MHD Generators & ALE3D

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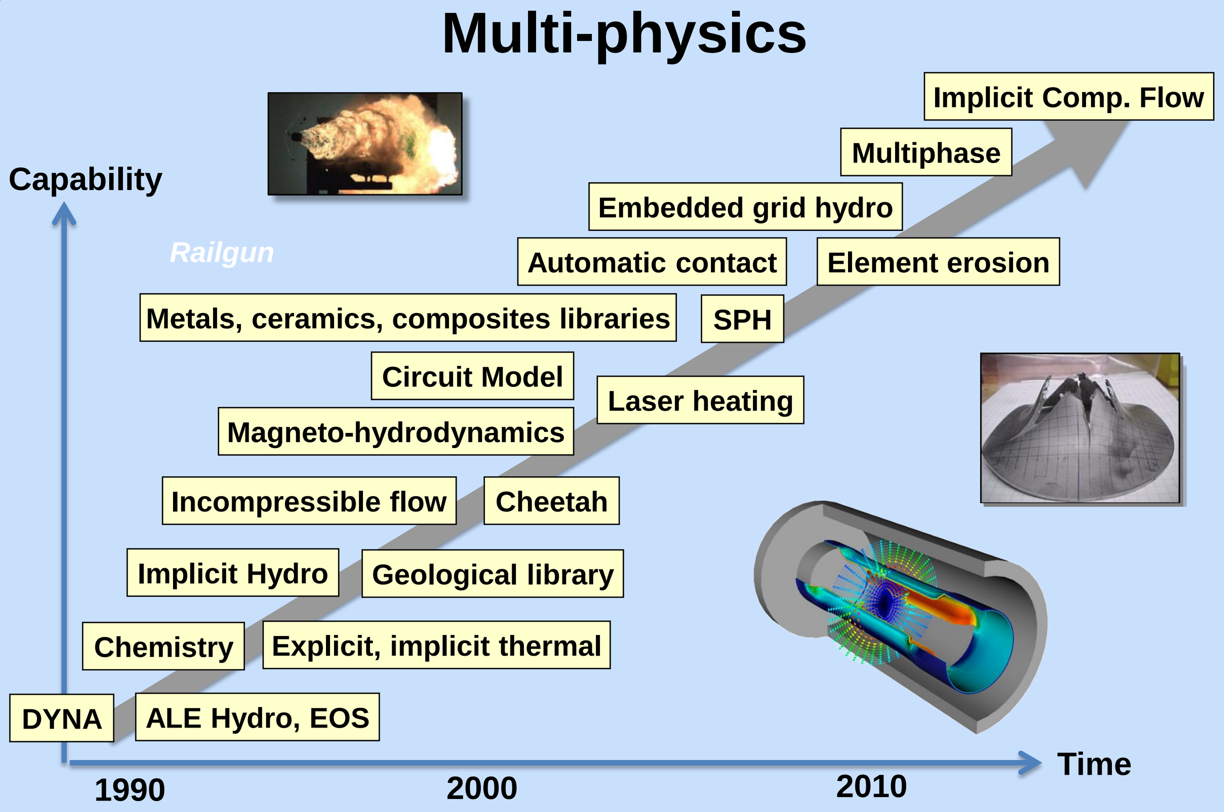
ALE3D Capabilities

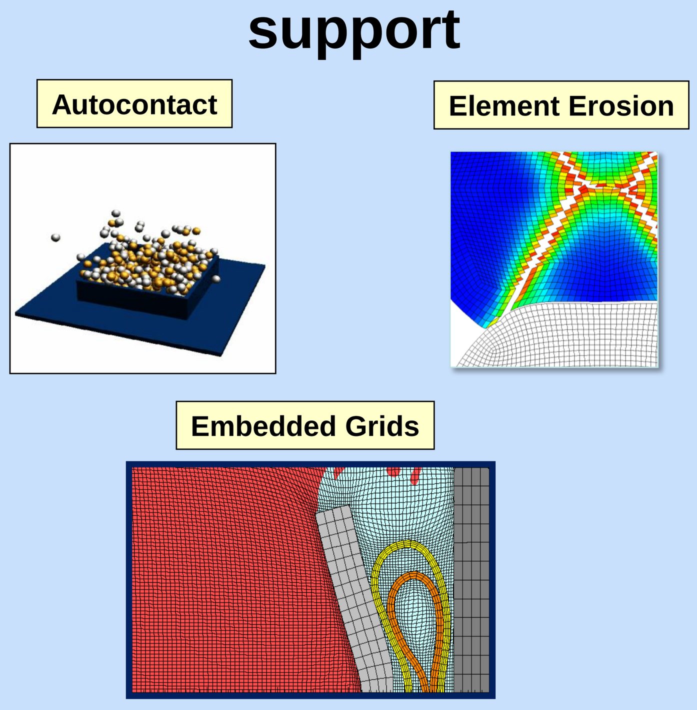
Multi-physics



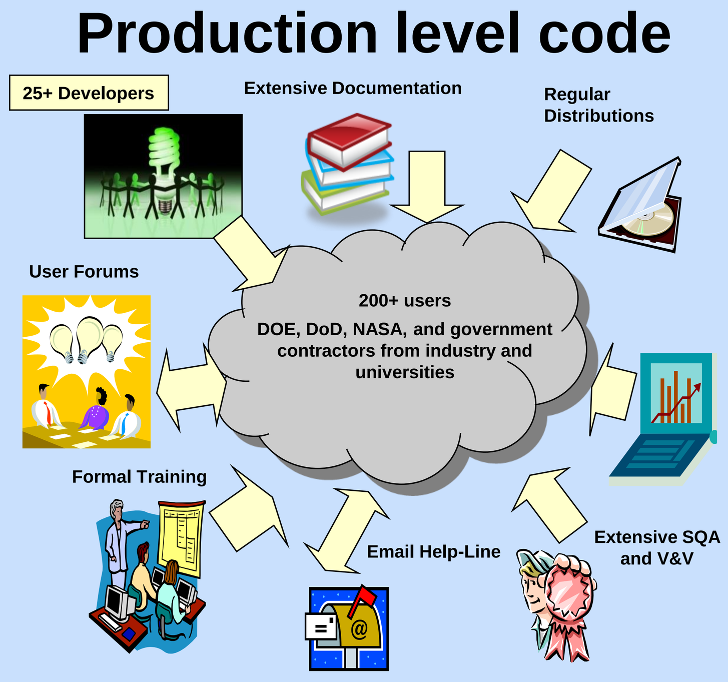
Key features:

- Solid-Fluid interaction
- Fully Coupled MHD
- Material damage
- Chemistry

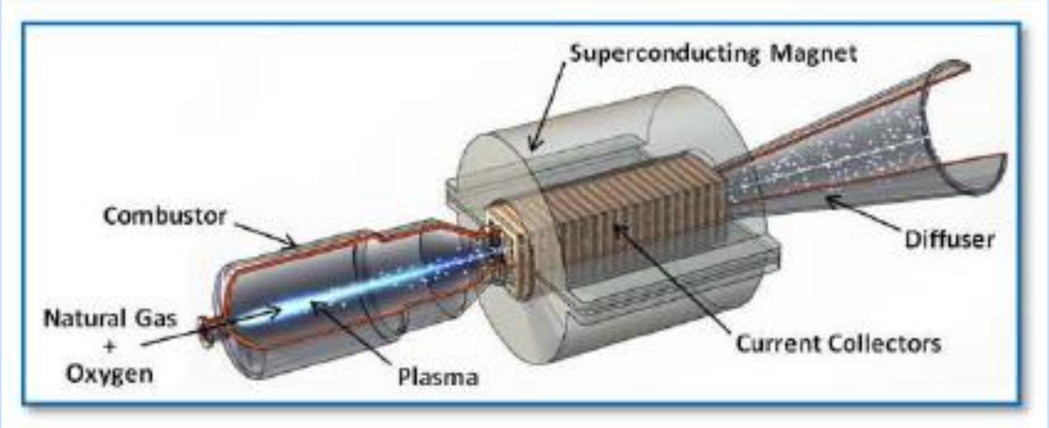
Advanced multi-domain support

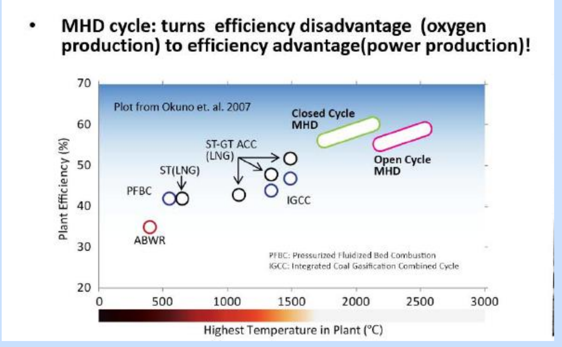


Production level code



MHD Generator Challenges





- Improving generator efficiency
  - Manage arcing across insulators
  - Manage hall instability induced current loops
  - Manage arc formation in boundary layer
- Extending electrode/insulator life
  - Manage erosion and cracking in electrodes
  - Manage the effects of slag and seed
- Reduce the need for ionization seeding
  - Consideration of non-equilibrium ionization techniques
  - Managing the seed-ionization process

Initial ALE3D Modeling Efforts

Introduce Hall Effect Without Feedback

$$[\mathbf{H}]_e = \frac{\beta_e}{\|\mathbf{B}\|}\begin{bmatrix} 0 & -B_z & B_y \\ B_z & 0 & -B_x \\ -B_y & B_x & 0 \end{bmatrix}$$

Hall Effect Tensor

$$[\boldsymbol{\sigma}]_e = \sigma\left[[\mathbf{I}] + [\mathbf{H}]_e\right]^{-1}$$

Hall-Modified Conductivity Tensor

$$\mathbf{J} = [\boldsymbol{\sigma}]_e(\mathbf{E} + \mathbf{v}\times\mathbf{B}_0)$$
$$\mathbf{E} = -\nabla\varphi$$
$$0 = \nabla\bullet\mathbf{J} \Rightarrow \nabla\bullet[\boldsymbol{\sigma}]_e(-\nabla\varphi + \mathbf{v}\times\mathbf{B}_0) = 0$$

Simplified Hall MHD without Feedback:
Poisson Equation Solved for Electric Potential (Voltage)

- Captures large scale current distribution
- Model electrode/insulator damage during operation and slag effects
  - Explicit hydrodynamics with heat transfer and solid fluid interaction
  - Modern solid mechanics models for ceramics and metals for damage and cracking
  - Use chemistry package to model slag formation

Future ALE3D Modeling Efforts

Incorporate Faraday and Ampere Laws

$$\frac{\partial\mathbf{B}}{\partial t} = -\nabla\times\mathbf{E}$$

Faraday's Law

$$\mathbf{J} = [\boldsymbol{\sigma}]_e(\mathbf{E} + \mathbf{v}\times\mathbf{B}) = \nabla\times\mathbf{H}$$

Ampere's Law with Hall-Modified Conductivity

$$\mathbf{E} = \mathbf{E}^{inductive} - \nabla\phi \qquad \mathbf{E}^{inductive} = -\frac{\partial\mathbf{A}}{\partial t}$$

- Inductive component requires more expensive solve for vector potential
- Non-linearity introduced into the conductivity tensor
  - Timestep-lag the Hall tensor to resolve non-linearity
    - May require addition limits on time step
- Additional improvements include:
  - Modeling separate electron/ion temperatures
  - Coupling to Implicit compressible flow model

- Captures fine grained magnetic behavior
- Model arcing instabilities, boundary effects, seed-ionization induced streamers, discharge ionization and recombination
  - Implicit compressible flow with heat transfer
  - Addition of separate elector/ion temperatures for non-equilibrium ionization

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

LLNL-POST-661660