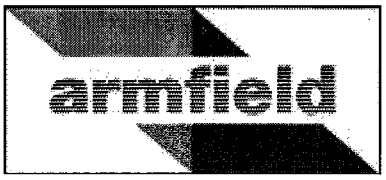

Bernoulli's Theorem Demonstration

Instruction Manual

F1-15

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General Overview

Fluid mechanics has developed as an analytical discipline from the application of the classical laws of statics, dynamics and thermodynamics, to situations in which fluids can be treated as continuous media. The particular laws involved are those of the conservation of mass, energy and momentum and, in each application, these laws may be simplified in an attempt to describe quantitatively the behaviour of the fluid.

The hydraulics bench service module, F1-10, provides the necessary facilities to support a comprehensive range of hydraulic models each of which is designed to demonstrate a particular aspect of hydraulic theory.

The specific hydraulic model that we are concerned with for this experiment is the Bernoulli's Theorem Demonstration Apparatus, F1-15. This consists of a classical Venturi machined out of clear acrylic. A series of wall tappings allow measurement of static pressure. A probe can be traversed along the centre of the section to obtain total head readings.

Equipment Diagrams

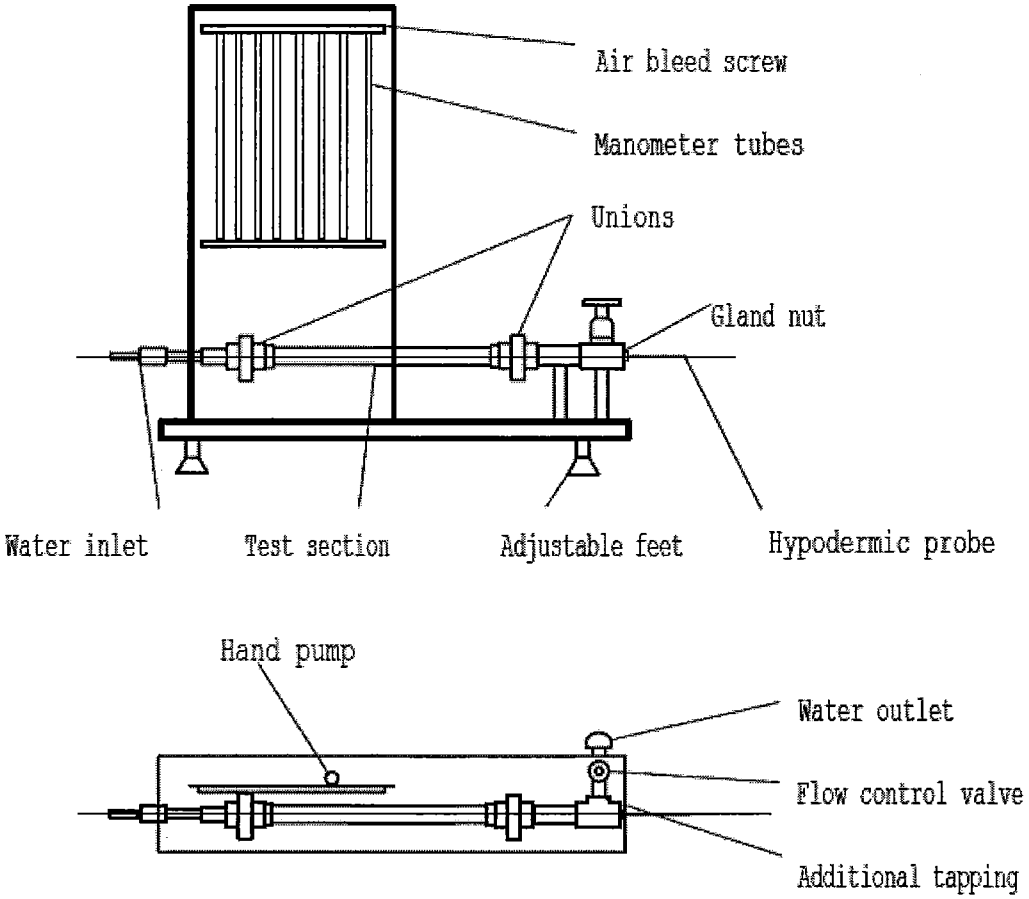


Figure 1: F15 Bernoulli's Theorem Demonstration

Important Safety Information

Introduction

Before proceeding to operate the equipment described in this text 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 electric shock
- Damage to clothing
- Risk of infection due to lack of cleanliness

Accidents can be avoided provided that equipment is **regularly maintained** and **staff** and **students** are made aware of potential hazards list of general safety rules is included in the F1 Product 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 in the F1 Product Manual regarding the Control of Substances Hazardous to Health Regulations.

Electrical Safety

The F1-10 Service Bench operates from a mains voltage electrical supply. The equipment is designed and manufactured in accordance with appropriate regulations relating to the use of electricity. Similarly, it is assumed that regulations applying to the operation of electrical equipment are observed by the end user.

However, to give increased operator protection, Armfield Ltd have incorporated a Residual Current Device (RCD, alternatively called an Earth Leakage Circuit Breaker or ELCB) as an integral part of the service bench. If through misuse or accident the equipment becomes electrically dangerous, an RCD will switch off the electrical supply and reduce the severity of any electric shock received by an operator to a level which, under normal circumstances, will not cause injury to that person.

Check that the RCD is 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 the equipment must be checked and repaired by a competent electrician before it is used.

Description

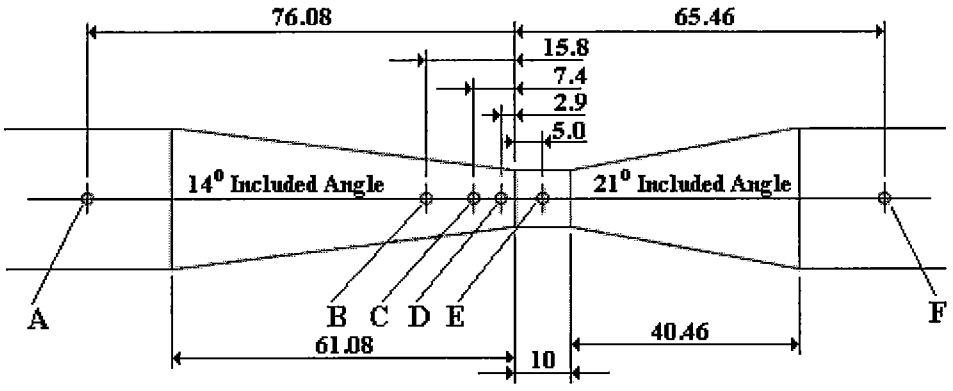
Where necessary, refer to the drawings in the Equipment Diagrams section.

Overview

The test section is an accurately machined clear acrylic duct of varying circular cross section. It is provided with a number of side hole pressure tappings which are connected to the manometers housed on the rig. These tappings allow the measurement of static pressure head simultaneously at each of 6 sections. To allow the calculation of the dimensions of the test section, the tapping positions and the test section diameters are shown on the following diagram:

Tapping Position	Manometer Legend	Diameter (mm)
A	h_1	25.0
B	h_2	13.9
C	h_3	11.8
D	h_4	10.7
E	h_5	10.0
F	h_6	25.0

Note: The assumed datum position is at tapping A associated with h1



The test section incorporates two unions, one at either end, to facilitate reversal for convergent or divergent testing.

A hypodermic, the total pressure head probe, is provided which may be positioned to read the total pressure head at any section of the duct. This total pressure head probe may be moved after slackening the gland nut; this nut should be re-tightened by hand. To prevent damage, the total pressure head probe should be fully inserted during transport/storage. An additional tapping is provided to facilitate setting up. All eight pressure tappings are connected to a bank of pressurised manometer tubes. Pressurisation of the manometers is facilitated by removing the hand pump from its storage location at the rear of the manometer board and connecting its flexible coupling to the inlet valve on the manometer manifold.

In use, the apparatus is mounted on a base board which is stood on the work surface of the bench. This base board has feet which may be adjusted to level the apparatus. A level glass is provided as part of the base.

The inlet pipe terminates in a female coupling which may be connected directly to the bench supply. A flexible hose is attached to the outlet pipe, which should be directed to the volumetric measuring tank on the hydraulics bench.

A flow control valve is incorporated downstream of the test section. Flow rate and pressure in the apparatus may be varied independently by adjustment of the flow control valve, and the bench supply control valve.

Installation

Installing the Equipment and Commissioning

The Bernoulli's Theorem Demonstration apparatus is supplied ready for use and only requires connection to the F1-10 Hydraulics Bench as follows:

Carefully remove the components from the cardboard packaging. Retain the packaging for future use.

Ensure that the clear acrylic test section is installed with the 14° tapered section (longest taper) upstream (left hand end). Also check that the unions are tightened (hand tight only). If it is necessary to reverse the test section then the total pressure probe must be withdrawn fully (but not pulled out of its guide in the downstream coupling) before releasing the couplings.

Locate the apparatus on the flat top of the bench with the outlet pipe over the moulded channel.

Using the spirit level attached to the baseplate, level the apparatus by adjusting the feet.

Connect the flexible inlet tube at the left hand end to the quick release fitting in the bed of the channel.

Place the free end of the flexible outlet tube in the volumetric tank of the bench.

Fully open the outlet flow control valve at the right hand end of the apparatus.

Close the bench flow control valve then start the service pump.

Gradually open the bench flow control valve and allow the pipework to fill with water until all air has been expelled from the pipework.

In order to bleed air from pressure tapping points and the manometers close both the bench flow control valve and the outlet flow control valve and open the air bleed screw. Remove the cap from the adjacent air inlet/outlet connection. Connect a length of small bore tubing from the air valve to the volumetric tank. Now, open the bench flow control valve and allow flow through the manometers to purge all air from them; then, tighten the air bleed screw and partly open both the bench valve and the outlet flow control valve. Next, open the air bleed screw slightly to allow air to enter the top of the manometers, re-tighten the screw when the manometer levels reach mid height.

Gradually increase the volume flowrate by opening the outlet flow control valve or the bench flow control valve as required until the maximum flowrate is achieved (maximum and minimum levels just within the range of the manometer scale).

If the pattern is too low on the manometer open the bench flow control valve to increase the static pressure. If the pattern is too high open the outlet flow control valve to lower the static pressure.

These levels can be adjusted further by using the air bleed screw and the hand pump supplied. The air bleed screw controls the air flow through the air valve, so when

using the hand pump, the bleed screw must be open. To retain the hand pump pressure in the system, the screw must be closed after pumping.

If the levels in the manometer are too high then the hand pump can be used to pressurise the top manifold. All levels will decrease simultaneously but retain the appropriate differentials.

If the levels are too low then the hand pump should be disconnected and the air bleed screw opened briefly to reduce the pressure in the top manifold. Alternatively the outlet flow control valve can be closed to raise the static pressure in the system which will raise all levels simultaneously.

If the level in any manometer tube is allowed to drop too low then air will enter the bottom manifold. If the level in any manometer tube is too high then water will enter the top manifold and flow into adjacent tubes.

Note: If the static pressure in the system is excessive, Eg. with the bench flow control valve fully open and the outlet flow control valve almost closed, it will not be possible to use the hand pump to lower the levels in the manometer tubes. The valves should be adjusted to provide the required flowrate at a lower static pressure.

Adjust the bench flow control valve and outlet flow control valve to provide a flow through the test section and observe that the pressure profile along the converging and diverging sections is indicate on the appropriate manometer tubes. The total head at any position in the test section can be measured by traversing the total pressure probe until the tip of the probe is at the required position then reading the head on the appropriate manometer tube.

Note: Manometer tube h_7 connected to the tapping adjacent to the outlet flow control valve, is used as a datum when setting up equivalent conditions for flow through the test section.

The actual flow of water can be established using the volumetric tank in conjunction with a stopwatch (not supplied).

Close the bench flow control valve then switch off the service pump.

Ensure that the hypodermic total pressure probe is fully retracted into the test section to prevent the probe from being damaged. Manometer tube h_8 is connected to the total pressure probe.

The F1-15 Bernoulli's Theorem Demonstration apparatus is ready for use.

Operation

Operating the Equipment

See Laboratory Teaching Exercises for details on operating the equipment.

Equipment Specifications

Environmental Conditions

This equipment has been designed for operation in the following environmental conditions. Operation outside of these conditions may result reduced performance, damage to the equipment or hazard to the operator.

a. Indoor use;

b. Altitude up to 2000m;

c. Temperature 5°C to 40°C;

d. Maximum relative humidity 80% for temperatures up to 31°C, decreasing linearly to 50% relative humidity at 40°C;

e. Mains supply voltage fluctuations up to ±10% of the nominal voltage;

f. Transient over-voltages typically present on the MAINS supply;

   Note: The normal level of transient over-voltages is impulse withstand (over-voltage) category II of IEC 60364-4-443;

g. Pollution degree 2.

   Normally only nonconductive pollution occurs.

   Temporary conductivity caused by condensation is to be expected.

   Typical of an office or laboratory environment

Routine Maintenance

Responsibility

To preserve the life and efficient operation of the equipment it is important that the equipment is properly maintained. Regular maintenance of the equipment is the responsibility of the end user and must be performed by qualified personnel who understand the operation of the equipment.

General

Little maintenance is required but it is important to drain all water from the apparatus and connecting pipework when not in use. The apparatus should be stored where protected from damage.

To prevent damage, the hypodermic total pressure probe should be fully retracted into the test section at all times when not taking readings. Slacken the gland nut then carefully slide the tube into the test section. The gland nut should only be hand-tightened.

Any manometer tube which does not fill with water or is slow to fill or empty indicates that the tapping in the pipework or the connection at the base of the manometer tube is blocked or partially blocked. Disconnect the flexible connecting tube between the pipe fitting and the manometer. Blowing through the tapping will usually dislodge any foreign body. Each manometer tapping is fitted with a snubber in the bottom manifold to minimise fluctuations in the reading.

Note: The length of the hypodermic total pressure probe will result in a slower response than the other tappings.

Following storage, remove the test section and wash the inside profile using warm water to which a few drops of wetting agent have been added, before using the apparatus. This will remove any dirt or grease adhering to the surfaces and improve the accuracy of readings obtained using the apparatus. A few drops of wetting agent injected into the manometer tubes will reduce the meniscus and improve the accuracy.

Laboratory Teaching Exercises

Index to Exercises

Nomenclature

Name	Unit	Symbol	Type	Definition
Volume Collected	m^3	V	Measured	Taken from scale on hydraulics bench. The volume collected is measured in litres. Convert to cubic metres for the calculations (divide reading by 1000)
Time to Collect	s	t	Measured	Time taken to collect the known volume of water in the hydraulics bench
Flow Rate	m^3/s^{-1}	Q_v	Calculated	$q_v = \frac{v}{T} = \frac{\text{Volume Collected}}{\text{Time to Collect}}$
Manometer Legend		hx	Given	Manometer identification labels
Distance into Duct	m		Given	Position of manometer tappings given as distance from the datum at tapping h_1. See Test Section Dimensions in Technical Data.
Area of Duct	m^2	A	Given	The area of the duct at each tapping. See Test Section Dimensions in Technical Data.
Static Head	m	h	Measured	Measured value from the appropriate manometer. The manometer readings are taken in mm Water. Convert to m Water for calculations.
Velocity	m^2s^{-1}	v	Calculated	Velocity of fluid in duct = Q_v/A
Dynamic Head	m		Calculated	$\frac{v^2}{2g}$ See Theory
Total Head	m	h^0	Calculated	$h + \frac{v^2}{2g}$ See Theory

Distance into Duct	m		Measured	Position of the Total Head Probe from the datum at tapping h_1
Probe Reading h_8	m		Measured	Measured value taken from h_8. This is the head recorded from the Total Head Probe.

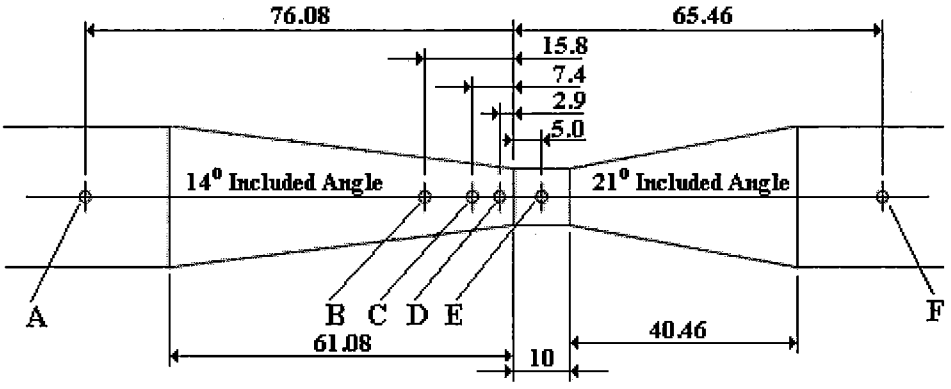
Technical Data

The following dimensions from the equipment are used in the appropriate calculations. If required these values may be checked as part of the experimental procedure and replaced with your own measurements.

The dimensions of the tube are detailed below:

Tapping Position	Manometer Legend	Diameter (mm)
A	h_1	25.0
B	h_2	13.9
C	h_3	11.8
D	h_4	10.7
E	h_5	10.0
F	h_6	25.0

Note: The assumed datum position is at tapping A associated with hl



Exercise A

Objective

To investigate the validity of the Bernoulli equation when applied to the steady flow of water in a tapered duct.

Method

To measure flow rates and both static and total pressure heads in a rigid convergent/divergent tube of known geometry for a range of steady flow rates.

Equipment

In order to complete the demonstration of the Bernoulli apparatus we need a number of pieces of equipment.

- The F1-10 Hydraulics Bench which allows us to measure flow by timed volume collection.
- The F1-15 Bernoulli's Apparatus Test Equipment
- A stopwatch for timing the flow measurement (not supplied)

Theory - The Bernoulli Equation

The Bernoulli equation represents the conservation of mechanical energy for a steady, incompressible, frictionless flow:

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+z_2$$

Where:

p = static pressure detected at a side hole,

v = fluid velocity, and

z = vertical elevation of the fluid, hence

$z_1 = z_2$ for a horizontal tube.

The equation may be derived from the Euler Equations by integration.

It may also be derived from energy conservation principles.

Derivation of the Bernoulli Equation is beyond the scope of this theory.

Theory - Other Forms of the Bernoulli Equation

If the tube is horizontal, the difference in height can be disregarded,

$$Z_1 = Z_2$$

hence:

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g}$$

With the Armfield F1-15 apparatus, the static pressure head p, is measured using a manometer directly from a side hole pressure tapping

The manometer actually measures the static pressure head, h , in metres which is related to p using the relationship:

$$h = \frac{p}{\rho g}$$

This allows the Bernoulli equation to be written in a revised form, ie:

$$h_1 + \frac{v_1^2}{2g} = h_2 + \frac{v_2^2}{2g}$$

The velocity related portion of the total pressure head is called the dynamic pressure head, h_d.

Theory - Total Pressure Head

The total pressure head, h^0 , can be measured from a probe with an end hole facing into the flow such that it brings the flow to rest locally at the probe end.

Thus, $h_t = h + \frac{v^2}{2g}$ (metres) and, from the Bernoulli equation, it follows that $ht_1 = ht_2$.

Theory - Velocity Measurement

The velocity of the flow is measured by measuring the volume of the flow, V, over a time period, t. This gives the rate of volume flow as : $Q_v = \frac{V}{t}$, which in turn gives the velocity of flow through a defined area, A , ie.

$$v = \frac{Q_v}{A}$$

Theory - Continuity Equation

For an incompressible fluid, conservation of mass requires that volume is also conserved,

$A_1v_1 = A_2v_2$ etc. ($m^3/s.$)

Equipment Set Up

Level the apparatus

Set up the Bernoulli equation apparatus on the hydraulic bench so that its base is horizontal; this is necessary for accurate height measurement from the manometers.

Set the direction of the test section

Ensure that the test-section has the 14° tapered section **converging** in the direction of flow. If you need to reverse the test-section, the total pressure head probe must be withdrawn before releasing the mounting couplings.

Connect the water inlet and outlet

Ensure that the rig outflow tube is positioned above the volumetric tank, in order to facilitate timed volume collections. Connect the rig inlet to the bench flow supply; close the bench valve and the apparatus flow control valve and start the pump. Gradually open the bench valve to fill the test rig with water.

Bleeding the manometers

In order to bleed air from pressure tapping points and manometers, close both the bench valve, the rig flow control valve and open the air bleed screw and remove the cap from the adjacent air valve. Connect a length of small bore tubing from the air valve to the volumetric tank. Now, open the bench valve and allow flow through the manometers to purge all air from them; then, tighten the air bleed screw and partly open the bench valve and test rig flow control valve. Next, open the air bleed screw slightly to allow air to enter the top of the manometers (you may need to adjust both valves in order to achieve this); re-tighten the screw when the manometer levels reach a convenient height. The maximum volume flow rate will be determined by the need to have the maximum (h_1) and minimum (h_5) manometer readings both on scale.

If required, the manometer levels can be adjusted further by using the air bleed screw and the hand pump supplied. The air bleed screw controls the air flow through the air valve, so, when using the hand pump, the bleed screw must be open. To retain the hand pump pressure in the system, the screw must be closed after pumping.

Results

Readings should be taken at 3 flow rates. Finally, you may reverse the test section in order to see the effects of a more rapid converging section.

Setting the flow rate

Take the first set of readings at the maximum flow rate possible (with all manometers reading on the backboard), then reduce the volume flow rate to give the h_1 - h_5 head difference of about 50mm. Finally repeat the whole process for one further flow rate, set to give the h_1 - h_5 difference approximately half way between that obtained in the above two tests.

Reading the static head

Take readings of the h_1 - h_6 manometers when the levels have steadied. Ensure that the total pressure probe is retracted from the test-section.

Timed volume collection

You should carry out a timed volume collection, using the volumetric tank, in order to determine the volume flow rate. This is achieved by closing the ball valve and measuring (with a stopwatch) the time taken to accumulate a known volume of fluid in the tank, which is read from the sight glass. You should collect fluid for at least one minute to minimise timing errors. Again the total pressure probe should be retracted from the test-section during these measurements. If not using the F1-15-301 software, enter the test results into the data entry form, and repeat this measurement twice to check for repeatability. If using the software, perform the collection as described in the walkthrough presentation.

Reading the total pressure head distribution

Measure the total pressure head distribution by traversing the total pressure probe along the length of the test section. The datum line is the side hole pressure tapping A associated with the manometer h_1.

Reversing the test section

Ensure that the total pressure probe is fully withdrawn from the test-section (but not pulled out of its guide in the downstream coupling). Unscrew the two couplings, remove the test-section and reverse it then re-assemble by tightening the coupling.

Repeat the set of readings as before.

Volume Collected V (m^3)	Time to Collect t (sec)	Flow Rate Q_v (m^3/sec)		Distance into Duct (m)	Area of Duct A (m^2)	Static Head h (m)	Velocity v (m/s)	Dynamic Head h_d (m)	Total Head h_t (m)
			h_1	0.00	490.9×10^{-6}				
			h_2	0.0603	151.7×10^{-6}				
			h_3	0.0687	109.4×10^{-6}				
Average flow rate			h_4	0.0732	89.9×10^{-6}				
			h_5	0.0811	78.5×10^{-6}				
			h_6	0.1415	490.9×10^{-6}				

Application of Theory

Comment on the validity of the Bernoulli equation for

- convergent flow
- divergent flow

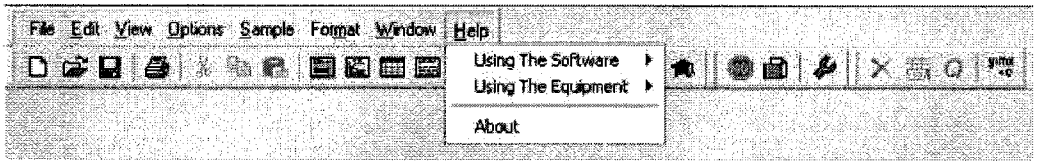
State clearly the assumptions made in deriving the Bernoulli equation and justifications for all your comments.

Comment on the comparison of the total heads obtained by the two methods you have carried out.

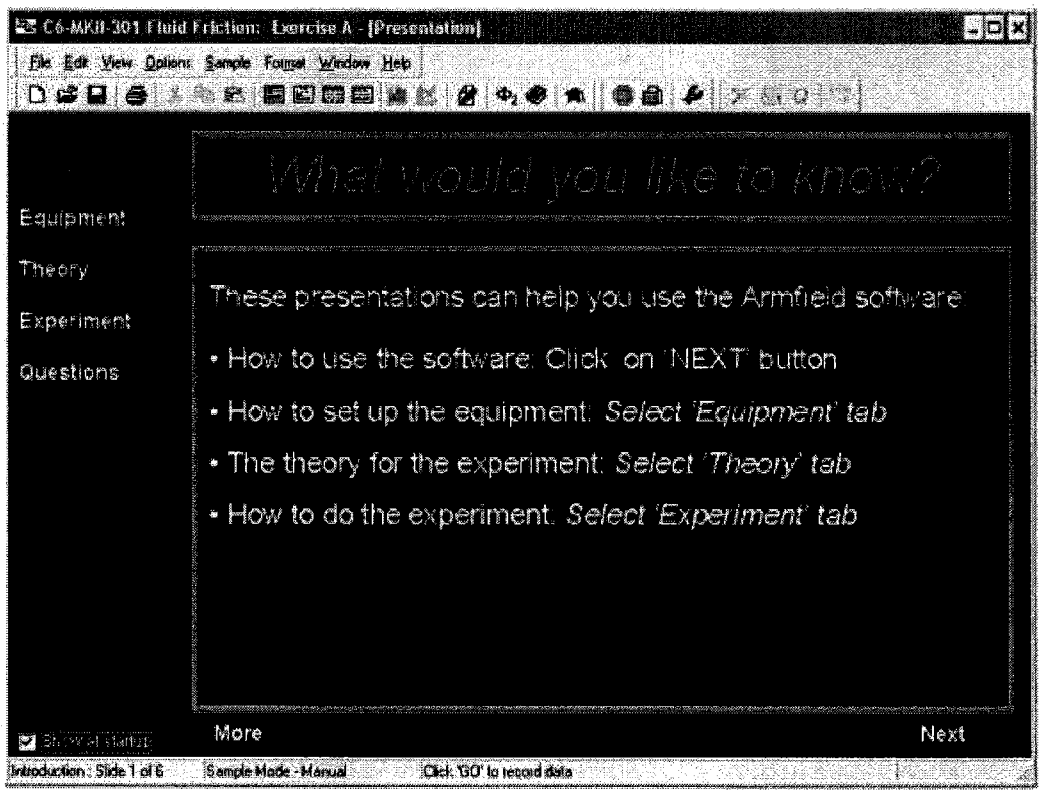
Operating the Optional Software (F1-301)

Note: The diagrams in this section are included as typical examples and may not relate specifically to an individual product.

The Armfield Software is a powerful Educational and Data Logging tool with a wide range of features. Some of the major features are highlighted below, to assist users, but full details on the software and how to use it are provided in the presentations and Help text incorporated in the Software. Help on Using the Software or Using the Equipment is available by clicking the appropriate topic in the **Help** drop-down menu from the upper toolbar when operating the software as shown:



Load the software. If multiple experiments are available then a menu will be displayed listing the options. Wait for the presentation screen to open fully as shown:

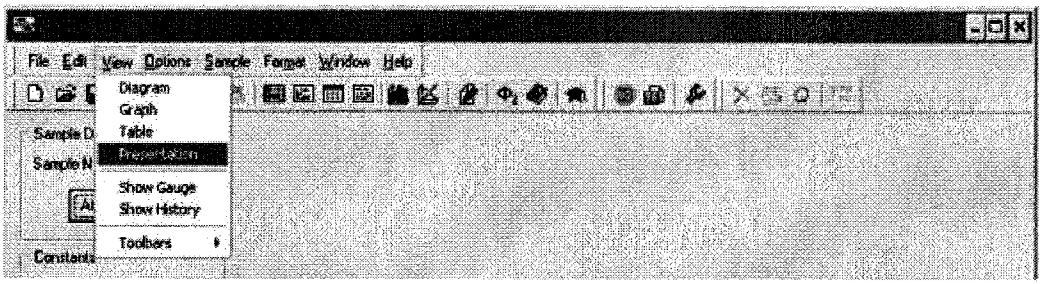


Presentation Screen - Basics and Navigation

As stated above, the software starts with the Presentation Screen displayed. The user is met by a simple presentation which gives them an overview of the capabilities of the equipment and software and explains in simple terms how to navigate around the software and summarizes the major facilities complete with direct links to detailed context sensitive 'help' texts.

To view the presentations click **Next** or click the required topic in the left hand pane as appropriate. Click **More** while displaying any of the topics to display a Help index related to that topic.

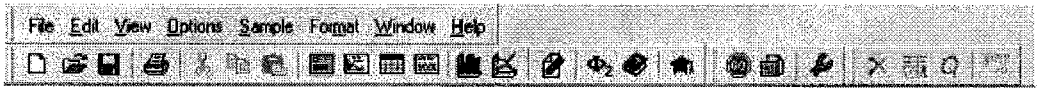
To return to the Presentation screen at any time click the View Presentation icon  from the main tool bar or click **Presentation** from the dropdown menu as shown:



For more detailed information about the presentations refer to the **Help** available via the upper toolbar when operating the software.

Toolbar

A toolbar is displayed at the top of the screen at all times, so users can jump immediately to the facility they require, as shown:



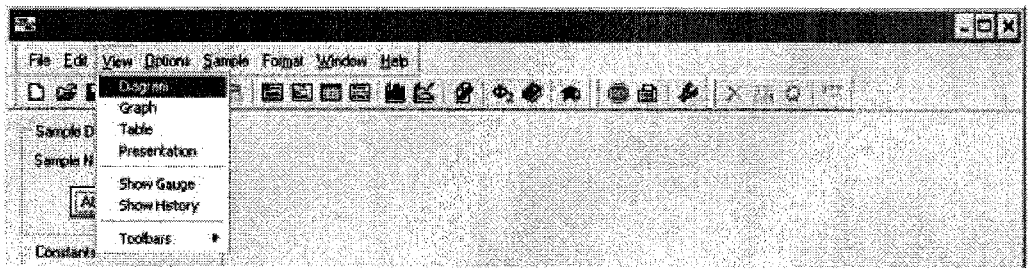
The upper menu expands as a dropdown menu when the cursor is placed over a name.

The lower row of icons (standard for all Armfield Software) allows a particular function to be selected. To aid recognition, pop-up text names appear when the cursor is placed over the icon.

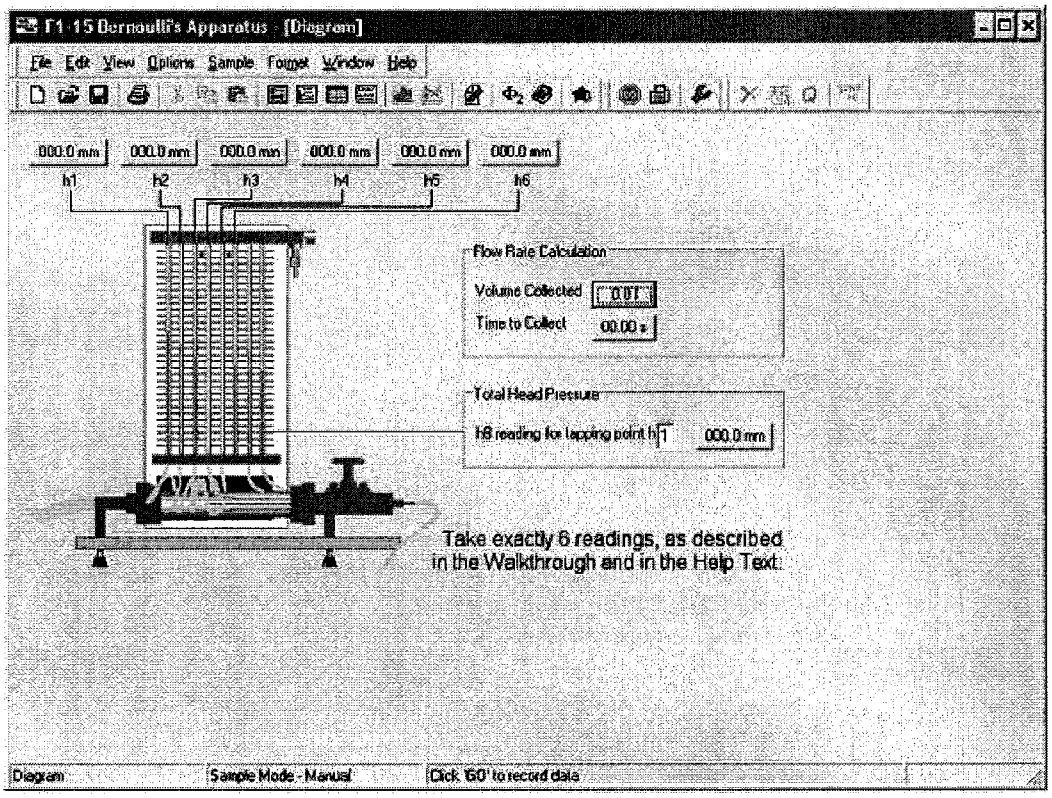
Mimic Diagram

The Mimic Diagram is the most commonly used screen and gives a pictorial representation of the equipment, with boxes to enter measurements from the equipment, display any calculated variables etc. directly in engineering units.

To view the Mimic Diagram click the View Diagram icon  from the main tool bar or click **Diagram** from the **View** drop-down menu as shown:



A Mimic diagram is displayed, similar to the diagram as shown:



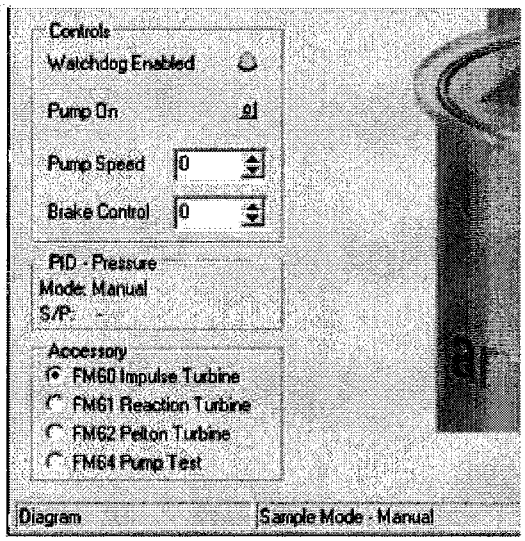
The details in the diagram will vary depending on the equipment chosen if multiple experiments are available.

Manual data input boxes with a coloured background allow measured variables, constants such as Orifice Cd and Atmospheric Pressure, as appropriate, to be changed by over-typing the default value. After typing the value press the Return key or click on a different box to enter the value.

In addition to measured variables such as Volume, Time, Temperature or Pressure, calculated data such as Discharge / Volume flowrate, Headloss etc are continuously displayed in data boxes with a white background. These are automatically updated and cannot be changed by the user.

After entering a complete set of data from measurements on the equipment click on the  icon to save the set of results before entering another set.

The mimic diagram associated with some products includes the facility to select different experiments or different accessories, usually on the left hand side of the screen, as shown:



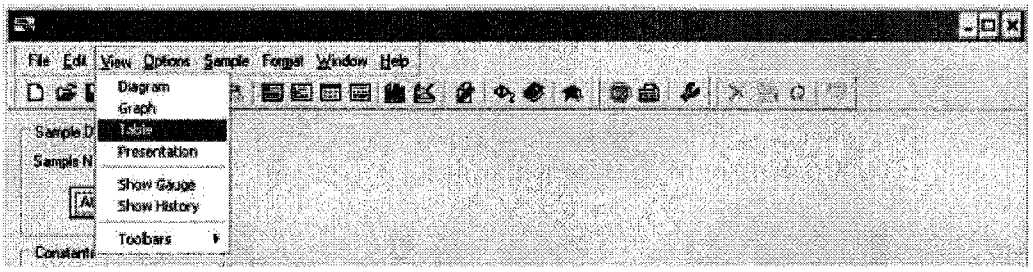
Clicking on the appropriate accessory or exercise will change the associated mimic diagram, table, graphs etc to suit the exercise being performed.

Data Logging Facilities in the Mimic Diagram

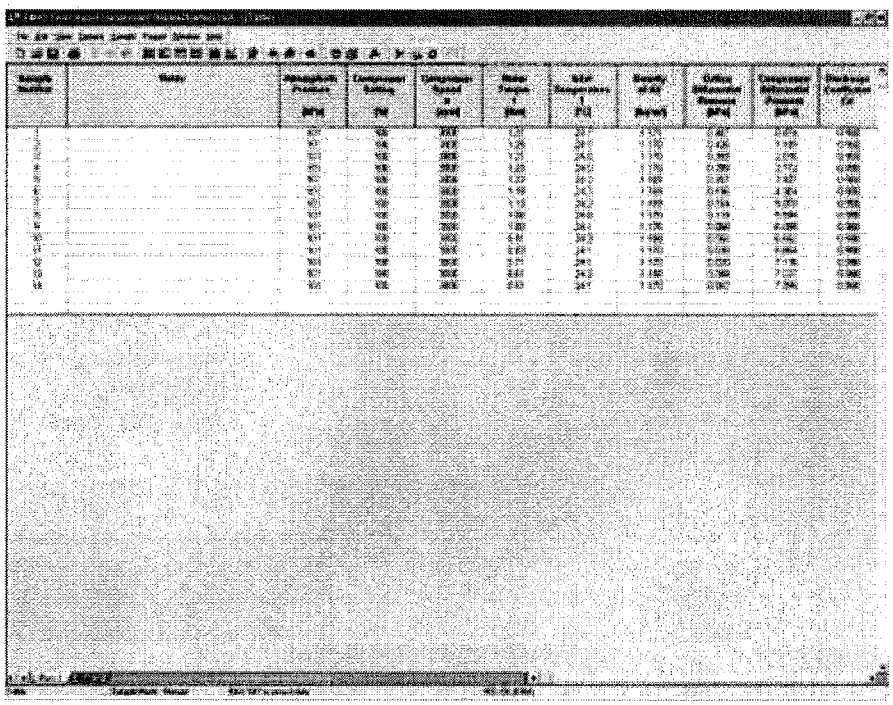
Armfield software designed for manual entry of measured variables does not include automatic data logging facilities and these options are greyed out where not appropriate. When manually entering data the  icon simply saves the set of entered data into a spreadsheet as described above.

Tabular Display

To view the Table screen click the View Table icon  from the main tool bar or click **Table** from the View dropdown menu as shown:



The data is displayed in a tabular format, similar to the screen as shown:



As the data is sampled, it is stored in spreadsheet format, updated each time the data is sampled. The table also contains columns for the calculated values.

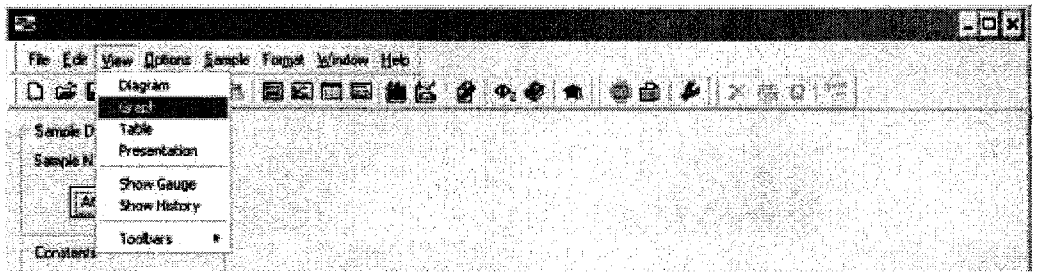
New sheets can be added to the spreadsheet for different data runs by clicking the  icon from the main toolbar. Sheets can be renamed by double clicking on the sheet name at the bottom left corner of the screen (initially Run 1, Run 2 etc) then entering the required name.

For more detailed information about Data Logging and changing the settings within the software refer to the Help available via the upper toolbar when operating the software.

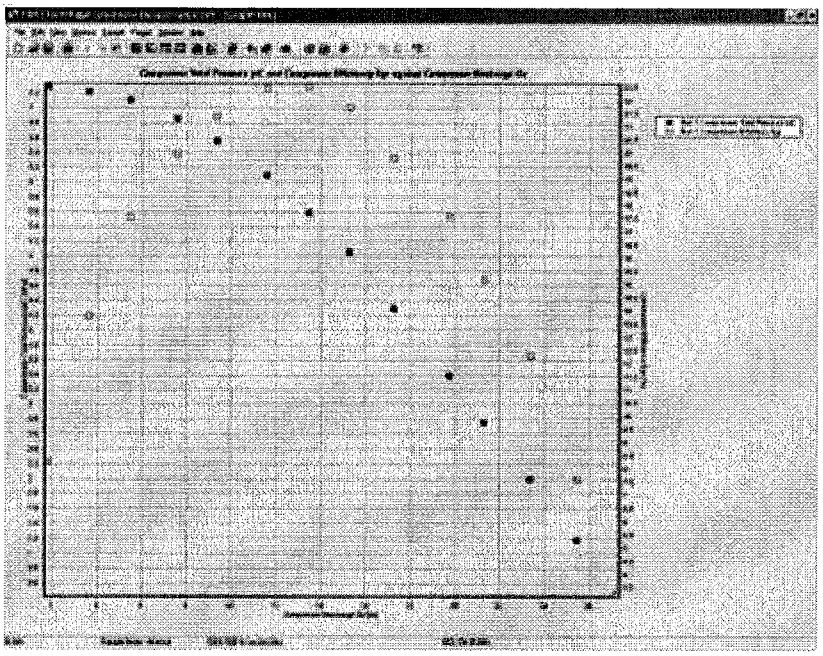
Graphical Display

When several samples have been recorded, they can be viewed in graphical format.

To view the data in Graphical format click the View graph icon  from the main tool bar or click **Graph** from the **View** drop-down menu as shown:



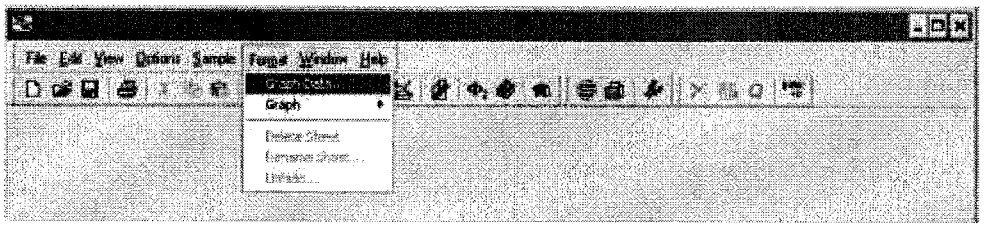
The results are displayed in a graphical format as shown:



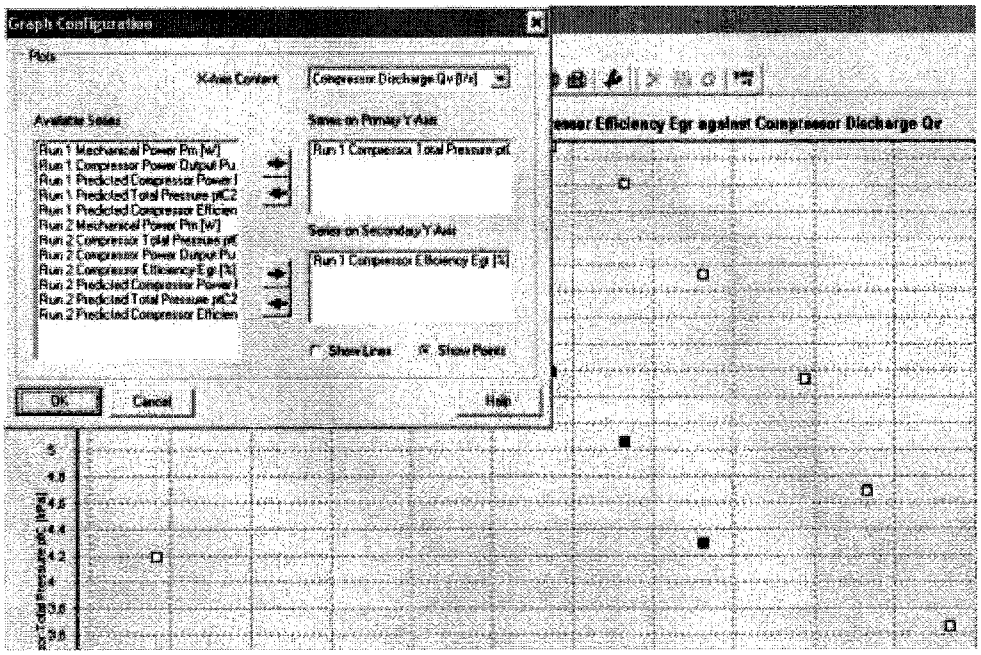
(The actual graph displayed will depend on the product selected and the exercise that is being conducted, the data that has been logged and the parameter(s) that has been selected).

Powerful and flexible graph plotting tools are available in the software, allowing the user full choice over what is displayed, including dual y axes, points or lines, displaying data from different runs, etc. Formatting and scaling is done automatically by default, but can be changed manually if required.

To change the data displayed on the Graph click **Graph Data** from the **Format** dropdown menu as shown:



The available parameters (Series of data) are displayed in the left hand pane as shown:



Two axes are available for plotting, allowing series with different scaling to be presented on the same x axis.

To select a series for plotting, click the appropriate series in the left pane so that it is highlighted then click the appropriate right-facing arrow to move the series into one of the windows in the right hand pane. Multiple series with the same scaling can be plotted simultaneously by moving them all into the same window in the right pane.

To remove a series from the graph, click the appropriate series in the right pane so that it is highlighted then click the appropriate left-facing arrow to move the series into the left pane.

The X-Axis Content is chosen by default to suit the exercise. The content can be changed if appropriate by opening the drop down menu at the top of the window.

The format of the graphs, scaling of the axes etc. can be changed if required by clicking **Graph** in the **Format** drop-down menu as shown:

For more detailed information about changing these settings refer to the **Help** available via the upper toolbar when operating the software.

Contact Details for Further Information

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