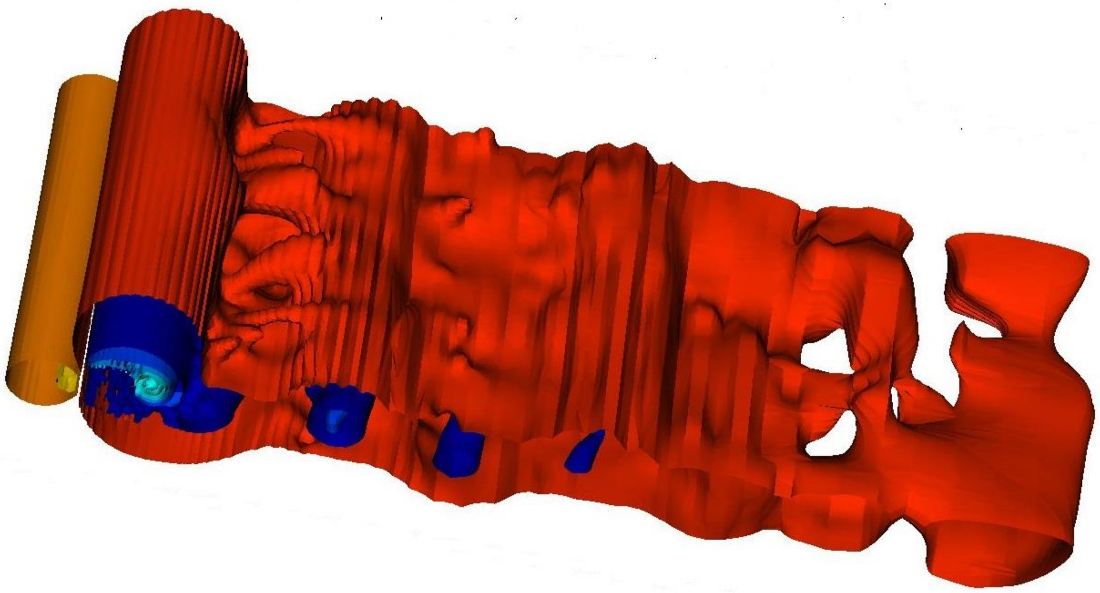
2.29 FINAL PROJECT PRESENTATION

5/17/2017

Investigation of Fluid-Structure Interactions Using Fourier Spectral Element Method

OUTLINE:

- Project Objectives
- High Order Schemes
- NEKTAR Code
- Results
- Summary
- References



3D pressure field of flow past a stationary cylinder at t= 222 (Re =100,000)

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Project Objectives

- Examine application of high order schemes for FSI problems
  - Pre-processing
  - Simulation set up
  - Post-processing

- Verification and validation of current algorithm
  - Mesh sensitivity analysis
  - Comparison of numerical results with experiment
  - Other results

High Order Schemes

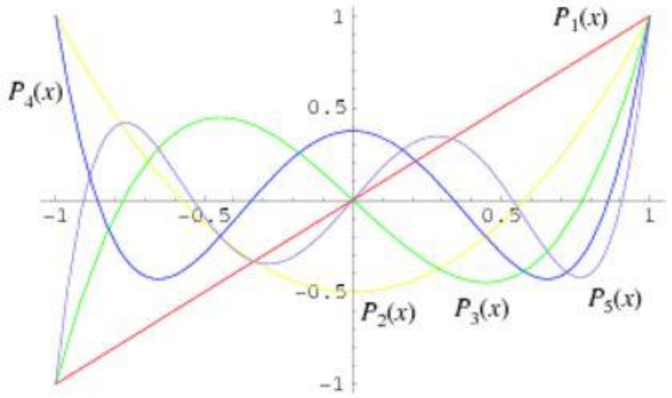
- Advantages
  - Greater accuracy for same resolution
  - Relevant for specialized cases
  - High accuracy + geometric flexibility (spectral element method)
- Challenges
  - Memory storage
  - Computational cost
  - Fragile stability (oscillation problems)

Spectral Element Method

- Originally developed at MIT by Anthony T. Patera (1984)
- Employs special polynomials
- Uses elemental application
- Quadrature rules

$$\int_{-1}^{1} u(\xi)\, d\xi = \sum_{i=0}^{Q-1} w_i u(\xi_i) + R(u) \qquad (Gauss\ method)$$

- Over-integration (Qmin= 3P/2 + 2 points for N.S conv. term)



Legendre Polynomials

Courtesy: Wolfram Web Resources

NEKTAR Code

Methodology

Fourier spectral/hp element method:

- Employs 2D (rectangular and/or triangular) spectral elements in XY plane
- Uses a set of Fourier planes for span-wise discretization in homogenous direction
- Applies Arbitrary Lagrangian-Eulerian (ALE) framework at moving boundaries
- Parallelized routine through Message Passing Interface (MPI)

Stabilized DNS model:

- Solves modified Navier-Stokes equation with entropy viscosity term
- Applies 3/2 quadrature rule for integration of non-linear advection term
- Employs implicit filtering (SVV) to achieve robust DNS but at low resolution

NEKTAR Code

Algorithm

- **Fluid Solver** (Splitting/Projection method)
  - High order splitting method (rotational form)
  - Explicit treatment of advection term
  - Implicit treatment of diffusion term
  - Consistent splitting error using appropriate pressure B.C

- **Structure Solver**
  - Newmark time integration
  - Implicit scheme
  - Second order accurate

$$\dot{u}_{n+1} = \dot{u}_n + \frac{\Delta t}{2}\left(\ddot{u}_n + \ddot{u}_{n+1}\right)$$

$$u_{n+1} = u_n + \Delta t\, \dot{u}_n + \frac{1-2\beta}{2}\Delta t^2 \ddot{u}_n + \beta \Delta t^2 \ddot{u}_{n+1}$$

where, $\beta = 1/4$

NEKTAR Code

Pre-processing

Case 1:

- Number of elements, k = 2516; dt = 4e−4;

Case 2:

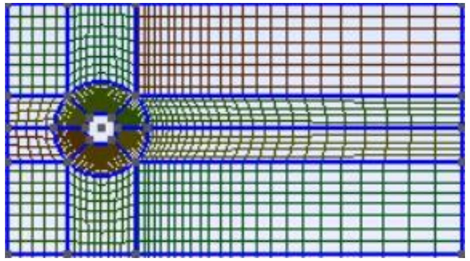
- Number of elements, k = 3370; dt = 2e−4;

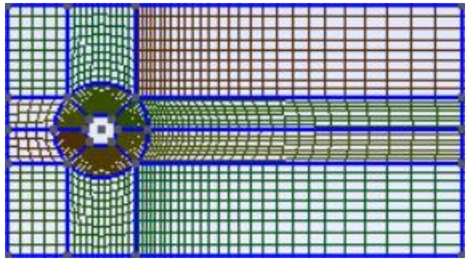
Case 3:

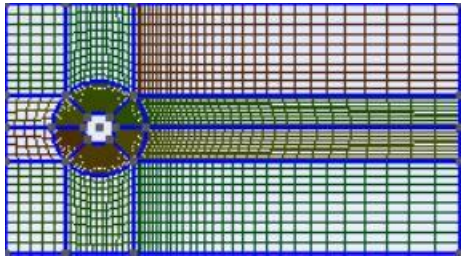
- Number of elements, k = 4438; dt = 2e−4;

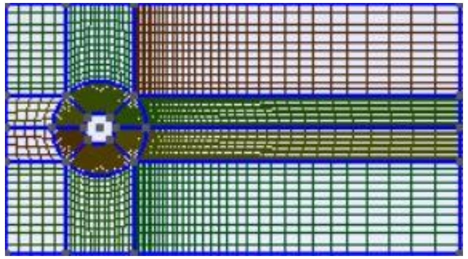
Case 4:

- Number of elements, k = 5538; dt = 1e−4;









NEKTAR Code

Simulation set up

- $\bar{L} = \frac{L}{D} = 2\pi$; Re = 100,000;
- Nz = 64 planes; NMODES = 3

Post-processing

- Vorticity derivation from velocity field
- Visualization tools (Visit, Tecplot, Paraview e.t.c)
- Supplementary MATLAB codes

```
%%
% Fourier analysis of forces on cylinder in uniform flow at Re=10,000 and
% 100,000
% Script written by ABIODUN OLAOYE working on 2.29 project
% May, 2017
clear
clc
%%
NL = 1;            % Number of cases per run
NUM_1= 140;        % Start time of signal
NUM_2= 192;        % End time of signal
for LC=1:NL
prompt= 'Enter file name : ';
str_1= input(prompt,'s');  % Obtain response from user
MM=load(str_1);
%Extract Time series of Wave Height
Time= MM(:,1);
Cx= 2*MM(:,2);
Cy= 2*MM(:,3);
ii=1;
% Find mean of force coefficients
iii= 2500;
CD_m= mean(Cx(iii:end)) %#ok<*NOPTS> % drag
CL_m= mean(Cy(iii:end)) % lift
% Find RMS value of Lift
CL_rms= sqrt(mean((Cy(iii:end)-mean(Cy(iii:end))).^2))
t_0= Time(1,1);
tt_s= Time(10,1)-Time(9,1);        % Time step of signal
Fs= 1/tt_s;        % Sampling frequency
figure ()
plot (Time(ii:end),Cy(ii:end))
title('Original Lift Coeficient Time Series')
xlabel('t')
```

Results

Mesh Sensitivity and Validation

Method	St
SDNS (N= 2516)	0.196
SDNS (N= 3370)	0.196
Exp (Schewe,1983*)	0.197

Method	–Cbp
SDNS (N = 2516)	1.212
SDNS (N = 3370)	1.335
Exp (Norberg,1994*)	1.336

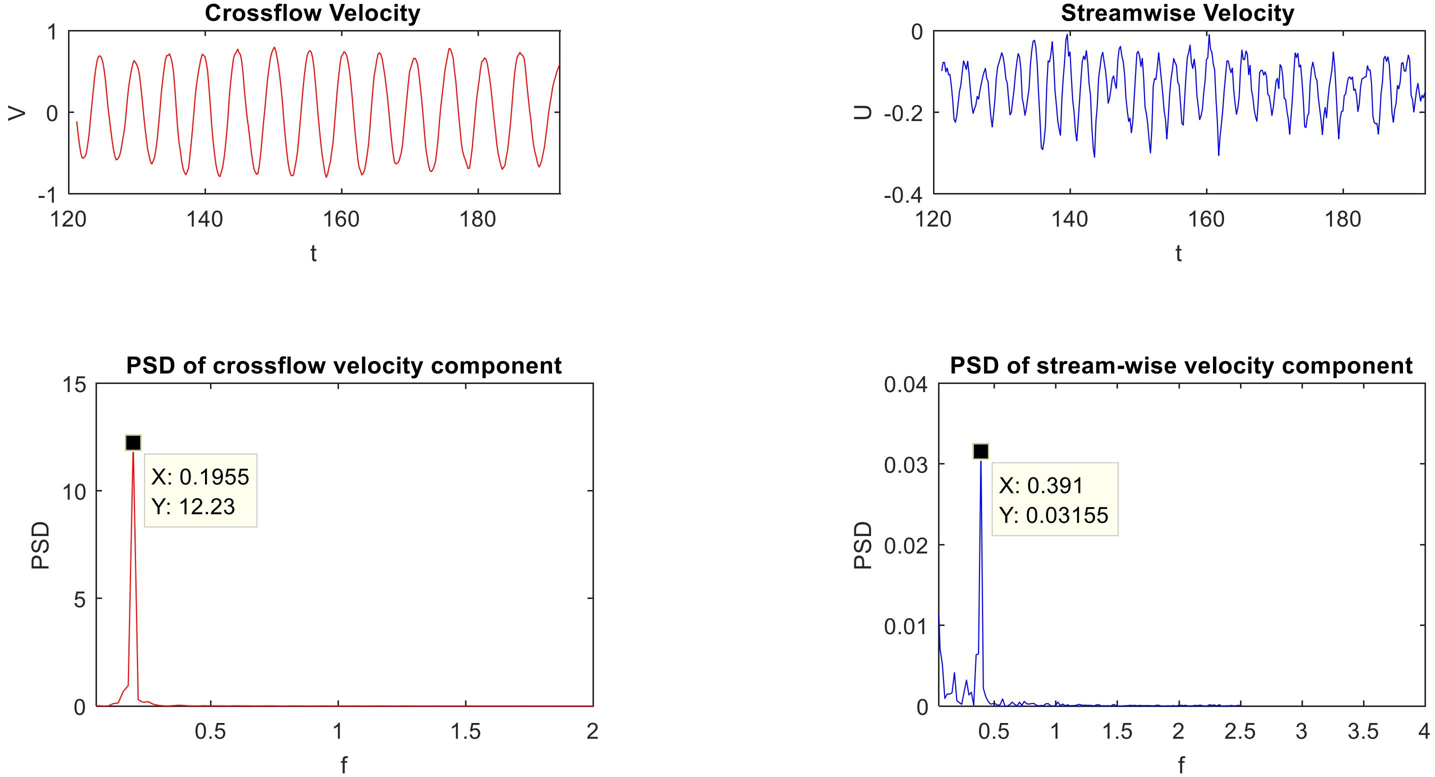
Method	CL’
SDNS (N = 2516)	0.421
SDNS (N = 3370)	0.679
Exp (West&Apelt, 1993)	0.593

Method	CD
SDNS (N = 2516)	1.170
SDNS (N = 3370)	1.293
Exp (Wieselsberger, 1921*)	1.248

* Extracted from Springer Handbook of Experimental Fluid Mechanics (2007)

Results

Wake Analysis

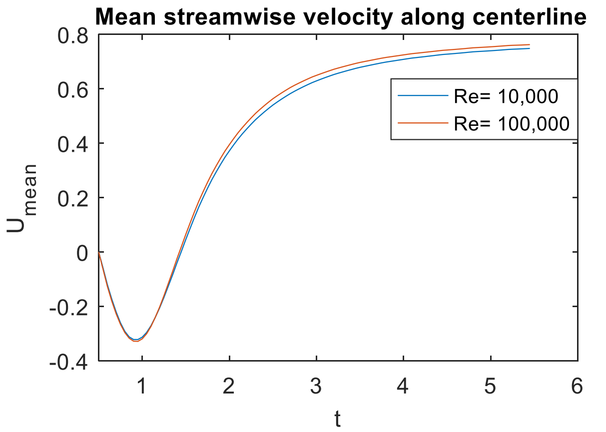


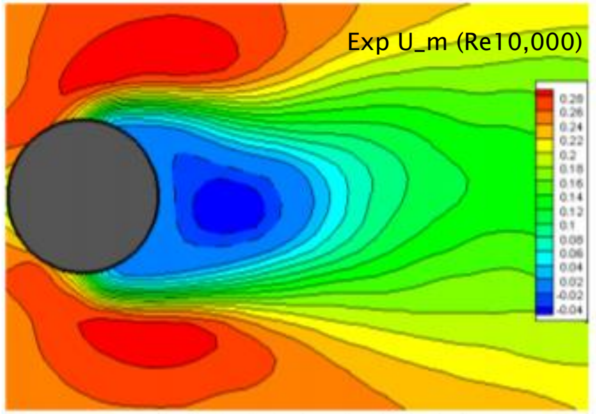
Frequency of Streamwise velocity is twice vortex shedding frequency!

Streamwise and crossflow velocity at x=0.6D, y=0 and z=0 (Re = 100,000)

Results

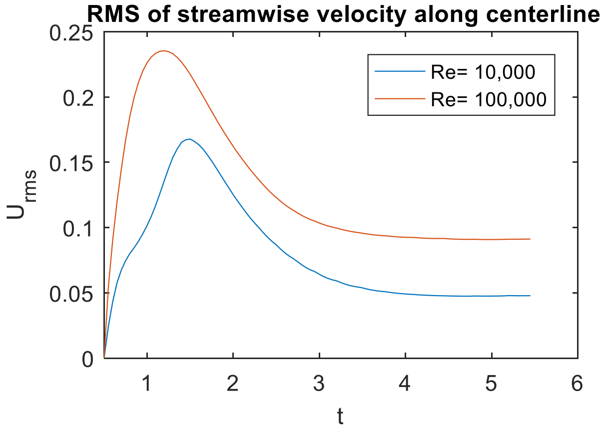
Wake Analyses

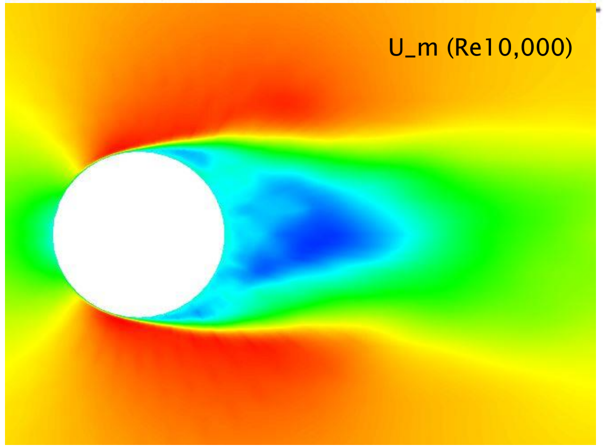


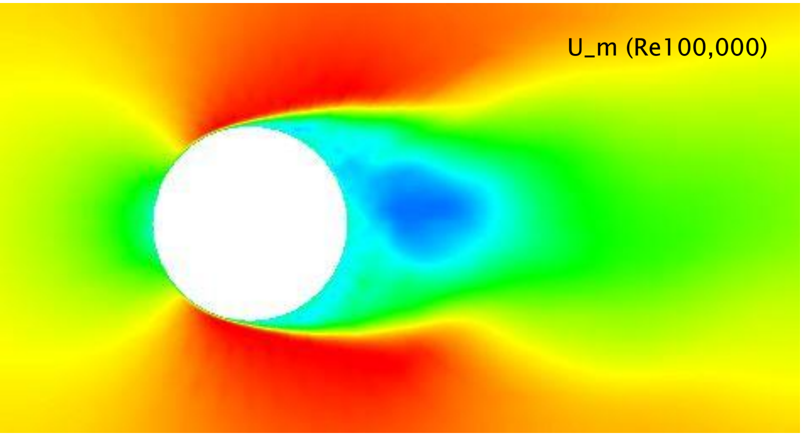


Accurate prediction of negative velocity region behind cylinder

Negative velocity region shorter for higher Re case

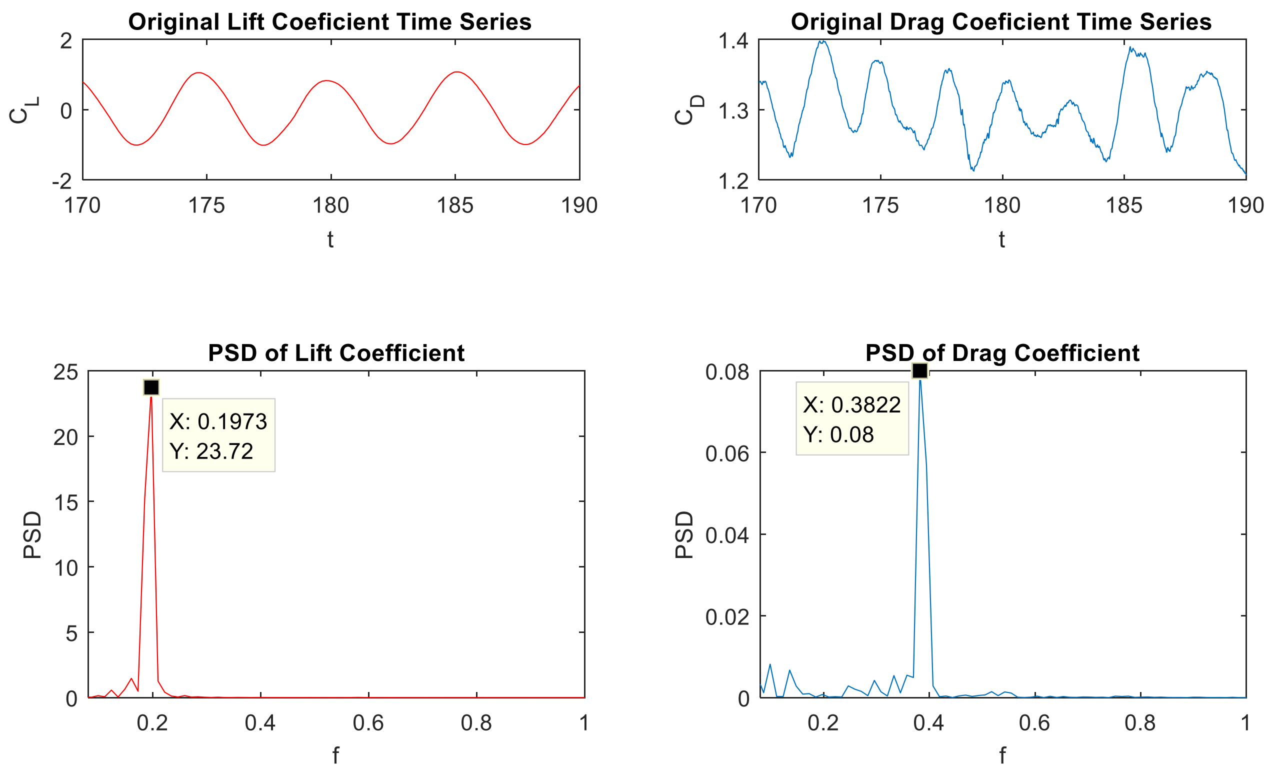


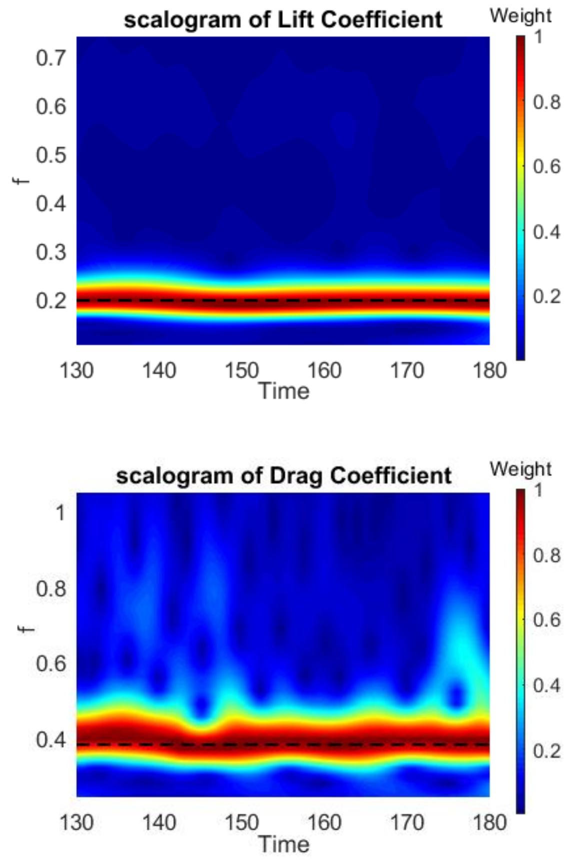




Results

Span-averaged forces





1st and 2nd harmonics dominant in Lift and drag forces respectively (Re= 100,000)

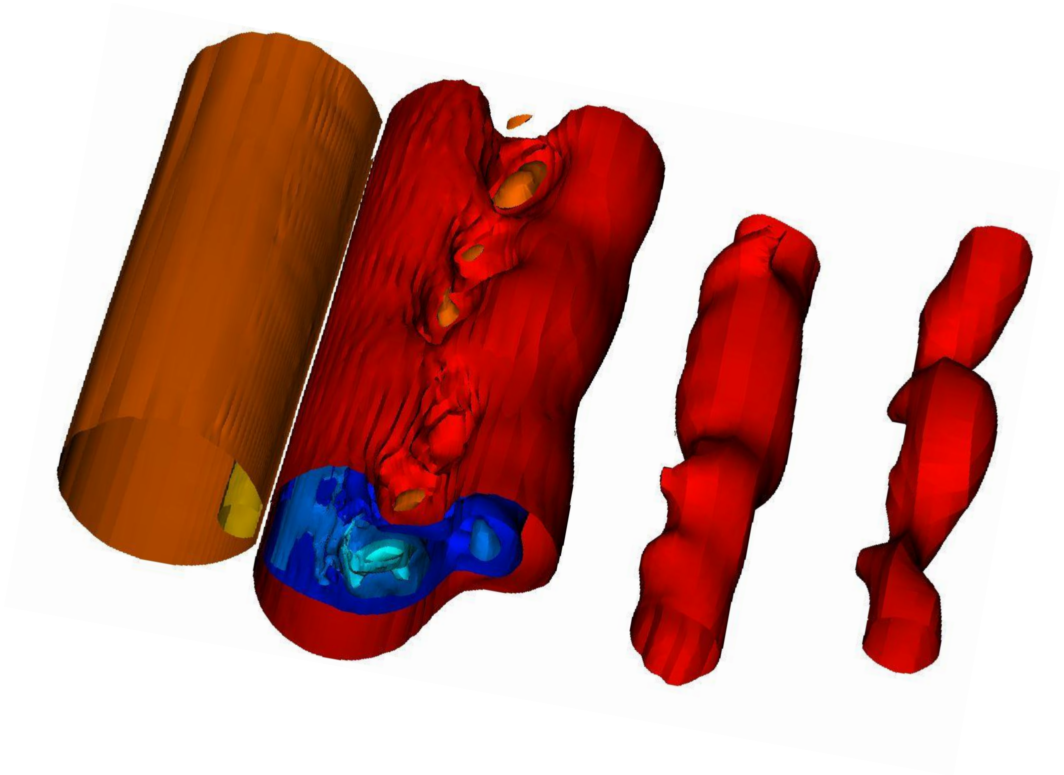
Summary

- SEM offers high accuracy in addition to geometric flexibility
- Current set up suitable for problems with at least one homogenous B.C

References

- Karniadakis G.E., Sherwin S., “Spectral/hp element methods for computational fluid Dynamics”, (2005)
- Patera A.T. “A Spectral element method for fluid dynamics: Laminar flow in a channel expansion” (1984). J. Comp. Phy. **54**, 468–488
- Cameron T., Alexander L.Y., John F. F. (Eds.) ,“Springer handbook of experimental fluid mechanics” (2007)

THANK YOU



3D pressure field of flow past a stationary cylinder at t = 270 (Re =100,000)

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