Advanced Fluid-Structure Interaction Issues

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FSI Overview

- Simulate the behavior of both the fluid and solid at the same time
  - Some interaction between the two
    - Motion of the solid drives and/or effects the fluid
    - Fluid forces imposed on the solid effect its deformation
- More complicated and difficult than "normal" CFD or Solid-Mechanics Simulations



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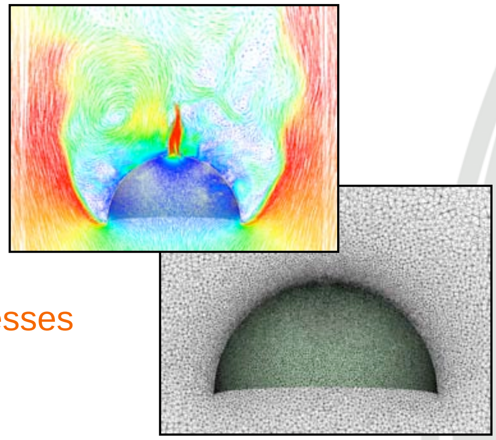
FSI Complexities



- Coupling
  - Explicit or implicit
- Interface
  - Conforming mesh or not
  - Exchange of variables and stresses
- Different time scales
- Load balancing
  - Different computational requirements of fluid and solid
  - Performance and scalability
    - Complexity's impact on performance
- Code organization, structure, and modularity
- Mesh moving to handle changes in domain shape

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Mesh Moving Issues

- Very challenging issue
  - May be the main limiting factor for FSI applicability
- Must move, deform, or change the mesh to accommodate the changing geometry
- Several methods exist
  - Specially designed "algebraic" methods
  - Overset and chimera methods
  - Immersed boundary methods
  - Mesh moving using a mesh-elasticity model and remeshing
  - **Dynamic-Mesh Methods**
- Parallelization and scalability makes implementation challenging

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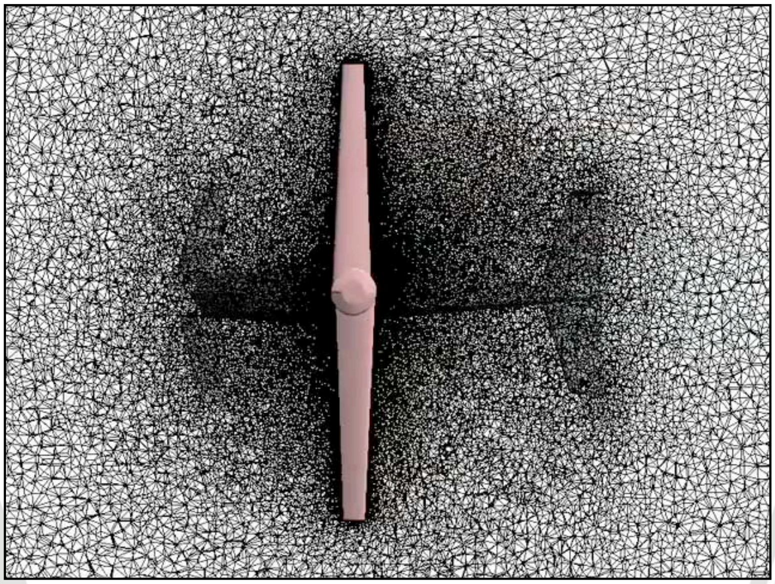
Demonstration (Rotorcraft)



Rotation of the blades showing the 3D unstructured mesh at a cross-section

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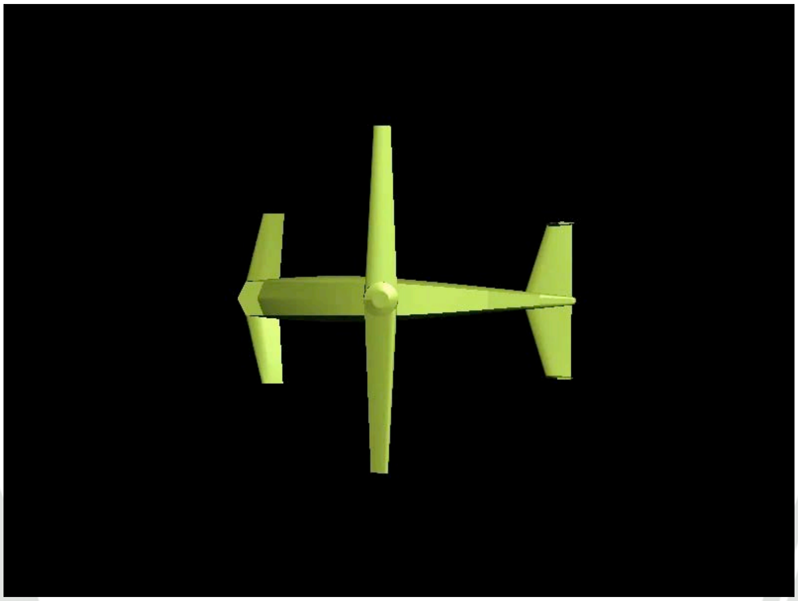
Demonstration (Rotorcraft)



Rotation of the blades showing the 3D flow using particle tracing

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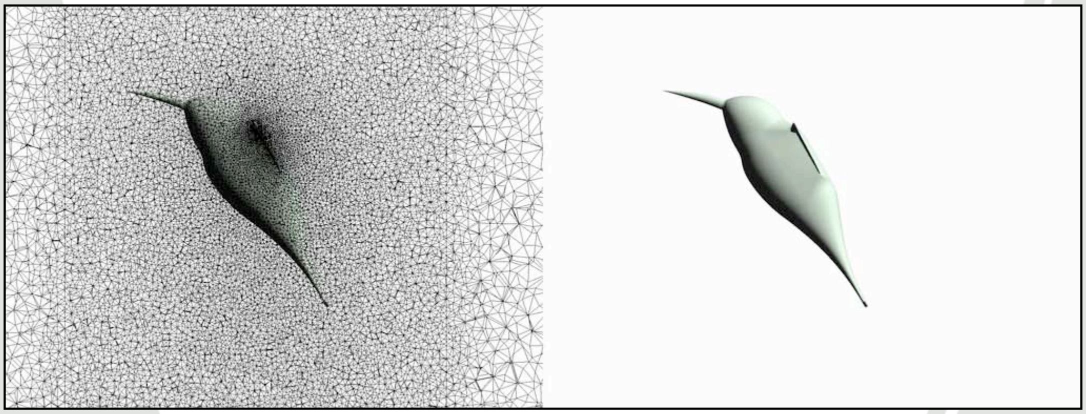
Demonstration (Hummingbird Aerodynamics)



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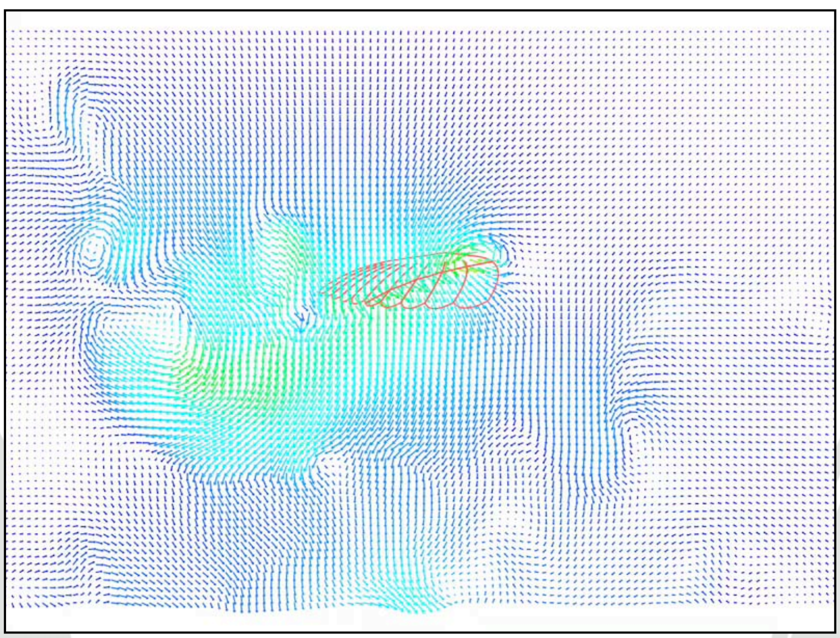
Hummingbird Wing Aerodynamic Study

(collaborations with Warrick and Tobalske, Oregon State and University of Portland)



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Digital DynamiX Framework

- A software framework for simulating complex fluid-structure interaction applications
  - Implements a 3D dynamic-mesh
  - Fully parallel implementation
  - Object-oriented and modular
  - Project is in the initial planning stages
- Methodology proven using a prototype simulation code called “XFlow”
  - Demonstrated for several fluid-structure interaction applications

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Digital DynamiX Framework (continued)

- Fully unstructured 3D mesh
  - Mesh moves and deforms to accommodate the changing domain shape
  - Structure of the mesh continuously changes to insure high quality throughout
    - New nodes added and/or removed when required
    - Elements re-configure themselves when required
    - Fully automatic procedure
  - Incorporates automatic mesh generation techniques
    - Delaunay methods with face-swapping techniques

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Digital DynamiX Framework (continued)

- Fully parallel implementation
  - Required when solving 3D applications
- Complexity of the method requires a PGAS implementation
  - Difficult if not impossible to implement with MPI
  - Prototype code implemented with Unified Parallel C
    - Cray X1E system
    - Very low latency which is good for small messages
- Experimenting with an OpenMP “PGAS” implementation
  - Need to identify architectures and programming models that support PGAS well

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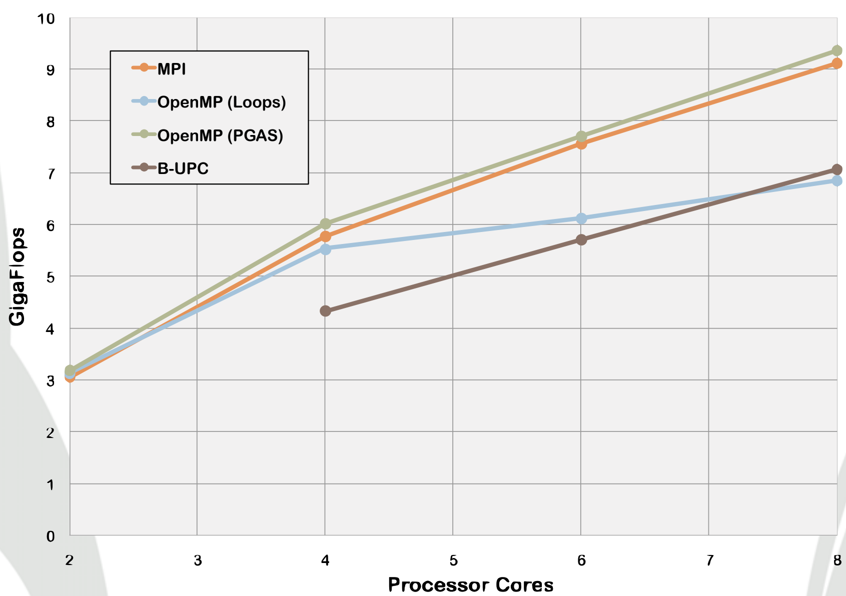
Multi-Core MacPro (3.0 GHz Xeon)

BenchC (non-FSI) CFD Simulation Code

(Incompressible Flow, Finite Element, GMRES Iterative Solver, 4.5 Million Tetrahedral Elements)



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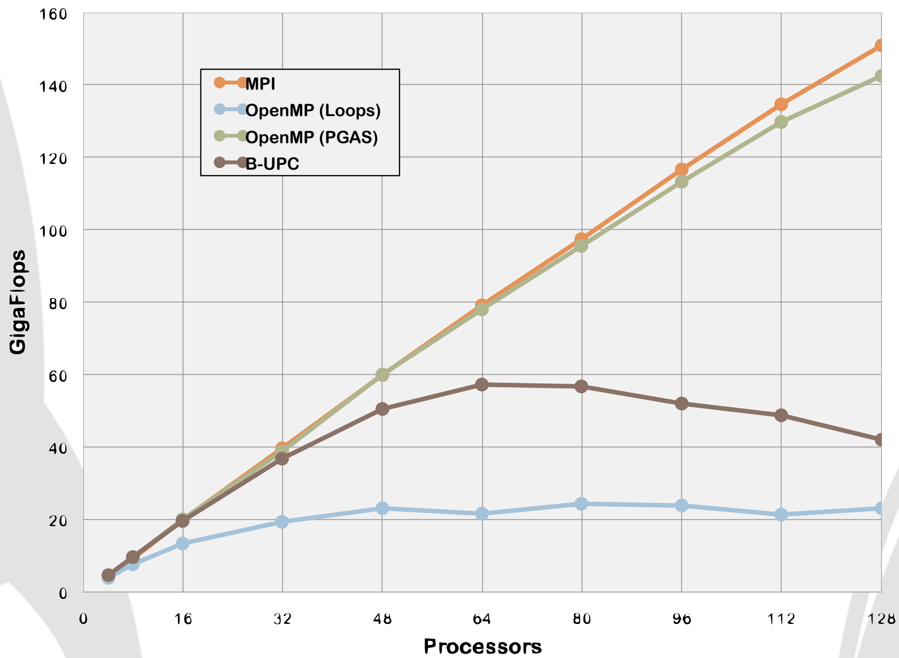
SMP Performance (SGI Altix 3700)



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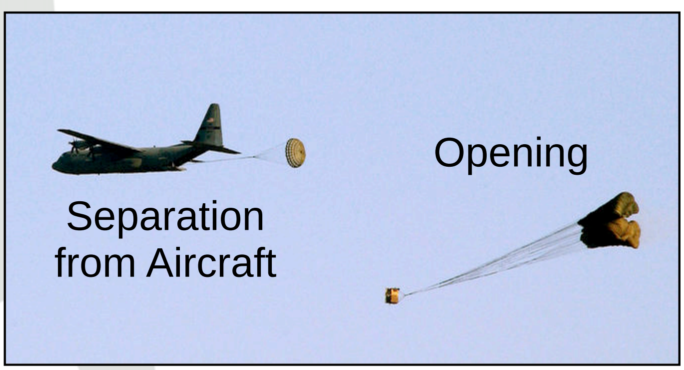
FSI Example: Airdrop Systems

- Very challenging and important application area
  - Army, Air Force, NASA, etc.
  - Simulations can help replace (limit) dangerous live tests
- Broad area with many aspects
- Demonstration runs of parachute opening



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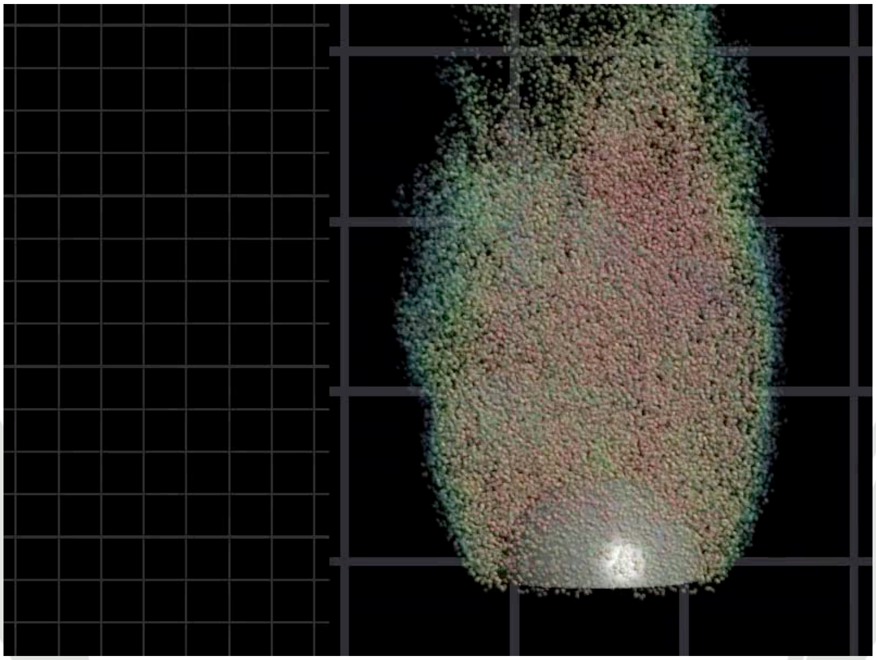
Airdrop Systems (continued)



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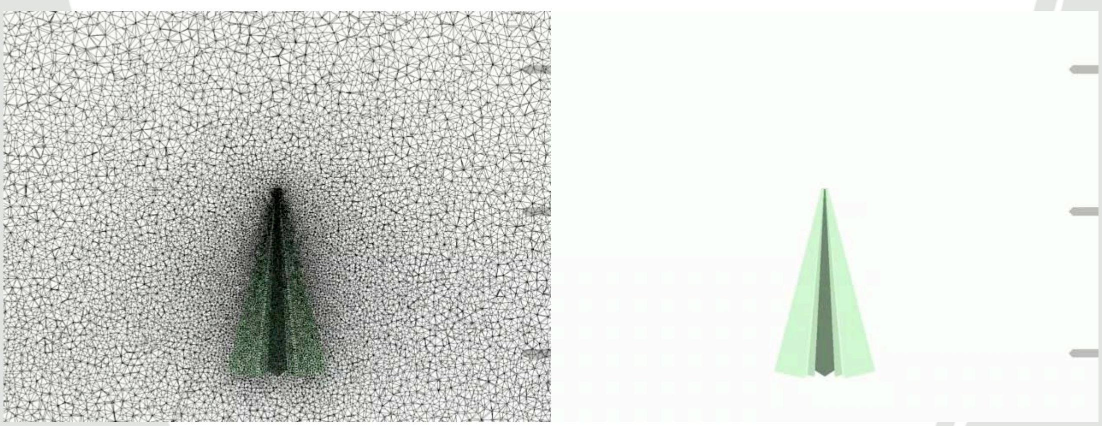
Airdrop Systems (continued)



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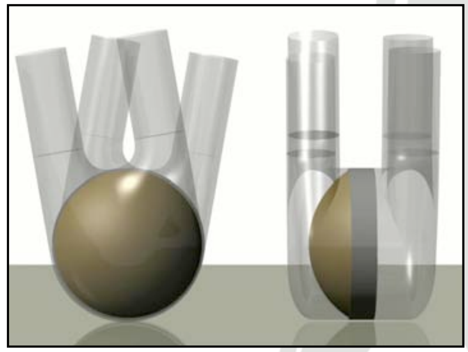
FSI Example: Biomedical Devices

- Emerging area (for HPC) with large potential benefits
- Blood flow through hearts, valves and arteries
  - Design and function of medical devices
  - Effects of abnormalities or disease
- Airflow through lungs and air passages
- Complicated FSI requirements
  - Flow driven by mechanical devices
  - Flexible arteries and membranes
- Initial demonstrations
  - Blood flow through an artificial heart
  - Artificial heart valves



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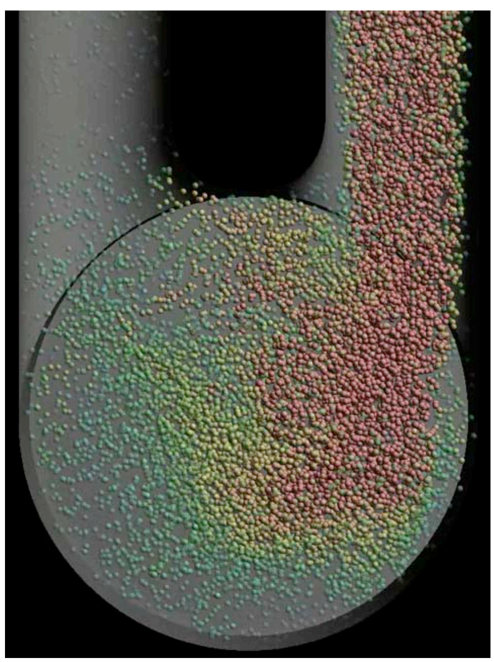
Biomedical Devices (continued)



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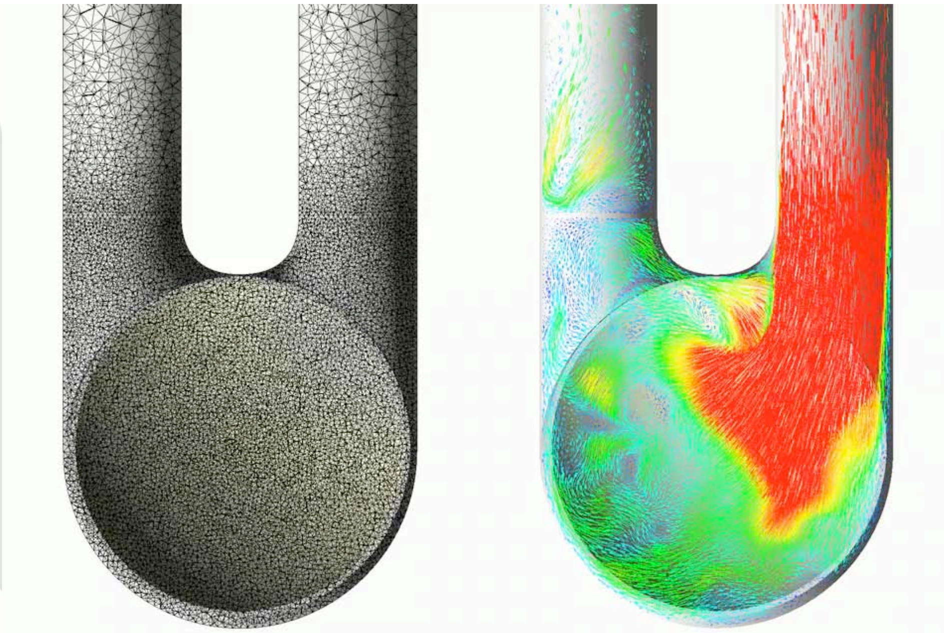
Biomedical Devices (continued)



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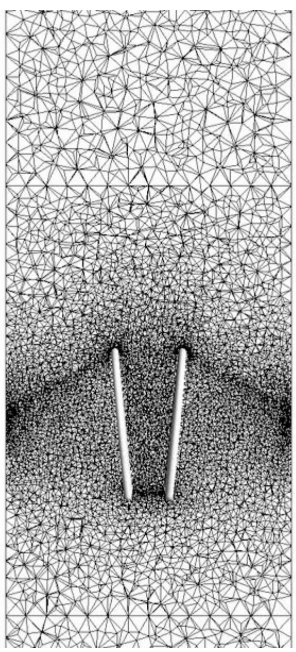
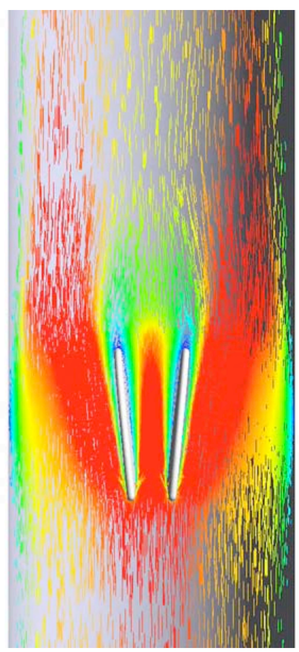
Biomedical Devices (continued)





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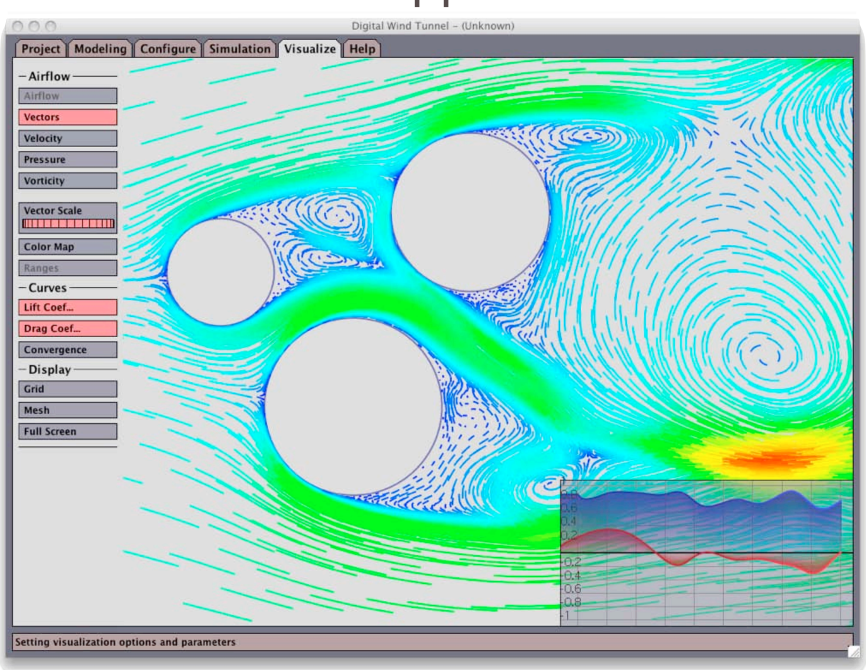
Dynamic-Mesh Method for Solution Adaptivity

- Should be able to provide a capability for both mesh moving (FSI) and full solution adaptivity
  - Addition/removal of mesh-nodes tied to an error measure
  - Increases accuracy while minimizing computational cost
- Demonstrated dynamic-mesh adaptivity in DRS's "*Digital Wind Tunnel*" desktop application
  - Easy-to-use but powerful CFD tool built specifically for education (high-schools and colleges)
    - Simulation in 2D
  - Fully unstructured and solution-adaptive meshes required for "novice" users
  - Utilizes scalable performance of multi-core desktop systems
  - Currently exists in a fully-functional prototype form
  - **Live Demonstration...**

Digital Wind Tunnel Application



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