Flow Through a Uniform Inclined Screen

Introduction

This example simulates the flow through a uniform inclined screen using the Screen feature in Single-Phase Flow physics and compares the results with an analytic solution due to Elder (Ref. 1). The Screen feature is a tool for modeling wire gauzes, perforated plates etc without resolving their geometric complexity (see the *CFD Module User's Guide* for further details).

Model Definition

The model geometry is shown in Figure 1.

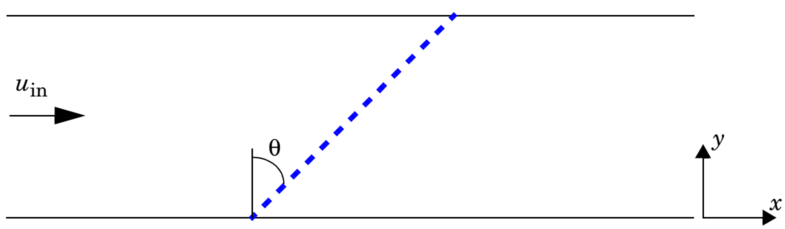

Figure 1: Model geometry showing flow direction and screen inclination.

Air at a temperature of $T = 20$ °C enters the channel on the left with a uniform inlet velocity of $u_{in} = 1$ m/s and exits on the right at uniform pressure, $p_0 = 0$ Pa. The flow through the channel is obstructed by a screen inclined at an angle θ. The combined effect of resistance and refraction (suppression of the tangential velocity component) creates a non-uniform velocity profile on the downstream side of the screen. An asymptotic solution valid for small inclinations is (Ref. 1),

$$\frac{(u/u_{in}-1)(1+\eta+K\cos^2\theta)}{(1-\eta)\tan\theta\cdot K\cos^2\theta} = \frac{2}{\pi}\log\left(\cot\left(\frac{\pi y}{2}\right)\right) \tag{1}$$

where K and η are the screen resistance and refraction coefficients. To facilitate comparison with the asymptotic solution, assume that the flow is incompressible and apply free-slip boundary conditions on the channel walls. Choose the user-defined option for both the screen type and refraction in order to set the resistance coefficient K to 2.2 and the refraction coefficient η to 0.78.

Results and Discussion

The study performs a Parametric Sweep with the angle θ taking the values,

$$\theta = \frac{\pi}{18}, \frac{\pi}{9}, \frac{\pi}{6}, \frac{2\pi}{9}, \frac{\pi}{4} \qquad (\theta = 10°, 20°, 30°, 40°, 45°)$$

Figure 2 shows the outlet velocity scaled according to the left-hand side of Equation 1 together with the asymptotic solution on the right-hand side.

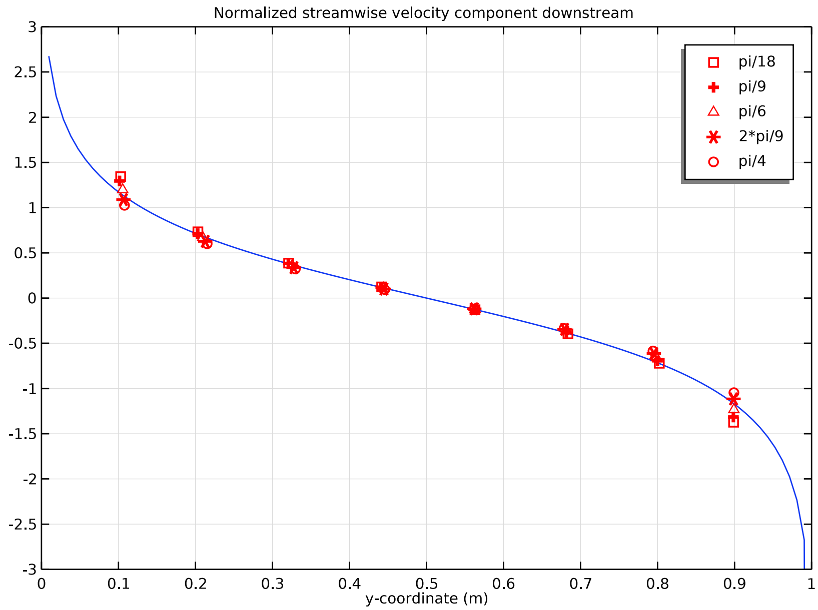

Figure 2: Comparison between the asymptotic solution (blue) and the simulations (red).

The agreement between the asymptotic solution and the simulations is good, surprisingly so even for $\theta = \pi/4$ (45 °). Figure 3 shows a surface plot of the pressure field together with velocity vectors on the upstream and downstream side of the screen. The velocity vectors are displaced from the screen for clarity. You can easily distinguish the induced pressure jump, the flow distribution and deflection. See Ref. 1 for asymptotic solutions to other related screen-flow problems if you are looking to extend the analysis to screens of varying shape and/or resistance.

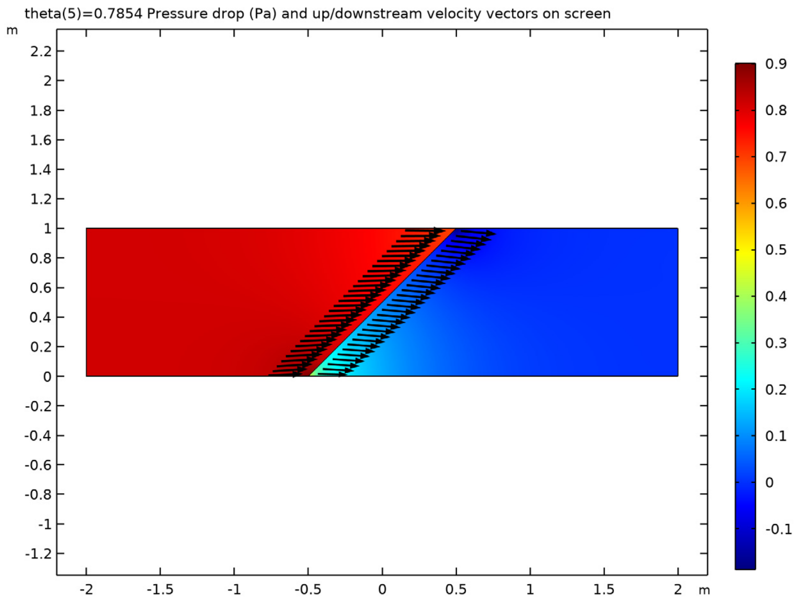

Figure 3: Pressure drop, flow distribution and deflection for a screen inclined at an angle of 45° to the incoming flow.

Notes About the COMSOL Implementation

The model uses the Screen feature together with a Parametric Sweep to vary the inclination angle of the screen.

Reference

1. J.W. Elder, “Steady Flow Through Non-Uniform Gauzes of Arbitrary Shape,” *J. Fluid Mech.*, vol 5, pp 355–363, 1959.

Application Library path: `CFD_Module/Verification_Examples/inclined_screen`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **2D**.

2 In the **Select Physics** tree, select **Fluid Flow>Single-Phase Flow>Laminar Flow (spf)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **General Studies>Stationary**.

6 Click **Done**.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
theta	pi/18	0.17453	Angle of inclination
u_in	1[m/s]	1 m/s	Inlet velocity

GEOMETRY 1

Rectangle 1 (r1)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type 4.

4 Locate the **Position** section. In the **x** text field, type -2.

Polygon 1 (pol1)

1 In the **Geometry** toolbar, click **Polygon**.

2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.

3 From the **Data source** list, choose **Vectors**.

4 In the **x** text field, type `-0.5*tan(theta) 0.5*tan(theta)`.

5 In the **y** text field, type `0 1 `.

6 In the **Geometry** toolbar, click **Build All**.

ADD MATERIAL

1 In the **Home** toolbar, click **Add Material** to open the **Add Material** window.

2 Go to the **Add Material** window.

3 In the tree, select **Built-in>Air**.

4 Click **Add to Component** in the window toolbar.

5 In the **Home** toolbar, click **Add Material** to close the **Add Material** window.

LAMINAR FLOW (SPF)

Wall 1

1 In the **Model Builder** window, under **Component 1 (comp1)>Laminar Flow (spf)** click **Wall 1**.

2 In the **Settings** window for **Wall**, locate the **Boundary Condition** section.

3 From the **Wall condition** list, choose **Slip**.

Inlet 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Inlet**.

2 Select Boundary 1 only.

3 In the **Settings** window for **Inlet**, locate the **Velocity** section.

4 In the U_0 text field, type `u_in`.

Outlet 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Outlet**.

2 Select Boundary 7 only.

3 In the **Settings** window for **Outlet**, locate the **Pressure Conditions** section.

4 Select the **Normal flow** check box.

Screen 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Screen**.

2 Select Boundary 4 only.

3 In the **Settings** window for **Screen**, locate the **Screen Type** section.

4 From the **Screen type** list, choose **User defined**. Locate the **Parameters** section. In the K text field, type `2.2`.

5 From the **Refraction** list, choose **User defined**. In the η text field, type `0.78`.

STUDY 1

Parametric Sweep

1 In the **Study** toolbar, click **Parametric Sweep**.

2 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
theta (Angle of inclination)	pi/18, pi/9, pi/6, 2*pi/9, pi/4	

5 In the **Study** toolbar, click **Compute**.

RESULTS

Create a new plot group to reproduce Figure 2.

1D Plot Group 3

In the **Home** toolbar, click **Add Plot Group** and choose **1D Plot Group**.

Line Graph 1

1 Right-click **1D Plot Group 3** and choose **Line Graph**.

2 Select Boundary 7 only.

Type in the analytic solution.

3 In the **Settings** window for **Line Graph**, locate the **y-Axis Data** section.

4 In the **Expression** text field, type `2/pi*log(cot(pi*y/2))`.

5 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

6 In the **Expression** text field, type `y`.

7 In the **1D Plot Group 3** toolbar, click **Plot**.

1D Plot Group 3

1 In the **Model Builder** window, click **1D Plot Group 3**.

2 In the **Settings** window for **1D Plot Group**, locate the **Axis** section.

3 Select the **Manual axis limits** check box.

4 In the **x minimum** text field, type 0.

5 In the **x maximum** text field, type 1.

6 In the **y minimum** text field, type -3.

7 In the **y maximum** text field, type 3.

Line Graph 2

1 In the **Model Builder** window, under **Results>1D Plot Group 3** right-click **Line Graph 1** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 From the **Dataset** list, choose **Study 1/Parametric Solutions 1 (sol2)**.

4 From the **Parameter selection (theta)** list, choose **From list**.

5 In the **Parameter values (theta)** list, select **0.17453**.

Scale the solutions for comparison with the analytic solution.

6 Locate the **y-Axis Data** section. In the **Expression** text field, type (u/u_in-1)/(1-0.78)/2.2/cos(theta)^2*(1+0.78+2.2*cos(theta)^2)/tan(theta).

7 Click to expand the **Coloring and Style** section. Find the **Line style** subsection. From the **Line** list, choose **None**.

8 From the **Color** list, choose **Red**.

9 Find the **Line markers** subsection. From the **Marker** list, choose **Square**.

10 Click to expand the **Legends** section. Select the **Show legends** check box.

11 From the **Legends** list, choose **Manual**.

12 In the table, enter the following settings:

Legends
pi/18

Line Graph 3

1 Right-click **Line Graph 2** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 In the **Parameter values (theta)** list, select **0.34907**.

4 Locate the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Plus sign**.

5 Locate the **Legends** section. In the table, enter the following settings:

Legends
pi/9

Line Graph 4

1 Right-click **Line Graph 3** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 In the **Parameter values (theta)** list, select **0.5236**.

4 Locate the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Triangle**.

5 Locate the **Legends** section. In the table, enter the following settings:

Legends
pi/6

Line Graph 5

1 Right-click **Line Graph 4** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 In the **Parameter values (theta)** list, select **0.69813**.

4 Locate the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Asterisk**.

5 Locate the **Legends** section. In the table, enter the following settings:

Legends
2*pi/9

Line Graph 6

1 Right-click **Line Graph 5** and choose **Duplicate**.

2 In the **Settings** window for **Line Graph**, locate the **Data** section.

3 In the **Parameter values (theta)** list, select **0.7854**.

4 Locate the **Coloring and Style** section. Find the **Line markers** subsection. From the **Marker** list, choose **Circle**.

5 Locate the **Legends** section. In the table, enter the following settings:

Legends
pi/4

1D Plot Group 3

1 In the **Model Builder** window, click **1D Plot Group 3**.

2 In the **Settings** window for **1D Plot Group**, click to expand the **Title** section.

3 From the **Title type** list, choose **Manual**.

4 In the **1D Plot Group 3** toolbar, click **Plot**.

5 In the **Title** text area, type `Normalized streamwise velocity component downstream`.

To generate Figure 3, continue with the steps below.

Surface

1 In the **Model Builder** window, expand the **Results>Velocity (spf)** node, then click **Surface**.

2 In the **Settings** window for **Surface**, locate the **Expression** section.

3 In the **Expression** text field, type `p`.

Arrow Line 1

1 In the **Model Builder** window, right-click **Velocity (spf)** and choose **Arrow Line**.

2 In the **Settings** window for **Arrow Line**, locate the **Expression** section.

3 In the **x component** text field, type `up(u)`.

4 In the **y component** text field, type `up(v)`.

5 Locate the **Coloring and Style** section. From the **Arrow base** list, choose **Head**.

6 Select the **Scale factor** check box.

7 In the associated text field, type `0.25`.

8 Locate the **Arrow Positioning** section. In the **Number of arrows** text field, type `30`.

9 Locate the **Coloring and Style** section. From the **Color** list, choose **Black**.

Selection 1

1 Right-click **Arrow Line 1** and choose **Selection**.

2 Select Boundary 4 only.

Deformation 1

1 In the **Model Builder** window, right-click **Arrow Line 1** and choose **Deformation**.

2 In the **Settings** window for **Deformation**, locate the **Expression** section.

3 In the **x component** text field, type `-0.05`.

4 In the **y component** text field, type `0`.

5 Locate the **Scale** section. Select the **Scale factor** check box.

6 In the associated text field, type `1`.

Arrow Line 2

1 Right-click **Arrow Line 1** and choose **Duplicate**.

2 In the **Settings** window for **Arrow Line**, locate the **Expression** section.

3 In the **x component** text field, type `down(u)`.

4 In the **y component** text field, type `down(v)`.

5 Locate the **Coloring and Style** section. From the **Arrow base** list, choose **Tail**.

Deformation 1

1 In the **Model Builder** window, expand the **Arrow Line 2** node, then click **Deformation 1**.

2 In the **Settings** window for **Deformation**, locate the **Expression** section.

3 In the **x component** text field, type `0.05`.

Velocity (spf)

1 In the **Model Builder** window, click **Velocity (spf)**.

2 In the **Settings** window for **2D Plot Group**, click to expand the **Title** section.

3 From the **Title type** list, choose **Manual**.

4 In the **Title** text area, type `Pressure drop (Pa) and up/downstream velocity vectors on screen`.

5 In the **Velocity (spf)** toolbar, click **Plot**.