INSTRUCTION MANUAL

C 10
LAMINAR FLOW TABLE

C10

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ARMFIELD LIMITED

OPERATING INSTRUCTIONS AND EXPERIMENTS
C10 - LAMINAR FLOW TABLE

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SAFETY IN THE USE OF EQUIPMENT SUPPLIED BY ARMFIELD

Before proceeding to install, commission or operate the equipment described in this instruction manual we wish to alert you to potential hazards so that they may be avoided.

Although designed for safe operation, any laboratory equipment may involve processes or procedures which are potentially hazardous. The major potential hazards associated with this particular equipment are listed below.

- INJURY THROUGH MISUSE
- INJURY FROM INCORRECT HANDLING
- DAMAGE TO CLOTHING
- RISK OF INFECTION THROUGH LACK OF CLEANLINESS

Accidents can be avoided provided that equipment is regularly maintained and staff and students are made aware of potential hazards. A list of general safety rules is included in this manual, to assist staff and students in this regard. The list is not intended to be fully comprehensive but for guidance only.

Please refer to the notes overleaf regarding the Control of Substances Hazardous to Health Regulations.

The COSHH Regulations

The Control of Substances Hazardous to Health Regulations (1988)

The COSHH regulations impose a duty on employers to protect employees and others from substances used at work which may be hazardous to health. The regulations require you to make an assessment of all operations which are liable to expose any person to hazardous solids, liquids, dusts, vapours, gases or micro-organisms. You are also required to introduce suitable procedures for handling these substances and keep appropriate records.

Since the equipment supplied by Armfield Limited may involve the use of substances which can be hazardous (for example, cleaning fluids used for maintenance or chemicals used for particular demonstrations) it is essential that the laboratory supervisor or some other person in authority is responsible for implementing the COSHH regulations.

Parts of the above regulations are to ensure that the relevant Health and Safety Data Sheets are available for all hazardous substances used in the laboratory. Any person using a hazardous substance must be informed of the following:

Physical data about the substance

Any hazard from fire or explosion

Any hazard to health

Appropriate First Aid treatment

Any hazard from reaction with other substances

How to clean/dispose of spillage

Appropriate protective measures

Appropriate storage and handling

Although these regulations may not be applicable in your country, it is strongly recommended that a similar approach is adopted for the protection of the students operating the equipment. Local regulations must also be considered.

Water-Borne Infections

The equipment described in this instruction manual involves the use of water which under certain conditions can create a health hazard due to infection by harmful micro-organisms.

For example, the microscopic bacterium called Legionella pneumophila will feed on any scale, rust, algae or sludge in water and will breed rapidly if the temperature of water is between 20 and 45°C. Any water containing this bacterium which is sprayed or splashed creating air-borne droplets can produce a form of pneumonia called Legionnaires Disease which is potentially fatal.

Legionella is not the only harmful micro-organism which can infect water, but it serves as a useful example of the need for cleanliness.

Under the COSHH regulations, the following precautions must be observed:-

Any water contained within the product must not be allowed to stagnate, i.e. the water must be changed regularly.

Any rust, sludge, scale or algae on which micro-organisms can feed must be removed regularly, i.e. the equipment must be cleaned regularly.

Where practicable the water should be maintained at a temperature below 20°C or above 45°C. If this is not practicable then the water should be disinfected if it is safe and appropriate to do so. Note that other hazards may exist in the handling of biocides used to disinfect the water.

A scheme should be prepared for preventing or controlling the risk incorporating all of the actions listed above.

Further details on preventing infection are contained in the publication “The Control of Legionellosis including Legionnaires Disease” - Health and Safety Series booklet HS (G) 70.

INTRODUCTION

The Armfield Laminar Flow Table is an extension of the Hele-Shaw Apparatus by the addition of sinks and sources. It allows comprehensive investigation of two-dimensional problems associated with laminar flow. Potential flow patterns which can be photographically recorded are vividly demonstrated by an efficient dye injection system.

The equipment forms a most valuable education aid but, in addition, may be used for the study of situations arising in conjunction with research investigations. An important feature is that which allows quantitative investigations involving the rate of flow in sinks and sources.

The table provides a large working area (610mm x 892mm) and incorporates 8 sinks and sources. Actual viewing area (through the bottom glass) is 495mm x 755mm.

The equipment is convenient and easy to use. The design is based on the previous highly successful equipment manufactured by the Company, examples of which are in service in many Colleges of Technology and Universities throughout the world. The principal improvement to the older model is the use of corrosion resistant moulded reinforced glass fibre for the working section and end tanks.

The Laminar Flow Table provides a basic laboratory facility which can be used in a wide range of applications.

RECEIPT OF EQUIPMENT

SALES IN THE UNITED KINGDOM

The apparatus should be carefully unpacked and the components checked against the Advice Note. A copy of the Advice Note is supplied with this instruction manual for reference.

Any omissions or breakages should be notified to Armfield Limited within three days of receipt.

SALES OVERSEAS

The apparatus should be carefully unpacked and the components checked against the Advice Note. A copy of the Advice Note is supplied with this instruction manual for reference.

Any omissions or breakages should be notified immediately to the Insurance Agent stated on the Insurance Certificate if the goods were insured by Armfield Limited.

Your own insurers should be notified immediately if insurance was arranged by yourselves.

DESCRIPTION

The apparatus is a floor standing unit with the working surface at a convenient height. Screws are provided for the accurate levelling of the equipment in the laboratory and this should be done when filled with water. A glass fibre tank is provided at the inlet and outlet of the working section, the discharge tank being provided with a height-adjustable knife-edged weir so that the table flow may be rapidly and accurately adjusted. The working section consists of two plate glass sheets, the distance between which is set as required by means of special spacers. The front edge of the upper glass plate may be raised by handles provided and secured in this position whilst the equipment is prepared for operation, or models are installed.

Eight sinks and/or sources are positioned along the centreline of the lower glass plate in a cruciform arrangement. The centre orifice is in the form of a doublet, i.e. two orifices in close proximity. A system of cocks and pipes enables all or any of the sinks and sources to be supplied simultaneously. Figure 1 is a schematic diagram of the equipment showing the pipework for one typical source/sink arrangement.

Once the apparatus has been calibrated it is possible for quantitative experiments to be carried out. A dye injection system is supplied consisting of a number of fine, stainless steel pipes positioned between the glass plates at the inlet edge. These feed pipes are supplied from a single manifold. Through each pipe an appropriate quantity of dye solution is injected and the direction of streamlines clearly illustrated. Photographs of the flow patterns form the most readily obtainable records.

A pressure regulator at the water inlet reduces the water to the required operating pressure and helps to minimise variations in flowrate due to pressure fluctuations in the water supply.

SCHEMATIC DIAGRAM

(Pipework for one sink and one source shown)

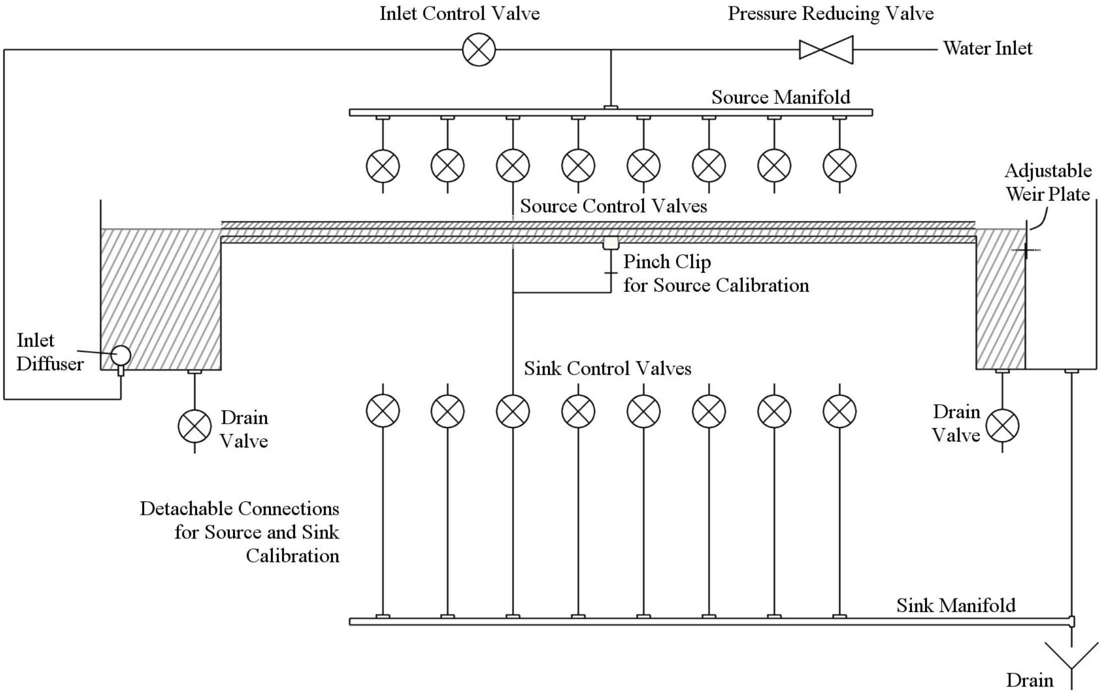

Figure 1: Schematic Diagram

INSTALLATION

Installation drawing ID 1008 (see Appendix B) gives relevant details of the overall size and weight of the equipment and indicates positions of the services required.

The equipment is constructed as a free standing unit and should be installed on a firm, flat floor adjacent to the laboratory services indicated below.

Water Supply

A supply of clean water will be required whenever the equipment is in use.

Connection to the apparatus should be via a 12.7mm (1/2”) I.D. flexible pipe. (Refer to ID 1008).

Supply pressure : 1 bar (Gauge)

Supply flow rate : 0.25 litres/sec

Drain facilities

A drain will be required adjacent to the equipment. A 22mm (7/8”) O.D. rigid outlet pipe is provided. The equipment may be positioned with this pipe above a suitable drain or a flexible tube may be fitted to feed into a remote drain (Refer to ID 1008).

The equipment may be totally drained by opening drain cocks in the base of the inlet and outlet tanks. This procedure will also require flexible tubing to discharge the contents to drain.

COMMISSIONING

General Notes

In general, the satisfactory operation of the equipment relies on it being level and free from dirt, grease and air bubbles. The initial setting up procedure should ensure that the following points are checked:

1. Level the working area using the screw adjusting feet provided. The level may be accurately checked using a spirit level on the lower glass laid normal, parallel and diagonal to the direction of flow.
2. Clean the inside surfaces of the glass plates using a de-greasing solvent such as methylated spirits or ethanol.
3. Close all of the sink and source taps and the drain cocks on the inlet and outlet tanks.
4. Ensure that the main drain on the equipment is located above a suitable grid or drainage channel. Alternatively connect the outlet to a drain using flexible tubing.
5. Close the pressure regulator to give minimum flow of water (pull the knob upwards then rotate the knob fully anticlockwise) then connect the water supply to the inlet on the regulator using ½” hose. Ensure that the hose is secured using a hose clip.
6. Open the flow control valve fully (rotate the valve fully anticlockwise) then allow water to enter the inlet tank by rotating the knob on pressure regulator clockwise. When water has filled the inlet and discharge tanks adjust the height of the knife-edged weir until the water flowing over the bottom glass is approximately 5mm deep.
7. Briefly stop the flow of water then check that the bottom glass is level in both planes using a spirit level.
8. Restart the flow of water. Gradually lower the top glass (as described below) ensuring that no air bubbles are trapped then make any final adjustment to the pressure regulator or the knife-edged weir as required to obtain maximum flow

between the two sheets of glass without water flooding over the top glass. Check that the knife edged weir is horizontal / parallel with the glass so that the flow of water is uniform across the width of the working section.

9. When set up correctly, the flow of water between the two sheets of glass can be varied between zero flow and maximum flow by adjusting the flow control valve. Further adjustment of the pressure regulator or downstream overshot weir should not be necessary.

Lowering the Top Glass

This operation must be performed carefully to ensure that air bubbles are eliminated from the space between the glass plates.

The leading edge (i.e. die injector end) of the top glass plate should coincide with the leading edge of the bottom plate.

With water flowing across the apparatus and the flow and depth adjusted as described above, the front edge of the glass is lowered slowly into position pivoting about the rear edge. The water surface should contact the lower surface of the glass progressively and evenly to ensure complete air expulsion.

Failure to exclude air may be due to the following causes:

1. Depth of water insufficient:	Increase flow of water or raise height of outlet weir.
2. Dirt or grease on glass:	Clean as described in 2 above.
3. Source or sink not fully closed:	Check that all sources and sink tops are closed.
4. Rapid or uneven lowering of top glass:	Raise glass and lower as described above.

Bleeding the Sink and Source Lines

If sinks or sources are to be used, the source lines must be de-aired by opening the valves and flushing the lines through. Air bubbles introduced between the glass plates through source lines may be removed as described below.

Dye Injection System

The fine tubes of the injector must be clean and this assembly should be flushed through with clean water prior to use. Any blockages may be cleared by passing a fine wire along the tubes.

Before use the packet of dye supplied must be diluted with 1 litre of deionised or distilled water: Open the 3gm packet of Blue Dye and pour the contents along with 1 litre of deionised or distilled water into the 1 litre bottle (supplied). Replace the lid securely and shake the bottle until the dye is completely mixed. The 1 litre bottle can be used to store any unused dye.

Any water or alcohol soluble dye may be used with this equipment. A simple dye consists of a concentrated solution of potassium permanganate crystals. In general, denser dyes will give better results since the dye control valve may be adjusted to give a narrower trace. Should a variety of colour be required then non-permanent fountain pen ink is ideal.

The injector rake should be located at the inlet edge of the glass sandwich with the fine tubes protruding between the plates.

In order to ensure a uniform delivery of dye to the injector rakes:-

1. Fill dye reservoir and open the regulating valve.
2. Ensure that the dye rake discharges are submerged and that dye flows freely from each rake.
3. Blockages caused by air bubbles may be relieved by a light tap or by pressurising the free surface of the dye in the reservoir.

Having completed the above procedures the apparatus is ready to conduct the experiments described in the Experiment Section of this manual.

If the equipment is to work efficiently, it is essential that it is well maintained and is always thoroughly cleaned before and after use.

When an experiment is completed, the whole system must be thoroughly flushed through with clean water to remove all traces of dye.

Calibration of Sinks and Sources

To perform several of the experiments, it is necessary to determine the flow rates associated with each of the source/sink orifices in the floor of the working section. In addition to these experiments, flow rates within the working section must be accurately determined where quantitative results are required for research or simulation exercises.

Measurement of the sink flow rate is determined by removing the sink drain pipe from the sink manifold and collecting the discharged water in a measuring cylinder. During this operation the corresponding source control valve should be fully closed and the orifice pinch clip fully open.

Measurement of the source flow rate is determined via the sink drain pipe in the same way. During this operation the corresponding sink control valve should be fully open and the orifice pinch clip fully closed. After measurement the sink control valve should be fully closed and the pinch clip fully opened.

TABLE OF FIGURES

THEORY

Introduction

When simulating or establishing by calculation the parameters of a specific system involving fluids, the situation is often simplified by ignoring the complex fluid properties involved. Calculation is usually based on ‘Ideal Fluid’ and the results obtained are modified in the light of empirical experience. This ‘Ideal Fluid’ can be defined as having zero viscosity with no shear forces between adjacent layers and no friction at boundaries. Hence there are no boundary layers and the sole purpose of a solid boundary is to give the flow without any frictional interference. The ‘Ideal Fluid’ is also considered to be incompressible.

The Laminar Flow Table is designed to demonstrate fluid flow in a two-dimensional plane. A low fluid velocity and small gap between the top and bottom plates results in a low value for Reynolds Number. Since Reynolds Number is the ratio of Inertial to Viscous forces, the former may be considered negligible and the flow achieved is totally dependent on Potential. This condition gives a near simulation of an ideal fluid and the flow patterns obtained can be considered to be Ideal Fluid Flow. Since the flow is dependent on Potential, the flow table may be used to simulate any system which obeys the Laplace Equation. For example, two-dimensional steady heat flow may be demonstrated where Temperature Difference in the system represents the Potential.

An analysis of the ‘Properties’ of Ideal Fluid Flow is included below to extend the benefit and understanding of experiments involving flow pattern generation.

Streamlines and Streamtubes

Streamlines are imaginary lines drawn in a fluid to characterise the flow field. A tangent drawn at any point on a streamline gives the direction of the fluid velocity at that point. Hence there can be no flow across a streamline.

Figure 2 shows a typical pair of streamlines.

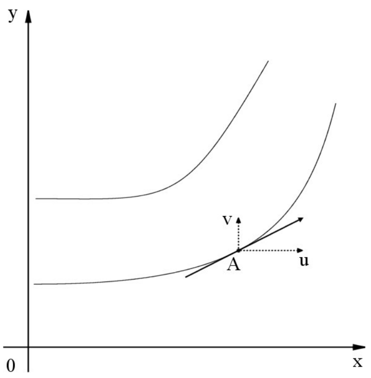

Figure 2: Streamlines showing motion vector for a point in the fluid

Slope of the streamline at A = $\frac{dy}{dx} = \frac{V}{u}$

Hence the equation of the streamline is $\quad udy - vd\,x = 0 \qquad$ ......(1)

A *streamtube* is a portion of moving fluid bounded by streamlines and the surface of this tube is called a *stream surface*.

Analysis of Two-Dimensional Flow

It is assumed that flow is steady state.

Figure 3 shows a point in the flow fluid which has been enlarged to a rectangle for clarity. Its velocity components are u and v.

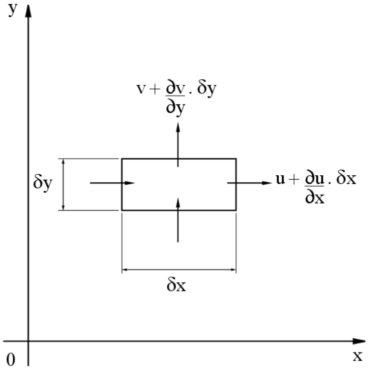

Figure 3: Two-dimensional analysis for a single point in the fluid

Density of the fluid ρ is constant.

For continuity of mass flow in the field and considering unit depth:-

$$\rho u\delta y.1 + \delta v\delta x.1 = \rho\left(v + \frac{\delta v\delta y}{\delta y}\right)\delta x + \rho\left(u + \frac{\delta u}{\delta x}\right)\delta y$$

$$0 = \rho\delta x\delta y\left(\frac{\delta v}{\delta y} + \frac{\delta u}{\delta x}\right)$$

Hence for continuity $\frac{\delta u}{\delta x} + \frac{\delta u}{\delta y} = 0$ ......(2)

Stream Function

As there can be no flow across a streamline, the mass flow rate through a streamtube must be constant for continuity. The velocity of the flow in a streamtube will therefore vary with the cross sectional area. Hence, if the position of the streamlines in a flow field are known then the velocity distribution in the field can be obtained.

Stream functions, denoted by the letter w, are necessary for obtaining the equation of a streamline and for indexing of the same.

Figure 4 shows two typical streamlines with datums AC and BD.

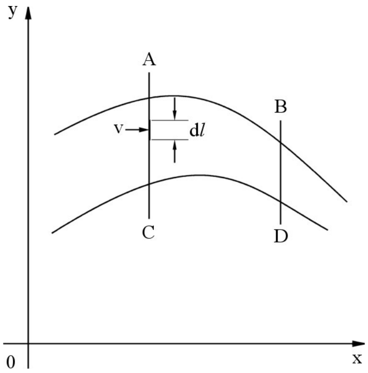

Figure 4: Typical streamlines with datum lines for stream function calculation

If v is the velocity of the fluid at any pint on the line AC or BD and dl is an element of a line normal to the streamline at that point, then:

Flow per unit depth crossing length dl = bdl = dψ

Total flow per unit depth between A and B = vdl = ψ

As no flow crosses streamline AB or CD then flow across AB = flow across BD.

A streamline may be indexed by using the numerical value of the Stream Function between it and a reference streamline.

Solid boundaries may be regarded as streamlines and if the origin point is placed on the solid boundary line then that streamline boundary may be regarded as (x,y) = O (due to no flow relative to the origin).

Succeeding streamlines may be numbered in some sequence (not necessarily 1, 2, 3, etc.) the number of the streamline being the Stream Function.

An example is shown in Figure 5. where flow around a sharp bend is considered.

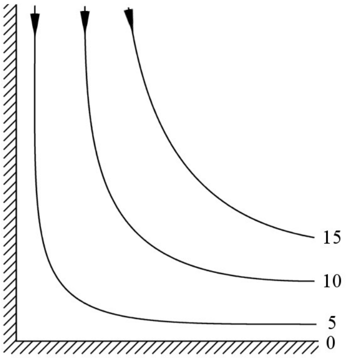

Figure 5: Flow around a sharp bend

The equations of the streamlines are defined by the relationship

axy = c2 (rectangular hyperbole)

and hence in general the Stream Function

$\psi = axy$

where a = constant.

N.B. Clockwise flow relative to O is regarded as a positive value of ψ.

Velocity Potential

For a complete analysis of velocity potential it is necessary to consider Circulation and Vorticity which are not defined in this text.

However, using the aforementioned, it can be demonstrated that equipotential lines exist which are normal to any streamline. The potential of any line, denoted by the letter ø, may be determined from the relationship ø = vdz where z is an element along the streamline (equivalent to the element l in the case of the Stream Function, but at right angles).

As in the case of Steam Functions, a datum is selected from which all equipotential lines are defined.

The theory outlined above is intended only as a brief introduction to the topic of Ideal Fluid Flow. The parameters outlined are all of specific importance when defining a typical flow situation and may be demonstrated practically on the Laminar Flow Table.

Reference to a suitable text book on the subject will provide details on predicting flow patterns for a given situation which can be proved on the Laminar Flow Table. The reverse can also be applied, predicting flow rates, velocities, etc., for a real situation using models on the Laminar Flow Table.

A suitable text book for work of this nature is:-

“A Text Book of fluid Mechanics for Engineering Students”

by J. R. D. Francis (Professor of Hydraulics, Imperial College of Science and Technology, London).

EXPERIMENTS

1. IDEAL FLOW AROUND IMMERSED BODIES

For this series of experiments all sink and source valves should be closed. The weir plate and inlet control valve should be adjusted to give the minimum steady flow rate available, without admitting air between the glass plates. The corresponding low water velocity through the test section will provide near-ideal flow conditions. The dye injection system should be set up as described on page 12. When inserting Perspex models in the test section, they should be positioned centrally in the test section using the grid on the lower glass plate to align significant features with the dye injector rakes. Care should be exercised when lowering the top glass plate as described on page 12.

Having set up a particular experiment, the dye regulating valve should be opened and adjusted to give fine, clearly defined dye streams, which will indicate relevant streamlines. The position of the dye streams relative to the model may be finely adjusted by carefully sliding the injector rake sideways to the desired position.

1a. IDEAL FLOW AROUND A CYLINDER

A cylinder is positioned centrally in the test section with its axis in line with one dye stream. The resulting pattern of streamlines, shown in Figure 6, is symmetrical with no eddy formation or breakaway. The narrowing of the streamlines at the ‘sides’ of the cylinder indicates a region of reduced pressure. The symmetry of the pattern, in both planes, shows that no resultant thrust is present.

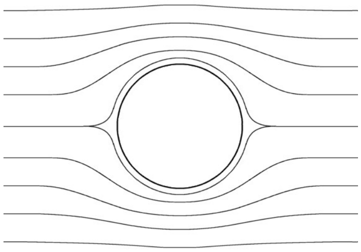

Figure 6: Flow around a cylinder

1b. IDEAL FLOW OVER AN AEROFOIL

The aerofoil section is positioned centrally in the test section at a small angle of incidence to the flow. The stagnation point on the leading edge should be positioned adjacent to a dye stream. The resulting streamline pattern is shown in Figure 7. At the thickest section of the aerofoil, the narrowing of the streamline spacing on the top surface and corresponding widening on the bottom surface, demonstrates the pressure forces on the aerofoil which generate lift. The downstream pressure change and downwash produced by the aerofoil can also be observed. The experiment may be repeated for different angles of incidence to demonstrate the change in stagnation point.

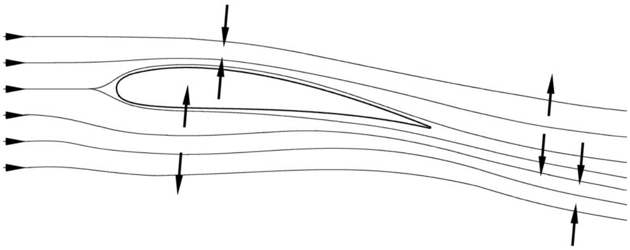

Figure 7: Flow around an aerofoil

1c. IDEAL FLOW AROUND A BLUFF BODY

A rectangle is positioned centrally in the test section with its long axis adjacent to the direction of flow. The central dye stream should coincide with its axis.

This experiment is intended as a check on the flow conditions present on the table. For ideal flow conditions the streamlines should be symmetrical in both planes as in the case of 1a. Any tendency to fluid breakaway on the downstream face of the rectangle will indicate that the fluid velocity is excessive and that ideal flow is not represented.

2. IDEAL FLOW IN CHANNELS AND AT BOUNDARIES

For this series of experiments, the Laminar Flow Table should be set up as described for Experiment 1 (page 21).

2a. IDEAL FLOW IN A CONVERGENT CHANNEL

A pair of canal banks should be positioned in the centre of the test section in line with the direction of flow. The separation of the contoured faces should be adjusted to accommodate a convenient number of dye streams. The pattern of streamlines obtained in the convergent section is shown in Figure 8. The narrowing of the streamline spacing towards the throat indicates an increase in fluid velocity and subsequent reduction in pressure. The experiment may be repeated for different spacing of the canal banks. In addition, the angle of the convergence may be changed by reversing the sections relative to the direction of flow.

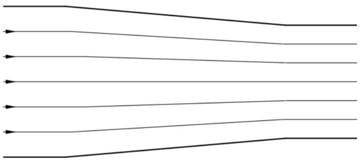

Figure 8: Flow in a convergent channel

2b. IDEAL FLOW IN A DIVERGENT CHANNEL

With the canal banks installed as described in 2a., a divergent channel is represented at the downstream end of the sections. Figure 9 shows a typical streamline pattern. The spacing and divergent angle may be adjusted as described in 2a.

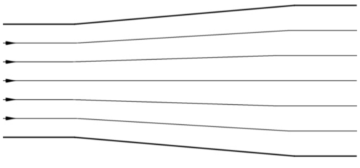

Figure 9: Flow in a divergent channel

2c. IDEAL FLOW THROUGH A 90° BEND

The two rectangles and canal banks (plain sides) may be positioned so as to generate a pair of square 90° bends. The streamline pattern for one typical 90° bend is shown in Figure 10.

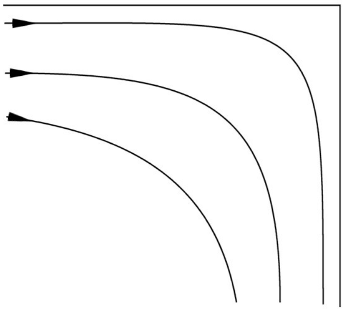

Figure 10: Flow around a 90° bend

2d. IDEAL FLOW THROUGH A SUDDEN CONTRACTION

The two rectangles and canal banks (plain sides) may be positioned so as to generate a step reduction in channel width. A typical streamline pattern is shown in Figure 11. In this ideal flow case the pattern is very similar to that produced by the convergent section 2a.

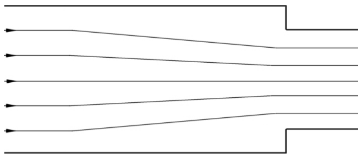

Figure 11: Flow through a sudden contraction

2e. IDEAL FLOW THROUGH A SUDDEN ENLARGEMENT.

The reverse situation of 2d. is simulated with a step increase in channel width. The resulting streamline pattern is shown in Figure 12. The pattern is very similar to that produced by the gradual divergence 2b.

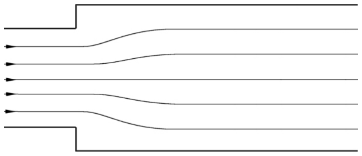

Figure 12: Flow through a sudden enlargement

2f. REPLACEMENT OF A STREAMLINE BY A SOLID BOUNDARY

As no fluid flow can cross a streamline, it is possible to replace any streamline by a solid boundary without changing the remainder of the streamline pattern. This may be demonstrated by setting up any of the previous experiments and noting the pattern produced. Without changing any of the parameters, a solid boundary should be introduced to replace on of the streamlines. The resulting pattern should be compared with the original to demonstrate that no change has occurred.

3. IDEAL FLOW ASSOCIATED WITH SINKS AND SOURCES

The weir plate and inlet control should be adjusted to give the minimum steady flow rate available, without admitting air between the glass plates. The corresponding low water velocity through the test section will provide near-ideal flow conditions. The dye injection system should be set up as described on page 12. When inserting Perspex models in the test section, they should be positioned centrally in the test section using the grid on the lower glass plate to align significant features with the dye injector rakes. Care should be exercised when lowering the top glass plate as described on page 12.

Having set up a particular experiment, the dye regulating valve should be opened and adjusted to give fine, clearly defined dye streams, which will indicate relevant streamlines. The position of the dye streams relative to the model may be finely adjusted by carefully sliding the injector rake sideways to the desired position.

As the sinks and sources will be used for these experiments it will be necessary to bleed the lines to expel all air, as described on page 12. Sinks and sources should be calibrated before beginning the experiments. Calibration of the flow rates is described on page 13.

3a. FORMATION OF A RANKINE HALF BODY

Ideal flow is generated on the table and the dye control valve adjusted to give clear, parallel dye streams. Flow from a central source orifice is introduced by opening the respective control valve. The pattern produced, shown in Figure 13, is referred to as a *Rankine Half Body*.

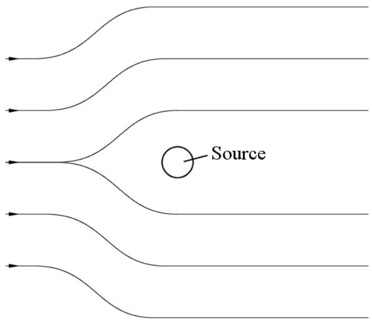

Figure 13: Rankine half body

Separation of the central dye steams is semi-infinite provided the source flow rate is constant.

The source flow rate may be adjusted to demonstrate the change in size of the body produced.

3b. FORMATION OF A RANKINE OVAL

The table is set up as described in 3a. with the addition of a sink downstream of the source. As the flow rate of the sink is increased, the half body is modified in shape. When the source and sink flow rates are equal, the streamlines close to produce a *Rankine Oval* as shown in Figure 14.

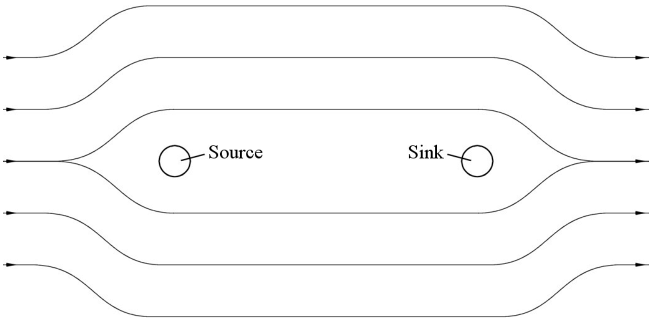

Figure 14: Rankine oval

3c. CIRCULAR STREAMLINES FROM A DOUBLET

The central orifice on the table is in fact two orifices in close proximity such that a coincident sink and source can be demonstrated. This combination is referred to as a Doublet and the streamline pattern produced is shown in Figure 15. The result is a circular streamline surrounding the Doublet which acts like a solid cylindrical boundary to the external flow (refer to part 1a.). Within this boundary, circulation patterns exist which may be demonstrated by introducing a few crystals of potassium permanganate. This effect is an extension of the Rankine Oval with source and sink coincidence.

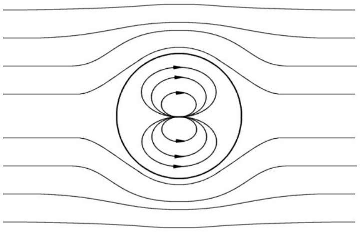

Figure 15: Doublet

3d. SUPERPOSITION OF SINKS AND SOURCES

Potential flow past a body may be simulated by superposition of sinks and sources of which the algebraic sum is zero. This may be demonstrated on the table by adjusting one source flow rate to equal two sink flow rates downstream. The result is a closed pear-shaped streamline which represents a symmetrical aerofoil with its corresponding flow pattern.

The experiment may be repeated for different combinations of sinks, sources and flow rates.

RESEARCH

As described previously, flow between the glass plates is dependent on potential and conforms to the Laplace Equation. The table may, therefore, be used as an analogue to simulate any two-dimensional system which is founded on this equation. A typical example of such an application is the visualisation and study of heat flow in a two-dimensional, uniform medium where temperature is the driving potential.

In the fluid sense, models may be fabricated to simulate a particular system under consideration. Sinks and sources may be included in these exercises to extend the range of application. Typical areas of research or demonstration include:-

1. Flow visualisation or study of flow around multiple bodies, e.g. flow around heat exchanger tubes, groins, etc.
2. Flow visualisation of airflow over bodies, e.g. airflow over the sails of a yacht at different angles to the wind - effect of the slot between head and mainsail.
3. Quantitative evaluation of underground water supplies in two dimensions (using calibrated sinks and sources to represent drains and wells).

APPENDIX A: EXAMPLE LABORATORY SAFETY RULES

All laboratories, classrooms and working areas should be covered by appropriate and comprehensive safety rules, which should reflect the hazards present, the uses to which the area will be put, and local regulations. The rules included in this appendix are provided **as an example only** and **must not be used** without appropriate risk assessment for the laboratory by properly qualified personnel, and corresponding modification of the document to suit.

All laboratories should be equipped with first aid supplies appropriate to the hazards present, which should include simple first aid instructions covering common emergency medical situations as well as instructions on using items specific to the hazards present (e.g. use of eye baths). Laboratories should also maintain Material Safety Data Sheets (or equivalent source of information) for any hazardous substances used or stocked within the laboratory. Depending on local regulations and laws, this may be a legal requirement. Basic training for staff and students in the use of any first aid equipment provided is also recommended.

1 Follow Relevant Instructions

a. Before attempting to install, commission or operate equipment, all relevant suppliers/manufacturers instructions and local regulations should be understood and implemented.

b. It is irresponsible and dangerous to misuse equipment or ignore instructions, regulations or warnings.

c. Do not exceed specified maximum operating conditions (e.g. temperature, pressure, speed etc.)

2 Installation

a. Use lifting tackle where possible to install heavy equipment. Where manual lifting is necessary beware of strained backs and crushed toes. Get help from an assistant if necessary. Wear safety shoes where appropriate.

b. Extreme care should be exercised to avoid damage to the equipment during handling and unpacking. When using slings to lift equipment, ensure that the slings are attached to structural framework and do not foul adjacent pipework, glassware etc. When using fork lift trucks, position the forks beneath structural framework ensuring that the forks do not foul adjacent pipework, glassware etc. Damage may go unseen during commissioning creating a potential hazard to subsequent operators.

c. Where special foundations are required follow the instructions provided and do not improvise. Locate heavy equipment at low level.

d. Equipment involving inflammable or corrosive liquids should be sited in a containment area or bund with a capacity 50% greater than the maximum equipment contents.

e. Ensure that all services are compatible with the equipment and that independent isolators are always provided and labelled. Use reliable connections in all instances, do not improvise.

f. Ensure that all equipment is reliably earthed and connected to an electrical supply at the correct voltage. The electrical supply must incorporate a Residual Current Device (RCD) (alternatively called an Earth Leakage Circuit Breaker - ELCB) to protect the operator from severe electric shock in the event of misuse or accident.

g. Potential hazards should always be the first consideration when deciding on a suitable location for equipment. Leave sufficient space between equipment and between walls and equipment.

3 Commissioning

a. Ensure that equipment is commissioned and checked by a competent member of staff before permitting students to operate it.

4 Operation

b. Ensure that students are fully aware of the potential hazards when operating equipment.

c. Students should be supervised by a competent member of staff at all times when in the laboratory. No one should operate equipment alone. Do not leave equipment running unattended.

d. Do not allow students to derive their own experimental procedures unless they are competent to do so.

e. Serious injury can result from touching apparently stationary equipment when using a stroboscope to `freeze´ rotary motion.

5 Maintenance

a. Badly maintained equipment is a potential hazard. Ensure that a competent member of staff is responsible for organising maintenance and repairs on a planned basis.

b. Do not permit faulty equipment to be operated. Ensure that repairs are carried out competently and checked before students are permitted to operate the equipment.

6 Using Electricity

a. At least once each month, check that RCD's (RCCB's / ELCB's) are operating correctly by pressing the TEST button. The circuit breaker must trip when the button is pressed (failure to trip means that the operator is not protected and a repair must be effected by a competent electrician before the equipment or electrical supply is used).

b. Electricity is the commonest cause of accidents in the laboratory. Ensure that all members of staff and students respect it.

c. Ensure that the electrical supply has been disconnected from the equipment before attempting repairs or adjustments.

d. Water and electricity are not compatible and can cause serious injury if they come into contact. Never operate portable electric appliances adjacent to equipment involving water unless some form of constraint or barrier is incorporated to prevent accidental contact.

e. Always disconnect equipment from the electrical supply when not in use.

7 Avoiding fires or explosion

a. Ensure that the laboratory is provided with adequate fire extinguishers appropriate to the potential hazards.

b. Where inflammable liquids are used, smoking must be forbidden. Notices should be displayed to enforce this.

c. Beware since fine powders or dust can spontaneously ignite under certain conditions. Empty vessels having contained inflammable liquids can contain vapour and explode if ignited.

d. Bulk quantities of inflammable liquids should be stored outside the laboratory in accordance with local regulations.

e. Storage tanks on equipment should not be overfilled. All spillages should be immediately cleaned up, carefully disposing of any contaminated cloths etc. Beware of slippery floors.

f. When liquids giving off inflammable vapours are handled in the laboratory, the area should be ventilated by an ex-proof extraction system. Vents on the equipment should be connected to the extraction system.

g. Students should not be allowed to prepare mixtures for analysis or other purpose without competent supervision.

8 Handling poisons, corrosive or toxic materials

a. Certain liquids essential to the operation of equipment, for example mercury, are poisonous or can give off poisonous vapours. Wear appropriate protective clothing when handling such substances. Clean up any spillage immediately and ventilate areas thoroughly using extraction equipment. Beware of slippery floors.

b. Do not allow food to be brought into or consumed in the laboratory. Never use chemical beakers as drinking vessels.

c. Where poisonous vapours are involved, smoking must be forbidden. Notices should be displayed to enforce this.

d. Poisons and very toxic materials must be kept in a locked cupboard or store and checked regularly. Use of such substances should be supervised.

e. When diluting concentrated acids and alkalis, the acid or alkali should be added slowly to water while stirring. The reverse should never be attempted.

9 Avoiding cuts and burns

a. Take care when handling sharp edged components. Do not exert undue force on glass or fragile items.

b. Hot surfaces cannot in most cases be totally shielded and can produce severe burns even when not `visibly hot´. Use common sense and think which parts of the equipment are likely to be hot.

10 Eye protection

a. Goggles must be worn whenever there is a risk to the eyes. Risk may arise from powders, liquid splashes, vapours or splinters. Beware of debris from fast moving air streams. Alkaline solutions are particularly dangerous to the eyes.

b. Never look directly at a strong source of light such as a laser or Xenon arc lamp. Ensure that equipment using such a source is positioned so that passers-by cannot accidentally view the source or reflected ray.

c. Facilities for eye irrigation should always be available.

11 Ear protection

a. Ear protectors must be worn when operating noisy equipment.

12 Clothing

b. Suitable clothing should be worn in the laboratory. Loose garments can cause serious injury if caught in rotating machinery. Ties, rings on fingers etc. should be removed in these situations.

c. Additional protective clothing should be available for all members of staff and students as appropriate.

13 Guards and safety devices

a. Guards and safety devices are installed on equipment to protect the operator. The equipment must not be operated with such devices removed.

b. Safety valves, cut-outs or other safety devices will have been set to protect the equipment. Interference with these devices may create a potential hazard.

c. It is not possible to guard the operator against all contingencies. Use common sense at all times when in the laboratory.

d. Before starting a rotating machine, make sure staff are aware how to stop it in an emergency.

e. Ensure that speed control devices are always set at zero before starting equipment.

14 First aid

a. If an accident does occur in the laboratory it is essential that first aid equipment is available and that the supervisor knows how to use it.

b. A notice giving details of a proficient first-aider should be prominently displayed.

c. A \`short list´ of the antidotes for the chemicals used in a particular laboratory should be prominently displayed.

APPENDIX B: INSTALLATION DRAWING 1008