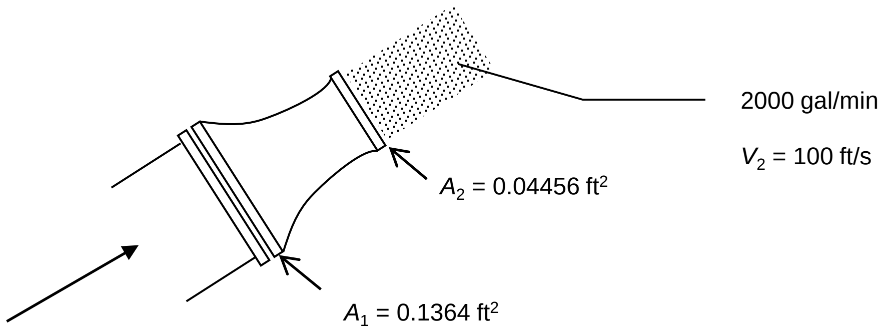
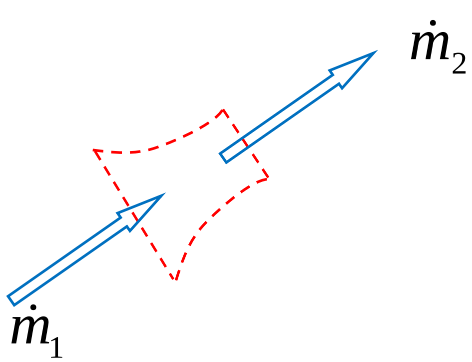
Active Learning Exercise

The nozzle on the firehose in the boat problem is pictured below. If the pressure at the inlet of the nozzle is 40 psi (lbf/in^2), calculate the reaction force needed to keep the nozzle stationary. Other conditions are the same as in the original problem. (P_{atm} = 14.7 psi, ρ_{wat} = 62.4 lbm/ft^3)

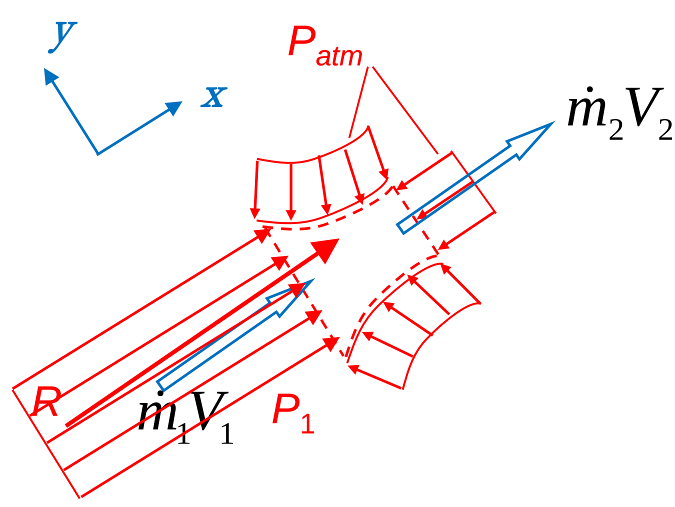


1. Draw a system boundary and draw all relevant mass and linear momentum related transport terms on it. Be sure to indicate a **coordinate system** on your diagram. Ignore weight

Mass

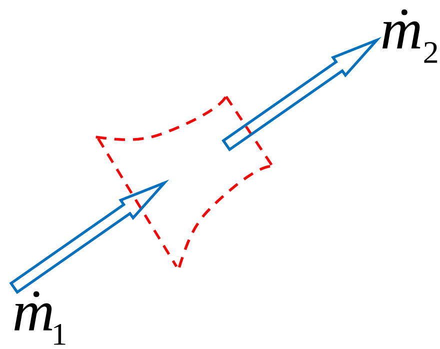


Linear Momentum



2. Apply **conservation of mass** to the system and any related equations. What can you use these to solve for? V_1

Mass



$$\frac{d}{dt}(m_{sys}) = \sum \dot{m}_{in} - \sum \dot{m}_{out}$$

0 (S-S)

$$0 = \dot{m}_1 - \dot{m}_2$$

$$\dot{m}_1 = \dot{m}_2 = \dot{m}$$

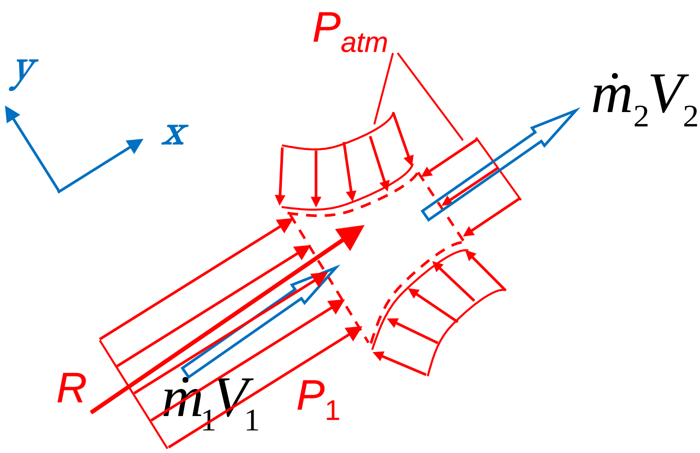
$$\dot{m}_1 = \rho A_1 \overset{?}{V_1}$$

$$\dot{m}_2 = \rho \dot{\forall}_2$$

$$= 62.4 \frac{lbm}{ft^3} 2000 \frac{gal}{\min} \left\langle \frac{ft^3}{7.48\ gal} \right\rangle \left\langle \frac{\min}{60\ s} \right\rangle = 278 \frac{lbm}{s}$$

$$V_1 = \frac{\dot{m}_1}{\rho A_1} = \frac{278\,\dfrac{\text{lbm}}{\text{s}}}{\left(62.4\,\dfrac{\text{lbm}}{\text{ft}^3}\right)\left(0.1364\text{ft}\right)} = 32.7\,\frac{\text{ft}}{\text{s}}$$

3. Apply *flow direction component* of **conservation of linear momentum** to the system. Be careful with pressures. Use this to solve for R.



$$\frac{d}{dt}(P_{x,sys}) = \sum F_{x,ext} + \sum_{in} \dot{m}\cdot V_x - \sum_{out} \dot{m}\cdot V_x$$

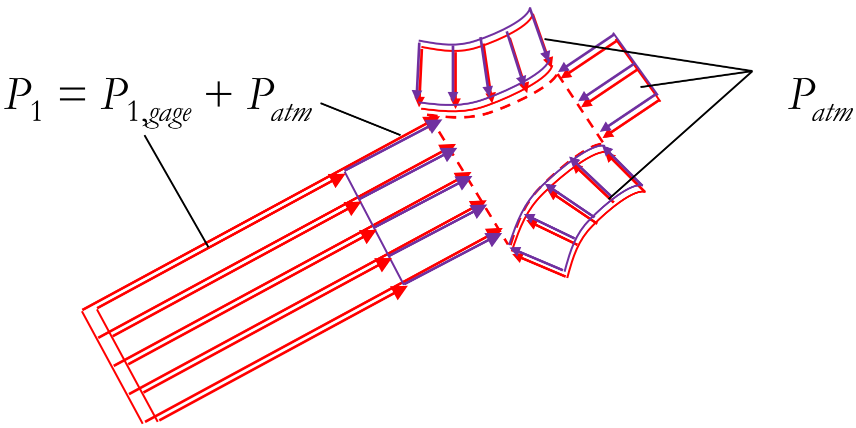
$$\underbrace{0 \text{ (Steady)}} = \underbrace{R + P_1 A_1 - P_{\text{atm}} \underset{A_1}{\cancel{A_{\text{projected}}}}} \underbrace{+\dot{m}\cdot V_1 \quad - \dot{m}\cdot V_2}$$

$$R = \dot{m}\left(V_2 - V_1\right) - \left(P_1 - P_{atm}\right)A_1$$

$$= \left(275\,\frac{\text{lbm}}{\text{s}}\right)\left(100 - 32.4\right)\frac{\text{ft}}{\text{s}}\left\langle \frac{\text{s}^2\text{-lbf}}{32.2\text{ lbm-ft}} \right\rangle - \left(40 - 14.7\right)\frac{\text{lbf}}{\text{in}^2}\left(0.1364\,\text{ft}^2\right)\left\langle \frac{144\text{ in}^2}{\text{ft}^2} \right\rangle$$

$$= 84.3\,\text{lbf}$$

4. Dealing with the pressures was a bit tedious. Here is a short cut we can use when *systems are almost completely surrounded by atmospheric pressure*. Treat the pressure at the inlet as the sum of two pressures, P_{atm} and the pressure above atmospheric, also called the **gage pressure**.



What is the resultant force due to P_{atm} and the atmospheric component of the inlet pressure? **0!**

5. Using the result of part 4., redraw your system and the any relevant transports. (I.e., use P_{gage} at the inlet.) Apply the *flow direction component* of conservation of linear momentum again and solve for *R*. Do you get the same answer? Which way was easier?