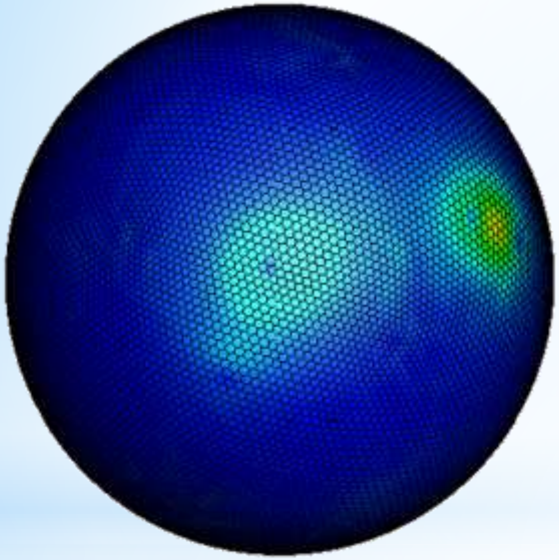

Application of the CABARET method for eight faces polyhedral cells in OpenFOAM framework

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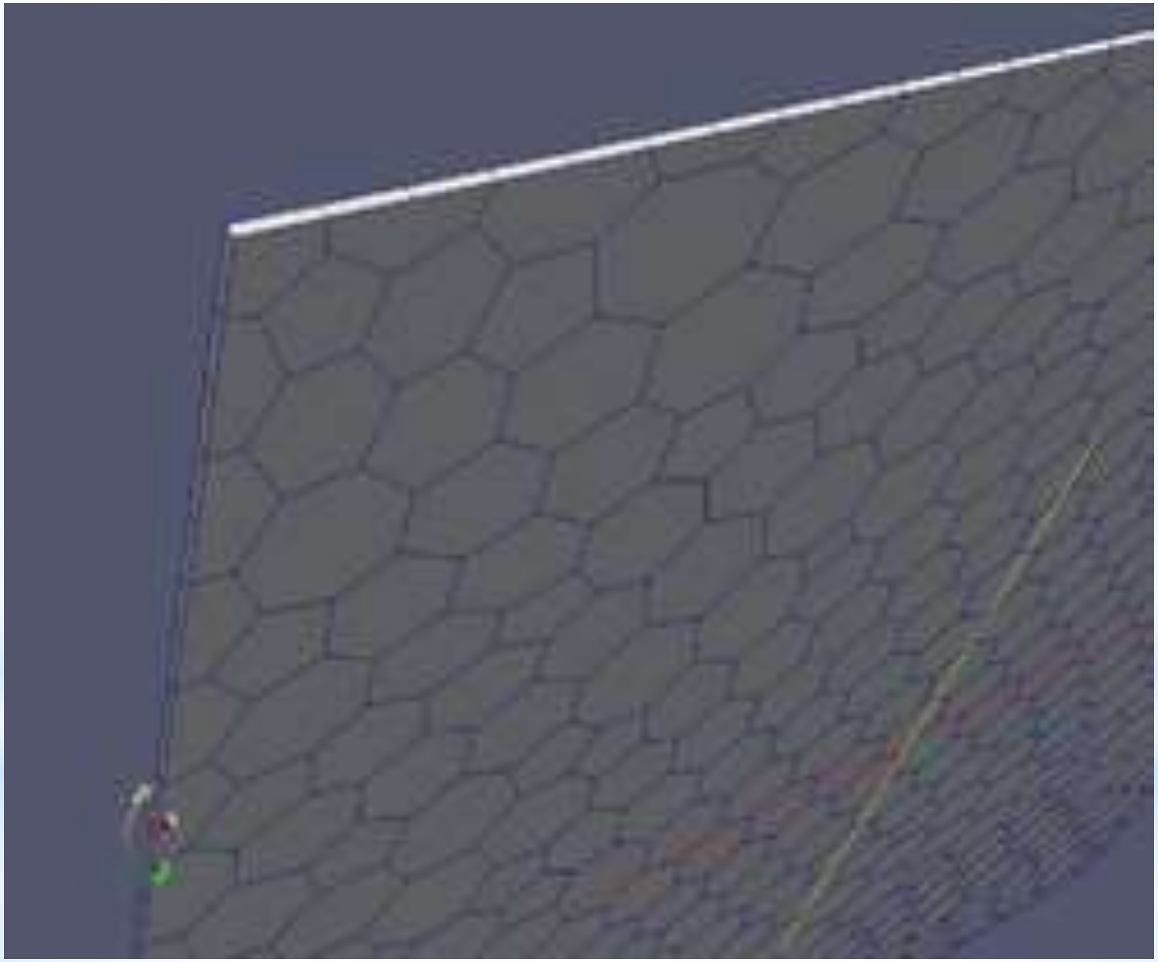
IBRAE

Application of polyhedral cells in CFD

Polyhedral cells are widely used in open-source and proprietary CFD software



https://openfoamwiki.net/index.php/Polyhedral_mesh_generation (23 June 2011)

Application of the CABARET method for eight faces polyhedral cells in OpenFOAM framework

Contents:

- Mathematical modelling of unsteady problems using the CABARET(case for linear compressible fluid)
- Development of algorithms for eight faces polyhedral cells
- Calculation results including regular and cutted hexagons

Problem solved:

- vortex flow
- unsteady backstep flow
- unsteady past cylinder flow
- unsteady jet flow of mixing two component gas
- undisturbed two vortex interaction on sphere surface
- disturbed two vortex interaction on sphere surface

Mathematical modelling of unsteady problems using the CABARET(case for linear compressible fluid)

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho u}{\partial x}+\frac{\partial \rho v}{\partial y}+\frac{\partial \rho w}{\partial z}=0$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho_0}\frac{\partial p}{\partial x}+\upsilon\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho_0}\frac{\partial p}{\partial y}+\upsilon\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho_0}\frac{\partial p}{\partial z}+\upsilon\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=0$$

ρ - density; u, v, w velocity components; x, y, z coordinates; p - pressure.

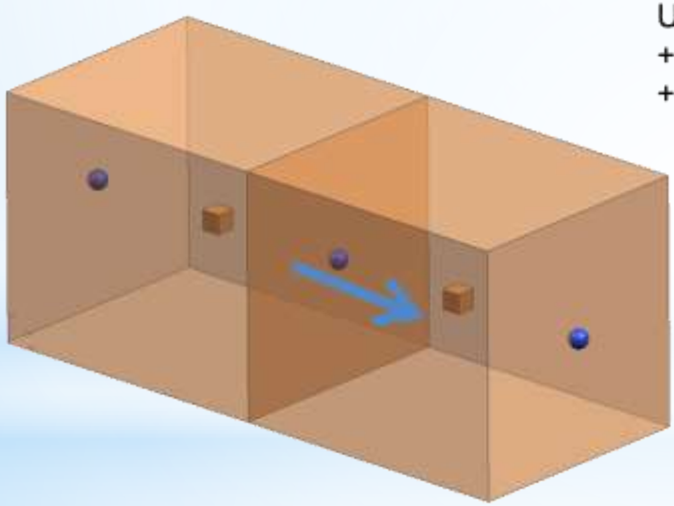
Cell computations(Phase 1 & 3)

 vol<Type>Field: p,U,T – conservative cell variables

 surface<Type>Field: Ps,Us,Ts - flux face variables

 Face Normal: mesh.Sf()

Cell B (Backward)



Cell F (Foward)

Phase 1-3

```
p=p-dt2*rss*fvc::surfaceIntegrate(mesh.Sf() & Us);
T=T-dt2*fvc::surfaceIntegrate((mesh.Sf() & Us)*Ts)
      +dt2*fvc::laplacian(kappa, T);
U=U-dt2*fvc::surfaceIntegrate((mesh.Sf() & Us)*Us
+Ps*mesh.Sf()/Rofon)+dt2*fvc::laplacian(nu, U)
+g*dt2*beta*(TRef-T);
```

thermodynamicProperties

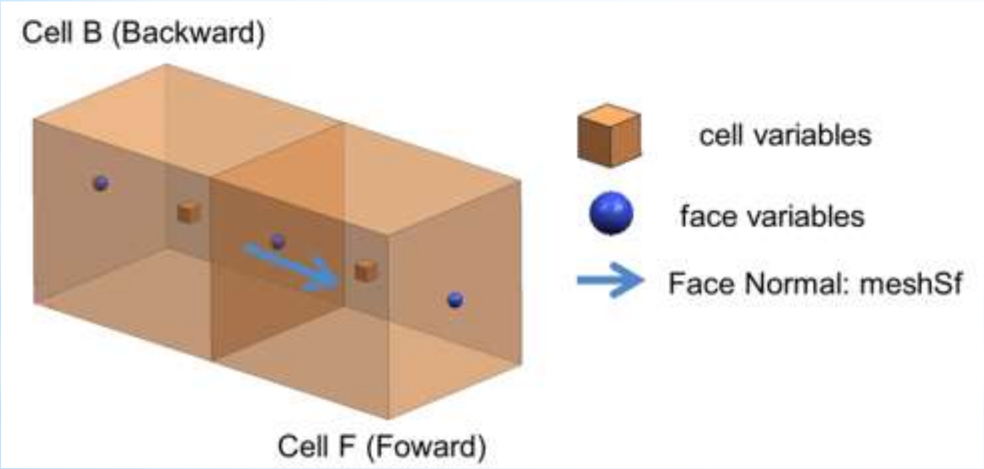
```
nu          nu [0 2 -1 0 0 0 0] 0.8929001e-06;
kappa       kappa [0 2 -1 0 0 0 0] 1e-06;
Rofon       Rofon [1 -3 0 0 0 0 0] 997.2;
g           g    [0 1 -2 0 0 0 0] (0 0 -9.81);
// Thermal expansion coefficient
beta        beta [0 0 0 -1 0 0 0] 0.65e-4;
// Reference temperature
TRef        TRef [0 0 0 1 0 0 0] 292;
```

Invariants and space and time stencils

$$I_+ = u - \frac{p}{\rho c}$$

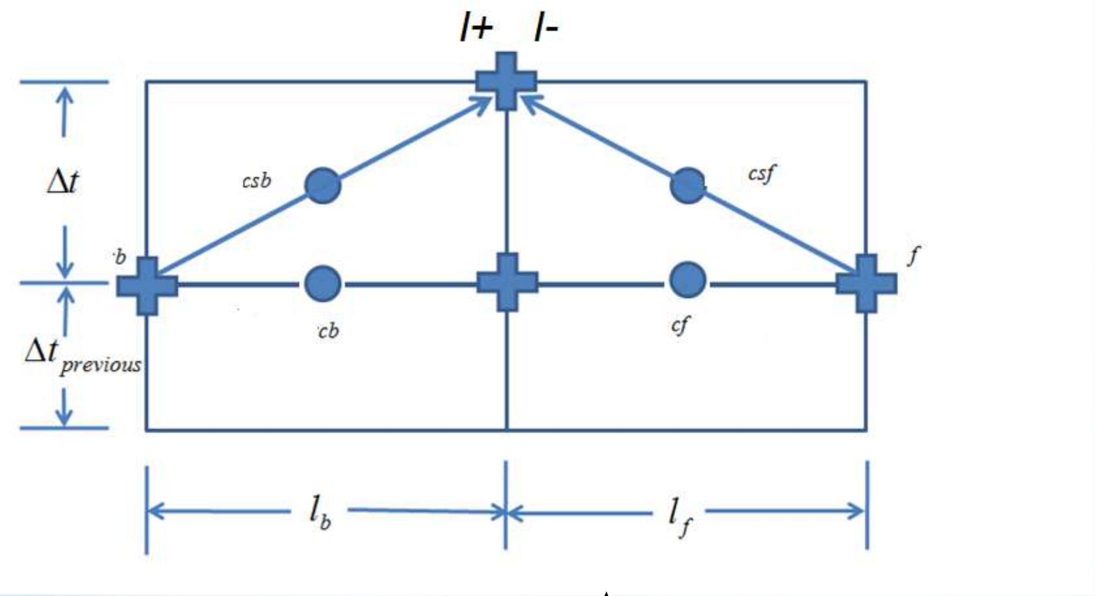
$$I_- = u + \frac{p}{\rho c}$$

Eigen values are equal positive and negative values of wave velocity. Zero eigen value is for Y and Z velocity.



OpenFOAM formulation:
Time loop
Phase 1;
Phase 2;
Phase 3;
Loop end
Phase 2 is external function.
Boundaries are OpenFOAM codedMixed type.

Face computations



c – invariant value, l – distance to opposite face, indices b и f are for backward and forward face invariant value, cb и cf are for backward and forward cell invariant value, csb и csf are for backward and forward cell invariant value on intermediate time step.

$$I_+^{\max} = \max(I, I_b, I_{cb}) + 2(I_{csb} - I_{cb}) + c\frac{\Delta t}{l}(I - I_b)$$

$$I_+^{\min} = \min(I, I_b, I_{cb}) + 2(I_{csb} - I_{cb}) + c\frac{\Delta t}{l}(I - I_b)$$

$$I_+^{new} = \begin{cases} I_+^{\max} & 2I_{csb} - I_b > I_+^{\max} \\ 2I_{csb} - I_b & I_+^{\min} <= 2I_{csb} - I_b <= I_+^{\max} \\ I_+^{\min} & 2I_{csb} - I_b < I_+^{\min} \end{cases}$$

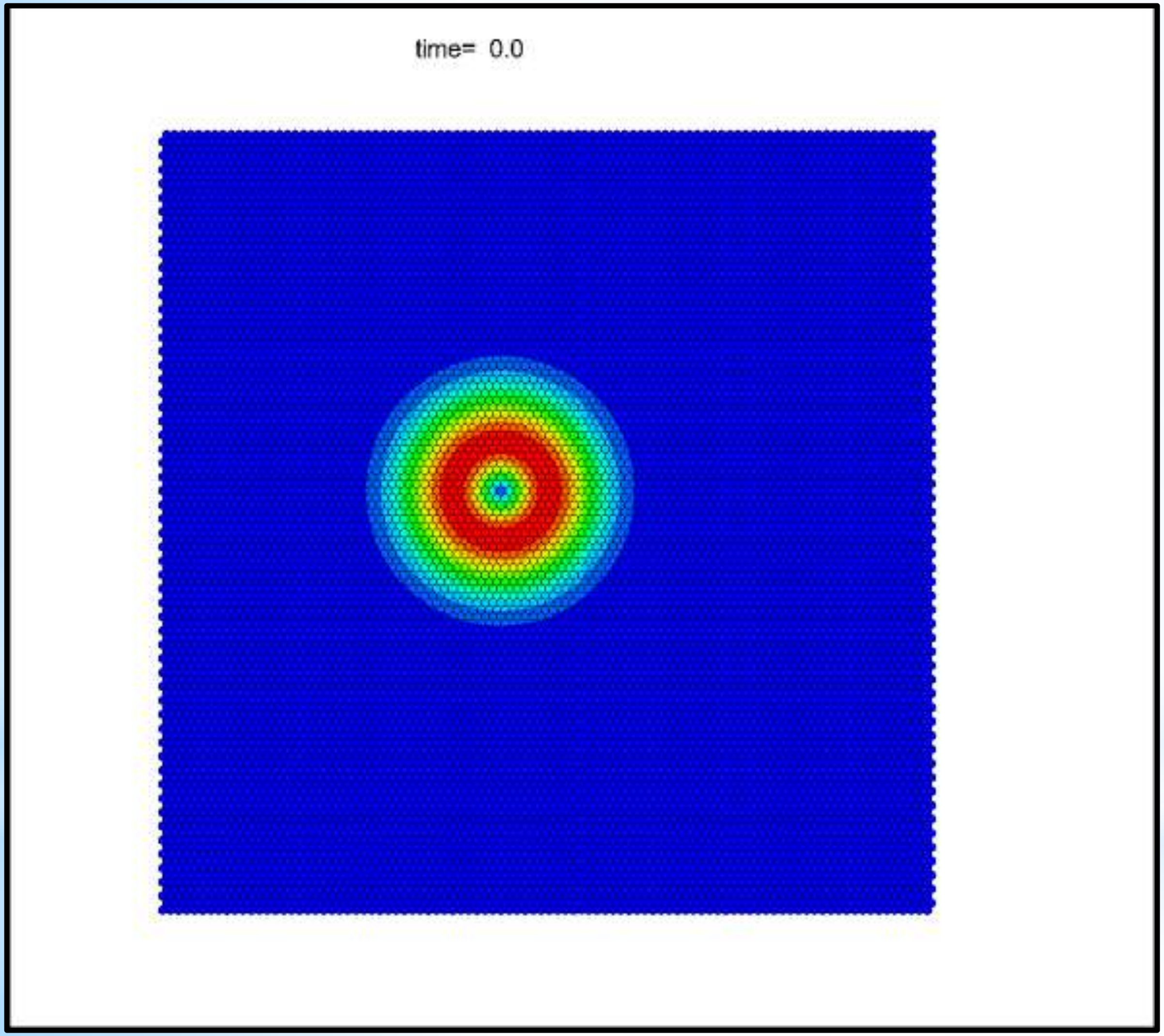
$$I_-^{\max} = \max(I, I_f, I_{cf}) + 2(I_{csf} - I_{cf}) + c\frac{\Delta t}{l}(I_f - I)$$

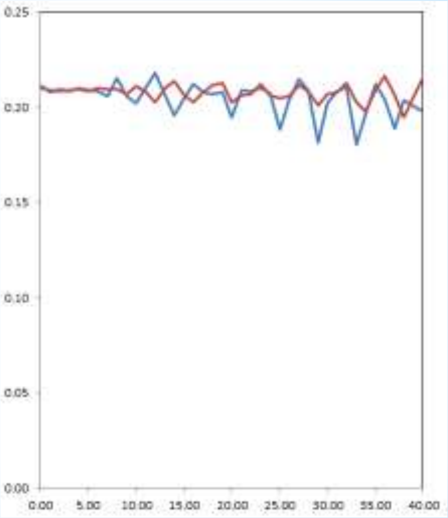
$$I_-^{\min} = \min(I, I_f, I_{cf}) + 2(I_{csf} - I_{cf}) + c\frac{\Delta t}{l}(I_f - I)$$

$$I_-^{new} = \begin{cases} I_-^{\max} & 2I_{csb} - I_b > I_-^{\max} \\ 2I_{csf} - I_f & I_-^{\min} <= 2I_{csb} - I_b <= I_-^{\max} \\ I_-^{\min} & 2I_{csb} - I_b < I_-^{\min} \end{cases}$$

New velocity values –half summ of invariants with indices “+” and “-”. Pressure – half difference, multiplied by factor ρc.

Vortex flow

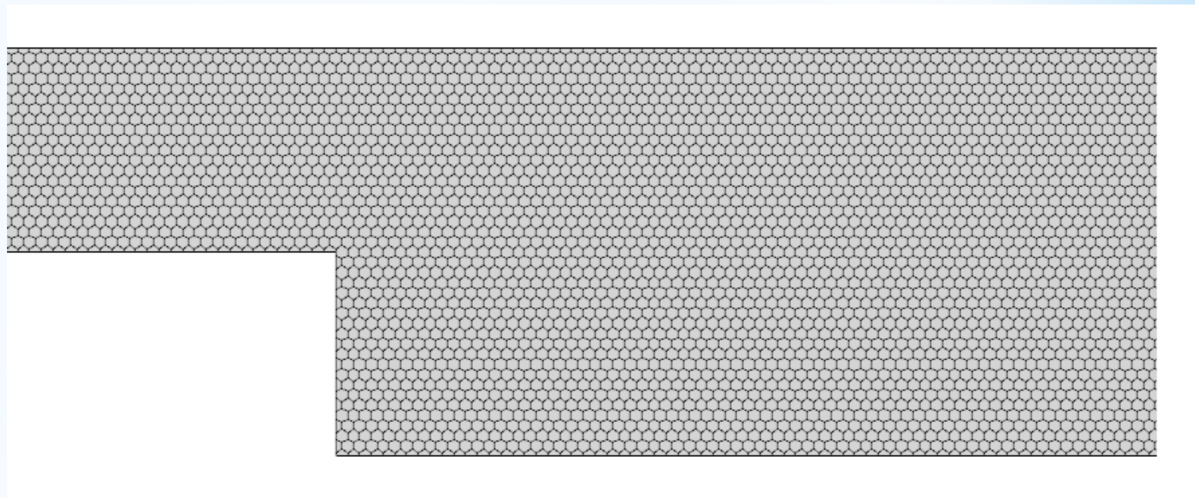


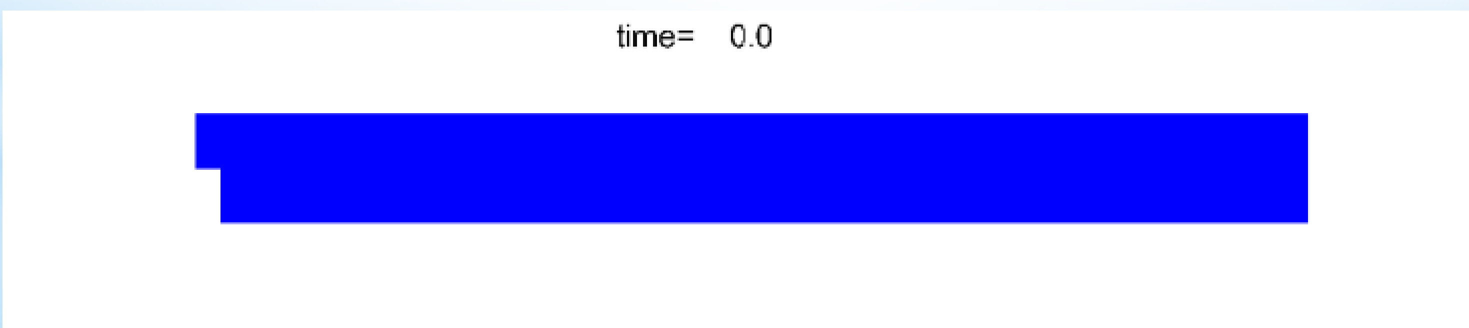


Maximal velocity versus time for different mesh (red -4x mesh)

Backstep flow

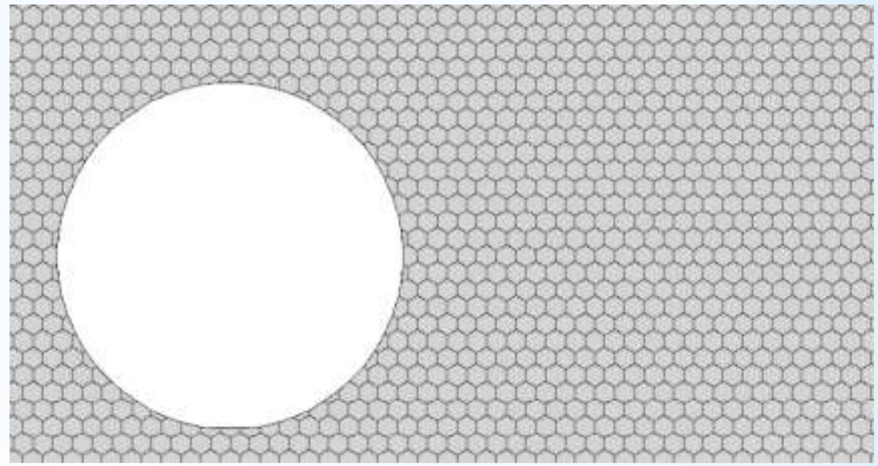
Zone Type:	FE - Polygon
Pts:	166563
Elem:	81240
Faces:	247802

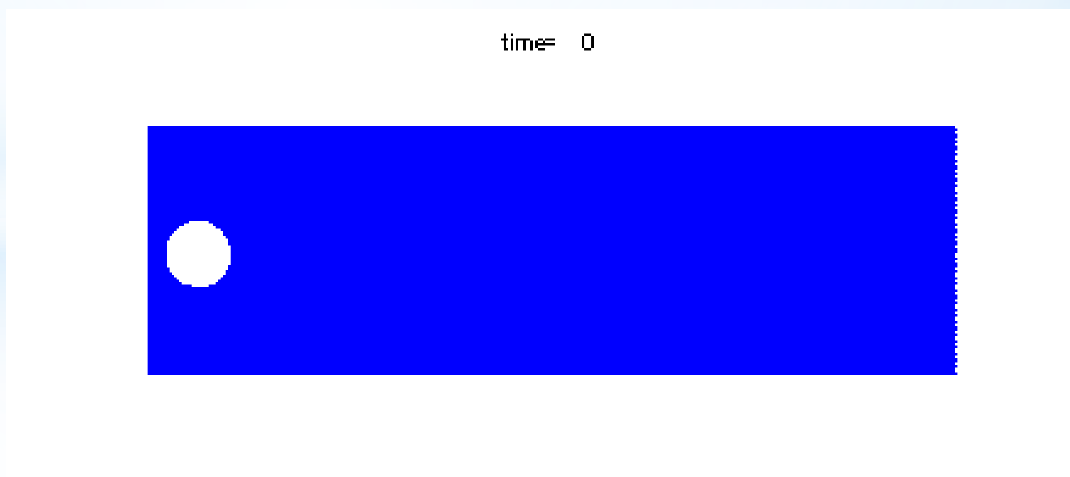




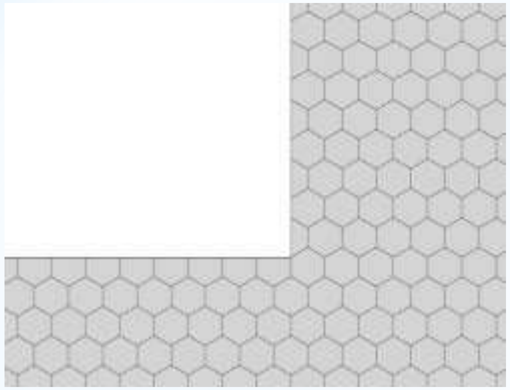
Unsteady past cylinder flow

Zone Type:	FE - Polygon
Pts:	170760
Elem:	28147
Faces:	85373

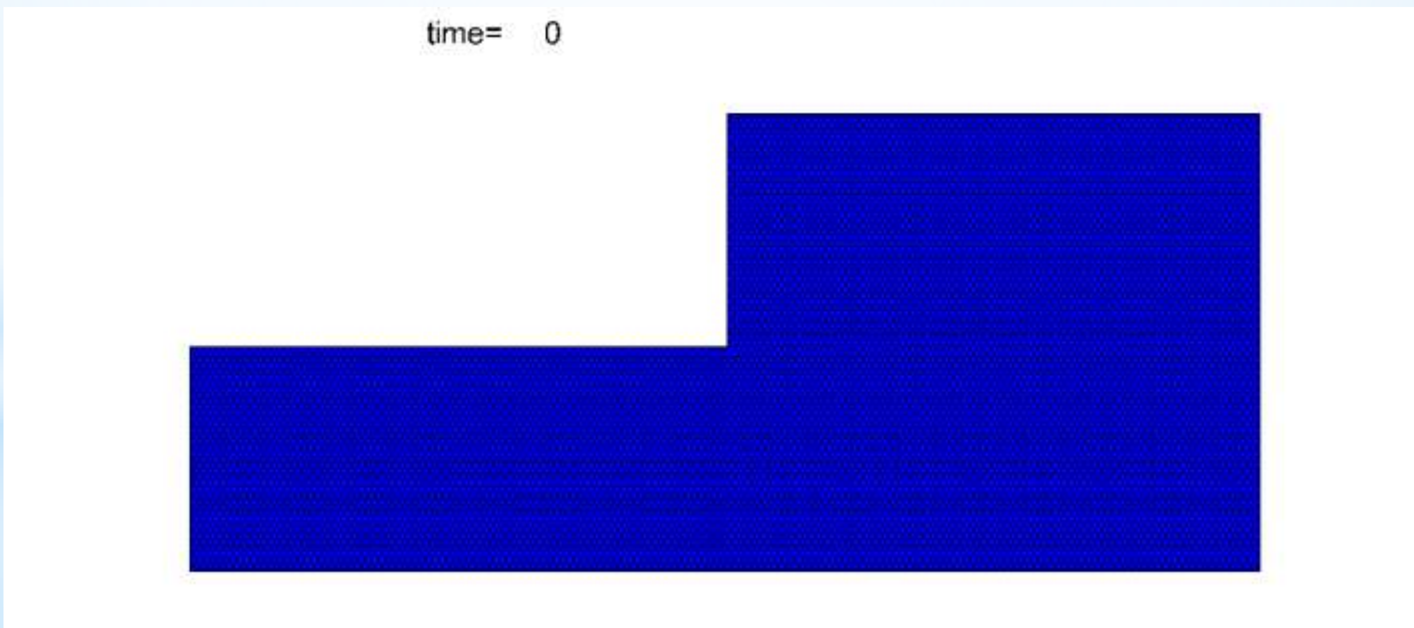




Unsteady jet flow of mixing two component gas

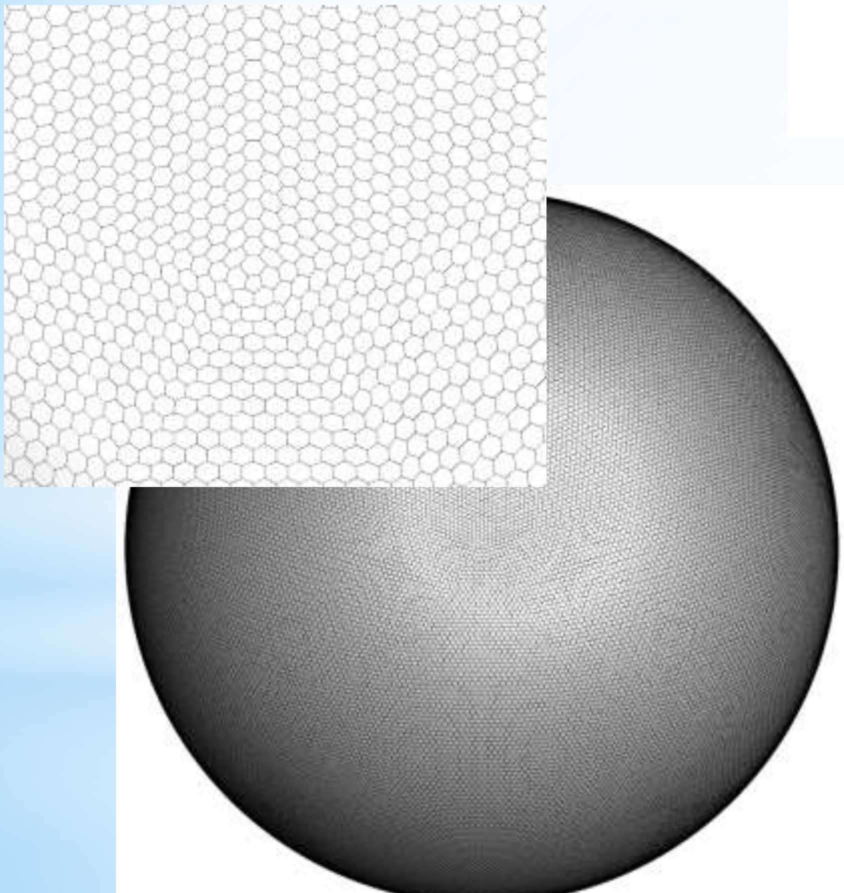


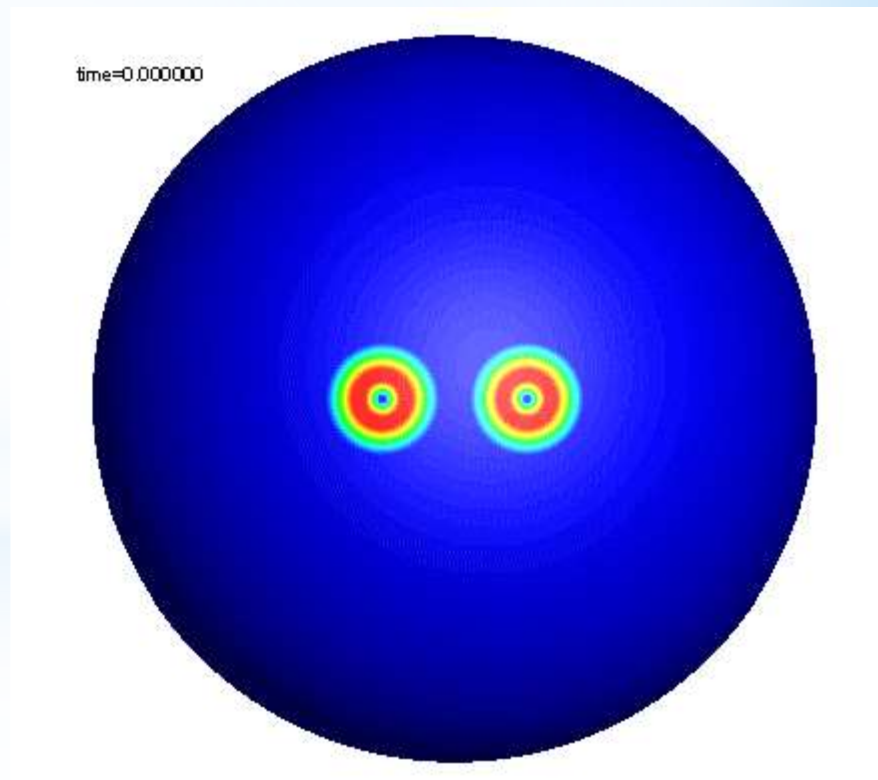
Zone Type:	FE - Polygon
Pts:	56400
Elem:	9400
Faces:	28675
Solution Time:	0
Time Strand:	1



Initially undisturbed two vortex interaction on sphere surface

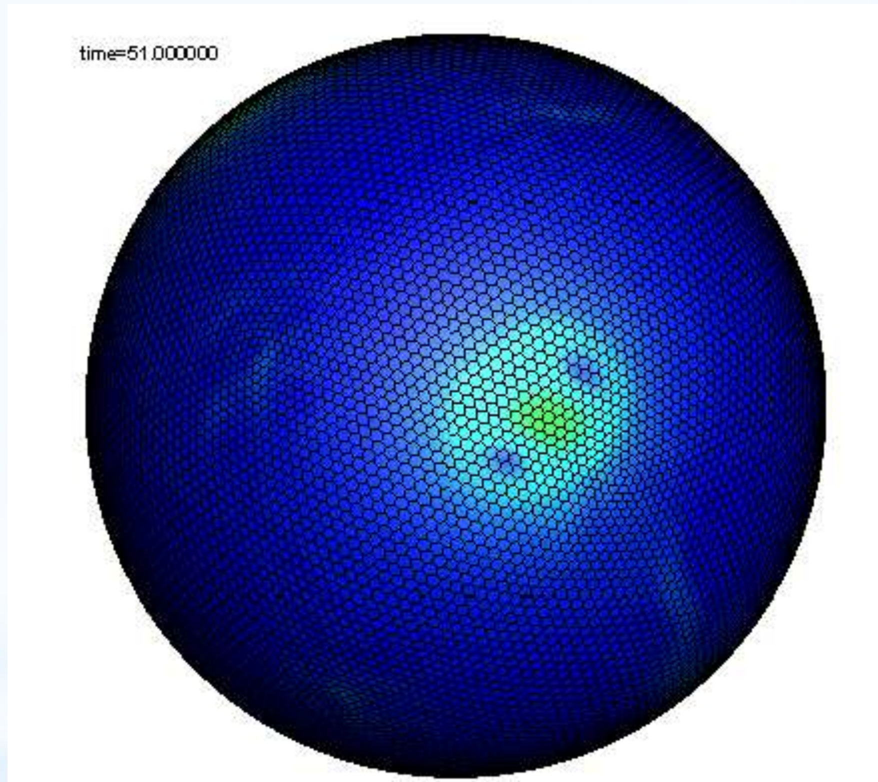
Zone Type:	FE - Polyhedron
Pts:	231040
Elem:	177644
Faces:	288804





Initially disturbed two vortex interaction on sphere surface

Zone Type:	FE - Polyhedron
Pts:	51840
Elem:	40976
Faces:	64804



Parallel computations and scalability

Step number	Processor number	Cell number	Cell number per processor	Performance (processor time per single step for single cell), μs	Total time, sec
14109	128	12962	102	21.69719	31.83
14109	64	12962	204	13.28509	38.13
14109	32	12962	409	8.17008	47.37
14109	16	12962	818	6.382148	72.62
14109	8	12962	1636	5.470367	125.3
14109	4	12962	818	4.699517	214.55
28395	256	57762	232	15.96	101.65
28395	128	57762	455	10.17	130.12
28395	64	57762	911	7.35	187.91
28395	32	57762	1823	6.65	341.42

Parallel computations were made on mesh
up to 100 cells per processor.

Conclusions

1. CABARET method realization for eight faces polyhedral cells in OpenFOAM framework have the same unique features that differentiate it from the another CFD realizations.
2. Time perfomance of polyhedral cells mesh is compatible with time perfomance of hexa mesh.
3. Parallel numerical algorithms have parallel cluster scalability.

Thanks !