

Flow in a Convergent-Divergent Nozzle

Spoken Tutorial Project
<https://spoken-tutorial.org>

National Mission on Education through ICT

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IIT Bombay

25 August 2023



Learning Objectives

We will learn to:



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We will learn to:

- ▶ **Create an** `axi-symmetric geometry using blockMesh`



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- ▶ **Set up and run a case of** `compressible flow`



System Specifications



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► Ubuntu Linux OS version 22.04



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- ▶ **Ubuntu Linux OS version 22.04**
- ▶ **OpenFOAM version 9**



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- ▶ **gedit Text Editor**



Prerequisites



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- ▶ **You should have basic knowledge of compressible flows and gas dynamics**



Prerequisites

- ▶ **You should have basic knowledge of compressible flows and gas dynamics**
- ▶ **You should be familiar with setting up a case and creating a mesh in OpenFOAM**



Prerequisites

- ▶ If not, please go through the prerequisite `OpenFOAM` tutorials on <https://spoken-tutorial.org>



Code Files

- ▶ **The files used in this tutorial are available in the `Code Files` link on the tutorial page**



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- ▶ **Please download and extract them**



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- ▶ **Please download and extract them**
- ▶ **Make a copy and then use them while practising**



Convergent-Divergent Nozzle

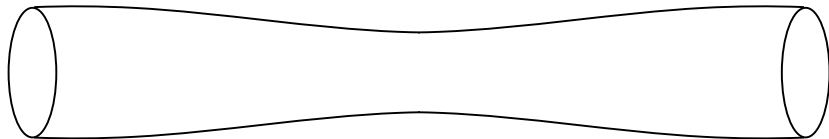
Inlet

$$p_0 = 10000 \text{ Pa}$$

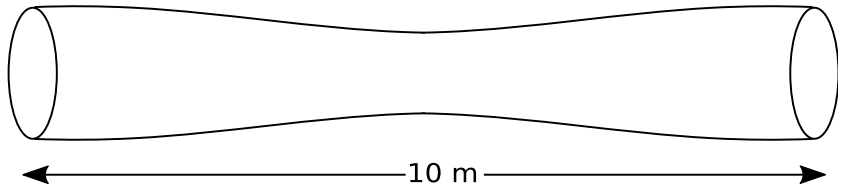
$$T = 298 \text{ K}$$

Outlet

$$p = 7500 \text{ Pa}$$

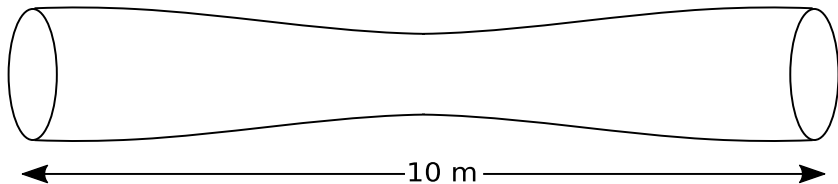


Convergent-Divergent Nozzle



Convergent-Divergent Nozzle

$$A(x) = 1.75 - 0.75\cos(0.2x-1)\pi$$



Axi-symmetric Geometry

- ▶ Axi-symmetric **geometry** can be **created in** OpenFOAM **using the** wedge **patch type**



Axi-symmetric Geometry

- ▶ Axi-symmetric **geometry** can be **created in** OpenFOAM **using the** wedge **patch type**
- ▶ The geometry is a wedge of small angle, usually less than 5°

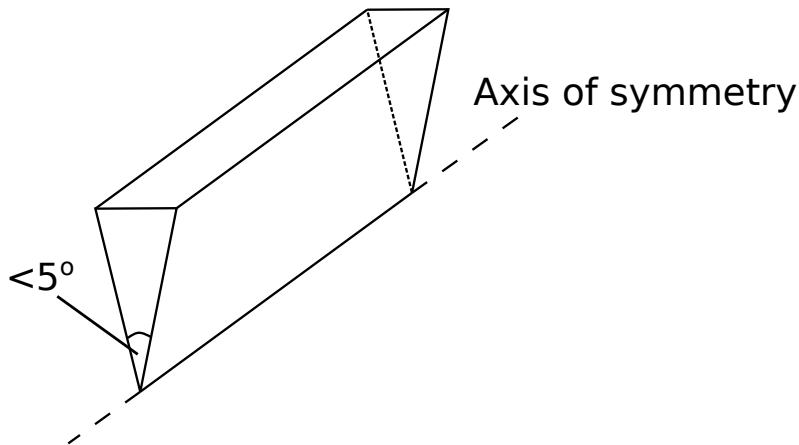


Axi-symmetric Geometry

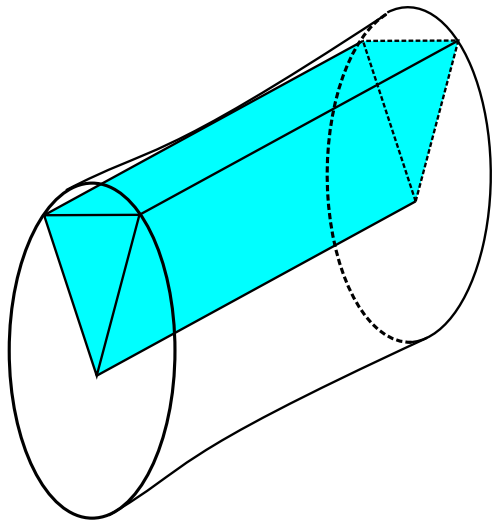
- ▶ Axi-symmetric **geometry** can be **created in** OpenFOAM **using the** wedge **patch type**
- ▶ **The geometry is a** wedge **of small** angle, **usually less than** 5°
- ▶ **It has 1 cell normal to the** planes of symmetry



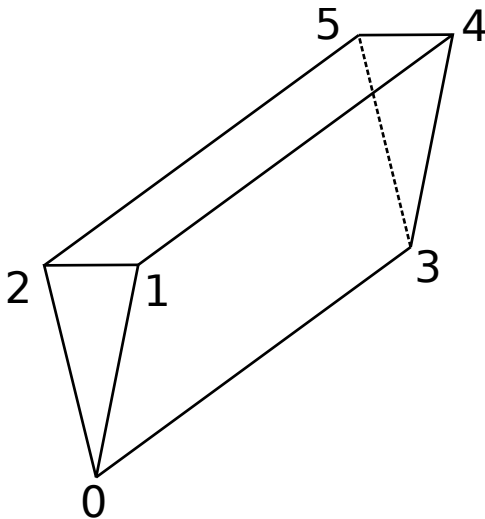
Axi-symmetric Geometry



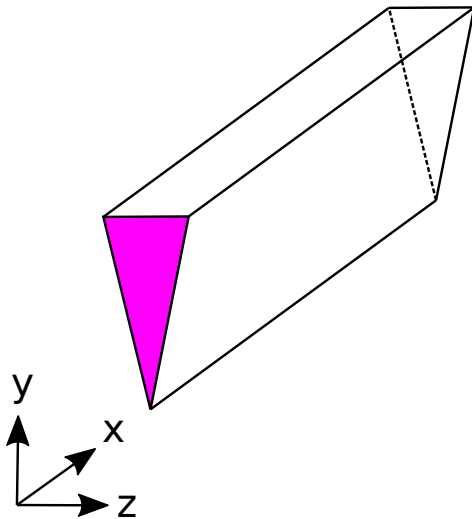
Axi-symmetric Geometry



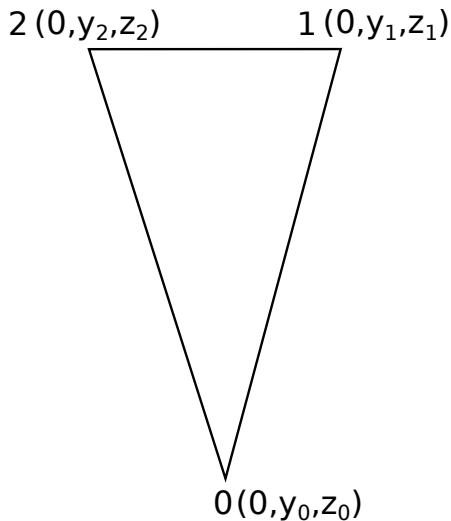
Vertices



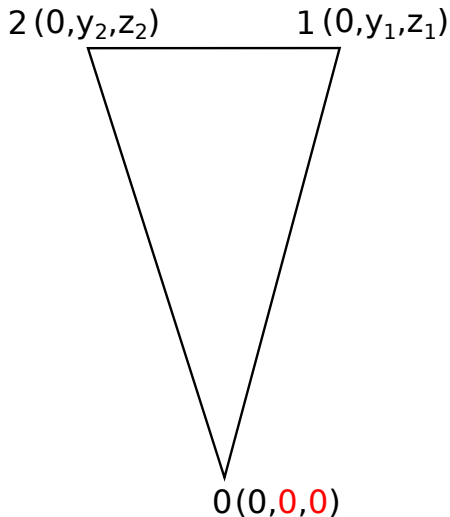
Vertex Coordinates



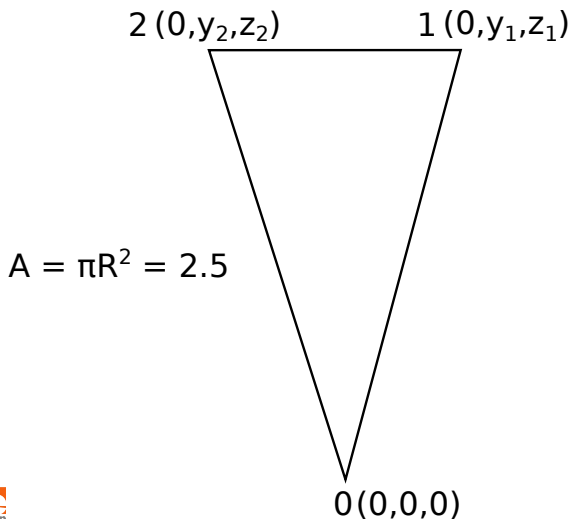
Vertex Coordinates-Inlet



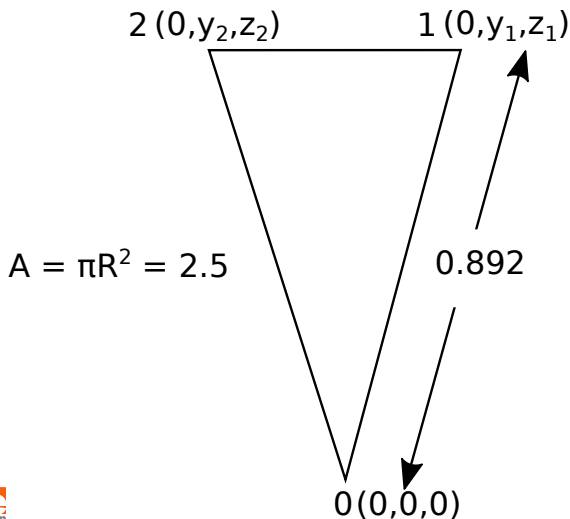
Vertex Coordinates-Inlet



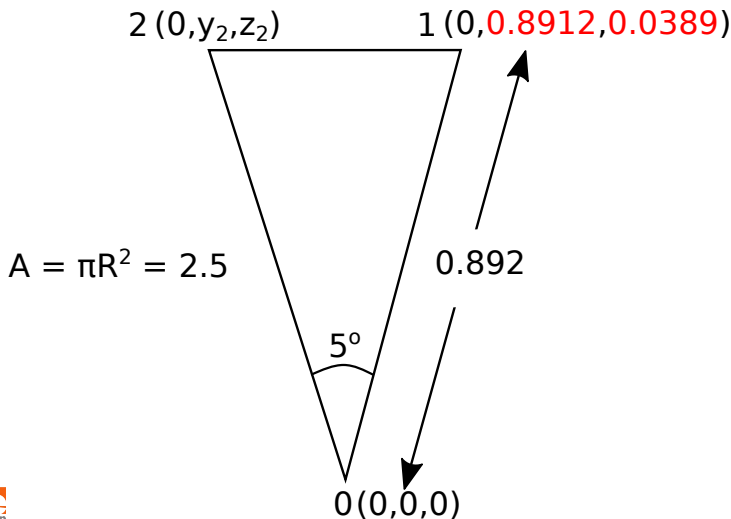
Vertex Coordinates-Inlet



Vertex Coordinates-Inlet



Vertex Coordinates-Inlet



Vertex Coordinates-Inlet

2 (0, **0.8912**, -0.0389)

1 (0, 0.8912, 0.0389)

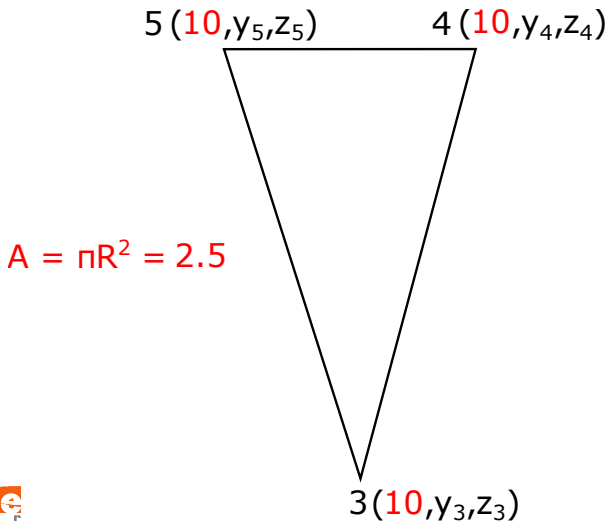
$$A = \pi R^2 = 2.5$$

0.892

0 (0, 0, 0)



Vertex Coordinates-Outlet



Vertex Coordinates-Outlet

5(10,0.8912,-0.0389) 4(10,0.8912,0.0389)

$$A = \pi R^2 = 2.5$$

3(10,0,0)



Spline



It requires:



Spline

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- ▶ **The 2 vertices that edge connects**



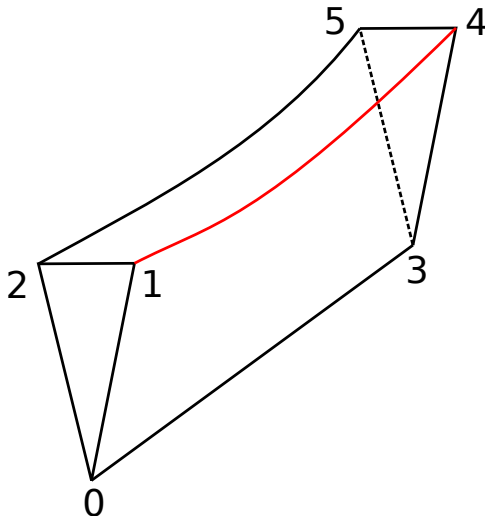
Spline

It requires:

- ▶ **The 2 vertices that edge connects**
- ▶ **The interpolation points through which edge passes**



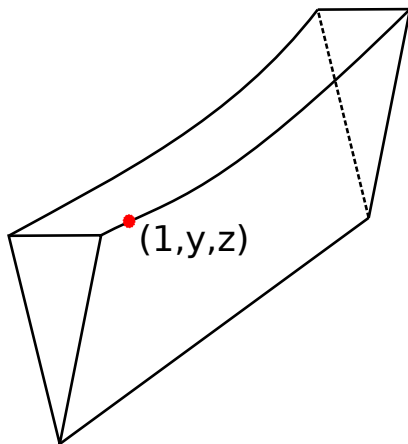
Front Edge



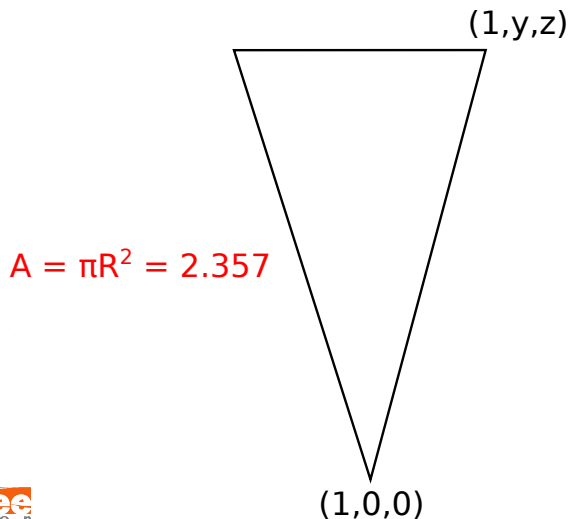
Interpolation Points



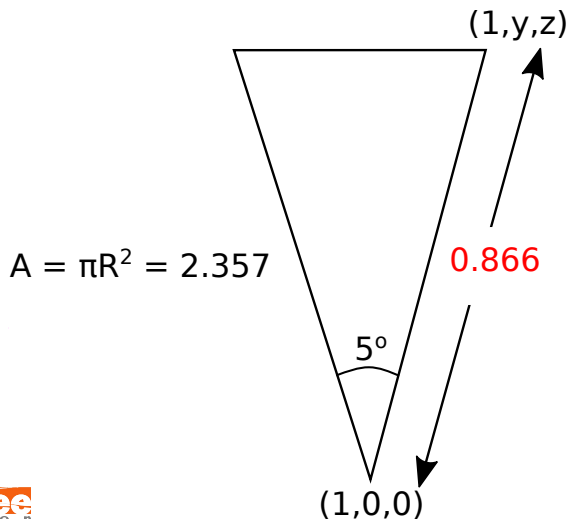
Interpolation Points



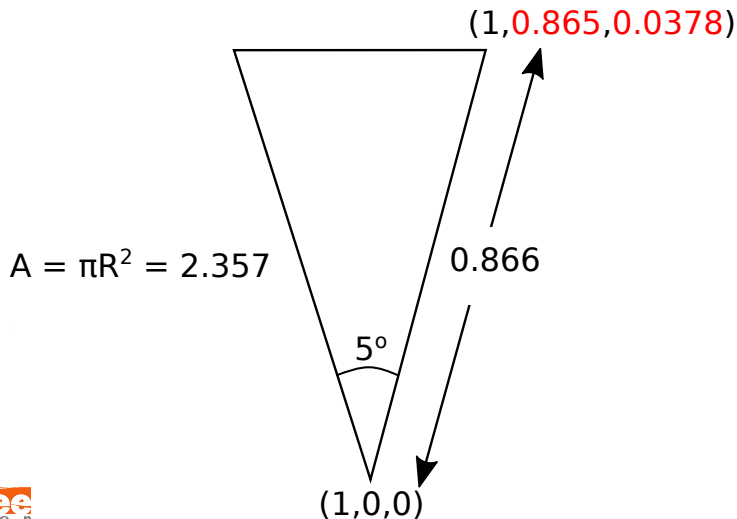
Interpolation Points



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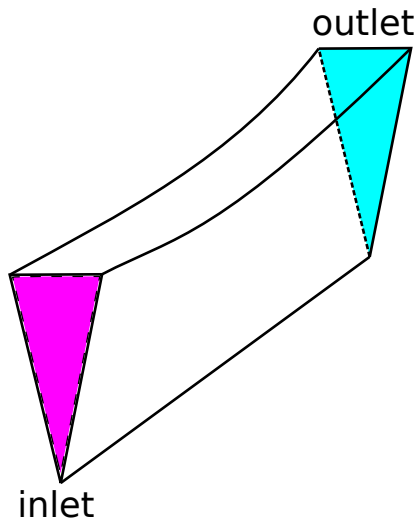
Interpolation Points



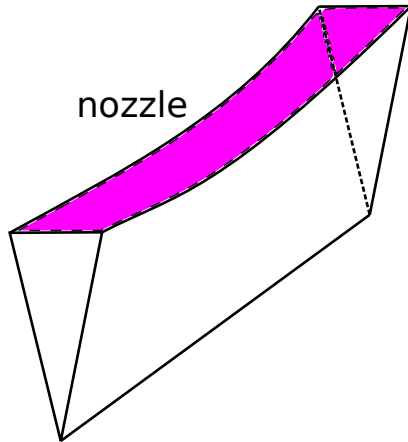
Boundary



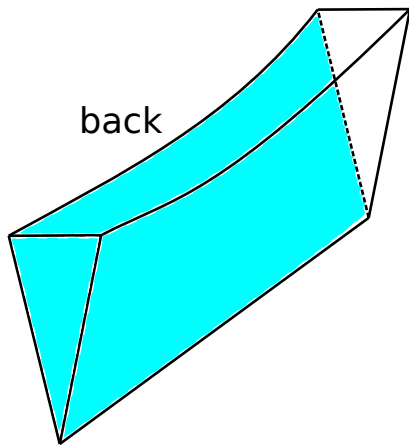
Boundary



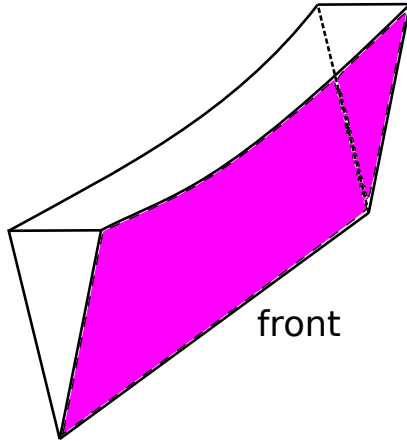
Boundary



Boundary



Boundary



Boundary Conditions

Boundary	Temperature	Velocity
inlet	298 K	zeroGradient
outlet	zeroGradient	zeroGradient
nozzle	zeroGradient	slip
back	wedge	wedge
front	wedge	wedge



Thermophysical Properties

- ▶ **The** molecular weight **of** air
is 29 g/mol



Thermophysical Properties

- ▶ **The** molecular weight **of** air **is** 29 g/mol
- ▶ **The** specific heat at constant pressure (c_p) **is** 1005 J/kg-K



Thermophysical Properties

- ▶ **Since we don't consider any phase change, the heat of fusion (H_f) can be taken as 0**



Transport Properties

Since the flow is inviscid,
viscosity **and** thermal
conductivity **effects are ignored**



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► Viscosity (μ) can be taken as 0



Transport Properties

Since the flow is inviscid,
viscosity **and** thermal
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- ▶ Viscosity (μ) can be taken as 0
- ▶ The Prandtl number (Pr) can be taken as 1



rhoCentralFoam



- ▶ **A** density-based compressible flow **solver**



rhoCentralFoam

- ▶ **A** density-based compressible flow **solver**
- ▶ **Based on** central-upwind schemes **of** Kurganov **and** Tadmor



Summary

We have learnt to:

- ▶ **Create an** `axi-symmetric geometry using blockMesh`
- ▶ **Create** `spline curved edge using blockMesh`
- ▶ **Set up and run a case of** `compressible flow`



Assignment



Assignment

- ▶ **Change the** outlet pressure **to** 8900 Pa
- ▶ **Keep all the other parameters the same and run the simulation**
- ▶ **View the** steady-state pressure contour **in** ParaView



About the Spoken Tutorial Project

- ▶ Watch the video available at https://spoken-tutorial.org/What_is_a_Spoken_Tutorial
- ▶ It summarises the Spoken Tutorial project
- ▶ If you do not have good bandwidth, you can download and watch it



Spoken Tutorial Workshops

The Spoken Tutorial Project Team

- ▶ Conducts workshops using spoken tutorials
- ▶ Gives certificates to those who pass an online test
- ▶ For more details, please write to contact@spoken-tutorial.org



Spoken Tutorial Forum

- ▶ **Questions in THIS Spoken Tutorial?**
- ▶ **Visit** <https://forums.spoken-tutorial.org>
- ▶ **Choose the minute and second where you have the question**
- ▶ **Explain your question briefly**
- ▶ **The Spoken Tutorial project will ensure an answer**

You will have to register to ask questions



FOSSEE Forum

- ▶ Questions not related to the Spoken Tutorial?
- ▶ Do you have general / technical questions on the Software?
- ▶ Please visit the FOSSEE Forum <https://forums.fossee.in/>
- ▶ Choose the Software and post your question



FOSSEE Case Study Project

- ▶ The FOSSEE team coordinates solving feasible CFD problems of reasonable complexity using OpenFOAM
- ▶ We give honorarium and certificates to those who do this
- ▶ For more details, please visit:
<https://cfd.fossee.in/>
<https://fossee.in/>



Acknowledgements

- ▶ **Spoken Tutorial and FOSSEE Projects was established by the Ministry of Education, Govt. of India**

