MDICE
An Integrated Framework for Multi-disciplinary Engineering Simulations

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Motivation for Building Distributed Systems for MDA

- Monolithic Applications are too Unwieldy to Maintain
  - Promote Little Software Reuse
  - Poor Extensibility due to Tightly-Coupled Nature
  - Increase Software Maintenance Needs
  - Prohibitive Costs in Building Complex Applications ad hoc from Scratch

- Distributed Systems Lead to Separation of Concerns
  - Promote Software Component Reuse
  - Offer Plenty of Scope for Extensibility
  - Enable Plug-and-Play of Components due to Loosely-Coupled Nature
  - Facilitate Software Maintenance

- Lack of Integration Among the Various Software Analysis Components is the Major Obstacle in Multi-Disciplinary Analysis

Issues in Design of Distributed Simulation Environments

- Coping with Heterogeneity in Hardware Platforms, Programming Languages
- Collaboration among Applications from Dissimilar Disciplines and Technology Providers
- Handling Data Communication between Applications
- Security Issues in a Networked Environment

Requirements of a Framework for Distributed Applications

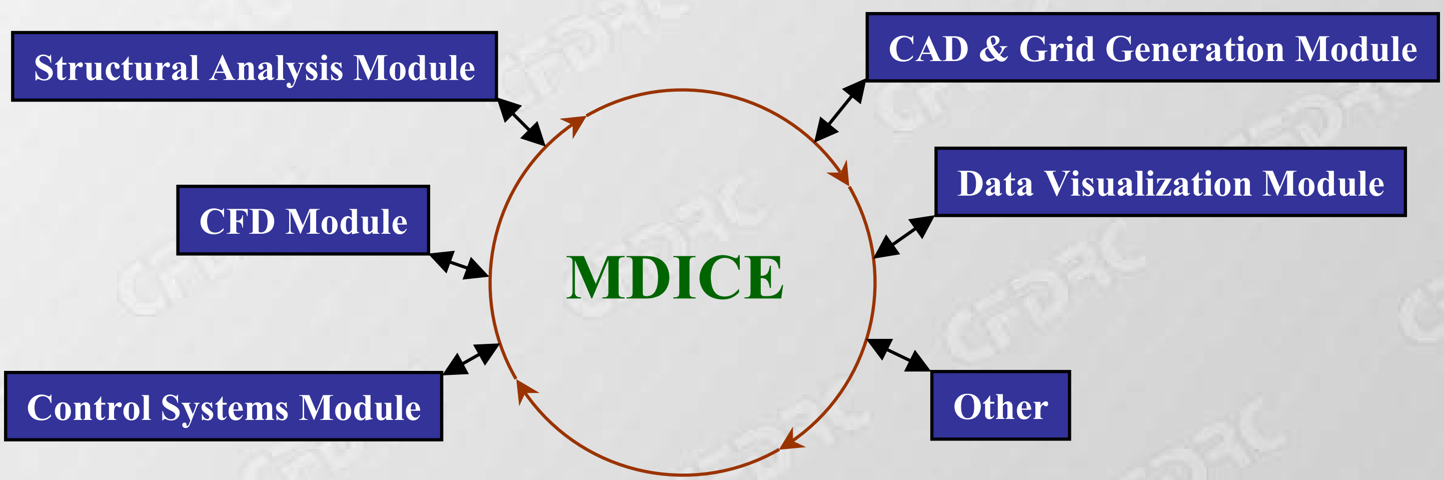
- What We Need is an Infrastructure Framework that Enables:
  - Applications to Interwork Seamlessly in Heterogeneous Environments
  - Components to Communicate with Each Other with Location Transparency, Using a Common Programming Model
  - Event-Driven Control Over Applications Using Remote Method Invocations; Most Engineering Applications have a Sequential Work Flow
  - Capability to Control the Level of Coupling Between Application Processes (Fine Grain *vs*. Coarse Grain, One-way *vs*. Two-way)
  - Dynamic Spawning/Removal of Application Processes
  - Hiding of Low-Level System Infrastructure Tasks from Application Developers

Conceptual Overview of MDICE

- MDICE - Multi-Disciplinary Computing Environment

- MDICE Enables Engineering Programs of Various Disciplines to Functions as One Multi-Disciplinary Application in a Distributed, Heterogeneous, Object-Oriented Framework

- MDICE is an ORB-like Middleware Designed to Bridge the Gap Between Application Programs and Lower-Level Hardware & Software Architecture and Coordinate their Interoperability.

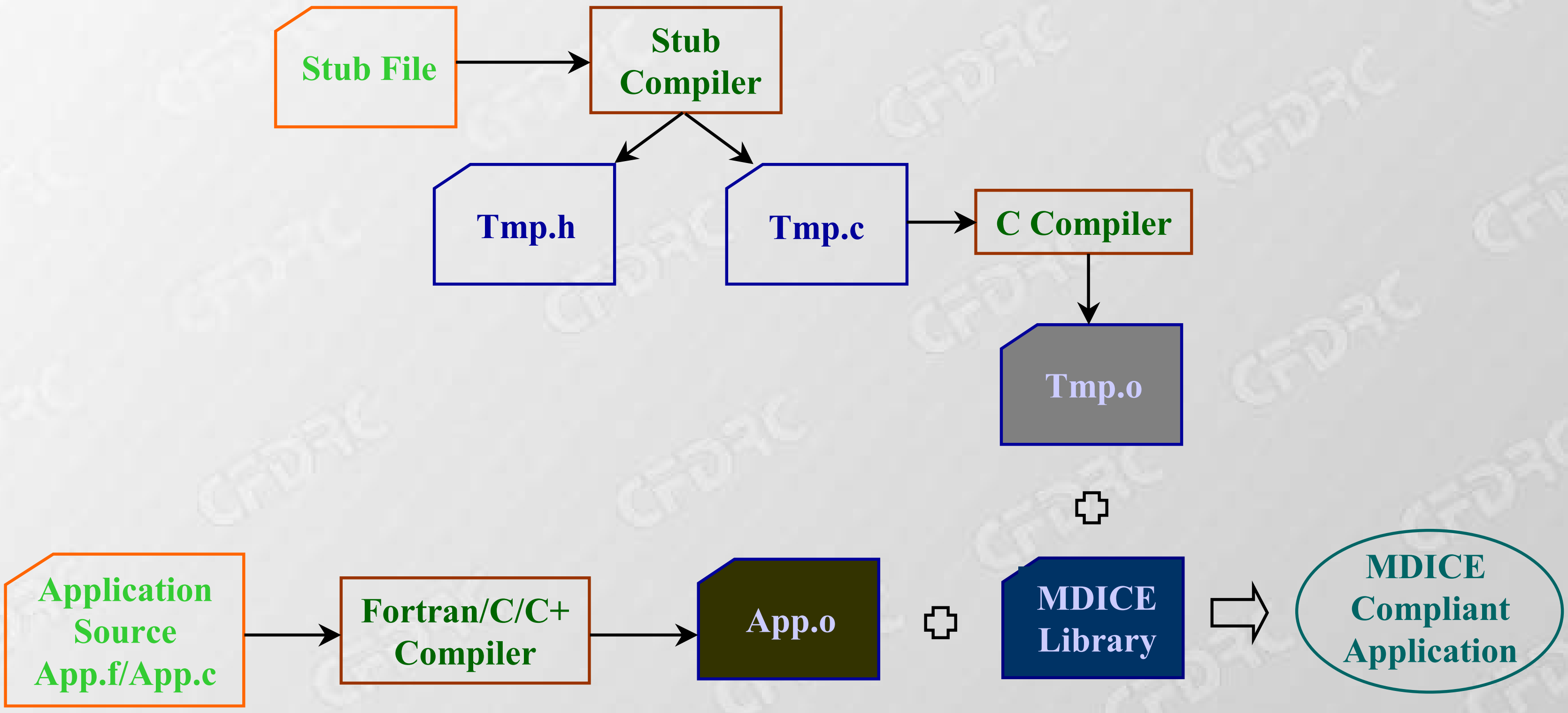


Salient Features of MDICE

- Workflow Management of a Multi-Disciplinary Simulation
- Dynamic Process Interactions by Virtue of Common Object Transfers Between Application Modules
- Temporal Synchronization of Application Modules for Time-Accurate Simulations
- Automatic Unit Conversions (Metric-SI) and Precision Conversion (Double-Single)
- Multi-Dimensional Coupling (1D, 2D, or 3D) Between Applications
- Special-Purpose Engineering Modules that are Integrated into the Environment

Creating an MDICE Compliant Application

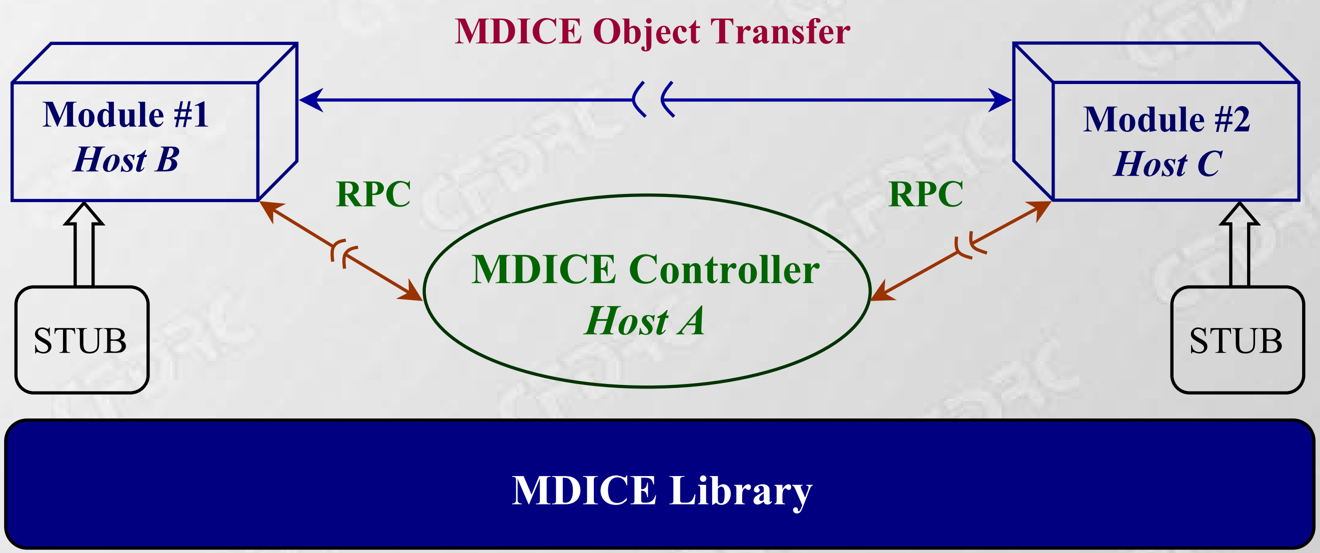
- A Stub Provides Mechanisms to Enable the Application to Work in a Distributed Setting; Stub is Created Using a Declarative Language
- Middleware Components are Linked into the Application at Compile Time using the MDICE Library.
- Legacy Applications Integrated into MDICE Using Wrapper-based Approach



Components in MDICE Framework

- MDICE Controller Performs the Role of the Central Nervous System of the Environment
  - Controls the Workflow of the Simulation & Module Interactions
  - Delegates Tasks to the Modules via Remote Method Invocations

- Modules Interact with Each Other by Exchanging MDICE Objects



Layered Approach to Middleware

- Implement the Middleware as a Layered Architecture

Engineering Applications

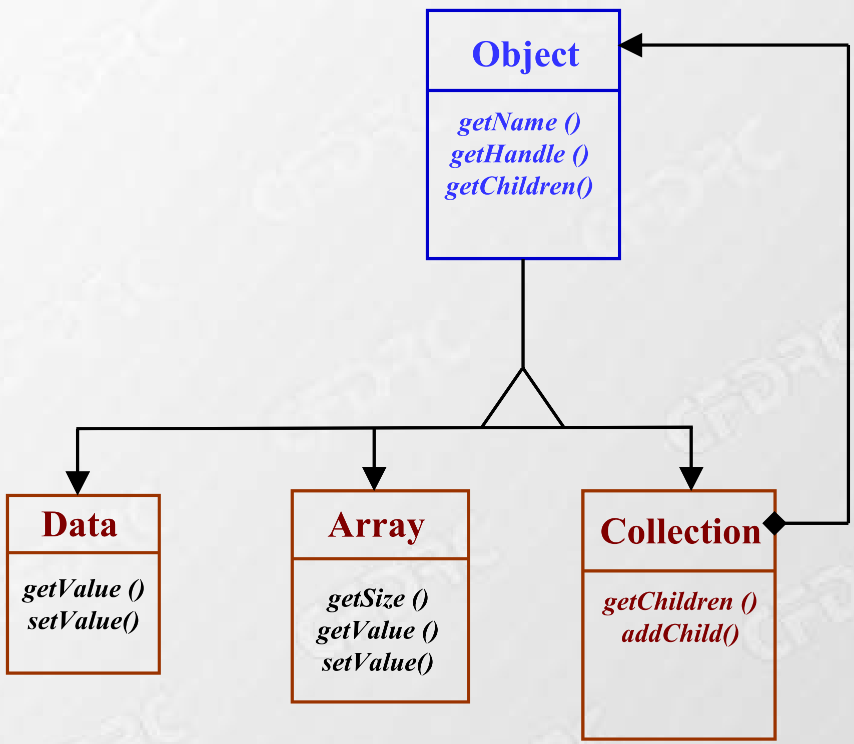
Upper Level — Services, Object Implementations for Engineering Disciplines, Data Unit Conversions, Data Type Conversion

Mid Level — Mechanisms to Enable Applications Interoperate without Dependencies on Location, OS Platform, Programming Language, Network Communication Protocols; Object Serialization/Deserialization, RPC

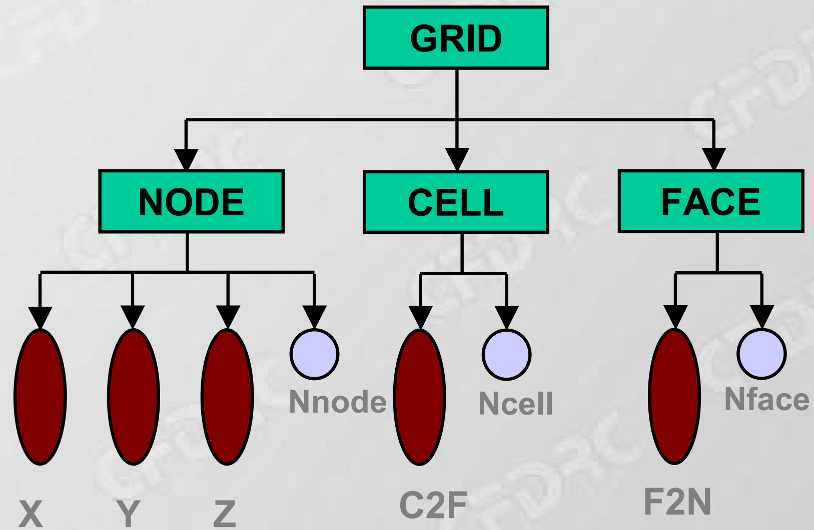
Base Level — Network Connection Management, IPC, TCP/IP Event De-multiplexing, Signal Handling, Other OS Mechanisms

Composite Pattern to Implement MDICE Objects

- MDICE Objects Contain One or More Scalars, Arrays or Sub-Objects
- MDICE Object Allow Hierarchical Tree-Like Structure
- MDICE Library is Comprised of a Suite of Objects Suited for Engineering Applications.



OMT Representation of MDICE Object



CFD Grid Representation

What is the Framework Good For ?

- The Goal is to Leverage Distributed Systems Design, Computer Networking Technology and Modern Software Architectures to Better Enable Multi-Disciplinary Engineering Simulations

- MDICE Applications have been Deployed in the Following Engineering Areas:
  - Parallelization of Large Scale CFD Applications
  - Aero-elastic Analysis
  - Semi-Conductor Manufacturing Process Modeling
  - Bio-Medical Device Modeling
  - Nuclear Industry Applications
  - Design Optimization
  - Aero-thermal-elastic Analysis

Available Platforms & Disciplines

- MDICE has been Ported to the Following Platforms:
  - Linux, IRIX, HP-UX, AIX, OSF, Solaris and Win32

- The Following Disciplines have been Integrated into MDICE and have been Successfully Employed for Multi-Disciplinary Simulations:
  - CAD – Unigraphics, Pro-Engineer
  - Grid Generation – CFD-GEOM
  - CFD Flow Solvers – CFD-FASTRAN, CFD-ACE, SPLITFLOW, ENS3DAE, ADPAC, COBALT, CORSAIR, GCNSfv
  - Structural Solvers – SI (Wrapper Interface for NASTRAN, ANSYS), ENS3DAE, EMS, CFD-ACE (Stress Module)
  - Post-Processing – CFD-VIEW, XMGR

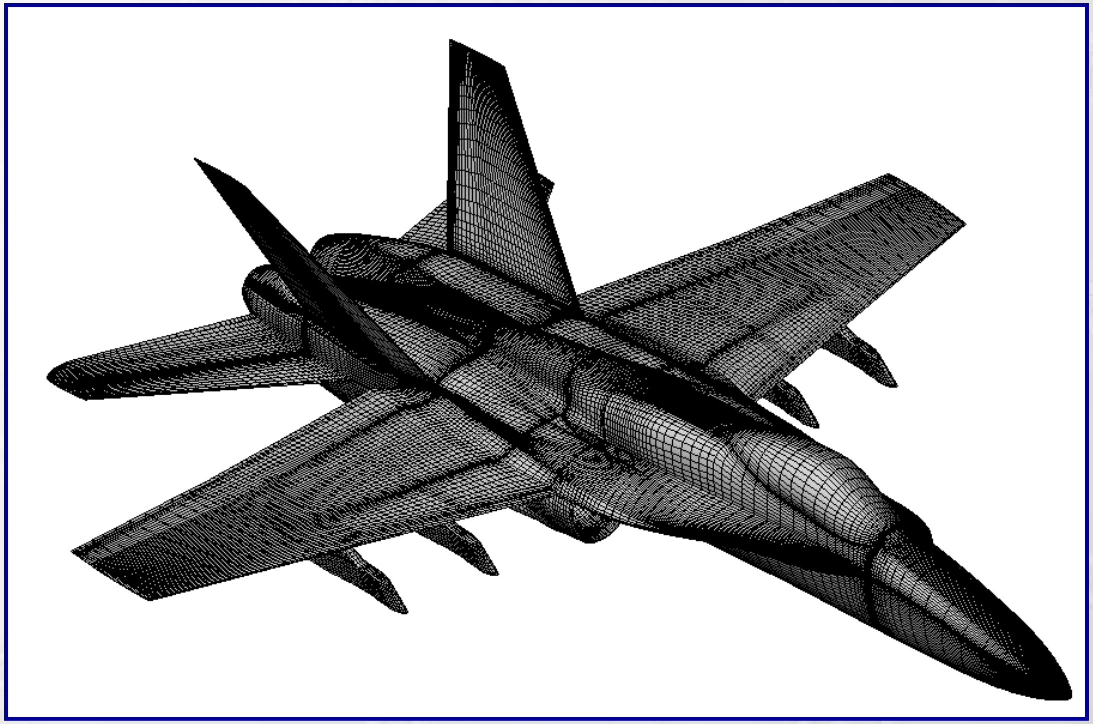
MDICE Applications

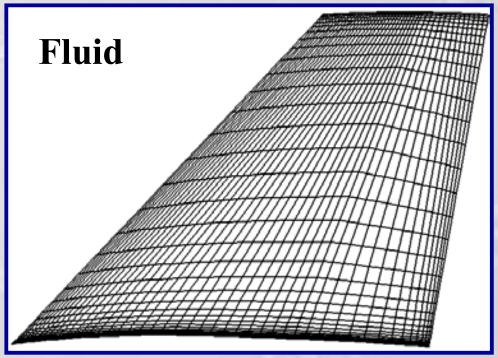
- A Quick Overview of MDICE-Enabled Applications in Several Engineering Disciplines

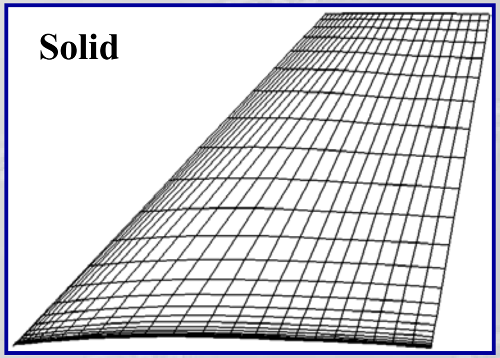
- All Examples Represent Cases where Requisite Modeling Capabilities were not Available all in the Same Simulation Software
  - Necessitated Integrating & Coupling Several Software Components Together with MDICE

Aero-elastic Modeling of F18 Buffet

- Numerical Simulation of Buffet Phenomenon in a Twin-Tail F18 Configuration; Coupled Fluid-Structure Interaction (FSI) Simulation
- Mach Number= 0.243, Reynolds Number= 11 x $(10)^6$

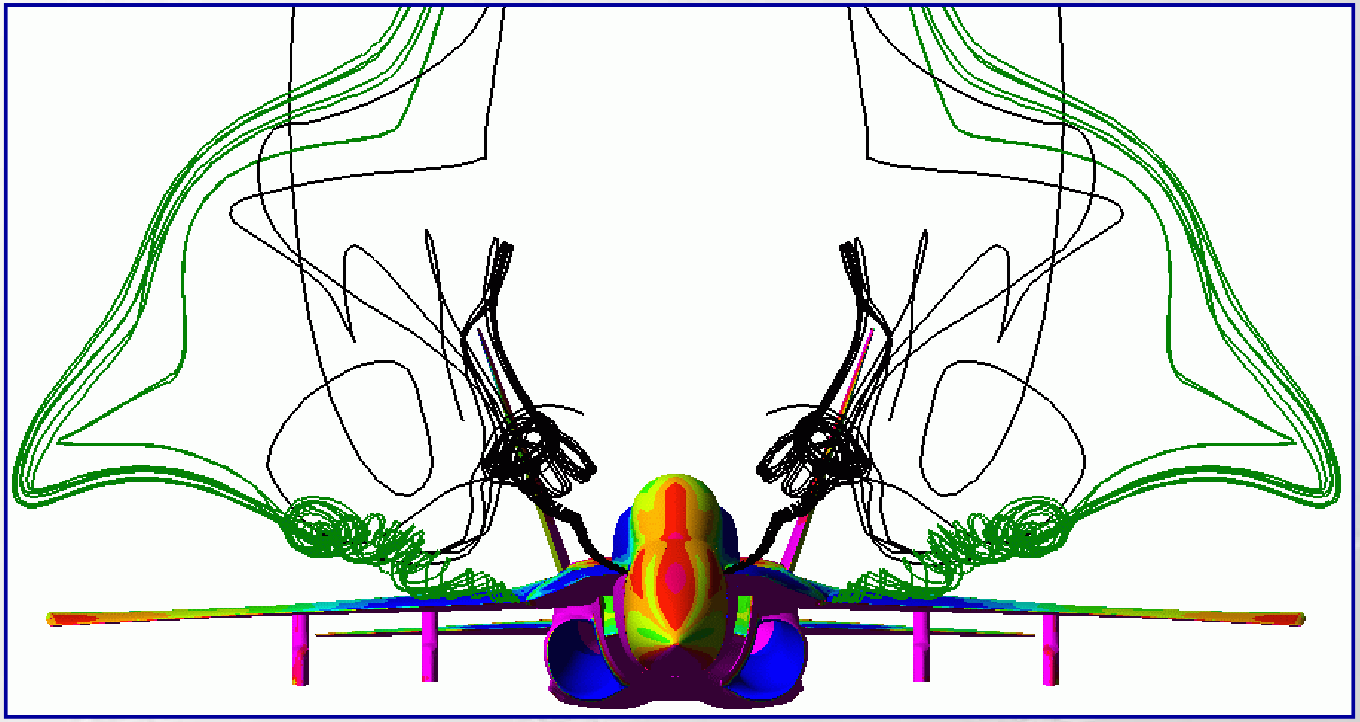






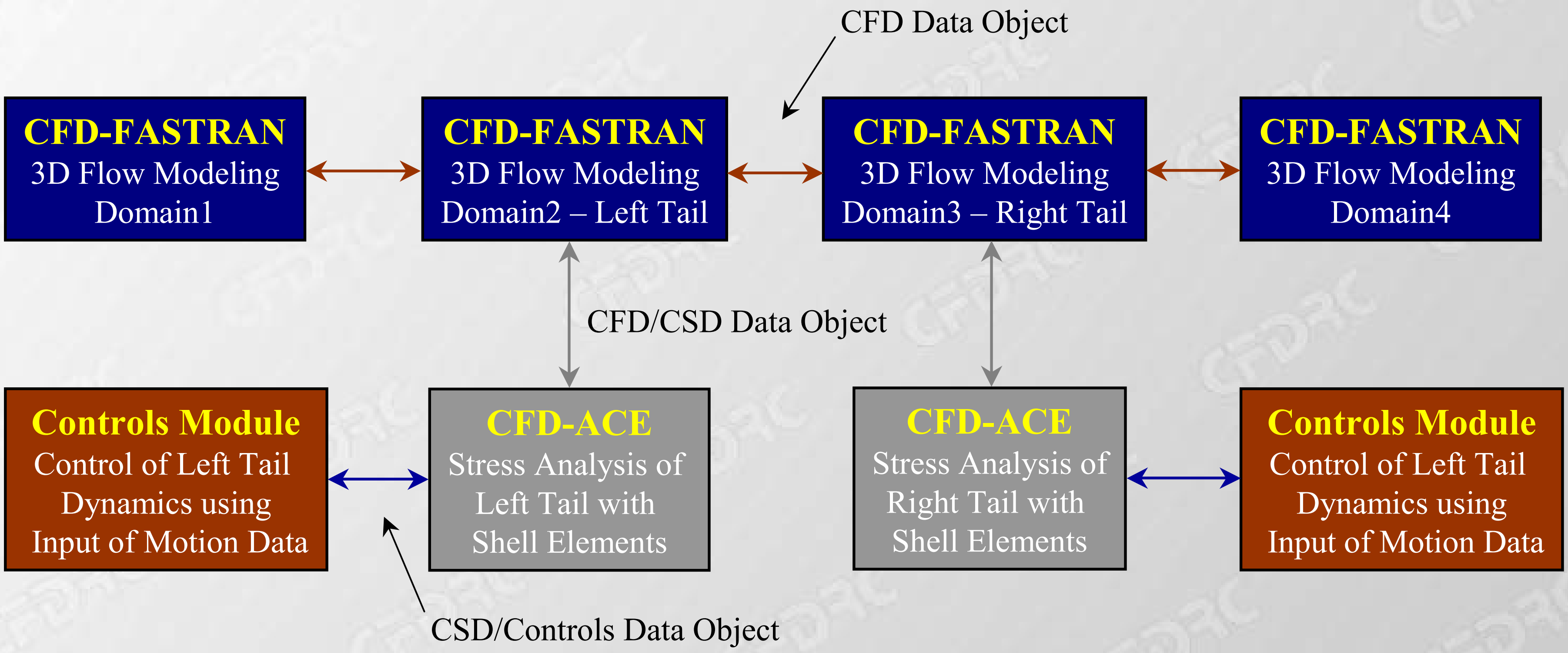
F18 Buffet Simulation

- Instantaneous Streamlines for Flow at an Angle of Attack of 40^o



Module Interactions in MDICE

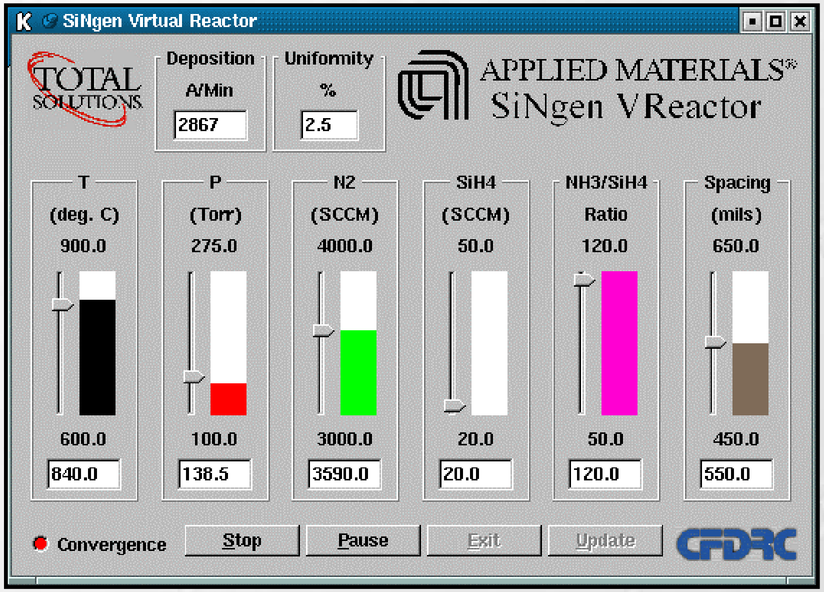
- Coupled FSI (Fluid-Structure Interaction) Performed in MDICE with Interactions Between 4 Instances of Flow Solver and 2 Instances of Structural Solve
- Proposal to Include Control Systems Module in the Framework to Enable Flow Control Using Piezoelectric Actuators

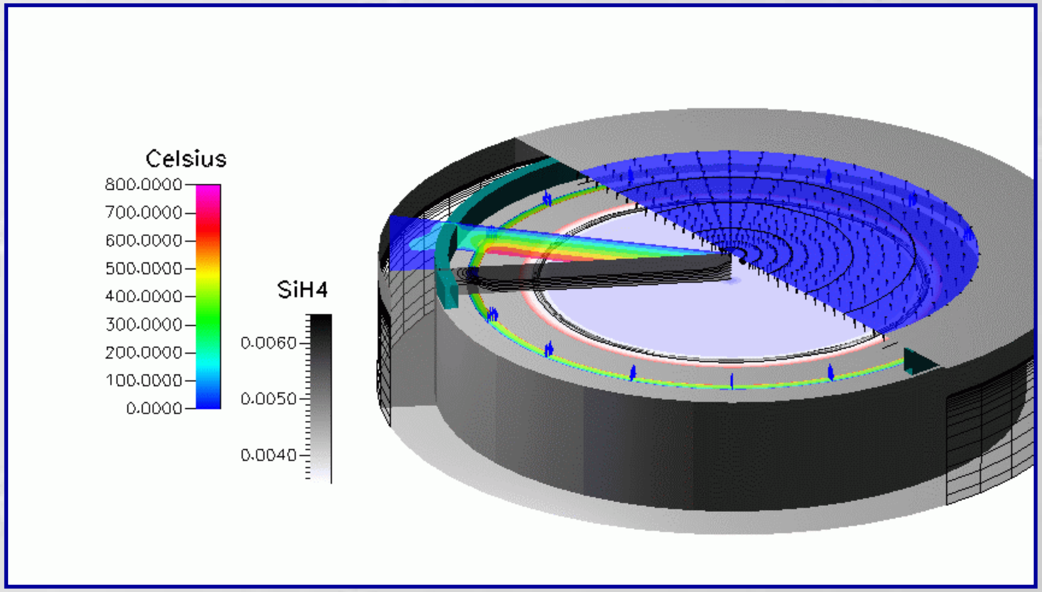


Virtual Reactor

❖ What is a Virtual Reactor

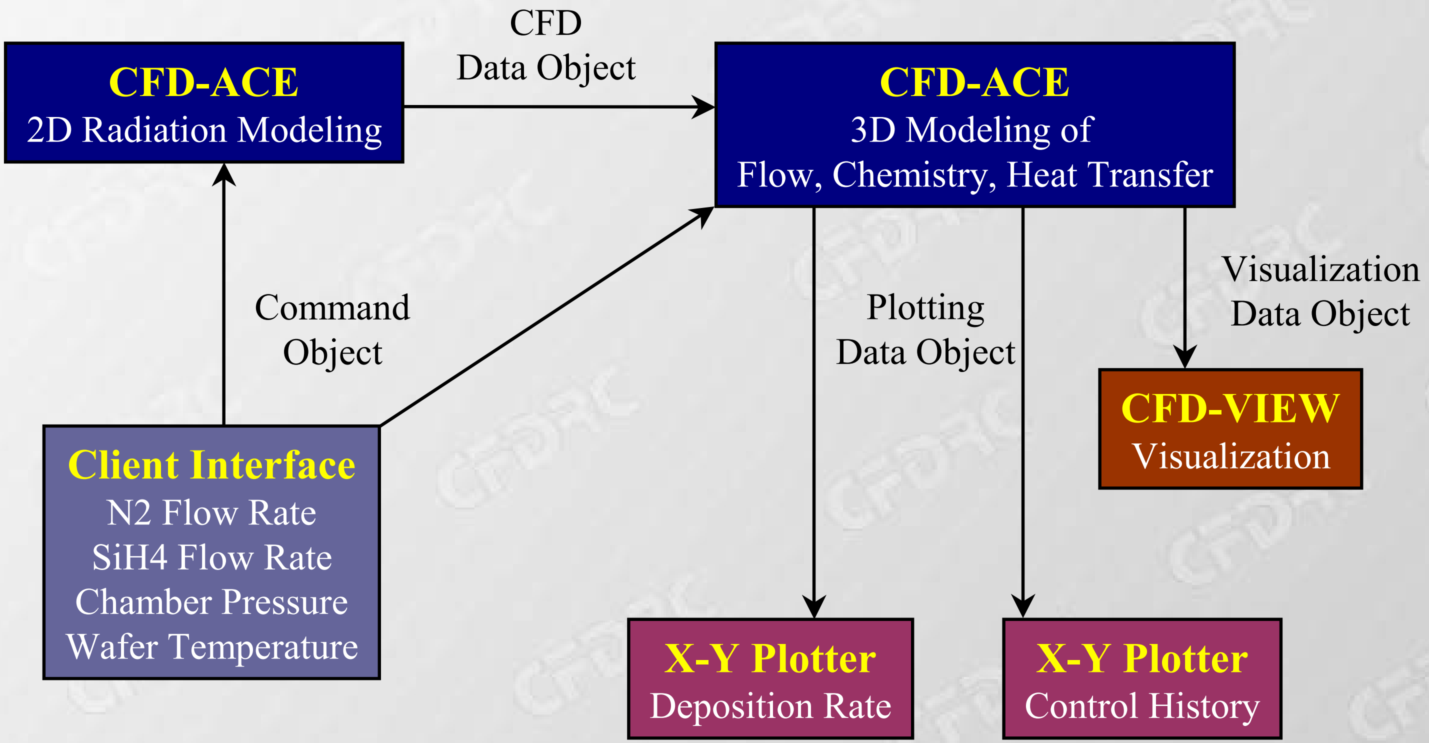
- Customized Interactive Simulation Tool for Modeling Semi-conductor Manufacturing Process in a CVD Reactor
- Integrated Physical Modeling of Flow, Heat Transfer, Chemistry, Visualization





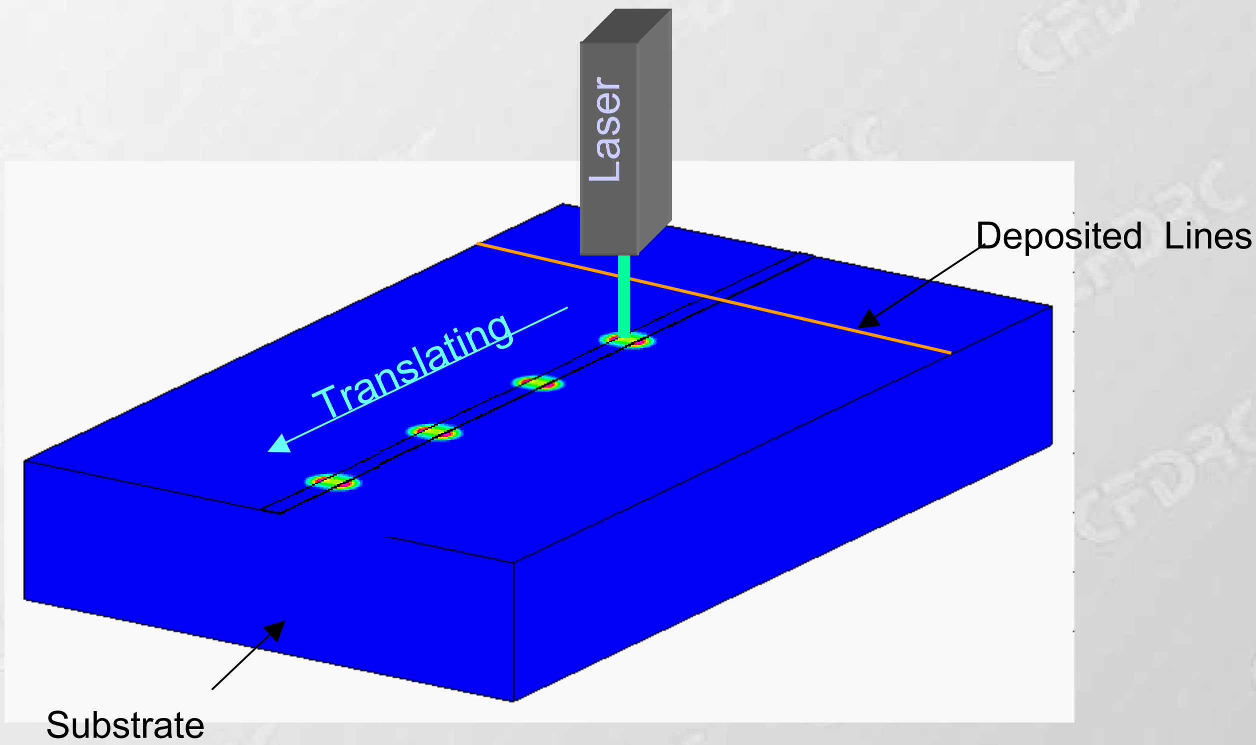
Virtual Reactor Architecture

- Application Module Interactions in Virtual Reactor
- User Drives the Entire Simulation from the Client GUI



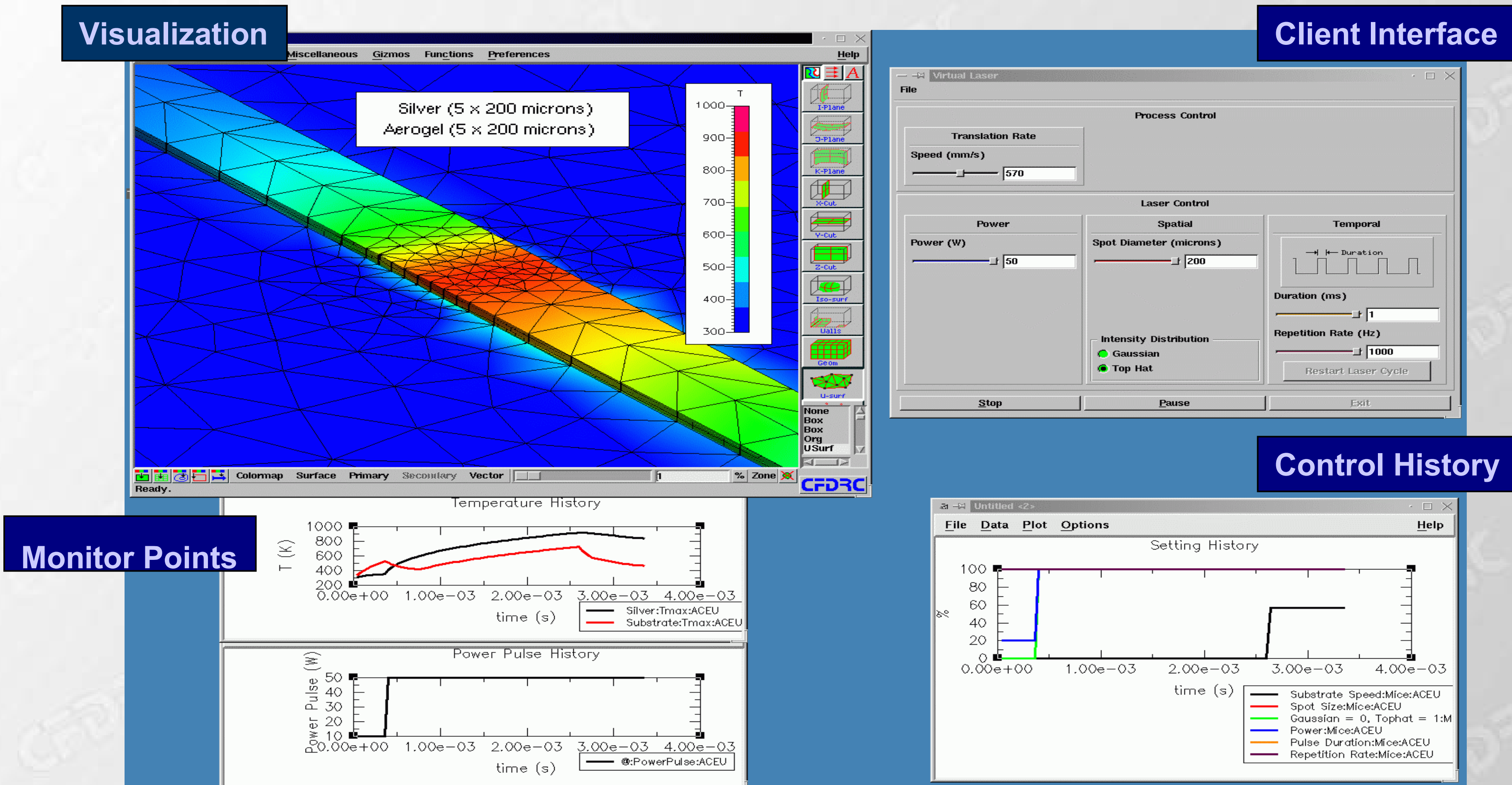
Simulation Tools for Direct Write of MICE

- MICE - Mesoscopic Integrated Conformal Electronics
- 3D Pulsed Model for Analyzing Thermal Profiles of Composite Layers as a Function of Translation Rate, Pulsing Profile, Intensity & Spot Size of Laser



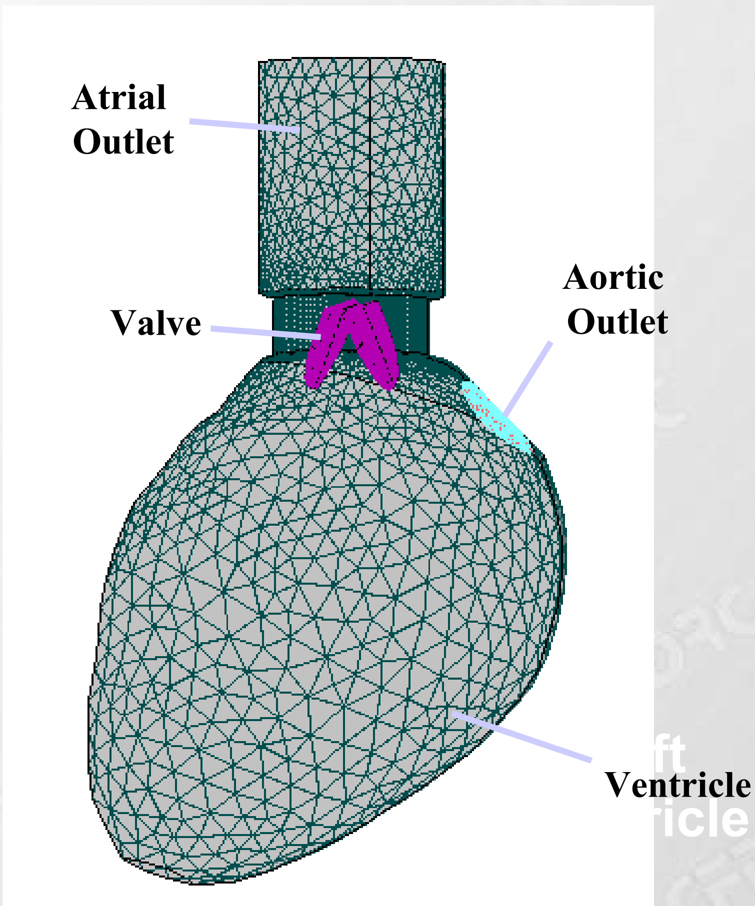
MDICE for MICE

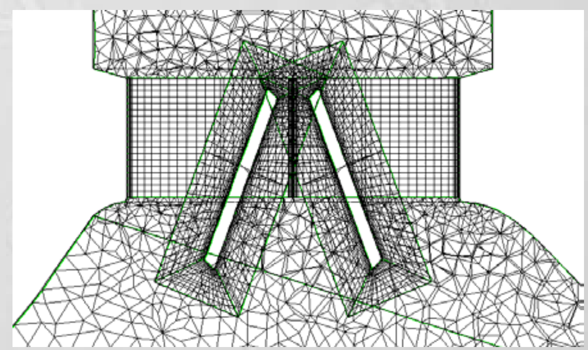
- Integrated, Interactive Simulation Tool for MICE - Physical Modeling of Radiation, Chemistry/Sintering, Grid Adaptation & Visualization



Bio-Medical Application

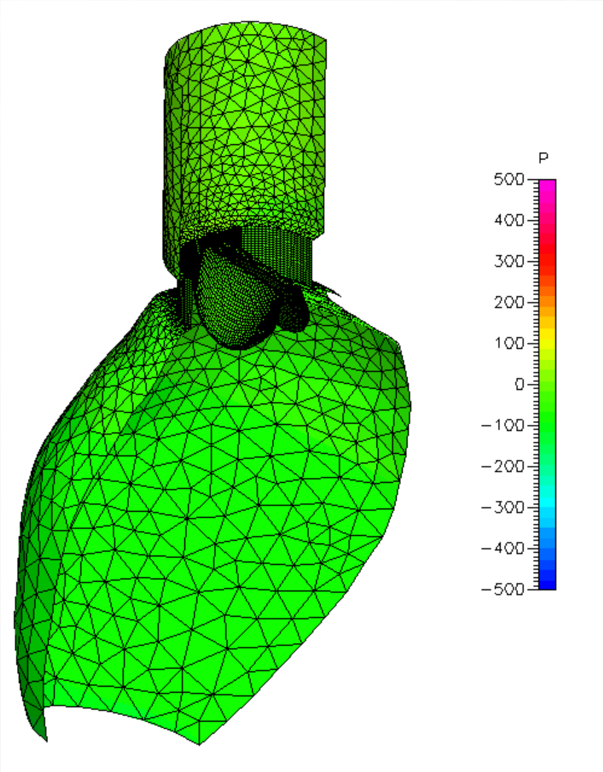
- Modeling Pulasatile Flow of Blood Through Mechanical Heart Valves due to Movement of the Ventricle
- Studying the Stresses in the Valves at Different Phases

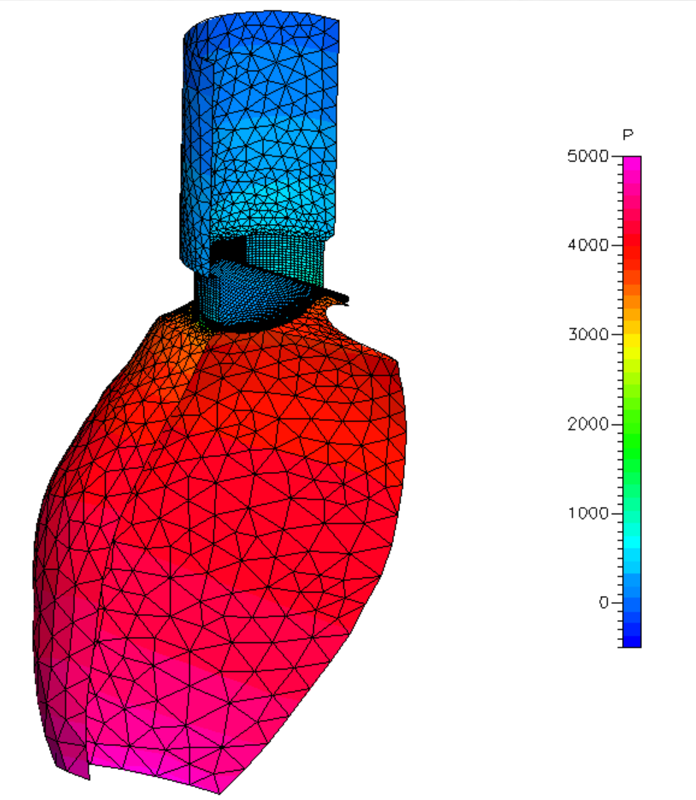




Heart-Valve Simulation

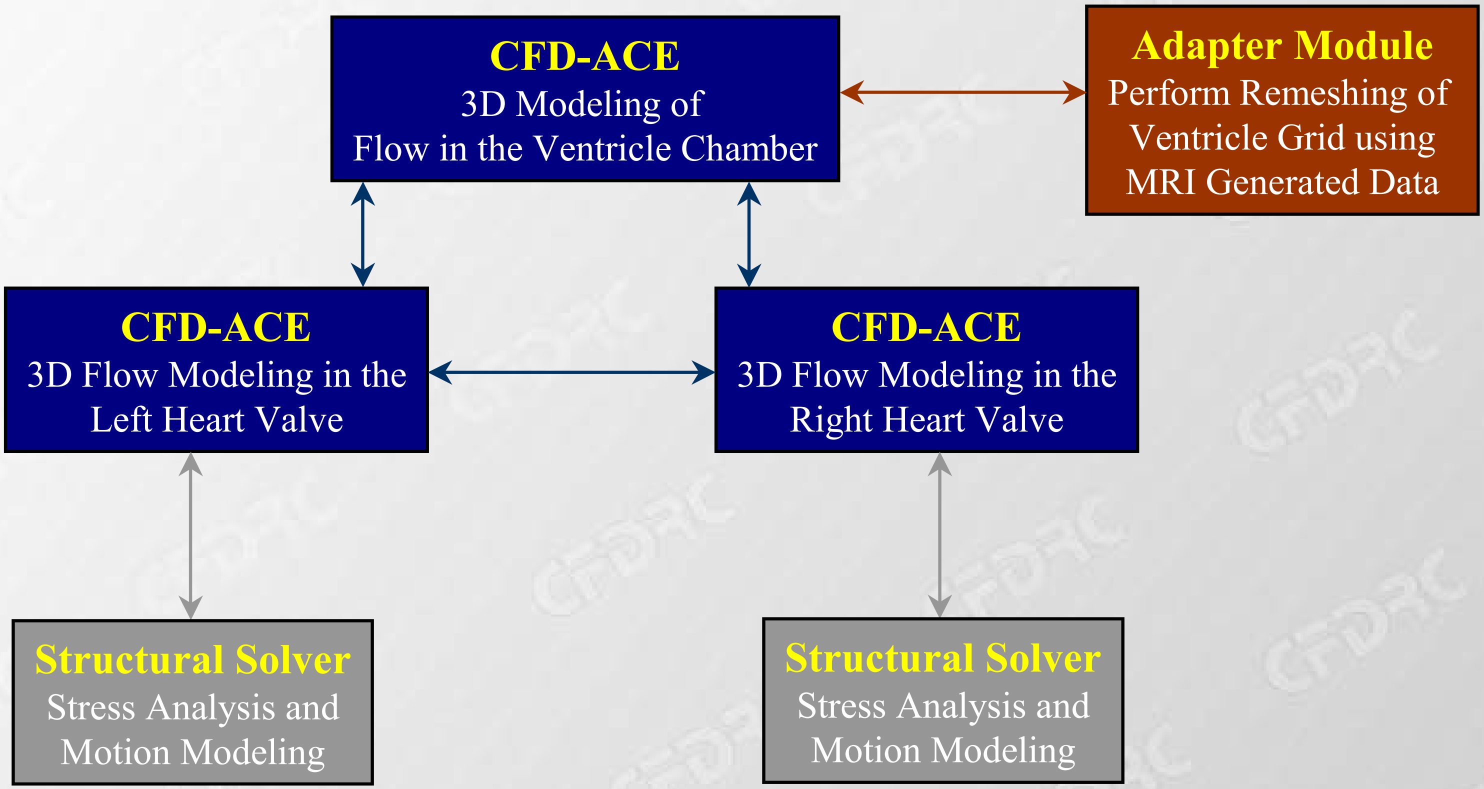
- Snap-Shots of a Transient Simulation at Fully-Open and Fully-Closed Position of the Valves





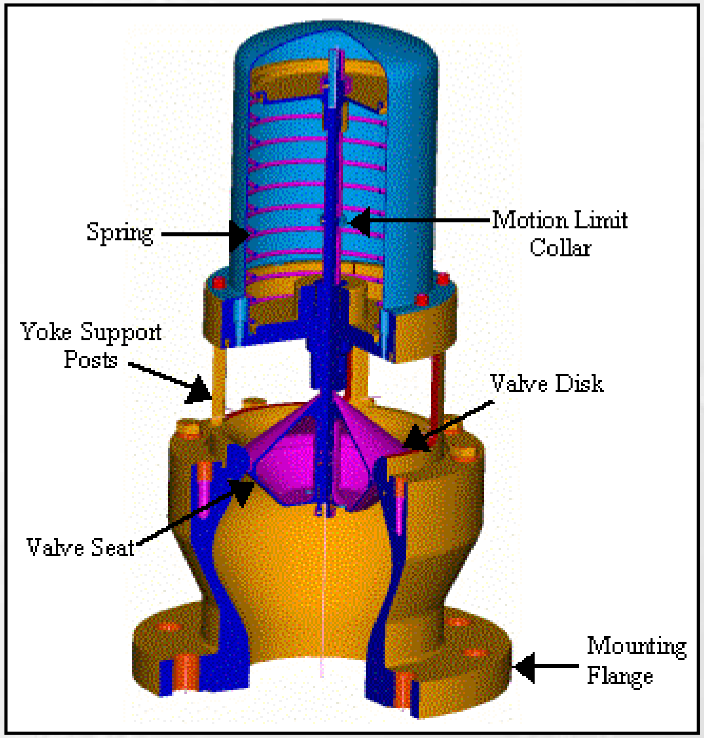
Heart-Valve Simulation

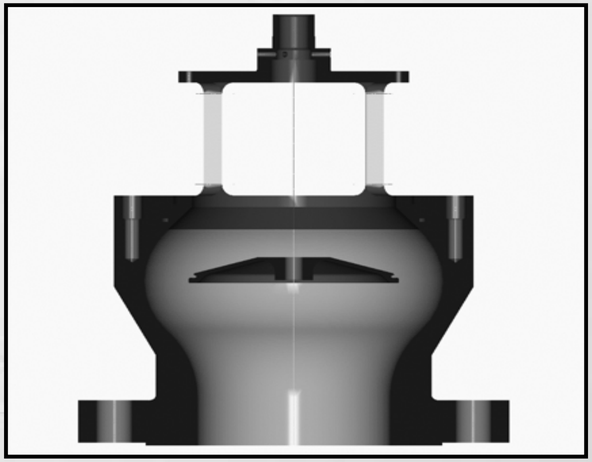
- MDICE Module Interactions in Heart Valve Simulation

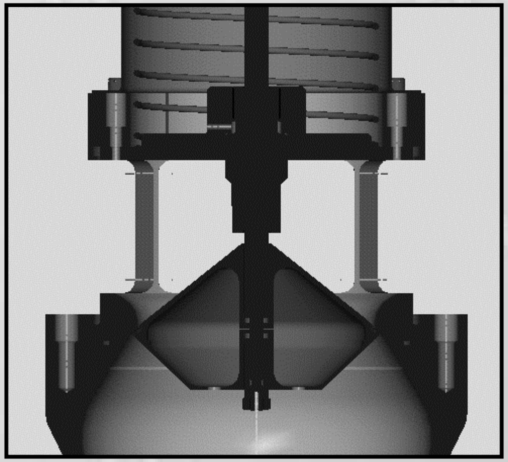


Nuclear Industry Application

- Vacuum Relief Valve Used for Nuclear Power Plant Storage Tanks
- During Emergency Cooling, Valve Opens to Allow Air into the Tank
- Simulation Results Lead to Improved Disk and Body Shape of the Valve







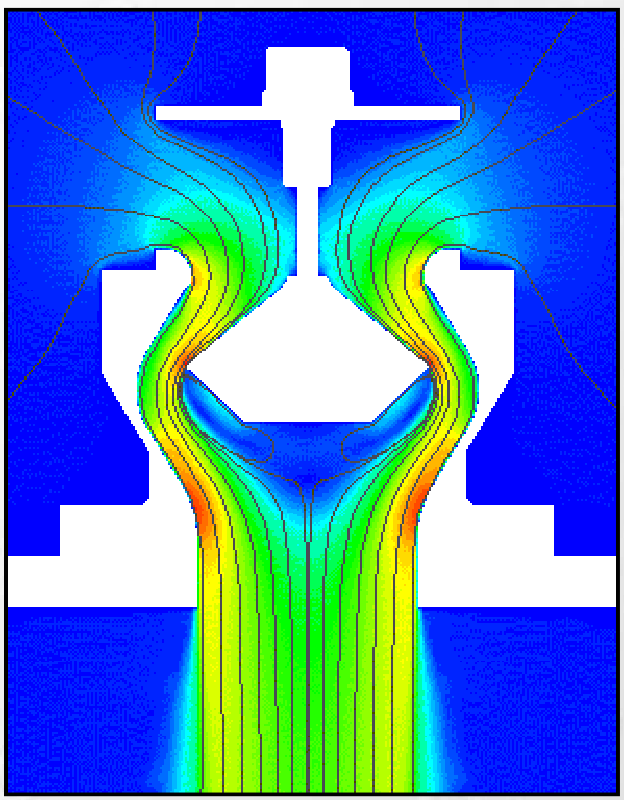
Vacuum Relief Valve Simulation

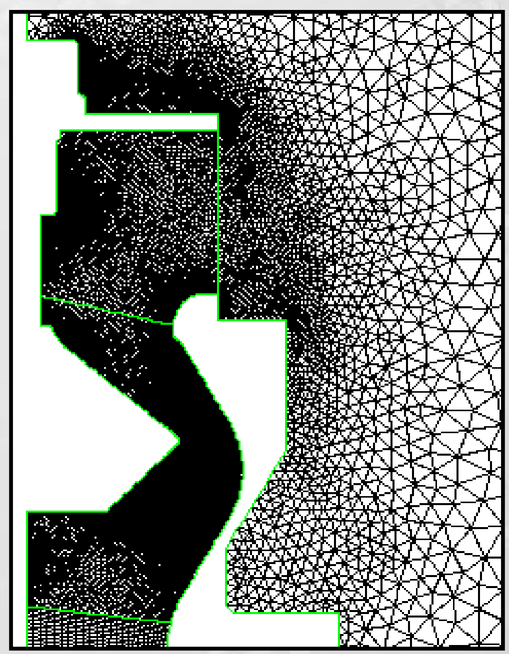
- Module Interactions in Coupled Fluid-Structure Interaction (FSI) Simulation

CFD-ACE
3D Modeling of Flow in Storage Tank

CFD-ACE
3D Modeling of Flow Around Moving Valve

Motion Analysis Module
Model the Dynamics & Kinematics of Valve Motion





Concluding Comments

- MDICE Provides Middleware Technology for Integrating Applications at the Source Level; Legacy Applications Integrated Using Wrapper Approach
- MDICE Provides an Environment that Enables Workflow Management of a Simulation
  - Parallelization
  - Optimization
  - Multi-Disciplinary Analysis
- Coupling Between Applications Controlled Using Dynamic Data Exchange
  - User may Control the Level of Coupling (Fine *vs*. Coarse, One-way *vs*. Two-way)
- Turnkey Solutions Available in Conjunction with CFDRC's Software for Specific Engineering Disciplines