The University of Melbourne

School of Engineering

Semester 1 Assessment 2016

ENGR30002 – Fluid Mechanics

Exam Duration: 3 hours

Reading Time: 15 minutes

This paper has ELEVEN (11) pages consisting of SEVEN (7) questions.

Authorized material:
Only electronic calculators approved by the School of Engineering may be used.

Instructions to Invigilators:
Script books to be provided.

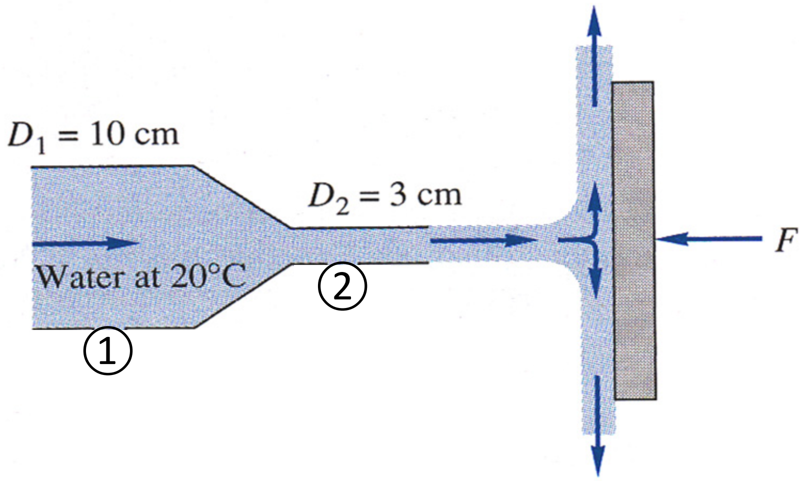
Instructions to Students:
All seven questions are to be attempted.
Total marks for the exam = 100.
Attachments after the questions:

- Moody diagram (Page 7)
- Supplemental figure A for Question 6 (Page 8)
- Fluid properties and physical constants (Page 9)
- Equation sheet (Pages 10-11)

This paper is to be held by the Baillieu Library

Question 1

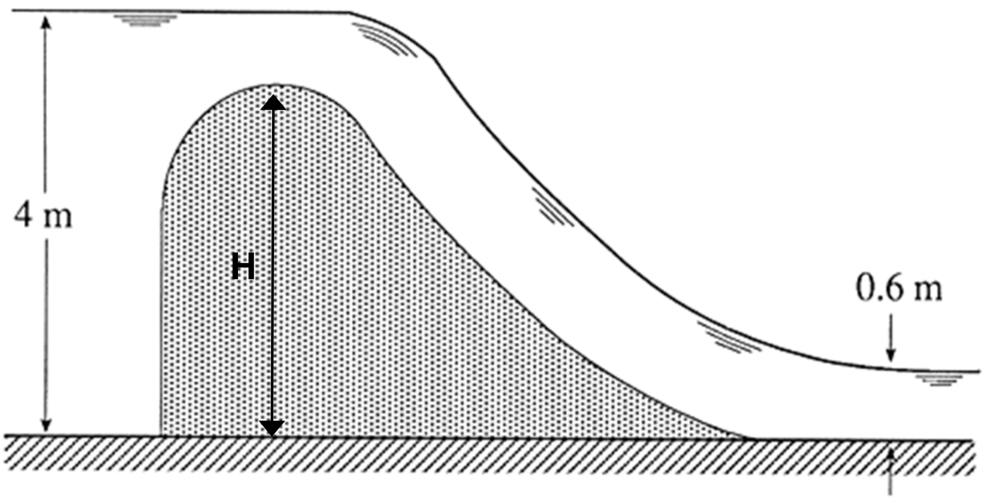
Water flows through a 10-cm-diameter pipe (which has a 3-cm-diameter circular nozzle at its end) before exiting into the air as a jet. The jet strikes a round plate (with a diameter of 20 cm). If the force required to hold the plate steady (F) is 70 N, determine the velocity and pressure in the pipe (i.e. at 1).



(Total for Question 1 = 15 marks)

Question 2

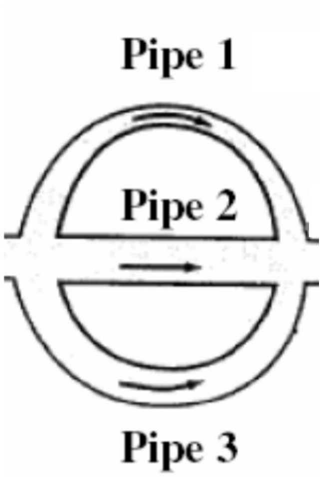
We have already examined flow over a spillway in this subject. For the same problem that we have looked at (shown in the figure below), calculate the height of the spillway (H).



(Total for Question 2 = 15 marks)

Question 3

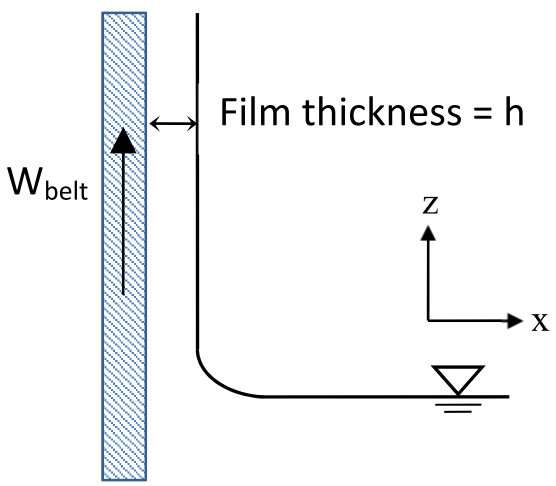
In the pipe network shown below, all three pipes are cast iron (with a roughness of 0.24 mm) and have a length of 2 m. Pipes 1 and 3 have diameters of 18 mm and Pipe 2 has a diameter of 24 mm. If the total flow rate of water through the network is 200 L/min, find the flow rate through each pipe (in L/min). You may neglect minor losses.



(Total for Question 3 = 15 marks)

Question 4

A vertical belt moves upwards and draws a thin film of fluid out of a tank. The fluid film maintains a constant thickness (h) along the belt. Assume the belt is very wide, and moves steadily at speed W_{belt}.



(a) If the ambient air is stationary such that it exerts no shear stress on the film, find the belt velocity for which there is no net flow (either up or down) in the film.

(10 marks)

(b) Sketch the velocity profile in the film for this value of the belt velocity, providing as much detail as possible. **(5 marks)**

(Total for Question 4 = 15 marks)

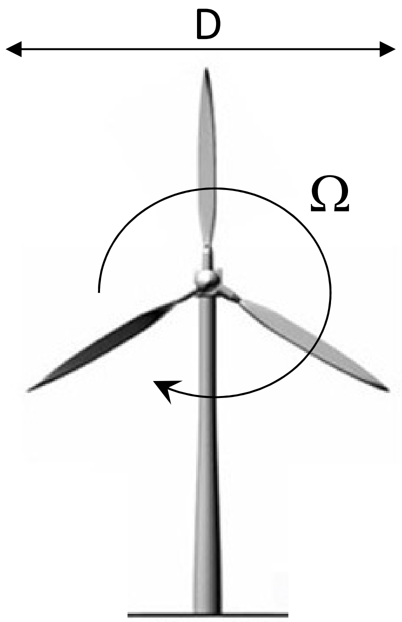
Question 5

The power generated by a single wind turbine in a wind farm depends upon several things:

(1) Properties of the turbine itself: diameter (D), rotation rate (Ω) and number of blades (n).

(2) Properties of the air: density (ρ) and velocity (U).

(3) Properties of the wind farm: the number of turbines per unit area (α)



You are looking at the power generation capacity of a proposed wind farm. The wind turbines on this farm will have a rotation rate of 12 rpm, and an average wind speed of 8 m/s. The wind farm will have 100 turbines in a 450 m x 450 m area.

(a) You create a model wind farm in a laboratory wind tunnel. Your model turbines are 1:40 scale models of the prototypes. If your model wind farm has 8 model turbines, what area should it cover? **(5 marks)**

(b) If the rotation rate of the model turbines is set at 120 rpm, what is the required air speed in the wind tunnel? **(5 marks)**

(c) If a model turbine generates 20 W, how much power will a real turbine generate? **(5 marks)**

(Total for Question 5 = 15 marks)

Question 6

(a) What type of pump is often used when pumping corrosive liquids? Why? **(1 mark)**

(b) What type of pump is often used when pumping biological samples? Why? **(1 mark)**

(c) What occurs when the pressure on the suction side of the pump is less than the vapour pressure of the fluid? Describe this phenomenon. What are the consequences of this phenomenon? **(2 marks)**

(d) You purchase a pump that has a discharge head of 15 m. Assuming the only loss in the piping system is due to pumping against gravity, how high can the pump elevate a column of water? How high could the pump elevate a column of light crude oil (the specific volume of the oil is 0.00116 m^3/kg and the dynamic viscosity is 9876 mPa.s)? Assume the pump is at $z = 0$ metres. **(2 marks)**

(e) Justin Bieber has recently purchased a new home in Melbourne, Australia. He has hired you to design a piping system to deliver water to a fountain in front of his house.

(e.1) The fountain requires a water flow rate of 30 L/min. You have decided to use a fixed speed pump. Pump curves are presented in Supplemental Figure A where head is measured in metres and flow is measured in L/min. List all of the pumps that could be used to supply the necessary flow rate.

(e.2) You've estimated the head loss of the system to be 4 m. Which of the pumps would be the most appropriate for this application?

(e.3) For a system head loss of 4 m, how much water will be supplied to the fountain?

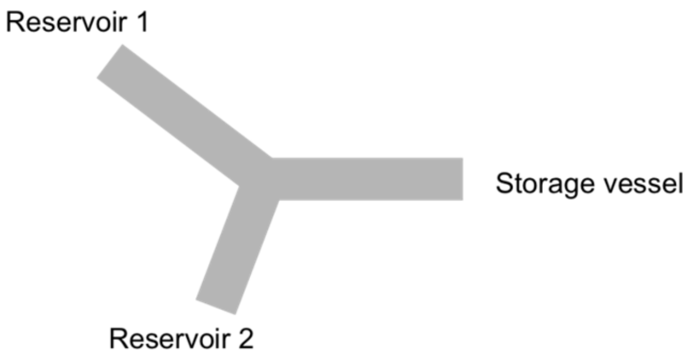
(e.4) What technique could you employ to supply closer to the desired 30 L/min? Briefly explain how this technique works?

(4 marks)

(Total for Question 6 = 10 marks)

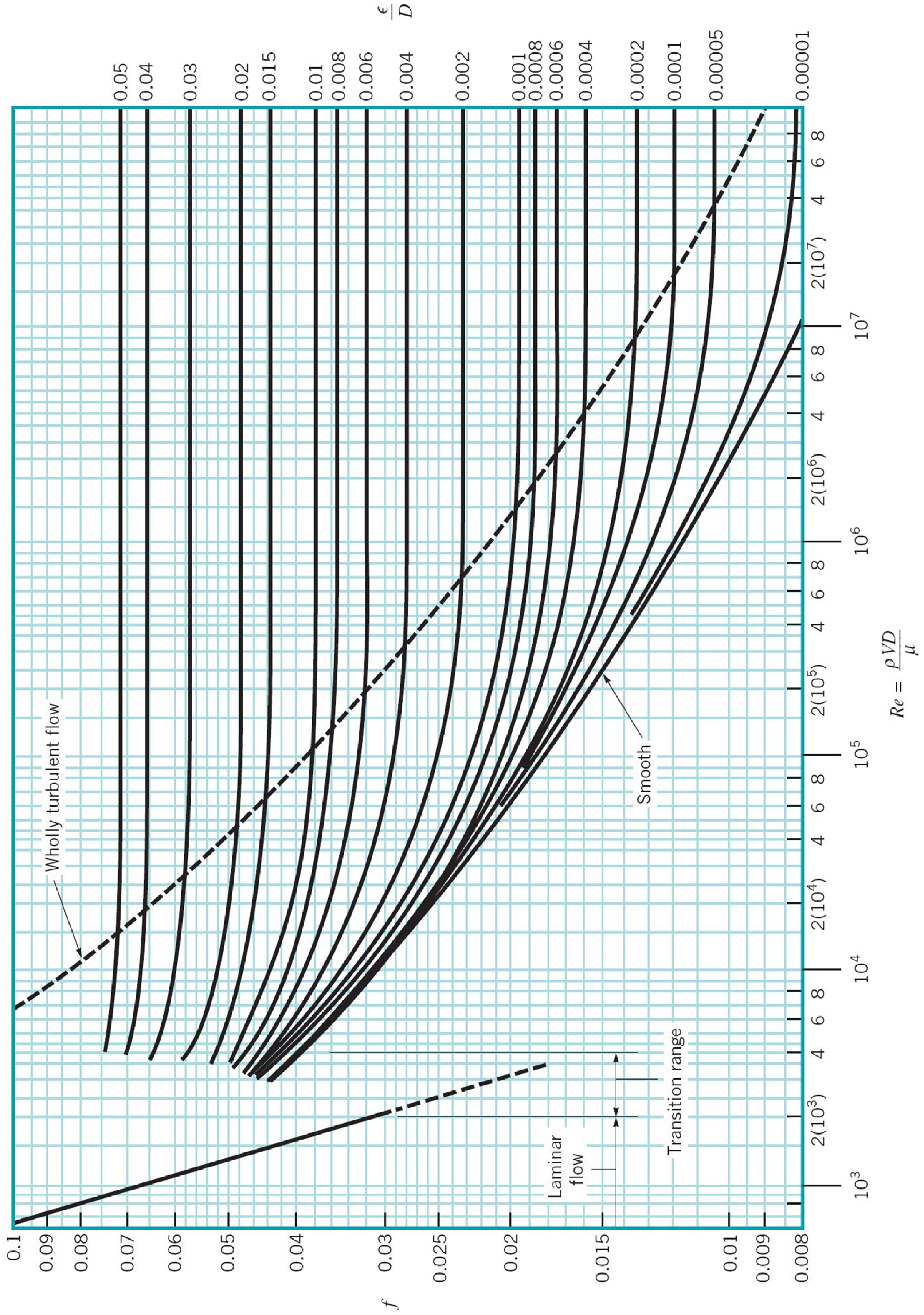
Question 7

Kim Kardashian has recently started her own natural gas company, KimWest Gas. At one of her production locations, she pumps gas from two underground reservoirs to a storage vessel, as shown below. The piping system is horizontal and isothermal. The gas pressure in reservoir 1 is 500 kPa and the pressure in reservoir 2 is 450 kPa. The mass flow rate of gas leaving reservoir 1 is 1.5 kg/s. The temperature is 25 ^{o}C, the molecular weight of natural gas is 19 g/mol, the density of the gas at 101 kPa is 0.85 kg/m^3, and the pipes have a constant Fanning friction factor (f_F) of 0.005 and a constant diameter of 15 cm. The length of the pipe from reservoir 1 to the joining point is 500 m. The length from reservoir 2 to the joining point is 300 m. The length from the joining point to the storage vessel is 500 m. Neglect kinetic energy and assume that the gas behaves ideally. What is the gas flow rate and gas velocity as it enters the storage vessel?

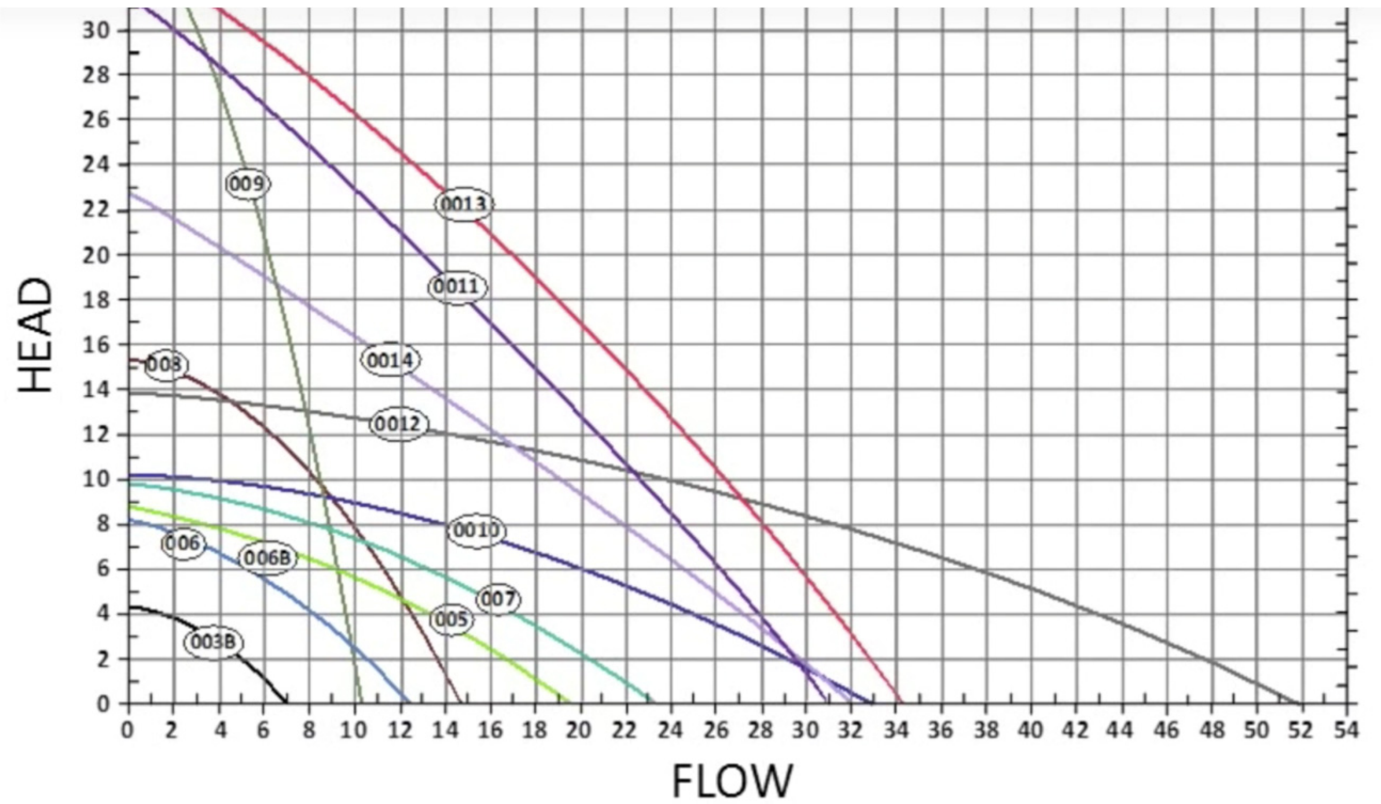


(Total for Question 7 = 15 marks)

MOODY DIAGRAM (FOR THE DARCY FRICTION FACTOR)



SUPPLEMENTAL FIGURE A



FLUID PROPERTIES AND PHYSICAL CONSTANTS

	Water	Air
ρ	998 kg/m^3	1.2 kg/m^3
ν	1×10^{-6} m^{2}s^{-1}	1.5×10^{-5} m^{2}s^{-1}
σ	0.07 N/m at the air-water interface	

Acceleration due to gravity, $g = 9.8$ ms^{-2}

Standard atmospheric pressure, $p_{atm} = 101.3$ kPa

EQUATION SHEET

Conservation of mass

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

Navier-Stokes equations

$$(x) \quad \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + g_x + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

$$(y) \quad \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + g_y + \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right)$$

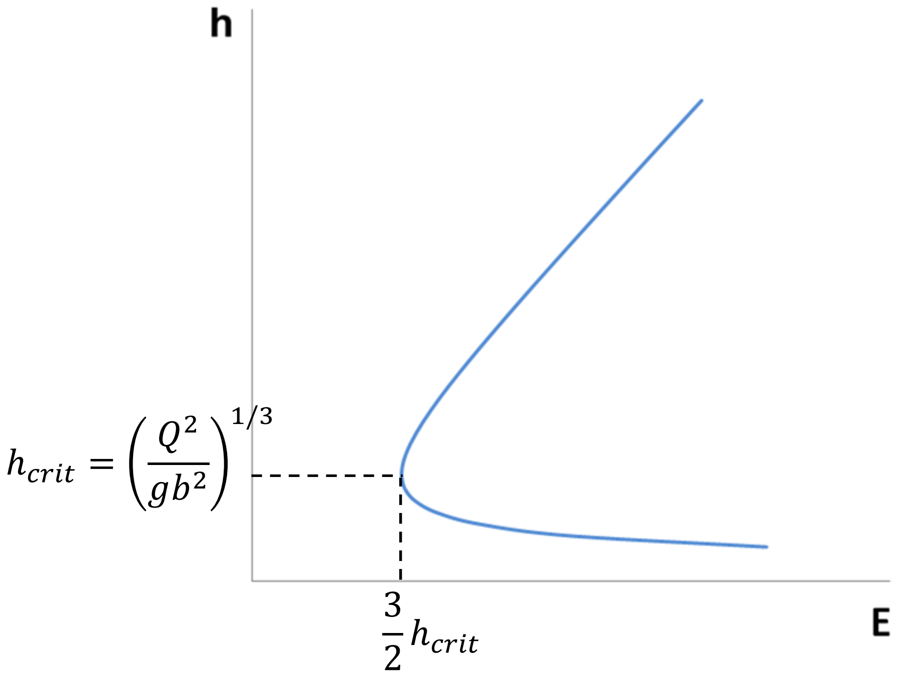
$$(z) \quad \frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} + g_z + \nu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right)$$

Manning's equation

$$U = \frac{1}{n} R_h^{2/3} S^{1/2}$$

Specific energy

$$E(h) = \frac{Q^2}{2gb^2h^2} + h$$



Hydraulic jumps

$$\frac{h_2}{h_1} = \frac{-1 + \sqrt{1 + 8Fr_1^2}}{2}$$

Compressible flow

$$\frac{P_2^2 - P_1^2}{2(RT/M)} + \left(\frac{G}{A}\right)^2 \ln\left(\frac{P_1}{P_2}\right) + \frac{2f_F L}{D}\left(\frac{G}{A}\right)^2 = 0$$

$$\frac{4f_F L_{crit}}{D} = \left(\frac{P_1}{P_w}\right)^2 - \ln\left(\frac{P_1}{P_w}\right)^2 - 1$$