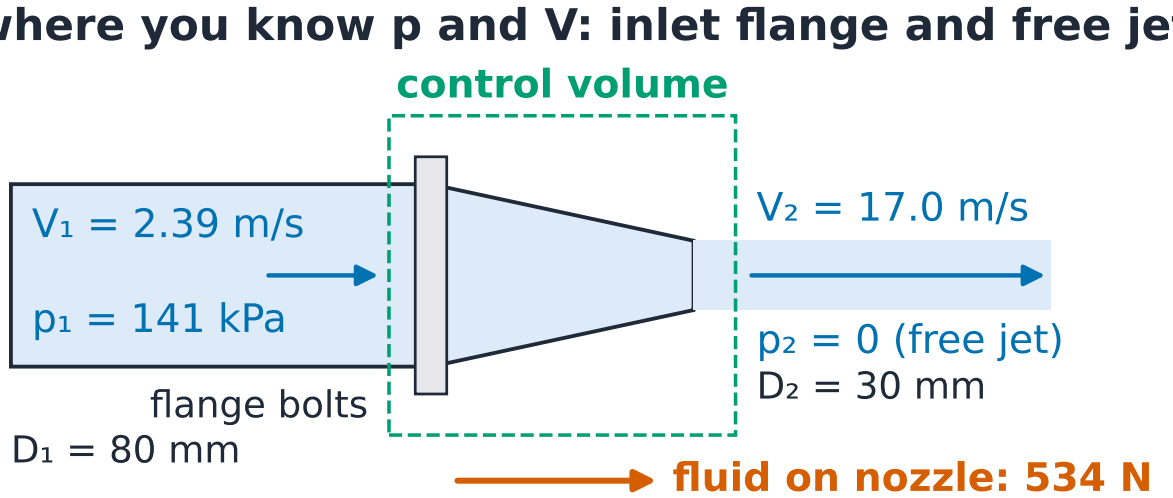
Exercise walk-through

7.2 Conservation and control volumes

University Mechanical Engineering

Control volume: the nozzle bolts



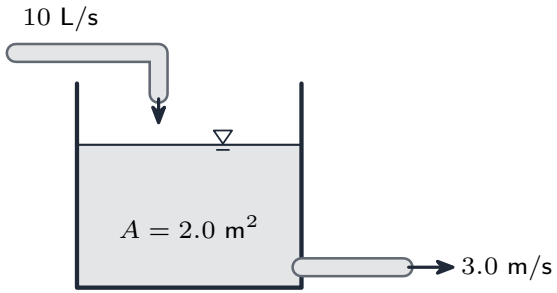
12 L/s from 80 mm into a 30 mm jet: $V_1 = \mathbf{2.39}$, $V_2 = \mathbf{17.0}$ m/s, $p_1 = \mathbf{141}$ kPa. $p_1 A_1 + F = \rho Q(V_2 - V_1)$: the fluid pushes the nozzle downstream with $\mathbf{534}$ N.

The bend and its thrust block

1. **Each direction** 90° bend, 80 mm, 150 kPa gauge, 12 L/s: $pA + \rho QV = 754.0 + 28.6 = \mathbf{782.6}$ N.
2. **Resultant** $\sqrt{2} \times 782.6 = \mathbf{1107}$ N at 45° - the thrust block's load.
3. **Lesson** At low speed pressure dominates momentum, so high-pressure lines need anchors even when the flow is slow.

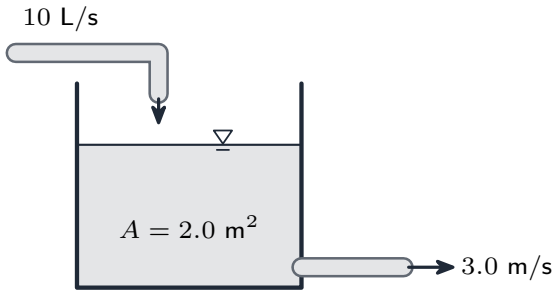
Exercise 2.1

2.1 A tank of plan area 2.0 m^2 is filled at 10 L/s and drained by a 50 mm pipe in which the water moves at 3.0 m/s. Find the rate at which the level changes. [3]



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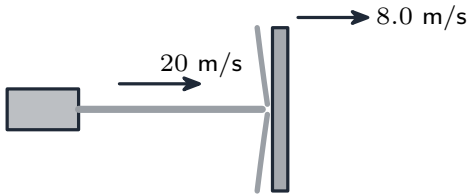


2.1

$$Q_{out} = \frac{\pi}{4}(0.050)^2 \times 3.0 = 5.89 \text{ L/s};\ \frac{dh}{dt} = \frac{(10 - 5.89) \times 10^{-3}}{2.0} = \mathbf{2.1\ mm/s}, \text{ rising}$$

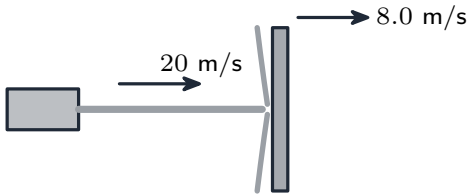
Exercise 2.2

2.2 The jet of worked example 2 hits a plate that moves away from it at 8.0 m/s. Find the force on the plate and the power delivered to it. [3]



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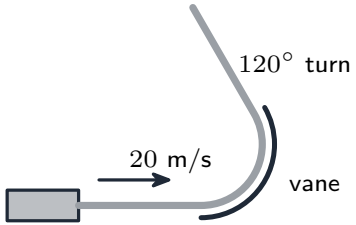


2.2

frame with the plate: relative speed 12 m/s, $\dot{m} = 1000 \times 4.91 \times 10^{-4} \times 12 = 5.89$ kg/s; $F = 5.89 \times 12 = \mathbf{71\ N}$; $P = Fu = 71 \times 8.0 = \mathbf{570\ W}$

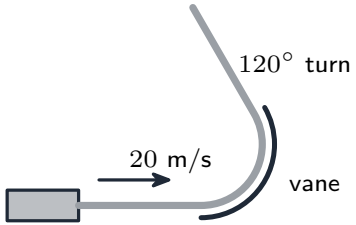
Exercise 2.3

2.3 The jet of worked example 2 is turned through 120° by a smooth fixed vane, with no loss of speed. Find the two components of the force on the vane. [3]



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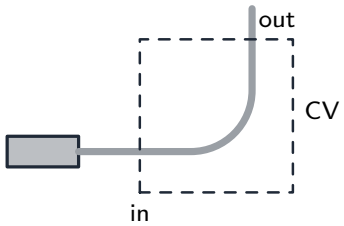


2.3

$\dot{m}V = 196$ N; along the jet: $F_x = 196(1 - \cos 120°) =$ **295 N**; across: $F_y = 196 \sin 120° =$ **170 N**

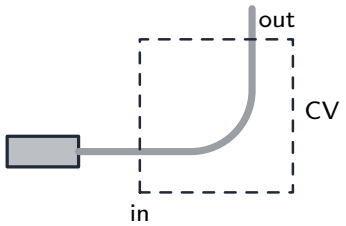
Exercise 2.4

2.4 Explain why the pressure term is zero where a jet leaves a nozzle into the air, and why a control volume around a moving vane should move with it. [2]



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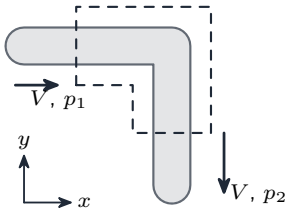
2.4

a free jet is at atmospheric pressure, so its gauge pressure is zero; in the vane's frame the flow is steady and the vane is at rest, so the steady momentum equation applies

Exercise 3.1

3.1 Water flows at 0.10 m^3/s through a horizontal 90° bend in a 200 mm pipe. The gauge pressure is 150 kPa at both ends.

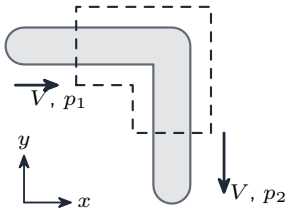
Find the velocity, the x and y components of the force the water puts on the bend, and the size of the resultant. [6]



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Find the velocity, the x and y components of the force the water puts on the bend, and the size of the resultant. [6]



3.1

$A = 0.0314\ \text{m}^2$, $V = \mathbf{3.18\ m/s}$

x: $p_1 A - R_x = \dot{m}(0 - V)$, so $R_x = p_1 A + \dot{m}V = 4712 + 318 = \mathbf{5.03\ kN}$

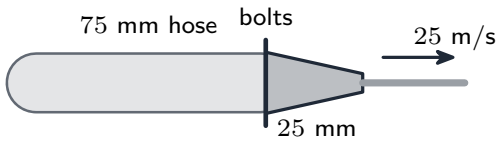
y: $R_y - p_2 A = \dot{m}(-V)$ for out-flow along $-y$: $|R_y| = \mathbf{5.03\ kN}$

resultant $\sqrt{2} \times 5.03 = \mathbf{7.1\ kN}$, at 45° outwards

Exercise 3.2

3.2 A fire hose of 75 mm diameter ends in a nozzle with a 25 mm outlet. The jet leaves at 25 m/s; the gauge pressure at the nozzle inlet is 309 kPa.

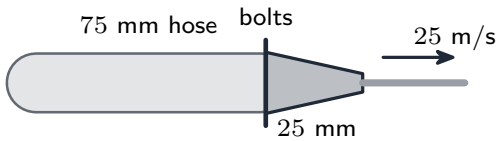
Find the flow rate, the inlet velocity, and the force on the bolts that hold the nozzle on. [5]



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Find the flow rate, the inlet velocity, and the force on the bolts that hold the nozzle on. [5]



3.2

$Q = \frac{\pi}{4}(0.025)^2 \times 25 = \mathbf{12.3\ L/s}$; $V_1 = \dfrac{12.3 \times 10^{-3}}{4.42 \times 10^{-3}} = \mathbf{2.78\ m/s}$

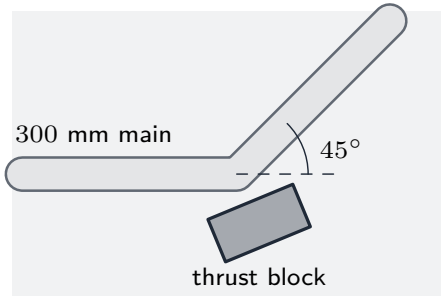
$p_1 A_1 - F = \dot{m}(V_2 - V_1)$: $1364 - F = 12.3 \times 22.2 = 273$

$F = \mathbf{1.09\ kN}$: the water pushes the nozzle forward and the bolts hold it back

Exercise 3.3 (a)

3.3 A buried 300 mm water main has a 45° horizontal bend. It is pressure-tested at 600 kPa, and in service the water moves at 2.0 m/s. A concrete thrust block behind the bend carries the force into soil that can bear 50 kPa.

(a) Find the thrust on the bend during the test, with no flow. The resultant of the two end forces is $2pA\sin\dfrac{\theta}{2}$. [3]

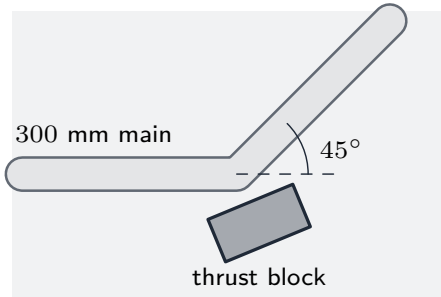


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(a) Find the thrust on the bend during the test, with no flow. The resultant of the two end forces is $2pA\sin\dfrac{\theta}{2}$. [3]



(a) $A = 0.0707\ \text{m}^2$; $F = 2 \times 600 \times 10^3 \times 0.0707 \times \sin 22.5^\circ = \mathbf{32.5\ kN}$

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Exercise 3.3 (b)

3.3 A buried 300 mm water main has a 45° horizontal bend. It is pressure-tested at 600 kPa, and in service the water moves at 2.0 m/s. A concrete thrust block behind the bend carries the force into soil that can bear 50 kPa.

(b) Find the extra thrust from momentum in service, as a percentage of (a). Is it worth including? [3]

Exercise 3.3 (b)

3.3 A buried 300 mm water main has a 45° horizontal bend. It is pressure-tested at 600 kPa, and in service the water moves at 2.0 m/s. A concrete thrust block behind the bend carries the force into soil that can bear 50 kPa.

(b) Find the extra thrust from momentum in service, as a percentage of (a). Is it worth including? [3]

(b) $2\dot{m}V\sin 22.5° = 2 \times 141 \times 2.0 \times 0.383 =$ **216 N**; 0.7% of (a): negligible; the test pressure governs

Exercise 3.3 (c)

3.3 A buried 300 mm water main has a 45° horizontal bend. It is pressure-tested at 600 kPa, and in service the water moves at 2.0 m/s. A concrete thrust block behind the bend carries the force into soil that can bear 50 kPa.

(c) Find the bearing area of the block for a factor of safety of 1.5. [2]

Exercise 3.3 (c)

3.3 A buried 300 mm water main has a 45° horizontal bend. It is pressure-tested at 600 kPa, and in service the water moves at 2.0 m/s. A concrete thrust block behind the bend carries the force into soil that can bear 50 kPa.

(c) Find the bearing area of the block for a factor of safety of 1.5. [2]

(c) $A_{block} = \dfrac{1.5 \times 32.5}{50} = \mathbf{0.97\ m^2}$, say 1.0×1.0 m