FLUID-STRUCTURE INTERACTION VIA EMBEDDING

- Motivation
- Options
- Implementation

MOTIVATION

Fluid-Structure Interaction With:

- Complex Geometry
- Complex CSD Physics
- Rupture/Cracking
- Topology Change

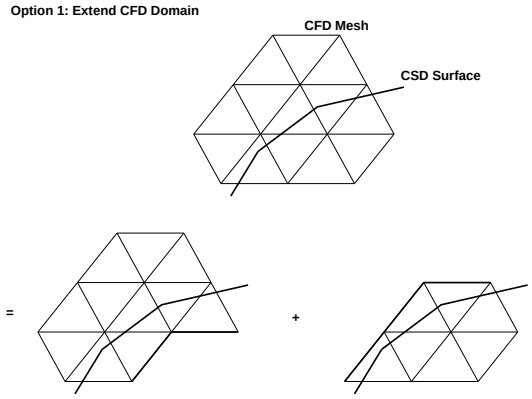
MOVING BODIES: POSSIBILITIES

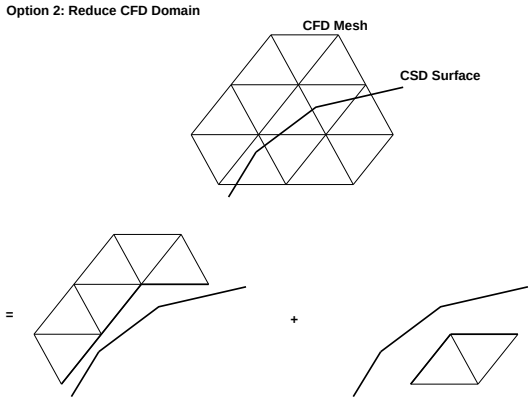
- Move Mesh
    - Body-Fitted Mesh
    - ALE Formulation
    - Mesh Movement Techniques
    - Topology Reconstruction
    - Remeshing
    - Interpolation
- Embed CSD Mesh
    - Mesh Not Body/Surface Conforming
    - Eulerian Formulation
    - Identification of Crossed Edges
    - Proper B.C. for Boundary Points

TRADITIONAL APPROACH

- Topology Reconstruction
    - Sometimes Fails for Singular Points
    - No Way to Remove Subgrid Features
- Meshing
    - Bad Elements due to Geometry
    - Bad Scaling Beyond 16 Procs
- Interpolation
    - Possible Loss of Info/Diffusion
- Recalculation (Expense) of:
    - Geometry
    - Distance to Wall
    - Mesh Velocities

EMBEDDED CSD IN CFD: OPTIONS





EMBEDDED CSD IN CFD

Given:

- Wetted Faces of CSD
- 3-D CFD Mesh

Then:

- See Which CFD Edges Are Cut by CSD Faces
- For Endpoints of Cut Edges:
  - Define Additional Boundary Conditions
  - Inherit Normal From CSD Face
- For Balance of Fluxes: Construct `geobp`
- For Cut Edges: Set `geoed(1:5,iedge)=0`
- Modify Normal Velocity From CSD Velocity [Euler, NS]
- Deactivate Points Totally Enclosed

AREAS OF WORK

- Masking of Edges and Points
- New Boundary Conditions
- Modification of `geobp`-Array
- Extrapolation of the Solution
- Movement for Display

MASKING OF EDGES AND POINTS (1)

Given:

- CSD Faces/Coordinates
- CFD Edges

Desired:

- CSD Face(s) Crossing an Edge
- CSD Face for New Boundary Conditions

MASKING OF EDGES AND POINTS (2)

Then:

- Build Face-Octree for CSD Faces
- `DO`: Loop over the Edges
  - Build Bounding Box of Edge
  - Get CSD Faces from Octree
  - In-Depth Test if Crossing
  - If Crossing:
    - Store CSD Face
- `ENDDO`
- From Edges: Mark Points

Remarks:

- Relatively Fast
- Parallel

MASKING OF EDGES AND POINTS (3)

Improvements for Transient Problems:

- If CSD Face Topology Has Not Changed:
    - See If Face no Longer Crosses Edge
      If So: Mark Point
- If CSD Face Topology Has Changed:
    - Mark Points of Crossed Edges
- From Marked Points: Mark Edges
- Only Test Marked Edges

Remarks:

- Very Fast
- Parallel

NEW BOUNDARY CONDITIONS

Need: Euler/RANS B.C. at CSD Surface

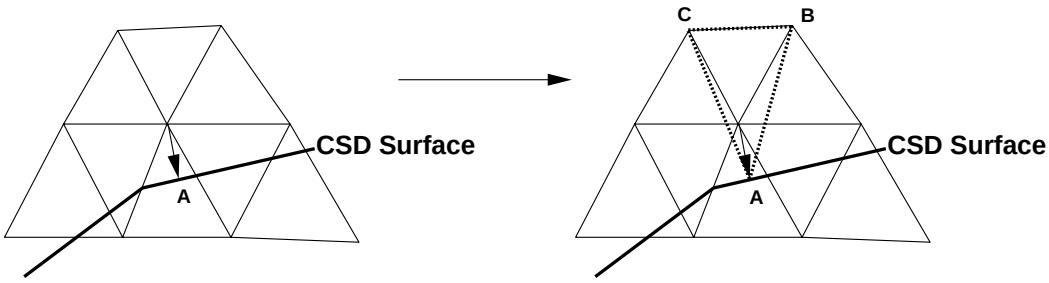
Given: Closest CSD Face to Point

- Impose Normal From CSD Face (Euler)
- Impose Normal (Total) Velocity from CSD Velocity

IMPROVED BOUNDARY CONDITIONS: NS

NS Velocity: Extrapolate From Surface

- $\mathbf{v} = 0$ at CSD Face
- Obtain Closest Point on CSD Face
- Obtain Best Element/Face for Extrapolation (Shape-Functions)
- Lag Boundary Velocity One Timestep/Iteration



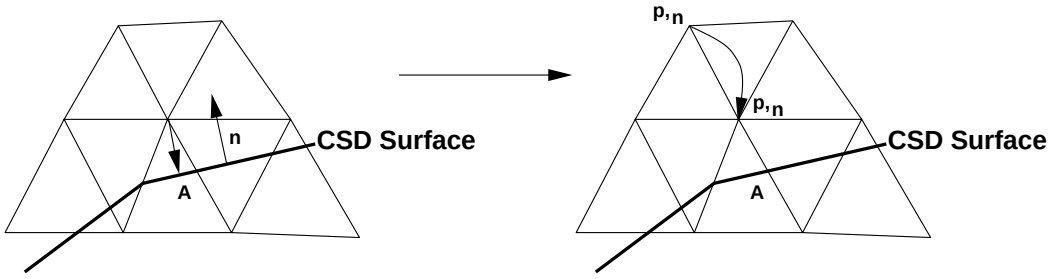
Other Options:

- Match to Known Exact Solution (e.g. Stokes (PHYSALIS))

IMPROVED BOUNDARY VALUES FOR PRESSURE

Normal Pressure Gradient: $\mathbf{n} \cdot \nabla p$

- Values for Points Attached to Crossed Edges Inaccurate
- Obtain Closest Point on CSD Face
- Obtain Best Point for Extrapolation (Alignment)



MODIFICATION OF `geobp`-ARRAY

Field Point:

$$\Delta \mathbf{u}^i = \frac{1}{M^i} \sum_{\Omega} C^{ij} \left(F_i + F_j \right)$$

Due to Cut Edge: $\Delta \mathbf{u} \neq 0$ For Uniform State/No B.C. $\Rightarrow$

$$\Delta \mathbf{u}^i = \frac{1}{M^i} \left[\sum_{\Omega} C^{ij} \left(F_i + F_j \right) + C^i_{\Gamma} F_i \right]$$

$\Rightarrow$ Need New Entries in `geobp`-Array

Imposed by Forcing: $\Delta \mathbf{u} = 0$ for $\mathbf{u} = const.$

MODIFICATION OF THE MASS-MATRIX

Need: Take Volume of Cut Elements into Account

Given: Edges Cut by CSD Faces

Idea:

- Compute Smallest 'Cut Edge Fraction' ξ of Points Belonging to Cut Edges
- Modified Mass-Matrix:

$$\mathbf{M}_l^* = \frac{1+\xi_{min}}{2}\mathbf{M}_l^0$$

$\Rightarrow$ Can Never Fall Below $0.5\mathbf{M}_l^0$ (!)

EXTRAPOLATION OF THE SOLUTION

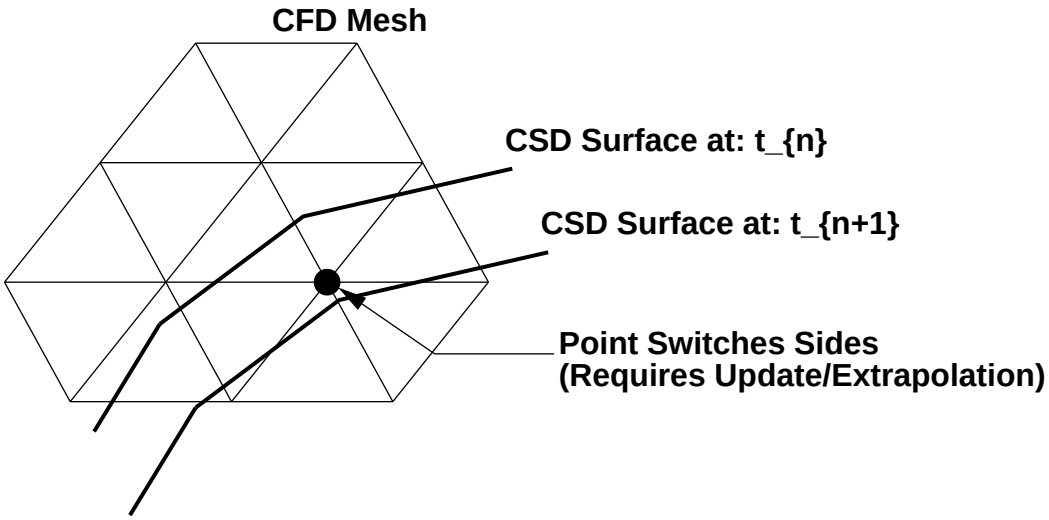


Figure 3 Extrapolation of Solution

EXTRAPOLATION OF THE SOLUTION

As CSD Faces Move Through Mesh:
Jump In Unknowns Possible

- Condition 1:
    - Edge Crossed Before
    - Edge No Longer Crossed
- Condition 2:
    - Free Point Donates Values to Constrained Point
- Condition 3:
    - CSD Face Velocity Aligned With Edge

COORDINATE MOVEMENT FOR DISPLAY

Why: Looks Better

How: For Each Point Close to CSD Faces

- Store the Nr. of Edges Crossed
- Attempt to Discern 'Directions of Movement'
- Add Non-Aligned 'Directions of Movement'
- Move Points
- Perform Displays With Moved Points

COORDINATE MOVEMENT FOR DISPLAY

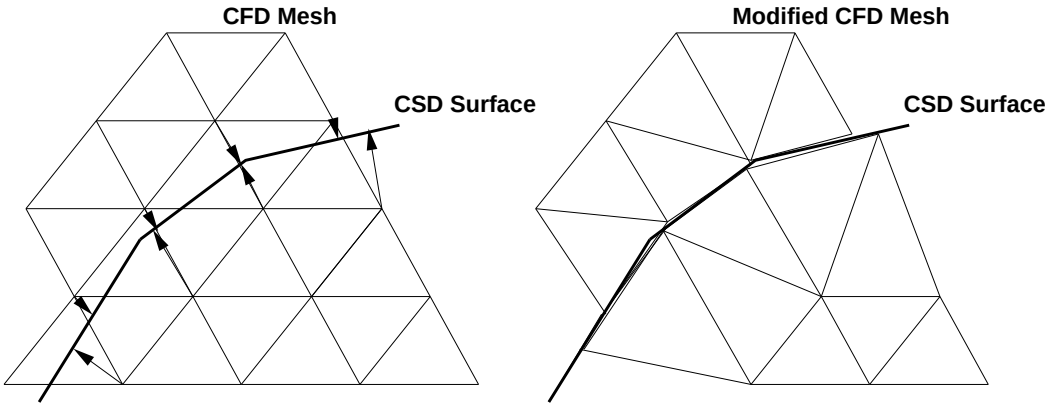


Figure 4 Mesh Movement for Visualization

SOD SHOCK TUBE PROBLEM

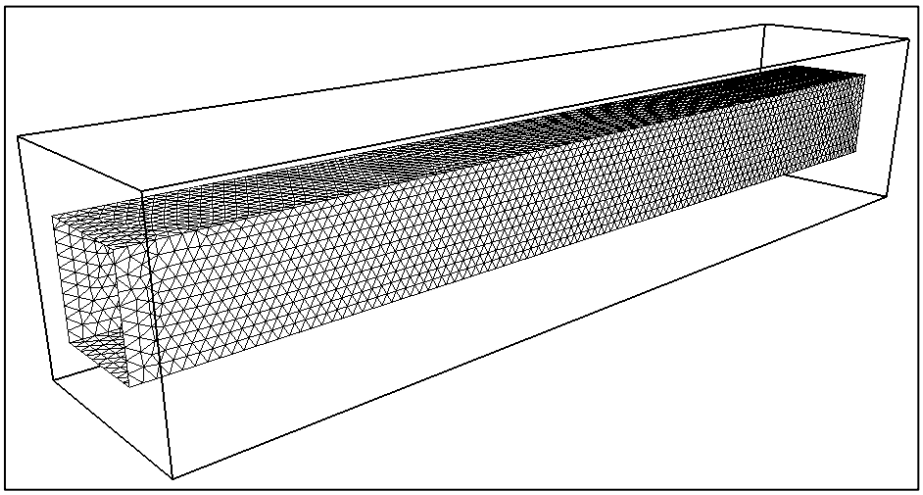
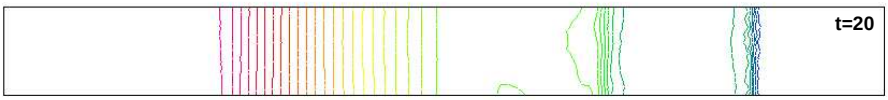
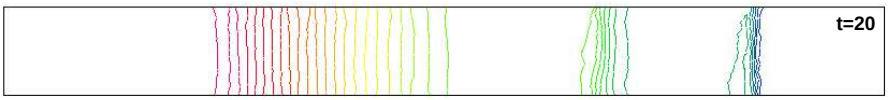


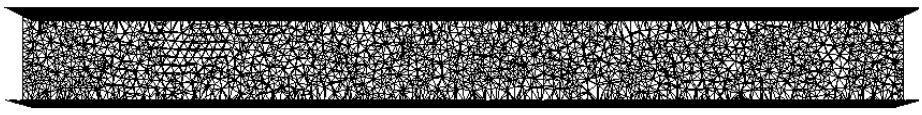
Figure : Sod Tube: Domain and CSD Faces



Density: Usual Body−Fitted Mesh



Density: Embedded CSD Faces in Mesh



Plane Cut With Embedded CSD Faces in Mesh

Figure : Sod Tube: Comparison of Densities