Fluid Mechanics - Course 223

FORCE - MOMENTUM

In mechanics, Newton's second law states that if a body experiences an acceleration then a force must have been applied.

Thus $F = m.a$ where F is the force
m is the mass
a is the acceleration.

Acceleration is the rate of change of velocity, ie, dv/dt. Mass x velocity is momentum - thus the force due to a change in velocity is equal to the rate of change of momentum.

$$\text{Thus} \quad F = \frac{m(V_2-V_1)}{t}$$

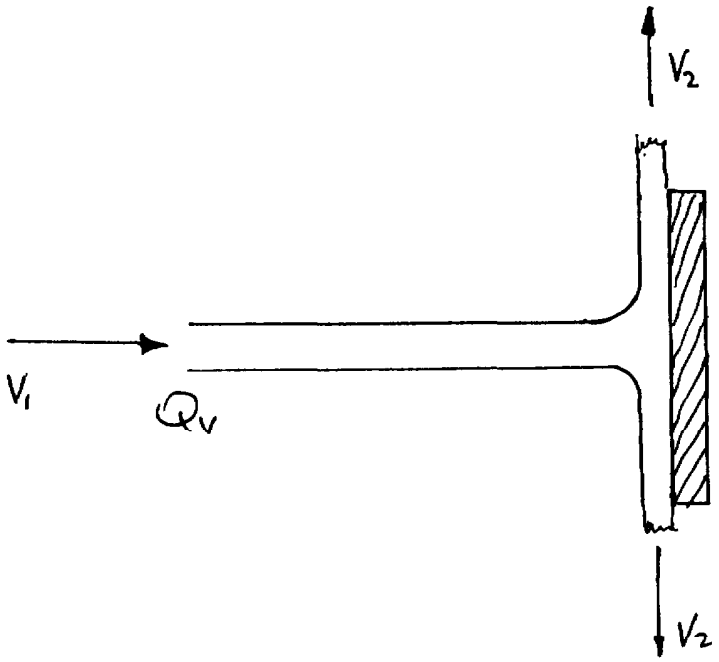
This relationship may be applied to fluid flow. If a change in velocity occurs, then there is a resultant force. If we consider the flow situation

$$F = \frac{m}{t}(V_2-V_1) \qquad V_2-V_1 = \text{Change in acceleration}$$

$$\frac{m}{t} = \text{mass flow}$$

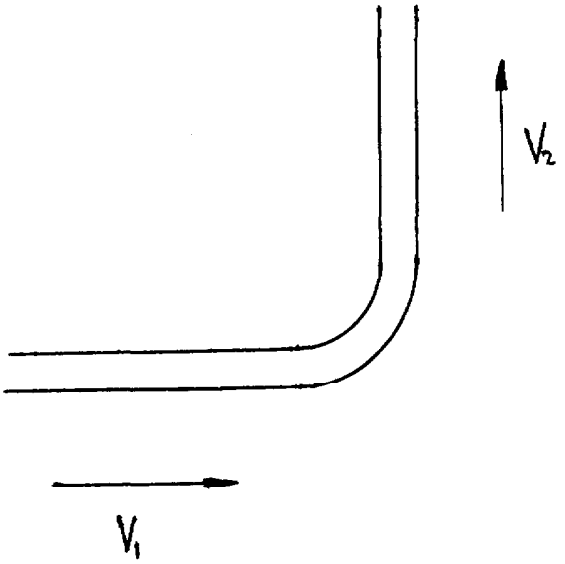
$$\therefore \quad F = \ell A V_1 (V_2-V_1)$$

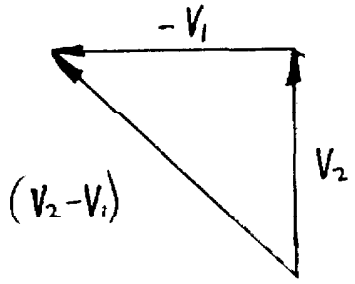
Thus the force due to the change in velocity of the fluid = $F = \ell Q_v (V_2-V_1)$. When the change in velocity is considered, it should be remembered that the direction must be taken into account as well as the magnitude.



Consider a jet striking a flat plate. The final velocity of the fluid is at 90° to the original velocity and the jet is split in radial directions, thus V_2 is zero. Thus the change in velocity = V_2-V_1 = $0-V_1$. Thus the force exerted by the plate, to deflect the jet, has to act in the opposite direction to the flow.

The magnitude of the force = $\ell Q_V V_1$. Consider a fluid **flowing in a pipe and turning through 90°.**





The change in velocity = V_2-V_1. (V_2-V_1) is the direction in which the force has to be applied to prevent the pipework moving.

Example

A 12" SCH 40 line carries water at 0.4 m^3/s. Calculate the force exerted on a 90° bend.

$$V_1 = \frac{Q}{A} = \frac{0.4}{722.1 \times 10^{-4}} = \underline{5.54}\ m/s.$$

The change in velocity = V_2-V_1.

$$= \sqrt{5.54^2 + 5.54^2}$$

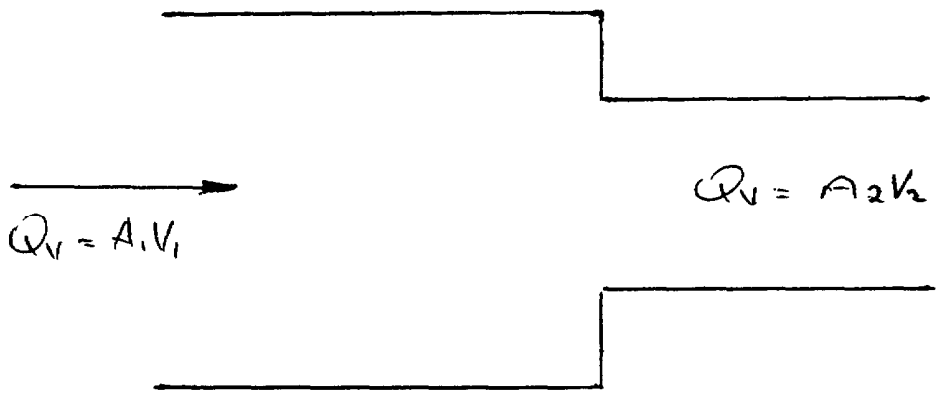
$$= \underline{7.83}\ m/s.$$

Force = $\ell \times Q_V \times (V_2-V_1)$

= 1000 x 0.4 x 7.83

= 3130N at 45° away from the centre of the bend.

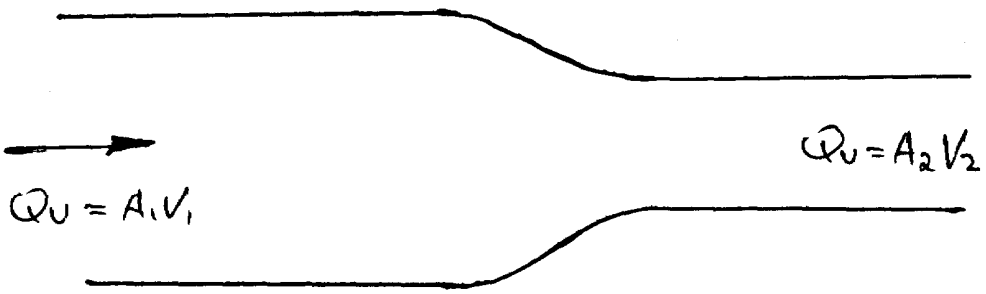
Consider a change in section of pipe.



Force due to change in area.

F = $\ell \times Q_V \times (V_2-V_1)$ in the direction of V_2.

Consider the reaction force from a jet or nozzle.



Force on nozzle = $\ell \times Q_V \times (V_2 - V_1)$

Example

A 3" fire hose has a 1" nozzle and discharges 500 gpm. Calculate the force required to hold the nozzle steady.

$$F = \ell \times Q_V \times (V_2 - V_1)$$

$$500 \text{ gpm} = \frac{500 \times 10}{62.4 \times 60} = \underline{1.34} \text{ cfs}$$

$$V_2 = \frac{Q_V}{A_2} = \frac{1.34 \times 4 \times 144}{\pi \times 1^2} = \underline{245.7} \text{ fps}$$

$$V_1 = \frac{V_2}{9} = \underline{27.3} \text{ fps}$$

$$\text{Force} = \ell \times Q_V \times (V_2 - V_1)$$

$$= 1.94 \times 1.34 \times (245.7 - 27.3)$$

$$= \underline{567.8} \text{ lbs}$$

ASSIGNMENT

1. A 6" line discharges 0.2 m^3/s, of oil, d = 0.8, at a plate, which is at 90° to the jet. What is the force required to deflect the jet.

2. A 14" SCH 40 line carries water at 0.35 m^3/s. Calculate the force on the pipe due to a 60° bend in the line.

3. Oil flows at 1800 gpm to the oil coolers, via a 6" line. The line reduces from 6" to 4". Calculate the thrust on the line due to the section change. d = 0.75.

4. A 6" line discharges water into a tank. The thrust on the line is 600 lbs. Calculate the flowrate.

J. Irwin-Childs