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Manufacturing Simulation Using Parallel Linear Solver and Contact in Adagio

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Introduction

- Manufacturing simulations (often contact-intensive) are a key application area for the Adagio finite element code.
- Recent work has greatly improved contact robustness with Adagio's parallel linear solvers.
- This robustness has been demonstrated in simulations of the manufacturing process of a component. Adagio is being used to give insight into performance of various design alternatives under consideration.

Role of Adagio

Adagio is the implicit (quasistatic & dynamic) nonlinear solid mechanics code in Sandia's SIERRA framework.

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Adagio Multilevel Solver Technology

- Nonlinear preconditioned conjugate gradient core solver.
- Multilevel solver developed in JAS3D legacy code is used to improve handling of poorly conditioned systems.
  - Series of well conditioned “model problems” are solved leading up to the solution of the real nonlinear system.
  - Several types of controls are available
  - Used for contact
    - Contact is tied in model problems, search and slip calculations occur between model problems

Flowchart for Control Contact with CG

- solve model problem using CG (constraints are tied)
  - compute residual (R)
    - enforce kinematic BCs & contact constraints on R
  - compute gradient direction ($G=M^{-1}R$)
  - compute search direction ($S=G+\beta S$)
    - enforce kinematic BCs & contact constraints on S
  - perform line search ($V=\alpha S+V$)
  - compute residual (R)
    - enforce kinematic BCs & contact constraints on R
  - check convergence
- compute slip
- perform contact search
- remove gaps
- release contact constraints in tension
- compute contact residual
- check convergence

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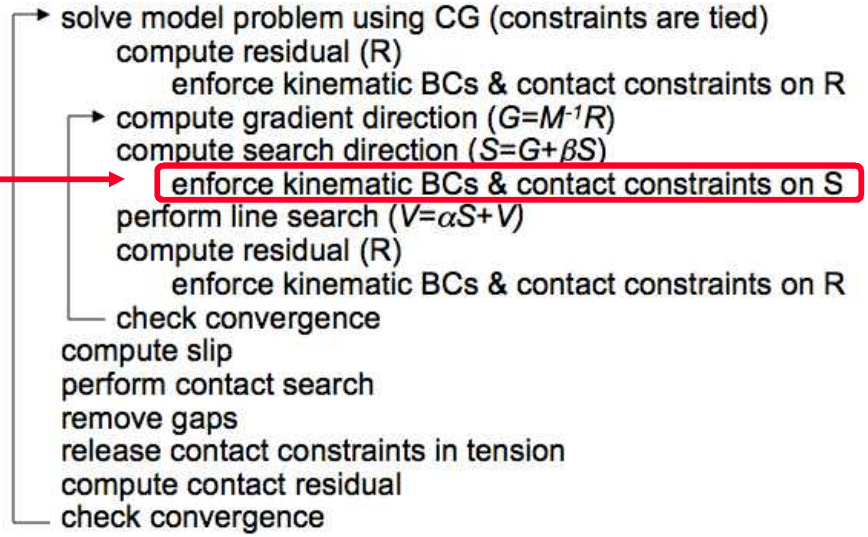
Linear Solvers in Adagio's CG Algorithm

- Legacy code (JAS3D) relied on diagonal or block diagonal (3x3) stiffness matrix for preconditioner
  - Simple, easy to invert, low cost per iteration
  - Requires many iterations
  - Performs very well on "blocky" problems, has more trouble with slender problems because system is poorly conditioned.
    - These problems are handled with constraint mesh in JAS3D.
- Linear solvers are a relatively new (~5 years) addition to Adagio
  - Uses full tangent stiffness matrix for preconditioner in nonlinear CG algorithm
    - Applied in compute gradient direction ($G=M^{-1}R$) step
  - Several iterative linear solvers are available, FETI is used most often.
  - Until recently, handling of constraints has been done in linear solver
    - Problematic in parallel, especially if contact surfaces are on processor boundary.

Alternative for Constraint Handling: Penalty Elements

- Represent constraints as penalty elements and add contributions to tangent matrix.
- No longer necessary to handle constraints in linear solver.
- Penalty constraints are usually problematic
  - Conditioning problems if stiffness is high
  - Incorrect results if stiffness is low.
- Errors introduced by compliance of penalty elements are removed in nonlinear CG algorithm.
  - Allows for low penalty stiffness to be used without affecting results.
- Has been extremely successful.



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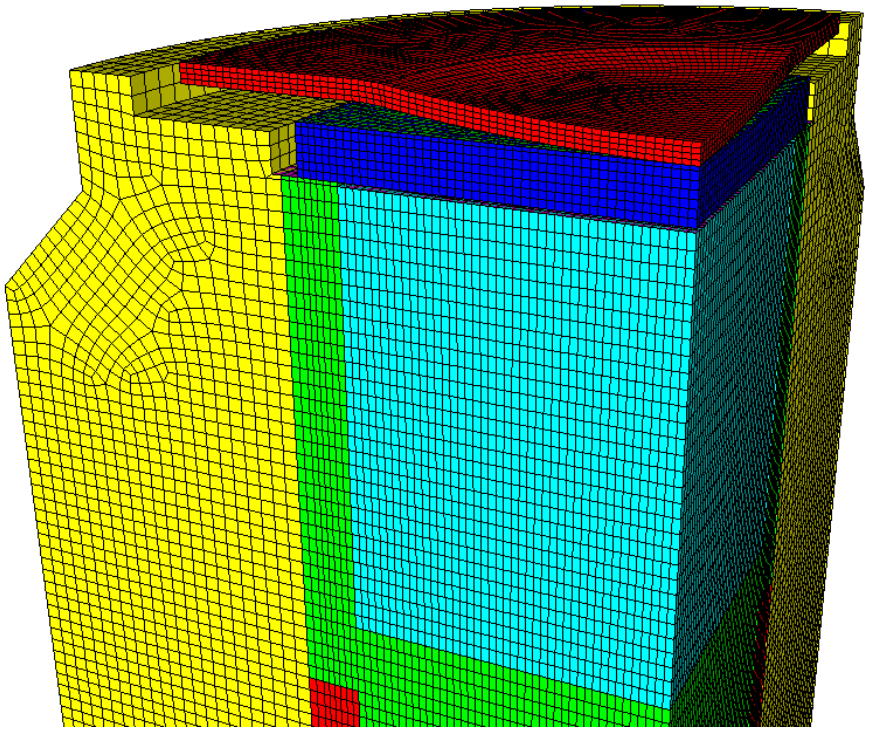
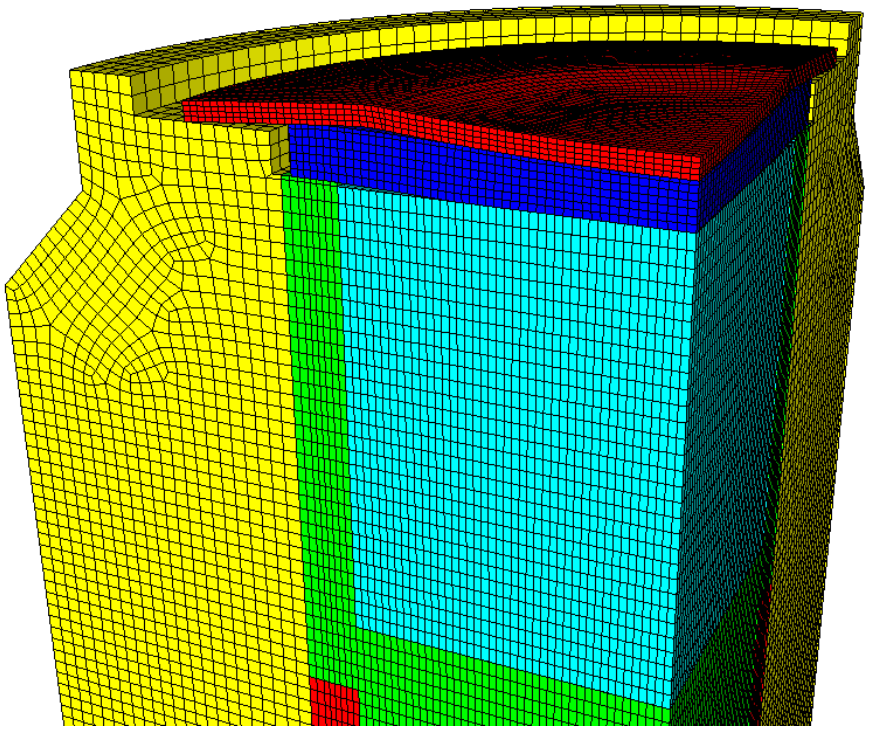
Application to Manufacturing Simulation

- Design alternatives for actuator are being considered
- Manufacturing process involves pushing down cap, welding around edge, and cool-down.
- Modeling is used to understand performance of part observed in tests.
- Simplifications were made for material models. Results are therefore intended to interpret trends rather than as exact representation of stress fields.



Analysis with Adagio

- One of the first real-world applications of new penalty constraint algorithm with FETI linear solver in Adagio.
- Initial attempts to use block diagonal preconditioner were unsuccessful due to poor conditioning of the problem.
- Fixes of parallel consistency bugs combined with penalty constraints allowed for robust, scalable solution of this model for production use.
- Model sizes of 100K - 300K elements on up to 100 processors.



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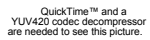
Example Animation



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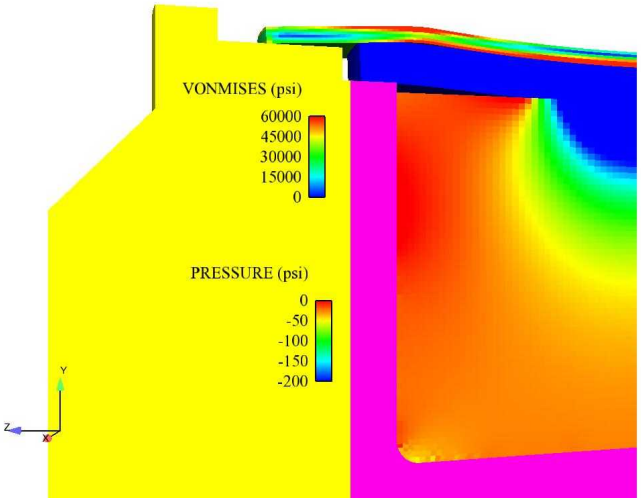
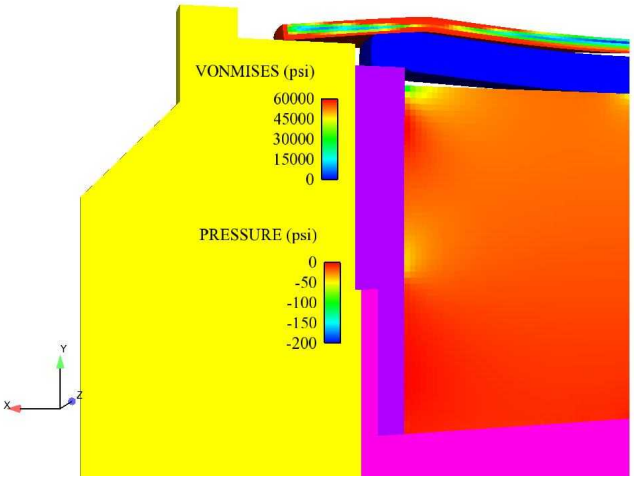
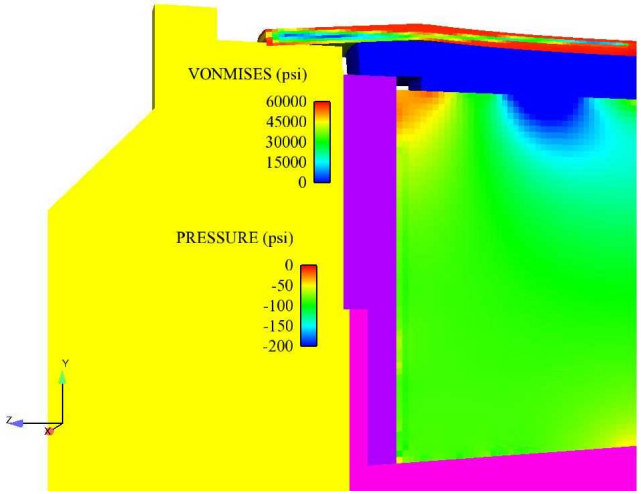
Results after Push-Down







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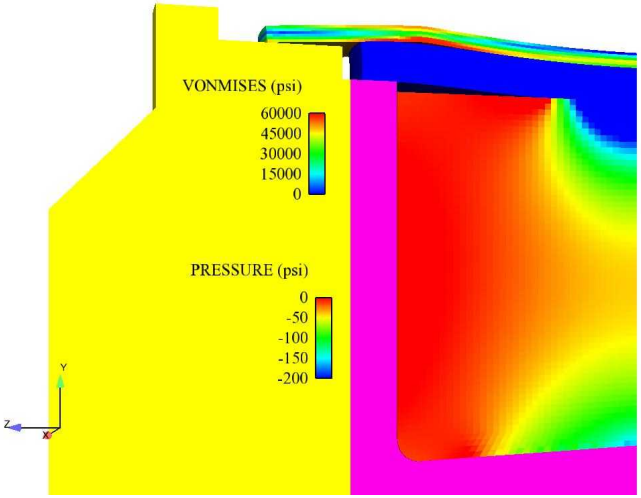
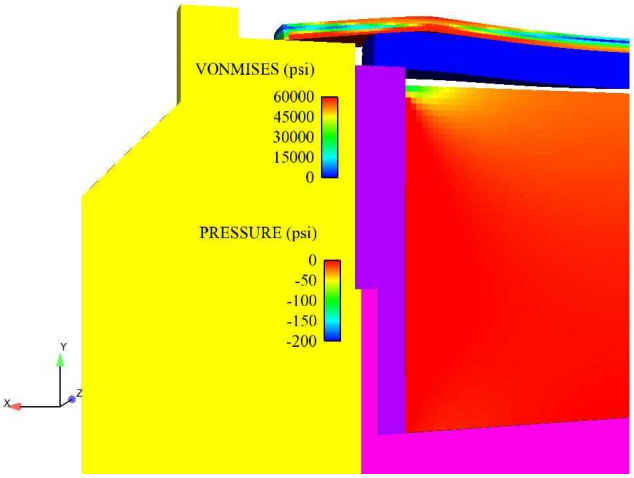
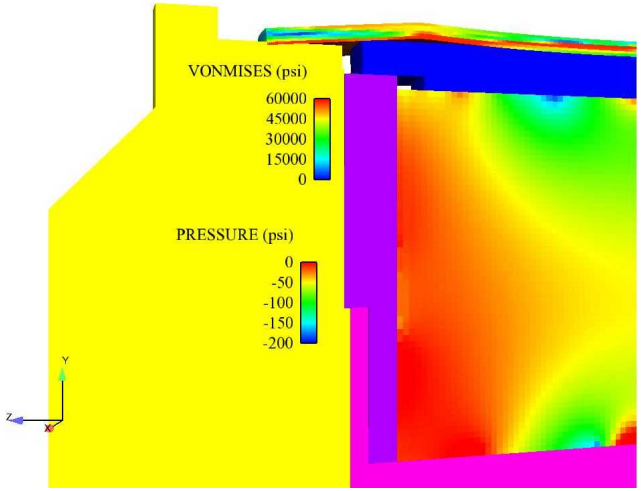
Results after Cool-Down







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Conclusions

- Penalty treatment of constraints in linear solver has proven to be very successful in the framework of Adagio's nonlinear preconditioned conjugate gradient algorithm.
- The robustness and scalability of this algorithm has been demonstrated in production manufacturing simulations.
- Modeling has been very helpful to designers in understanding performance of design alternatives.