MAE 494/598, Fall 2019, Project 2 – System of internal flow: design and analysis (12 points)
Hard copy of report is due at the start of class on the due date. As usual, please follow the rules for collaboration as given in the first page of the problem statement of Project #1.

All tasks are for both MAE598 and MAE494.

Background: A miniature irrigation system is shown in Fig. 1. It consists of a main pipe and 5 evenly spaced side pipes. All pipes are circular. Figure 1 also shows the cross sections of the apparatus along (i) the plane of symmetry and (ii) a plane perpendicular to the plane-of-symmetry that runs through the axis of a side pipe (e.g., side pipe 1). ***Water*** is pumped into the system through inlet "A" and leaves the system through the 5 side pipes and outlet "B". This project will quantify how the design of the system affects the mass flow rates associated to the side pipes. Task 2 serves as a mini example of using Ansys-Fluent to assist the design of an engineering system.

All tasks will seek *steady solution* using turbulence *k-epsilon* model (with default setting). The density of water is set to constant using the value in Fluent database. As usual, the mesh should be properly set up to ensure a reasonable resolution for the flow, particularly near the wall and within the side pipes.

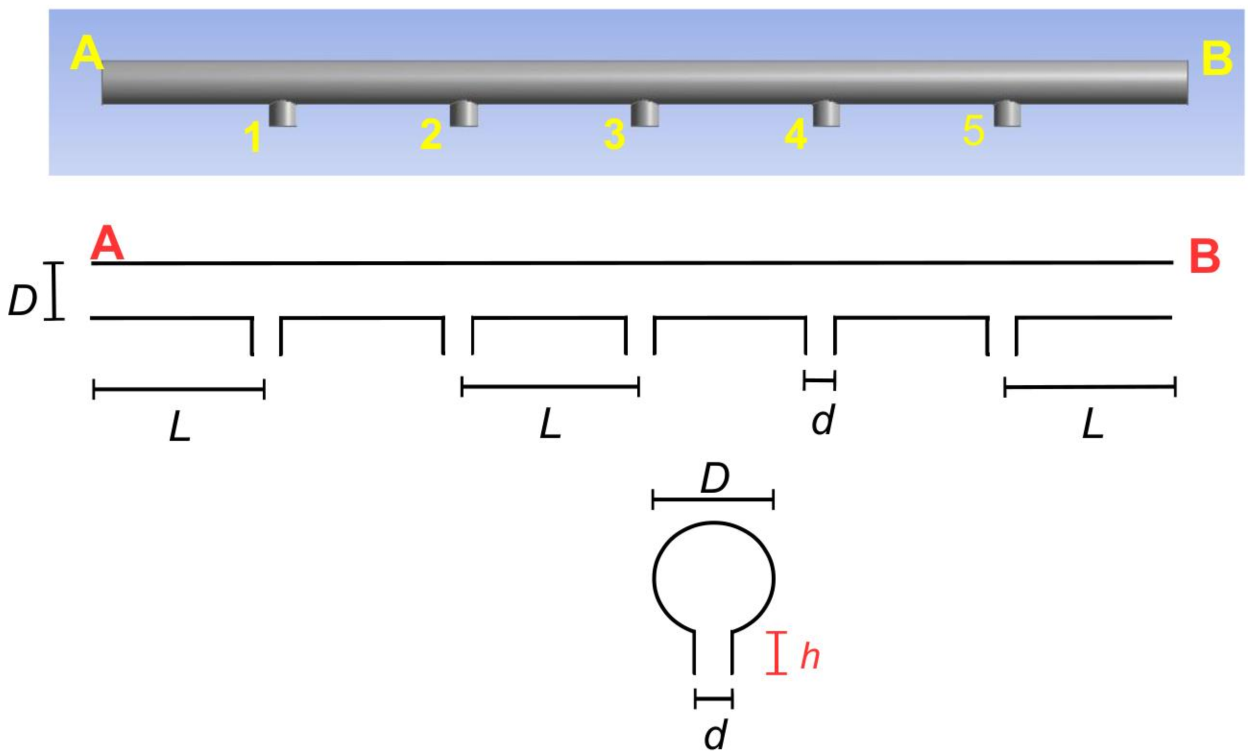

Fig. 1 The geometry of the prototypical irrigation system (not drawn to scale).

Task 1

Use the design shown in Fig. 1 with $L = 40$ cm, $D = 6$ cm, $d = 3$ cm, and $h = 5$ cm. Be aware that L is not the total length of the main pipe but only the spacing between two side pipes. The total length of the main pipe, from A to B, is 240 cm. (The "5 cm" for h is understood as measured along the axis of a side pipe. When creating a side pipe in the geometry, the actual extrusion should be longer than 5 cm or there will be a "kink" at the junction where the side pipe meets the main pipe.)

To precisely describe the boundary conditions, we assume that the main pipe runs in the positive *x*-direction (i.e., *x* increases from A to B), and the center of the circular opening of inlet A is the origin with $(x, y, z) = (0, 0, 0)$. Set inlet A as *velocity inlet* with zero gauge pressure and with a parabolic velocity profile for the *x-velocity* (not to be confused with *velocity magnitude*) as

$$u = 0.1\left(1 - \left(\frac{r}{R}\right)^2\right) \ m\, s^{-1} \quad ,$$

where $r = \sqrt{y^2 + z^2}$ is the radial distance from the center of the circular opening of the inlet, and $R = D/2 = 3$ cm is the radius of that circular opening. With this setup, u reaches the maximum of 0.1 m/s at $r = 0$, and minimum of 0 at the wall where $r = R$. Note that $u > 0$ so the flow goes *into* the pipe. Also, set the *y-velocity* and *z-velocity* to zero at the inlet.

(Note: It is important to set the inlet velocity as instructed. If u is set to just a constant, the result will be different and it will lead to a major deduction.)

Set the openings of all 5 side pipes and outlet "B" as *pressure outlet* with zero gauge pressure.

The deliverables are:

(i) A contour plot of the *x-velocity* on the surface of the inlet. This is to confirm that the boundary condition of parabolic profile is set correctly.

(ii) A plot of the mass flow rates (in kg/s) associated to the 5 side pipes. (Do not include the mass flow rate at outlet “B” in the plot.)

(iii) Line plots of *static pressure* and *x-velocity* (two separate plots) as a function of *x* along the axis of the main pipe.

Task 2 (This is the key task and is worth 80% of the total score for this project)

From the results of Task 1, one will find that mass flow rate decreases monotonically from side pipe 1 to 5 when all side pipes have the same diameter. Suppose that, for some applications, it is desirable to have a uniform mass flow rate across all side pipes. This task asks one to modify the system to make the mass flow rates associated to the 5 side pipes equal, or as close to equal as possible. Using the design in Task 1 as the basis, one is only allowed to modify the diameters of the side pipes. (The 5 side pipes are allowed to have different diameters. An obvious constraint is that the diameter of a side pipe cannot exceed the diameter of the main pipe.) Otherwise, the location (*x* coordinate) of the center of each side pipe has to remain the same as that in Task 1. All other settings must also be kept the same as in Task 1. The outcome of the exercise will be measured by the *S* index (the smaller it is, the better):

$$S = \frac{1}{M}\sqrt{\frac{1}{5}\sum_{k=1}^{5}(m_k - M)^2} \quad ,$$

where

$$M = \frac{1}{5}\sum_{k=1}^{5} m_k \quad ,$$

and m_k is the mass flow rate associated to the k-th side pipe. (M is the mean of the mass flow rate and S measures the deviation from the mean, normalized by M.) An “optimal design” with a uniform mass flow rate for all side pipes corresponds to $S = 0$. The deliverables of this task are:

(i) A description of the "best case" (i.e., the one with the smallest S) you are able to obtain, including

(1) The values of the diameters of the 5 side pipes
(2) A plot of the mass flow rates of the 5 side pipes similar to deliverable (ii) in Task 1
(Optionally, you might combine this plot with that in deliverable (ii) of Task 1 to show the contrast.)
(3) The value of "S" for this “best case” (To show the improvement, please also provide the value of “S” for the unmodified case from Task 1.)
(4) Line plots of *static pressure* and *x-velocity* along the axis of the main pipe, similar to deliverable (iii) in Task 1 but for the “best case”

(ii) A discussion on how the “best case” is obtained. What is your strategy to systematically lower the S value with successive modifications of the design? What is the justification for the strategy? How do you make the process of successive improvement efficient?

[Note: The discussion in (ii) is important. Expect a significant deduction if it is missing or deficient.]