AEGIS BALLISTIC MISSILE DEFENSE

"Custos Custodum Ipsorum"
Guard of the Guardians, Themselves

Computational Analysis of Vehicle Break-up

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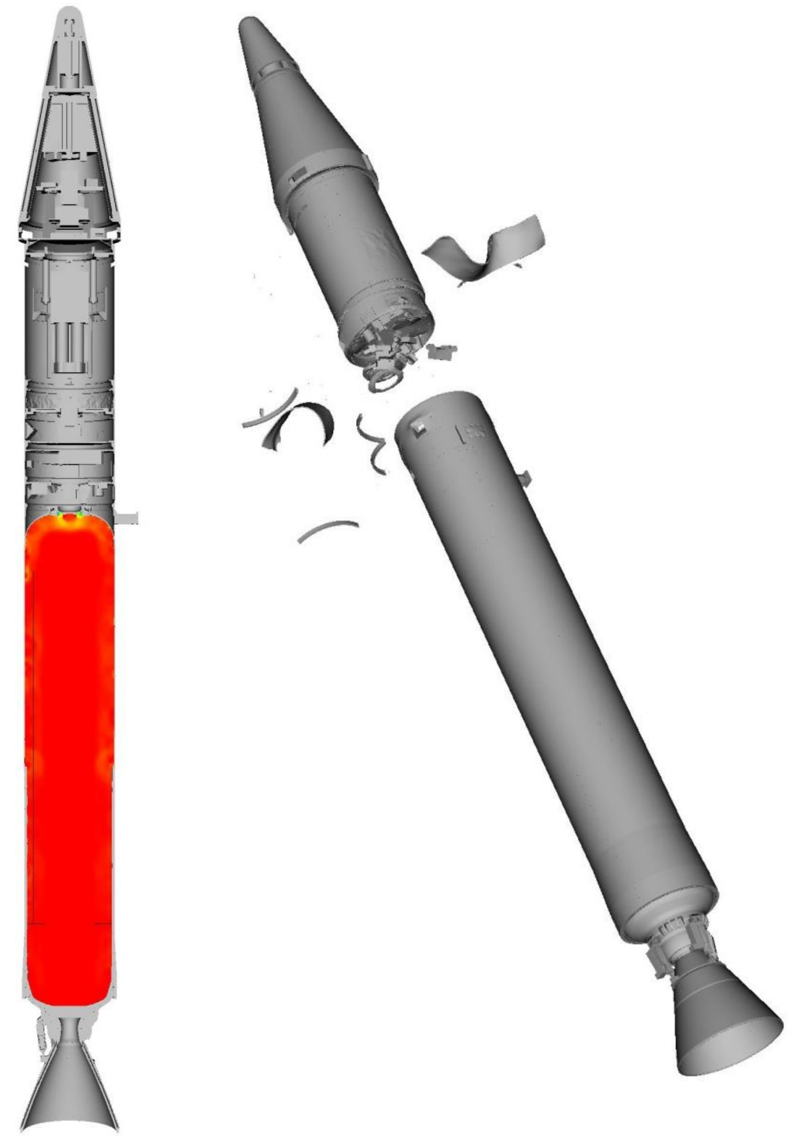
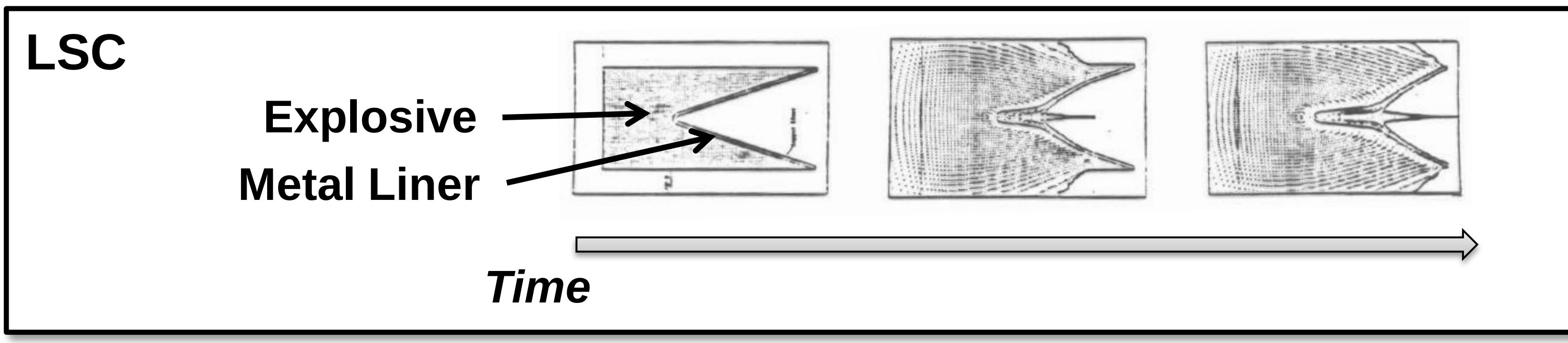


Analysis Overview

Flight Termination System (FTS):

- Used to cut thrust when vehicle control has been lost
- Linear Shape Charge (LSC) used to cut a hole in the motor dome



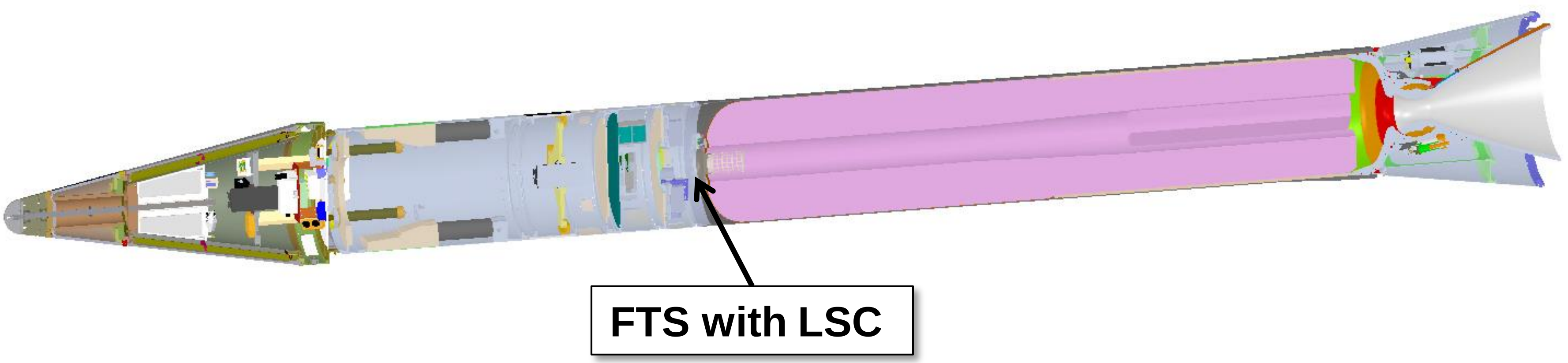
- Exhaust gases escape through the forward end of the motor
- Zero thrust achieved
- Escaping gases launch detached portion of motor dome forward
- Exhaust gases pressurize the vehicle structure
- Vehicle break-up ensues

Analysis Overview

Aegis BMD

Objective:

- **Simulate FTS initiation with LSC assembly**
- **Predict debris formation resulting from**
  - **Break-up of motor casing**
  - **Impact of motor dome fragments on other vehicle components**
  - **Exhaust gas pressure**
- **Determine debris footprint after flydown**



Numerical Approach

<u>Eulerian</u> *(Pressurized Exhaust Gas)*

- Large deformations w/out mesh tangling
- Material interfaces not tracked precisely
- Breaks down late in time (~1 millisecond)
- Relatively computationally expensive

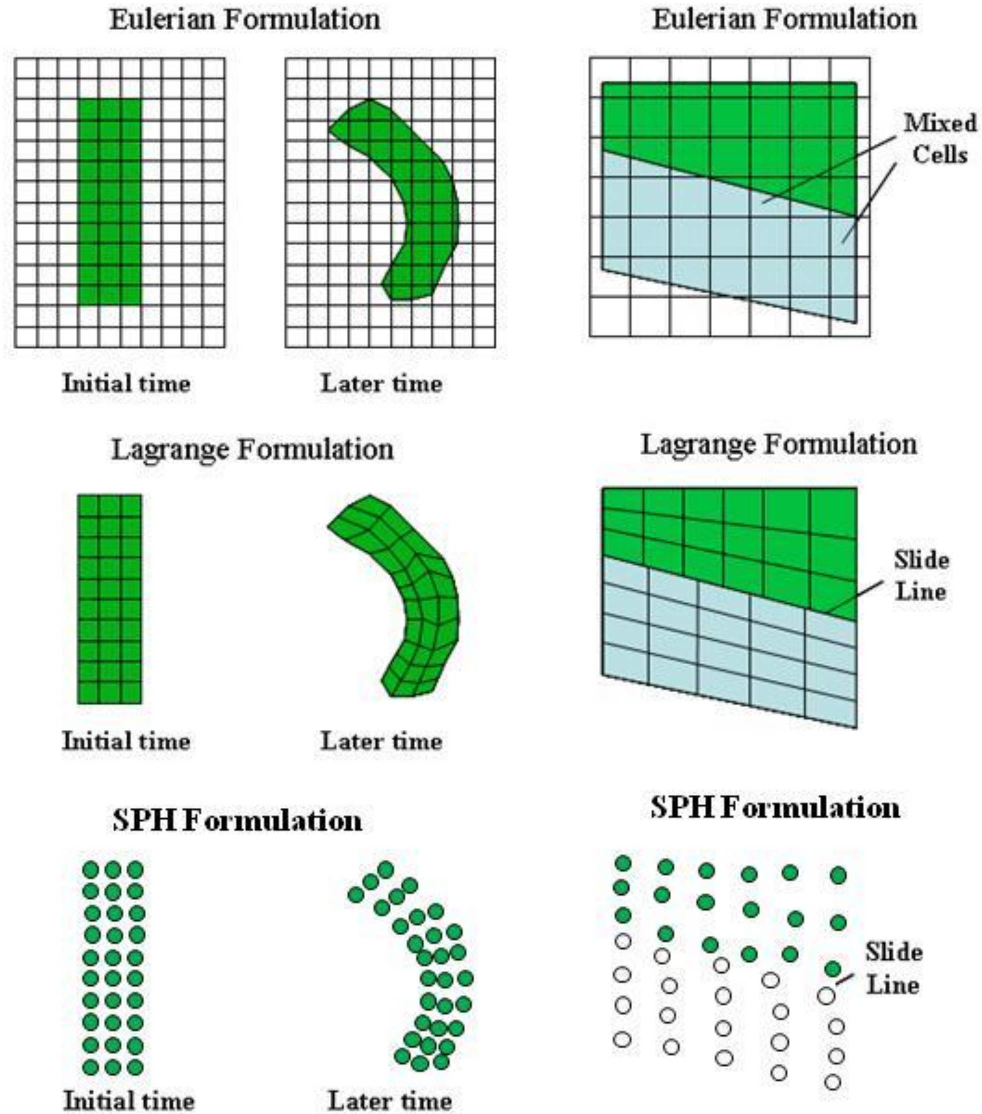
<u>Lagrangian</u> *(Vehicle Structure)*

- Computationally efficient
- Precise material interfaces
- Well suited for late-time analysis (seconds)
- Mesh entanglement issues (cell deletion)

<u>SPH</u> *(Vehicle Fragments and LSC)*

- Mesh-free Lagrangian (no entanglement)
- Continuum of "neighboring" particles

Simulation Requires Coupling of All Three Numerical Techniques



Numerical Approach

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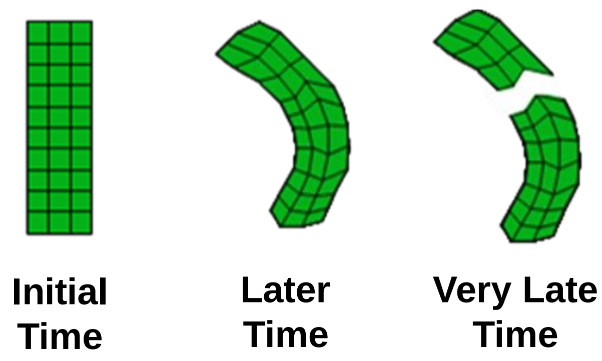
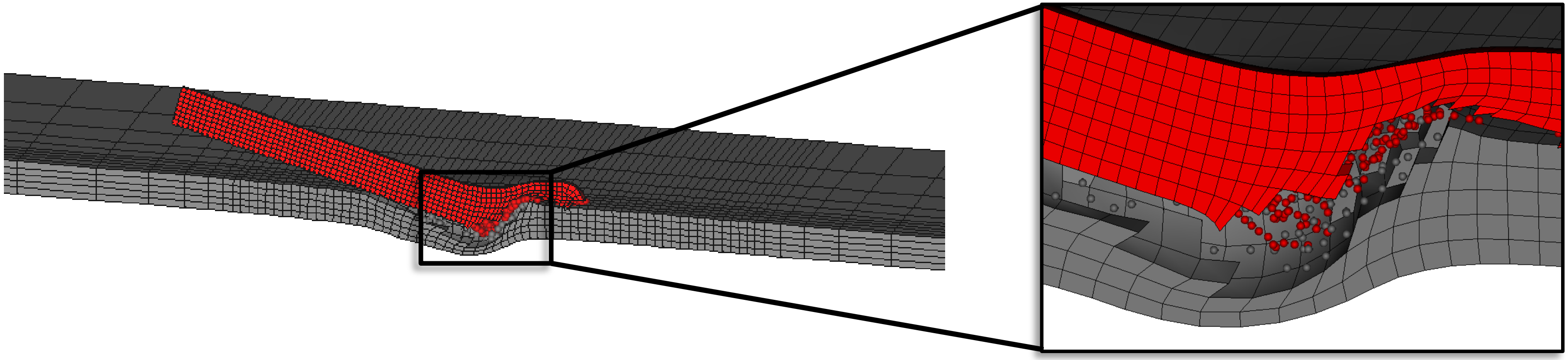
Limitation of Traditional Lagrangian Solvers:

- **Severe deformation causes mesh entanglement**
- **Requires element deletion to stabilize numerics**
  - ➢ ***Violates Conservation Laws***



Solution Using Advanced Numerics:

- **Convert highly deformed elements to particles that carry the same mass/momentum**
  - ➢ ***Obeys Conservation Laws***



Inclusion of SPH Allows Lagrangian Calculation to Obey Conservation Laws

Discretization

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- **Lagrangian mesh generated from 3D CAD**
  - Hexahedral elements
  - Structural features simplified to remove unimportant details and improve mesh uniformity
  - Average element edge length: 3mm
- **Eulerian mesh generated during analysis using adaptive mesh refinement (AMR)**
  - Domain includes entire vehicle
  - Flooding routine used to pressurize the rocket motor
- **SPH particles generated as needed**
  - All SPH particles are generated using an element conversion routine in this case

Discretization

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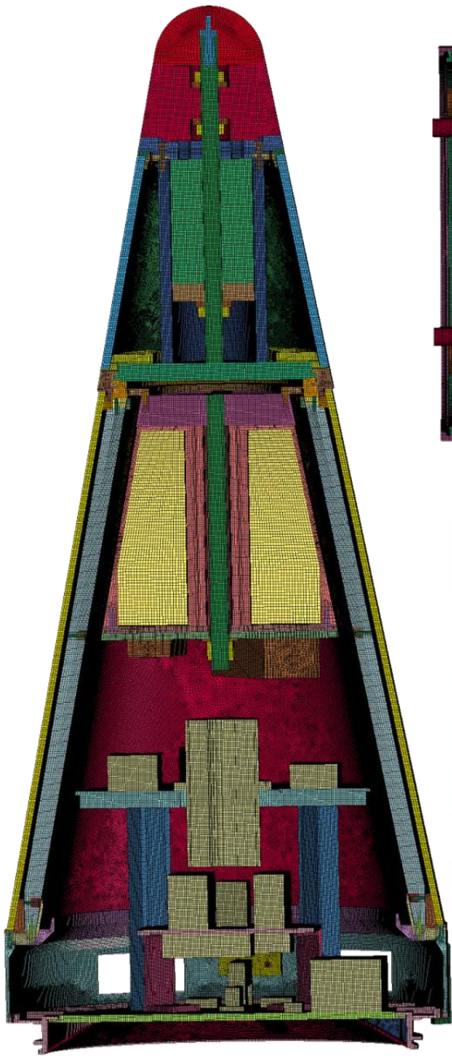
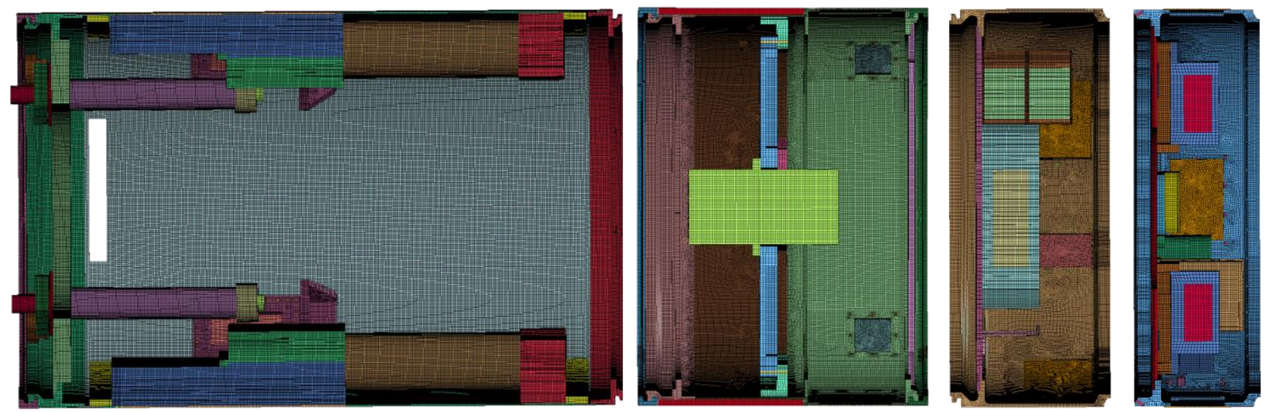
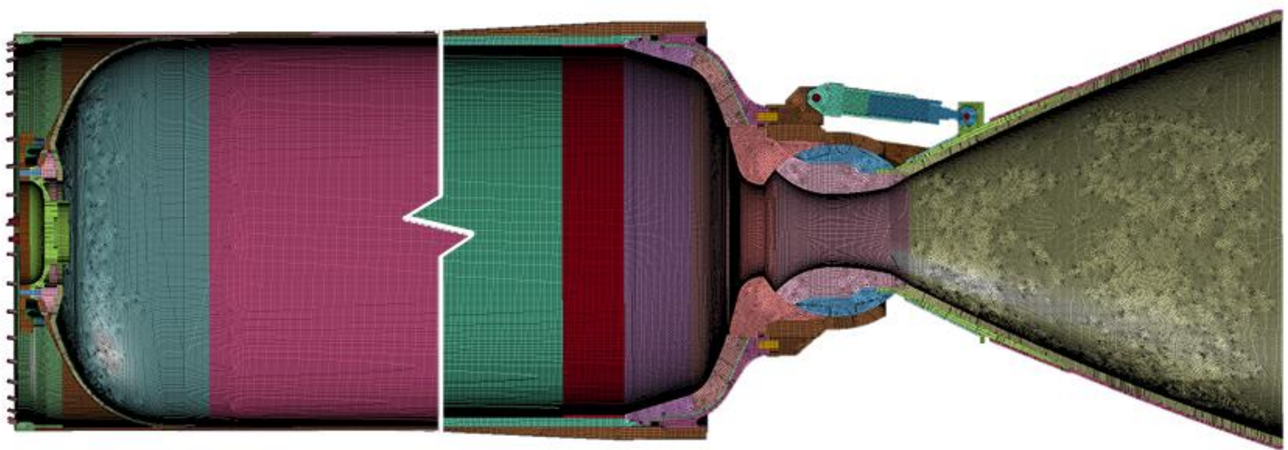
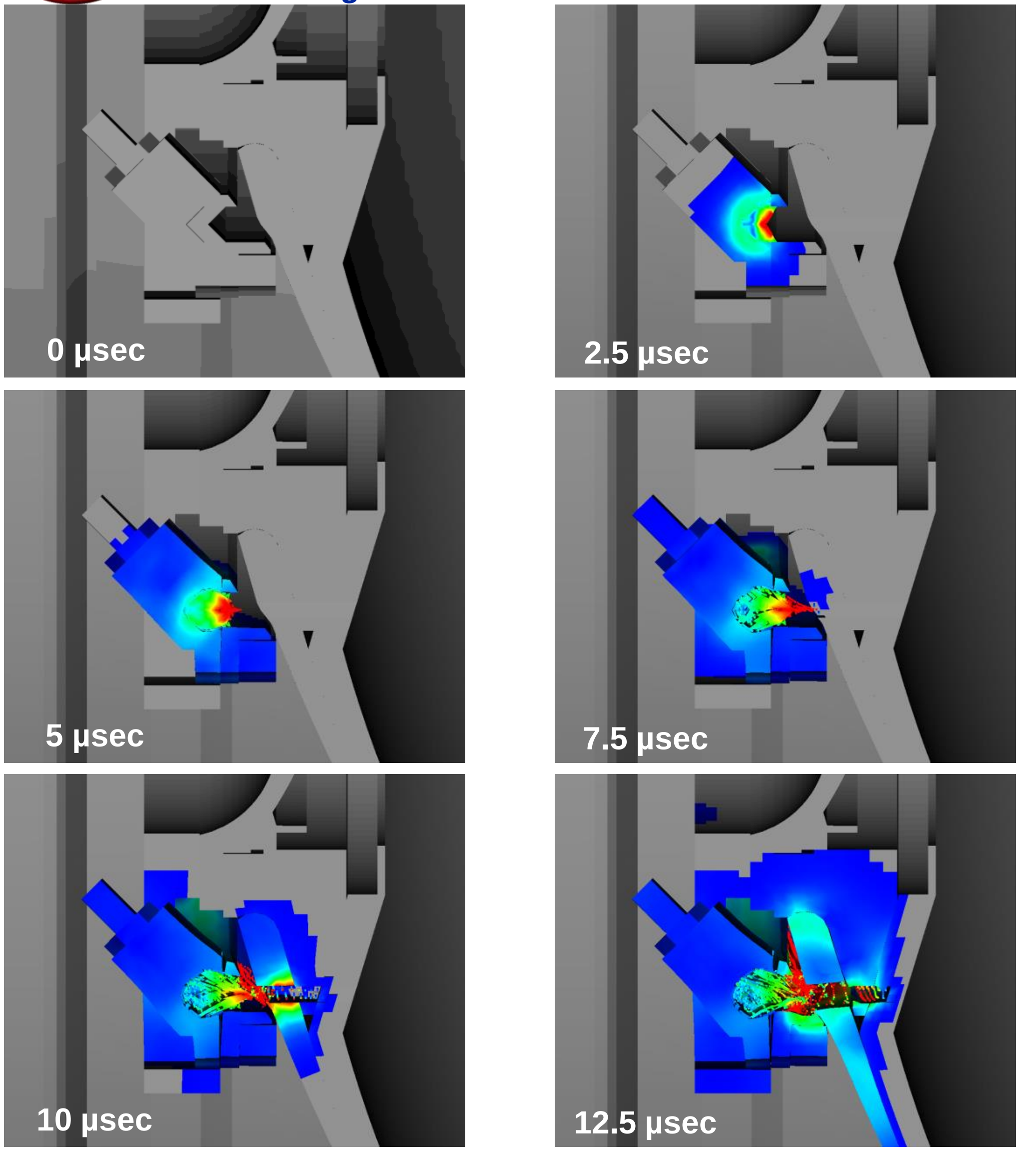
Total Lagrangian Element Count: **13,562,816**







FTS Deployment



- LSC detonated at max pressure
- Dual detonators are modeled
- SPH particles used to approximate LSC cutting action
- After chamber material is cut, pressure escapes, generating debris

FTS Deployment

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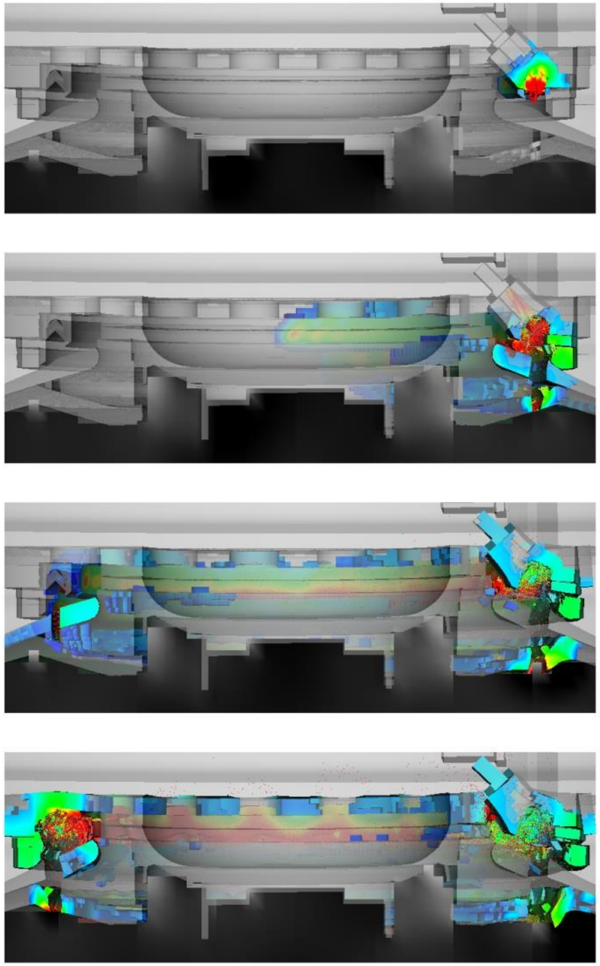
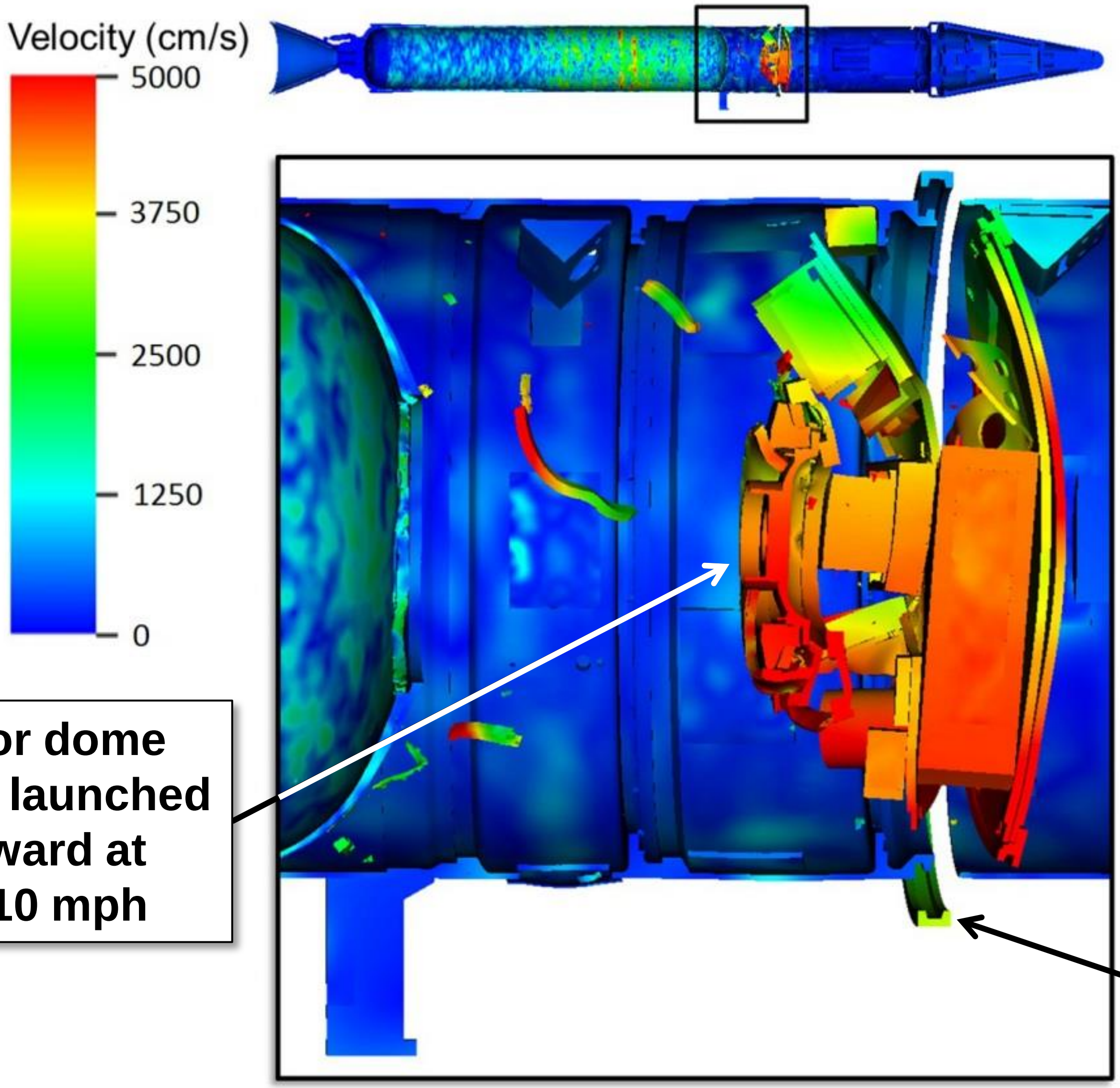


FTS Deployment

Aegis BMD



Motor dome center launched forward at ~ 110 mph

Separation occurs at manacle ring

FTS Deployment

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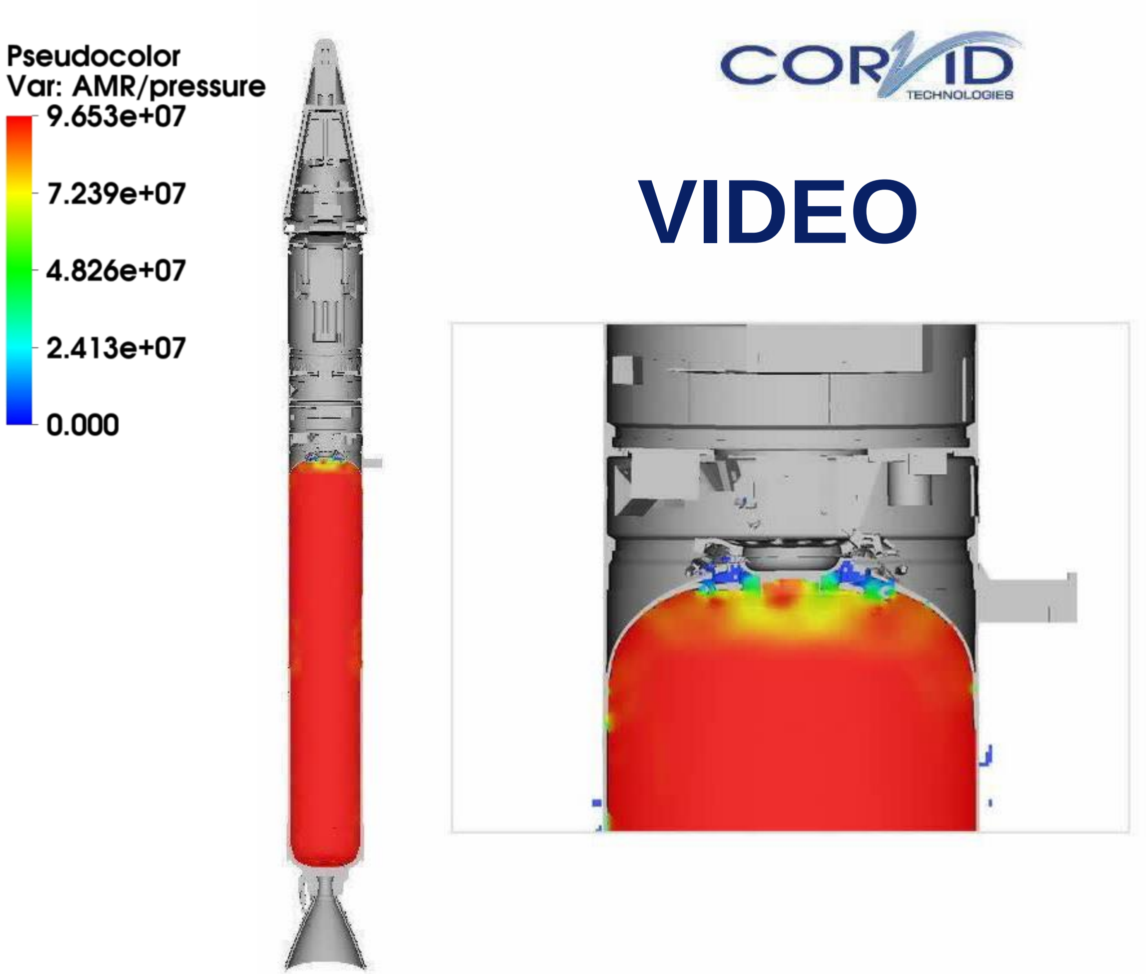
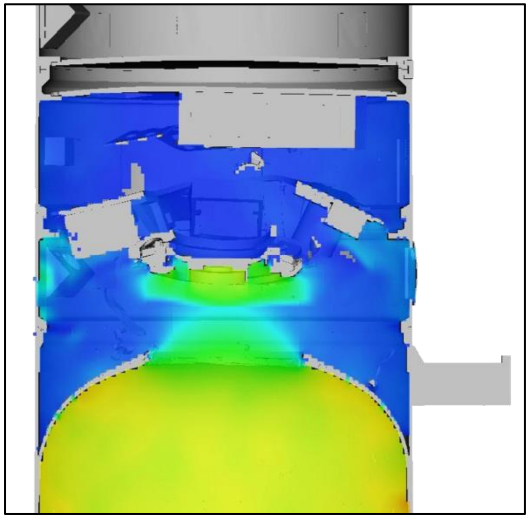


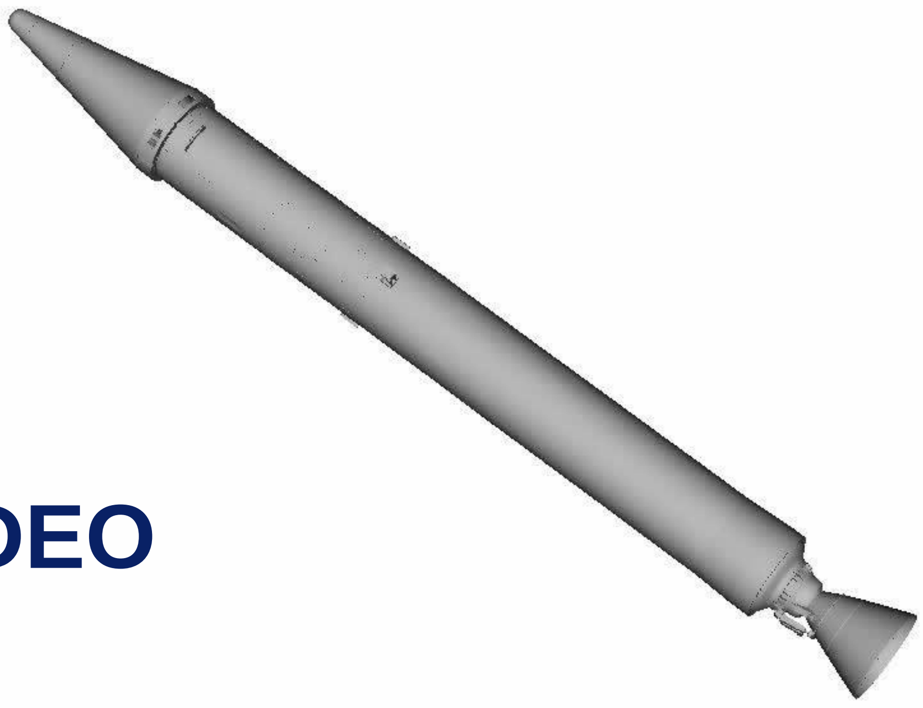
t = 2.7ms

Pressurized gas fills vehicle interior



Motor dome center launched toward forward end of vehicle

Debris Formation



VIDEO

Debris Generation

Final Debris Scene

Flydown: Trajectories

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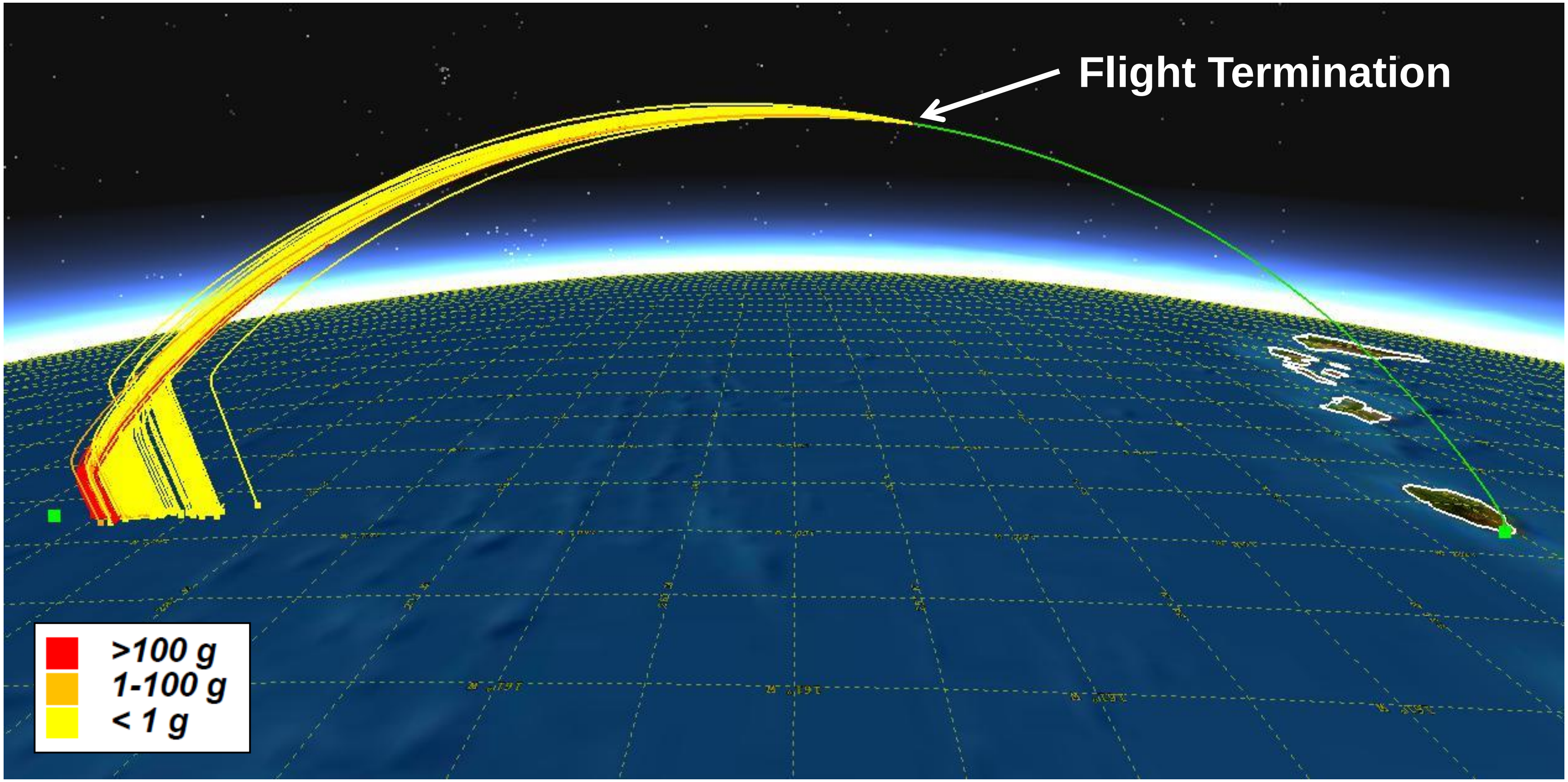

- Notional vehicle and debris trajectories
- 6 DOF rigid body dynamics solver used to calculate trajectories
- Forces and moments calculated from atmospheric properties, debris state, detailed geometry, and fast-running aero model

Flydown: Hazardous Debris

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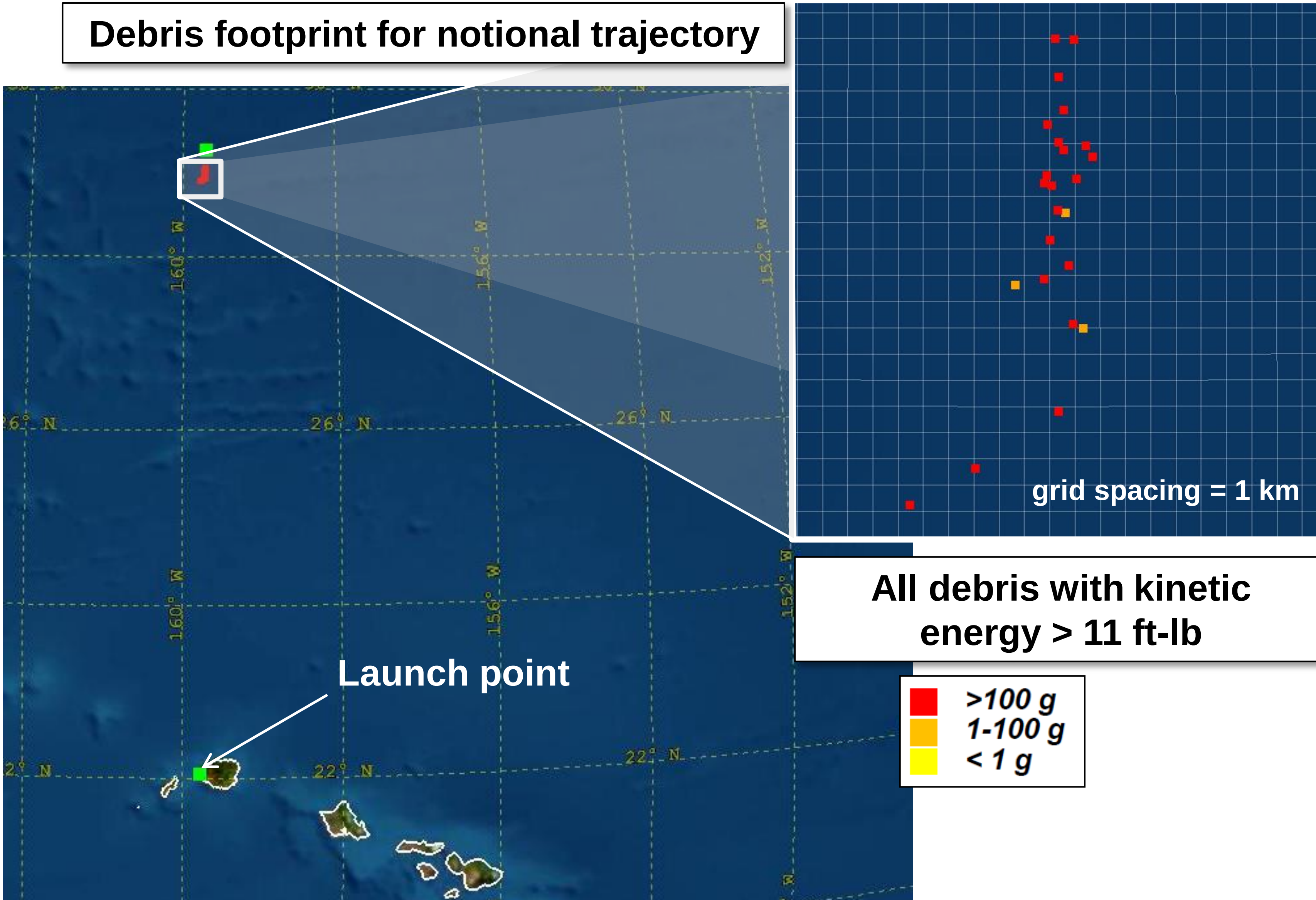

Concluding Remarks

- Vehicle break-up and debris flydown successfully simulated
- Coupled interactions between vehicle structure and propellant gas modeled with coupled Lagrangian/Eulerian framework
- Assumed the majority of the damage results from pressure release
- Future work
  - Temperature effects
  - Solid fuel debris