FRACSTIM/I: A Fully Coupled Fluid Flow/Heat Transport and Geomechanical Deformation/Fracture Generation Simulator

aka

FALCON: Fracturing and Liquid CONservation

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Chemistry, Reservoir and Integrated Models

Overview

- Timeline
  - Project start date: 27 August 2009
  - Project end date: 30 September 2011
  - Percent complete: ~30%
- Budget
  - Total project funding: $977K (currently in house)
  - DOE share: 100%
  - Funding received in FY09: $586K, Funding received in FY10: $391K
  - Only had 1 month to work in FY09 (Spent ~$28K)
  - Planned funding for FY10: $545K, Carryover in FY11: $402K
- Barriers
  - Model the reservoir conductivity at an EGS system demonstration by 2011
- Partners
  - None

Relevance/Impact of Research

- Develop a fully coupled, fully implicit approach for EGS stimulation and reservoir simulation
- Solve all governing equations simultaneously in fully implicit way
  - Fluid Flow
  - Heat Transport
  - Geomechanics and Fracturing
- Enable massively parallel performance and scalability
- Apply state of the art nonlinear PDE solvers: Jacobian Free Newton Krylov (JFNK) method
- Enable the prediction and modeling of reservoir stimulation

Scientific/Technical Approach

- Conventional Approach: Operator-Splitting
  - Fully coupled???
    - Code coupling versus physics coupling
  - Operator splitting, essentially decoupling the processes and solving the equation separately
  - Couple different codes via input files, e.g., TOUGH2-FLAC3D, STOMP-ECKEChem
- FALCON Approach: Fully Implicit Coupling
  - Develop ‘kernels’ for small, manageable parts of the problem
  - Couple the kernels
  - Solve all simultaneously, fully coupling the physics
  - Multiphysics Object Oriented Simulation Environment (MOOSE)

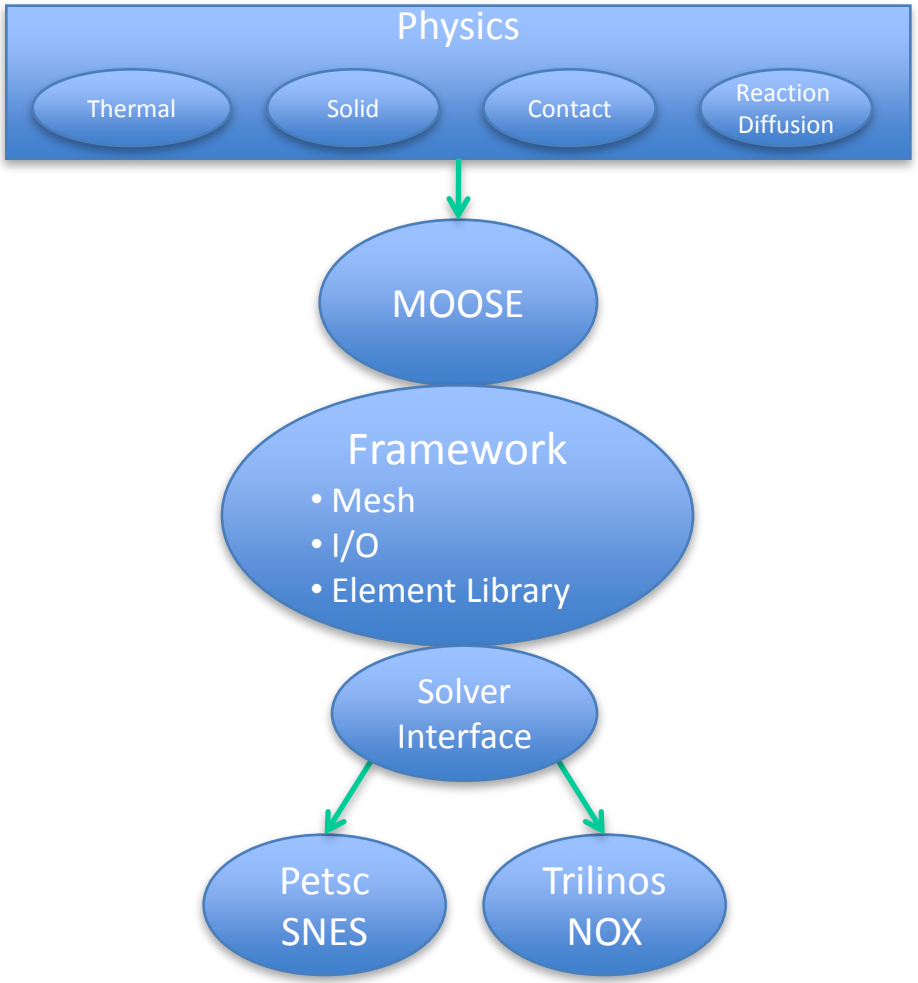
Scientific/Technical Approach(2)

- Developmental Framework
  - Finite element methods, coded in C++
  - Start easy, e.g., single phase flow and transport, continuum mechanics
  - Add in more complex behavior, e.g., multiphase flow, rock failure, etc.
  - Couple the kernels and test the code as the new kernels are added
- Milestones
  - September 2010, Development of fully parallelized 3D DEM model
  - March 2011, Development of hybrid-coupled continuum and DEM model
  - September 2011, Report on model development, capabilities, and performance

Scientific/Technical Approach(3)

Code Platform

- Plug-and-play API
  - Simplified coupling
- MOOSE Physics Interface conceals framework complexity
- Framework provides core set of common services
  - libMesh: http://libmesh.sf.net
- Solver Interface abstracts specific solver implementations.
  - Common interface to linear and non-linear solvers
  - More flexible
- Utilize state-of-the-art linear and non-linear solvers
  - Leverage SciDAC and NNSA software projects



Accomplishments, Expected Outcomes and Progress

Kernels Written to Date

- Fluid Flow – Darcy's Law
  - Single phase
  - Nonlinearity
    - Density and viscosity as a function of temperature
- Heat Transport
  - Set in terms of temperature (Boussinesq Approximation)
- Continuum geomechanics
  - Solve in terms of displacement
    - Use stress as indication of near failure conditions
  - Basic geomechanics equation couples to both temperature and pressure
- Time derivatives
  - 1st and 2nd order

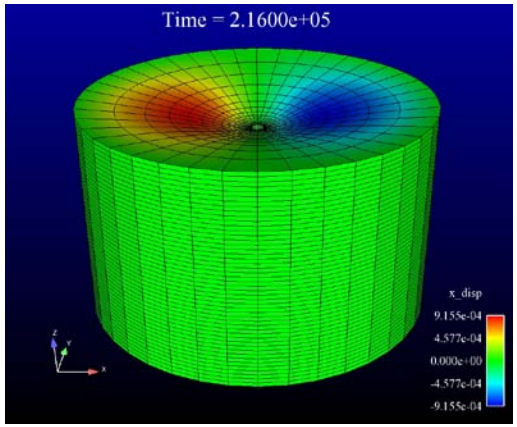
Accomplishments, Expected Outcomes and Progress(2)

Kernels Under Development

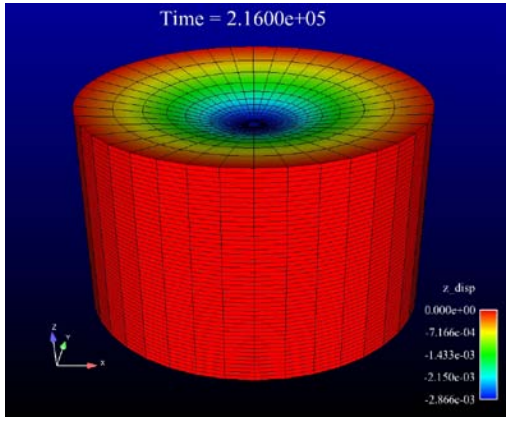
- Discrete Element Model (DEM) for explicit rock failure and fracture propagation
  - Fracture density, aperture, connectivity etc. → porosity and permeability
  - Geomechanical failure simulation is critical for developing EGS simulators
- Multiphase fluid flow
  - Enthalpy for energy transport

Accomplishments, Expected Outcomes and Progress(3)

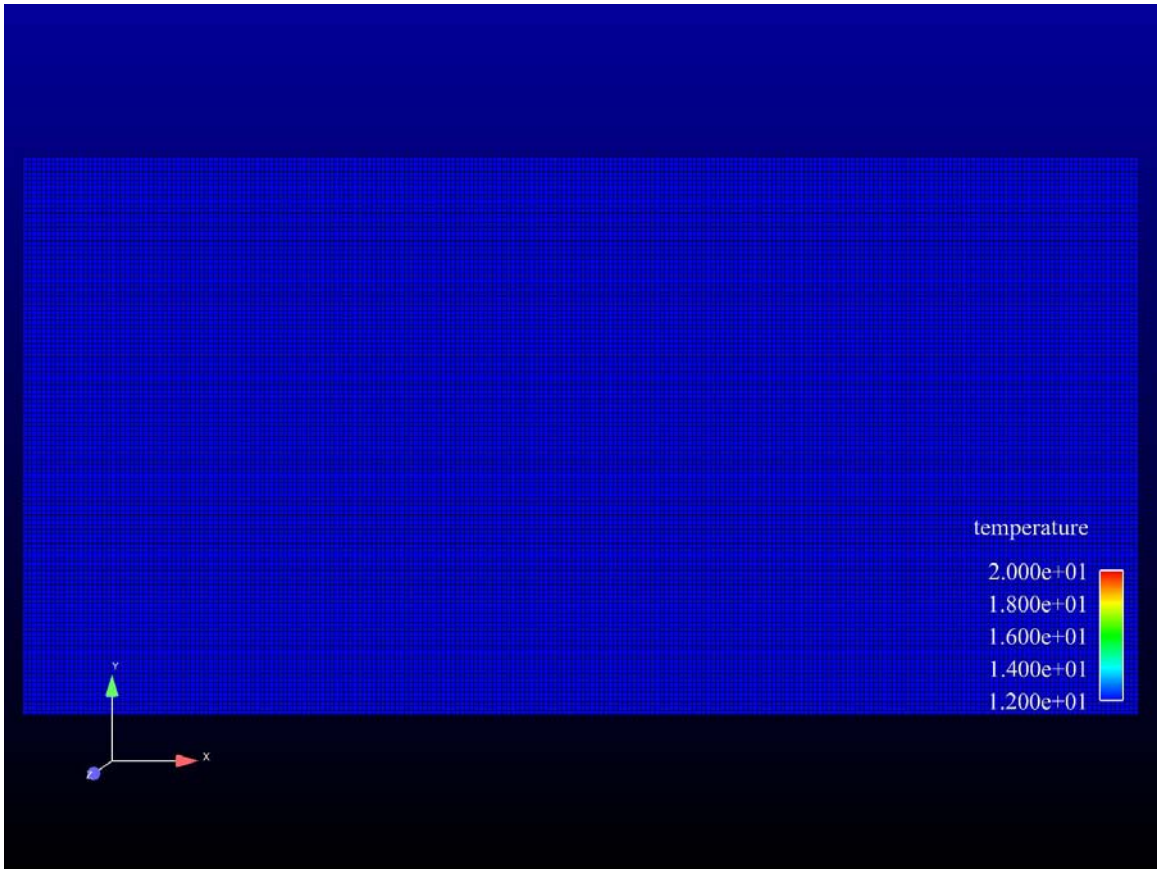
Example 1: Coupling and Advanced Features



3D x-displacement field



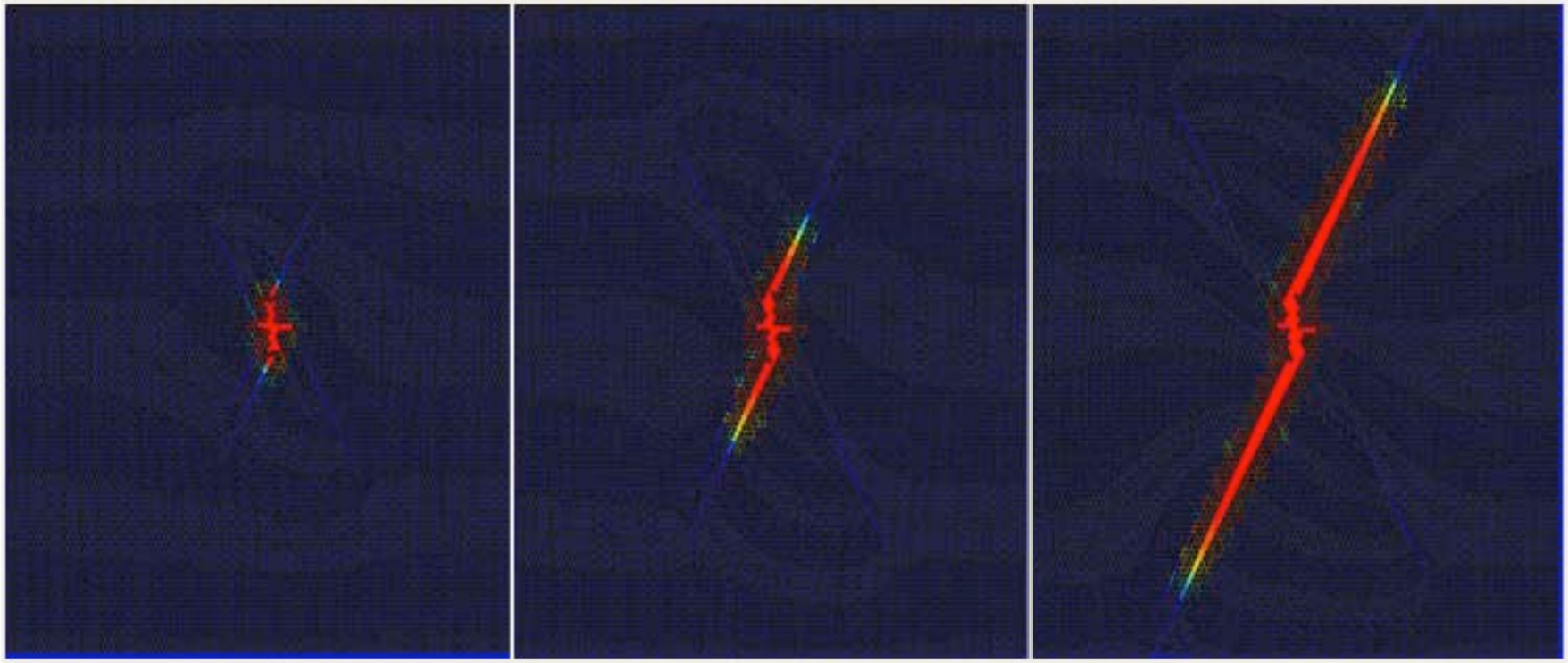
3D z-displacement field



Unstable thermal convection problem solved w/ AMR and MPI

Accomplishments, Expected Outcomes and Progress(4)

Example 2: Hydraulic Fracturing



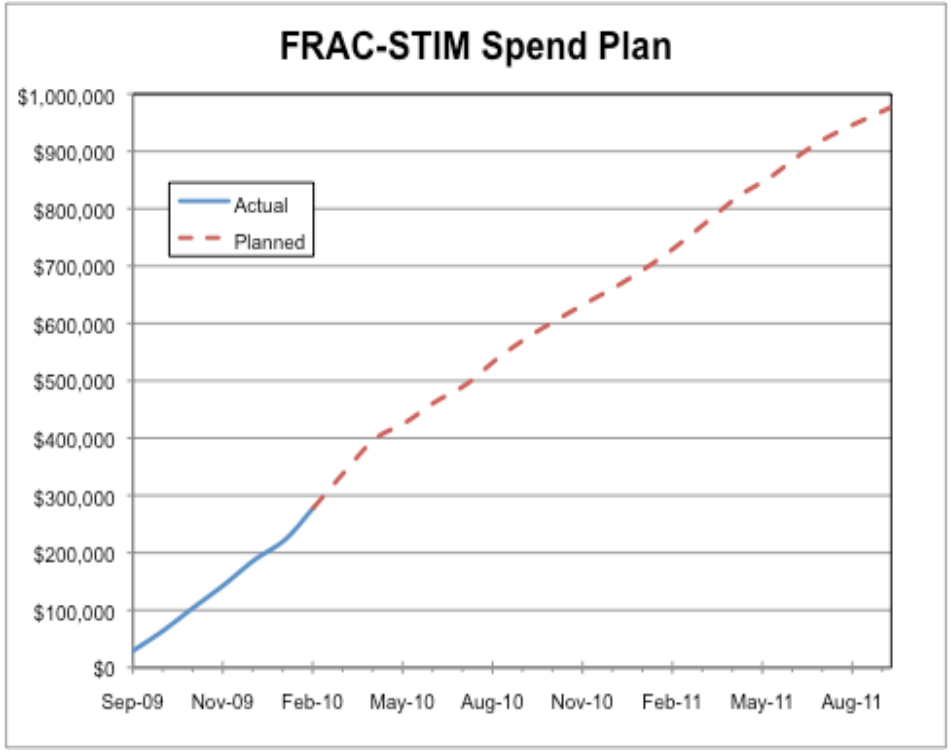
Critical strain: 2%, weakly ductile

Project Management/Coordination

- Upon notice of Year 3 funding would not be provided, the schedule was revised to drop activities related to acoustic emission modeling and field scale simulation demonstration.
- Revised schedule and status
  - Year 1 (FY10)
    - Develop and fully couple single-phase flow and continuum mechanics—complete as of Feb 2010, functionality continually being enhanced
    - DEM code development—two dimensional development complete, parallelized three dimensional underway
    - Test and verify kernels and coupling against existing codes—on-going
  - Year 2 (FY11)
    - Develop multiphase flow and transport capabilities—coding to begin in June 2010, 3 months ahead of schedule
    - Develop and couple DEM and continuum mechanics—rigorous coding to begin in October 2010. Preliminary coding underway.

Project Management/Coordination(2)

Date	Spend Plan	Actual	Difference
Sep-09		$28,800	--
Oct-09		$63,627	--
Nov-09		$104,778	--
Dec-09		$143,662	--
Jan-10		$187,754	--
Feb-10		$223,697	--
Mar-10	$278,744	$249,944	$28,800
Apr-10	$341,223	$306,668	$34,555
May-10	$397,973		
Jun-10	$427,349		
Jul-10	$463,345		
Aug-10	$493,940		
Sep-10	$538,733		
Oct-10	$575,437		
Nov-10	$607,883		
Dec-10	$637,727		
Jan-11	$667,706		
Feb-11	$701,932		
Mar-11	$737,049		
Apr-11	$780,525		
May-11	$822,592		
Jun-11	$854,918		
Jul-11	$894,397		
Aug-11	$927,953		
Sep-11	$977,080		



Future Directions

- FY10
  - Continue development of fluid flow and energy transport model
    - Multiphase flow and transport, steam tables, well hydraulics(?), constitutive relations, etc.
  - Continue DEM development
    - Extend code to 3 dimensions and parallelize
    - Begin preliminary coupling with flow and transport, hybrid methods, grid/mesh interface and data transfer
  - Publish results of single phase code development
- FY11
  - Continue development of fluid flow and energy transport model
    - Spatial heterogeneity, user interface, other enhancements as necessary
  - Full implicit coupling between DEM and FE
    - Logic for AMR, data structures, constitutive relations, etc.
  - Publish results

Summary

- FALCON (FRACSTIM) code capabilities envisioned to allow for fully implicit simulations of reservoir stimulation
- Code being built upon a tested and supported Multiphysics framework
- Development in parallel and planned in logical steps
- Preliminary development results encouraging
- Coupling DEM method with continuum mechanics enables simulation of failure and fracture propagation
- Final Product: Adaptive Hybrid DEM-Continuum Mechanics Coupled with Fluid Flow and Heat Transport at Reservoir Scale