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Adagio Status
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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
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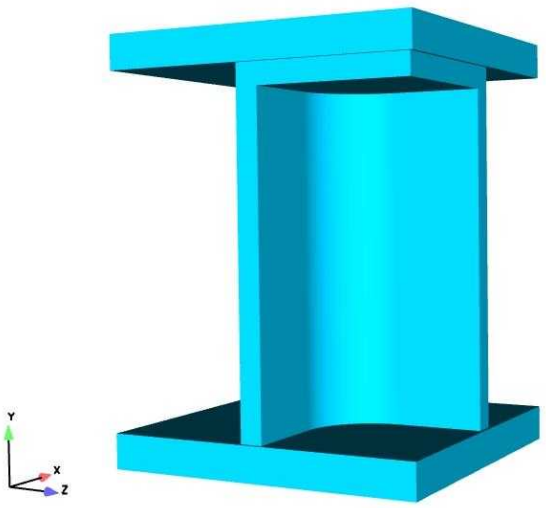
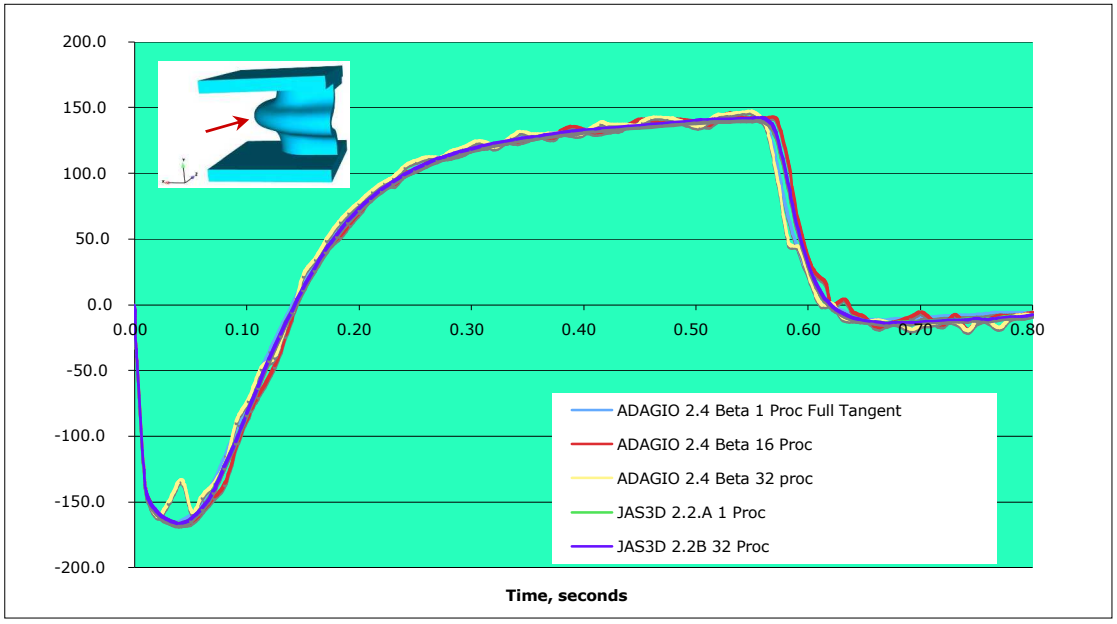
Outline

- Use of JAS3D contact – Legacy Contact Library
- Solver improvements
- Material model status
- Capability test suite – High standard for comparison with JAS3D

Example Application: Can Crush





Design of energy absorbing barrier

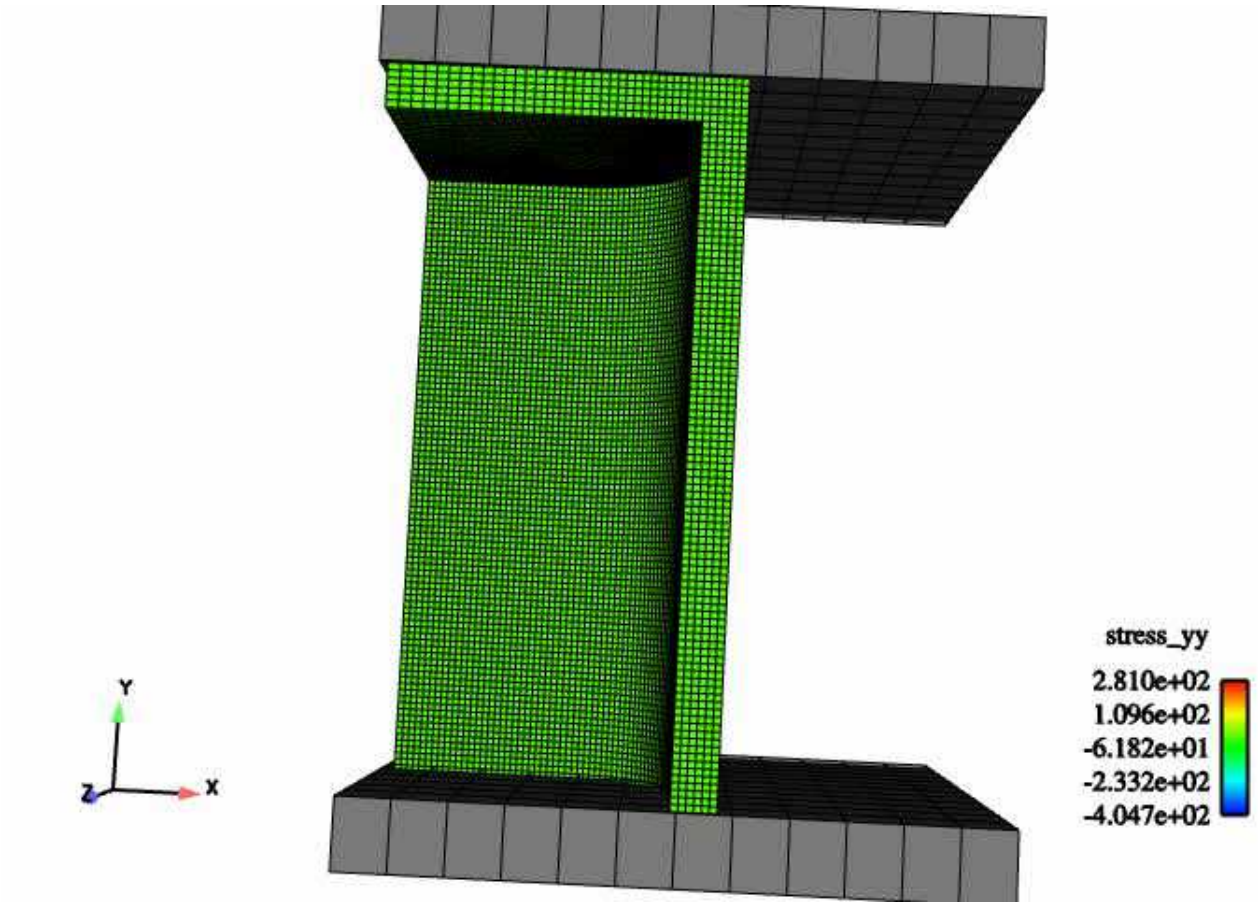
Quasi-static displacement controlled crush

Uses multilinear elastic-plastic constitutive model

Model contains 61680 hex8 elements

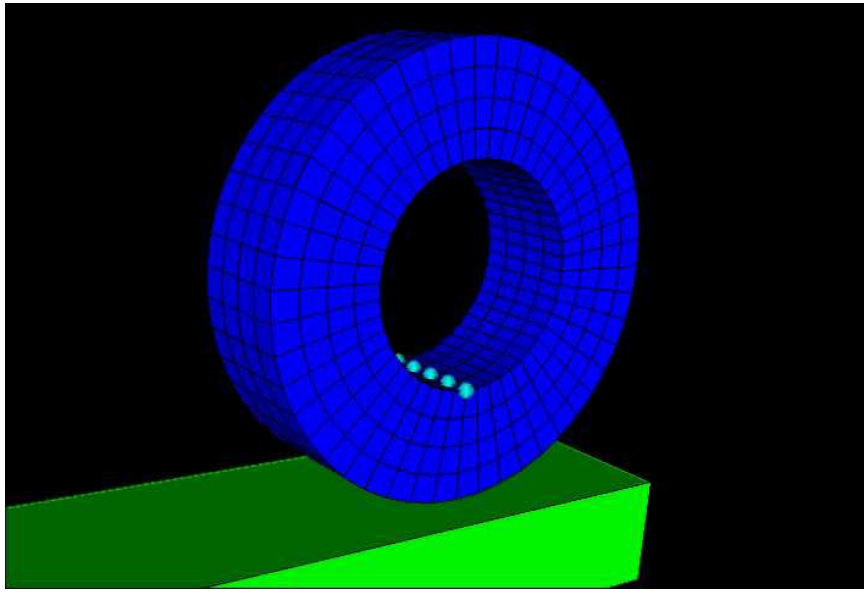
Demonstrates frictional contact, geometric and material nonlinearities, parallel scalability

Can Crush Animation



h-Adaptivity Example

- Sierra Framework handles element refinement and coarsening
- Adagio refinement based on
  - Geometric location
  - ZZ error estimation
- Optimal methods for state variable transfers being investigated



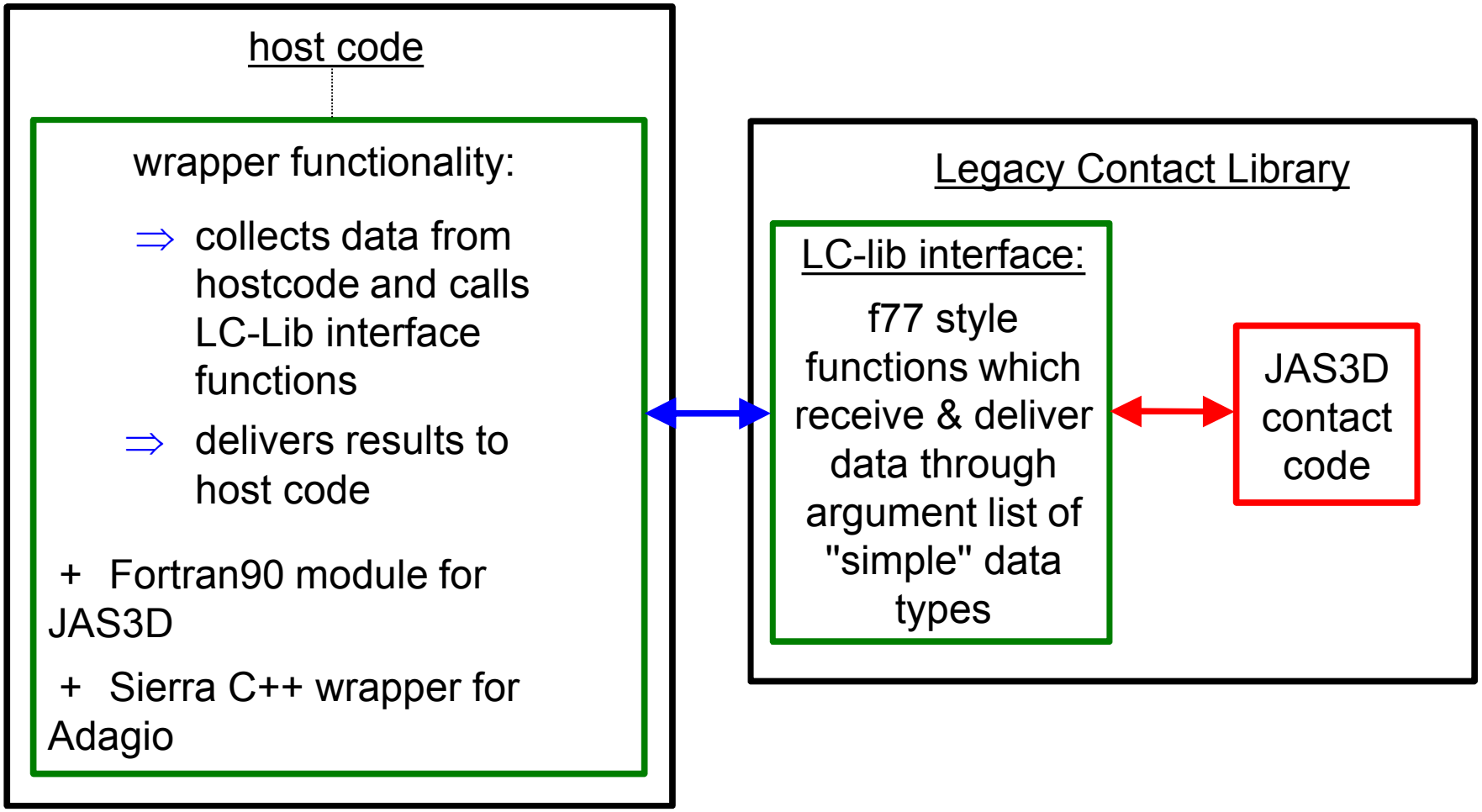
FE mesh is refined or coarsened as elements enter or leave a “box” at the contact region

Legacy Contact Library

Objective: Create Legacy Contact Library from JAS3D contact code and use this library to provide contact search/enforcement algorithms to both JAS3D and Adagio.

Benefits: Future legacy contact developments available to both JAS3D and Adagio, re-use of proven contact technology, multiple contact & friction laws are included.

Legacy Contact Library Design



Supporting
Fortan90 in the SIERRA World

- Legacy Contact Library is derived from Fortran90 parent code
- Legacy Contact Library is treated as 3rd party library:
  - ⇒ PathScale Fortran90 compiler is used to generate the library

  GNU and PathScale generated object files are binary compatible

- current procedure:
  - ⇒ generate LC-Lib using pathf90
  - ⇒ link LC-Lib into Adagio using g++

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What can affect the Solver?

- Elements
  - Kinematics
  - Hourglass
  - Formulation
  - nodal stiffness probing
- Materials
  - To scale or not to scale?
  - Incremental vs. total
  - Incompressibility
  - Coefficient jumps across boundaries
- Boundary Conditions
  - Periodic
  - Rigid Bodies
  - Kinematic
  - External forces
- Contact
  - Parameters (I.e. push back)
  - Stick/Slip
  - Algorithm (Master/Slave, AL)
  - Tolerances
- Nonlinear solution algorithms
  - CG, DR, Newton
  - Levels?
  - Controls?
  - Convergence criteria
- Preconditioners
  - Diagonal, block, tangent

Basically Everything!

Transplant of Multilevel Solver
Major components investigated…

- **Nonlinear Conjugate Gradient**
  Line searches, Preconditioners, CG Resets,
  Reporting, Diagnostics, Integration with Multilevel Solver

- **Multilevel Solver Algorithms**
  Control Stiffness, Control Modes, Control Contact, Error reporting
  Algorithm sequencing, Predictors

- **Legacy Contact Library**
  JAS3D Extraction, Adagio integration, Contact algorithms,
  Debugging capabilities, Impact on internal users

- **Algorithm Sequencing**
  Implemented according to “solver_action” trace

Nonlinear CG: Line Search Algorithm

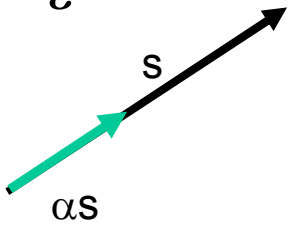
❑ Line search algorithm

Implemented change in internal force line search
Added step length restrictions (heuristics)
Verified coarse and fine grid line searches

$$s^T\left(F_{\text{int}}\left(v+s\right)-F_{\text{int}}\left(v\right)\right)$$
$$s^T F_{\text{int}}\left(v+s\right)-s^T F_{\text{int}}\left(v\right)$$

$$Ks \approx \frac{F_{\text{int}}\left(v+\varepsilon s\right)-F_{\text{int}}\left(v\right)}{\varepsilon}$$

$$\alpha = \frac{s^T r}{s^T K s}$$



V = velocity

S = search direction

F_{int} = internal force

K = tangent stiffness matrix

R = residual

ε = scaling factor (default = 1.0)

❑ Algorithm Improvements

Search direction scaling factor
Reduces risk of element inversion
δ=1e-6 default

$$\varepsilon = \delta\left(\frac{\|v\|}{\|s\|}+\delta\right)$$

The Good, The Bad, and The Ugly

- **The Good**
  - Nonlinear CG compared versus journal paper algorithm
  - RESET logic reviewed and organized
  - Line search algorithms reviewed, bugs fixed for control modes version
  - Residual “flavors” identified, implemented and tested
  - Identical log files in JAS3D and Adagio
- **The Bad**
  - Incorrect orthogonality check in Adagio CG
  - Extra CG reset found and corrected in JAS3D
  - Algorithmic ordering issues identified and corrected in Adagio
  - Possible consistency issues with AL & stress update for IS, SE, IF
- **The Ugly**
  - Configuration not updated in JAS3D after periodic BCs were applied.
  - Membrane hourglass incorrect in Adagio

Multilevel Solver
Summary

- **New Multilevel Solver in Adagio**
  - Rewritten instead of reworking old multilevel solver
  - Allowed complete control over algorithmic details
  - Adagio's version of GSOLVE from JAS3D
  - Same solver algorithm sequence
  - Easily extendable, highly modular

- **Controls**
  - Each control maintains convergence tolerances and iteration counters
  - Modularity emphasized over abstraction (I.e. update method)
  - Matched solver actions to function names

- **Impact**
  - JAS3D multilevel solver implemented in Adagio
  - Robust solution strategies for contact integrated
  - Both JAS3D and Adagio have benefited from high level of scrutiny

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LAME Material Model Status

36 models implemented in LAME

Regression tests for LAME

- Adagio and Presto
- small tests
  - implementation verification

Performance tests for LAME

- Adagio and Presto
- large tests
  - timing
  - convergence behavior

Have over 100 tests in Adagio/Presto

Need to complete documentation

- Theory
- Implementation
- User-guide
- Test

Some models of interest currently in LAME

- Elastic
- Thermoelastic
- Incompressible Solid
- Neo-Hookean
- Mooney-Rivlin (with T-dependent moduli)
- Swanson
- Viscoelastic Swanson
- Viscoelastic

Augmented-Lagrange Wrappers work for models both in Strumento and LAME

LAME Status & Planning

Named state variable output:

- Completed

Functions:

- Currently using SIERRA capability
- Stand alone fast LAME capability to come in the future

Structural models:

- Currently no plans for moving structural models over like plane stress shell/membrane models or beam models

Operational Excellence Plans:

- Ultimate plan is to use LAME for all 3D solid material models
- Focus this year is on **completing the transition** to LAME
  - library robustness -- in the computer science sense (error reporting, compiler and platform issues, name conflicts, etc)
  - documentation
  - additional testing by beta users
- Additional planning needed for ITAR version of LAME

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Capability Test Suite

•**Testing basic capabilities to diagnose & align algorithmic differences between Adagio & JAS3D**

Subset A: Basic CG in multiple time steps in 1 soln period

Subset B: Basic CG with time steps in 2 soln periods
(2 soln periods used in all subsequent test sets)

Subset C: Control Stiffness (in 2 soln periods): All Scalings = 1

Subset D: Control Stiffness: K Scaling = 0.7

Subset E: Control Stiffness: 2G Scaling = 3.0

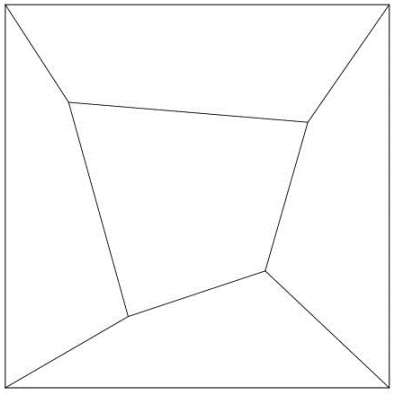
Subset F: Control Stiffness: K Scaling = 0.7, 2G Scaling = 3.0

Subset G: Control Stiffness: Anisotropy Scaling = 0.7

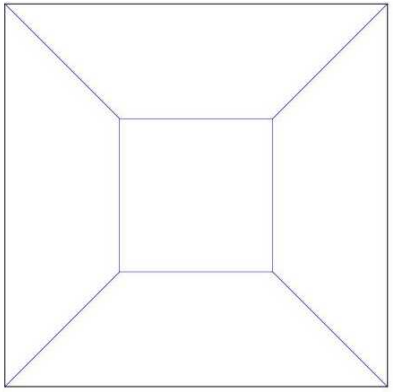
Subset H: Control Stiffness: K Scaling =3.0, 2G Scaling = 3.0

Subset I: Control Stiffness: K scaling = 0.95, 2G scaling = 0.95

7 Element Hex Patch



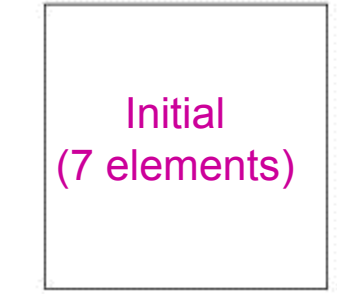
5 Element Membrane Patch



Capability Test Suite

Each capability test subset is nominally 49 problems:

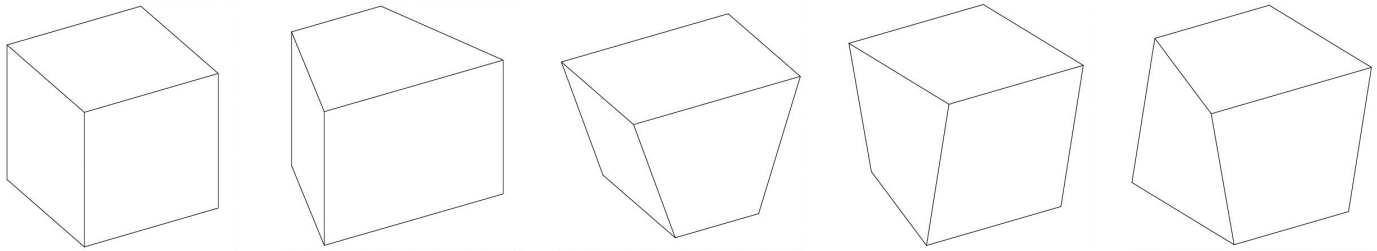
- **Strain / Rotation Incrementation:**
  - **MI:** Midpoint Incrementation
  - **SO:** Strongly Objective
- **Hourglass Control for Deviatoric Behavior:**
  - **UG:** Uniform Gradient
  - **SD:** Selective Deviatoric
  - **MX:** Mixed Mesh (both UG, SD elements)
- **Material Models:**
  - **EL:** Elastic
  - **IS:** Incompressible Solid
  - **SE:** Stiff Elastic
  - **MR:** Mooney-Rivlin
  - **SW:** Swanson
  - **OE:** 3D Orthotropic Elastic with isotropic inputs
  - **OE2:** 3D Orthotropic Elastic with orthotropic inputs
  - **FB:** Fiber
- **Applied Deformation:**
  - **PATCH:** Combined strain with no rotation ([R] = [I])
  - **SHEAR:** Simple shear ([R] ≠ [I])



Exercises broad range of capabilities

Hourglass & Diagnostic Test Suites

- **Diagnostic Test Suite:**
  - Raw CG
  - Control Stiffness
  - Control Modes
  - Control Modes & Control Stiffness
  - Control Modes & Control Contact
  - Control Modes, Control Stiffness, & Control Contact
- **Hourglass Test Suite:**
  - Hourglass modes:
    - 4 for each coordinate direction
  - Material models tested:
    - Elastic, Incompressible Solid, Mooney-Rivlin, Orthotropic 3D Elastic, Stiff Elastic, Swanson



All Diagnostic Tests and Hourglass Tests Currently Pass

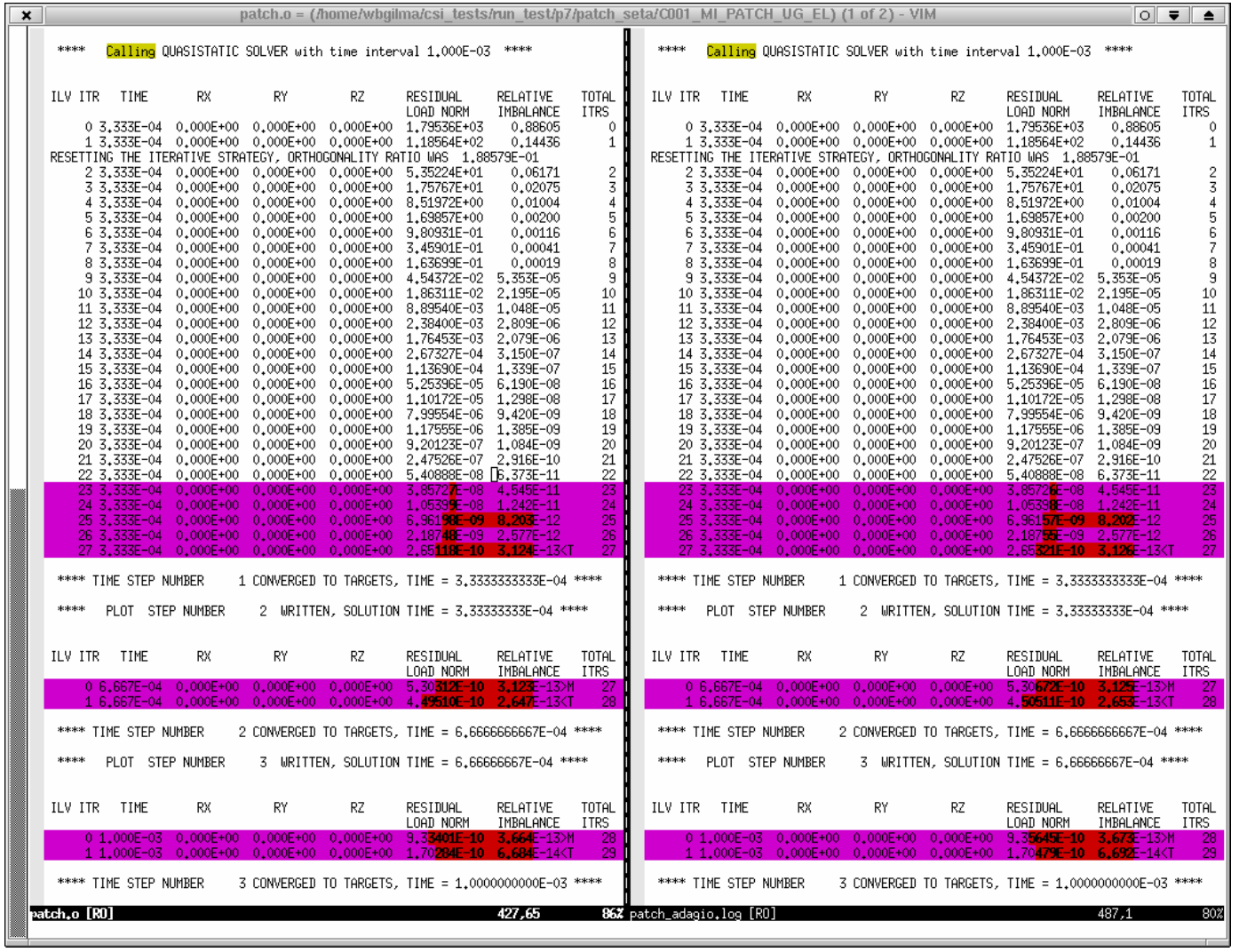
Stringent Criteria for Capability Tests

Typical Criteria:

- Results Agree

Current Criteria:

- Results Agree
- Iterations Match
  - Iteration counts match
  - Residuals match (within 1e-8)
  - CG Resets match
- Controls Match
  - Model problem histories match
  - Strain Errors match



Verification Entities

What does Adagio/JAS3D comparison pass really mean?

- **Gradient/Divergence & Kinematics operators:**
  - Same element strains from the same nodal displacements
  - Same internal force from element stresses
- **Stress evaluation:**
  - Same constitutive response from corresponding models
- **Hourglass stiffness:**
  - Same hourglass resistances applied
- **Diagonal / Block Preconditioners:**
  - Same or nearly same Level 0 equilibrium CG iteration path
- **Multi-level solver:**
  - Same model problem series building up to full solution
- **Predictor:**
  - Same starting point for the next time step

Capability Test Matrix

All tests produce same stress results within 1e-6 relative tolerance

			set A		set B		set C		set D		set E		set F		set G		set H		set I	
			MI	SO	MI	SO	MI	SO	MI	SO	MI	SO	MI	SO	MI	SO	MI	SO	MI	SO
Patch	Elastic	UG	c001	c021	c001b	c021b														
		SD	c002	c022	c002b	c022b														
		MX	c003	c023	c003b	c023b														
	IncSol	UG	c004	c024	c004b	c024b	c004c	c024c	c004d	c024d	c004e	c024e	c004f	c024f						
		SD	c005	c025	c005b	c025b	c005c	c025c	c005d	c025d	c005e	c025e	c005f	c025f						
		MX	c006	c026	c006b	c026b	c006c	c026c	c006d	c026d	c006e	c026e	c006f	c026f						
	StiffElas	UG	c007	c027	c007b	c027b	c007c	c027c	c007d	c027d										
		SD	c008	c028	c008b	c028b	c008c	c028c	c008d	c028d										
		MX	c009	c029	c009b	c029b	c009c	c029c	c009d	c029d										
	Mooney	UG	c010	c030	c010b	c030b	c010c	c030c	c010d	c030d	c010e	c030e	c010f	c030f						
		SD	c011	c031	c011b	c031b	c011c	c031c	c011d	c031d	c011e	c031e	c011f	c031f						
		MX	c012	c032	c012b	c032b	c012c	c032c	c012d	c032d	c012e	c032e	c012f	c032f						
	Ortho Ela	UG	c013	c033	c013b	c033b	c013c	c033c	c013d	c033d	c013e	c033e	c013f	c033f						
		SD	c014	c034	c014b	c034b	c014c	c034c	c014d	c034d	c014e	c034e	c014f	c034f						
		MX	c015	c035	c015b	c035b	c015c	c035c	c015d	c035d	c015e	c035e	c015f	c035f						
	Ortho Ela2	UG	c016	c036	c016b	c036b	c016c	c036c	c016d	c036d	c016e	c036e	c016f	c036f	c016g	c036g	c016h	c036h	c016i	c036i
		SD	c017	c037	c017b	c037b	c017c	c037c	c017d	c037d	c017e	c037e	c017f	c037f	c017g	c037g	c017h	c037h	c017i	c037i
		MX	c018	c038	c018b	c038b	c018c	c038c	c018d	c038d	c018e	c038e	c018f	c038f	c018g	c038g	c018h	c038h	c018i	c038i
	Swanson	UG	c051a	c054a	c051b	c054b	c051c	c054c	c051d	c054d	c051e	c054e	c051f	c054f						
		SD	c052a	c055a	c052b	c055b	c052c	c055c	c052d	c055d	c052e	c055e	c052f	c055f						
		MX	c053a	c056a	c053b	c056b	c053c	c056c	c053d	c056d	c053e	c056e	c053f	c056f						
Fiber	fiber	UG	c061a		c061b		c061c		c061d											
Shear	Elastic	UG	c019	c039	c019b	c039														
	IncSol	UG	c071a	c073a	c071b	c073b	c071c	c073c	c071d	c073d	c071e	c073e	c071f	c073f						
	Mooney	UG	c020	c040	c020	c040	c020c	c040c	c020d	c040d	c020e	c040e	c020f	c040f						
	Swanson	UG	c072a	c074a	c072b	c074b	c072c	c074c	c072d	c074d	c072e	c074e	c072f	c074f						