H8
Impact of a Jet

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SECTION 1 INTRODUCTION

Figure 1.1 Impact of a jet apparatus

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. The jet is directed on to the vanes of a turbine wheel, which is rotated by the force generated on the vanes 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%.

In this experiment, the force generated by a jet of water as it strikes a flat plate or hemispherical cup may be measured and compared with the momentum flow rate in the jet. Also available from TecQuipment are a Conical Plate H8a and a 30° Angled Plate H8b.

SECTION 2 DESCRIPTION OF APPARATUS

The **Impact of a Jet (H8)** apparatus has been designed for use with the TecQuipment Hydraulic Bench. This provides the necessary water supply and flow measurement facility.

Figure 2.1 shows the arrangement in which the bench supply is led to a vertical pipe terminating in a tapered nozzle. This produces a jet of water which impinges on the vane in the form of a Flat Plate, Hemispherical Cup, Conical Plate (H8a) or 30° Angled Plate (H8b). The nozzle and vane are contained within a transparent cylinder; at the base of the cylinder there is an outlet by which the flow may be directed to the weighing tank.

As indicated in Figure 2.1, the vane is supported by a pivoted beam, which carries a jockey weight and is restrained by a light spring. The lever may be set to a balanced position (as indicated by the tally suspended from it) by placing the jockey weight at its zero position and then adjusting 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 has been restored to its original balanced position.

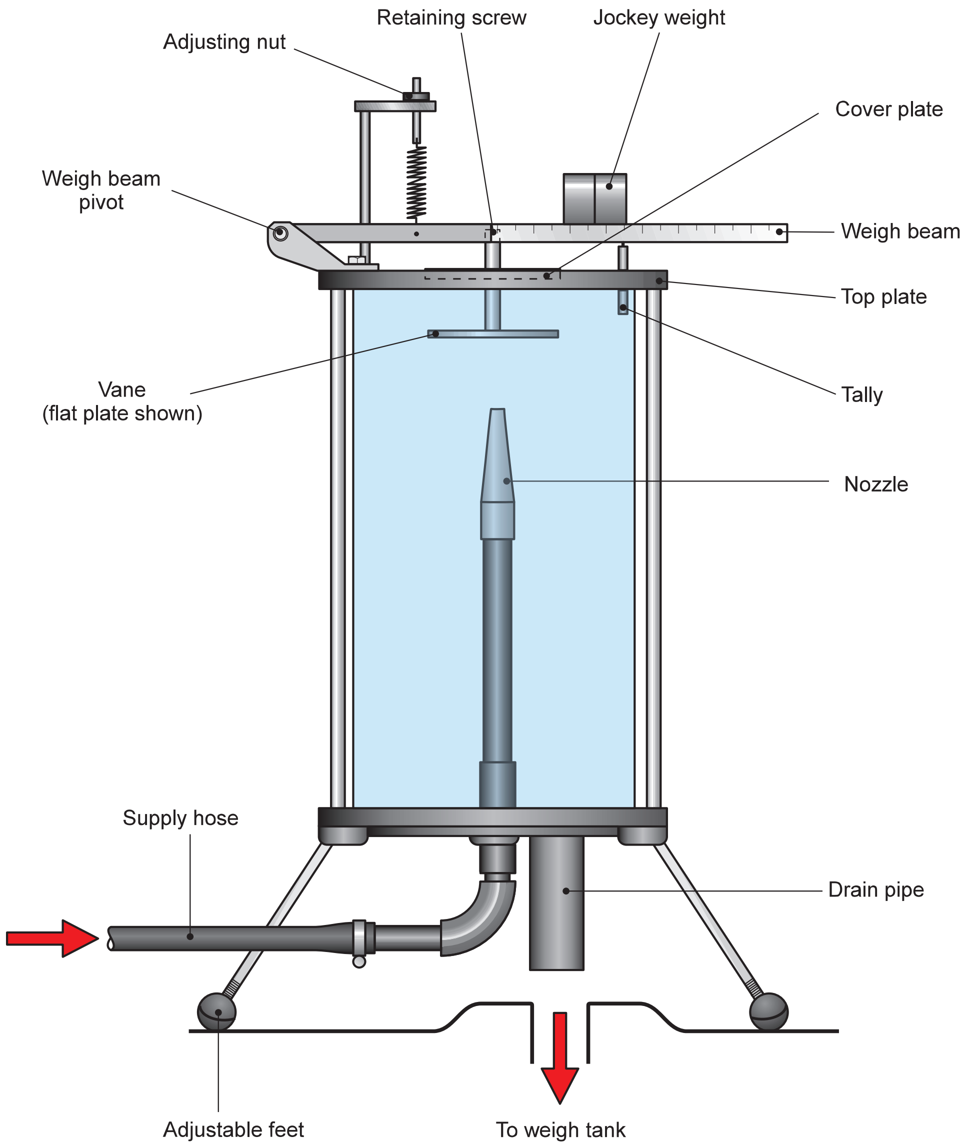

Figure 2.1 Diagrammatic arrangement of apparatus

Assembly

The weigh beam assembly is dismantled from the main glass cylinder unit during despatch. To assemble, fit the weigh beam assembly to the top plate and secure using the three locating screws supplied, as shown in
Figure 2.2.

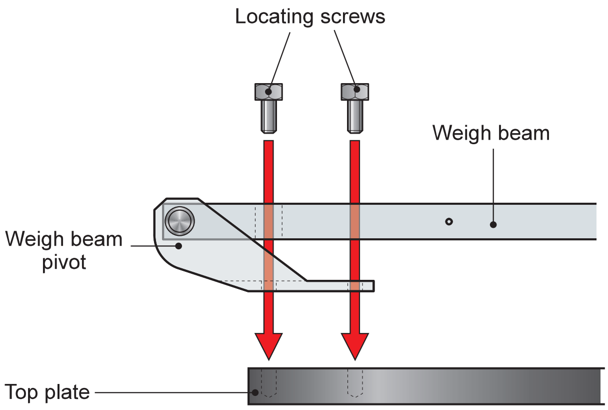

Figure 2.2 Assembly of the weigh beam

Fit the vane and cover plate as shown in Figure 2.3.
The unit is now assembled and ready for installation.

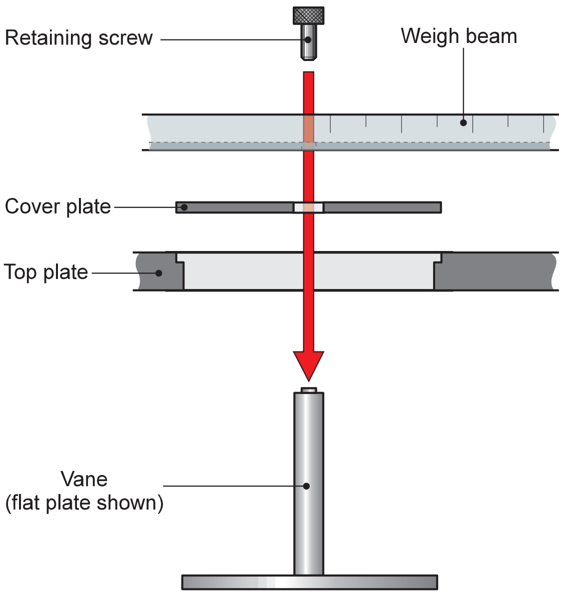

Figure 2.3 Fitting the vane

Installation

Place the Jet Apparatus on the top of the Hydraulic Bench, H1, ensuring that the drain pipe is situated over the drain hole in the Bench top.
If using the Hydraulic Bench, H1D, position the apparatus as shown in Figure 2.4. Connect the plastic tube from the supply valve to the nozzle inlet tube and secure using the clip provided.

Level the apparatus with the plastic knobs on the base legs.

Rest the jockey mass on the zero mark of the beam and level the weigh beam with the balanced spring. When level, the grooves on the tally should be equally spaced on either side of the tank top; adjust the length of the tally suspension if necessary.

Admit water to the apparatus and shift the jockey mass until the weigh beam is level again.

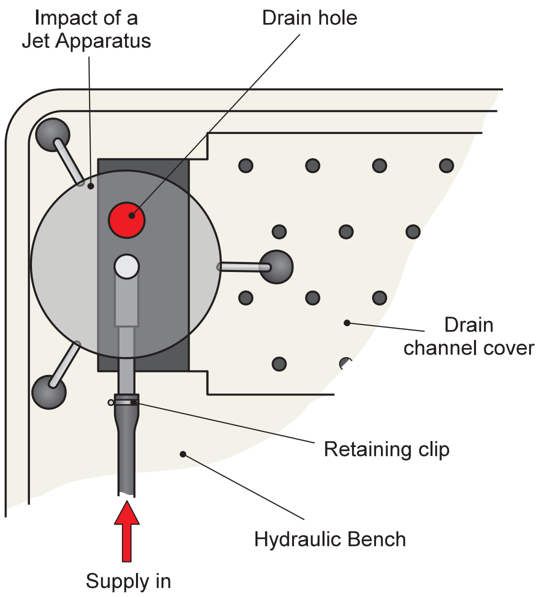

Figure 2.4 Positioning the apparatus on to the hydraulics bench, H1D

Routine Care And Maintenance

After use, the apparatus should be drained and all external surfaces dried with a lint free cloth.

The appearance of the painted parts can be maintained by polishing with a good quality car body cleaner, once a year. The plated parts and glass should be cleaned periodically with good quality cleaners.

The apparatus should always be stored in the working upright position to avoid any sagging or distortion of the plastic nozzle tube.

Noise Levels

The maximum sound pressure levels measured for this apparatus are fewer than 70 dB(A).

SECTION 3 THEORY

Consider a vane symmetrical about the x-axis as shown in Figure 3.1. A jet of fluid flowing at the rate of $\dot{m}$ kg/s along the x-axis with the velocity u_0 m/s 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 inclined at an angle β to the x-axis. Changes in elevation and in piezometric pressure in the jet from striking the vane to leaving it are neglected.

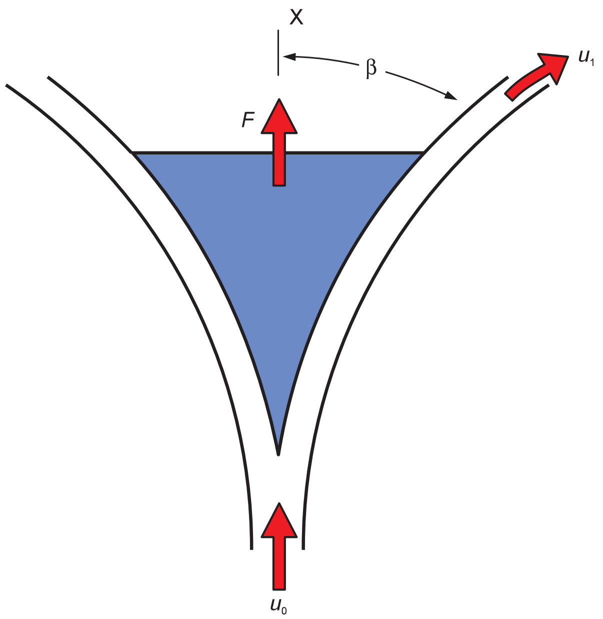

Figure 3.1 Vane symmetrical about x-axis

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

$$\dot{m}u_0 \quad \left(\mathrm{kg\,m/s^2}\right)$$

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

$$\dot{m}u_1 \cos\beta \quad \left(\mathrm{kg/ms^2}\right)$$

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

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

Ideally, jets are 'isotachtic', or constant velocity so that $u_0 = u_1$. Therefore:

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

Shape	β	***F***
→|	90°	$\dot{m}\beta u_0$
→>	120°	1.5 $\dot{m}u_0$
→)	180°	2 $\dot{m}u_0$
→\	30°	0.87 $\dot{m}u_0$

Table 3.1

SECTION 4 EXPERIMENTAL PROCEDURE

The apparatus is first levelled and the lever set to the balanced position (as indicated by the tally) with the jockey weight at its zero position. Water is admitted through the bench supply valve. The rate of flow is then increased to the maximum and the position of the jockey weight which restores the lever to the balanced position is noted, while the discharge is weighed in the weighing tank. A series of about eight readings with roughly equally spaced positions of the jockey weight, are then taken by decreasing the flow rate from the bench. (Adjust weight of water collected to ensure discharge over 60 seconds).

The experiment may then be repeated using the hemispherical cup, conical plate and angled plate in turn. The diameter of the nozzle, the height of the vane above the tip of the nozzle when the lever is balanced, the distance between the centre of the vane and the pivot of the lever and the jockey weight should be noted.

Results and Calculations

Density of water ρ	=	10^3 kg/m^3
Diameter of nozzle	=	10 mm
Cross-sectional area of nozzle, A	=	78.5 mm^2
Mass of jockey weight	=	0.6 kg
Distance from centre of vane to pivot of lever	=	0.15 m

The jockey weight weighs ($0.6 \times g$) Newtons. When it is moved a distance y metres from its zero position, the corresponding force F Newtons on the vane is obtained, by taking moments about the pivot, as:

$$F \times 0.15 = 0.6 \times g \times y$$

$$F = 4gy \qquad \text{(Newtons)}$$

Height of vane above tip of nozzle, s = 35 mm.
The flow is measured as $\dot{m}$ (kg/s).

Since $\dot{m} = \rho A u$, the speed if the jet at exit from the nozzle is equal to:

$$u = \frac{\dot{m}}{\rho A} \quad (\text{m/s}) \tag{4-1}$$

$$u = \frac{\dot{m}}{10^3 \times 78.5 \times 10^{-6}} = 12.75\dot{m} \quad (\text{m/s}) \tag{4-2}$$

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 and may be calculated from the expression:

$$u_0^2 = u^2 - 2gs$$

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

or

$$u_0^2 = u^2 - 0.687 \tag{4-3}$$

Results and calculations should each be presented in the form of Table 4.1. Values of quantities collected, times required and y are recorded from experimental observations. Values of u are calculated from Equation (4-2), u_0 from Equation (4-3) and F from Table 4.1.

Figure 4.1 shows the form of a theoretical set of results in graphical form and the experimental results from Table 4.1 should be used to plot the same graph.

Note: 'Quantity' in Table 4.1 refers to the actual weight of water collected.

Quantity (kg)	***t*** **(s)**	***y*** **(m)**	$\dot{m}$ **(kg/s)**	***u*** **(m/s)**	u_0 **(m/s)**	$\dot{m}u_0$ **(N)**	***F*** **(N)**

Table 4.1 Suggested form of results

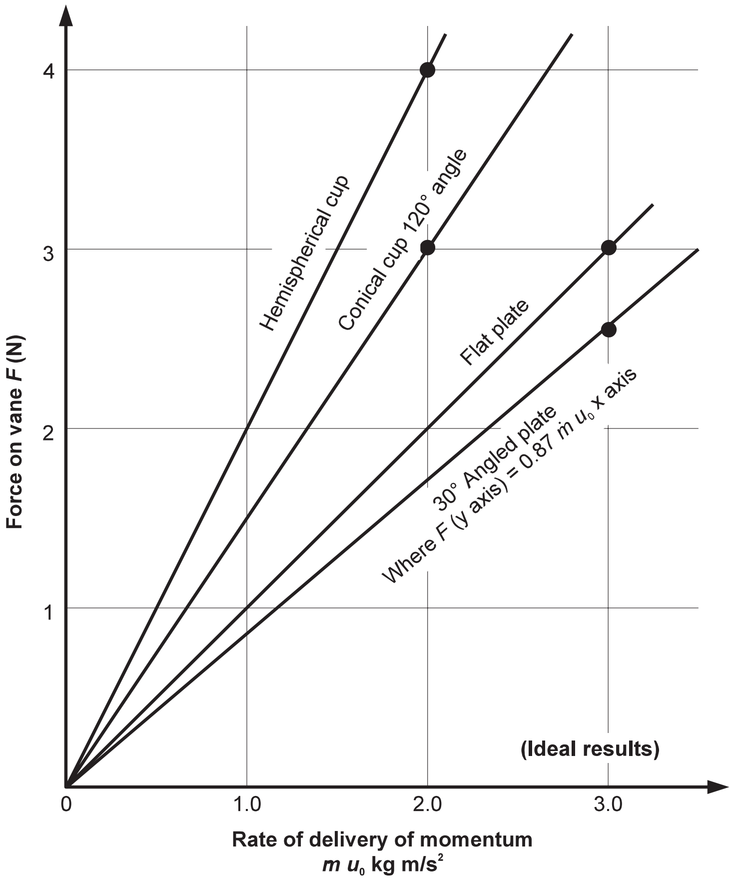

Figure 4.1 Force developed on vanes of various shapes

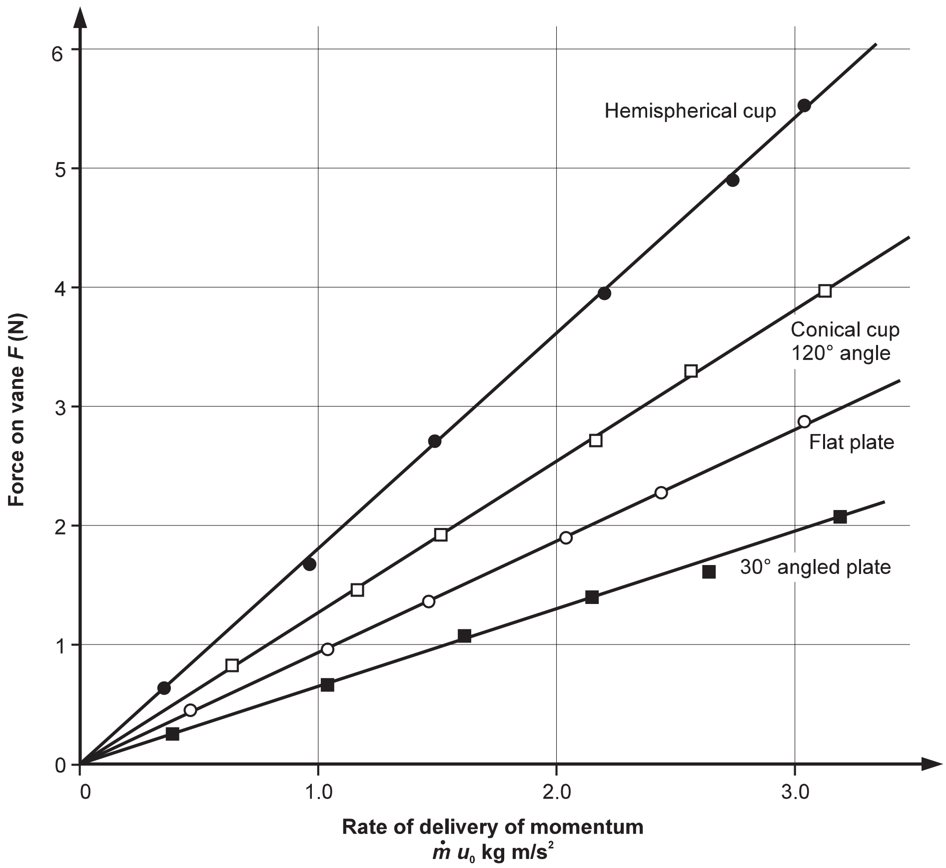

Figure 4.2 Typical test results.
(The actual experimental results being slightly less than the theoretical results)

Discussion of Results

It is clear from Figure 4.2 that the force produced on each of the vanes is proportional to the rate at which momentum passes in the jet. For the flat plate the straight line through the experimental points does not quite pass through the origin of the graph but indicates as small force when the jet is cut off. This corresponds to a small displacement of the jockey weight and it is possible that the initial balancing of the lever was responsible for this zero error. Ideally the slope of the graphs should be:

Flat Plate	1
Cone	1.5
Hemisphere	2

Actual experimental results will be slightly less than these values. Measure the actual slopes (if the experimental points do not pass through the origin, this will not effect the results).

$$\text{The ratio } \frac{\text{actual slope}}{\text{ideal value}}$$

is a measure of the deviation of a real flow from the ideal uniform constant speed assumption. Results obtained from experiments have given values such as:

Flat plate	98%
Cone	96%
Hemisphere	95%

Questions for Further Discussion

1. What suggestions have you for improving the apparatus?

2. What would be the effect on the calculated value of the efficiency of the following systematic errors of measurement?
   a) Jockey weight in error by 1 g;
   b) Distance from centre of vane to pivot of lever in error by 1 mm.

3. The ideal flow model has assumed that the jet has a uniform velocity distribution and is constant around the vane. A real jet has a velocity distribution from zero at the edge to a maximum in the centre. It is not actually parabolic, but consider the effect that this would have on the force.
   The average value is still u_0.

4. Real jets also spread and slow down. What would be the effect of a jet 10% greater area and 10% slower at the vane compared with that emerging from the apparatus?

5. If the cone and the hemisphere faced the other way, i.e. the open section away from the jet, what would the ideal force be? Why does momentum theory not predict the actual results?
   This problem puzzled D'Alembert before the actual flow around shapes was known in detail and is known as D'Alembert's Paradox.