Simulation of flow over a bridge using OpenFOAM

Sahl Abdelsayed

University of Sheffield

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Outline

Introduction

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We need some context...

A bit of context

In 1879, Tay bridge in Dundee Scotland has collapsed due to a violent storm [1].

A bit of context

Tacoma Narrows Bridge has collapsed in an unexpected manner in 1940.

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Improving the fundamental understanding of flow past a bridge by carrying out the appropriate simulations.

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As we all know, simulations bring about numerous advantages.

Aims and assumptions

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Assumptions

- Flow is laminar.
- Flow is incompressible.
- Air is a Newtonian fluid.
- Flow is transient, single phase, and isothermal.

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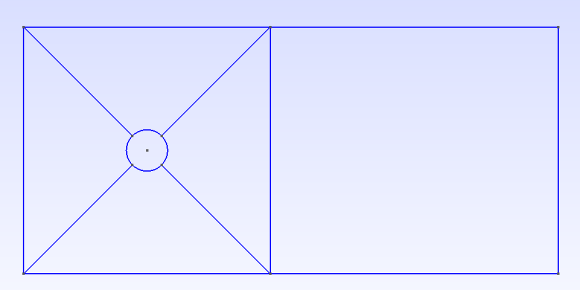

Figure 3.1: Shows the outline of the cylinder

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Extrusion is important as it will add surfaces as shown in Figure 3.2.

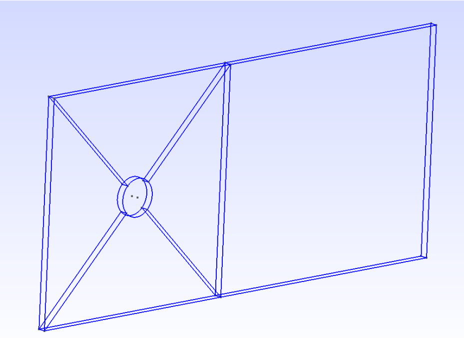

Figure 3.2: Shows the extruded cylinder.

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The result obtained are shown in Figure 3.3.

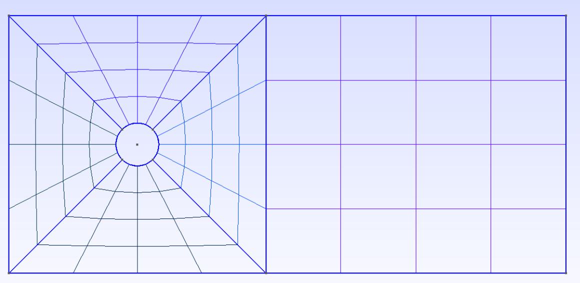

Figure 3.3: Shows the cylinder with the applied meshing.

Geometry

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This is an important step as it plays a big role in setting the boundary conditions.

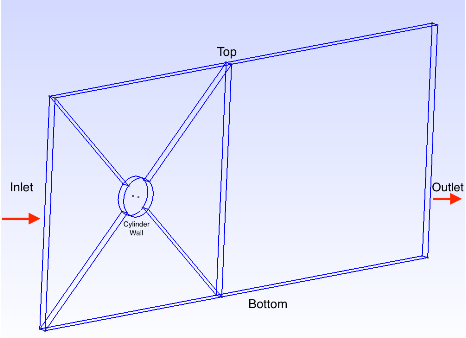

Figure 3.4: Shows the final geometry with labelled surfaces

Boundary conditions

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- Zero gradient at the outlet.
- Back and front wall were set as empty.

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To understand why outlet was set to 0, the Navier-Stokes equation should be studied.

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$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \overrightarrow{\mathbf{V}}) = 0 \tag{3.1}$$

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$$\nabla \cdot (\overrightarrow{\mathbf{V}}) = 0 \tag{3.2}$$

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Navier-Stokes equations

Navier-stokes momentum equation can be expressed as [2]

$$\frac{\partial(\rho\overrightarrow{\mathbf{V}})}{\partial t} + \rho\nabla\cdot(\overrightarrow{\mathbf{V}}\,\overrightarrow{\mathbf{V}}) = -\nabla\overline{P} + \mu(\nabla^2\overrightarrow{\mathbf{V}}) \qquad (3.3)$$

Dividing by ρ on both sides Equation 3.3 can be written as [3]

$$\frac{\partial(\overrightarrow{\mathbf{V}})}{\partial t} + \nabla\cdot(\overrightarrow{\mathbf{V}}\,\overrightarrow{\mathbf{V}}) = -\nabla\overline{p} + \nu(\nabla^2\overrightarrow{\mathbf{V}}) \qquad (3.4)$$

[2] ρ is the density, $\overrightarrow{\mathbf{V}}$ is the velocity vector, $\overline{P}$ is the pressure, and μ is the dynamic viscosity.

[3] $\overline{p}$ is the pressure per unit density and ν is the kinematic viscosity.

Non-dimensionalisation

Definition

Non-dimensionalisation is the process of eliminating units by suitable substitution.

Non-dimensionalisation facilitated setting the Reynolds number of each flow.

Non-dimensionalisation

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Hence...

$$\nu = \frac{1}{Re} \tag{3.7}$$

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Kinematic viscosity should be set at 0.05, 0.02, and 0.01 respectively.

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Having obtained the forces, the coefficient of lift C_L and coefficient of drag C_D can be calculated. [5]

$$C_L = \frac{2F_L}{\rho u^2 A} \tag{4.1}$$

$$C_D = \frac{2F_D}{\rho u^2 A} \tag{4.2}$$

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Time traces

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$$\hat{t} = \frac{tu}{D} \tag{4.3}$$

We know that velocity u=$1\,\mathrm{m\,s^{-1}}$ and diameter D= 1m hence..

$$\hat{t} = t \tag{4.4}$$

Time traces were then obtained by plotting coefficient of lift and coefficient of drag vs non-dimensional time.

Vortex shedding frequency and Strouhal number

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Having obtained the vortex shedding frequency, Strouhal number can be calculated using Equation 4.5

$$St = \frac{fD}{u} \tag{4.5}$$

Being given that u= $1\,\mathrm{m\,s^{-1}}$ and D= 1m Equation 4.5 simplifies to

$$St = f \tag{4.6}$$

The entire methodology process was done on MATLAB.

Velocity profile at Re=20

Stable flow and short separation length.

Velocity profile at Re=20

Stable flow and short separation length.

Pressure profile at Re=20

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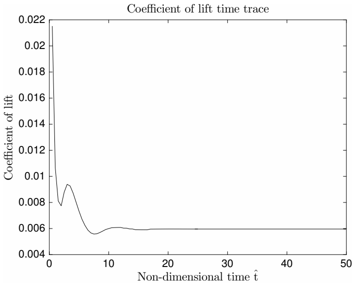
Constant difference in pressure, which creates constant force.

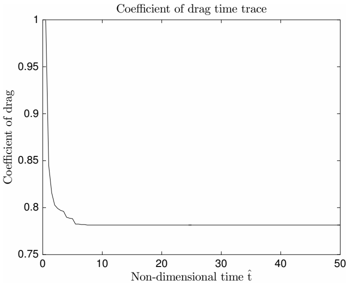
Pressure profile at Re=20

Constant difference in pressure, which creates constant force.

Time traces obtained at Re=20.

Having obtained the forces, time traces were plotted as shown below

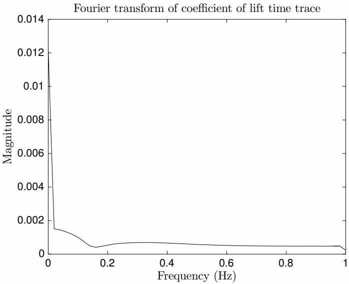




$C_L = 0.006$
$C_D = 0.7815$

Vortex shedding and Strouhal Number at Re=20

Applying Fourier transformation to coefficient of lift time trace we get..



No peaks observed, hence no vortex shedding

Velocity profile at Re=50

Velocity profile at Re=50

Initial oscillation occurs and larger separation length.

Velocity profile at Re=50

Initial oscillation occurs and larger separation length.

Pressure profile at Re=50

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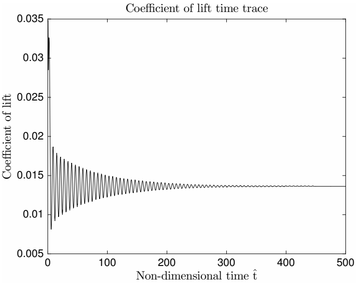
Slight fluctuation in pressure creates a slightly varying force.

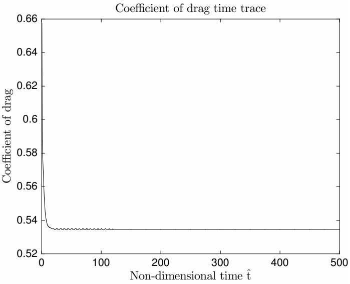
Pressure profile at Re=50

Slight fluctuation in pressure creates a slightly varying force.

Time traces obtained at Re=50

The time traces now can be plotted.



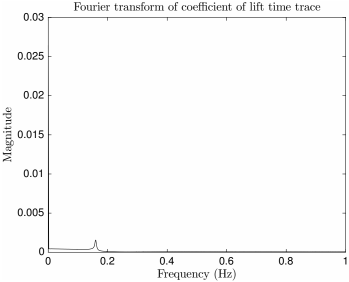


$C_L = 0.0136$

$C_D = 0.5345$

Vortex shedding and Strouhal Number Re=50

Applying Fourier transformation to coefficient of lift time trace we get..



$$\mathrm{St} = \mathrm{f} = 0.16$$

Velocity profile at Re=100

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Airflow constantly oscillating.

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Airflow constantly oscillating.

Pressure profile at Re=100

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Fluctuation in pressure creates a fluctuating force.

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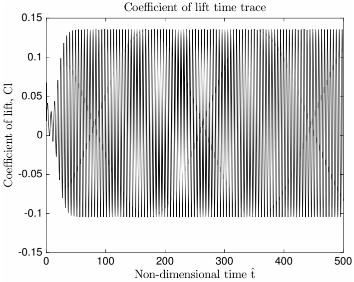
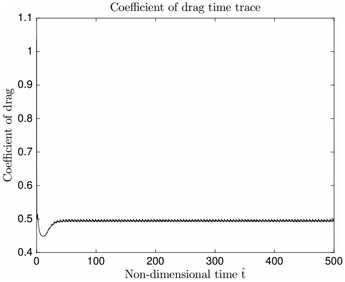
Time traces obtained at Re=100

Time traces obtained are shown below.



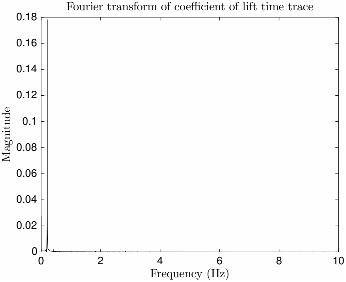


$C_L = 0.136 \leq C_l \leq$ -0.1048

$C_D = 0.493$

Vortex shedding and Strouhal number at Re=100

Applying Fourier transformation to coefficient of lift time trace we get..



St = f = 0.202

Velocity profiles

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Relative pressure per unit density at leading edge was 0.74, 0.619, and 0.542 m^2s^{-2} respectively.

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While, the pressure difference on top and bottom of the cylinder generates the lift force.

Fluctuation in pressure occurred in Reynolds number beyond 50.

Time traces and vortex shedding

	C_L	C_D	frequency f/Hz	Strouhal Number St
Re20	0.006	0.7815	none	none
Re50	0.0136	0.5345	0.16	0.16
Re100	0.136 $\leq C_l \leq$ -0.1048	0.493	0.202	0.202

Table 1: Shows the summary of results obtained.

Time traces and vortex shedding

	C_L	C_D	frequency f/Hz	Strouhal Number St
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Time traces and vortex shedding

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Re100	$0.136 \leq C_l \leq$ -0.1048	0.493	0.202	0.202

Table 1: Shows the summary of results obtained.

It can be established:

- As Reynolds number increases C_D decreases.
- As Reynolds number increases C_L increases.
- Vortex shedding starts forming from Reynolds number 50.
- As Reynold's number increases Strouhal number increases.

Next Step?

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Further work to be done:

Next Step?

Further work to be done:

- Explore Turbulence models.
- Set Variable boundary conditions.
- Attempt to use a real bridge geometry.

OpenFOAM vs ANSYS

	OpenFOAM	**ANSYS**
Advantages	1) Free license and open source 2) Improves understanding of flow	1) Good user interface 2) More matured
Disadvantages	1) Lack of user interface 2) No structured learning guidelines	1) Expensive license 2) Can be used as a black box

References I

[1] **Biezma, María Victoria and Schanack, Frank**, "Collapse of steel bridges," *Journal of performance of constructed facilities*, vol. 21, no. 5, pp. 398–405, 2007.

[2] **Green, Daniel and Unruh, William G**, "The failure of the tacoma bridge: A physical model," *American journal of physics*, vol. 74, no. 8, pp. 706–716, 2006.

Thank you for your undivided attention.