid flow velocities. The experiments were carried out at different flow rates ranging from 2 L/s to 14 L/s and the corresponding wake lengths were measured. The results show that the wake length increases as the velocity increases. The second part of the study was on the investigation of the resultant drag force on the immersed objects during different combinations of object shapes and fluid flow velocities. Based on the experimental data, the Reynolds number for each immersed object was calculated and the drag coefficient of each immersed object was obtained from graphs and tables in established publications. It was found that the Reynolds numbers for both square and circular shape of the immersed objects were similar due to the frontal area of the objects that were taken into account in the calculations. The resultant drag force was calculated based on the drag coefficient obtained. From the results, the flowing water exerted the highest drag force on the immersed object that was rectangular-shaped compared to the other two shapes that was investigated. This is the effect of different drag coefficient values that are in turn based on the respective Reynolds number and object shape. Another finding was that when the velocity and drag coefficient were increased, the drag force values also increased.

ABSTRAK

Seperti yang diketahui bahawa apabila aliran mengalir di sekeliling objek, objek akan mengalami daya yang disebabkan oleh interaksi di antara objek dan cecair sekitarnya. Kajian ini dijalankan dalam saluran terbuka dengan menggunakan tiga jenis objek tenggelam (bentuk bulat, bentuk segi empat tepat, bentuk segi empat sama) dan dibahagikan kepada dua bahagian. Bahagian pertama adalah mengenai penyiasatan panjang 'wake' akibat kerana bentuk objek tenggelam berbeza dan halaju aliran bendalir. Kajian ini telah dijalankan pada kadar aliran yang berbeza dari 2 L / s 14 L / s dan panjang 'wake' sepadan telah diukur. Keputusan menunjukkan bahawa panjang 'wake' bertambah apabila halaju bertambah. Bahagian kedua kajian ini adalah berkenaan dengan penyiasatan daya seretan yang terhasil pada objek tenggelam dalam kombinasi yang berbeza bentuk objek dan halaju aliran bendalir. Berdasarkan data eksperimen, nombor Reynolds bagi setiap objek tenggelam dikira dan pekali seretan setiap objek tenggelam telah diperolehi daripada graf dan jadual dalam penerbitan ditubuhkan. Ia telah mendapati bahawa nombor Reynolds bagi kedua-dua bentuk persegi dan bulat objek tenggelam adalah sama kerana kawasan hadapan objek yang telah diambil kira dalam pengiraan. Daya seretan terhasil dikira berdasarkan pekali seretan yang diperolehi. Daripada keputusan, air yang mengalir dikenakan daya seretan yang paling tinggi pada objek yang terendam yang segi empat tepat berbentuk berbanding dua bentuk yang lain yang telah dikaji. Ini adalah kesan daripada nilai-nilai pekali seret yang berbeza yang seterusnya berdasarkan bilangan Reynolds masing-masing dan bentuk objek. Penemuan lain adalah bahawa apabila halaju dan pekali seretan telah meningkat, nilai daya seretan juga meningkat.

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LIST OF SYMBOLS

C_D	Drag coefficient
Re	Reynolds number
Ma	Mach number
Fr	Froude number
L	Lift
F_D	Drag force
V	Velocity
ρ	Density
D	Diameter
A	Area of the body
l	Length
V	Kinematic viscosity
T	Temperature

LIST OF ABBREVIATIONS

FKASA	Faculty of Civil Engineering & Earth Resources
LDV	Laser Doppler Velocimetry
LES	Large Eddy Simulations
UMP	Universiti Malaysia Pahang
Vs.	Versus

CHAPTER 1

INTRODUCTION

1.1 Introduction

Whenever fluid moves past the body of an object, an interaction between the body of an object and the fluid happens. This study deliberates on the flow over bodies that are immersed in water. This situation includes flow past objects. When an object is immersed in moving water, it experiences a force due to the interaction between the object and the water surrounding it. The forces are namely drag force, lift force, shear force and pressure force. Besides that, flow past an object such as a circular cylinder will produce a wake or vorticity due to shear present in the boundary layer. This vorticity in the flow field combines into areas of concentrated vorticity recognized as vortices on either side of the cylinder (Stappenbelt, 2010).

There are various phenomena related to flow around bodies. One of the most important of these is the force acting on the body due to the fluid. They happen in many engineering circumstances, such as bridges, stacks, transmission lines, aircraft control surfaces, offshore structures, thermo wells, engines, heat exchangers, marine cables, towed cables, drilling and production risers in petroleum production, mooring cables, moored structures, tethered structures, buoyancy and spar hulls, pipelines, cable-laying, members of jacketed structures, and other hydrodynamic as well as hydro acoustic applications (Sarpkaya, 2004).

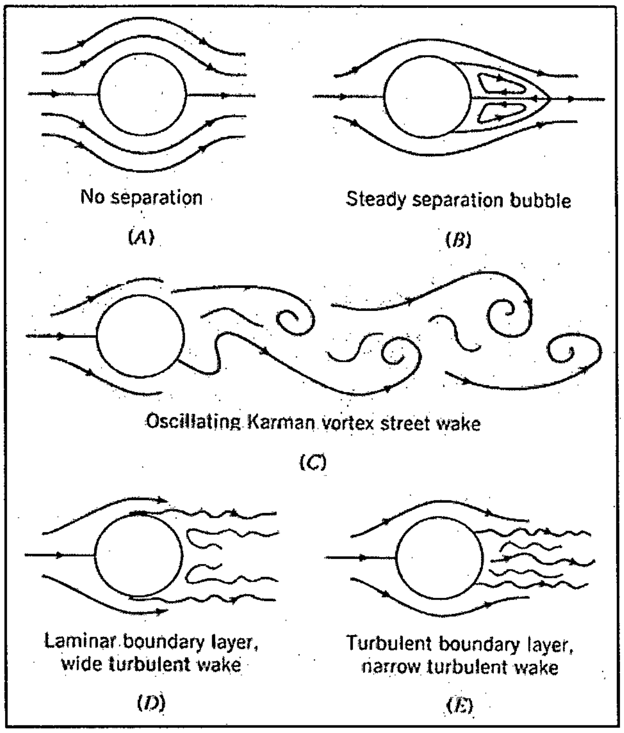

Figure 1.1: Flow pattern past a cylinder (Munson et. al, 2002)

In this study, the focus is more on the wake of the flow behind the bodies shown in Figure 1.1 which have been studied extensively because of their many practical applications and is very important in engineering fields. Besides that, this study also aims to find the drag coefficients, C_D as well as calculate drag force at different velocities for different object shapes.

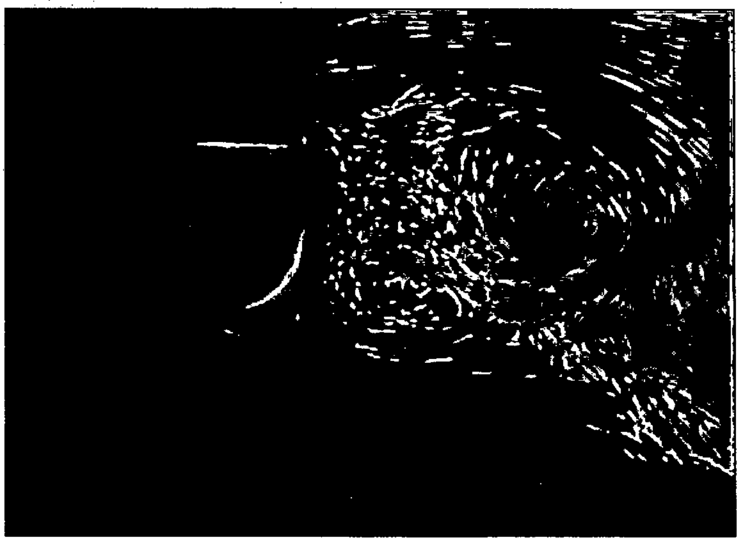

Figure 1.2: Water flowing around the object

The wake of the flow as shown in Figure 1.2 is determined by numerous parameters such as the size of the shapes, orientation, fluid speed and fluid properties. The shape of an object can affect the length of the wake behind it. Besides that, the drag coefficient for objects is influenced by the shape of the objects. In this study, several physical bodies were used to obtain the results based on different form of shapes. One part of the experiment deliberates on the length of the wake that appears when water is flowing past the immersed objects. The part of the experiment endeavors, to estimate the drag force exerted on the immersed objects. The experiments are conducted under different flow rates for each different form of the object. Finally, the conclusions of the accomplishments in this experiment are prepared.

1.2 Problem Statement

Several practical circumstances contain flow past bodies. When a fluid moves through bodies, an interaction between the bodies and the fluid arises. According to Suh et al. (2011), flow past bodies is an important topic because of its varied applications in engineering and its abundant flow physics including separations, reattachment, vortex shedding, etc. For example, take the piers of a bridge. Piers act as the main support for a bridge, on which the bridge superstructure rests. The shape of the piers can affect the flow of the water. The piers will obstruct the flow, causing vibrations at the piers which may lead to structural failure. The shape of an object also affects the flow wake. Furthermore, whatever may be the shape of pier provided, the obstruction to flow within the channel is unavoidable (Suribabu et al., 2011). Besides that, the drag coefficient for an object is influence by the shape of the objects.

1.3 Objectives of the Research

The objectives of this study are:

i. To investigate the relationship between wake length and flow velocity for different immersed object shapes
ii. To estimate the drag force exerted on immersed objects of different shapes at different velocities

1.4 Scope of Study

For this study, the consideration is more to flow past or around immersed bodies. This study used the hydraulic laboratory to perform the experiment. In the laboratory, the open channel flow experiment facility was used. There are three form objects that were used to figure the results for different type of shapes. The shapes include circular, rectangular and square objects such as plastic pipe. In the experiment, the works done are:

i. To measure the length of the wake that arises when water is flowing past the immersed objects.
ii. To measure velocity and the height of the water that occurs when water is flowing past the immersed objects.
iii. To estimate the drag force at different flow velocities.

CHAPTER 2

LITERATURE REVIEW

2.1 Characteristics of Flow past an Object

Flow past immersed objects or external flows past objects, are flows of fluids surrounding objects with solid walls, subject to no outer boundary, except in the particularly infinite distance from the object. Examples are flows around ground structure or land, and water flows around marine and water vehicles. In contrast, internal flows are those in which the following fluid is surrounded by solid walls, such as flows through pipes, ducts and canals or within fluid machinery.

When fluid moves through or around objects, an interaction between the objects and the fluid happens. An object immersed in a flowing fluid will commonly experience a force, whose magnitude and direction depend on several parameters. This effect can be defined in terms of the forces on the fluid and body boundary. An entirely immersed solid object, causing a constant relative speed with regard to an unbounded, incompressible and frictionless fluid, will receive zero strength.

In general, the characteristics of the flow depend intensely on several parameters such as object size, object orientation, fluid velocity, and fluid properties (Munson et al., 2002). Besides that, the shapes of the objects can affect the flow characteristics. Obviously the character of the flow is a function of the shape of the objects. According to Munson et al. (2002), simple geometric objects shapes such as sphere or circular cylinder are expected to have less complex flow than flows past a complex shape such as airplane or tree. However, the simplest object shapes can produce rather complex flows. Three general categories of bodies are shown in Figure 2.1. They include:

a) Two-dimensional objects – considerably long and of continuous cross-sectional size and configuration
b) Axisymmetric bodies – shaped by their rotational cross-sectional shape about the axis of symmetry
c) Three-dimensional bodies that may or may not possess a line or plane of symmetry.

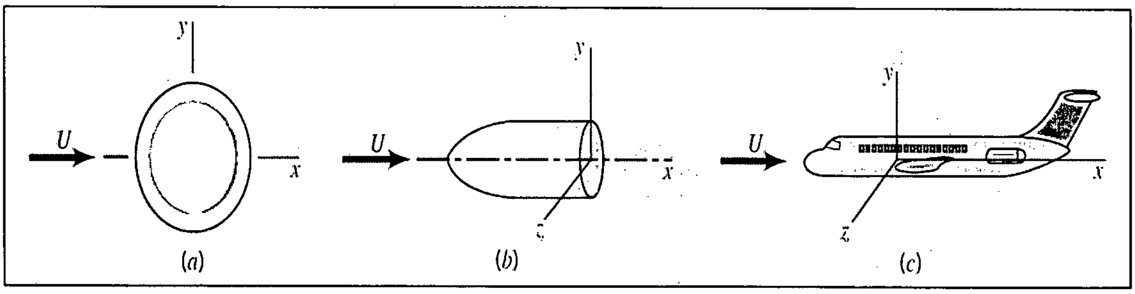

Figure 2.1: Categories of bodies (Munson et al., 2002)

In addition, the quality of the flow should depend on the various dimension parameters. The most significant of these parameters are the Reynolds number (Re), the Mach number (Ma) and the Froude number (Fr). Meanwhile, the character of flow past an object is dependent on the value of the Reynolds number.

There are many external flows in which the Reynolds number is considerable. In the following example, the depicted in Figure 2.2 fluid flows past three flat plates of different length with different Reynolds number. According to Munson et al. (2002), if the Reynolds number is low, the viscous effects are relatively substantial and the plate involves the uniform upstream flow far in front, above, below and behind the plate. On the other hand, as the Reynolds number is increased such as by increasing the velocity, U, the sections in which viscous effects are present become smaller in all directions. If the Reynolds number is big, the flow is subjected to inertial properties and the viscous effects are insignificant excluding the section close to the plate.

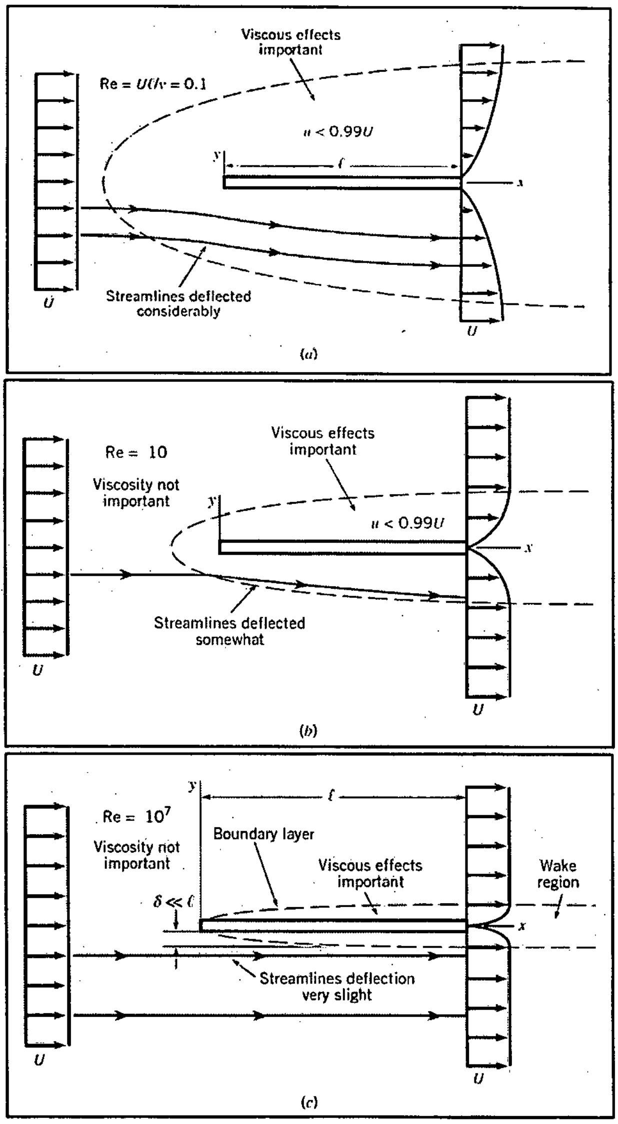

Figure 2.2: Flows past flat plate (Munson et al., 2002)

2.2 Boundary Layer

Commonly, the viscosity of a fluid only plays a role in a thin layer, for example laterally in a solid boundary as Prandtl showed for the first time in 1904 (Veldman, 2012). The thin layer is called a boundary layer depicted in Figure 2.3 by Prandtl. Besides that, ,Prandtl overcome of a thin section close to the solid surface where the effects of viscosity are felt and the velocity passes from zero at the wall to the value corresponding to not rotating flow (Buresti, 2000).

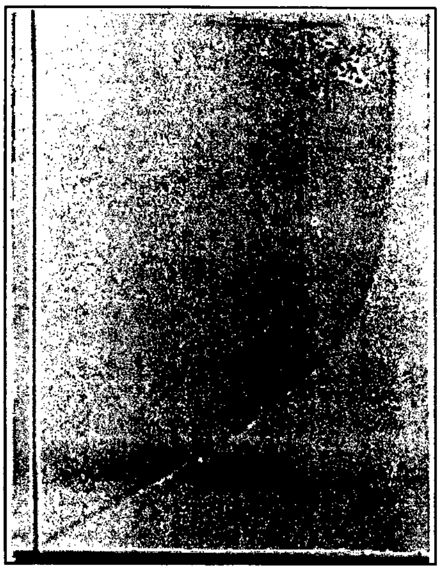

Figure 2.3: Boundary layer profile over a flat plate (Buresti, 2000)

In theory, the equations capable of describing the flow (liquid or gas) past any object can be obtained by solving the Navier-Stokes equations. Meanwhile, the Navier-Stokes equations can be simplified for boundary layer flow analysis.

The dimensions of boundary layer and the structure of the stream can show a wide diversity within it. This variation occurs due to the configuration of the object on which the boundary layer forms. For example, the boundary layer which is organized along a long flat plate along which flows a viscous, incompressible fluid.

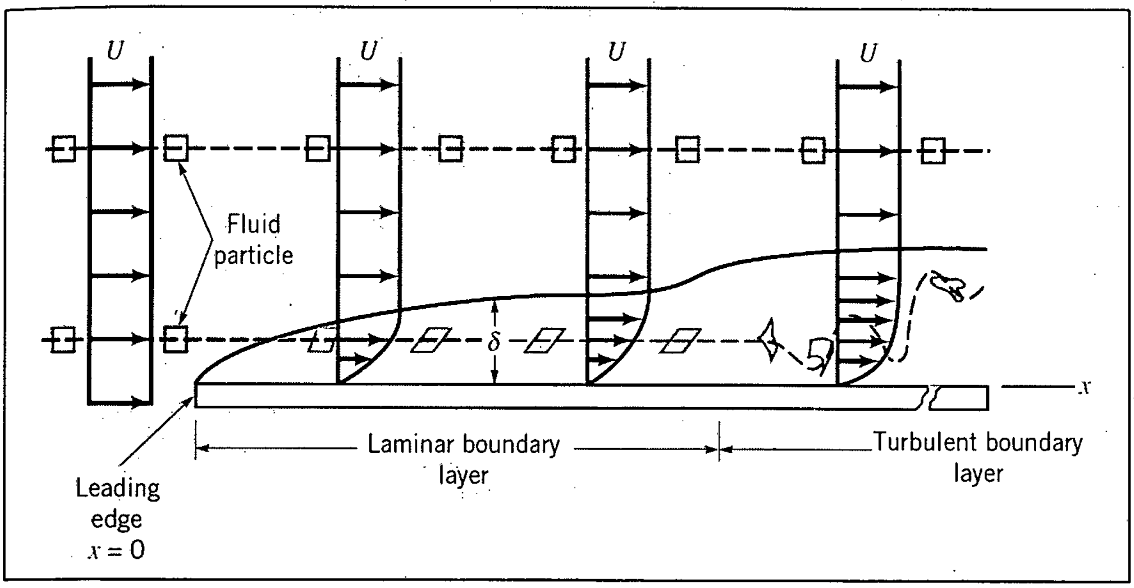

Figure 2.4: Flows within the boundary layer along flat plate (Munson et al., 2002)

Munson et al. (2002) stated that the boundary layer structure would be more complex if the surface were rounded such as a circular cylinder. Nevertheless, if the Reynolds number is large, the relatively thin boundary layer on the plate will feel the consequence on the plate as shown in Figure 2.4. Clearly, the fluid within the boundary layer experience viscous effects.

2.3 Drag Force

When a fluid flows around a stationary object or when an object moves through a stationary fluid, the fluid exudes a force on the object. This force is called the drag force. The causes of this drag are:

i. Resistance between the fluid and the surface of the object
ii. A non-uniform pressure distribution

In fluid flow, considering the drag characteristics of the bodies is important for engineering design features, such as the drag on pipes, towers, buildings and other hydraulic structures. This is for safety and stability of the structures. There are several phenomena related to flow around object and one of the most significant of these is the force acting on the object due to the fluid. When any object moves through a fluid, it will experience forces. The forces are a combination of drag force, lift force, shear force and also pressure force. Meaning the drag, D term is the resultant force in the direction of the upstream velocity and for the lift, L, it is the resultant force normal to the upstream velocity as shown in Figure 2.5 (Munson et al., 2002).

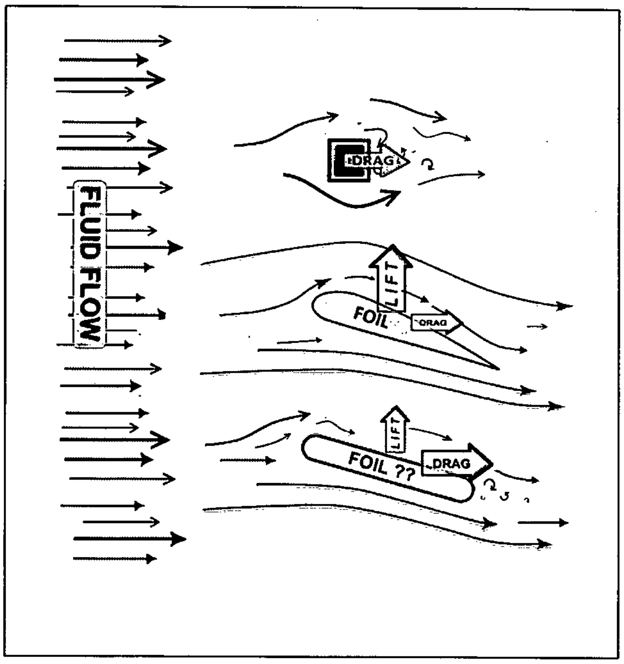

Figure 2.5: Lift and drag concepts (Munson et al., 2012)

As a fluid is moving past an object, the fluid will act on the object slowly because of the forces. These force involved is the drag force, which is ordinarily split into two parts, friction drag and pressure drag.

Most of the information relating to drag on objects is a resolution of several experiments, for example, like water tunnels, wind tunnels, towing tanks and others that are employed to measure the drag on a scale model. The most usual technique of mathematically showing the drag force is the equation,

Drag force:

$$F_D = \frac{1}{2} C_D \rho V^2 A \quad (2.1)$$

Where F_D is the drag force, C_D is the drag coefficient of the object, ρ is the fluid density, V is the velocity of the free stream and A is the platform area of the object.

2.3.1 Friction Drag

Friction drag, D_f, is a force that arises from friction between the fluid and the surface of the body over which it is flowing. It is the force that acts on a submerged object moving within a fluid due to viscous forces and produce a shear stress on the object.

2.3.2 Pressure Drag

Pressure drag, Dp, is the function of the drag force that is due to the different in pressure in front of and behind the object as fluid flows past it. Yet, this is often mentioned as form drag because of its strong dependence on the form of the bodies.

2.4 Drag Coefficient

The total drag force is a combination of pressure force and shear stress. These two forces are considered together and drag coefficient, C_D is used for this forces. However, the drag coefficient, C_D is a function of other dimensionless parameters or is not a constant value. C_D depends upon the shape of the body, flow conditions (Reynolds number) and other things.

Drag coefficient:

$$C_D = \frac{D}{\frac{1}{2}\rho U^2 A} \tag{2.2}$$

D	= drag force. SI: N
C_D	= drag coefficient. SI: Dimensionless
A	= cross sectional area. SI: m^2
ρ	= density of the fluid. SI: kg/m^3
U	= velocity of the body within the fluid. SI: m/s

The drag coefficient, C_D is a function of other dimensionless parameters. C_D depends upon the velocity, viscosity of the fluid, the shape of the object, and the roughness of the object surface.

2.4.1 Object Shape

An object shape plays an important role in defining the drag. Apparently, the drag coefficient for an object is subject to influence by the form of the bodies. According to Munson et al. (2002), the drag coefficient may be based on the frontal area.