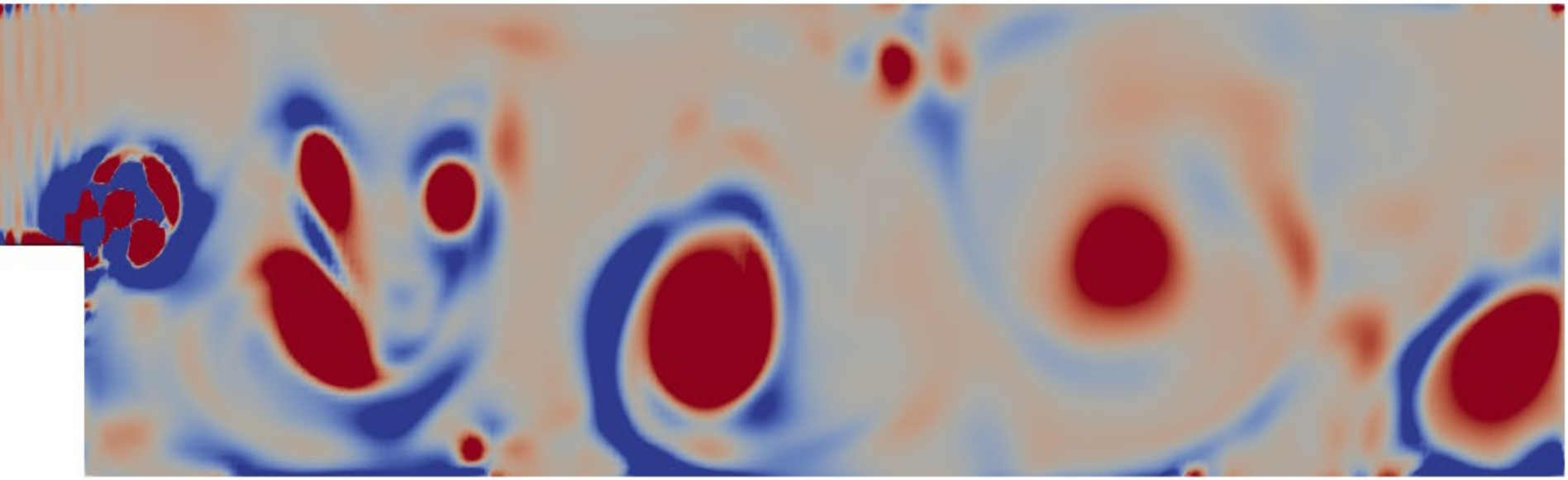

COMMUNITY CHRISTMAS COMPETITION IV
SIMULATION OF THE BACKWARD FACING STEP

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Problem Description and workflow

Steps	Validation of the backward facing step using openFOAM simulations
1.	Generation of 2D blockMesh of given geometry and applied appropriate initial boundary conditions (BC)
2.	Selection of turbulence model and solver from RAS, LES and laminar
3.	Comparison of incompressible and compressible solvers using RAS models
4.	Selection of a compressible solver to simulate non-reacting flow and combustion solver for reacting flow

blockMesh (2D)

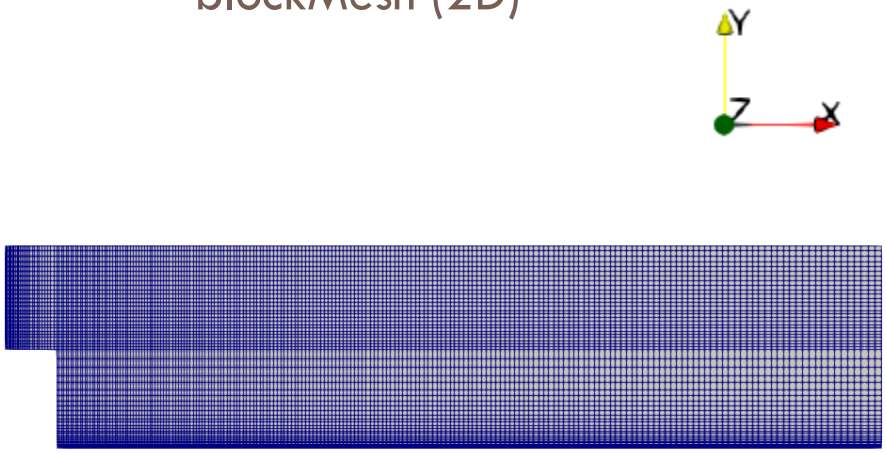

Fig.1: Generated blockMesh configuration for 11k cells.

Mesh Independency & BC

Mesh	For mesh independency, n=1.5 factor used to increase cells in x and y directions. Coarse mesh (4.8k), medium mesh (11k) and fine mesh (25.6k) cells.
common BC	T = 300 k p = 1 bar Ø = 0.57
Terminal ogy	X_R Reattachment length fun = {k, epsilon, omega} fun1= fun(U1), fun2= fun(U2), fun3= fun(U3)

Boundary Conditions : non-Reacting and reacting flow

Solvers/Turbulence Model Velocity (U), m/s	inlet	outlet	Wall (remaining)
rhoPimpleFoam & pimpleFoam & pisoFoam k-epsilon / realizable k-epsilon	U, k, epsilon: fixedValue k_1= 0.286 k_2= 0.56 k_3= 1.366 U_1= 9,1 U_2=13.3 U_3=22.2 $epsilon_1$= 14.37 $epsilon_2$=39.34 $epsilon_3$=150	U, k, epsilon: ZeroGradient	U: noSlip k: kqRWallFunction epsilon: epsilonWallFunction
rhoPimpleFoam & pimpleFoam & pisoFoam k-omega / k-omega SST	U, k, omega: fixedValue U and k are same as above $omega_1$= 558 $omega_2$= 781$omega_3$=1219	U, k, omega: ZeroGradient	U: noSlip omega: omegaWallFunction
rhoPimpleFoam LES (keqn model)	U: fixedValue nut: calculated	U: ZeroGradient Nut: calculated	U: noSlip nut: nutkWallFunction
XiFoam (k-omega SST)	U, omega, k, nut are same as above Su/Xi: fixedValue $Su\_C_3H_8$=0.44 m/s; Su_(premixed)~0.09 m/s	U: ZeroGradient Su/Xi: inletOutlet	U: noSlip omega: omegaWallFunction Su/Xi: zeroGradient

Model Validation : non-Reacting flow (rhoPimpleFoam)

Turbulence Model (RAS) Velocity (U), m/s		Cell count: 4.8 k		Cell count: 11 k		Cell count 25.6 k	
		X_R (in m)	Error %	X_R (in m)	Error %	X_R (in m)	Error %
k-epsilon	$U_1 = 9.1$	0.147	-10.5	0.155	-7.5	0.156	-4.1
	$U_2 = 13.3$	0.146	-19.8	0.153	-14.3	0.158	-10.7
	$U_3 = 22.2$	0.16	-6.2	0.155	-9.6	0.157	-8.2
k-omega	$U_1 = 9.1$	0.151	-7.6	0.164	0.9	0.164	0.91
	$U_2 = 13.3$	0.147	-19.0	0.151	-15.8	0.157	-11.4
	$U_3 = 22.2$	0.145	-17.2	0.15	-13.3	0.147	-15.6
Realizable k-epsilon	$U_1 = 9.1$	0.179	9.2	0.183	11.2	0.187	13.1
	$U_2 = 13.3$	0.182	3.8	0.184	4.8	0.189	7.4
	$U_3 = 22.2$	0.176	3.4	0.182	6.5	0.188	9.5
k-omega SST (* selected)	$U_1 = 9.1$	0.166	2.1	0.166	2.1	0.161	-0.93
	$U_2 = 13.3$	0.163	-7.3	0.169	-3.5	0.168	-4.1
	$U_3 = 22.2$	0.15	-13.3	0.165	-2.9	0.169	-0.59

Model Validation : comparison of solvers (non-reacting flow)

Solvers U (velocity in m/s)		Cell count: 11 k	
		X_R (in m)	Error %
pimpleFoam laminar	U_1	0.125	>15
	U_2	0.15	>15
	U_3	0.162	-4.9
pisoFoam k-omega SST	U_1	0.149	-9.0
	U_2	0.156	-12.1
	U_3	0.159	-6.9
pimpleFoam k-omega SST	U_1	0.151	-7.6
	U_2	0.155	-12.9
	U_3	0.168	-1.2
rhoPimpleFoam LES	U_1	0.16	-1.5
	U_2	0.164	-6.7
	U_3	0.16	-6.25

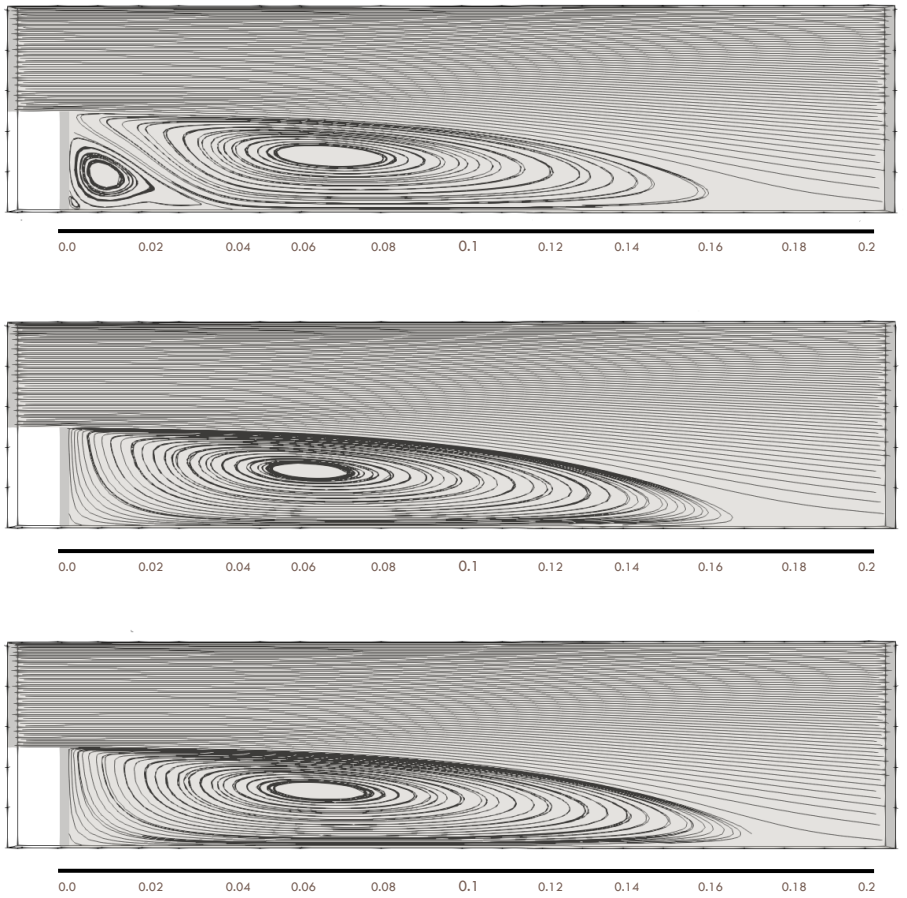

Fig.2: Stream line plots for fine mesh are generated using rhoPimpleFoam solver. Plots are shown for U_1, U_2, U_3.

Model Validation : continuation

Solvers U (velocity in m/s)		Cell count: 11 k	
		X_R (in m)	Error %
XiFoam k-omega SST	U_1	0.12	10.4
	U_2	0.125	10
	U_3	0.134	1.12

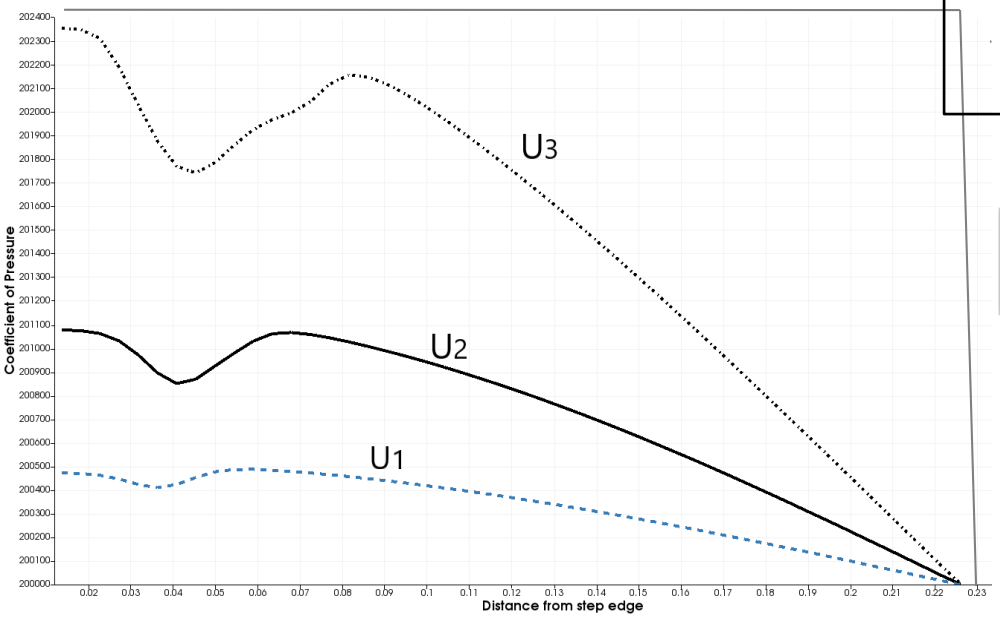

Fig.3.1: Static pressure coefficient values are plotted using rhoPimpleFoam for U_1, U_2, U_3.

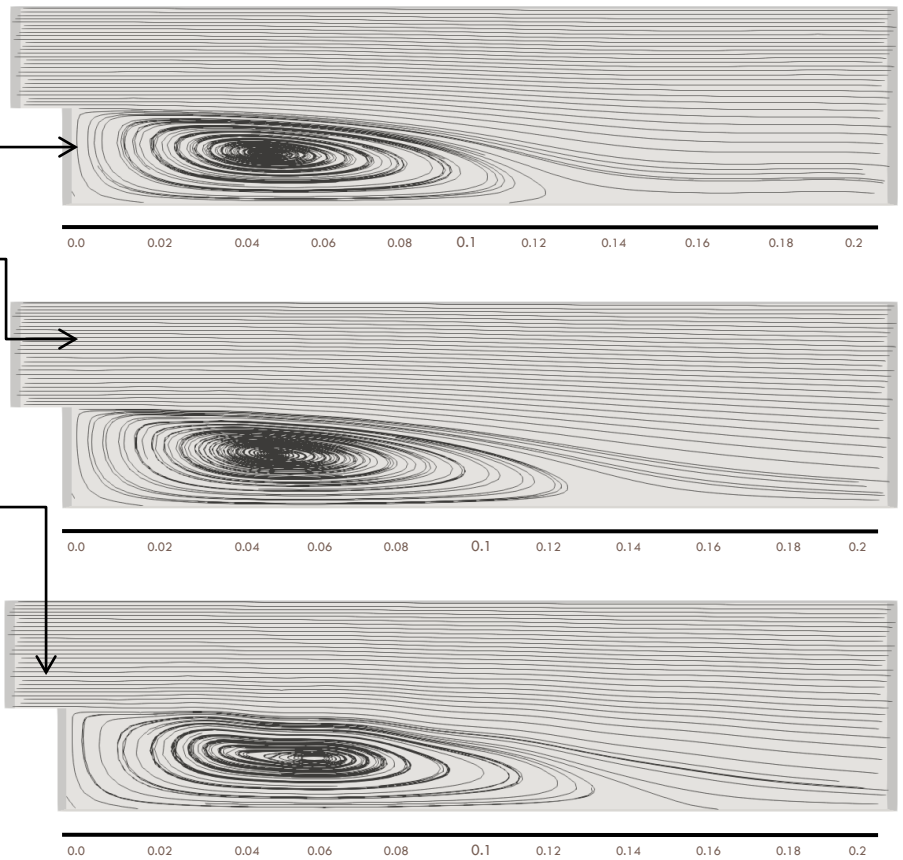

Fig.3.2: Stream line plots for fine mesh are generated using XiFoam solver. Plots are shown for U_1, U_2, U_3.

Conclusions:

- The simulations are performed using incompressible solvers (pimpleFoam, pisoFoam), compressible solver (rhoPimpleFoam) and combustion solver (XiFoam).
- 4 different RAS turbulence models used along with laminar and LES (keqn) to conduct the simulations.
- The rhoPimpleFoam gave numerical error < 5% with k-omega SST turbulence model.
- LES results of rhoPimpleFoam gave better visualization of flow phenomena.
- Coefficient of pressure plots are analyzed and plotted for rhoPimpleFoam for three velocities here.
- The simulation times for XiFoam are longer than remaining others. A compromise between accuracy and computation time has been made. So medium mesh is used to simulate the flow for 3 velocities.

Simulation figures

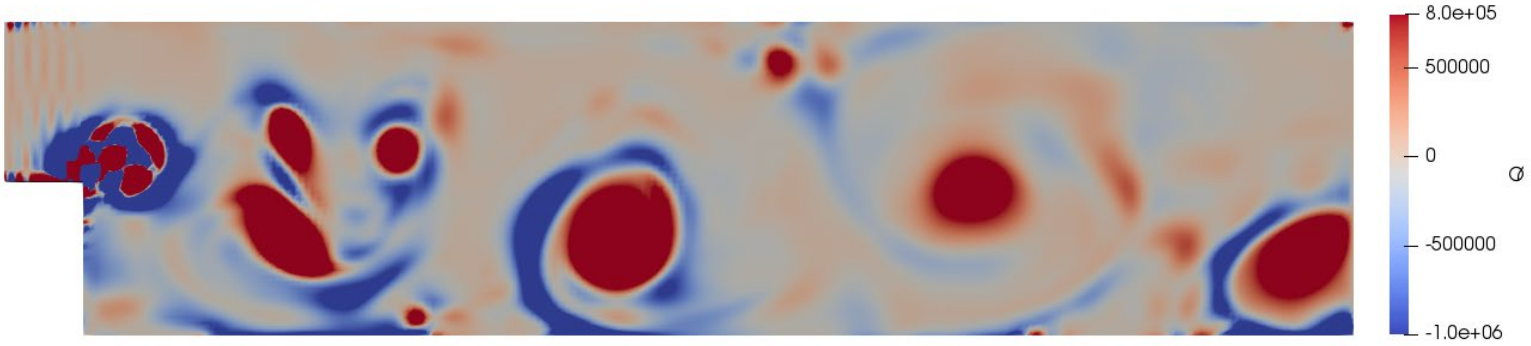

Fig.4: Q-factor plot for U_1 obtained from rhoPimpleFoam simulated using LES (keqn).

Simulation figures: conti.

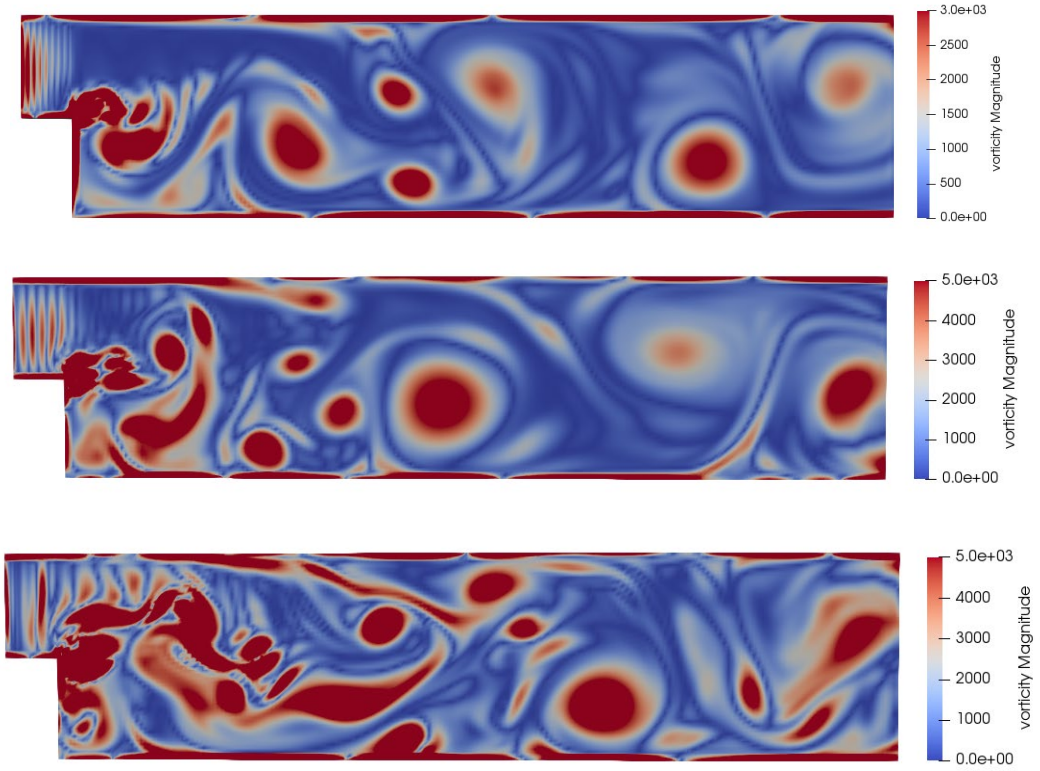

Fig.5: rhoPimpleFoam (LES) plots for voriticity of different magnitudes for U_1, U_2, U_3.

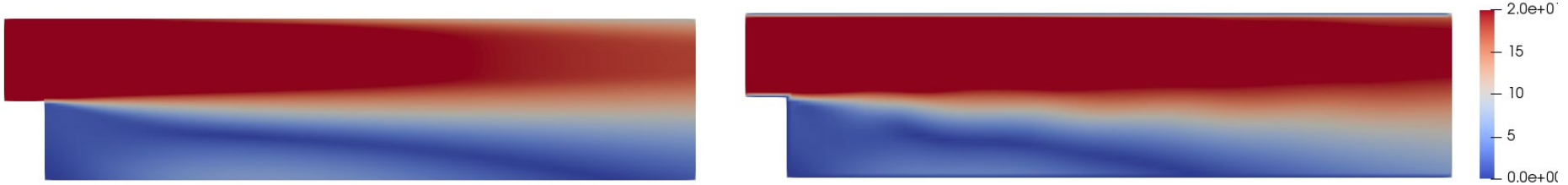

Fig.6: U_3 comparison for rhoPimpleFoam (k-omegaSST) and XiFoam (k-omegaSST)

References

- https://www.openfoam.com/documentation/guides/latest/api/

Formulas:

Calculation of k

$$k = \frac{3}{2}(I|\mathbf{u}_{ref}|)^2$$

omega

$$\omega = \frac{k^{0.5}}{C_\mu^{0.25} L}$$

epsilon

$$\epsilon = \frac{C_\mu^{0.75} k^{1.5}}{L}$$

Calculation of error %

Error = (Numerical value-Experimental value)/ Numerical value