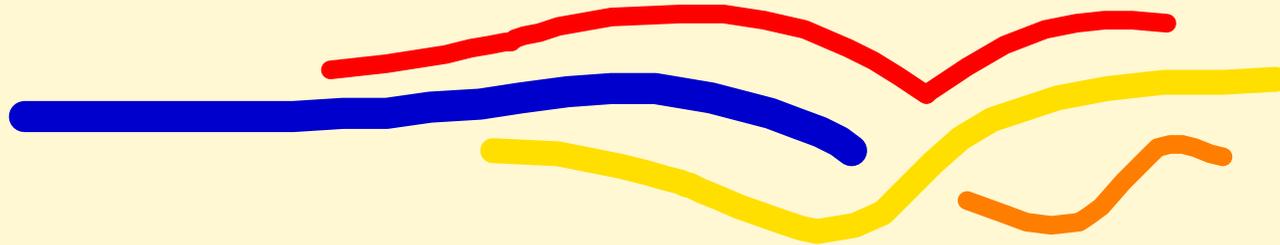


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©

3-D Coupled Multiphysics Rocket Simulations at CSAR

Mark D. Brandyberry

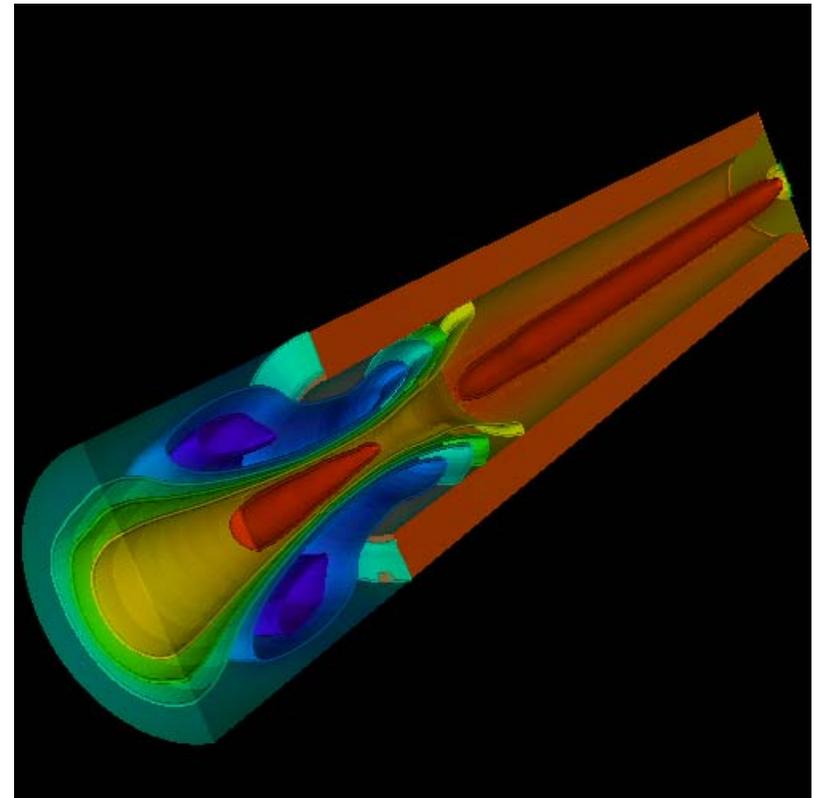
Senior Research Scientist

19 November 2002



Overview

- **Mission**
- **Roc* - GEN2.5 integrated code architecture**
- **Technologies**
- **Performance**
- **Visualization**



Motor 13 temperature isosurfaces

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Mission and Goals

- **Advance state of art in computational simulation**
- **Simulate complex, multicomponent systems**
- **Model components and their interactions accurately**
- **Create flexible framework for software integration**
- **Demonstrate scalability on ASCI platforms**
- **Validate simulations empirically**
- **Train new generation of computational scientists and engineers**

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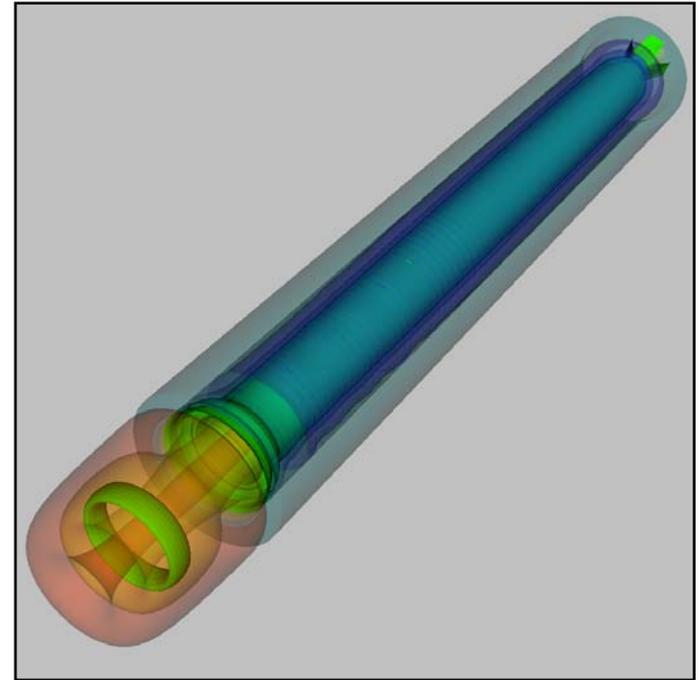


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Roc*

■ Computer Science

- *Rocface – non-matching mesh association*
- *Rocom – intercode communication*
- *Rocman – integration (run manager)*
- *Rocpanda – parallel I/O*
- *Rocketeer - visualization*



■ Fluids

- *Rocflo-explicit, structured*
- *Rocflu-explicit, unstructured*

■ Combustion

- *Rocburn – propellant burning, ignition*
- *Rocfire – microscale combustion*

■ Structures

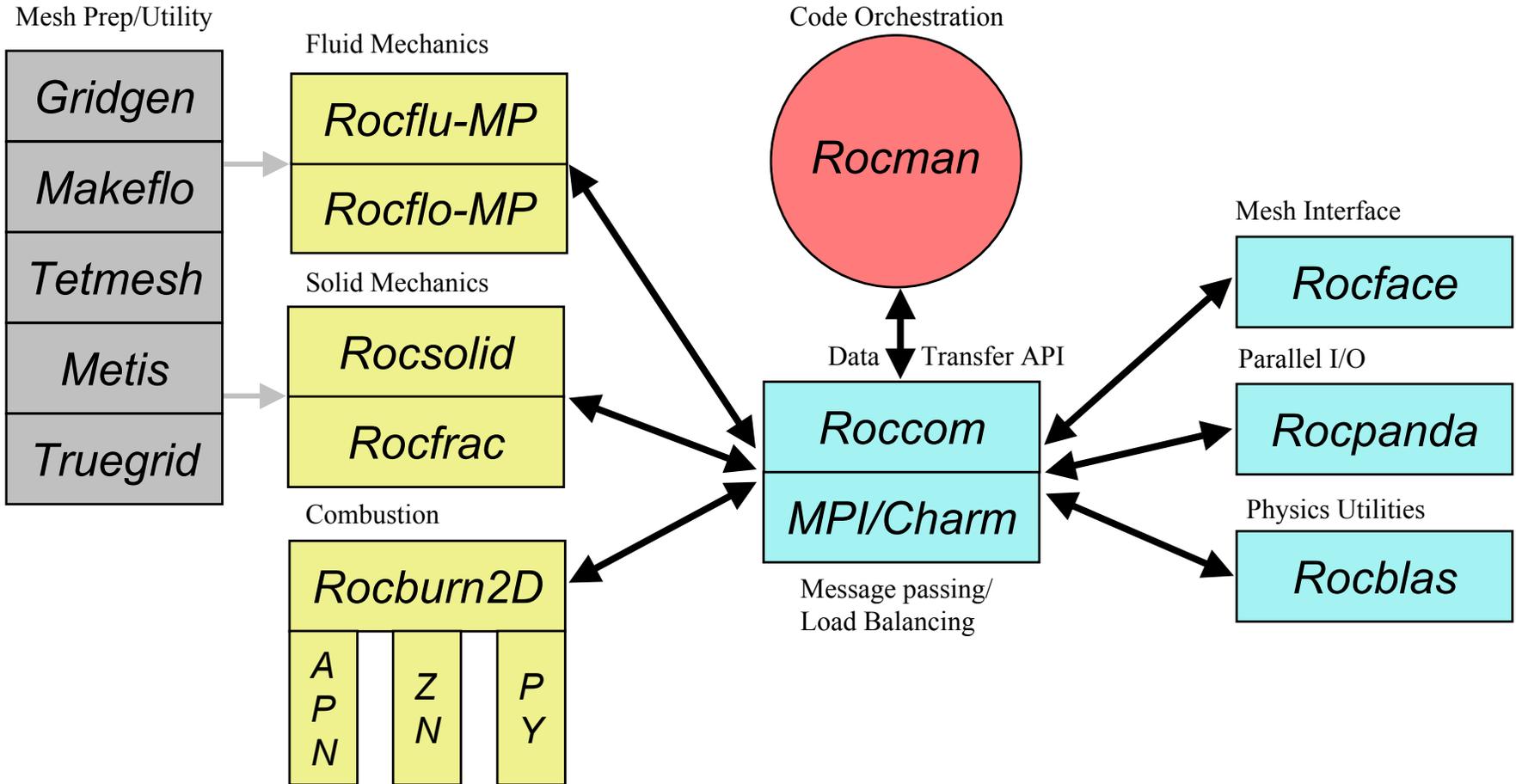
- *Rocsolid – implicit, unstructured*
- *Rocfrac – explicit, unstructured*

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GEN2.5 Architecture



Example Rocket Components

TWR-16851, Rev A

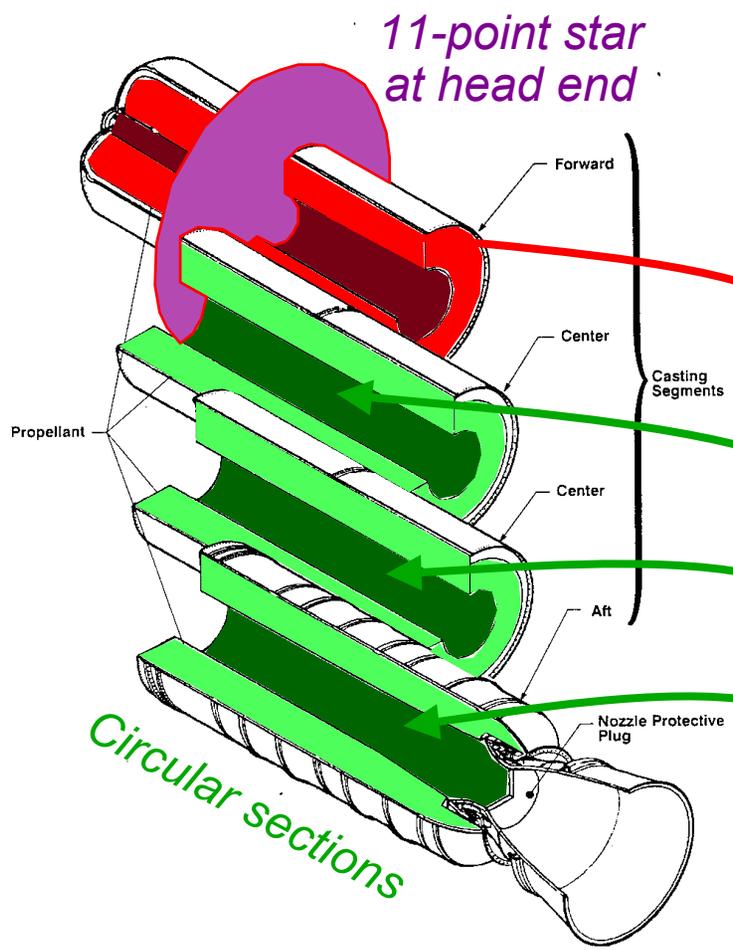


Figure 4.3-1. RSRM Propellant Configuration

THIOKOL

4-58

930460

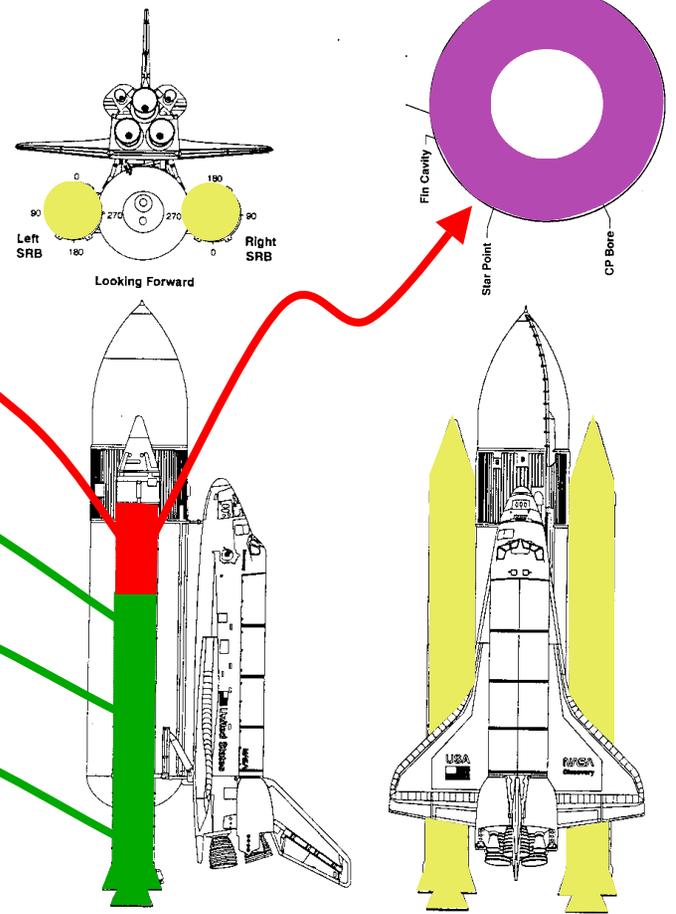


Figure 3.1-1. Boosters Attached to External Tank

THIOKOL

3-2

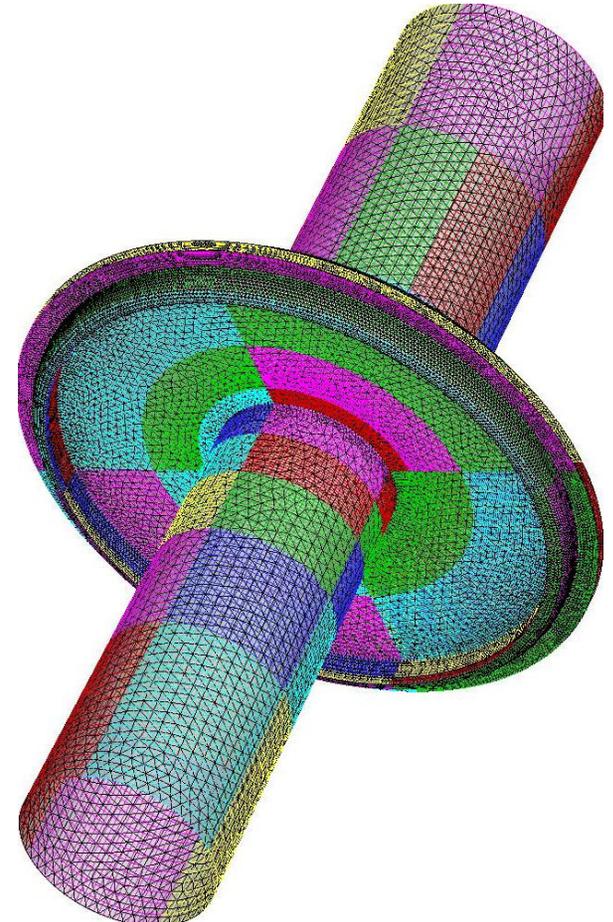
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Data Transfer Between Components

- **Common refinement of nonmatching meshes (e.g., at fluids – structure interface)**
 - Differing topological structures, geometric realizations, and partitionings
 - Complex geometries
 - Efficient data structures
- **New method for accurate and conservative data transfer**
 - Node- or element-centered data
 - Conservation enforced
 - Errors minimized
 - Efficient parallel implementation



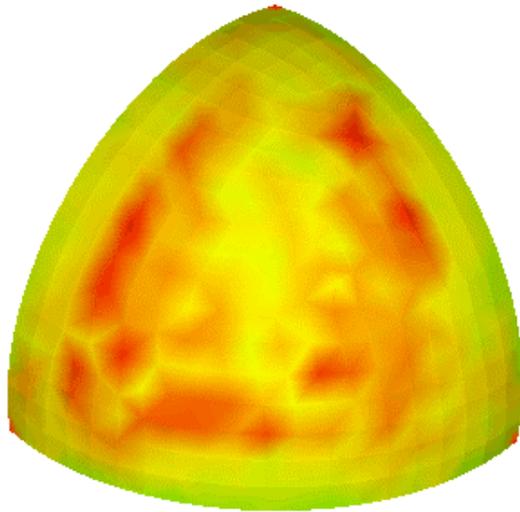
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Data Transfer Experimental Results

Burning cavity with uniform pressure and regression



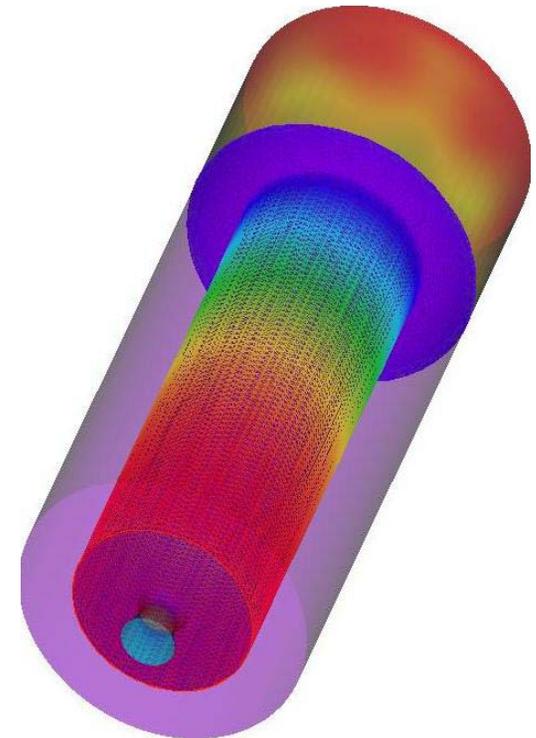
Conventional method



CSAR method

Cumulative fluid to solid data transfer error in displacements after 500 time steps (red color indicates errors)

Shortened lab-scale rocket with triangular solid and quadrilateral fluid interface meshes



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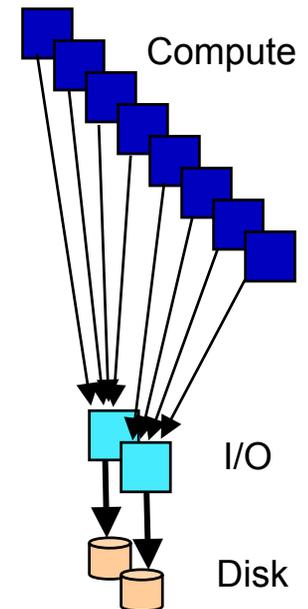
Adaptive Load Balancing Frameworks

- **CHARM++**
 - Run-time load balancing, performance monitoring and visualization, checkpoint/restart
 - Serves as foundation for AMPI and FEM Framework
- **Adaptive Message Passing Interface (AMPI)**
 - MPI plug-in replacement that supports dynamic load balancing and multithreading for MPI applications – Used by Rocflo, Rocfrac, Rocsolid
- **Finite Element Method Framework**
 - Hides the details of parallel communication below a clean, application-level interface. This allows a parallel FEM Framework code to be developed quite easily, and closely resemble a serial code. Used by Rocflu.
- **<http://charm.cs.uiuc.edu/>**



Parallel I/O and Data Migration

- **Parallel output of checkpoint data**
 - Data sent as messages from compute processors to I/O processors
 - Computation continues on compute processors while I/O nodes write, store, and migrate data files
 - Supports HDF4 for Rocketeer
- **Automatic tuning of parallel I/O performance**
- **Data migration concurrent with application**
- **Automatic choice of data migration strategy**
- **Rocpanda 3.0 integrated into GEN2.5**
 - For 256 compute processors, 80 MB snapshot takes
 - 2.3 seconds with Rocpanda (8 I/O nodes)
 - 66 seconds without



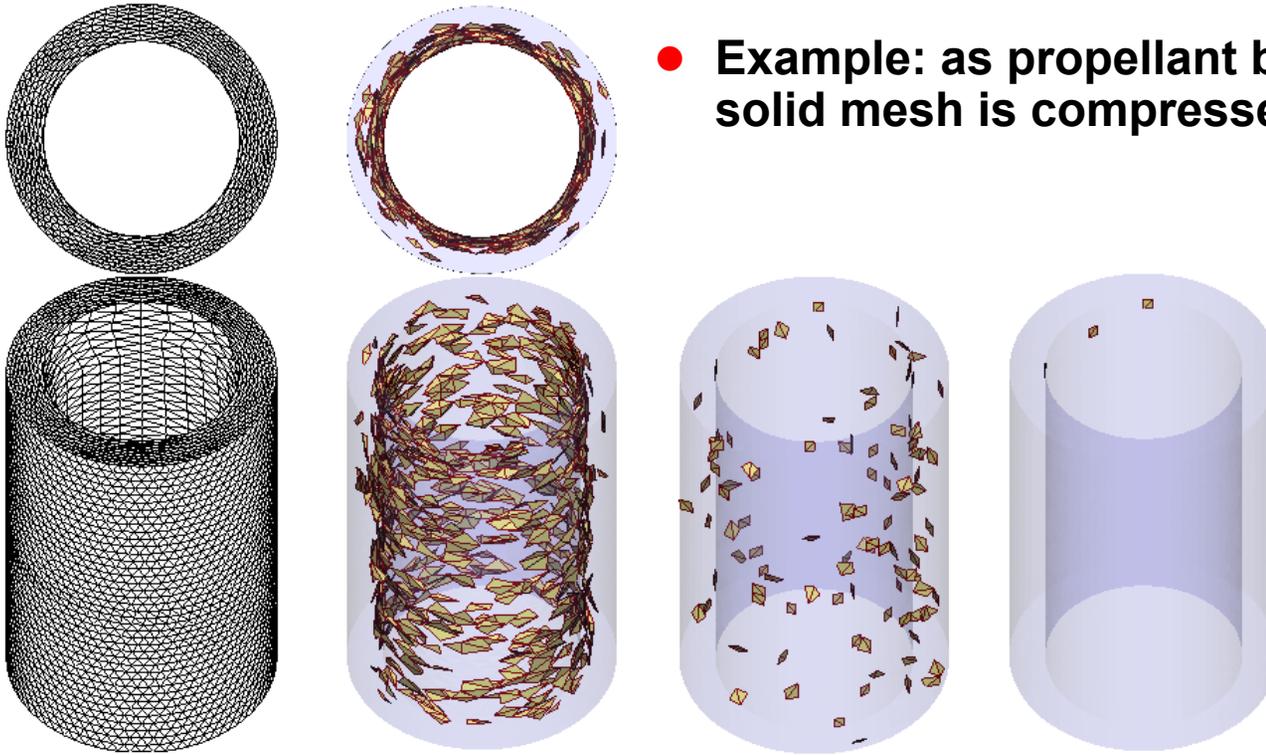
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Mesh Adaptation and Refinement

- Dynamic global refinement or coarsening of mesh
- Adapt mesh to changing geometry in 3-D

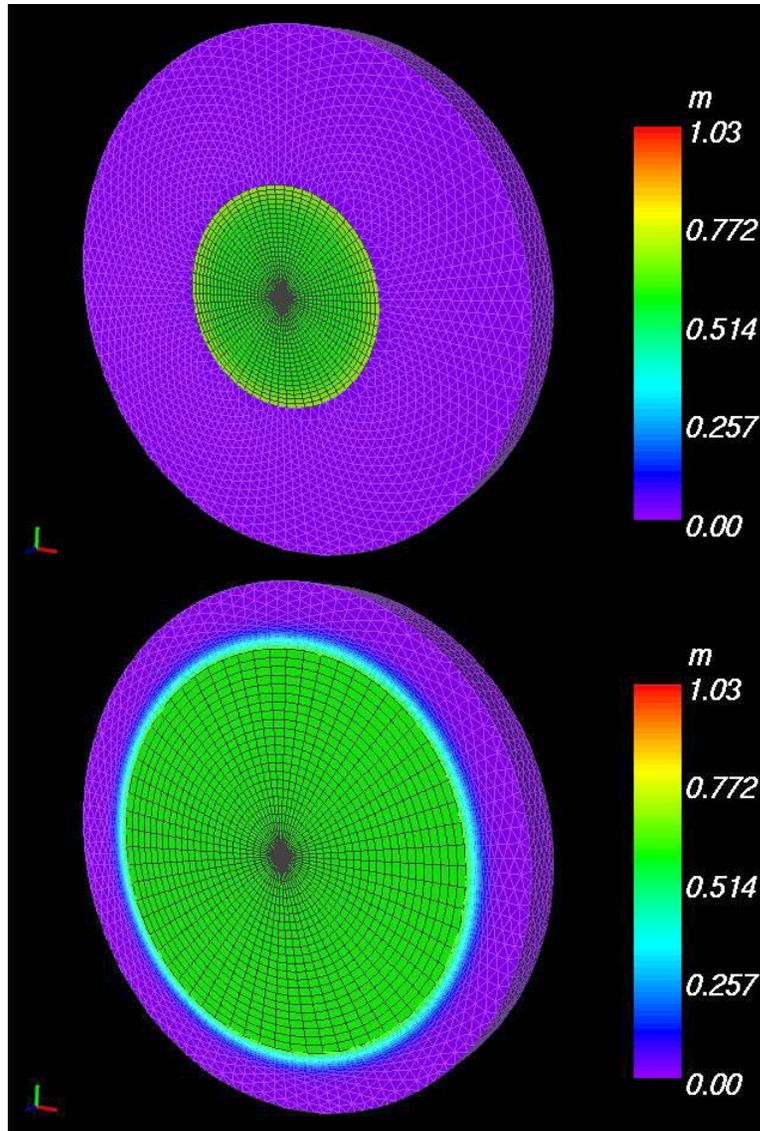


- Example: as propellant burns away (60%), solid mesh is compressed, needs repair

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ALE Scalability Test



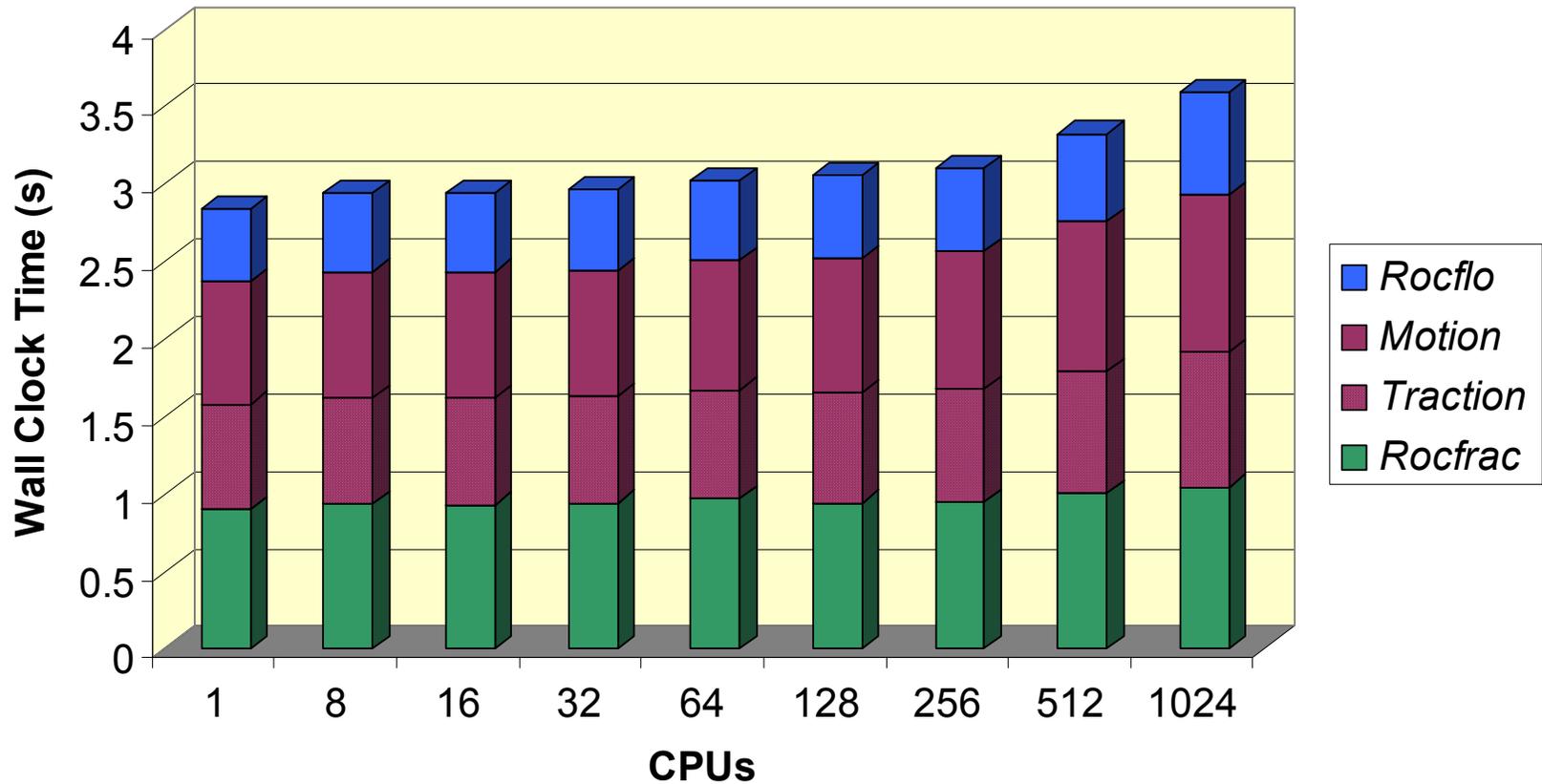
- Fluid domain expands as propellant burns
- Meshes are moved and smoothed
- Fixed amount of work per processor
- Interior slices added to scale problem

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GEN2 Performance on Blue Horizon*



*IBM SP - San Diego Supercomputer Center

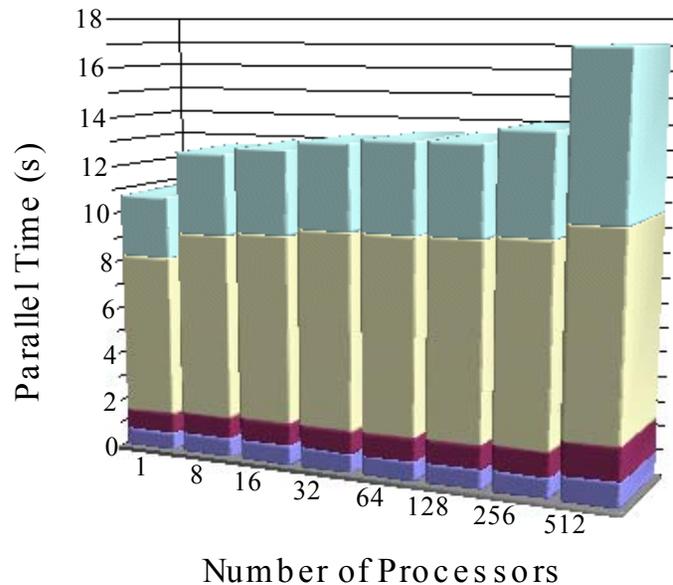
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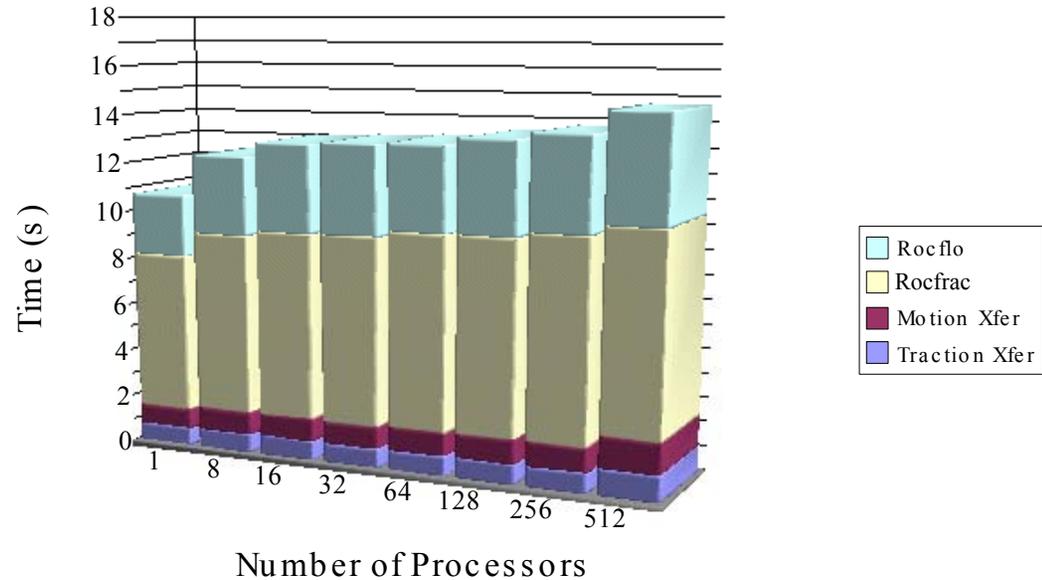
Performance Tuning with SvPablo

- Source code browsing and performance instrumentation.
 - Instrumented GEN2 produces SDDF performance data.
 - SDDF performance data linked to source code.
 - Helps identify problematic source code.

Untuned Gen2 on Blue Pacific



Tuned Gen2 on Blue Pacific



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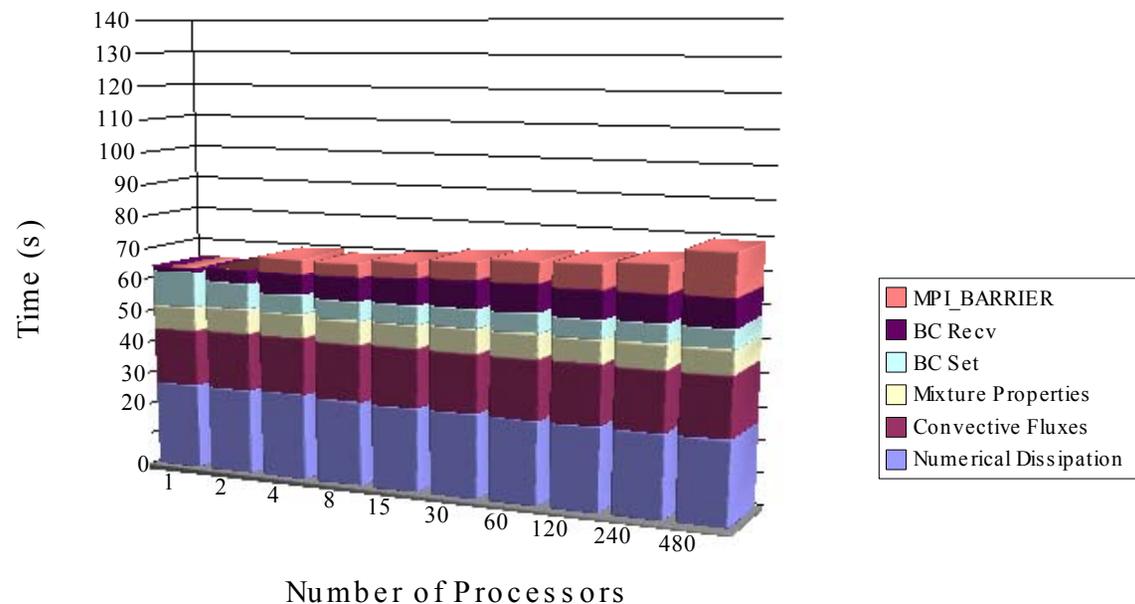
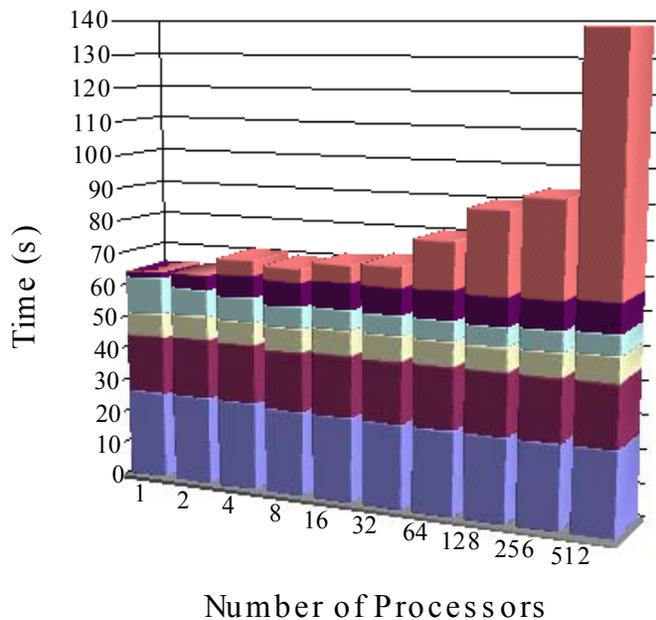
Effect of Job Topology on Performance

■ Communication bottleneck identified with SvPablo

- RocfloMP on Frost (16 processor per node IBM SP3)
- System OS uses cycles on one processor per node
- Bottleneck eliminated by leaving OS processor idle

16 processors per node

15 processors per node



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The *Rocketeer* Suite

Rocketeer

- Original version for workstations

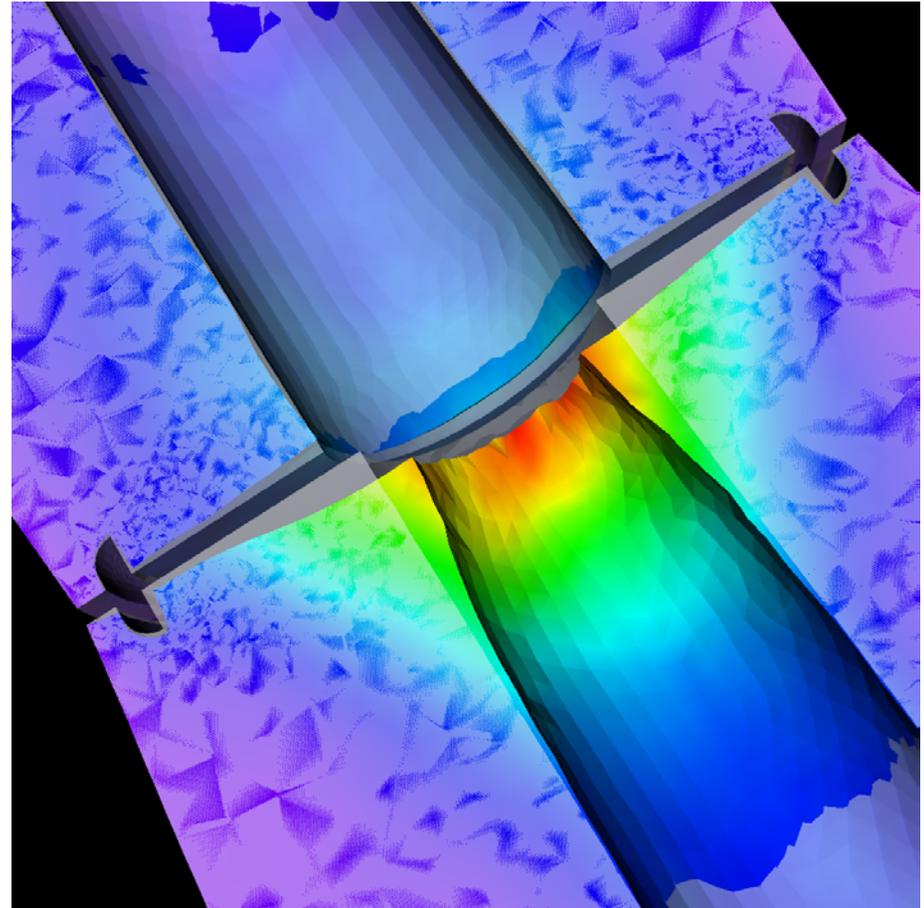
Apollo/Houston

- Apollo -- client GUI on workstation
- Houston – MPI parallel sever on remote system

Voyager

- Concurrent processing of many snapshots

- All versions share same code base
- Run on Windows, AIX, Solaris, Linux



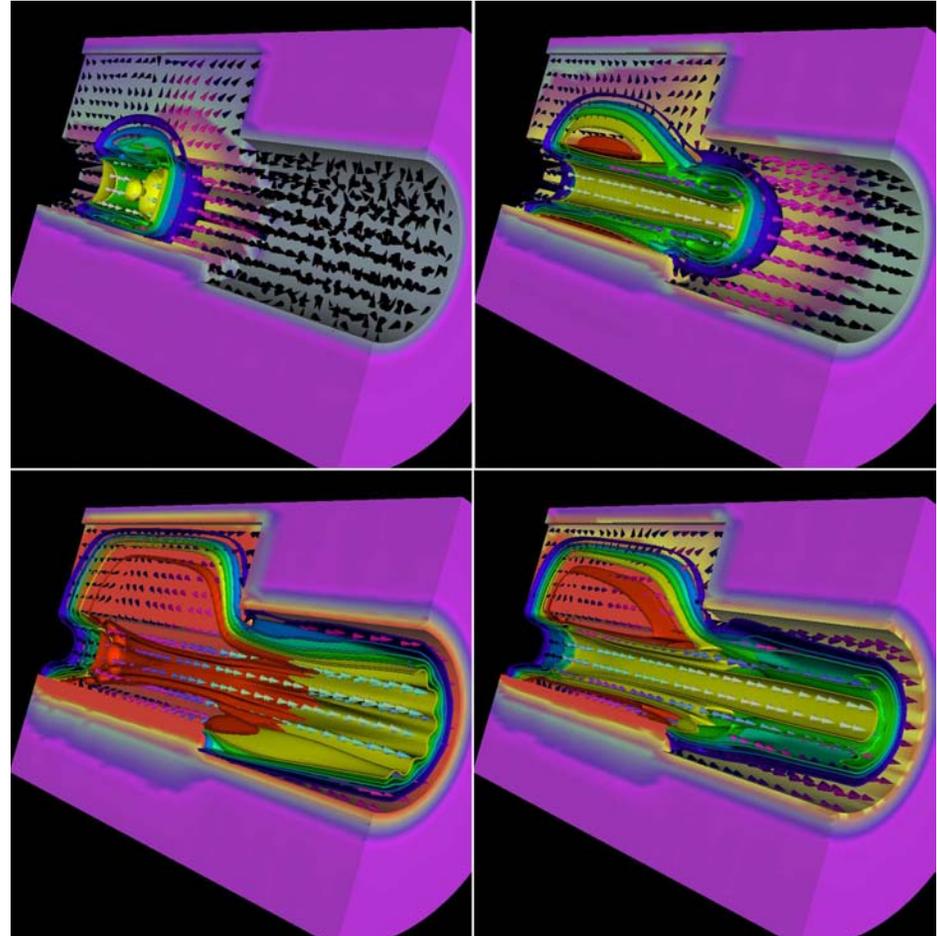
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Visualization with *Rocketeer*

- Built on Visualization Toolkit (VTK) and OpenGL
- Supports
 - Structured and unstructured grids
 - Cell-centered and node-centered data
 - Ghost cells
 - Seamless merging of multiple data files
 - Automated animation
 - Smart HDF reader
 - Translucent isosurfaces

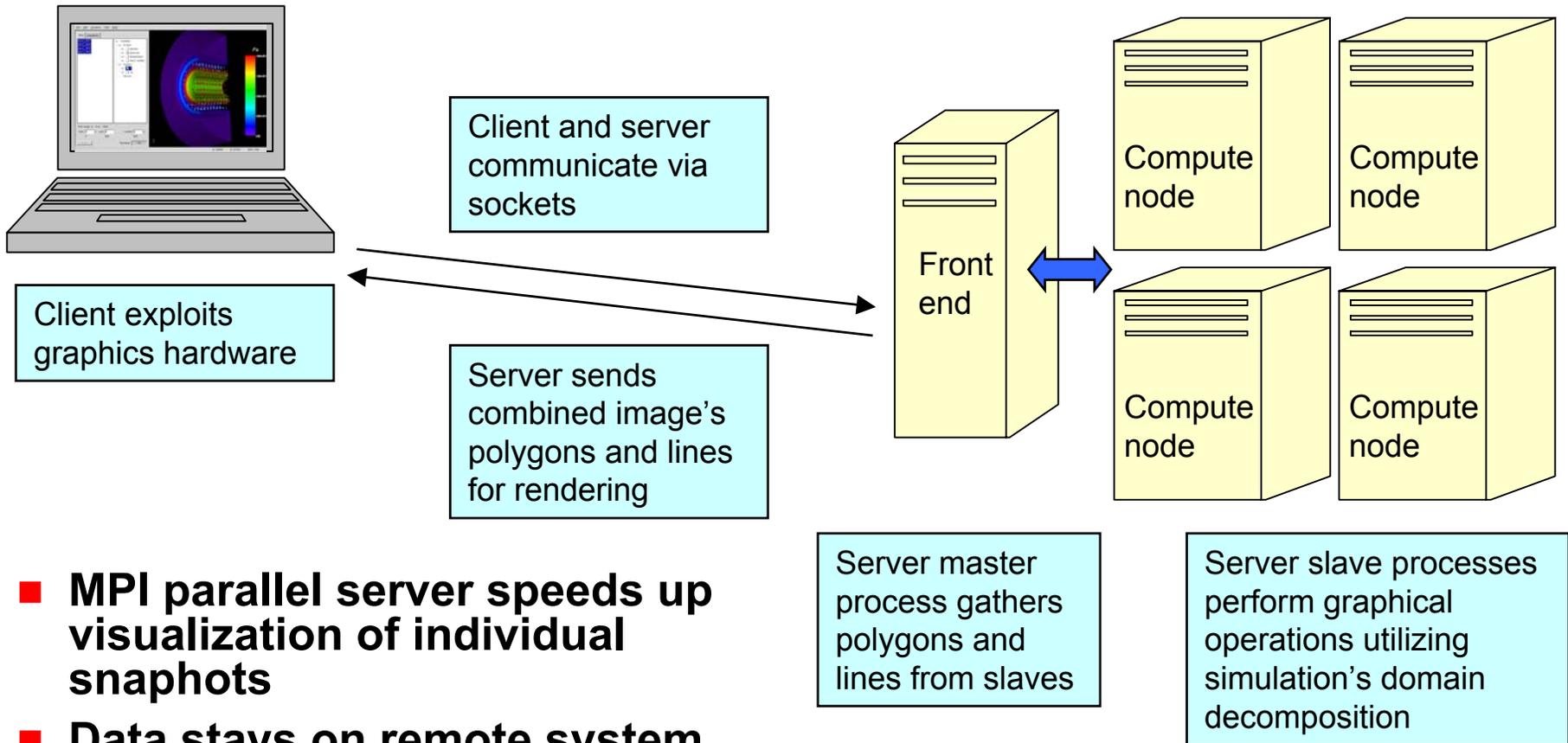


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Apollo/Houston



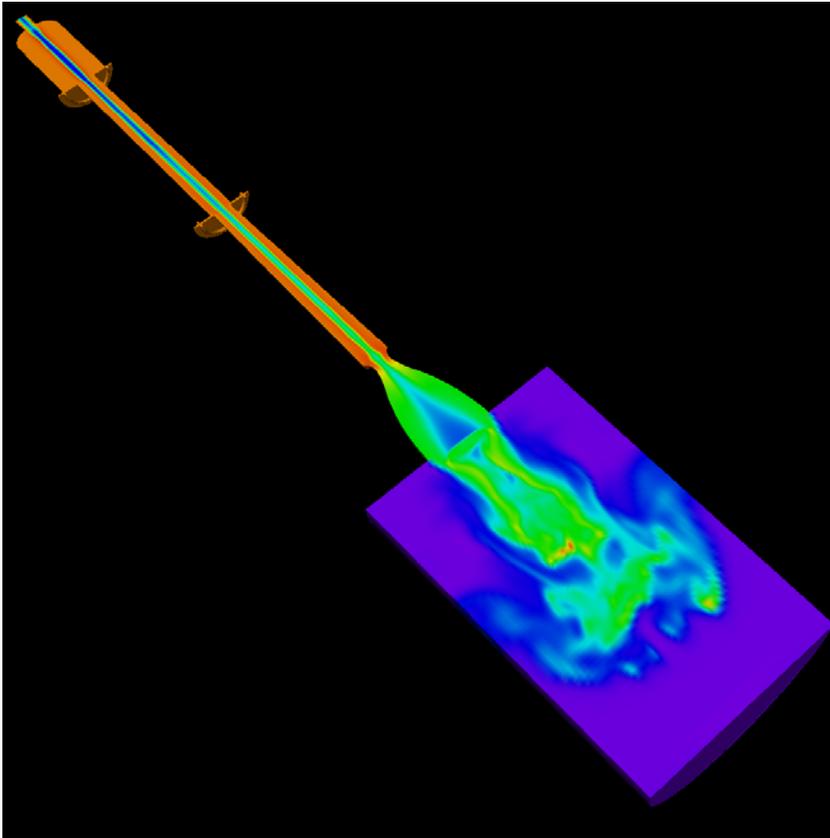
- **MPI parallel server speeds up visualization of individual snapshots**
- **Data stays on remote system**
- **Only lines and polygons in final image are transferred to client**

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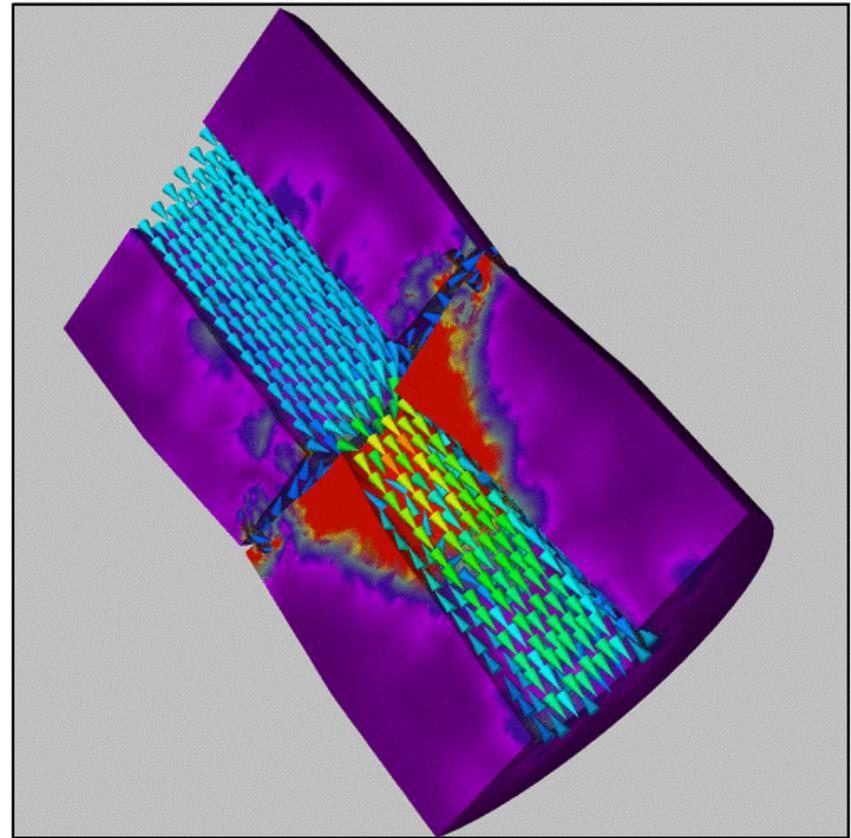


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Titan IV SRMU Movies



Gas temperature



Propellant displacement, gas velocity

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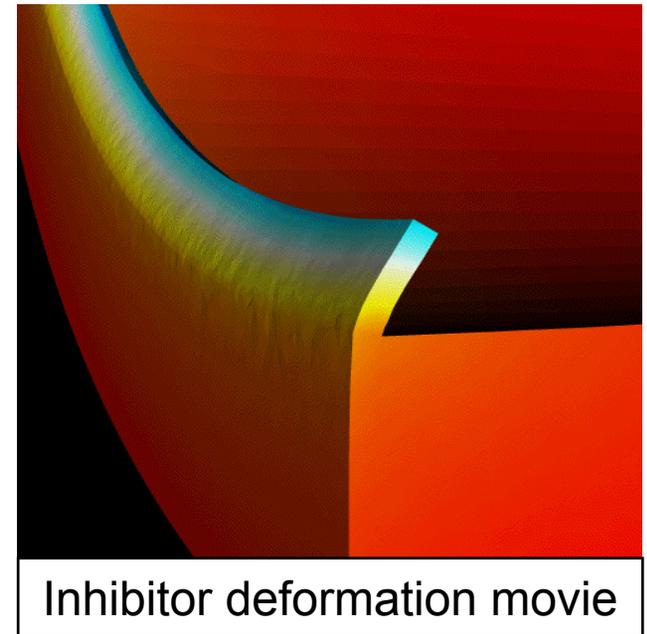
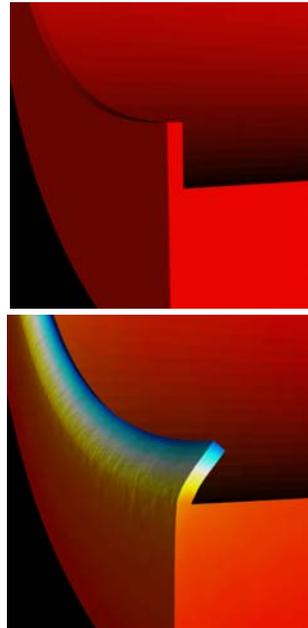
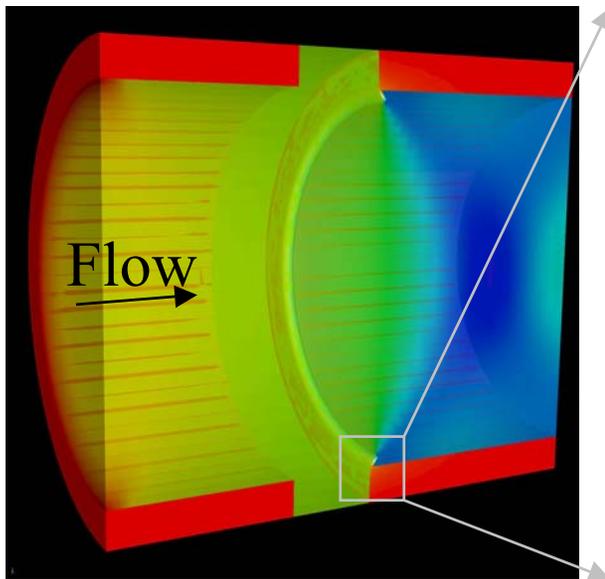
Flexible Inhibitor in RSRM

■ Problem

- Booster section
- Specified inflow at forward end
- 3-D fully coupled

■ Results

- Inhibitor flaps
- Damps slowly over 40 ms
- Deflection angle 30 to 40 degrees



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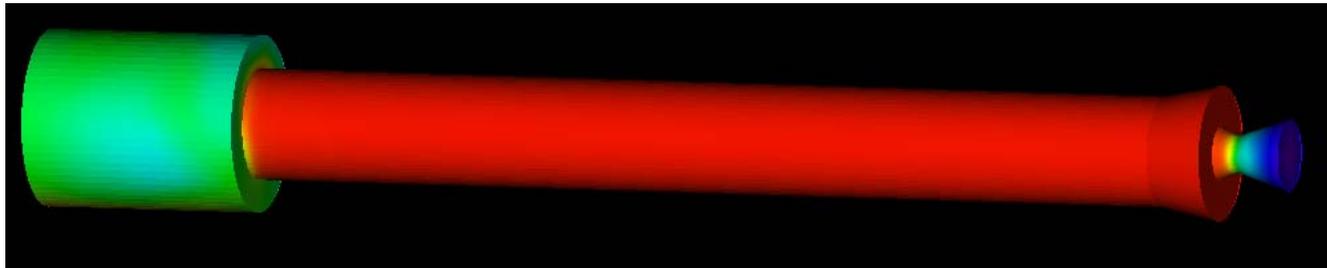
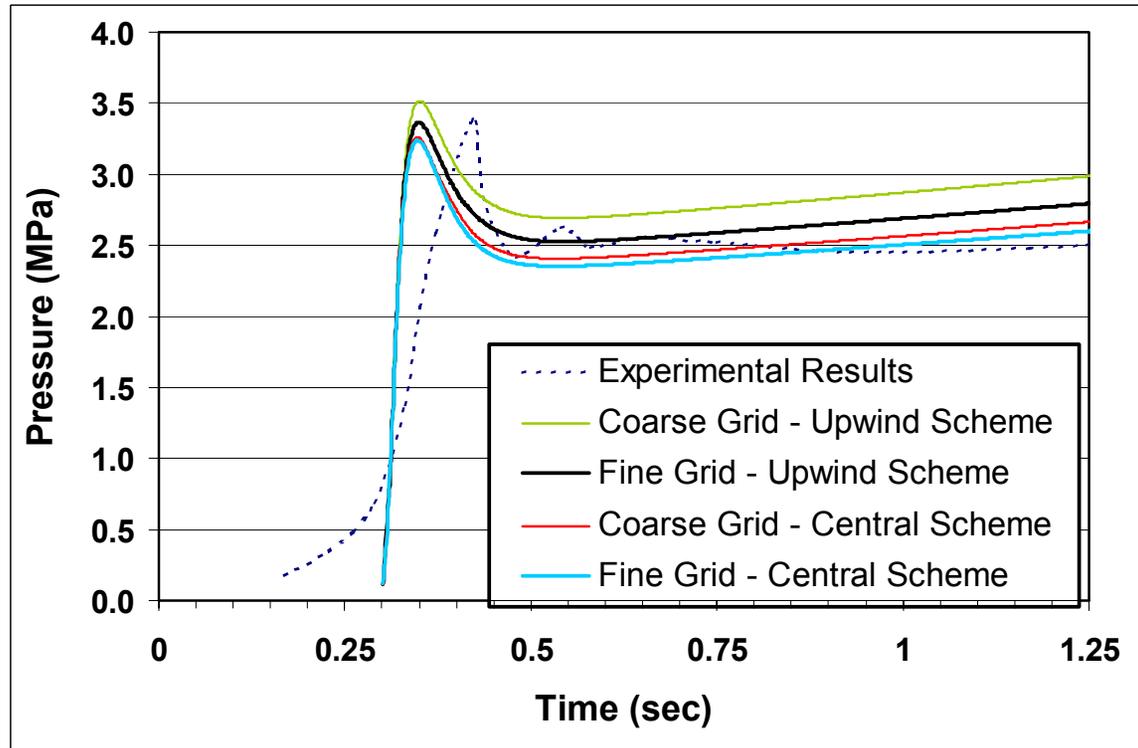
Example of Component Verification: Fluids

■ Problem

- Cylindrical tactical motor (F. Blomshield)
- Ignites all at once
- Dynamic burning
- 3-D fully coupled

■ Results

- Pressure overshoot
- Central scheme best
- Coarse grid adequate



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System Integration Team

■ Interdisciplinary

M. Brandyberry, R. Fiedler

■ Fluids

J. Blazek, A. Haselbacher

■ Structures

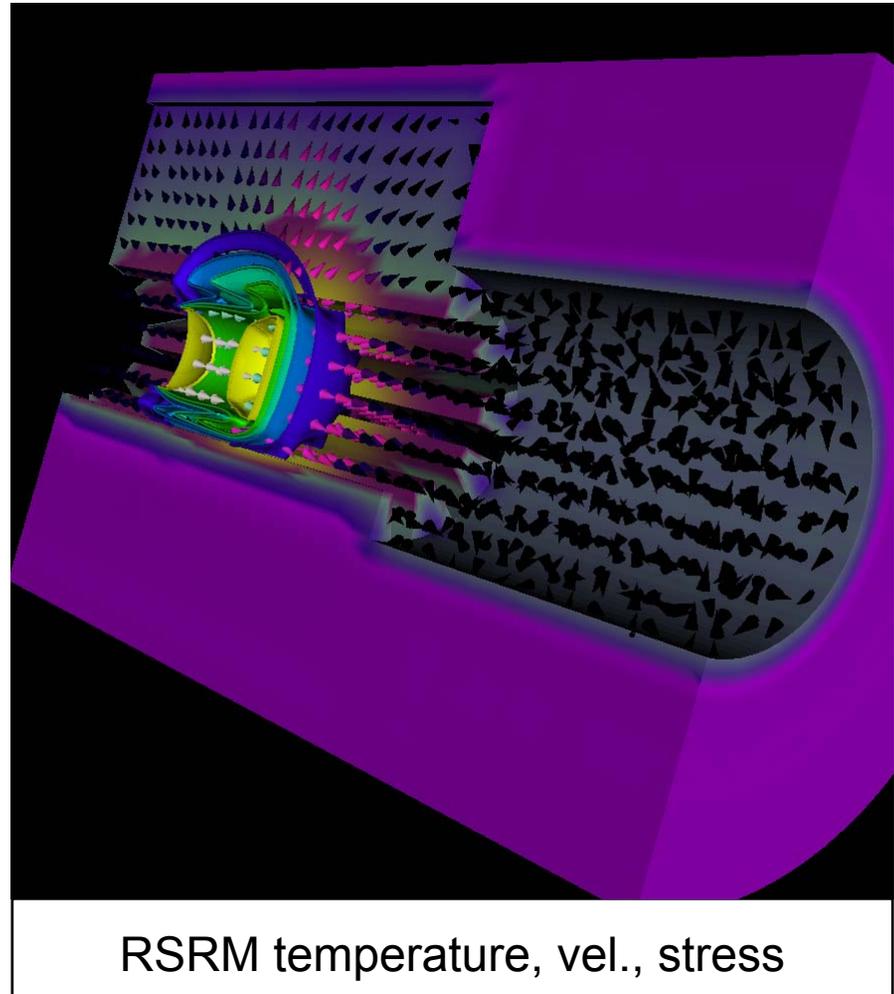
S. Breitenfeld, P. Geubelle,
A. Namazifard

■ Combustion

T. Jackson, L. Massa,
K.-C. Tang

■ CS

M. Campbell, D. Guoy,
M. Heath, X. Jiao,
O. Lawlor, X. Ma, J. Norris,
E. de Sturler



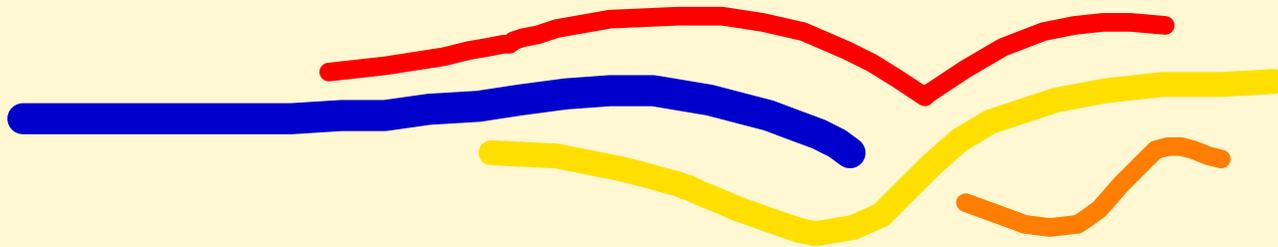
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<http://www.csar.uiuc.edu>

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