University of Jordan
Faculty of Engineering & Technology
Mechanical Engineering Dept.

Fluid Mechanics Lab. Manual

Prepared by

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September 2008

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INSTRUCTIONS TO STUDENTS

Each student should not forget the following when coming to the laboratory class:

1. The completed report of the previous experiment. Any report submitted late without an acceptable reason will be considered late for marking. Delays such as those related to stapling, binding and computer outputs are not acceptable.
2. Preparation for the experiment to be done. The student should read the manual related to the experiment before coming to the lab. He is expected to answer questions by the lab instructor regarding the objectives and the background of the experiment.
3. The laboratory manual and note book.
4. Pen or pencil
5. An electronic pocket calculator.

A timetable will be distributed which shows the date on which laboratory groups will perform each particular experiment. Each student should read introductory notes to his experiment before coming to the laboratory, and can start work without undue delay. This is particularly important in the early part of the session when the theoretical background may not have been covered in lectures, and reference to textbooks is more likely to be necessary.

Each student must keep a tidy laboratory notebook, recording all measurements exactly as they are taken, and tabulating them where appropriate. Where possible, a graph should be drawn as the experiment proceeds to ensure that the results are systematic and that sufficient readings have been obtained, especially in sensitive or particularly important parts of the range of the variables. Results are preferably reduced in the laboratory, but if this is not practicable, sufficient reduction should be done to ensure that no vital information is missing.

LABORATORY REPORTS

1. Introduction

As a part of the requirements for this course you will have to carry out **nine** experiments. The student performance will be assessed on the basis of his preparation, alertness and skills during the actual experimental stage as well as on the basis of written reports for each experiment.

The purpose of these experiments is to help the student understand some of the concepts discussed in class, and to develop skills in experimentation, measurement, instrumentation design and communication skills.

The student will be assigned nine tasks (experiments) by the Laboratory Instructor, to whom he must report his findings in writin,. **Seven** of the reports should follow the **short** format described in the next section. The other **two** reports will be formal **full** technical reports.

Generally the student should observe the following guidelines when writing a technical report, whether short or full. Failure to do so will result in mark penalties.

1. Writing: All reports must be **hand-written** in standard letter-size paper (A4). **Typed reports will not be accepted** unless the report is full and it contains material from references other than the lab manual. This hand writing measure is required to encourage ones own ethical responsibility towards other students reports by avoiding plain copying.
2. Margins: All material within the body of the report (this include text, tables, and figures) must be within the following margin: 35 mm from the left edge of the paper, 25 mm from the top, right, and bottom edge of the paper.
3. Orientation: Every attempt should be made to orientate all text, tables and figures in such a way that they can be read in an upright position, that is when the paper is held with its longer edge in the vertical position. Sometimes, wide tables or large figures must be rotated 90°. When doing this make sure that the bottom of the table or figure is parallel and closer to the right edge of the paper.
4. Bindings: binding of the pages should be at the top left corner, when using staples, or at the left edge of the paper when using other means.
5. Cover page: Please use the cover page format shown at the end of those instructions.

2. Short Technical Report

It must be emphasized here that this SHORT report should not be more than 6 to 8 pages long. Lengthy duplication of text or formulas found in the book and / or in other texts should be avoided; References should be given instead. Artistic renditions of the lab equipment used should be avoided. Simple line sketches are sufficient.

The report must include the following:

1. **Title page:** Use the title page supplied at the beginning of each experiment manual
2. **Objectives**
3. **The apparatus**
4. **The collected data**
5. **Sample calculation.**
6. **Results and discussion.**
7. **Conclusions**

3. Formal Technical Report (Full Report)

In the engineering profession a great value is attached to the substance or content of a report and, at the same time, to the presentation, which should be as neat as possible, without compromising contents by form. In other words: honesty is important in presenting results, even if they do not look highly reasonable. Following are some guidelines for the preparation of a formal (full) technical report. The format proposed here attempts to reflect current practice in engineering.

The elements of a formal (full) technical report are shown below:

1. **Abstract**
2. **Introduction**
3. **Theory**
4. **Apparatus**
5. **Procedure**
6. **Data collected**
7. **Sample calculation**
8. **Results and discussion**
9. **Error analysis**
10. **Conclusions**
11. **References**
12. **Appendices**

4. Figures

1. Each figure should be given a number and a title, **underneath** it.
2. The titles should help to explain what the figures show. For example: Relation between pressure and flow rate.
3. They should be neatly drawn, using proper curve fitting techniques.
4. The units should be shown clearly on each coordinate, using SI units only.
5. Each coordinate should have the name of the variable written on it.
6. The scale should be uniform; i.e. distances between scale points should be equal.
7. The size of the figure should be adequate.

5. Tables

1. Each table should be given a number and a title located above it.
2. The title should help to fully explain what information the table contains. For example: Pressure and flow rate raw data.
3. The units of the variables should be clearly stated. Only SI units should be used.

6. An Ethical Word of Caution

The formal reports must represent an individual work of a student. Obviously, the experimental data and any other material resulting from an experiment, and obtained during the experiment session, may be shared freely and be presented in anyone's report. However, copying a text or graphics from another person's report may be viewed as an attempt of plagiarism, and will be heavily penalized.

7. Safety Code of Practice

1. Do not enter the laboratory until the lecturer is present, and do not come later than 10 minutes after the lab has started.
2. Bring only necessary items into the laboratory.
3. Do not operate or turn off any machinery until instructed to do so.
4. Do not interfere with any other equipment.
5. Report any breakage to the laboratory supervisor.
6. Always seek advice, either from the lecturer or technician if the equipment is not operating as expected.
7. In the event of a catastrophic failure, try to isolate the equipment from the energy source and / or consult the lecturer or supervisor.
8. On completion of experiment tidy your working area.
9. Report to the lecturer / supervisor before leaving the laboratory.

Elements of Lab. Report

Two types of reports are required: short and long.
Following the type of report required, the proper element should be selected from the following in the same order shown:

1- Title (cover) Page

In the first page of the report (not to be numbered), the University, Faculty, Department, Lab, Student and Supervisor Names and Dates should be included. The experiment Title and number should be included as indicated in the Lab. Manual. Use black color only.

2- Abstract

A brief description of the experiment should be given. This should include the objectives, the method and a summary of the findings. The abstract should not be more than 100 words. (1/2 page). For example one of the findings of the ratio of specific heat experiment is that it is equal to 1.4 for air. It is recommended to write the Abstract AFTER the report is completed in order to be able to include all important aspects and findings of the experiment.

3- Introduction

After a proper definition of the level of the reader is made, this should introduce the reader into the subject. It is composed of tow parts: significance and method. The introduction should not be more than 200 words (1 Page). If a short report is required, only the objectives should be stated to replace the introduction. The objectives are the aims or the goals of the experiment. For example, one of the objectives of the Work-to-Heat experiment is to experimentally find the Jouls' work equivalent of heat, which is equal to 4.178 k cal/KJ.

4- Theory

In order to enable the reader to understand the implications of the reported work (experimental or theoretical), the main assumptions should be stated and justified, with the theory written out in sentences, so that the reader is led through the equations without confusion. It should be free from unnecessary details, such as excessively detailed algebraic work. The units used should be defined as they appear. Use SI units where appropriate.

5- Experimental Apparatus and Procedure

Describes the experimental apparatus (if applicable). Tells the reader what was done in brief, and a sketch of the apparatus should be included. The experimental procedure should be also presented.

6- Raw Data

This should include collected data, usually in the format of tables and; possibly as graphs. In either case, as the title indicates, this data should be reported as collected, without treatment or modification. The tables should be numbered and titled at the top.

7- Sample Calculation

The calculation should include all necessary steps to obtain the required results. The equations used should be stated in the theory. All parameters used to obtain the required results should be clear and their symbols and units should be as stated in the theory.

8- Results

This should include all the findings required from the experiment, usually in the form of graphs. All figures should be numbered and titled at the bottom. The coordinates should be defined with proper scale and units. Do not just connect the dots. If you know the trend of the phenomena, use a proper curve-fitting technique to show the plot, which should not be a continuous line, but rather, a dotted line to indicate that it is experimental. Only theoretical curves can be made with a continuous line.

Do not make stupid mistakes such as:

- Irregular Scale: some computer graphing techniques give a scale point at each data point, which may result in an irregular scale (It's like a rule where the first centimeter may be longer or shorter than any other centimeter on the scale).
- The scale increases in the negative direction of x.
- Undefining each plot in a graph that includes several plots.

9- Discussion

This is the most important part of the report. The presented results should be interpreted in view of theoretical background. It should explain why the phenomena looks that way. Do not just say, for example, in the Marcet boiler experiment, that it is noticed that the pressure increasesas the temperature increases. Instead, explain why. Show how close the experiment was to the theory and indicate the sources of error which lead to disagreement between experiment and theory. This should include error, or uncertainty analysis. This analysis should tell how much the error is in obtaining each and every parameter in the results.

10- conclusions

This should tell the reader in brief what was covered in the experiment and what were the most important results. It should not include any thing that was not mentioned before in the previous sections of the report.

11- References

All other related work, either mentioned in Theory or elsewhere should be documented here. All references should be numbered, and those numbers should be indicated in the text at the place they were used. Do not just put a bunch of references without referring to them in the text. This will not impress the reader. The reference format should follow this:

a) Book

Duffie, J.A., and Beckmen, W. A., "Solar Engineering of Thermal Processes", John-Wiley Pub. 1980.

b) Journal

Takeish, K., Aoki, S., Sato, T., and Tsukagoshi, K., 1991. Film Cooling on a Gas Turbine Rotor Blade, ASME Journal of Turbomachinery, Vol. 114, 12-34.

12- Appendices

An Appendix is used to remove all detailed information from the report. The following materials may appear in the appendices.

a- Detailed mathematical derivations.
b- Calibration of instrumentation.
c- Tabulation or graphs of material properties.
d- Detailed computer programs.
e- Calculations and charts obtained from other work.

Description of the Hydraulics Bench

This is a complementary laboratory sheet and is intended to be used in conjunction with the experiments that are performed with the H1 hydraulics bench,

The bench is intended to provide facilities for performing a number of simple experiments in hydraulics. Figure 1, and Figure 2 show a single unit in which a small centrifugal pump P draws water from a sump S resting below the bench and delivers it to a bench supply valve V.

Below the bench there is a weighing tank W into which the discharge from the apparatus being tested is directed through a short pipe D terminating at flange F just above the bench level. The weighing tank W is supported at one end of a weighing beam, the other end of which carries a weight hanger sufficient to balance the dry weight of the tank, plus a small amount of water. The outlet valve B in the base of the tank may be operated through a mechanism by an external handle.

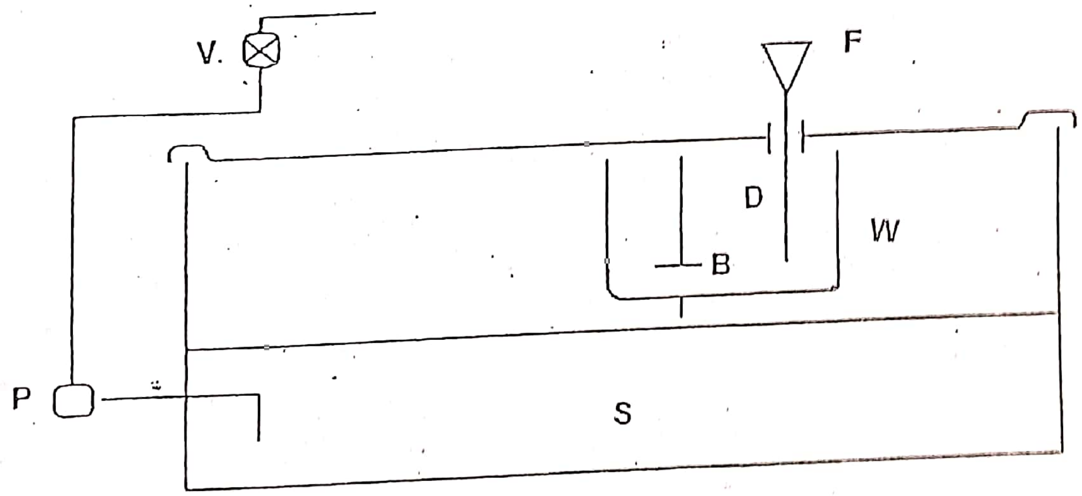

Figure 1 A diagrammatic sketch for a simple hydraulic bench.

The apparatus under test is placed on the bench and connected by flexible pipe to a bench supply valve V, which normally serves to regulated the rate of flow through the apparatus. Another flexible pipe is led from the exit of the apparatus to the flange above the weighing tank, so that the discharge is returned through the open valve in the base of the tank through to the sump tank. Having set a desired condition in the apparatus, the discharge is normally measured in the following manner. The outlet valve B in the back of the weighing is closed by operating the handle connected to the valve mechanism.

As water steadily collects in the weighing tank, see Figure 3, there comes a time when the weigh-beam moves to its upper stop; a stop-clock is started at this instant. A known weight is then added to the hanger which brings the weigh-beam down to its lever stop again. The stop-clock is stopped as the weigh-beam moves to its upper stop for the second time, this makes the water collected during the time interval corresponds to the further known added weight. The outlet valve of the weighing tank is then opened to allow it to drain and the weights are removed from the hanger in preparation for the next measurement. The weight suitable for collection will vary with the discharge and one or two trials may be necessary at the start of an experiment to determine a suitable weight. An interval of about 100 seconds is normally sufficient to give a satisfactory measurement. The weighing and draining operation is shown in Figure 4.

Attention is drawn to the following points which should be observed for a safe and satisfactory operation of the bench.

1. Before starting the pump ensure that the sump is filled to a minimum depth of approximately 320 mm, and that the bench supply valves are turned off.
2. If a leak develops so that the water drops on the electric motor or starter, stop the pump immediately and isolate it from the electrical supply by withdrawing the plug which supplies it. The connection should not be remade until the leak has been sealed. A small amount of water leaking into the bench top, however, is of little concern, as it drains back into the sump.

3. When making connections by a flexible hose it is usually sufficient to rely on friction between the metal pipe and the hose to maintain the tightness of the connection. Where however, the connection is subjected to the full pressure delivered to the bench supply valve, or if the hose is a loose fit on the metal pipe, it is advisable to secure the connection with a hose clip tightened by a screwdriver.
4. At all times other than when a discharge measurement is being made, the valve B in the base of the weighing tank should be kept open. However, even if the tank over-flows it is not serious as any surplus water spills back automatically into the sump tank.
5. To avoid unnecessary effort when operating the lever mechanism on the hydraulics bench, always:-
   - Leave the calibrated weights on the hanger when opening the drain valve and then,
   - Remove these weights before lowering the weigh beam to its initial position.

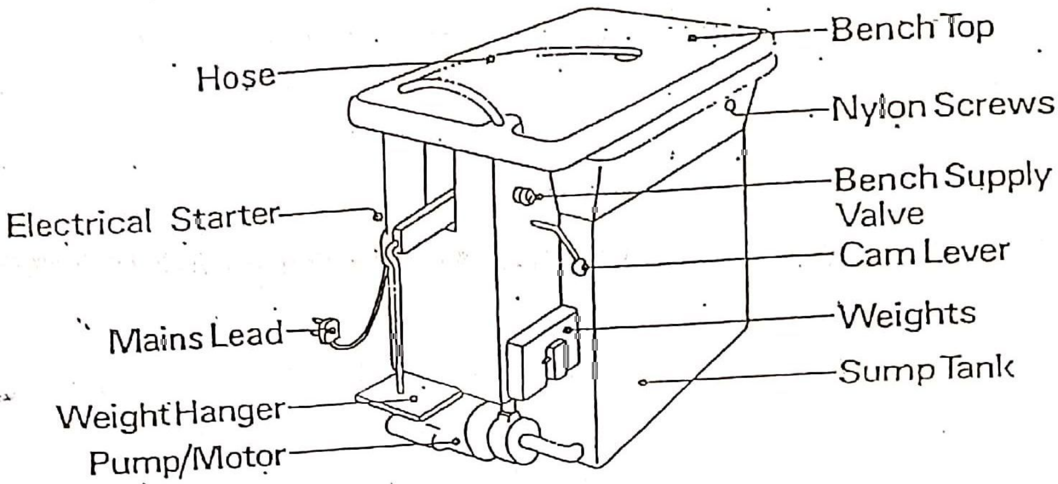

Figure 2 Features of a hydraulic bench

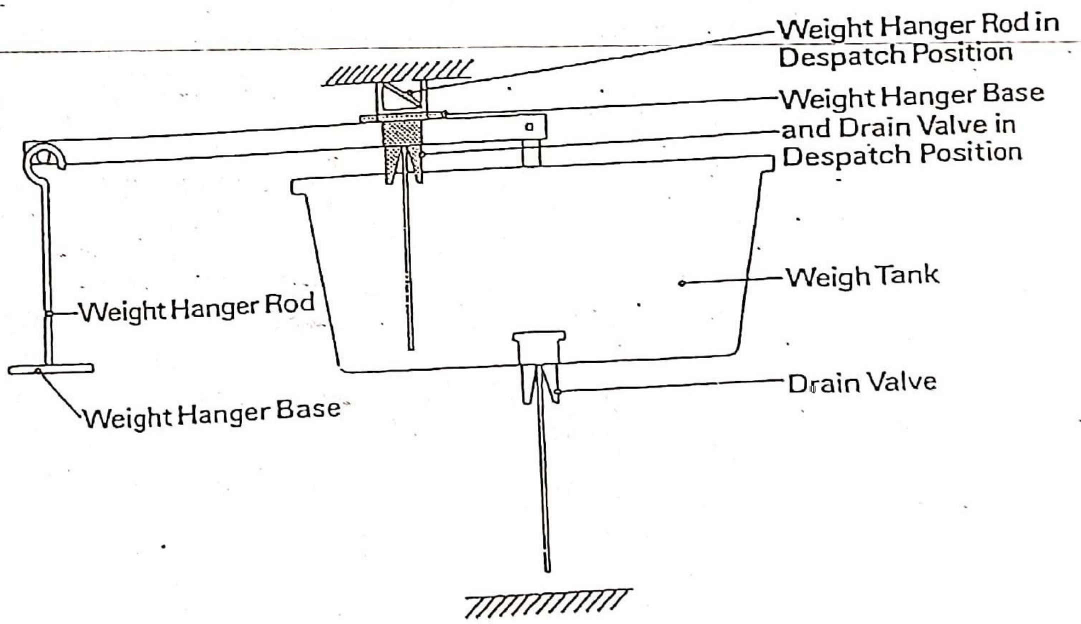

Figure 3 Assembled position of weight hanger and drain valve.

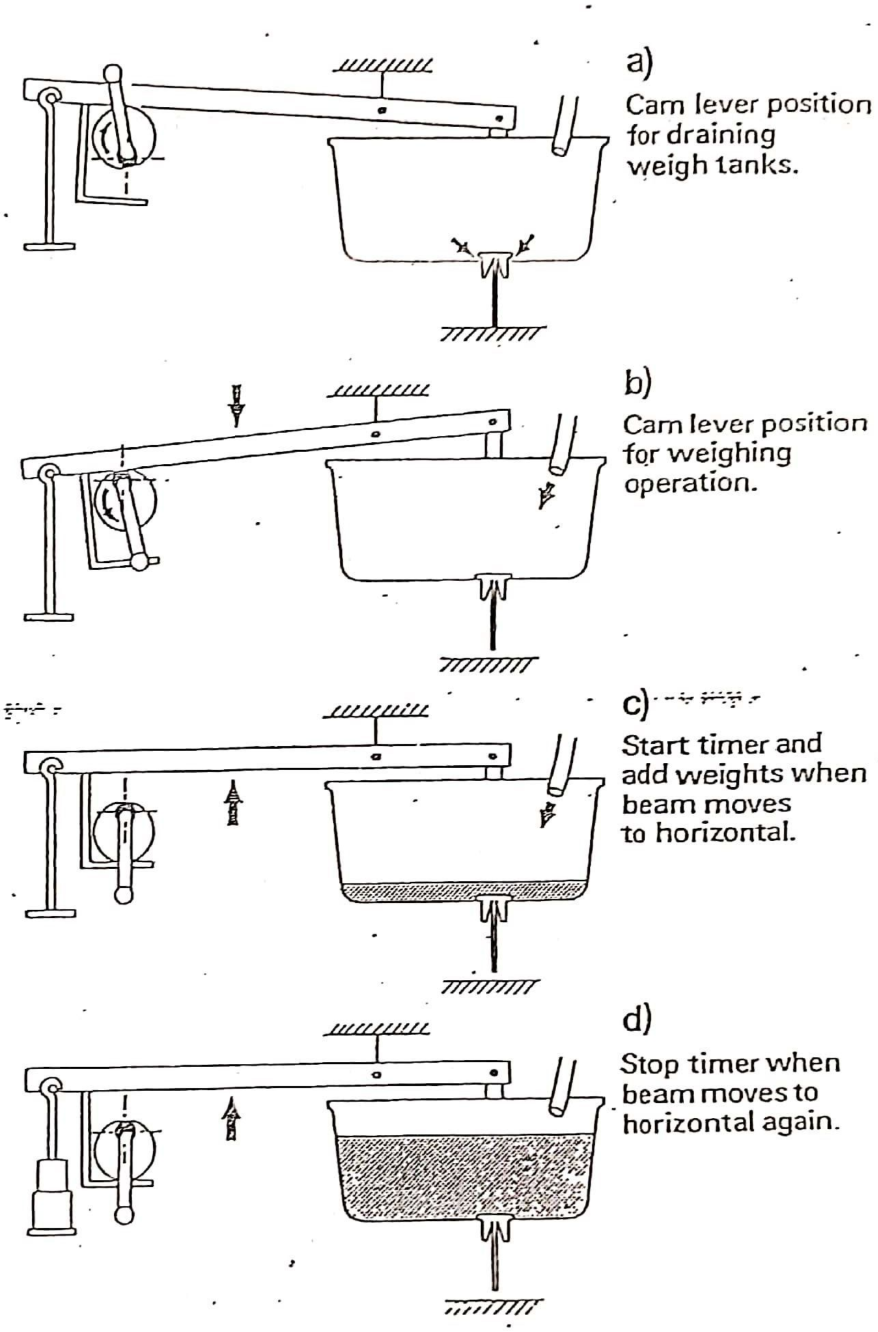

Figure 4 Weighing and draining operation.

University of Jordan
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Mechanical Engineering Dept.

Fluid Mechanics Lab.

Experiment Title Page

Instructor: *Prof. Ali Badran*

Experiment 1: *Center of pressure on a surface*

Report ☐ *Full* ☐ *Short*

Student Name :-----------------------------------
Student Number :-----------------------------------
Student Branch (الشعبة): ☐1 ☐2
Student Group: ☐A ☐B ☐C

Center of pressure on a Plane Surface

Important in design tanks, ships, dams.

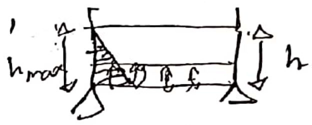
* Objectives

$F = PA$

1. To determine the position of the center of pressure on the rectangular face of the toroid.
2. To compare the measured value with that predicted from the theoretical analysis.

* Theory

Figure 1 shows a plane surface inclined at an angle α to the free surface of the liquid 00. Since there can be no shear stress in a static fluid medium, the force on the plane is due to pressure only and must act normal to the surface. This pressure force is found to be $F = \rho g A y_c \sin\alpha$



where

A	is the area of the surface	(m^2)
ρ	is the density of the liquid	(kg/m^3)
g	is the gravitational acceleration	(m/s^2)
y_c	is the coordinate of the centroid	(m)

$P = \rho g h$

$F = \rho g h A_f$

$F_{wall} = f$

The force, F, may be taken as acting at the center of pressure CP. Now to determine the position of the center of pressure we take moments about O. After some arrangements and eliminations we can prove that the position of the center of pressure is given by

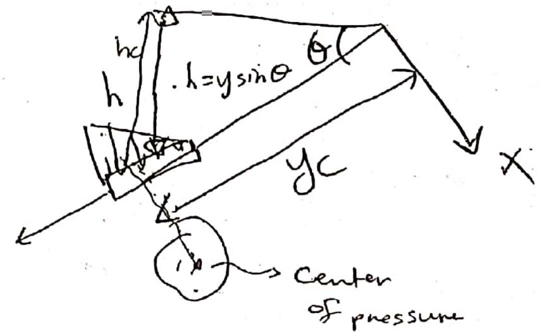
$$y_{cp} = y_c + \frac{I_{xx,c}}{y_c A}$$

Where $I_{x\,x,c}$ is the second moment of area (also called the moment of inertia) about the axis parallel to the x-axis and passing through the centroid C.

Where is F_R?
y-coordinate

$P_a = 0$ (gauge)

1.2



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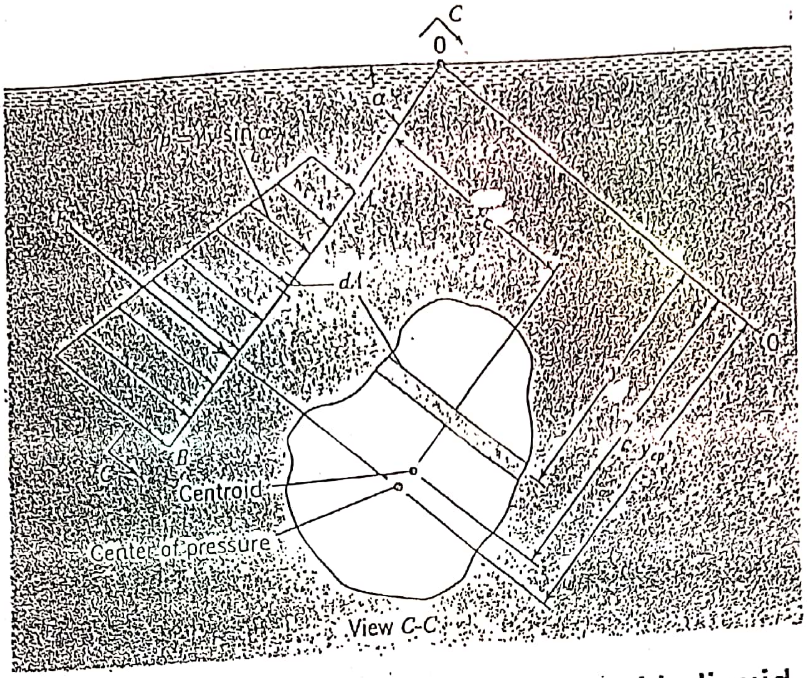

Figure 1 A plane surface immersed in liquid.

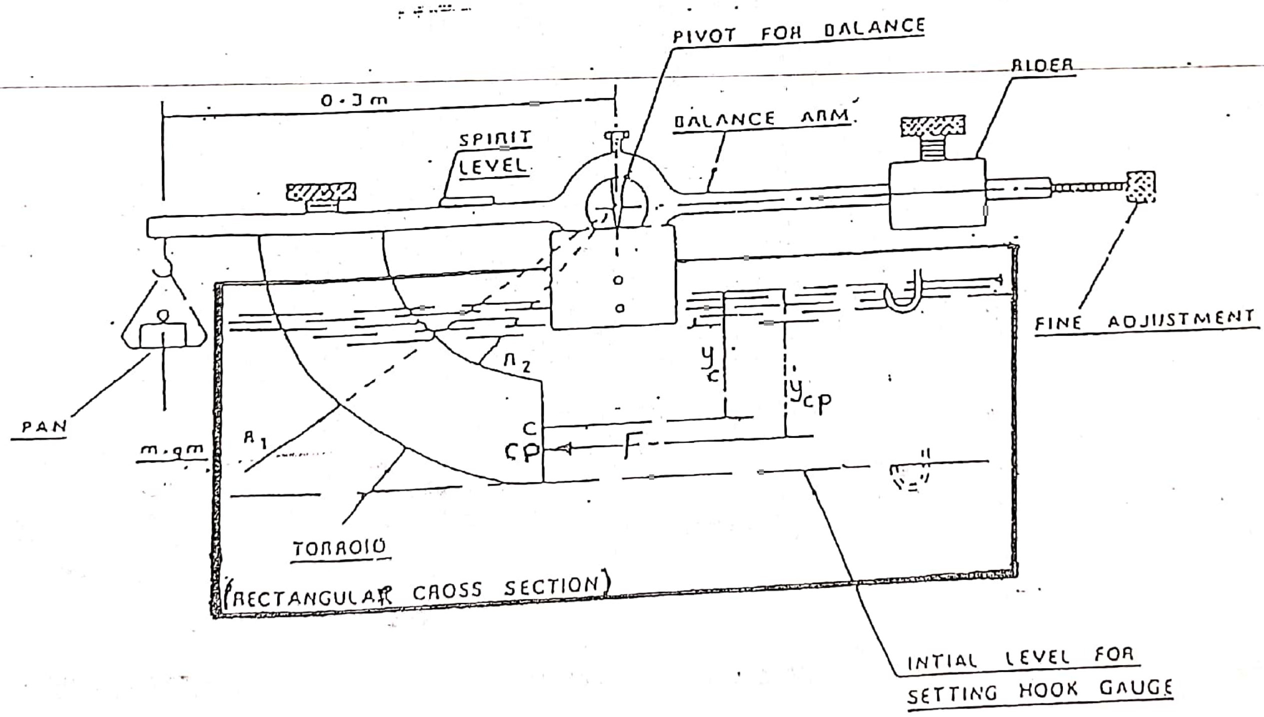

Figure 2 The apparatus.

* Apparatus

The apparatus is shown in Figure 2. A toroid is mounted on a balance and pivoted about the center of curvature of the toroid. Thus only the vertical face along GC of the toroid has any moment about the balancing point. A rider weight balances the weight of the toroid in the dry, so that the moment of the hydrostatic force on C is measured by the weight at the pan. The toroid is immersed in a tank containing water and the depth of immersion is measured by a hook gauge.

* Procedure

1. Measure the dimensions a, b, c, and d , see Figure 3.
2. Level the tank under the toroid and adjust the weight W_1 to level the balance arm. Carefully, admit water to the tank until it just touches the bottom of the quadrant. Take the vernier reading.
3. Raise the water level in increments of about 10 mm and add weight to the balance pan to level the balance arm for each depth of water. Note the mass M and the depth of immersion h for each reading.

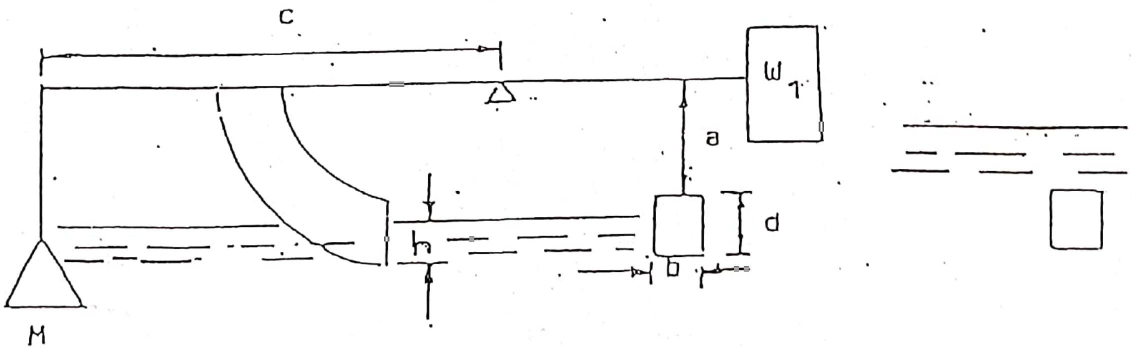

Figure 3 A schematic diagram of the toroid and the balancing weight

* *Data collected*

a = 0.1 m   b = 0.075 m   c = 0.3 m   d = 0.1 m

Partial Immersion

h (cm)	M (g)	Immersed Area (m^2)	Theoretical y_{cp}(cm)	Experimental $\bar{y}_{cp}$(cm)	M/h^2
1.5					
3					
4.5					
6					
7.5					
9					

Total Immersion

h (cm)	M (g)	Theoretical y_{cp}(cm)	Experimental y_{cp}(cm)	$\left(h-\frac{d}{2}\right)$
10				
11				
12				
13				
14				

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* Results and discussions

Partial immersion (h < d)

(1) Derive an expression for the depth of the center of pressure (y_{cp}) below the surface and, for each level, compare it with the experimental depth of center of pressure. (You may assume the force F to be that calculated from the formula).

(2) Derive the equation

$$\frac{M}{h^2} = \frac{\rho b(a+b)}{2c} + \frac{\rho bh}{6c}$$

(3) Plot (M/h^2) versus h and obtain the slope and intercept.

Total Immersion (h > d)

(1) As in (1) above.

(2) Derive the equation

$$M = \frac{\rho bd^3}{12c} + (h-d/2)\left[\frac{\rho bd}{c}(a+1/2(d))\right]$$

(3) Plot (M) versus (h – d/2) and obtain the intercept and slope.

* Conclusions

1. How do the experimental values of the position of center of pressure correspond with the calculated theoretical values from physical dimensions?
2. How do the measured values of slope and intercept obtained in 3 above correspond with theoretical values?
3. The pressure force act on the four surfaces of the rectangular toroid which are submerged were ignored in the experiment. Are they zero, negligible or is there a mistake in the experiment method?
4. You ignored the buoyancy effect of the submerged part of the toroid comment on the implications.
5. Would the location of the center of pressure change if a different fluid were used in the tank? Explain.

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Experiment Title Page

Instructor: ***Prof. Ali Badran***

Experiment 2: *Impact of a water jet*

Report ☐ *Full* ☐ *Short*

Student Name :-----------------------------------
Student Number :-----------------------------------
Student Branch (الشعبة): ☐1 ☐2
Student Group: ☐A ☐B ☐C

Impact of A Water Jet

* Objectives

1. To determine the force produced by a water jet when it strikes a flat vane and a hemispherical cup.
2. To compare the results measured with the theoretical values calculated from the momentum flux in the jet.

* Introduction

Over the years, engineers have found many ways to utilize the force that can be imparted by a jet of fluid on a surface diverting the flow. For example, the pelton wheel has been used to make flour. Furthermore, the impulse turbine is still used in the first and sometimes the second stage of a steam turbine. Firemen make use of the kinetic energy stored in a jet to deliver water above the level of the nozzle to extinguish fires in high-rise buildings. Fluid jets are also used in industry for cutting metals and debarring. Many other applications of fluid jets can be cited which reveals their technological importance.

This experiment aims at assessing the different forces exerted by the same water jet on a variety of geometrically different plates. The results obtained experimentally are to be compared with the ones inferred from theory through utilizing the applicable versions of the Bernoulli and momentum equations.

* Theory

For the general case shown in Figure 1, the momentum flux in the jet is $m^{\cdot}u_0$ where $m^{\cdot}$ is the mass flow rate and u_0 is the jet velocity just upstream of the vane. After being deflected through an angle β, the momentum flux is $m^{\cdot}u_1 \cos\beta$ in the x-direction.

The force on the fluid is therefore $m^{\cdot}u_1 \times \cos\beta - m^{\cdot}u_0$ in the x-direction. Thus the force F in the x-direction on the vane is therefore.

$$F = m^{\cdot}(u_0 - u_1 \cos\beta) \qquad (1)$$

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Experiment Title Page

Instructor: *Prof. Ali Badran*

Experiment 2: *Impact of a water jet*

Report ☐ *Full* ☐ *Short*

Student Name :---
Student Number :---
Student Branch (الشعبة): ☐1 ☐2
Student Group: ☐A ☐B ☐C

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$$F = m^{\cdot}(u_0 - u_1 \cos\beta) \qquad (1)$$

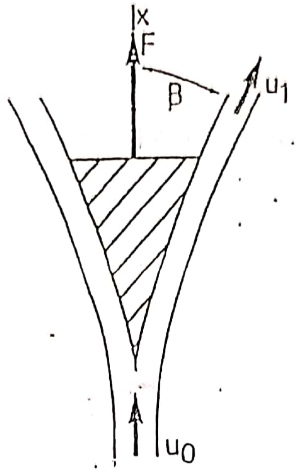

Figure 1 Flow of a jet over a curved vane.

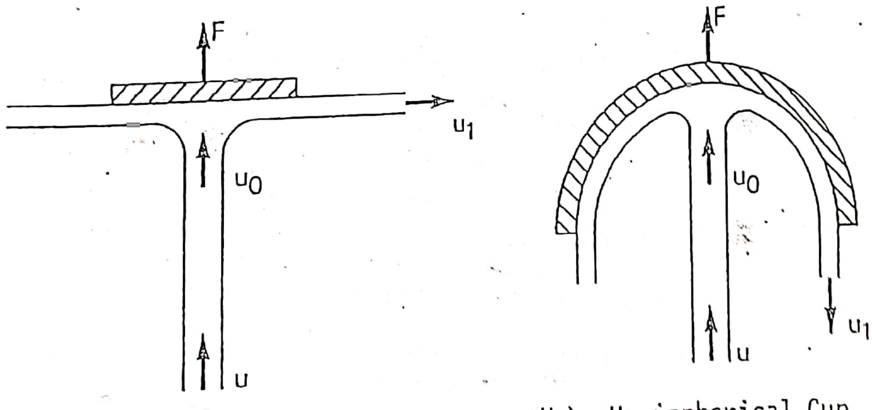

Figure 2 Flow of a jet over a flat plate and hemispherical cup.

Now in the case of a flat plate, Figure 2a , $\beta = 90°$. So $\cos\beta = 0$ and equation (1) reduces to

$$F = m^{\bullet}u_0 \tag{2}$$

For a hemispherical cup, Figure 2b, $\beta = 180°$, so $\cos\beta = -1$ and equation (1) reduces to

$$F = m^{\bullet}(u_0 - u_1) \tag{3}$$

Furthermore, if there is a negligible reduction of speed so that $u_1 = -u_0$. Then

$$F = 2m^{\bullet}u_0 \tag{4}$$

In the experiment it is not possible to measure directly the velocity just upstream of the vane. However, the velocity u at the exit of the nozzle can be experimentally determined. The velocity u_0 is somewhat less than this due to declamation caused by gravity and can be calculated from the Bernoulli equation, that is

$$\frac{u^2}{2g} + z + \frac{P}{\rho g} = \frac{u_0}{2g} + z_0 + \frac{P_0}{\rho g} \tag{5}$$

Now from figure 2a, $Z = 0$, $P_0 = P$, $Z_0 = s$ and this yields

$$u^2 = u_0^2 + 2gs \tag{6}$$

which can be written as

$$u_0^2 = u^2 - 2gs \tag{7}$$

Where s is the distance between the nozzle exit and the surface of the vane.

u can be determined from the continuity equation $\dot{m} = \rho uA$

Where A is the cross-sectional area of the nozzle

Hence $u = \frac{\dot{m}}{\rho A} = \frac{\dot{m}}{\rho \pi d^2}$

Where d is the diameter of the nozzle

In order to calculate the force on the vane due to the jet we take moment about the pivot of the weighing beam, Figure 3, and substitute known values into the equation we get.

$$F \times 0.1525 = 0.610 \times g \times \Delta x$$

$$\text{or} \quad F = 4g\,\Delta x \tag{8}$$

which is considered the experimental value of F

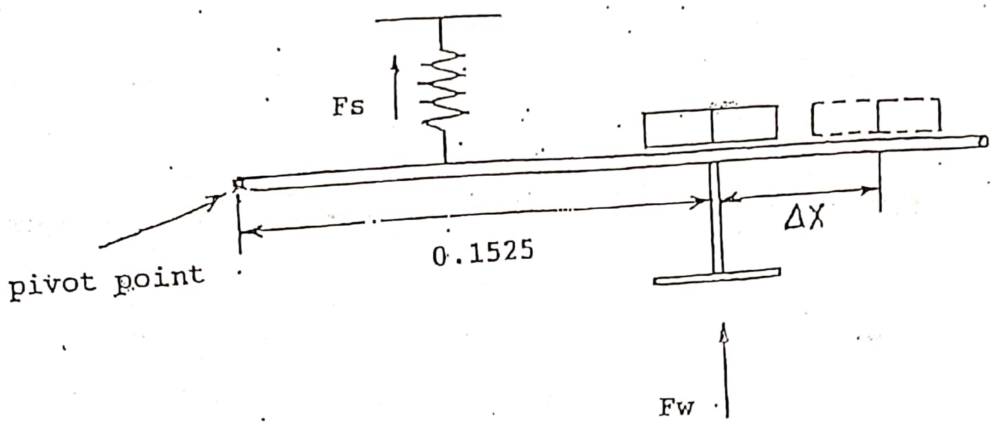

Figure 3 The balancing arm attached to the vane.

* *Apparatus*

Hydraulic Bench, Water Jet Apparatus, Stop Watch

The water is supplied to the jet apparatus in a closed loop by a pump. The flow rate is determined with the use of a weighing tank and a stopwatch. The water issues vertically upwards into the air, through a nozzle. Two objects are available: a flat plate and a hemispherical cup. Each object can be mounted on a horizontal lever above the water jet and receive its impact. The force on the object can be determined with the use of weights that can be hung at different positions on the lever, see Figure 4.

Technical Data

Mass of jockey weight,	m	= 0.610	kg
Distance from center-line of vane to weigh-beam pivot		= 0.1525	m
Diameter of nozzle,	d	= 0.01	m
Height of vane above nozzle outlet,	s	= 0.04	m
Diameter of hemispherical cup		= 0.06	m

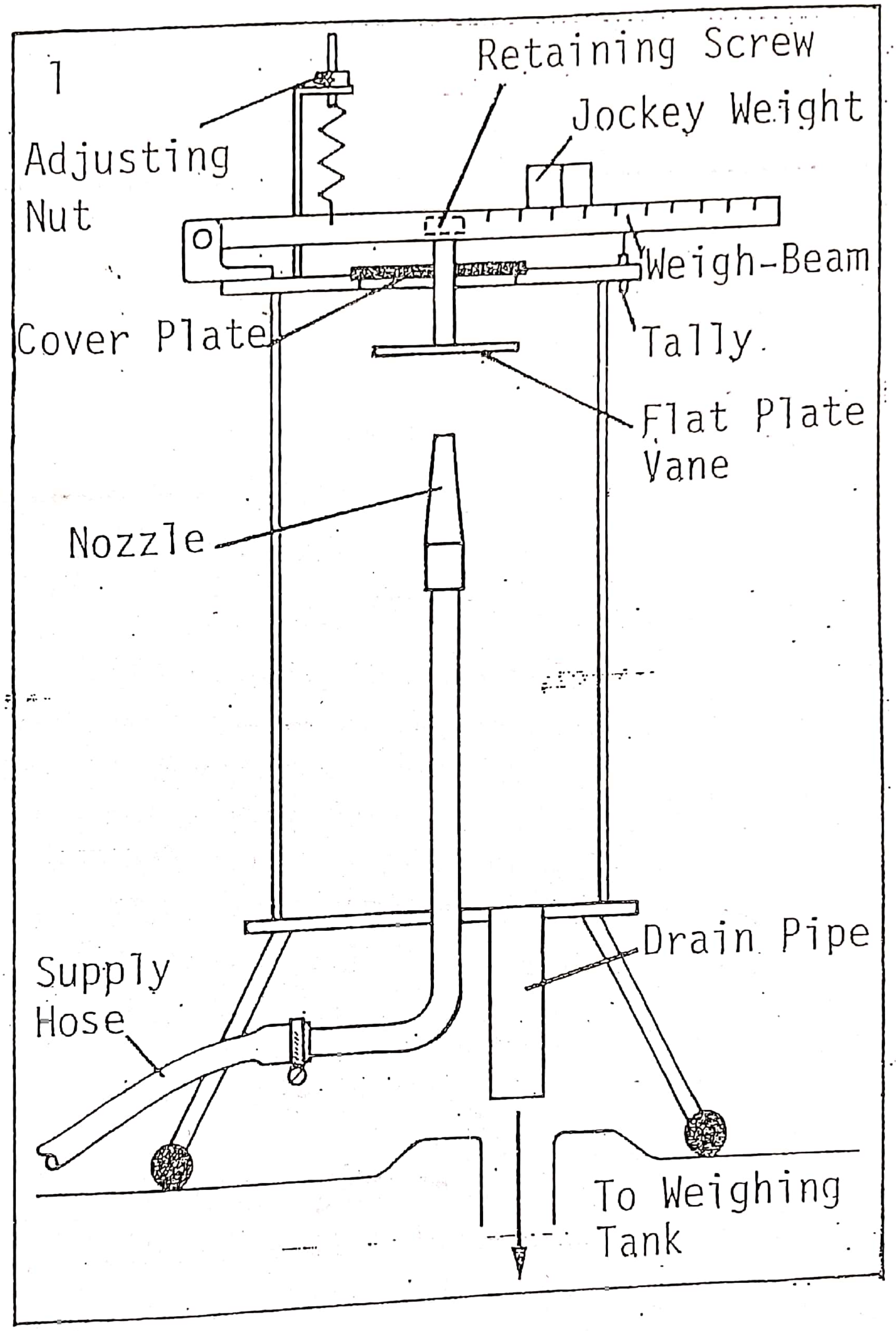

Figure 4 The Apparatus.

* *Procedure*

(1) Stand the apparatus on the hydraulic bench, with the drain pipe immediately above the hole leading to the weighing tank, see Figure 4. Connect the bench supply hose to the inlet pipe on the apparatus, using a hose-clip to secure the connection.

(2) Fit the flat plate to the apparatus. If the cup is fitted, remove it by undoing the retaining screw and lifting it out, complete with the loose cover plate. Take care not to drop the cup in the plastic cylinder.

(3) Fit the cover plate over the stem of the flat plate fitting and hold it in position below the beam. Screw in the retaining screw and tighten it.

(4) Set the weigh-beam to its datum position. First, set the jockey weight on the beam so that the datum groove is at zero on the scale, Figure 5. Turn the adjusting nut, above the spring, until the grooves on the tally are in line with the top plate as shown in Figure 6. This indicates the datum position to which the beam must be returned, during the experiment, to measure the force produced by the jet.

(5) Switch on the bench pump and open the bench supply valve to admit water to the apparatus. Check that the drain pipe is over the hole leading to the weighing tank.

(6) Fully open the supply valve and slide the jockey weight along the beam until the tally returns to the record the reading on the scale corresponding to the groove on the jockey weight.

(7) Measure the flow rate by timing the collection of, say, 30 kg of water in the bench weighing tank.

(8) Move the jockey weight inwards by 10 to 15 mm and reduce the flow rate until the beam is approximately level. Set the beam to exactly the correct position (as indicated by the tally) by moving the jockey weight, and record the scale reading. Measure the flow rate.

(9) Repeat step 8 until you have about 6 sets of readings over the range flow. For the last set, the jockey should be set at about 10 mm from the zero position. At the lower flow rates you can reduce the mass of water collected in the weighing tank to 15 kg.

(10) Switch off the bench pump and fit the hemispherical cup to the apparatus us the method in steps 2 and 3. Repeat step 4 to check the datum setting.

(11) Repeat steps 5 to 9, but this time move the jockey in steps of about 25 mm a take the last set of readings at about 20 mm.

(12) Switch off the bench pump and record the mass m of the jockey weight, diameter d of the nozzle, and the distance s of the vanes from the outlet of nozzle.

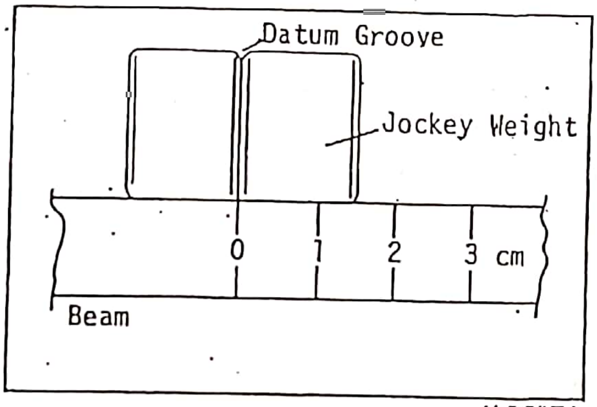

Figure 5 Jockey in datum position

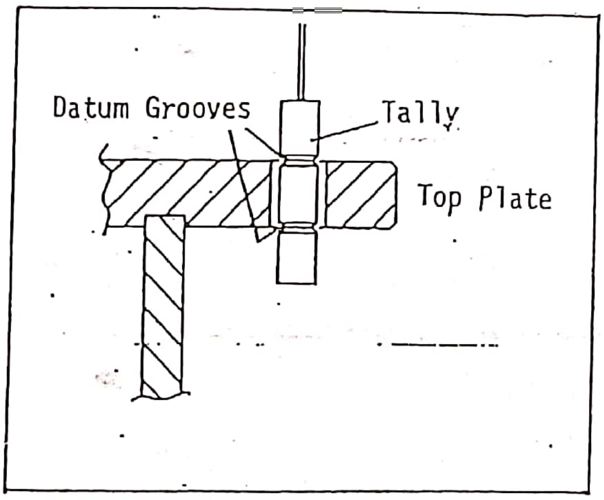

Figure 6 Tally in datum position

* *Data collected* and

Results for flat plate:

Mass of water m(kg)	t (s)	Δx (mm)	$m^{\bullet}$ (kg/s)	u (m/s)	u_0 (m/s)	$m^{\bullet}u_0$ (N)	F Theo. N	F Exp. N	Error
7.5									
7.5									
7.5									
7.5									
7.5									
7.5									
7.5									

Results for hemispherical cup:

Mass of water m(kg)	t (s)	Δx (mm)	$m^{\bullet}$ (kg/s)	u (m/s)	u_0 (m/s)	$2m^{\bullet}u_0$ (N)	F Theo. N	F Exp. N	Error
7.5									
7.5									
7.5									
7.5									
7.5									
7.5									
7.5									

* Results and discussions

(1) Plot F against $\dot{m}u_0$ for the two vanes, and, for the two values of F, the theoretical and the experimental, comment on their linearity.

(2) If the lines on your graph do not pass through the origin, what reason might there be for this?

(3) Why is the force on the hemispherical cap somewhat less than twice that on the flat plate?

* Conclusions

(1) How well do your results compare with the theory?

(2) What accuracy have you achieved in measuring the force on each of the vanes (calculated from the displacement)?

University of Jordan
Faculty of Engineering & Technology
Mechanical Engineering Dept.

Fluid Mechanics Lab.

Experiment Title Page

Instructor: *Prof. Ali Badran*

Experiment 3: Losses in pipes

Report ☐ *Full* ☐ *Short*

Student Name :--------------------------------
Student Number :--------------------------------
Student Branch (الشعبة): ☐1 ☐2
Student Group: ☐A ☐B ☐C

Losses in Pipes and Pipe bends

* *Objectives*

1. To determine the variation of friction factor with Reynolds Number.
2. To determine the relationship between total head loss and flow rate for pipe bends and other common pipe fittings.
3. To determine the loss coefficient for each fitting

* *Theory*

The energy loss in internal flows (laminar or turbulent) is due to :

(a) Friction losses due to the shear stress on the wall of the duct. These losses are often called the *"Major Losses"*. The head loss occurs from fiction effects is designated "h_f".

(b) *Minor Losses*, which are the losses that the flow experiences at the pipe inlet and exit in addition to the losses caused by valves, bends, elbows, sudden and gradual contractions and expansions. The head loss occurs from each of the above is h_m and Σh_m is designated for all minor losses.

Both losses, major and minor, are expressed in a head loss h_L in the energy equation as shown below

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}+Z_0+h_p=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}+Z_2+h_T+h_L$$

Where

$h_L = h_f + \Sigma h_m$

h_p = Pump head

h_T = Turbine head

Major Losses

It is found convenient to express the head loss due to friction effects for internal flows, circular or non circular pipes, smooth or rough surfaces as

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$$h_l = f\frac{L}{D}\frac{V_m^2}{2g}$$

Where

L and D are the length and diameter of the pipe

V_m is the mean velocity of the fluid.

f is the friction factor (also called the Darcy friction factor)

For laminar flow (i.e Reynolds number, Re < 2300)

$$f = \frac{64}{Re}$$

For turbulent flow the friction factor depends on Reynolds number and the relative roughness ε/D, which is the ratio of the mean height of roughness of the pipe to the pipe diameter:

Experimental results of this dependence are presented in the relation known as the "Colebrook equation":

$$\frac{1}{\sqrt{f}} = -2.0\log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

This form was plotted into the famous "Moody chart".

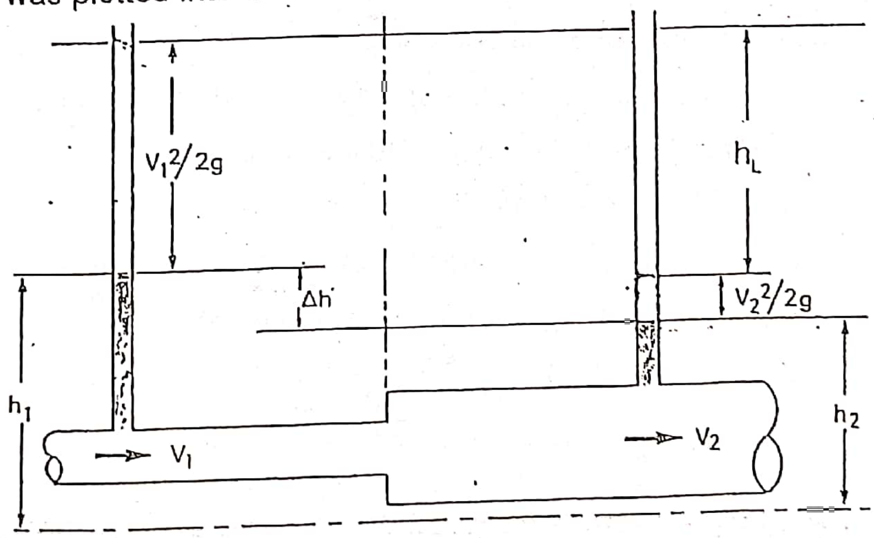

Figure 1 Pressure tapping upstream and downstream of a sudden expansion.

Minor Losses

In general it is not possible to use simple theory to predict the head loss due fittings such as bends and valves. The loss for any particular fitting therefore has be determined by experiment. In order to avoid errors due to the disturbance in tl flow close to the fitting, the head loss is measured using pressure tapping plac several pipe diameters upstream and downstream. Considering a general case a shown in Figure 1, in which the upstream and downstream pipe diameters a different, the Bernoulli's equation can be written as

$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_1^2}{2g} + h_L$$

if $\quad h = \dfrac{P}{\gamma} + Z \quad$ then

$$h_1 + \frac{V_1^2}{2g} = h_2 + \frac{V_2^2}{2g} + h_L$$

Where h_L is the total head loss between the pressure tapping.

The total head loss has two components:

a- Friction loss h_f in the upstream and downstream pipes.

b- Minor head loss h_m due to the fitting alone.

Re-writing Bernoulli's equation and noting that $(h_1 - h_2)$ is the measured head loss Δh recorded by the manometer, we have

$$h_m = \Delta h + \left[\frac{V_1^2 - V_2^2}{2g}\right] - h_f$$

In order to obtain the head loss due to fittings we therefore have to correct the measured head loss for the change in velocity head and also subtract the head loss due to friction. If the upstream and downstream diameters are the same, then $V_1 = V_2$ and we have

$$h_m = \Delta h - h_f$$

The minor head loss is usually expressed in terms of the loss coefficient K defined

$$K = \frac{h_m}{V^2 / 2g}$$

Where V is the velocity in the smaller pipe (in this case V_1).

* Apparatus

The apparatus shown diagrammatically in Figure 2, consists of two separate hydraulic circuits each one containing a number of pipe system components. Both circuits are supplied with water from the same hydraulic bench. The components in each of the circuits are as follows

Dark Blue Circuit (DBC)

1. Gate valve (D)
2. Standard Elbow Bend (C)
3. 90° Miter Bend (B)
4. Straight pipe

radius = 12.7 mm

length = 914.4 mm

Small diameter = 13.6 mm

Large diameter = 26.2 mm

Pipe material is copper

(ε =0.0015 mm)

Light Blue Circuit (LBC)

1. Globe Valve (K)
2. Sudden Expansion (E)
3. Sudden Contraction (F)

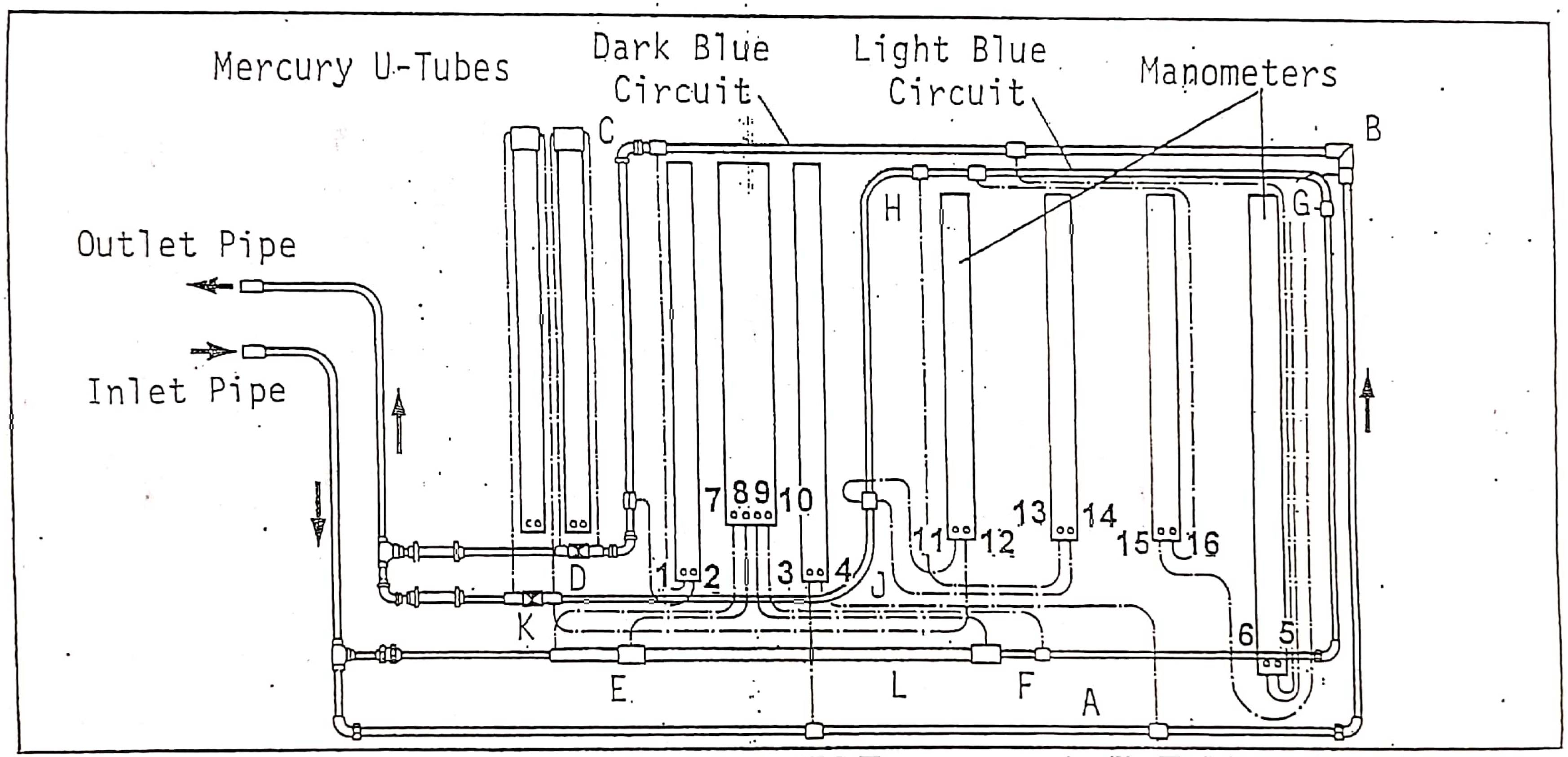

Figure 2 The Apparatus

4. 150 mm radius 90° bend (J) , R/d = 11.1

5. 100 mm radius 90° bend (H) , R/d = 7.4

6. 60 mm radius 90° bend (G) , R/d = 3.7

In all cases (except the gate and globe valves) the pressure change across each of the components is measured by a pair of pressurized piezometer tubes. In the case of the valves pressure measurement is made by U-tube manometer containing mercury.

* *Procedure*

(1) Close the globe valve K and open the gate valve D, see Figure 2. Switch on the bench pump and open the bench supply valve to admit water to the dark blue circuit. Allow water to flow for 2 to 3 minutes.

(2) Close the gate valve D and bleed all of the trapped air into the top of the manometers tubes. Check that all the manometers show zero pressure difference.

(3) Open the gate valve and then, by carefully opening the bled screws at the top of the mercury U tube, fill each limb with water. Make sure that all air bubbles have been expelled, then close the bleed screws.

(4) Close the gate valve, open the globe valve, and repeat the procedure for the light blue circuit.

(5) Open fully the bench supply valve. Then close the globe valve and open fully the gate valve to obtain the maximum flow rate through the dark blue circuit.

(6) If necessary, adjust the water levels in the manometers by pumping air into, or releasing air from the bleed valves at the tops of the manometers.

(7) Record the readings of each of the manometer across the straight pipe in the dark blue circuit. Note the reference number of that manometer.

(8) Measure the flow rate by timing the collection of water in the bench weighing tank.

(9) Measure the water temperature by holding a mercury thermometer in the flow at exit-from the outlet hose.

(10) Close the gate valve to reduce the differential manometer reading by about 10% . Again read the manometer as in step (7).

(11) Repeat this procedure until you have about 10 sets of readings over the whole range of flow.

* *Data*

Table 1,a Readings from the dark blue circuit

No.	m kg	Time S	$\Delta h = h_f$ m
1			
2			
3			
4			
5			

Table 1,b Calculation of the friction factor f

No.	$\dot{m}$ kg/s	V m/s	R_e	Flow type	f
1					
2					
3					
4					
5					

* *Data*

Table 2 Readings from the light blue circuit

Mean temperature = ----------------°C

No	m	t	Manometer readings and differential heads (mm water)															U-tube (mm Hg)		
			Expansion			Contraction			Bend J			Bend H			Bend G			Globe Valve		
	kg	S	7	8	Δh	9	10	Δh	11	12	Δh	13	14	Δh	15	16	Δh	h_1	h_2	Δh
1																				
2																				
3																				
4																				
5																				

Table 3 Results for light blue circuit

No.	V	Re	f	Head losses for different fittings (mm water)																	
				Expansion			Contraction			Bend J			Bend H			Bend G			Globe Valve		
	m/s			Δh	h_f	h_m	Δh	h_f	h_m	Δh	h_f	h_m	Δh	h_f	h_m	Δh	h_f	h_m	Δh	h_f	h_m
1																					
2																					
3																					
4																					
5																					

Table 4 The minor loss coefficient K

Fitting type	Test No. 1	2	3	4	5	Average	Standard Value
Expansion							
Contraction							
Bend J							
Bend H							
Bend G							
Globe Value							

* *Results and discussions*

(1) Complete all of the attached tables

(2) Plot the relationship between the friction factor and Reynolds Number and, the graph should also show the theoretical relationships. (DBC only)

(3) Does the loss coefficients vary with the flow rate?

(4) How do your values of K compare with standard data?

University of Jordan
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Mechanical Engineering Dept.

Fluid Mechanics Lab.

Experiment Title Page

Instructor: *Prof. Ali Badran*

Experiment 5: *Flow visualization*

Report ☐ *Full* ☐ *Short*

Student Name :---

Student Number :---

Student Branch (الشعبة): ☐1 ☐2

Student Group: ☐A ☐B ☐C

Flow Visualization

* *Objectives*

To make the student familiar with the flow patterns and to see the stream lines when different shapes of objects are inserted in the flow path.

* *Apparatus*

a - Flow Visualization equipment

The flow visualization equipment is powered by a synchronous A.C. motor driving a centrifugal blower, which produces a maximum wind speed of about 12 m/s in the test section. A particularly uniform low-turbulence flow is achieved by the use of 3 gauze screens, a small-cell honeycomb and a 9:1 light hill contraction. The test section is effectively 2-dimensional, being 25.4 mm wide, 254 mm deep and 267 mm long. A viewing area of 267 mm X 229 mm is illuminated by an integral strip light and fitted with a window incorporating the model attachment and means of rotation. Provision is made for the fitting of a smoke generator.

b- Integrated smoke generator. (Figure 1)

In this equipment, an oil mist is formed by the atomization of a heated mineral oil in an air stream. The resultant "vapor" being largely a suspension of fine liquid droplets, from a highly visible "smoke" with contrast characteristics particularly suitable for photography.

Oil is gravity-fed from an oil reservoir to a pyrex vaporizing tube incorporating an electrical heater. The vapor, entrained in an air stream provided by a twin diaphragm pump, is then passed to a flexible smoke reservoir which serves to smooth the flow and damp out variations in density. (It also facilitates clearance of condensed oil from the outlet tubes). Fine control over the generation of smoke is provided by a valve adjacent to the vaporizing tube. The contents of the smoke reservoir are discharged through on outlet pipe to the smoke rake provided with the equipment. A throttle clamp enables smoke circuit oscillations to be damped out.

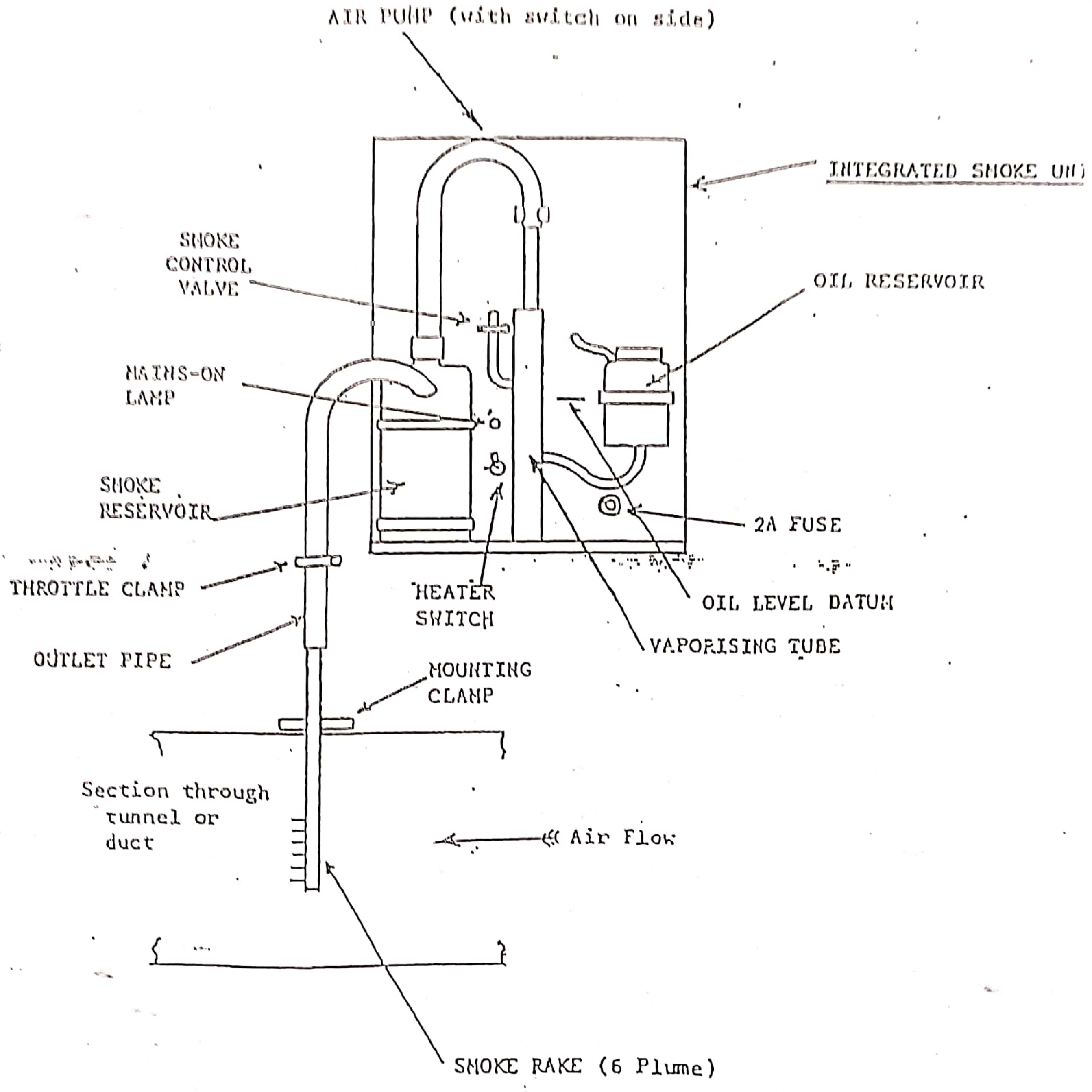

Figure 1 Integrated smoke generator for flow visualization system.

* *Procedure*

(1) Remove the test section window by undoing the four knurled screws located near the corners of the frame.

(2) Remove the model already mounted by unscrewing the knurled knob of the model pivoting assembly. Fit the required model, (cylinder, faired cylinder, double wedge, single wedge, aerofoil, flapped aerofoil) ensuring that the location pins are engaged with the holes in the model, and clamp it by tightening the knurled knob.

(3) Replace the window into the test section and screw it up tightly to compress the foam gasket. Failure to do this will result in smoke leaking from around the frame.

(4) Check the oil level, ensuring that the reservoir has been filled and that the oil level has become established at the correct level.

(5) Check that the white knob on the air pump is screwed out four turns from the fully closed position.

(6) Switch on the air pump.

(7) Switch on the heater.

(8) Close the smoke control valve to achieve optimum filament thickness and density. Adjust to suit air speed changes.

(9) Pulsating smoke filament at low air speeds can be smoothed by adjusting the throttle clamp on the outlet pipe. Always re-open this throttle when its use becomes unnecessary.

(10) Ribbon-like filament may be rendered more cylindrical by turning the rake on its vertical axis to align the emitters with the flow.

(11) To rotate the model on its pivot, apply finger pressure to the pointer near its tip. The angle of incidence or "attack" is indicated on a scale of ± 30 degrees divided into 5 degrees.

(12) Adjust the tunnel wind speed to achieve the desired results by sliding the blank choke plate vertically in and out of the slot near the tunnel outlet. For most purposes slow speeds tend to provide the best visualization.

(13) Repeat this for the models you have, and draw the flow lines for each model at different speed and different attack angle.

(14) When you finish the experiment switch off the heater only leaving the air pump running for at least one minute to assist cooling.

(15) Switch off the air pump and disconnect the electrical supply.

* *Results and discussions*

(1) Draw the shape of stream line for each model you will use.

(2) What is the engineering meaning of stream line?

(3) Dose the shape of stream line depend on the shape of the model being used?

(4) What are the engineering values for stream line?

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Mechanical Engineering Dept.

Fluid Mechanics Lab.

Experiment Title Page

Instructor: *Prof. Ali Badran*

Experiment 6: *Hydraulic jump in open channel*

Report ☐ *Full* ☐ *Short*

Student Name :--
Student Number :--
Student Branch (الشعبة): ☐1 ☐2
Student Group: ☐A ☐B ☐C

EXPERIMENT 6 Hydraulic Jump In Open Channel Flow

1 OBJECTIVES

- To confirm the theory relating to the flow under a sluice gate with the formulation of a hydraulic jump in a rectangular channel.
- To estimate the force exerted by the sluice gate on the flow from momentum function considerations.
- To estimate the energy head loss and power loss at the jump section by specific energy considerations.

2 APPARATUS

(a) Rectangular open channel.

(b) Constant and steady supply of water to the channel with means of varying the flow.

(c) Sluice gate.

(d) Depth measuring device.

(e) Flow rate measuring facility.

(f) Stopwatch.

3 THEORY

At any point in the flow the specific energy E and momentum function M will be given by

$$E = y + \frac{q^2}{2gy^2}$$

$$M = \frac{q^2}{gy} + \frac{y^2}{2} \quad \textit{per unit width}$$

where y = depth of flow

q = quantity of flow per unit width $= \frac{Q}{b}$

Q = total quantity of flow

b = channel width, = 7.62 cm

Application of the E and M concepts to the flow under a sluice gate with the formulation of the hydraulic jump gives:

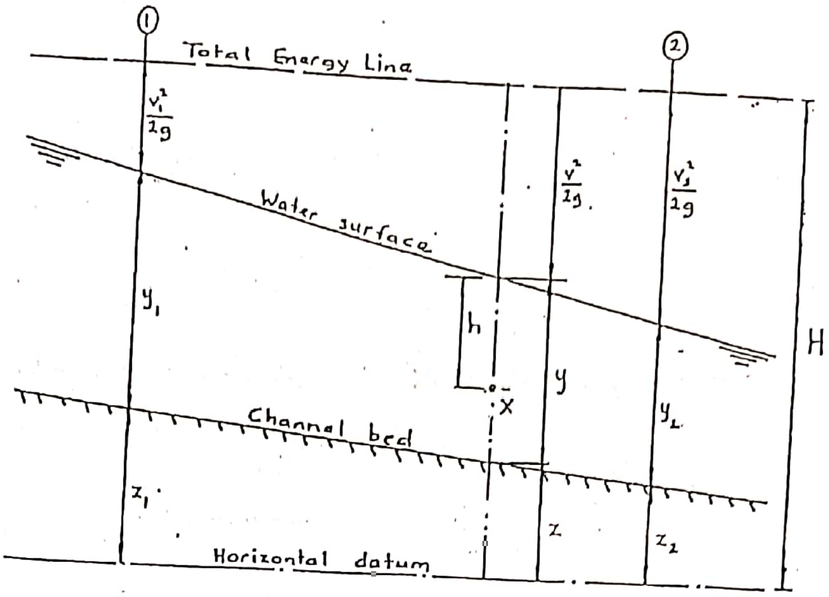


Figure 1:

For flow under the sluice gate

$$E_1 = E_2$$

$$\frac{P}{\rho g} = M_2 - M_1$$

where P = force per unit width exerted by the sluice gate on the fluid.

For the hydraulic jump

$$M_2 = M_3$$

$$\frac{q^2}{gy_2} + \frac{y_2^2}{2} = \frac{q^2}{gy_3} + \frac{y_3^2}{2}$$

or

$$y_3 = \frac{y_2}{2}\left[\sqrt{1+8F_{r2}^2} - 1\right]$$

where Fr_2 = Froude number at section (2) $= q/\sqrt{gy_2^3}$

If dE is the energy loss in the jump, then

$$dE = E_2 - E_3$$

and power loss in the jump $= \rho g Q dE$.

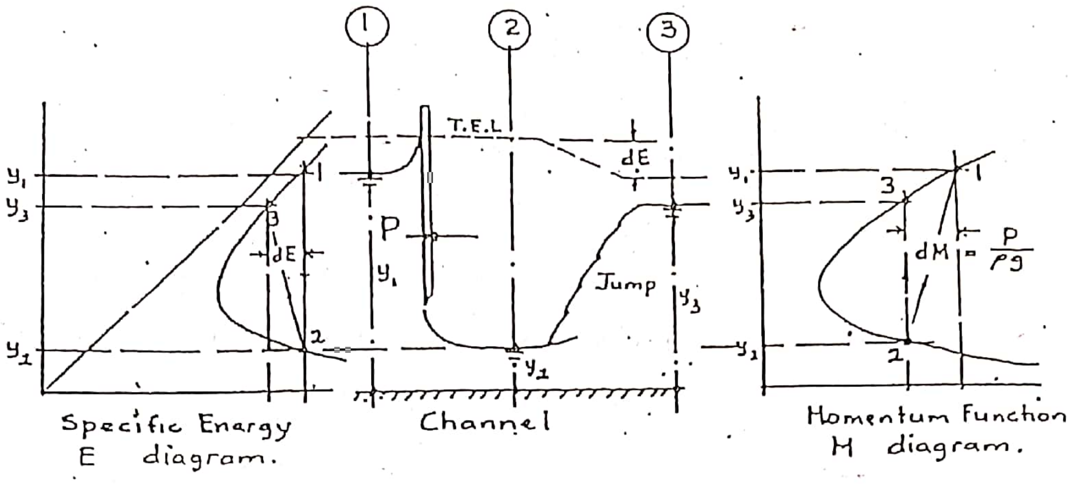


Figure 2:

4 EXPERIMENTAL PROCEDURE

1. The flow channel was adjusted so that the bed was horizontal and the moveable sluice gate is set up about 1 m from the inlet

2. The water supply was admitted to the channel and the flow control valve and the sluice gate opening are adjusted to give the range of flow depth upstream and downstream of the hydraulic jump.

3. The system was allowed to reach steady state before the total flow rate Q and the depth y_1, y_2 and y_3 were recorded.

5 ANALYSIS & CONCLUSIONS

1. Calculate the specific energy E and the momentum function M corresponding to the three measured depths of flow.

2. Calculate the force per unit width and hence the total force acting on sluice gate.

3. From energy consideration calculate y_1 and compare this with the measured y_1

4. Calculate the energy head loss and the power loss.

5. Using the experimental value of y_2 calculate Fr_2.

6. Calculate y_3 and compare it with the measured y_3.

7. Plot the theoretical specific energy and momentum function curves corresponding to one experimental quantity of flow per unit width for several chosen depths. Please superimpose the measured depths of flows over theoretical curves.

8. Show how can you present the force P on the momentum function diagram.

University of Jordan
Faculty of Engineering & Technology
Mechanical Engineering Dept.

Fluid Mechanics Lab.
Experiment Title Page

Instructor: *Prof. Ali Badran*

Experiment 7: *Performance of a radial flow fan*

Report ☐ *Full* ☐ *Short*

Student Name :--
Student Number :--
Student Branch (الشعبة): ☐1 ☐2
Student Group: ☐A ☐B ☐C

EXPERIMENT 7 — The performance of a radial flow fan

1 OBJECTIVE

The performance of a radial flow rotor in air is to be determined over a wide range of operating conditions and for interchangeable impellers with forward, backward and radial blades.

2 APPARATUS

Single stage radial flow fan equipped with interchangeable impellers, wit[h] forward-curved, backward-curved and radial blades, variable speed D.C. elec tric motor with swinging field dynamometer, a counter for speed measure ments,three single column manometers, standard 75 mm nozzle, figure 1 The fan draws air from the atmosphere by way of the measuring nozzle, : flow straighter, and a diffuser, while the fan discharge into the atmosphere i: regulated by a throttle valve.

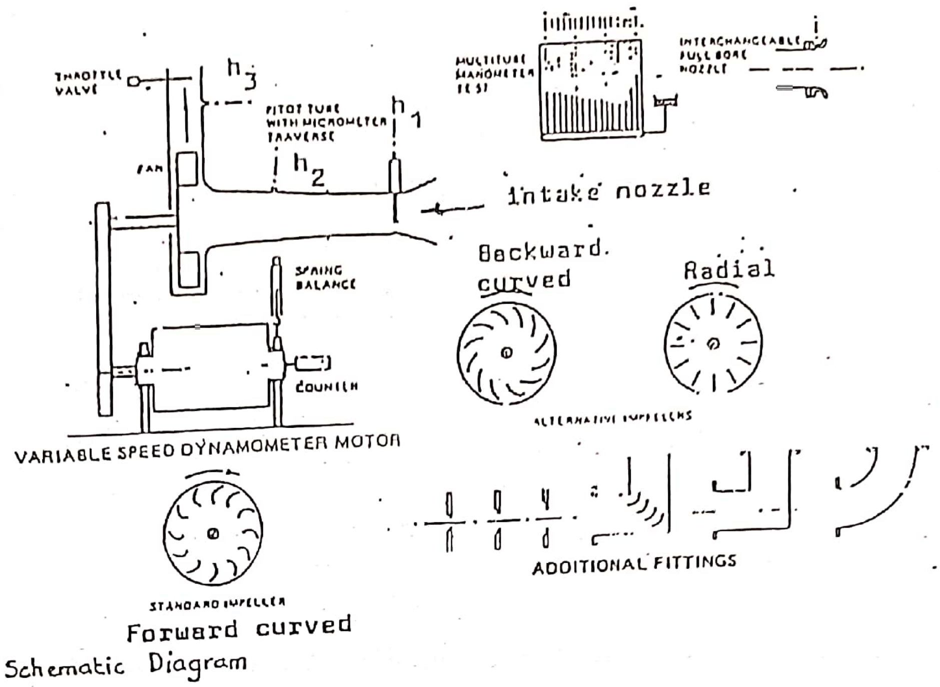


Figure 1:

3 EXPERIMENTAL PROCEDURE

The fan is to run at a series of constant speeds not exceeding 3000 rev/min, and the flow rate is to be varied in each test by means of the throttle. Measure the speed N, torque T by noting the balancing force, the pressure rise H generated by the fan and measurable by a manometer across the machine graduated in cm of water. For each run keep N constant and alter the throttle from open to fully shut, thus changing T, H and Q.

4 THEORY

Any pumping job can be done with rotodynamic machines, having rotating elements called impeller. Rotodynamic machines are classified as radial, mixed (centrifugal) or axial flow. Centrifugal machines are prefered when high pressure differences are required. Very high pressure may be produced by multi-stage radial flow machines. The air compressor for a jet engine is an exam of a multi-stage fan. The fan total pressure rise is defined as the differe between the total pressures at fan outlet and fan inlet i.e. It is a measure the total pressure difference imposed on air by the fan. In the apparatus (f the cross-sectional area at inlet and exit are equal. It follows that the veloc pressure at inlet and outlet are equal and the fan total pressure rise is eq to the difference between the corresponding static pressure.

$$\Delta P = 98.1(h_3 - h_2) \quad N/m^2$$

If Q = volumetric rate of flow (m^3/s) and is calculated by :-

$$Q = 1.006\sqrt{\frac{h_1 T}{P_a}}$$

Where

T = air temperature in $^\circ K$

h_1 = drop in head at the standard nozzle in $cm\ H_2O$

P_a = atmospheric pressure in N/m^2

The total air power of the fan or the useful work done, is equal to tl product of fan total pressure and volumetric rate of flow.

$$Power_{air} = 98.1(h_3 - h_2)Q$$

Note $h_3 > 0$ and $h_2 < 0$

The power input from the dynamometer is given by :

$$Power_{shaft} = T\omega = \frac{Fr2\pi N}{60}$$

Where

T = Torque = $F \times r$

F = Load

ω = Angular velocity (rad/s)

N = Angular velocity rev/min

r = 17.9 cm

The losses in the driving belt and fan bearing may be measured by driving the fan with the impeller removed and subtracting the resulting loss from the shaft power to give the impeller power.

The net efficiency $= \eta = \frac{Total\ \ Air\ \ power}{Impeller\ \ power}$

5 ANALYSIS & CONCLUSIONS

1. Plot (h_3 - h_2) ,total air power , η , against Q for each speed.
2. Plot ($h_3 - h_2)/N^2$, total air power/N^3 ,and η , against Q/N.
3. Comment on any points of general interest which arise from the test results.
4. Can this type of fan test be used to predict the performance of a geometrically similar pump proposed for drainage scheme.
5. Discuss the effect of blade angle at exit on the performance curve.

Comparison of Pumps Characteristics

* Objectives

1. To establish a set of pump characteristics, at constant and variable speeds, for the following pumps :
   a) Positive (single cylinder double acting pump) displacement reciprocating pump.
   b) Centrifugal pump (horizontal)
2. To compare the performance characteristics of each pump under identical speed conditions.

* Theory

The primary function of pumps is not only transportation of fluids, but to add energy to the transported fluids. Different types of pumps are designed to process fluids under variable engineering conditions.

1. Calculation of pump characteristic parameters:

   a) Water power = $\rho g Q^{\bullet} h_p 10^{-3}$ (kW) , also called the pump power

   Where

   ρ = Density of water (kg/m^3).

   g = Acceleration due to gravity (m/s^2).

   $Q^{\bullet}$ = Volumetric flow rate (m^3/s).

   hp = Head gain in meter of water (the pump head). In terms of pressure difference ΔP, through the pump, the pump head is given by:

   $$hp = \Delta P / g\rho 10^{-5}.$$

   Where

   ΔP = Delivery pressure (P_d) – suction pressure (P_s), bar

   b) Brake power = $2\pi\ \omega F R 10^{-3}$ (kW).

   Where

   ω = Motor speed (rev/s).

   F = Brake load (N) = Spring load (kg) × 9.81.

   R = Torque arm radius (m) = 0.15 m.

   c) Overall efficiency $\eta_0 = \dfrac{\text{Water power}}{\text{Brake power}}$

d) Volumetric efficiency $\eta_v = \dfrac{\text{measured volumetric flow rate } \dot{Q}}{\text{Calculated volumetric flow rate } \dot{Q}_c}$

e) The calculated volumetric flow rate $\dot{Q}_c$ is obtained as follows:-

a. **For Positive displacement reciprocating pump:-**

For single acting pump

$$\dot{Q}_c = A_p L \omega \quad (m^3/s)$$

For a double acting pump

$$\dot{Q}_c = 2A_p L \omega \quad (m^3/s)$$

Where

A_p = Total cross sectional area of cylinder (m^2) = 15.55×10^{-4} m^2

L = Stroke of piston (m) = 0.0413 m

ω = Pump speed (rev/s)

For the present arrangement $\omega = \dfrac{motor\ speed}{5}$

b. **For centrifugal pump:-**

$$\dot{Q}_c = \frac{0.75}{12.5} \times 10^{-3} \quad \omega \quad (m^3/s)$$

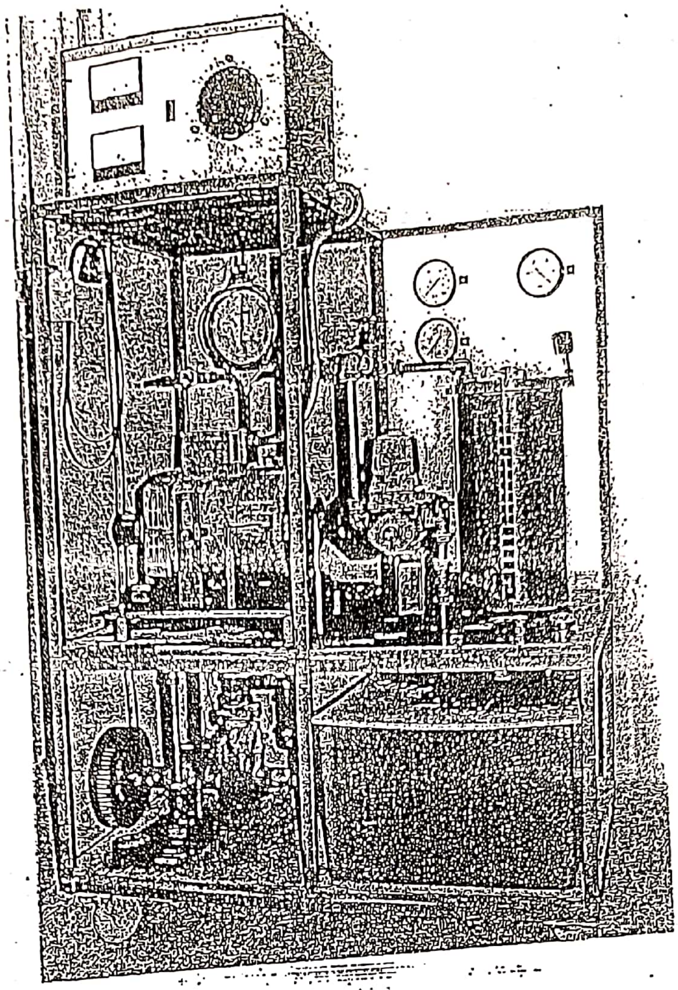
For the present arrangement ω=2(motor speed)

* *Apparatus*

The water circuit incorporates a reservoir, a volumetric measuring tank with ove flow, and bottom release valve mounted above the reservoir. In addition th necessary pipe work and valve are provided. The driving motor is a D.C. machin coupled to a spring dynamometer, Figure 1, The system is instrumented for th measurement of speed, torque, flow rate and the necessary pressures. Th Universal Pump Test Bed comprises three pumps.

a. **Positive displacement reciprocating Pump.**

A reciprocating pump driven by a motor (power pump), where the pump pistc or plunger is connected to a crank-shaft that is geared to counter-shaft ar connected to the driving motor by toothed belt. The operation of power drive reciprocating pump is such that the outward stroke of plunger creates a suctic behind it enabling the liquid to flow into the cylinder through the suction valve.



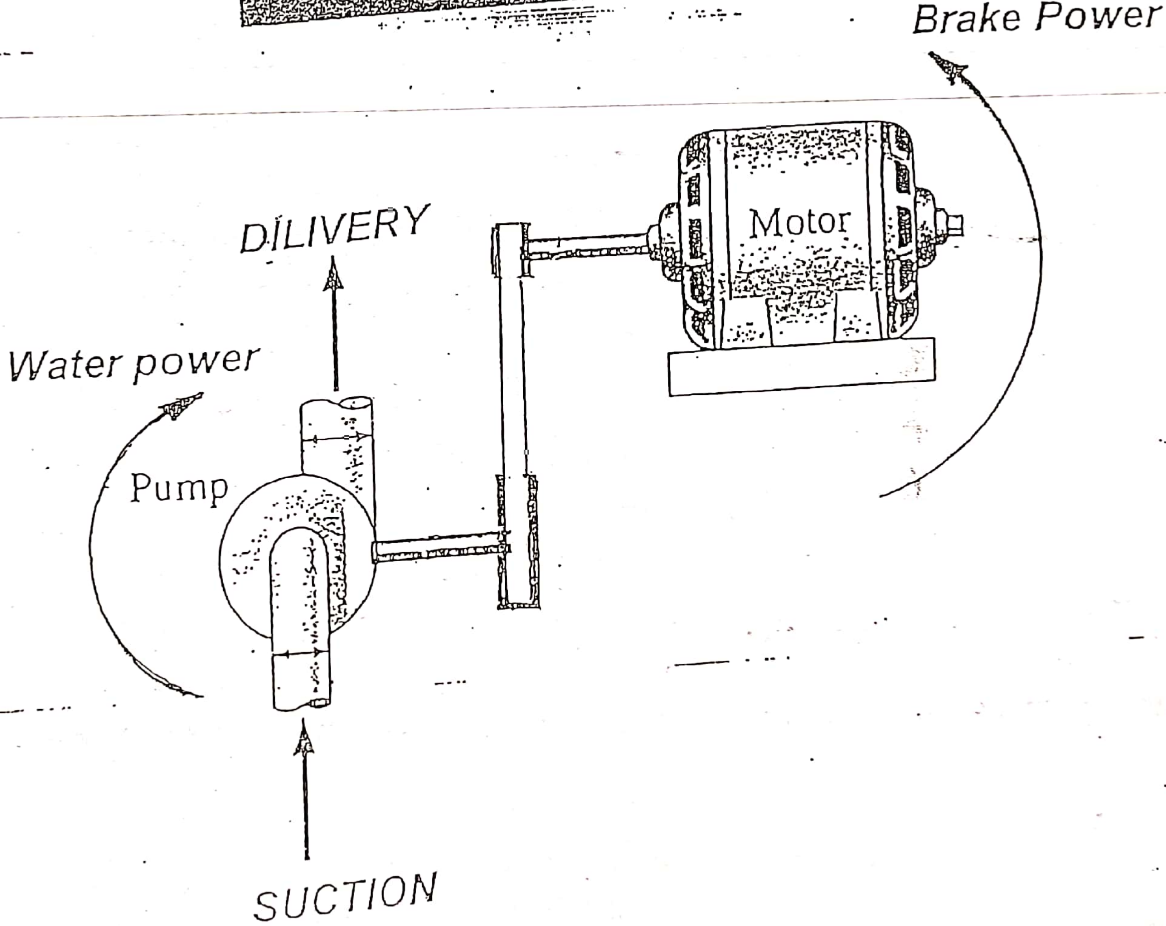


Figure 1 The Apparatus.

On the reverse stroke the liquid is forced to flow out of discharge valve.

This is a Stuart Turner single cylinder double acting pump having a nomina output of 0.45 liters/s at a head of 53 meters when running at the maximum speed of 4 rev/s. Bore and stroke are 44.5 and 41.3 mm respectively.

The Reciprocating pump is connected to the D.C. motor using a toothed belt and pulley giving a motor/pump speed ratio of 5 to 1.

b. Centrifugal Pump.

This is a horizontal centrifugal pump which has a nominal output of 0.75 liters/s a a head of 1.06 meters when running at 12.5 rev/sec. Connection to the D.C motor by toothed belt and pulleys gives a motor/pump speed ratio of 1 to 2.

c. Gear Pump.

This is an inviolute gear type with a nominal output of 0.2 liters/sec when running at 5 rev/sec. It is connected to the D.C. dynamometer by a toothed bel drive and pulley system giving a motor/pump speed ratio of 3 to 1.

Pressure angle 20°	No. of teeth 12
Diametrical pitch 0.236 teeth/mm	Face width 41.3 mm
Root diameter 41.5 mm	Clearance 0.7 mm

Note: This pump is not working in the present set-up.

* *Procedure*

<u>**Starting**</u>

1. Fully open the suction and delivery valves of the pump to be tested and isolate any other pumps in the system by closing their corresponding valves.
2. Open the pressure gauge valves for the pump to be tested.
3. Position the motor variable speed control on the control at zero volts (fully anti-clockwise).
4. Switch on the power supply to the unit .
5. With the motor torque arm in the horizontal position adjust the spring dynamometer to give a zero reading. The unit is now ready to run tests.

Precaution

Do not run the motor for periods of more than10 minutes at an armature current of amps which is the maximum permitted current for continuous running.

Stopping

1. Return the motor variable speed control to the zero position. (fully anti-clockwise)
2. Close the pump inlet valve (s). When using the centrifugal pump first close the discharge valve before the inlet valve if the pump is to remain primed.

Constant speed test

1. **Positive displacement reciprocating Pump**
   - Gradually increase the voltage applied to the motor until the pump is running at the operation speed selected.
   - Adjust the delivery pressure to the maximum value.
   - Record the brake load.
   - Record the shaft speed.
   - Measure the water flow rate by recording the time taken to collect a measured volume of water. (15 Liters)
   - Read suction and delivery pressures. Repeat this procedure for lower values of delivery pressure.

2. **Centrifugal pump:-**
   - Bring the pump gradually up to the selected operating speed and open inlet and outlet valves to allow maximum delivery.
   - Note suction and delivery pressures.
   - Note brake load.
   - Note pump speed.
   - Note flow rate.
   - Repeat for increments of delivery pressure closing the delivery valve in several steps.

Variable speed tests

1. Positive displacement reciprocating pump

   - Bring the pump gradually to maximum speed and delivery pressure.
   - Note delivery pressure, suction pressure, brake load, pump speed and volumetric flow rate.
   - Repeat this procedure for lower values of pump speed.
   - For each pump speed selected, maintain a constant pressure rise by adjusting the delivery valve.

* *Data collected*

* **Centrifugal Pump:**

Table 1 Data for the centrifugal pump

w = 15 rev/s

Current ....(A)

P_s (bar	P_d (bar)	Spring load (kg)	Mass of water (kg)	Time (s)
0	0.4		5	
0	0.5		5	
0	0.6		5	
0	0.7		5	
0	0.8		5	

For a constant P_d = 0.4 (bar)

Current ....(A)

P_s (bar)	w (rev/s)	Spring load (kg)	Mass of water (kg)	Time (s)
0	10		5	
0	12		5	
0	15		5	
0	17		5	
0	20		5	

* Reciprocating Pump

Table 2 Data for the reciprocating pump

* w = 15 rev.sec.

P_s (bar)	P_d (bar)	Spring load (kg)	Mass of water (kg)	Time (s)	Curren (A)
0	0.5		5		
0	1.0		5		
0	2.0		5		
0	3.0		5		
0	4.0		5		

* P_d = 1.5 (bar) Current ....(A)

w (rev/s)	P_s (bar)	Spring load (kg)	Mass of water (kg)	Time (s)	Current (A)
10	0		5		
12	0		5		
14	0		5		
16	0		5		
18	0		5		
20	0				

Results

Table 3 Results for the centrifugal pump

Centrifugal Pump

* w = 10 rev/s

P_d (bar)	Q' (m^3/s)	Brake Load F (N)	Water Power (kW)	Brake Power (kW)	Overall Efficiency η_o	Pump Head h_p (m)	Volumetric Efficiency η_v
0.1							
0.2							
0.3							
0.4							
0.5							

* w = 15 rev/s

0.4							
0.5							
0.6							
0.7							
0.8							

* P_d = 0.4 (bar)

W = 10							
12							
15							
17							
20							

Reciprocating Pump

Table 4 Results for the reciprocating pump

P_d (bar)	Q° (m^3/s)	Brake Load F (N)	Water Power (kW)	Brake Power (kW)	Overal Efficiency η_0	Pump Head h_p (m)	Volumetric Efficiency η_v
0.5							
1.0							
2.0							
3.0							
4							

ω Rev/s.	P_d (bar)	Q° (m^3/s)	Brake Load F (N)	Water Power (kW)	Brake Power (kW)	Overal Efficiency η_0	Pump Head h_p (m)	Volumetric Efficiency η_v
10	1.5							
12	1.5							
14	1.5							
16	1.5							
18	1.5							
20	1.5							

Results and discussions

Constant speed tests

1. For both pumps
   On the same figure, but using different scales, show the relationship between water power, brake power, overall efficiency and volumetric efficiency with output pressure .

2. For the centrifugal pump
   On the same figure, but using different scales, show the relationship of pump head, water power, overall efficiency with volumetric flow rate.

3. Comment on the most suitable applications for these two types of pumps and on their limitations.

Variable speed tests

For the positive displacement pump only, and on the same figure, show the relationship between brake power, input torque and volumetric flow rate with pump speeds .

University of Jordan
Faculty of Engineering & Technology
Mechanical Engineering Dept.

Fluid Mechanics Lab.

Experiment Title Page

Instructor: ***Prof. Ali Badran***

Experiment 9: *Performance of a turbine*

Report ☐ *Full* ☐ *Short*

Student Name :--
Student Number :---
Student Branch (الشعبة): ☐1 ☐2
Student Group: ☐A ☐B ☐C

Performance of a turbine

Objectives

1. To establish a set of turbine characteristics, at variable speeds, for the following variables: mechanical power, hydraulic power, volumetric flow rate and efficiency
2. To find the relation between the mechanical power and the moment for different speeds.

Theory

Turbines are devices that can be used to extract mechanical power out of fluids that are stored at high elevation or high pressure. The working fluid could be water, and in that case the turbine is called a hydraulic turbine, it could be gas, and the turbine is called a gas turbine, and as in this experiment, the turbine works on air, and it is called **air turbine.**

The turbine is composed of a **stator**, where the working fluid expands from high pressure through nozzles that are part of the stator, and a **rotor**, where the working fluid hits a row of blades and its potential energy is transformed into kinetic energy.

Two types of turbines are generally used for mechanical drive:

1- **Impulse**, where the working fluid completely expands in the nozzles of the stator and hits the rotor with a high speed or high impulse.

2- **Reaction**, where part of the working fluid expansion occurs in the nozzles of the stator and the other part occurs in the rotor. The ratio of the expansion that occurs in the rotor to the expansion that occurs in the whole turbine is called the **degree of reaction.** The apparatus is based on a reaction turbine that uses air as a working fluid. In this device, the degree of reaction is 100%.

The mechanical power out of a work-producing rotating machine is given by

$$P_{mech} = \omega . T \qquad (1)$$

Where: ω is the angular speed, in radian/second

T is the torque, in Newton-meters

In practice, it is common to put the angular speed in terms of revolutions per minute, n, or

$$\omega = 2 \pi n / 60 \qquad (2)$$

Hence, the mechanical power becomes $P_{mech} = 2\pi . n . T / 60 = \pi . n . T / 30$,

And if the torque is measured in Newton-centimeters instead of Newton-meters, the mechanical power becomes

$$P_{mech} = \pi . n . T / 3000 \quad \text{.....(3)}$$

The hydraulic power is the theoretical power given by the working fluid to the machine. It is given by

$$P_{hyd} = p_d . \dot{V} \quad \text{.....(4)}$$

Where p_d is the air pressure before entering the turbine(Nozzle pressure), in Pa, a $\dot{V}$ is the volumetric flow rate of air in m^3/s,

The efficiency of the turbine is given by

$$\eta = P_{mech} / P_{hyd} \quad \text{.....(5)}$$

- ***Apparatus***

Figure 1 shows the unit layout on a base frame (1). Compressed air is fed to the turbine(14) through a hose at the middle of the turbine. The flow of air is regulated by a regulation valve (12) and its flow rate is measured using a glass cone flow meter(3). The load is measured by a load unit (or brake unit) with force transducer (7). A schematic of the device which traces the path of compressed air within the system (flow diagram) is shown in Fig. 2. Details of the load unit (or brake unit) are shown in Fig. 3. A section in the turbine is shown in Fig. 4. A view in the turbine wheel (impeller) including four nozzles is shown in Fig. 5.

The major specifications of the turbine are listed as follows

Maximum power = 25 W

Maximum speed = 30,000 rpm

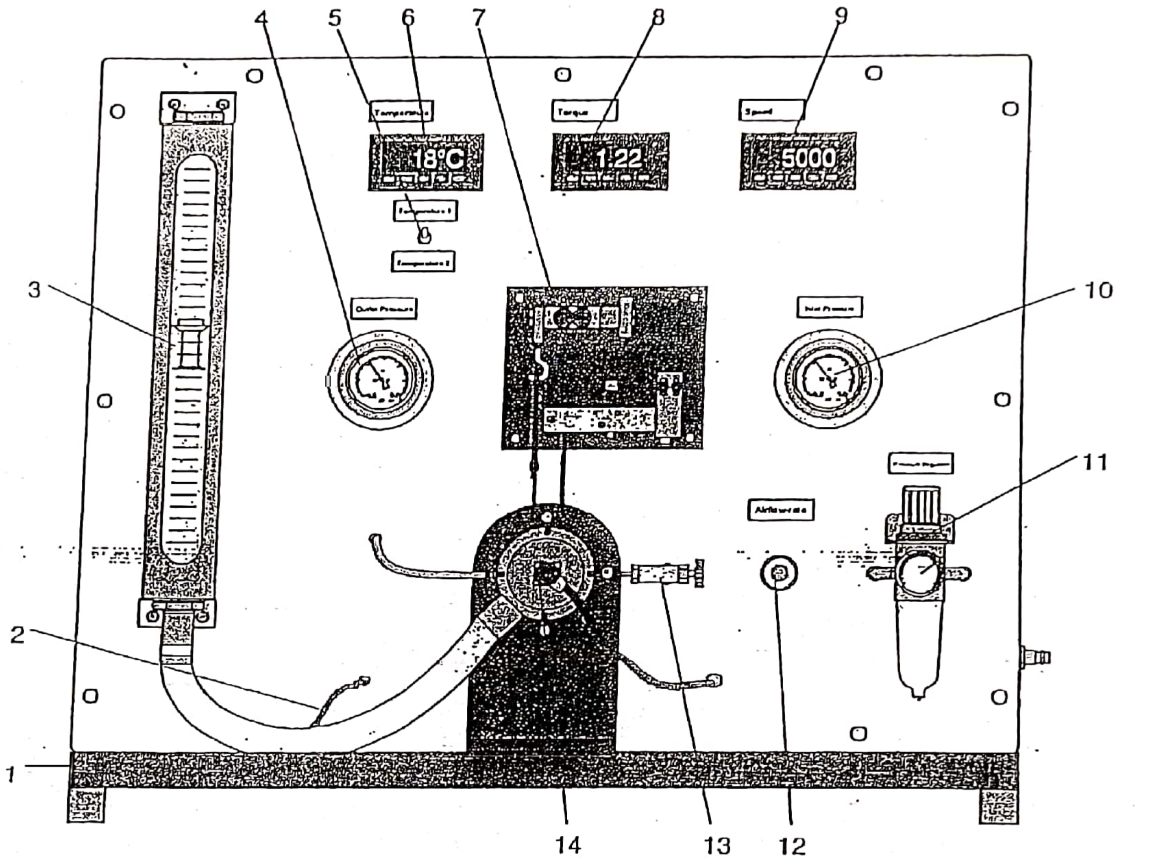
Turbine wheel diameter = 50 mm

Outlet nozzle diameter = 1.5 mm

Maximum torque = 10 N

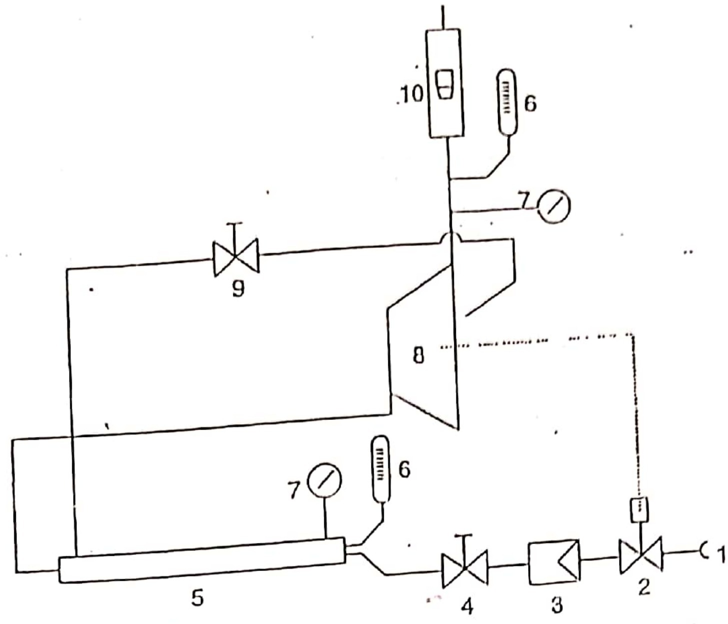
Maximum inlet pressure = 2.5 bar

Maximum flow rate = 315 liters/min.



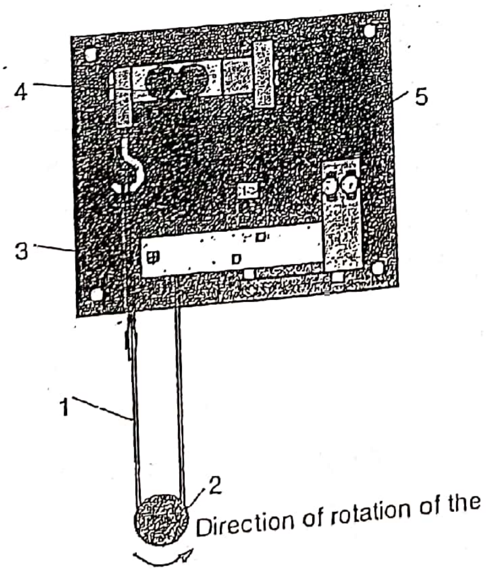
1. Base frame
2. Thermocouple
3. Glass cone flowmeter
4. Outlet manometer
5. Selection switch for temperature measurement point
6. Temperature display
7. Load unit with force transducer
8. Torque display
9. Speed display
10. Inlet manometer
11. Pressure regulator with filter
12. Fine regulation valve for volumetric flow rate
13. Shut-off valve for air cooling
14. Reaction turbine

Fig.1- Unit layout



1. Coupling connection for compressed air supply
2. Solenoid valve as rapid stop for overspeed
3. Compressed air regulator
4. Fine regulation valve for adjusting the volumetric flow rate
5. Compressed air manifold
6. Temperature measuring point
7. Pressure measuring point
8. Reaction turbine
9. Shut-off valve for air cooling
10. Flowmeter

Fig. 2- System schematic



So that torque can be drawn from the turbine, a special loading unit is fitted to the demonstration unit. A braking torque can be applied using a belt (1) that links the turbine shaft (2) and the rotating guide roller (3) on the loading unit. The belt is also linked to a force transducer (4). The torque is calculated from half the roller diameter (lever arm = 10mm) and the braking force. The braking torque can be adjusted with a knurled bolt (5). The more the belt is placed under tension, the larger the braking torque..

Fig. 3- Brake unit

The turbine is a single-stage **reaction turbine** with horizontal shaft.

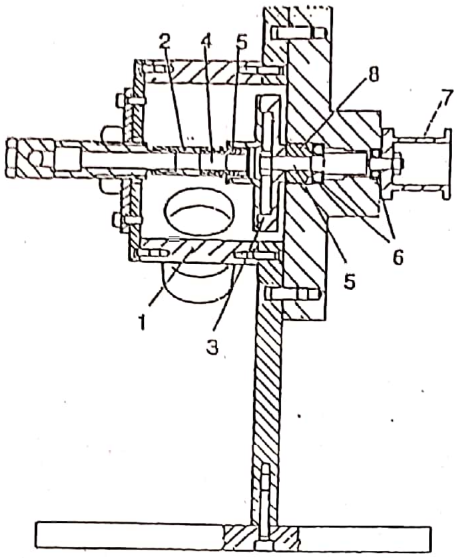


Fig. 4- A section in the turbine

In the turbine housing (1), the air is fed via a hose (2) to the wheel (3). Correct transition from fixed air feed to the rotating wheel is ensured by a hose fitting (4) at the wheel mounting that can rotate in a plain bearing (5). The wheel is a pure reaction wheel with nozzle-shaped outlets. The conversion of pressure into kinetic energy only occurs at the wheel. As this is a single-stage turbine, the air leaves the turbine immediately after the wheel.

The wheel (3), with an effective diameter of 50mm, has 4 outlet nozzles with a diameter of 1.5 mm. The wheel is overhung-mounted on the **turbine shaft** (5). This runs in two ball bearings (6) made of stainless steel. The bearings, fitted with cover discs, are lubricated with grease.

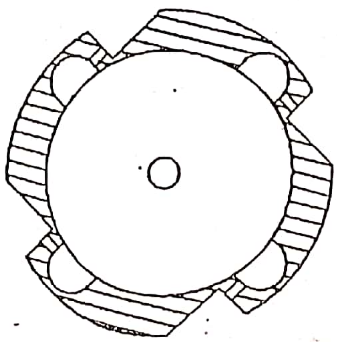
An air-cooled **brake drum** (7) is fitted to the other end of the turbine shaft for measuring power. The braking device consists of a fixed flat belt; the tension on the belt is changed using an adjustment bolt. The belt force is measured using a strain gauge.

The **speed** is measured using a photoelectric reflex switch. The measuring mark is on the top end of the brake drum.

The wheel runs in a Plexiglass housing, so that it is also visible during operation.

A non-contact **labyrinth seal** (8) seals the turbine shaft from the environment. For this purpose a ridged bush is in contact with the turbine shaft.

Fig. 5- A view of the turbine wheel



Experimental procedure

1- Fully open shut-off valve(13) for air cooling.
2- Undo the loading device and slowly increase the air nozzle pressure to 2 bar using fine regulation valve (12).
3- As the turbine runs to its no-load speed, a rapid stop will be triggered to prevent over speeding of more than 30,000 rpm.
4- Using the loading device, the turbine is braked in steps ranging from 2000 to 4000 rpm and the speed, torque, nozzle pressure, temperatures and air volumetric flow rate are recorded by filling Table-1, termed Raw data. Make sure that the nozzle pressure is constant; otherwise re-adjust using the fine regulation valve.

Results and discussion

1- Make your calculations of mechanical power, hydraulic power and efficiency, showing a sample calculation.
2- Fill in the Table-2, termed Measured and calculated results.
3- Plot the mechanical power, hydraulic power and torque against speed on one diagram by making the speed on the x-axis, the torque on the left y-axis and the mechanical and hydraulic power on the right y-axis. These curves are called performance or characteristic curves.
4- How does the mechanical power compare with the maximum power given in the machine specifications? What is the reasons of discrepancy?
5- How does the mechanical power compare with the hydraulic power
6- Where is such a turbine used? Provide an example of a similar turbine that is used in actual life and runs on air.

Table-1 Raw data

Speed n rpm	Torque M_d Nm	Nozzle pressure p_d bar	Inlet Temperature T_1 °C	Outlet Temperature T_2 °C	Volumetric flow rate $\dot{V}$ liters/sec

Table-2 Measured and calculated results

Speed n rpm	Torque M_d Ncm	Mechanical Power P_{mech} W	Volumetric flow rate $\dot{V}$ m^3/sec	Hydraulic Power P_{hyd} W	Efficiency %