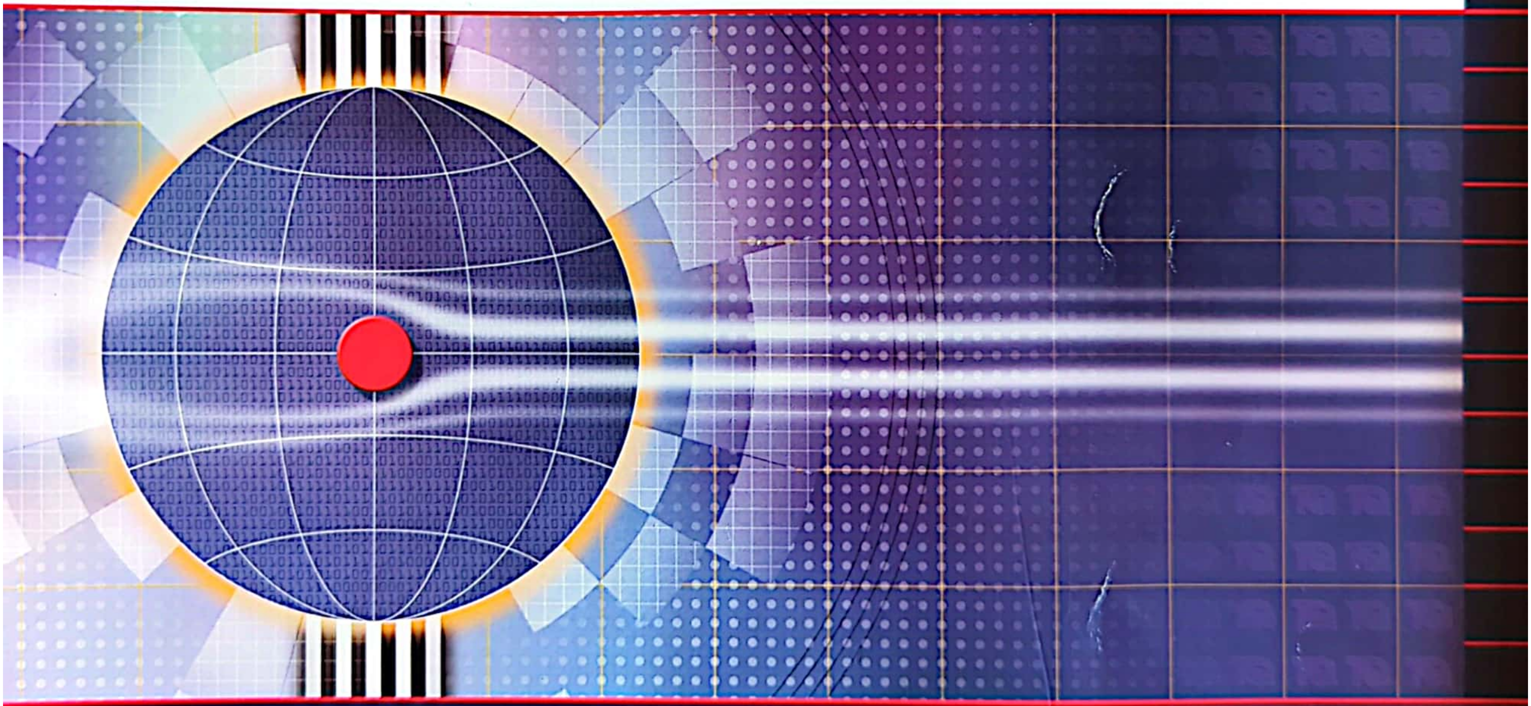
TecQuipment

H8

Impact of a Jet

User Guide



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TecQuipment has taken care to make the contents of this manual accurate and up to date. However, if you find any errors, please let us know so we can rectify the problem.

TecQuipment supply a Packing Contents List (PCL) with the equipment. Carefully check the contents of the package(s) against the list. If any items are missing or damaged, contact TecQuipment or the local agent.

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TecQuipment

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Introduction

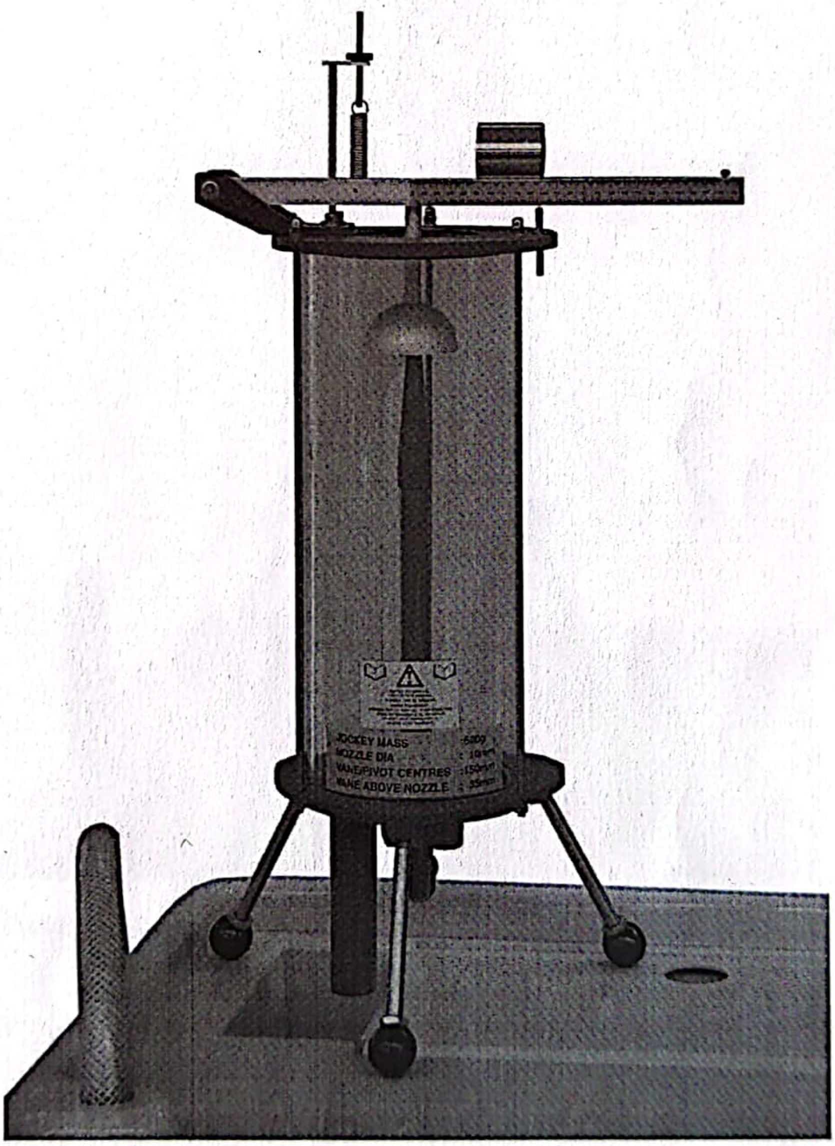

Figure 1 H8 Impact of a Jet (shown on top of a Hydraulic Bench)

One way of producing mechanical work from fluid under pressure is to use the pressure to accelerate the fluid to a high velocity in a jet. When directed on to the vanes of a turbine wheel, the force of the jet rotates the turbine. The force generated is due to the momentum change or 'impulse' that takes place as the jet strikes the vanes. Water turbines working on this impulse principle have been constructed with outputs of the order of 100 000 kW and with efficiencies greater than 90%.

The TecQuipment Impact of a Jet (H8) fits onto either of TecQuipment's Hydraulic Benches. It allows students to experiment with the force generated by a jet of water as it strikes a vane in the shape of a flat plate or hemispherical cup, and to compare it with the momentum flow rate in the jet. Also available from TecQuipment are a 120 Degree Conical Plate and a 30 Degree Angled Plate (H8a).

Description

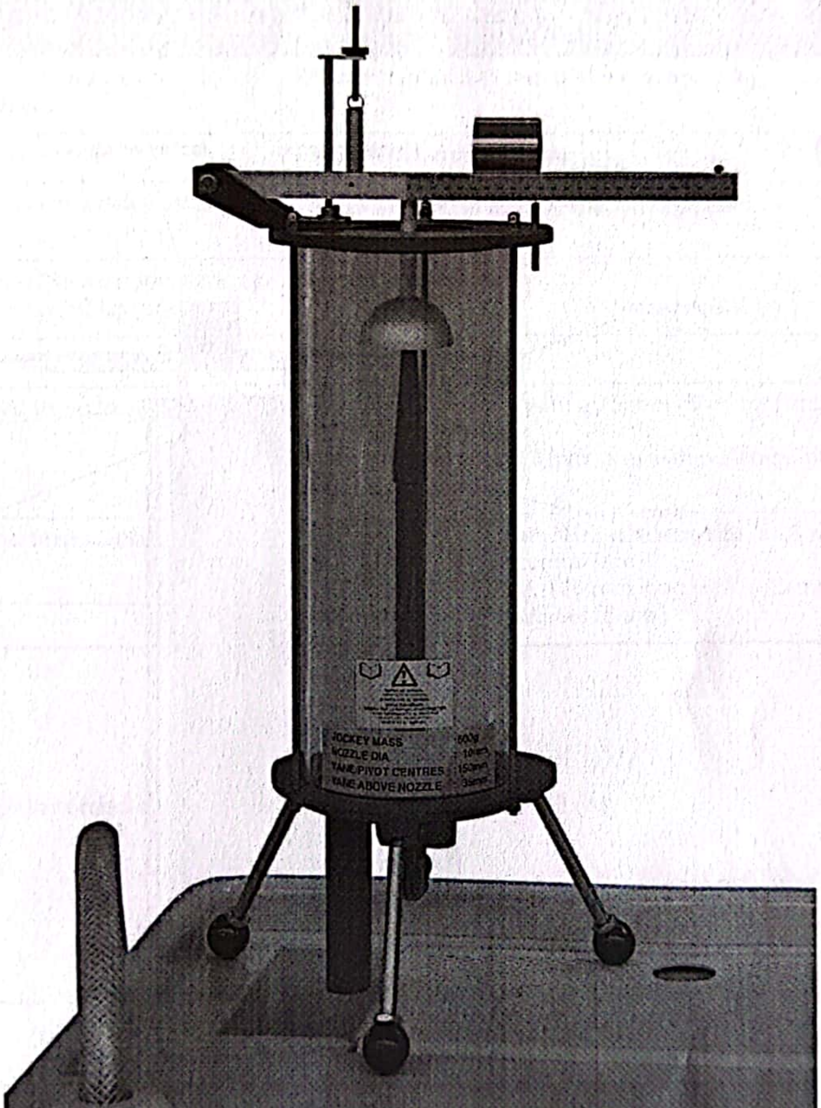

Figure 2 Main Parts

The Main Parts

Figure 2 shows the main parts of the equipment - shown on the top of a TecQuipment Hydraulic Bench (supplied separately). Figure 3 shows a more detailed drawing of the apparatus. The unit fits onto either a H1 or H1D bench (supplied separately), which can supply water and measure flow.

The main part is a transparent cylindrical tank held between a top and bottom plate by three threaded bars. The whole assembly sits on three adjustable legs.

The water enters the tank through a vertical inlet pipe that ends in a tapered nozzle inside the tank. This produces a jet of water which hits the vane in the form of a Flat Plate and Hemispherical Cup (supplied as standard) or 120 degree Conical Plate and 30 degree Angled Plate (Optional H8a). The water leaves the tank through a drain pipe to allow you to direct it back into the hydraulic bench to measure flow.

Figures 2 and 3 show the vane (hemispherical cup or the flat plate) supported by a pivoted beam, restrained by a light spring. The beam carries a jockey weight. Adjusting the jockey weight sets the beam to a balanced position (as indicated by the tally) along with adjustment of the knurled nut above the spring. Any force generated by impact of the jet on the vane may now be measured by moving the jockey weight along the lever until the tally shows that the lever is back at its original balanced position.

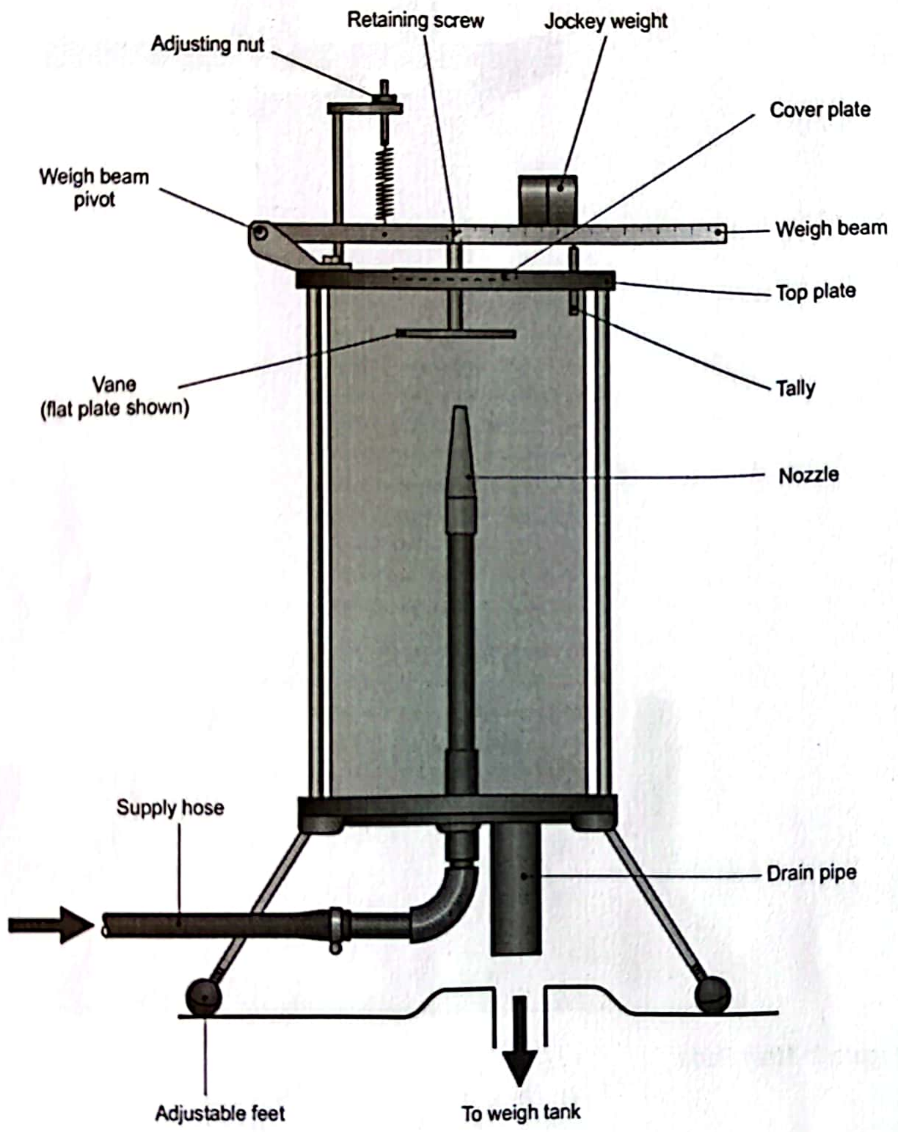

Figure 3 General Layout

The Standard and Optional Plates

TecQuipment supply a flat plate and a hemispherical cup with the equipment, but they also offer additional plates H8a (supplied separately). A retaining screw holds the plate in position from the weigh beam and above the nozzle.

Technical Details

Item	Details
Dimensions and weight (assembled)	720 mm high x 520 mm x 470 mm and 6 kg
Weigh Beam scale	250 mm in 1 mm divisions
Nominal nozzle diameter and area	10 mm and 78.54 mm^2 or 0.00007854 m^2
Nominal distance from nozzle tip to impact point on vane	35 mm or 0.035 m
Jockey Weight	600 g or 0.6 kg
Standard Vanes (supplied)	Flat Plate 80 mm long with a 75 mm diameter flat face at right angles to the jet. Hemispherical Vane 110 mm long with a 30 mm internal radius hemisphere.
Optional Plates (H8a)	120 degree conical plate: 100 mm long with a 75 mm diameter 120 degree conical face. 30 degree angled plate: 100 mm long with a 75 mm diameter plate at 30 degrees to the jet.

Noise Levels

The noise levels recorded at this apparatus are lower than 70 dB (A).

Installation and Assembly

The terms **left, right, front** and **rear** of the apparatus refer to the operators' position, facing the unit.

NOTE

- *A wax coating may have been applied to parts of this apparatus to prevent corrosion during transport. Remove the wax coating by using paraffin or white spirit, applied with either a soft brush or a cloth.*
- *Follow any regulations that affect the installation, operation and maintenance of this apparatus in the country where it is to be used.*

TecQuipment may supply the apparatus disassembled for transport. To reassemble:

1. Fit the weigh beam assembly to the top plate and secure using the screws supplied (see Figure 4).

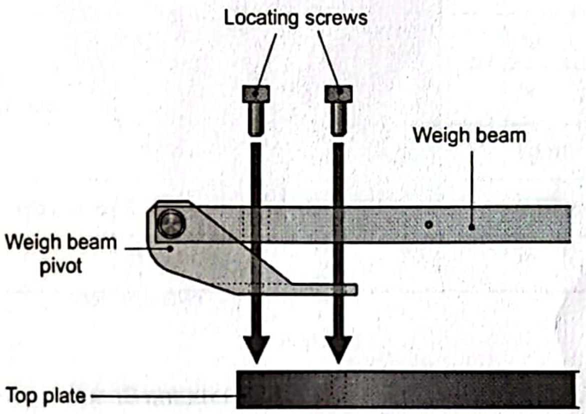

Figure 4 Fit the Weigh Beam

2. Use the retaining screw to fit your chosen vane (plate) and the cover plate (see Figure 5).

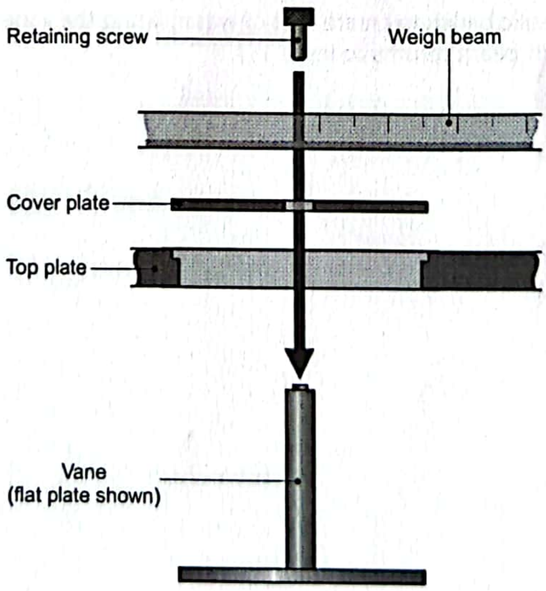

Figure 5 Fit the Vane

3. Put the equipment on the top of a TecQuipment Hydraulic Bench (H1 or H1d).
4. Connect the supply pipe from the Hydraulic Bench to the inlet at the bottom of the tank.
5. Put the exit of the drain pipe tank directly over the hole in the middle of the Gravimetric Bench (see Figure 3), or over the open channel of the Volumetric Bench (see Figure 6).
6. Use the adjustable feet to level the tank.

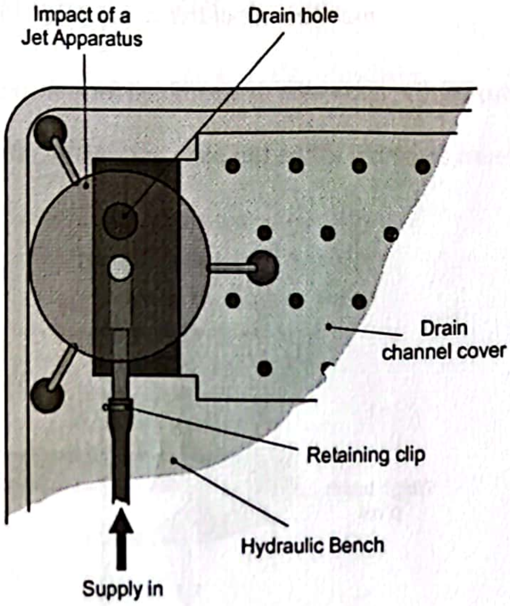

Figure 6 Put Over the Open Channel of the Volumetric Bench

7. Rest the Jockey weight on the zero mark of the weigh beam.
8. Use the adjusting nut of the balance spring to level the weigh beam. When level, the grooves on the tally should be equally spaced on either side of the top of the tank. Adjust the length of the tally suspension if necessary.
9. Use the hydraulic bench to create a jet of water, lifting the vane. Stop the water flow and make sure that the weigh beam returns to level.

Theory

Notation

Symbol	Meaning	Units
u, u_0 and u_1	Velocity of flow	$m.s^{-1}$
$\dot{m}$	Mass flow rate	$kg.s^{-1}$
A	Nozzle Area	m^2
β	Angle	degrees
M	Mass of Jockey Weight	kg
F	Force on vane	N
ρ	Density of water	$kg.m^{-3}$
g	Acceleration due to gravity	$9.81\ m.s^{-2}$
y and s	Distances	m

Table 1 Notation

Unit Conversions

Volume Flow: 1 m^3/s = 1000 L/s

Gravimetric Flow: 1 kg/s = approximately 1 L/s or 0.001 m^3/s of clean water at room temperature.

Key Dimensions

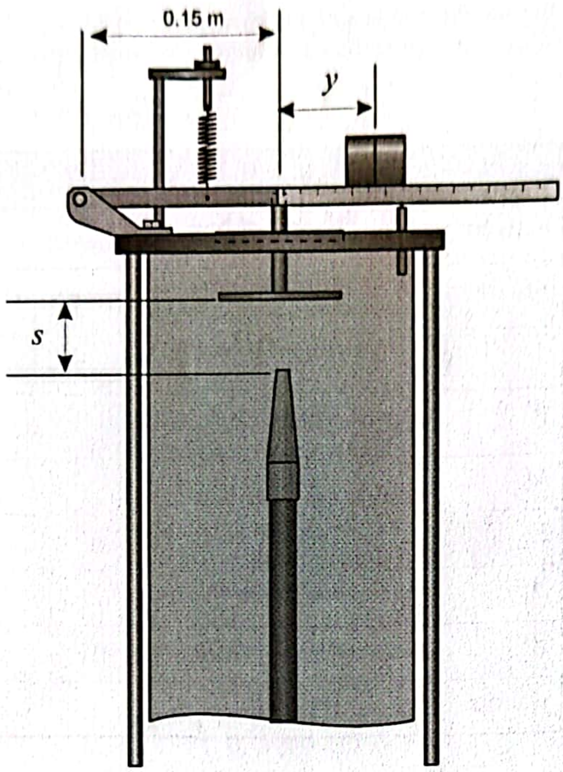

Figure 7 Key Dimensions

Force on the Vane

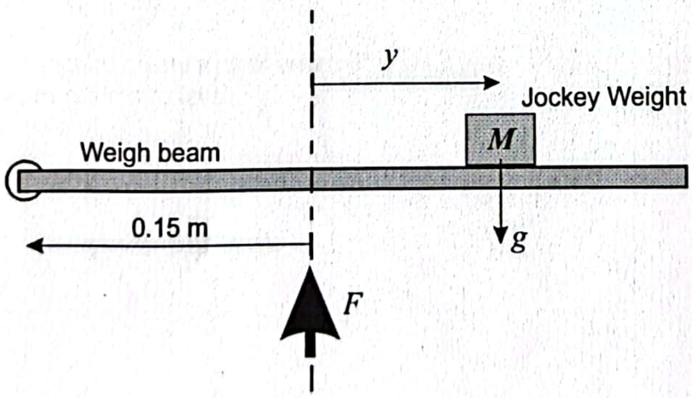

Figure 8 Finding Force on the Vane

The weight beam forms a lever, pivoted at one end, with the jet force upwards at a distance of 150 mm from the pivot. The mass of the jockey weight and gravity are an opposing force downwards. At initial balance, you cancel out the mass of the weigh beam itself using the balance spring. This allows you to calculate the force using moments, so that:

$$F \times 0.15 = Mgy \qquad (1)$$

or

$$F = \frac{Mgy}{0.15} \tag{2}$$

As the mass M of the Jockey Weight is 0.6 kg, then

$$F = 4gy \tag{3}$$

and as gravity g is constant, then

$$F = 39.24y \tag{4}$$

Vane Theory

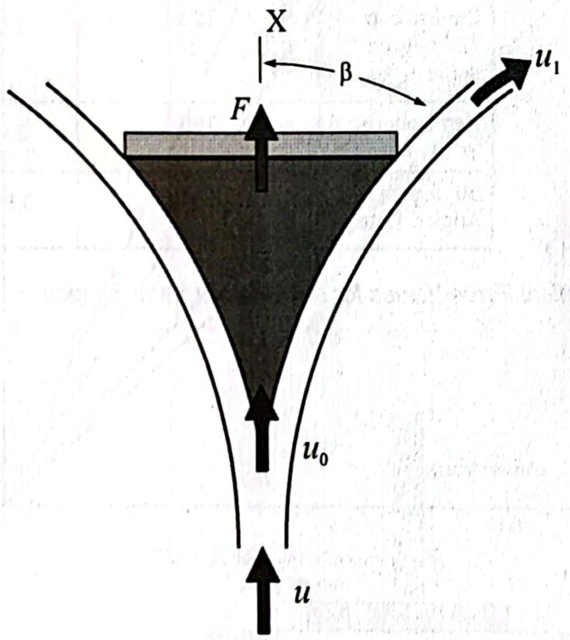

Figure 9 Vertical Jet of Fluid Striking a Symmetrical Vane

Consider a vane symmetrical about the X-axis as shown in Figure 9. A jet of fluid flowing at the rate of $\dot{m}$ kg.s^{-1} along the X-axis with the velocity u_0 m.s^{-1} strikes the vane and is deflected by it through angle β, so that the fluid leaves the vane with the velocity u_1 m.s^{-1} inclined at an angle β to the x-axis. Note that this ignores changes in elevation and in piezometric pressure in the jet from striking the vane to leaving it.

Momentum enters the system in the X direction at a rate of:

$$\dot{m}u_0 \ kg\ m.s^{-2} \tag{5}$$

Momentum leaves the system in the same direction at the rate of:

$$\dot{m}u_1\cos\beta \ kg\ m.s^{-2} \tag{6}$$

The force on the vane in the X direction is equal to the rate of change of momentum change. Therefore:

$$F = \dot{m}(u_0 - u_1 \cos\beta) \text{ (Newtons)} \qquad (7)$$

Ideally, jets are of constant velocity, so that $u_0 = u_1$. Therefore:

$$F \approx \dot{m}u_0(1 - \cos\beta) \text{ (Newtons)} \qquad (8)$$

From this, you can calculate the theoretical force for each vane as shown in Table 2.

Vane Type or Shape	β (degrees)	F (N)
Flat Plate	90	$\dot{m}u_0$
Conical cup 120 degree angle	120	1.5 $\dot{m}u_0$
Hemisphere	180	2.0 $\dot{m}u_0$
30 degree Angled Plate	30	0.87 $\dot{m}u_0$

Table 2 Theoretical Force Values for the Different Vane Shapes

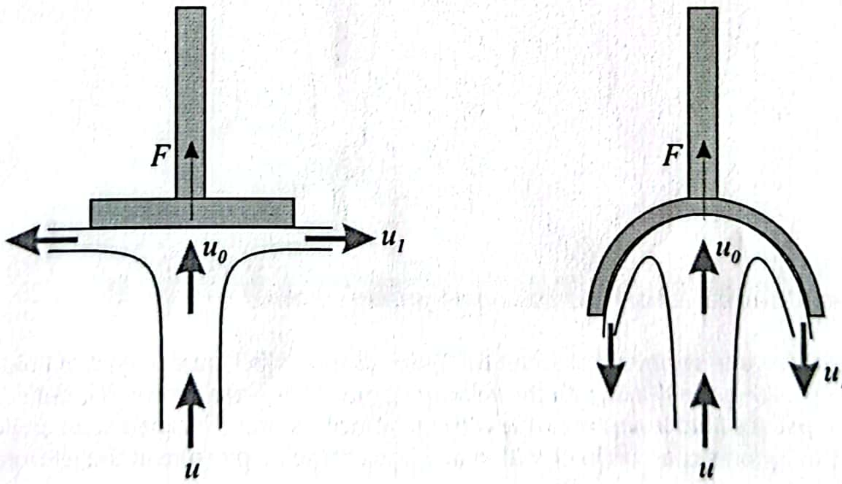

Figure 10 Force Against Flat and Hemispherical Vanes

Therefore, a chart of results of tests of the force (y axis) against the rate of momentum change (x axis) should produce slopes for the vanes as shown in Table 3 and Figure 11. Note that as there should be no force with no water jet, any results from tests must pass through the 0,0 origin of the chart.

Flat Plate	120 Degree Cone	Hemisphere	30 Degree Plate
1	1.5	2	0.87

Table 3 Typical Slopes of Results for the Vanes

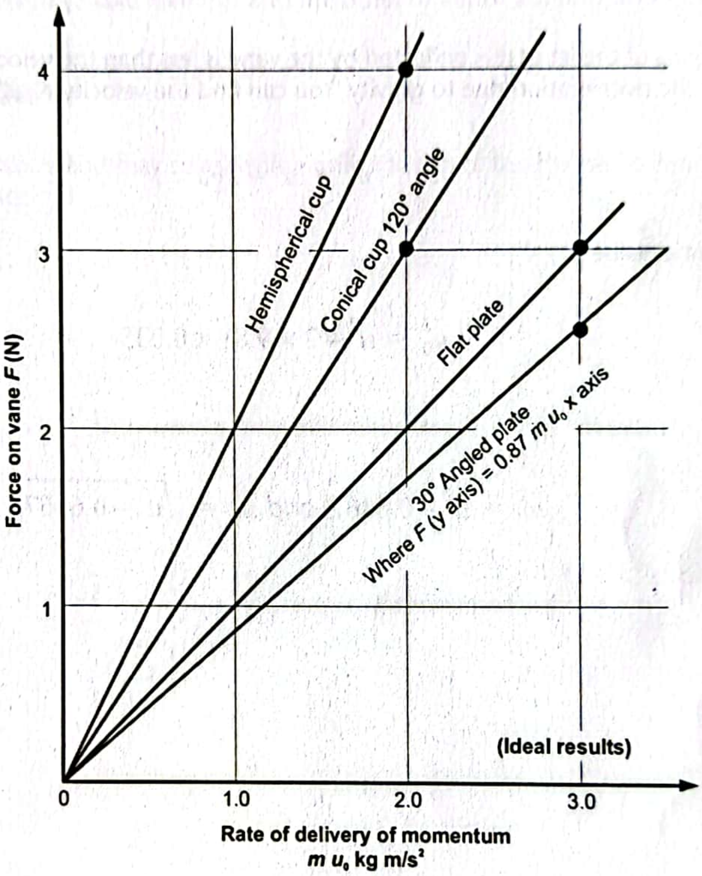

Figure 11 Typical Chart of Results

Finding Velocity

Fluid mass flow is equal to the product of its density, the area of the flow and the velocity:

$$\dot{m} = \rho A u \quad (9)$$

From this, if you know the fluid (water) density, the cross-sectional area through which it passes (the nozzle in this equipment) and the mass flow (from the hydraulic bench), then you may find the velocity:

$$u = \frac{\dot{m}}{\rho A} \quad (10)$$

Water density changes with temperature, but assuming that you use the equipment at normal room temperature, you can use a value of 10^3 kg.m^{-3}.

Using this with the nominal value of A:

$$u = \frac{\dot{m}}{1000 \times 0.00007854} \qquad (11)$$

$$u = \frac{\dot{m}}{0.07854} \text{ or } u = \dot{m} \times 12.76 \qquad (12)$$

The velocity u_0 of the jet as it is deflected by the vane is less than the velocity, u, at exit from the nozzle because of the deceleration due to gravity. You can find the velocity u_0 at the vane using:

$$u_0^2 = u^2 - 2gs \qquad (13)$$

Using nominal values:

$$u_0^2 = u^2 - 2 \times 9.81 \times 0.035 \qquad (14)$$

therefore:

$$u_0^2 = u^2 - 0.6867 \text{ and } u_0 = \sqrt{u^2 - 0.6867} \qquad (15)$$

Experiments

Useful Notes

Two People

This equipment is safe to use, but TecQuipment recommend that at least two people do the experiments. One person to take readings and the other to adjust the flow and jockey weight.

Splashes of Water

This apparatus uses water and may splash some onto the top of the Hydraulic Bench. Be prepared for small splashes of water.

Experiment

Aims

- To demonstrate that the force on a vane is proportional to the rate of delivery of momentum.
- To show that you can predict the force on a vane from a combination of its surface shape and the properties of the jet directed at it.

Procedure

Vane:						
Flow rate (kg/min or L/min)	Mass Flow rate $\dot{m}$ kg.s^{-1}	Distance y (m)	Velocity u (m.s^{-1})	Velocity u_0 (m.s^{-1})	Rate of delivery of momentum $\dot{m}u_0$ (kg m.s^{-2})	Force F (N)

Table 4 Blank Results Table

1. Create a blank results table similar to Table 4.
2. Make sure the weigh beam is at balance with the jockey weight at the zero position.
3. Start the hydraulic bench and set to maximum flow.
4. Move the jockey weight until the beam balances again. Note the distance y from the zero position.
5. Record the flow rate using your hydraulic bench.
6. Reduce the hydraulic bench flow in steps to give at least eight more readings of distance y and flow in relatively equal increments.
7. Repeat for the other vanes (plates) that you need to test.

Results Analysis

Convert your flow rate into mass flow rate $\dot{m}$.

Calculate the flow velocity u and use this to calculate u_0.

Calculate the rate of delivery of momentum $\dot{m}u_0$ and force F.

Create a chart of force F on the vane (vertical axis) against rate of delivery momentum $\dot{m}u_0$.

Add to the chart, the results for each of the plates (vanes) that you test.

Compare your actual results with the theoretical results and identify any differences or causes of error.

Typical Results

All results are for reference only. Actual results may differ slightly.

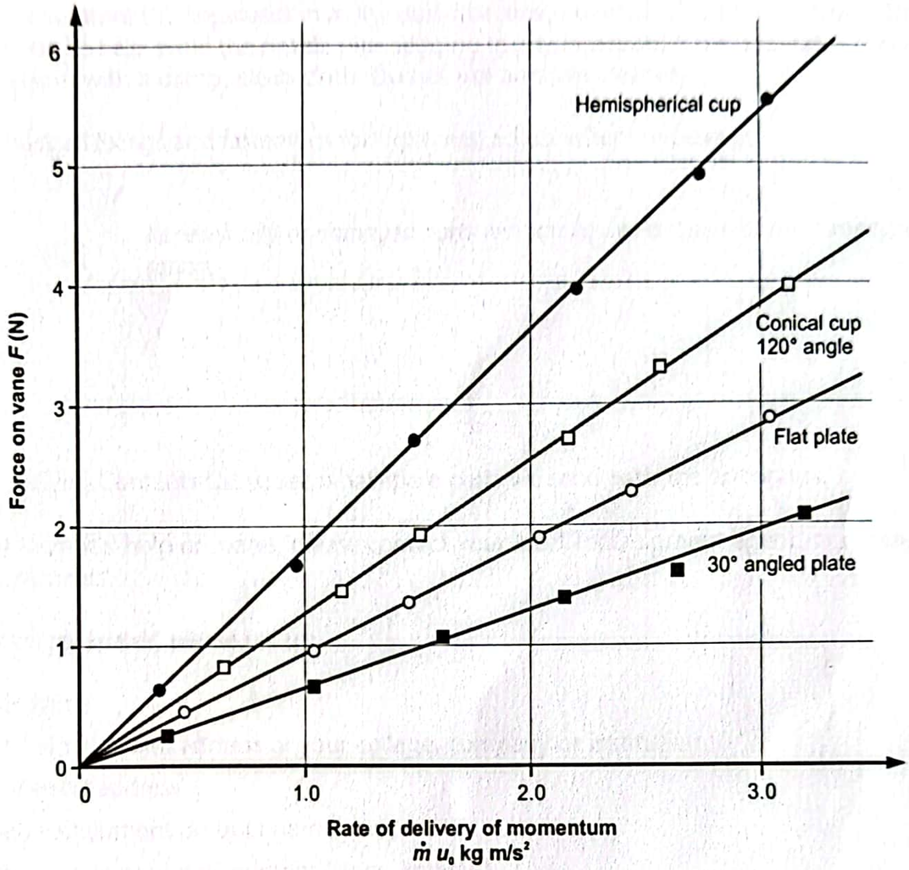

Table 5 Typical Results

All results gave fairly linear plots, showing that the force produced on the vanes is proportional to the rate of momentum. Table 6 shows the approximate gradients.

Flat Plate	120 Degree Cone	Hemisphere	30 Degree Plate
Roughly 0.9	Roughly 1.3	Roughly 1.8	Roughly 0.7

Table 6 Approximate Gradients

Actual results are very similar to theory, but overall slightly lower. This suggests that the measured forces were lower than expected or the momentum was higher than expected. A consistent measurement error would make the plots pass just above or below the 0,0 origin, so it is more likely to be due to other factors that the 'ideal' theory does not account for. For example, the theory assumes a uniform velocity distribution around the jet and on the vane, but a real jet has a parabolic distribution with a slightly higher velocity in the centre.

Maintenance, Spare Parts and Customer Care

Maintenance

Regularly check all parts of the apparatus for damage, renew if necessary.

When not in use, store the apparatus in a dry, dust-free area, covered with a plastic sheet. Store in an upright position to help avoid the nozzle pipe sagging in any direction. If the apparatus becomes dirty, wipe the surfaces with a damp, clean cloth. Do not use abrasive cleaners.

Regularly check all fixings and fastenings for tightness, adjust where necessary.

NOTE *Renew faulty or damaged parts with an equivalent item of the same type or rating.*

Spare Parts

Check the Packing Contents List to see what spare parts we send with the apparatus.

If you need technical help or spares, please contact your local TecQuipment agent, or contact TecQuipment direct.

When you ask for spares, please tell us:

- Your name
- The full name and address of your college, company or institution
- Your email address
- The TecQuipment product name and product reference
- The TecQuipment part number (if you know it)
- The serial number
- The year it was bought (if you know it)

Please give us as much detail as possible about the parts you need and check the details carefully before you contact us.

If the product is out of warranty, TecQuipment will let you know the price of the spare parts.

Customer Care

We hope you like our products and manuals. If you have any questions, please contact our Customer Care department:

Telephone: +44 115 954 0155

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For information about all TecQuipment products visit: **www.tecquipment.com**