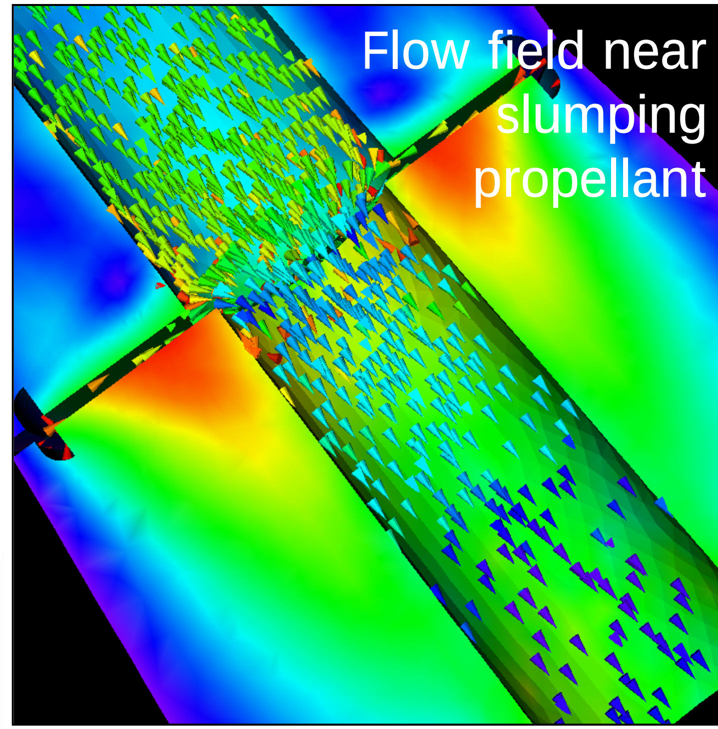
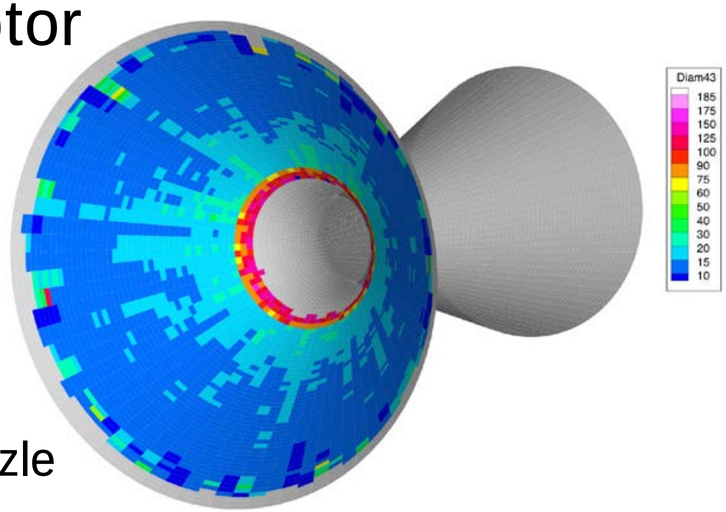
Section 2
Selected Simulations

Major Simulations "Science with the Code"

- Full RSRM
- Titan propellant slumping
- Turbulence around flexible inhibitor
- Aluminum impingement on nozzle
- LAS Motor

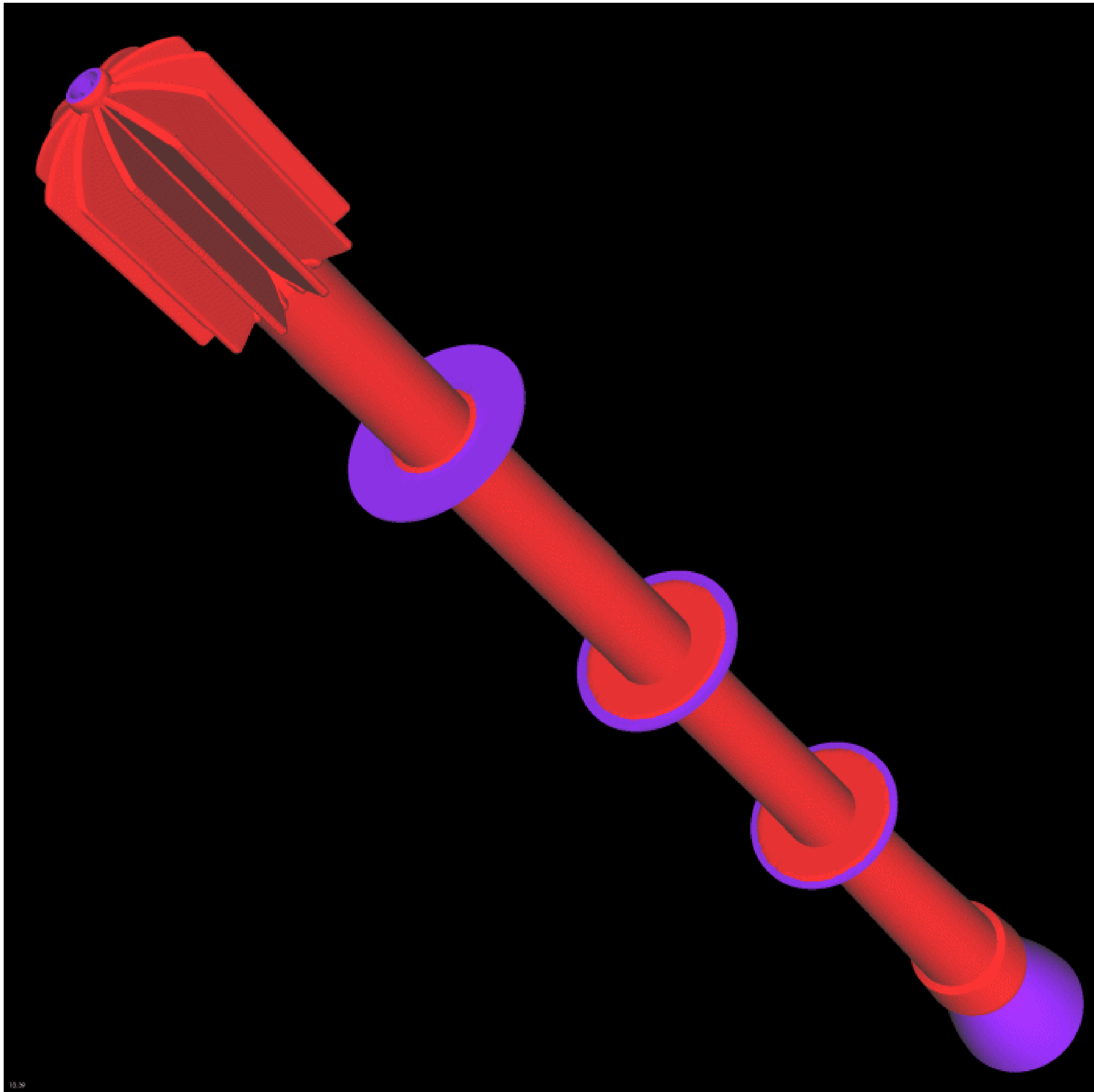


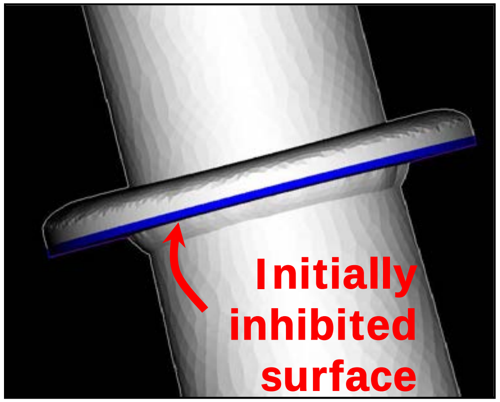


Al particles impacting nozzle

NASA RSRM

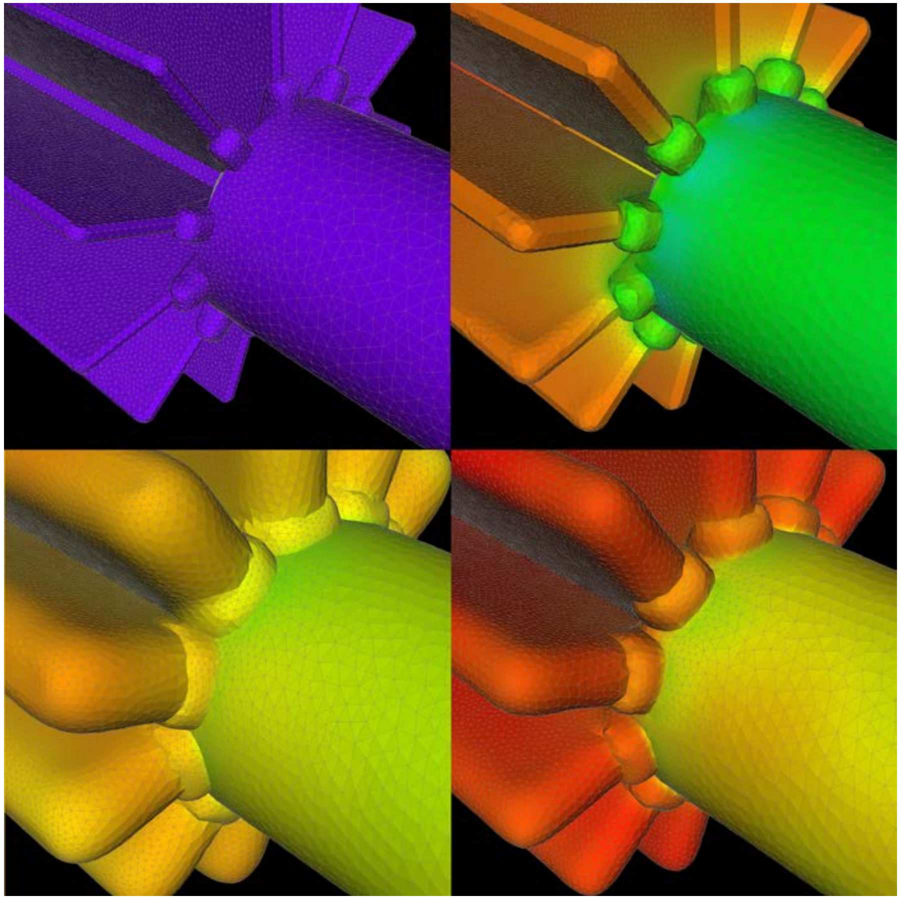
- Burnout simulation
  - Red is burning propellant; blue is at insulated surface
- Viewing
  - Propellant/fluid interface
  - Inhibited surfaces
- Unique capabilities
  - High rate "time zooming"
  - Significant burnout — never seen in industry
  - Case constraints
  - Propellant walkback
  - Inhibitor regression
  - Dynamically changing topology





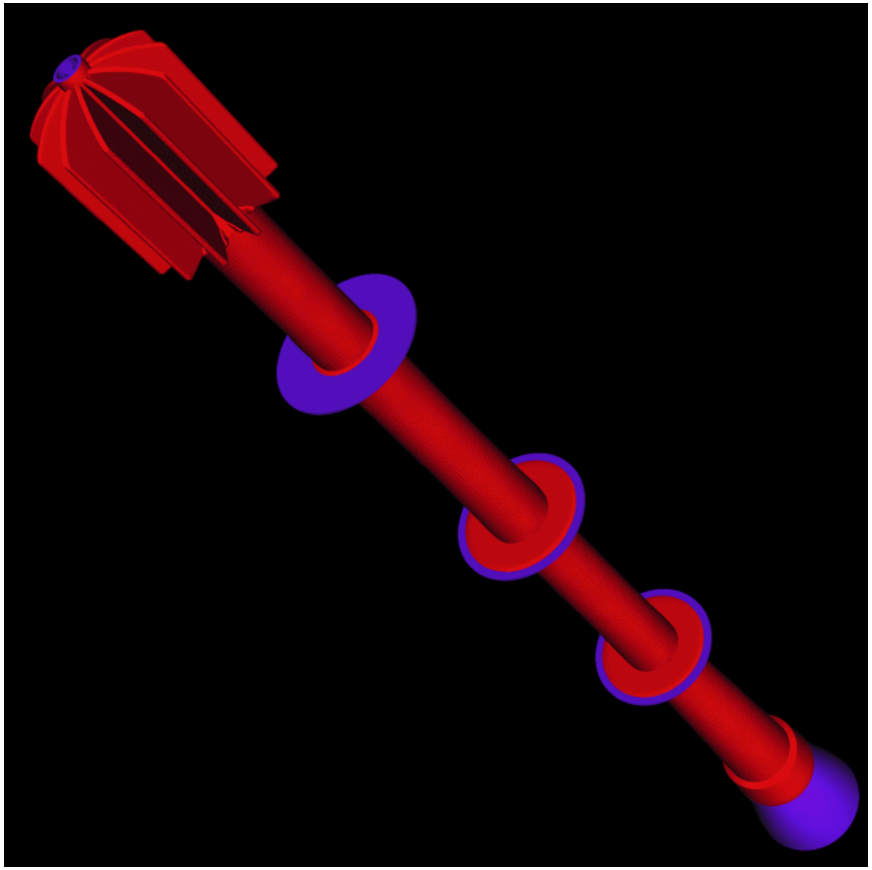
RSRM Burn-Out with Simplified Physics

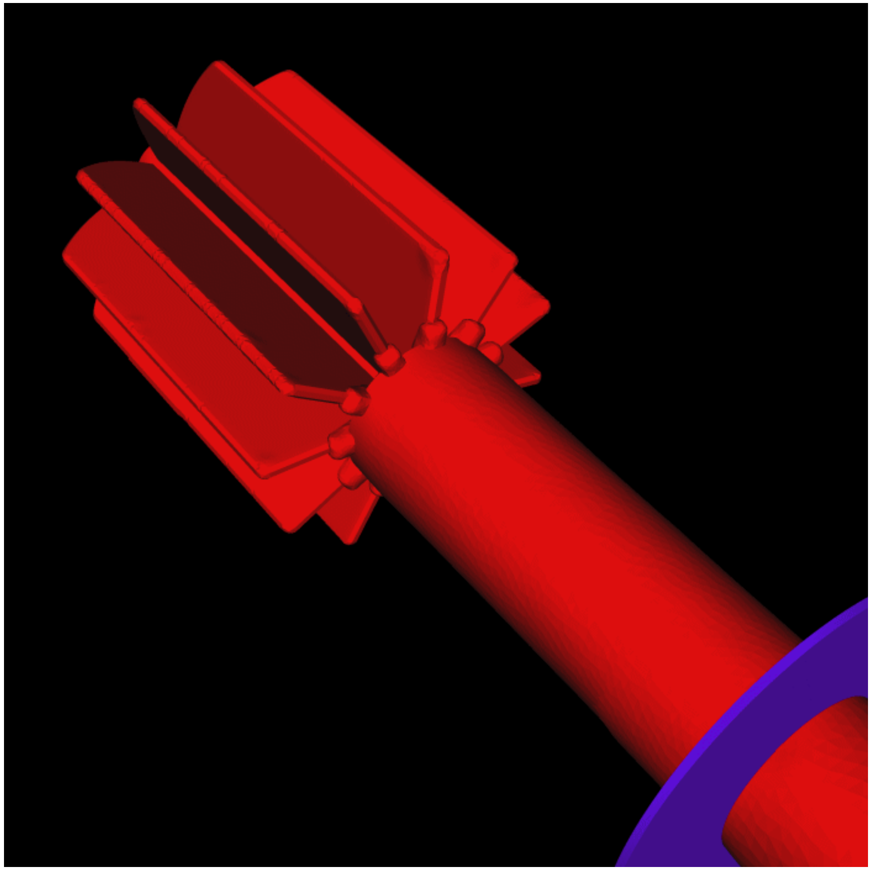
- Time zooming essential to reach full burn-out
- Fluid (*Rocflu*)
  - Single phase, inviscid
  - 1st order in space
- Combustion
  - Full ignition transient
  - (P, T, t)-dependent burn rate
- Surface regression
  - Surface mesh smoothing
  - Constraints at case
    - Domes fore and aft
- Volume mesh modification
  - Smooth every few steps
  - Remesh every 0.5 s



Gas Pressure

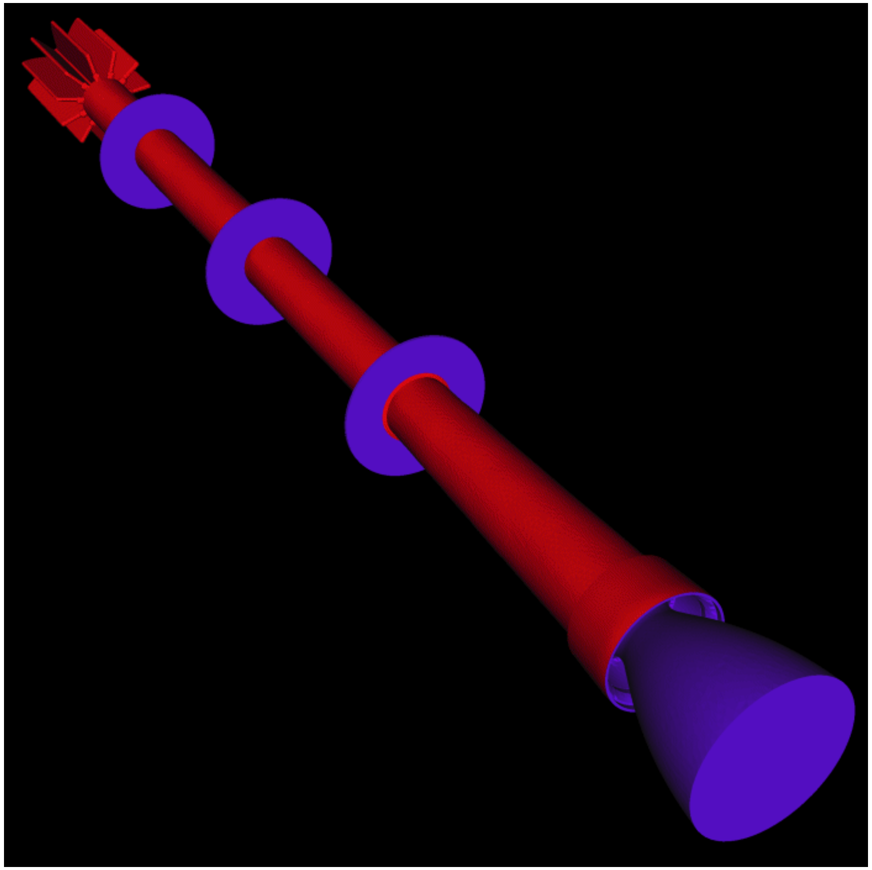
RSRM Burn Out, I

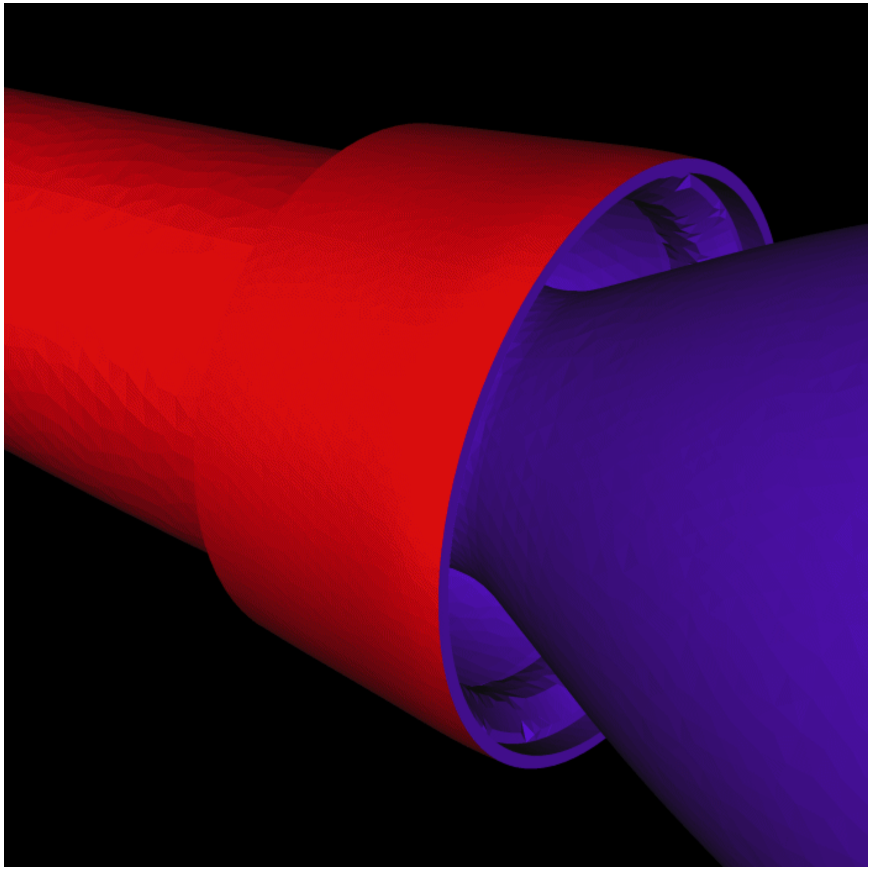




- Exercise Face-Offsetting method, mesh modification
- After ignition, use aP^n regression rate
- Star grain burns out completely at ~ 55 s

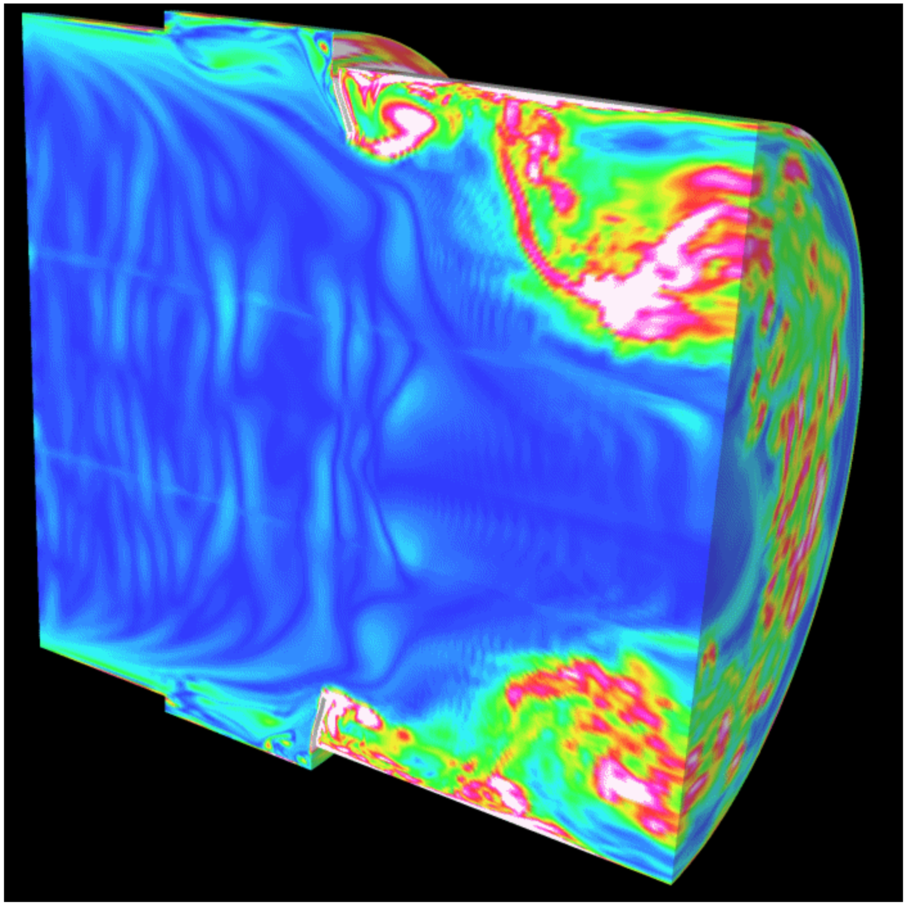
RSRM Burn Out, II





- Handle burn-out of inhibited areas, “walk-back” along case at joints
- Constrain burning at case, including fore and aft domes
- Nearly all propellant gone by 116 s

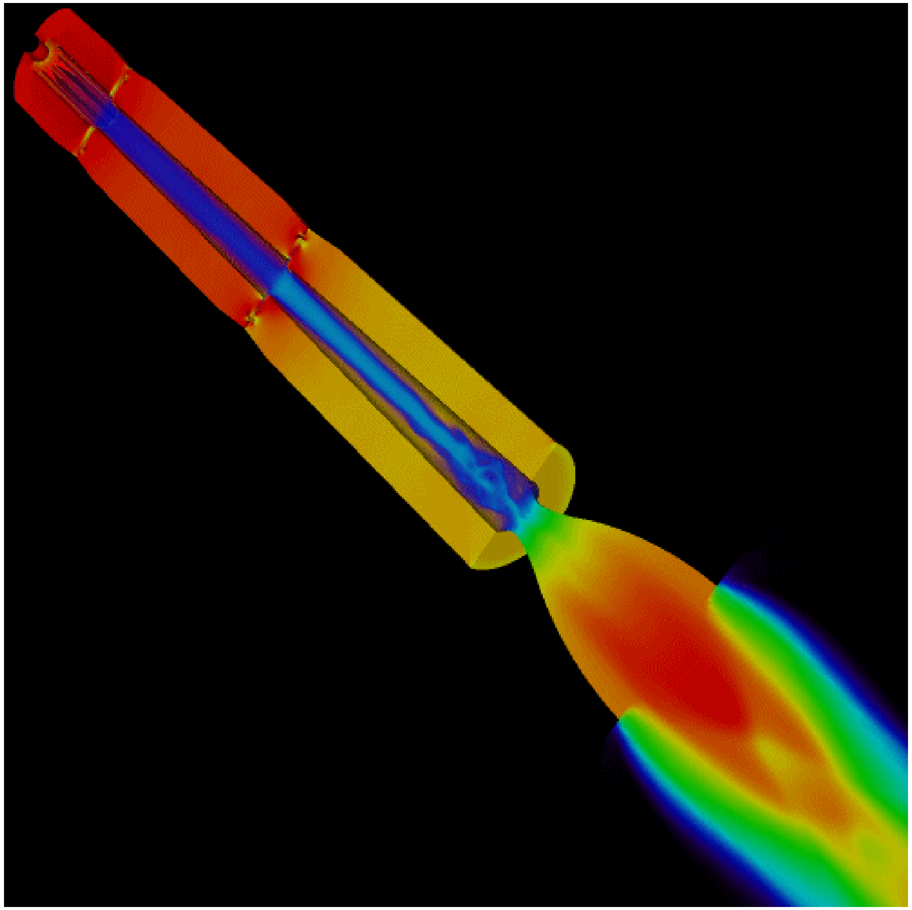
Large Booster Joint Near Burnout



Fully 3-D simulation cutaway showing vorticity magnitude

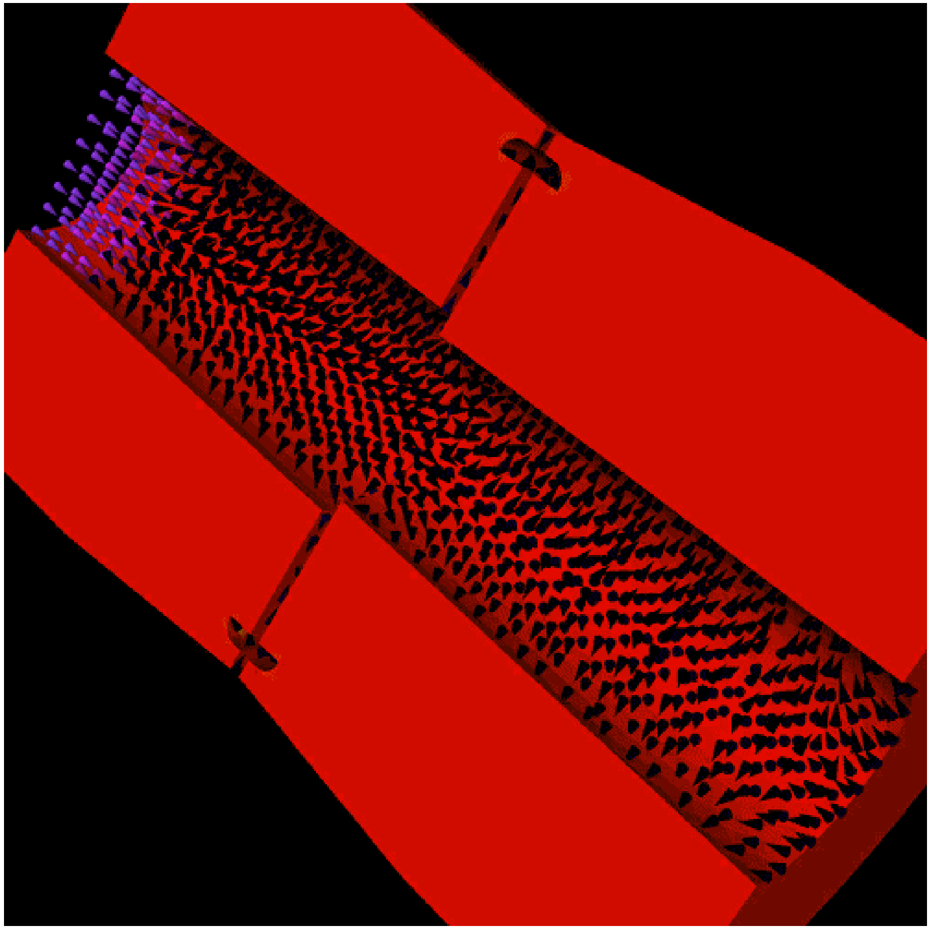
- Fluid-solid coupled simulation
- High-fidelity CFD with LES subgrid model
- Coupled solid mechanics for inhibitor
- Advanced mesh motion; block structured grid

Titan Booster Accident Requires Multiphysics



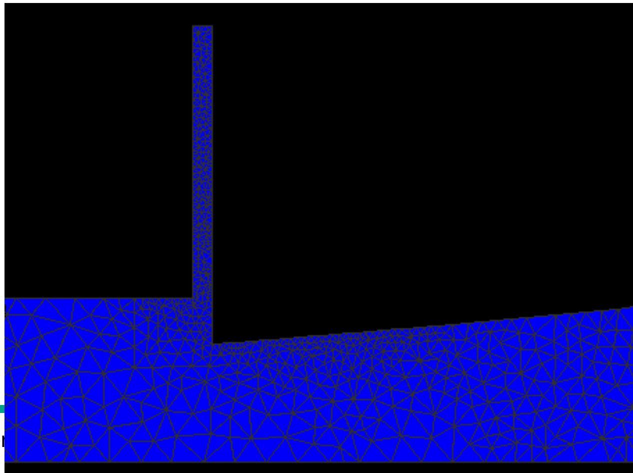
- Large multi-segment booster with star grain
- 1990's early design resulted in test stand failure
  - Cause: grain collapse due to fluid-structure interaction
- Goal of simulation: to duplicate conditions and response
  - Show that simulation could be predictive if used early in design

Titan Joint Slot Simulation

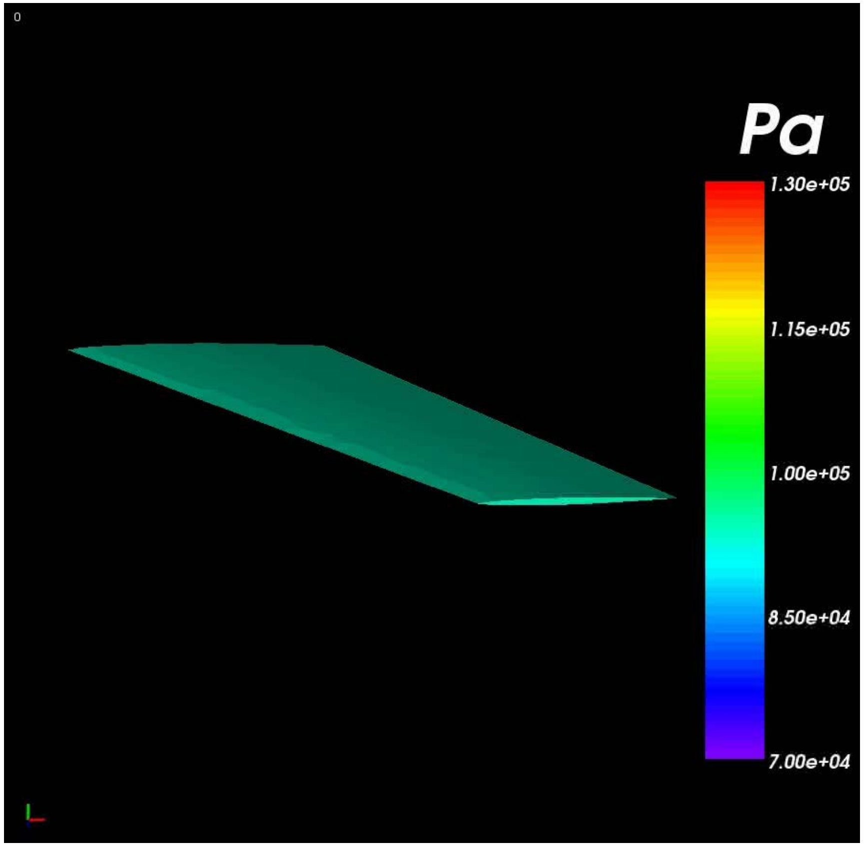


Velocity (in core flow) and stress (in grain)

- Flow interaction over lip caused low pressure downstream
- Grain collapsed inward
- Ultimately grain separated from case and destroyed booster
- Multiphysics simulation would have demonstrated problem



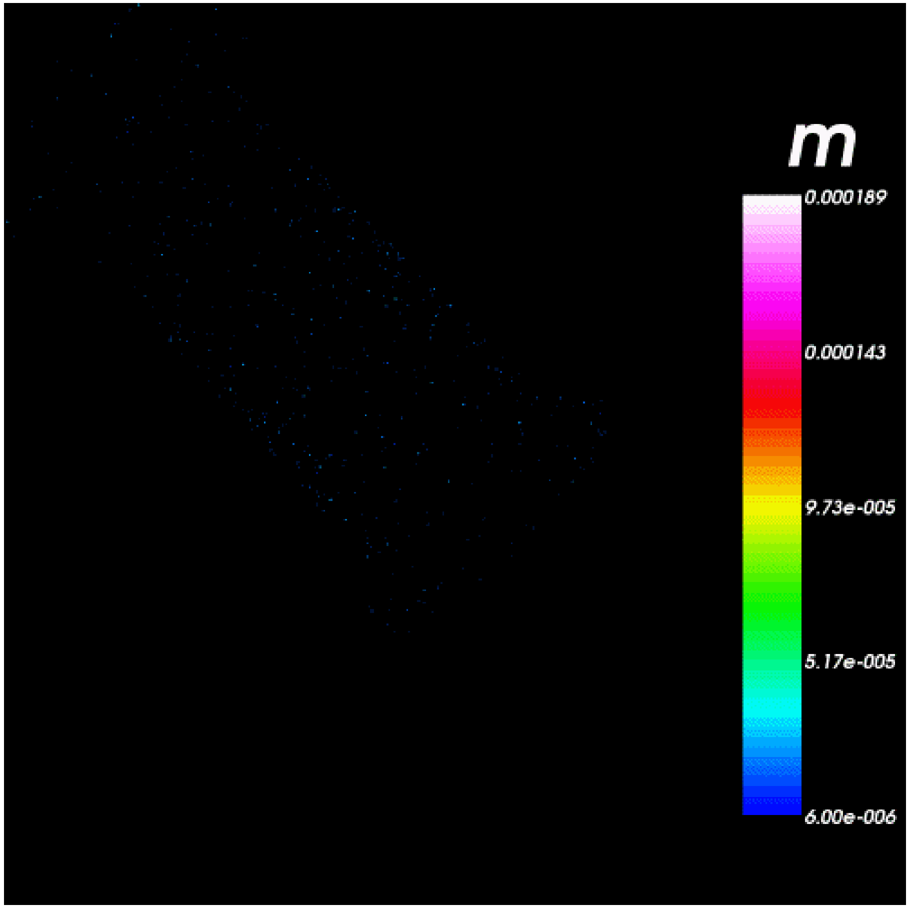
AGARD Wing Flutter



- Rocflu/Rocfrac
- AGARD wing flutter problem (Yates et al., 1963)

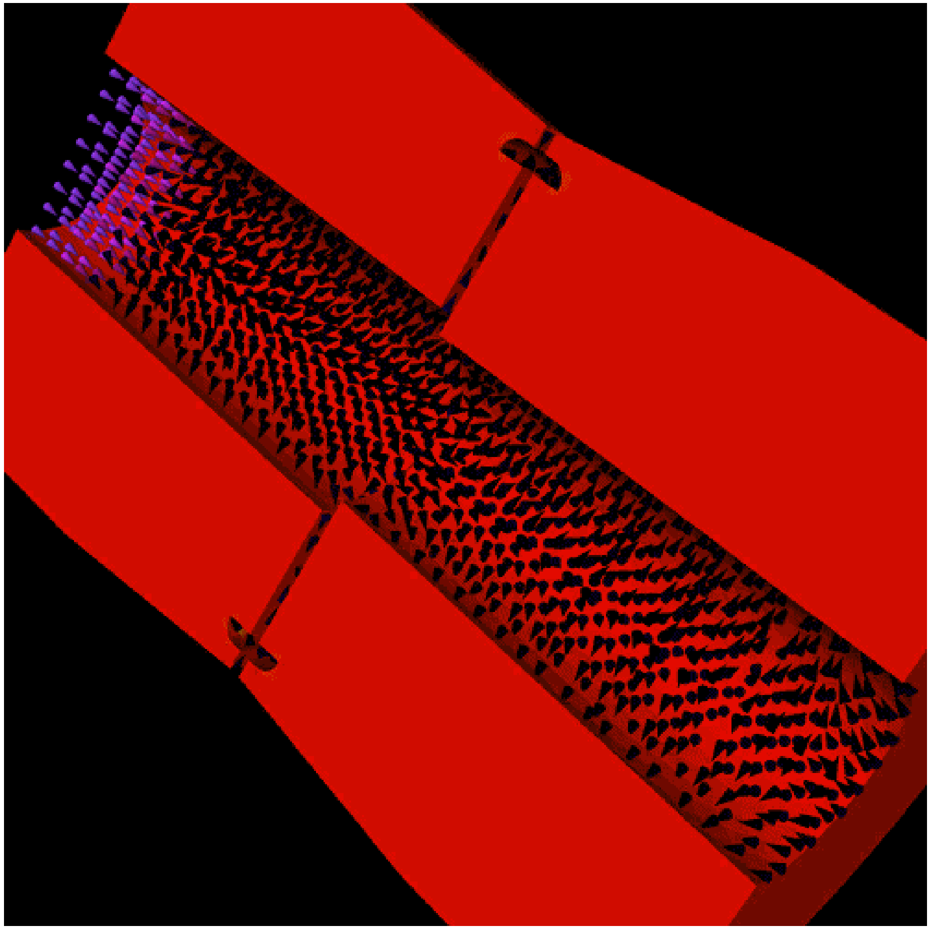
- Shows the large bending and torsion deformations (captured with the implicit structure solver using mixed-enhanced finite elements) experienced by the wing in the flutter regime.

BATES Efficiency



- 15 lb BATES motor
- Studied effects of different aluminum loadings on ISP (AIAA-2005-3997)
- Full 3-D fluid solution with Lagrangian particles
- Coupled fluid-combustion model
- New model for Aluminum and Al_2O_3 Phase change just added to *Rocflo*

Titan Joint Slot Simulation



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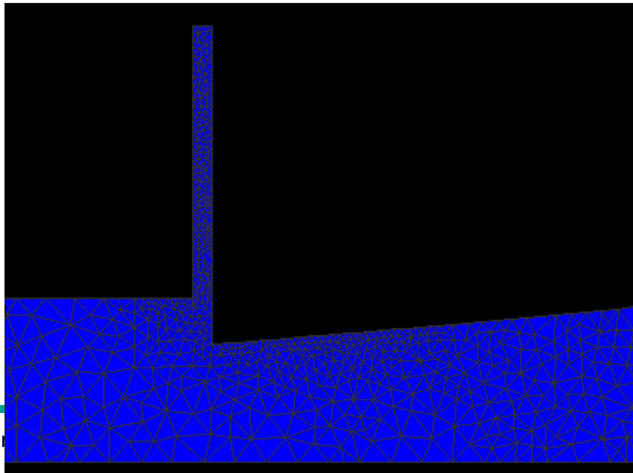
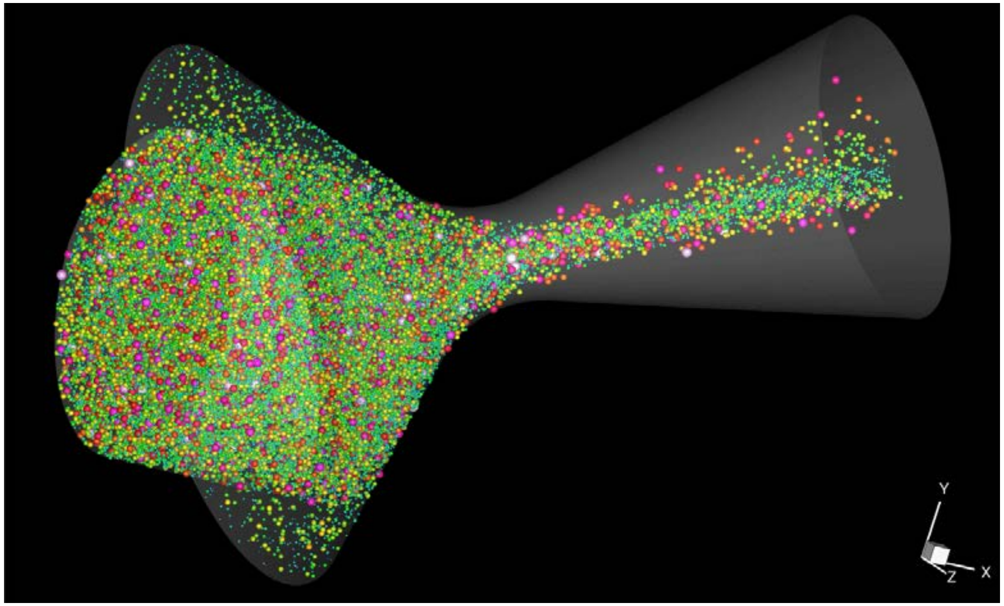
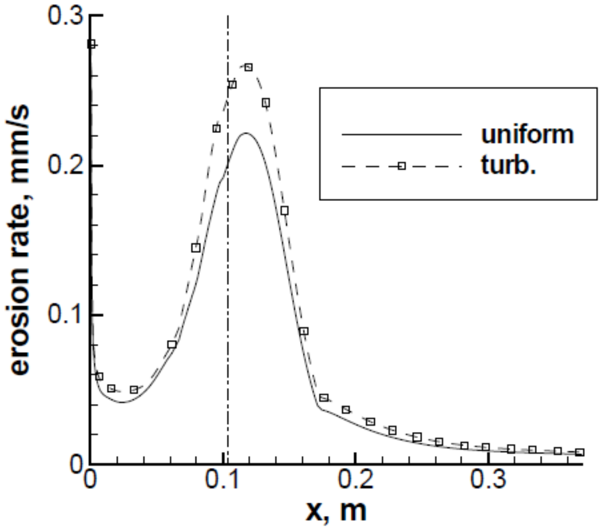


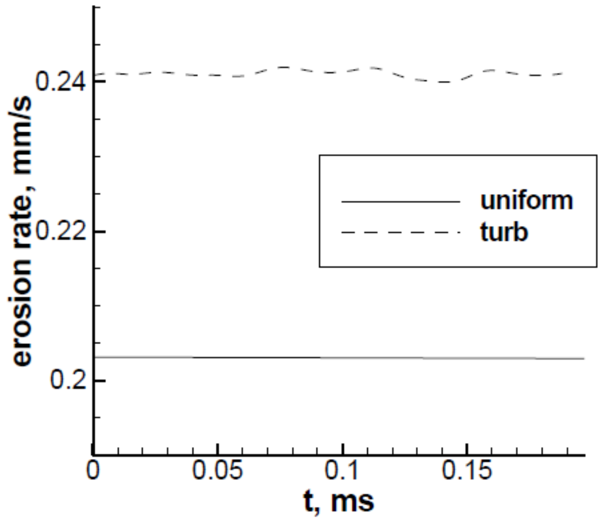
Nozzle Erosion

- **Studied difference between turbulent and uniform injection at nozzle inlet plane**
- **Simulation results without particles show a 20% difference in erosion rates between uniform and turbulent inflow conditions**





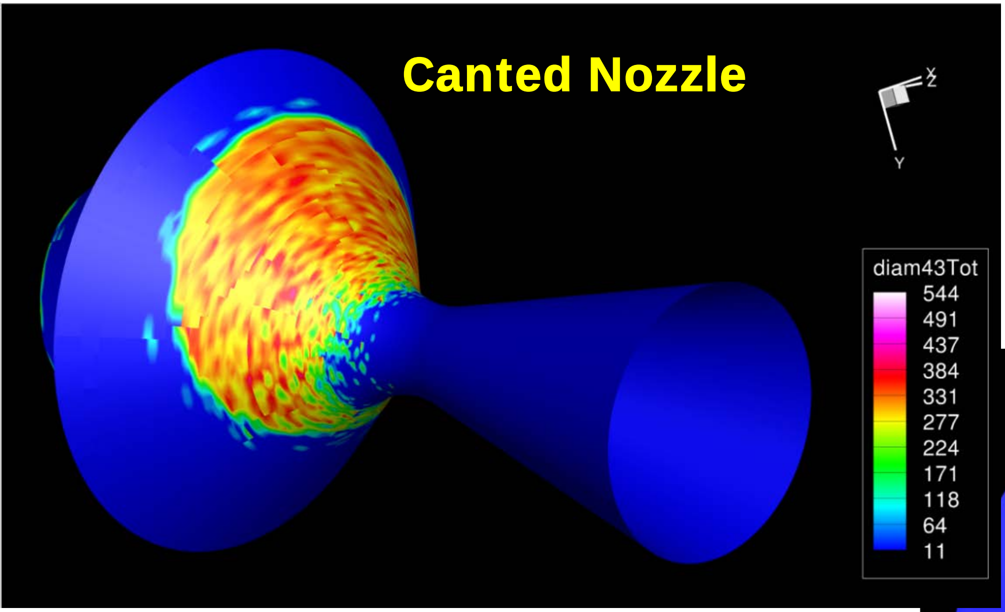
a)



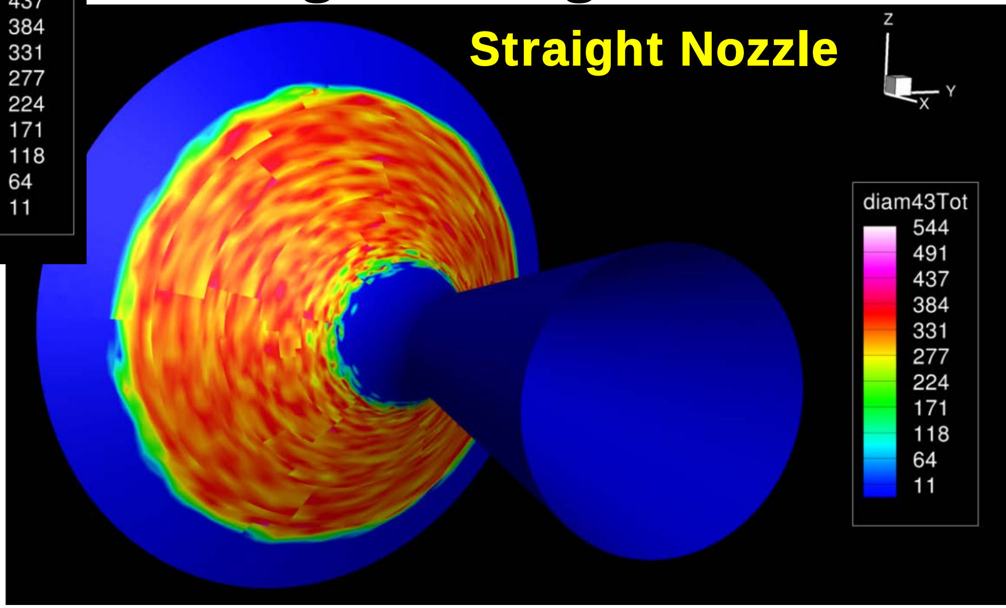
b)

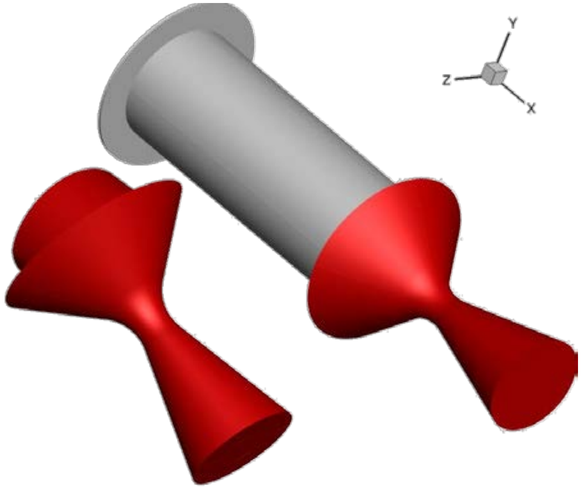
- **Lagrangian particle flow using turbulent inflow conditions**

Comparison Between Straight and Canted Nozzle



Nozzle wall impact statistics very different for 25 degree canted nozzle versus straight-through nozzle





Orion Launch Abort System

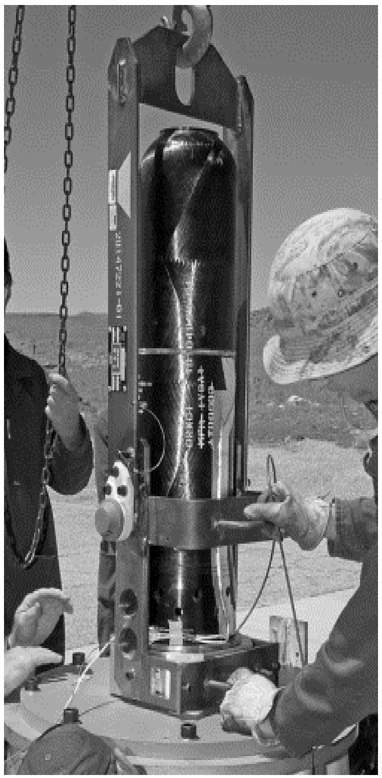
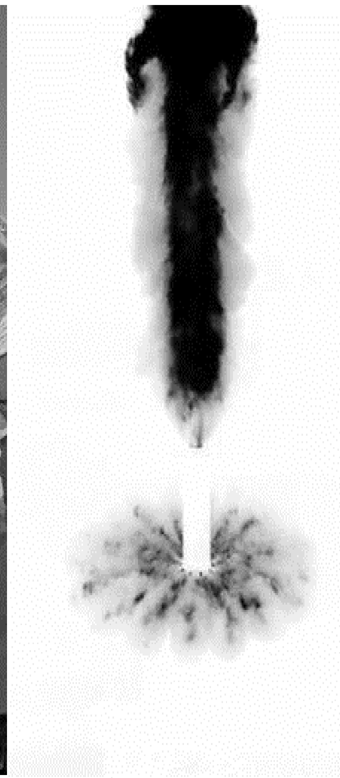
Orion Launch Abort System

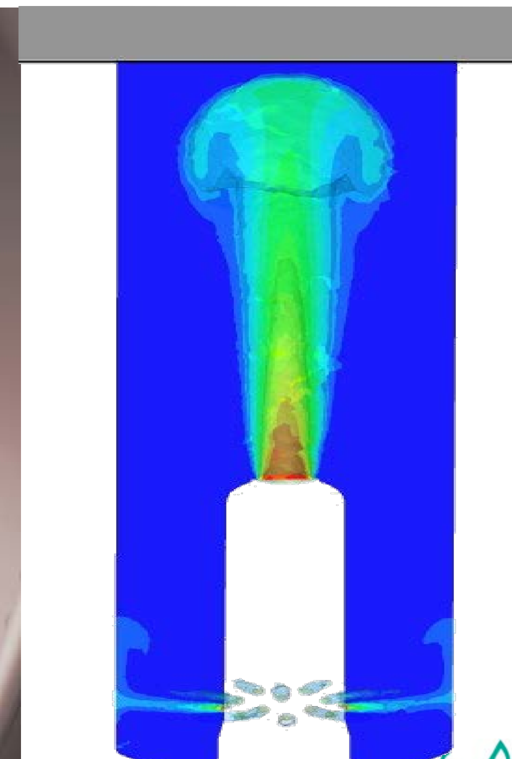
- Motor description
  - NASA designed, ATK built
  - 4 nozzles, thrust reversal
  - ~ .5M lbs thrust, ~14G's!
  - Unique, innovative igniter design
  - Very fast ignition, fast burning
  - 2s main burn, long tail-off
- Model
  - 5M+ elements for Euler
  - No boundary layer
  - Estimated igniter
  - Nominal propellant/gas

ATK Static Test, November 2008

LAS Igniter Modeling

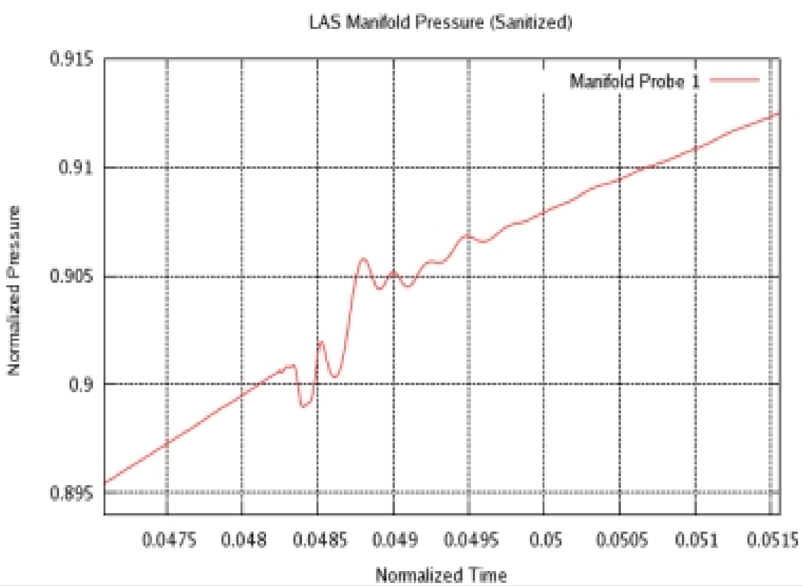
- Igniter modeled from public domain images and information
  - Port geometries estimated from images
  - Gas properties and mass flux tuned to match publicly released info

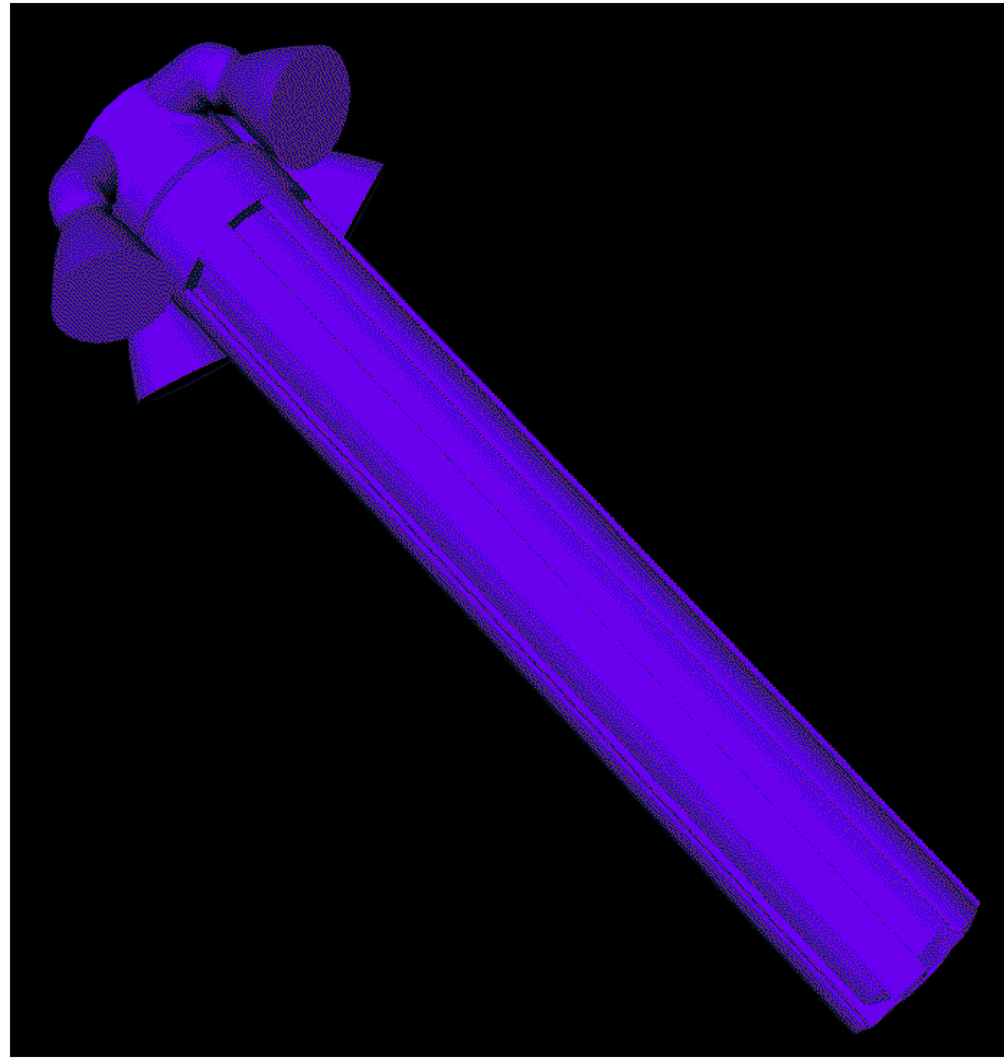





Rocstar Simulation of the LAS

- Euler with *Rocflu*
- Heavy gas
- 4.7M Tets
- Instantaneous ignition
- Zoom factor of 20
- Automated remeshing as needed





Rocstar Simulation vs. ATK Prediction