Multiphysics Prediction Capability for Launch Environment

Modelling the Water-Based IOP/SS System

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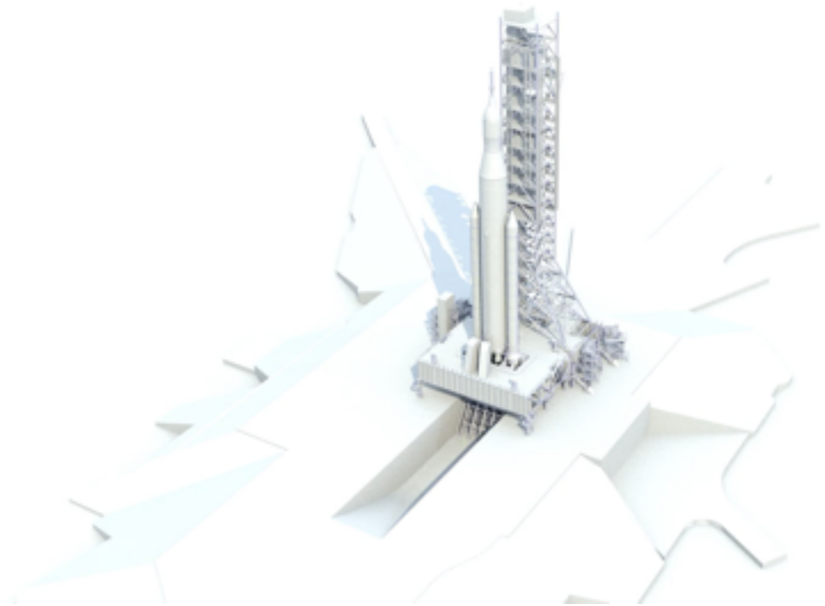
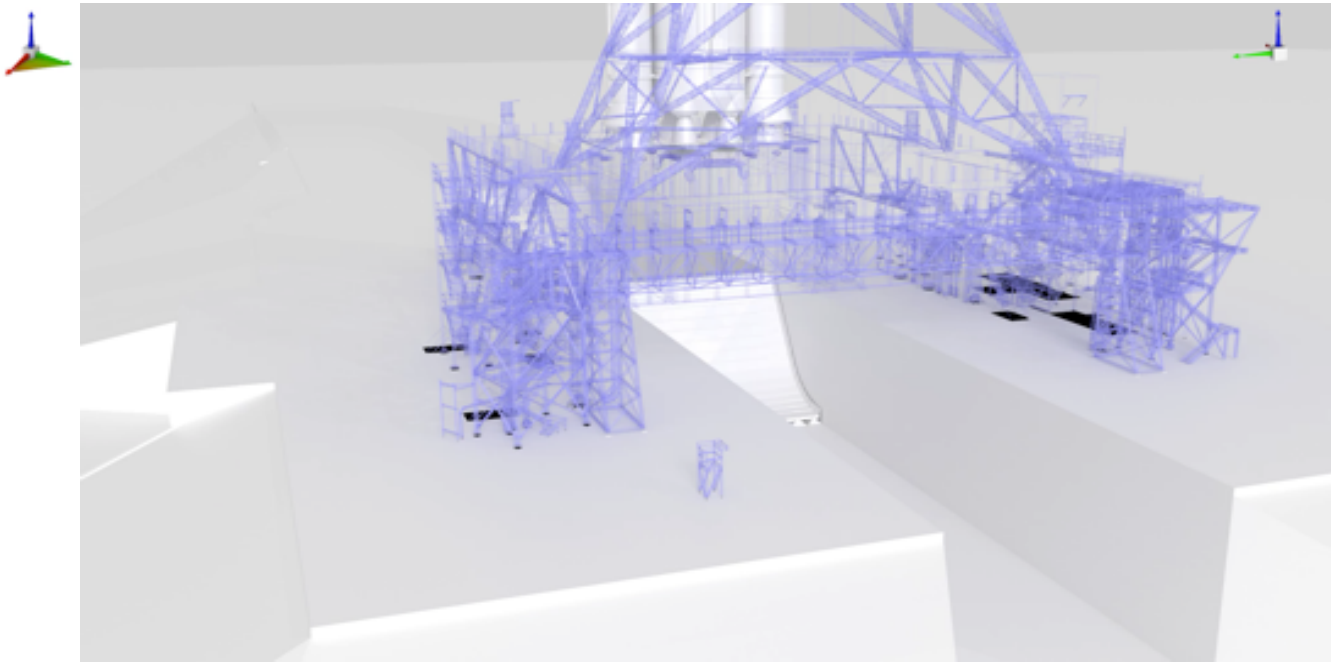
Existing Flame Trench Analysis without IOP/SS system

- Highly accurate numerical scheme for IOP with shocks
- Adaptive mesh refinement for tracking key flow features
- Immersed boundary Cartesian method for highly complex launch pad environment
- Multispecies fluid model for SSME/SRB/Air gases
- Ignores water sound suppression system

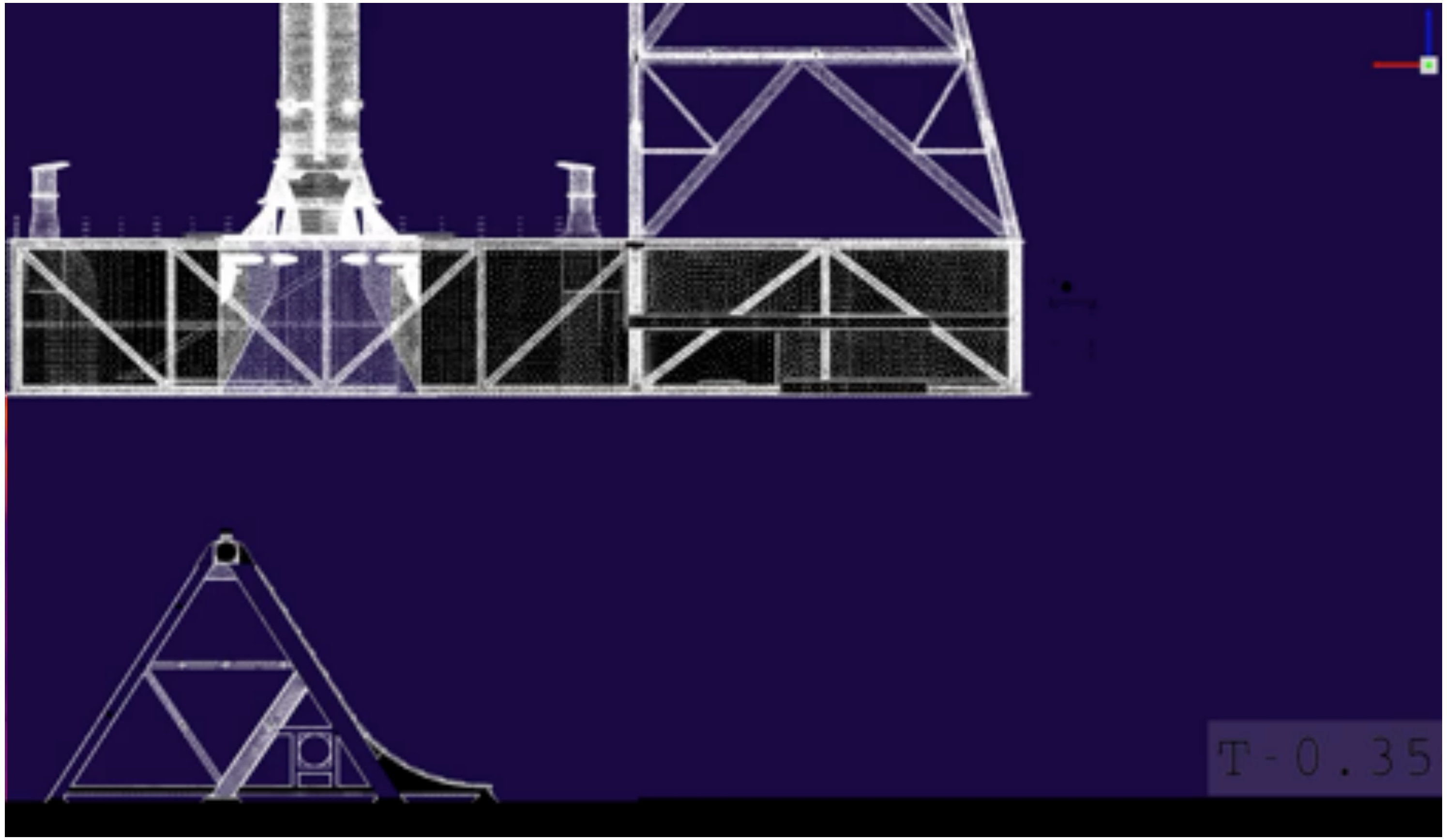




Simulations used for MFD gap analysis. (Plume is colored by temperature)

Why do we need to do this?/ How will it benefit KSC, its mission, vision or goals?

- We propose to add the capability to accurately include the effects of the water-based Ignition Overpressure and Sound Suppression (IOP/SS), as well as debris tracking, to assess the risk of damage to the launch vehicle and the KSC infrastructure for a range of configurations.
- With this new capability, the program can reduce schedule risks/conservatism, operations and maintenance costs and improve safety of future launches.



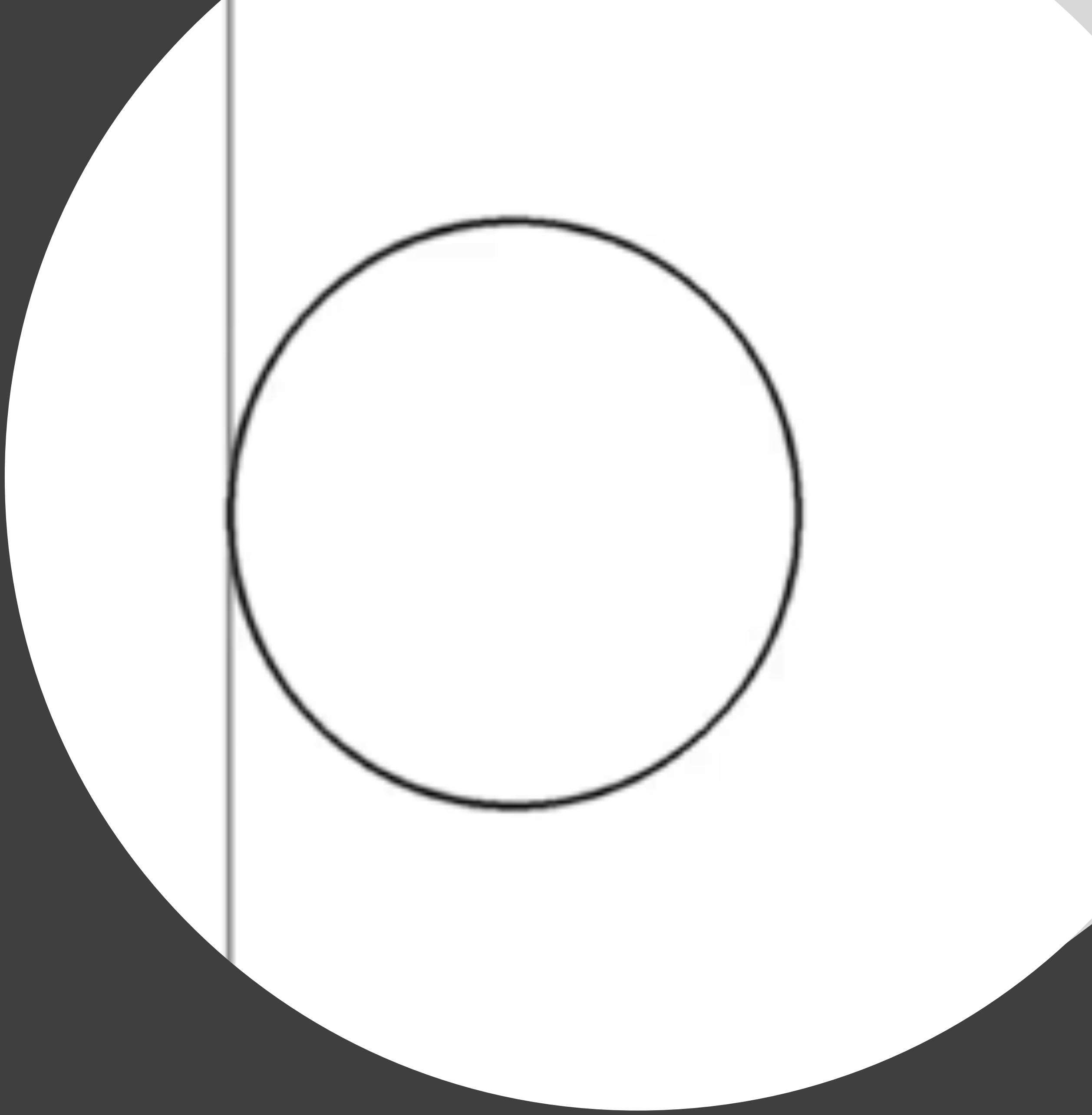
Return on Investment by Reducing Cost and Improving Safety

- Previous work informed flame deflector and ML/tower redesign. Conservative high fidelity CFD analysis was previously used in the absence of water to predict loads. Multiphase analysis is expected to refine estimates and in some cases reduce expected loads and some cases cost.
- Refined estimation of acoustic environment by including water effects leads to more accurate prediction of loads on the vehicle, ML, tower, and flame trench.
- Debris transport analysis in/near plumes follows naturally from a multiphase approach where the fluid dynamics is better represented, potentially further reducing cost.

Progress Towards Simulating IOP/SS using the LAVA CFD Solver

Build into existing LAVA solver as follows:

- Improve the robustness of current high-order shock capturing numerical schemes for strong discontinuities
- Implement multicomponent/multiphase equations such as Kapila's five-equation model
- Add suitable equation of state (EOS) such as stiffened-gas EOS for liquid water
- Add phase transition model for water
- Apply to KSC's flame trench

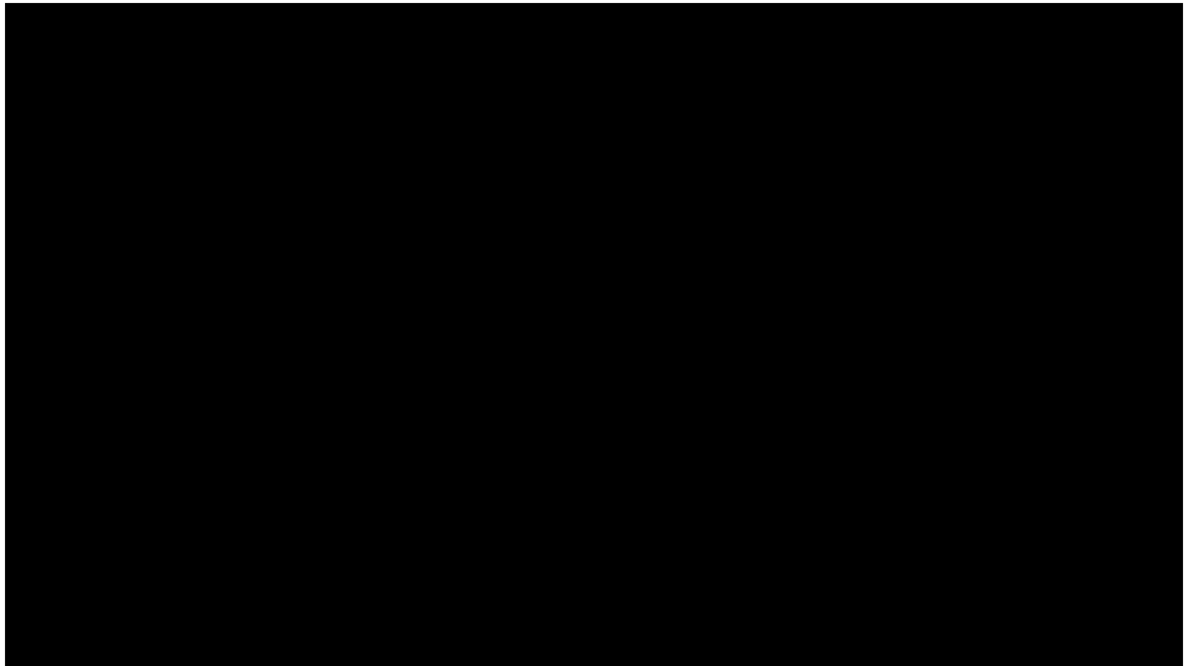


- *Test case of Mach 3 shock on stationary water column. (blue is water vapor, grey is density gradient)*

Previous Work

Recent Flame Trench Redesign at Kennedy Space Center’s Pad 39B

https://www.youtube.com/watch?v=9matDigB2w4



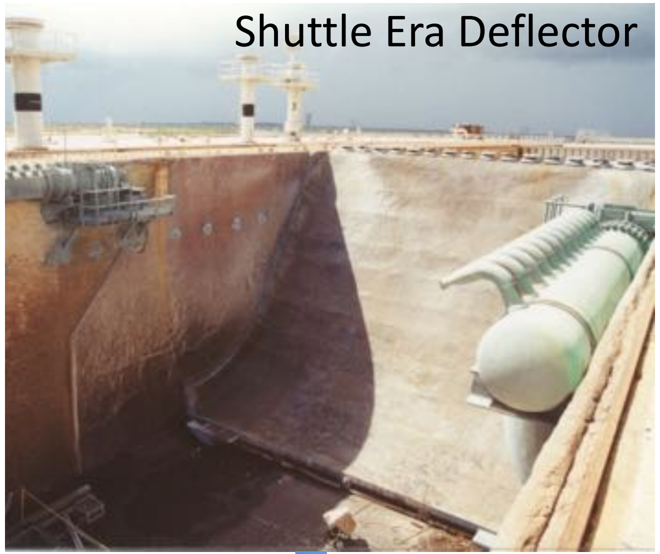
After many years of harsh rocket launches, the Main Flame Deflector (MFD) at Kennedy Space Center has been upgraded in anticipation of flights of NASA’s next generation Space Launch System.

The new MFD has a much easier to maintain shingled steel surface.

Recent Flame Trench Redesign at Kennedy Space Center's Pad 39B

Gaps between the MFD and the trench wall, and the gaps between the steel plates of the MFD itself could allow hot plume gases and strong acoustic waves to affect structures under the MFD.

A team of experts from the NASA Advanced Supercomputing (NAS) Division was called in to apply high-resolution computational fluid dynamics (CFD) to help identify thermal, pressure, and flow environments on and around the geometrically complex MFD.



LAVA Cartesian Grid Simulations

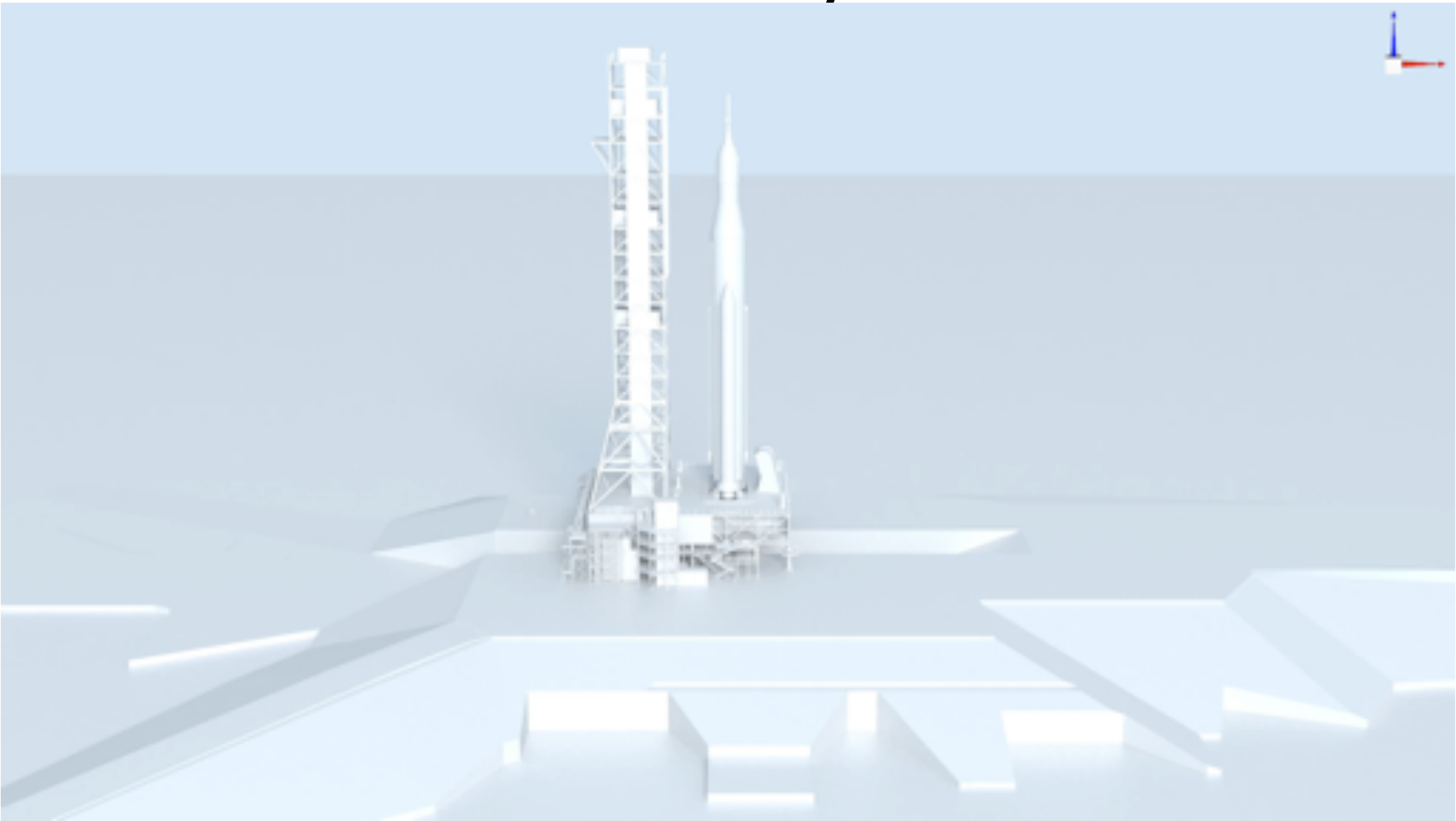
- Significant CAD cleanup and surface mesh generation.
  Kept most detail from as-built CAD.

- LAVA Cartesian computational fluid dynamics:
  - Immersed boundary representation for complex geom.
  - WENO5 high-order space discretization
  - RK4 high-order time discretization
  - Homogeneous mixture model with 3 species: air, SRB, RS-25D (no water)
  - Viscous/thermal boundary layers, combustion, conjugate heat transfer, water, and other effects are not included for the Cartesian simulation. Temperatures are shown to indicate trends. Thermal analysis conducted separately.

- Engine sequence:
  - RS25D Liquide Engines: Steady, radially varying bc is started at T-0.35
  - Solid Rocket Boosters (SRB): Unsteady, radially varying bc is started at T+0

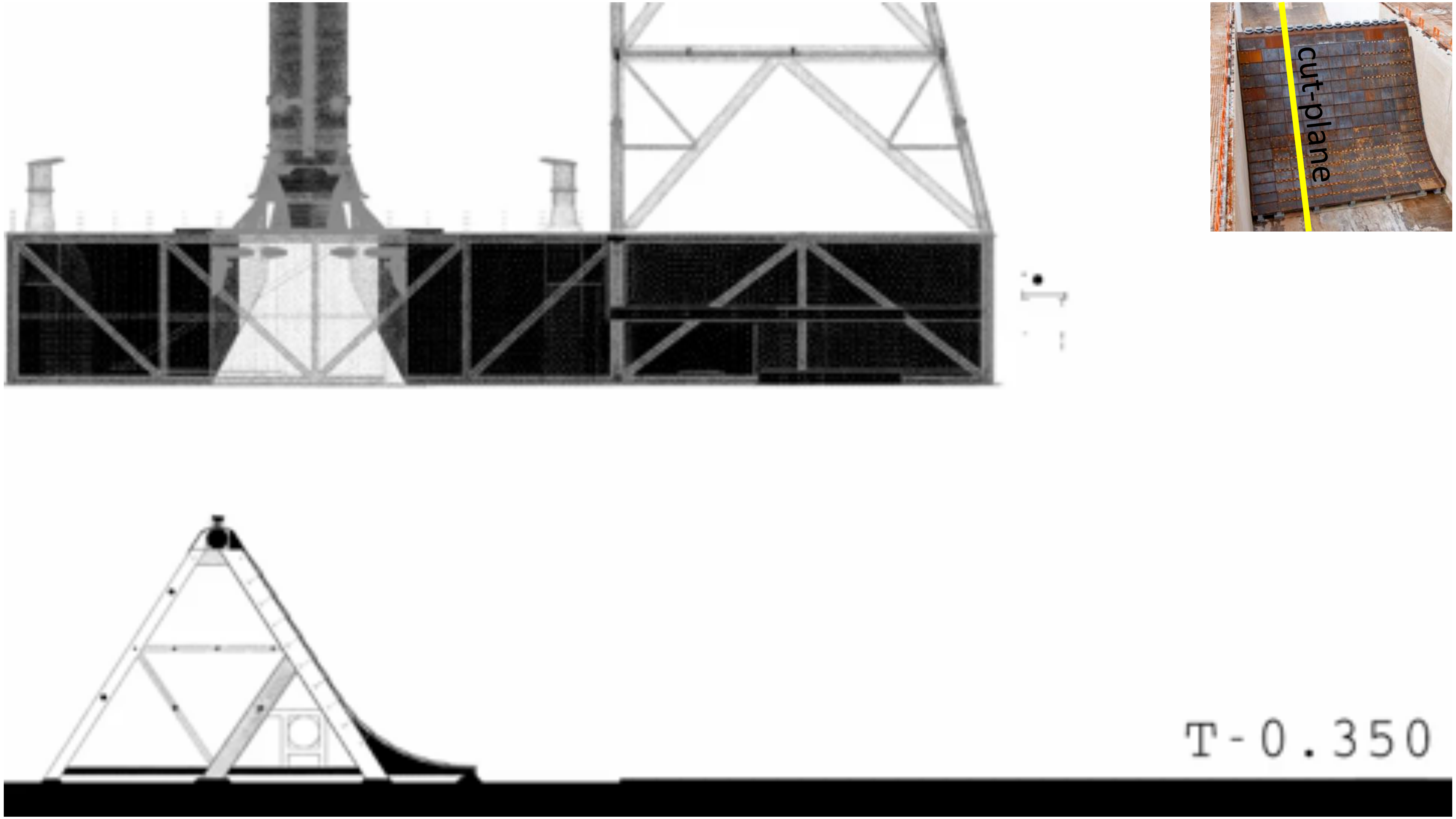
- Simulation is much more complex than our previous Main Flame Deflector (MFD) analysis:
  - Geometric detail is significantly higher, focused on gaps adjoining the MFD
  - Mesh is now 555 million cells vs 200 million previously
  - Timestep is much smaller, due to CFL constraint

Cartesian Grid IOP Simulations: Geometry



Visualization of geometry used in LAVA Cartesian simulation

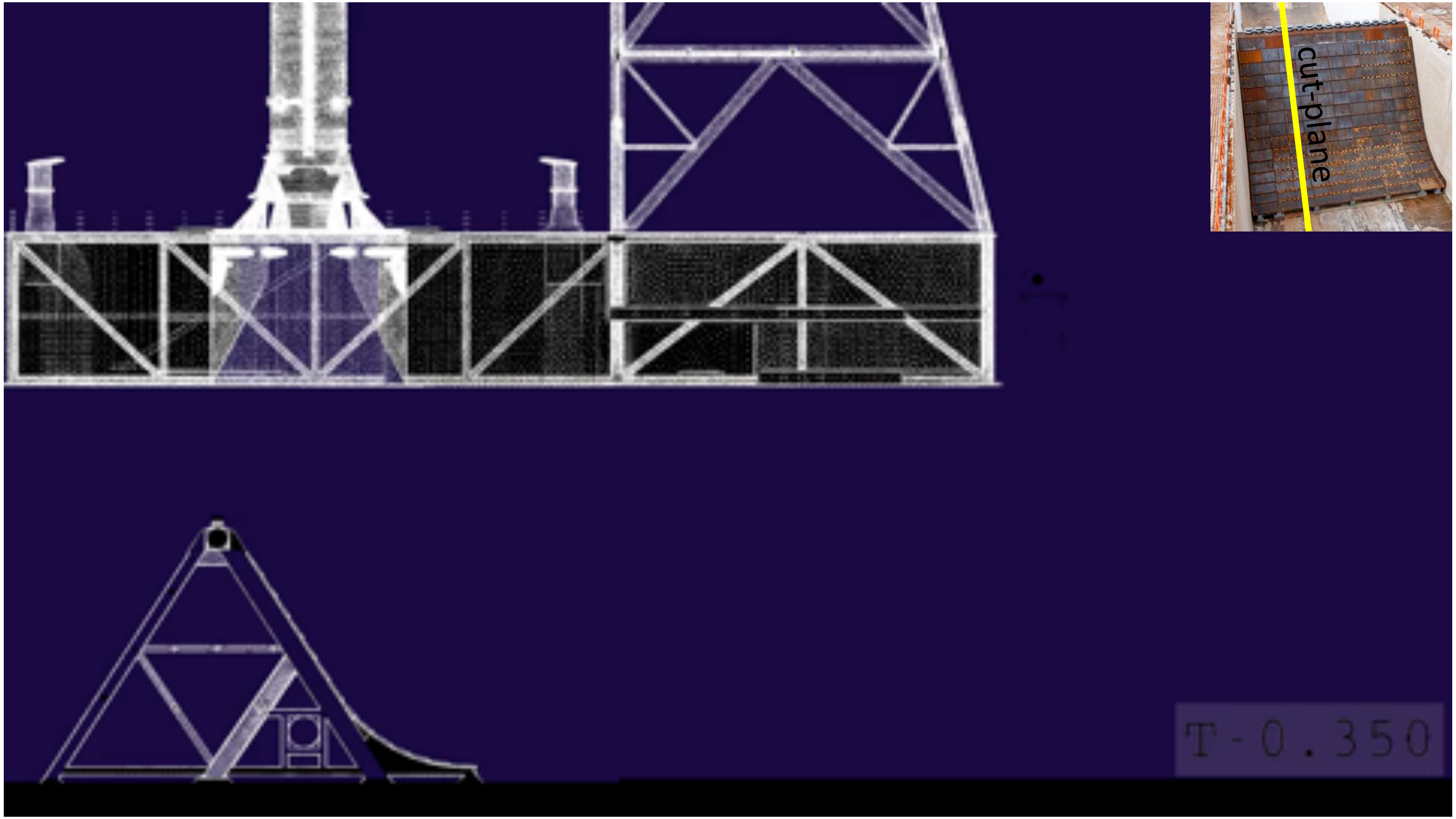
Cartesian Grid IOP Simulations: Flow Visualizations



Pressure cutting plane passing through an SRB centerline

Note: Viscous/thermal boundary layers, combustion, conjugate heat transfer, water, and other effects are not included for the Cartesian simulation.

Cartesian Grid IOP Simulations: Flow Visualizations



Temperature cutting plane passing through an SRB centerline

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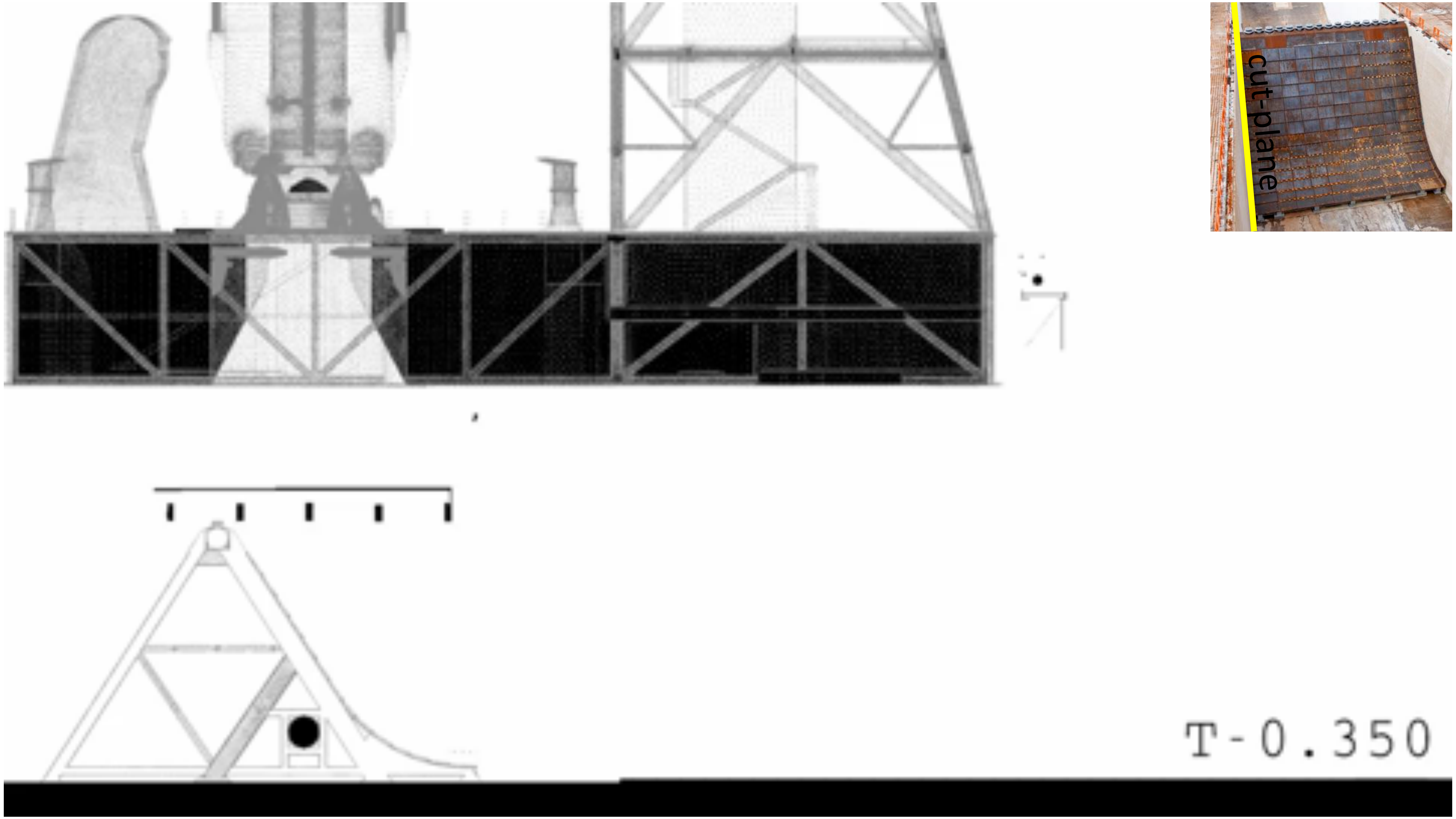
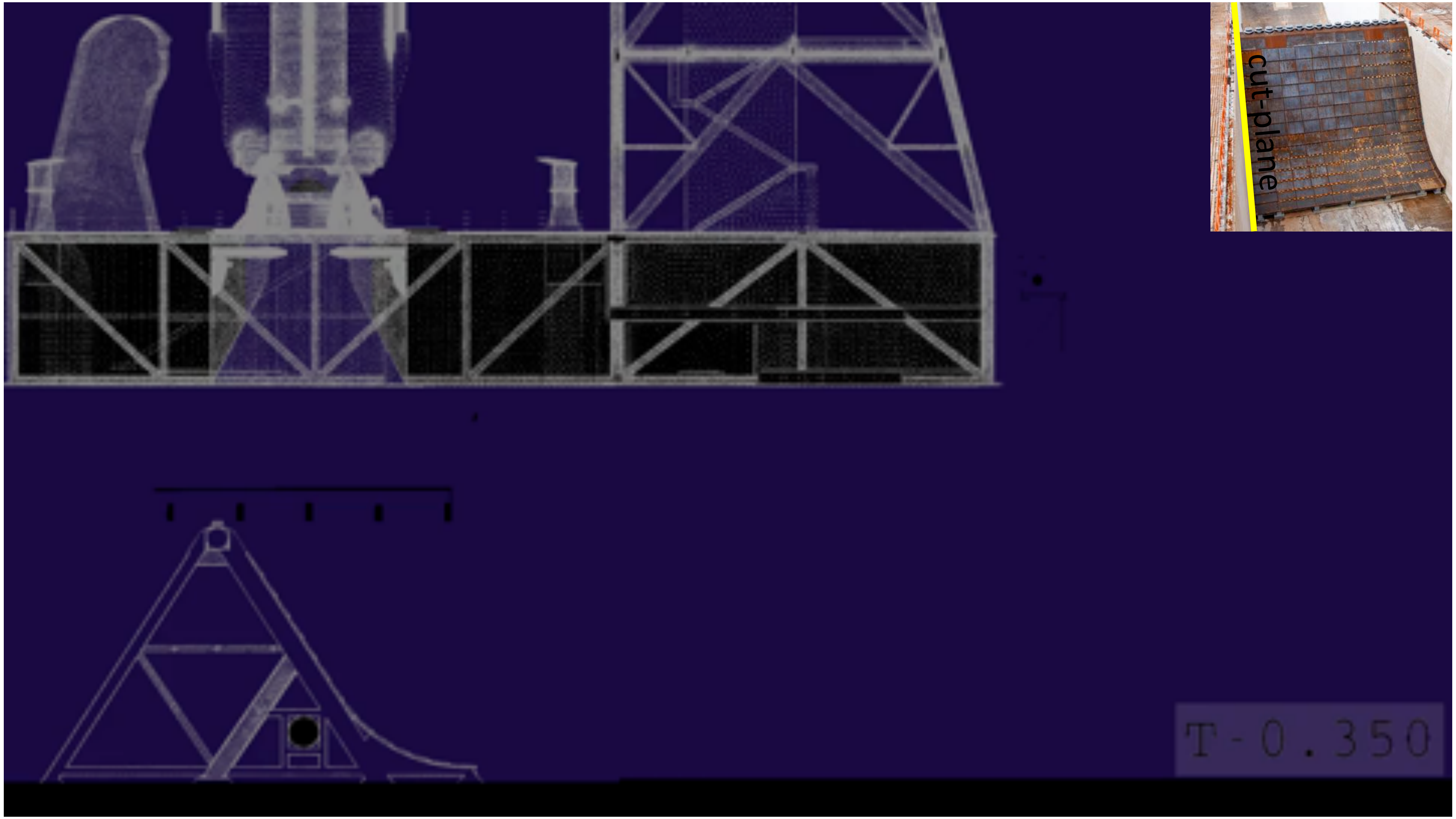
Cartesian Grid IOP Simulations: Flow Visualizations



Pressure cutting plane passing through the MFD/Wall gap

Note: Viscous/thermal boundary layers, combustion, conjugate heat transfer, water, and other effects are not included for the Cartesian simulation.

Cartesian Grid IOP Simulations: Flow Visualizations



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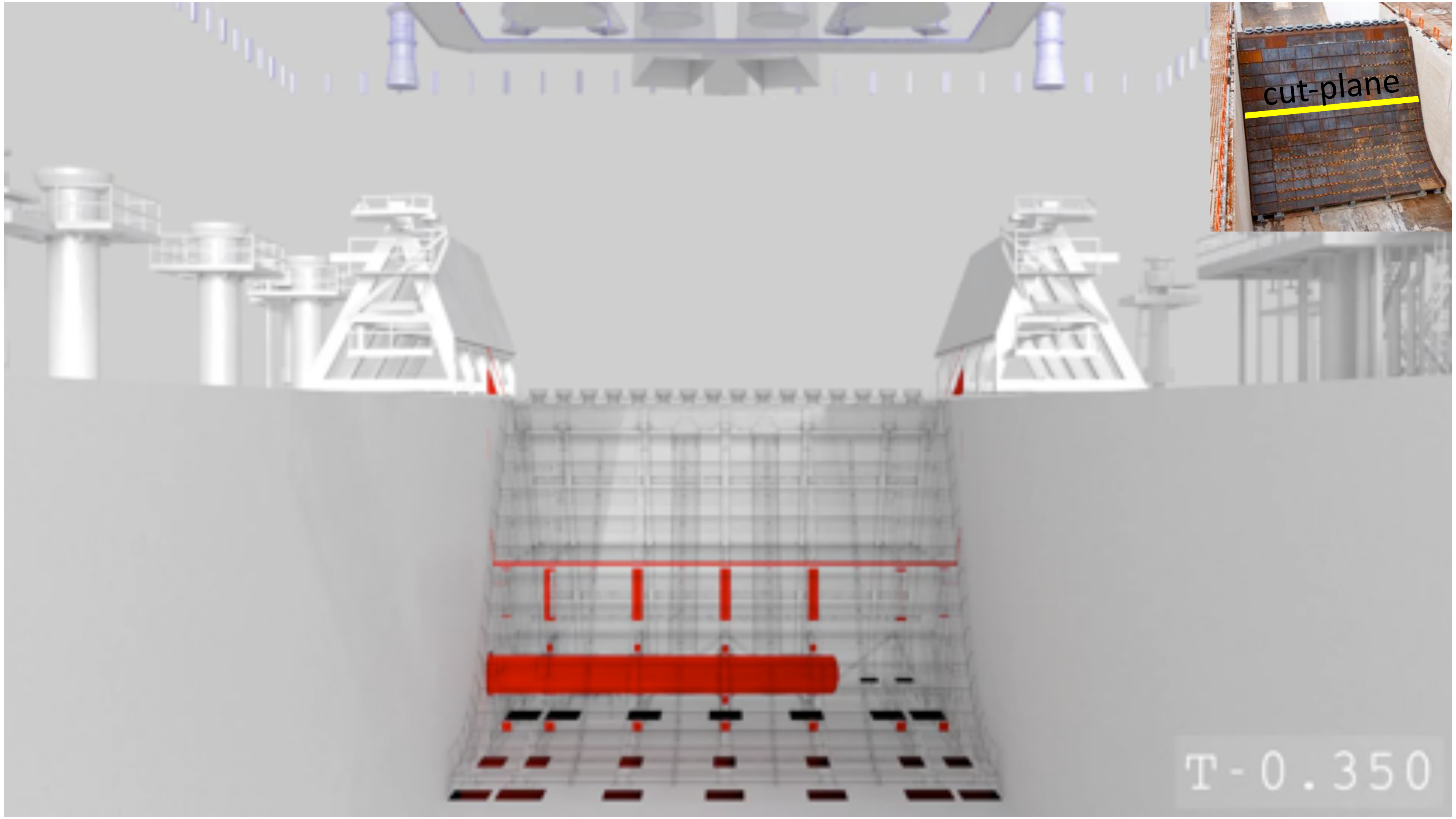
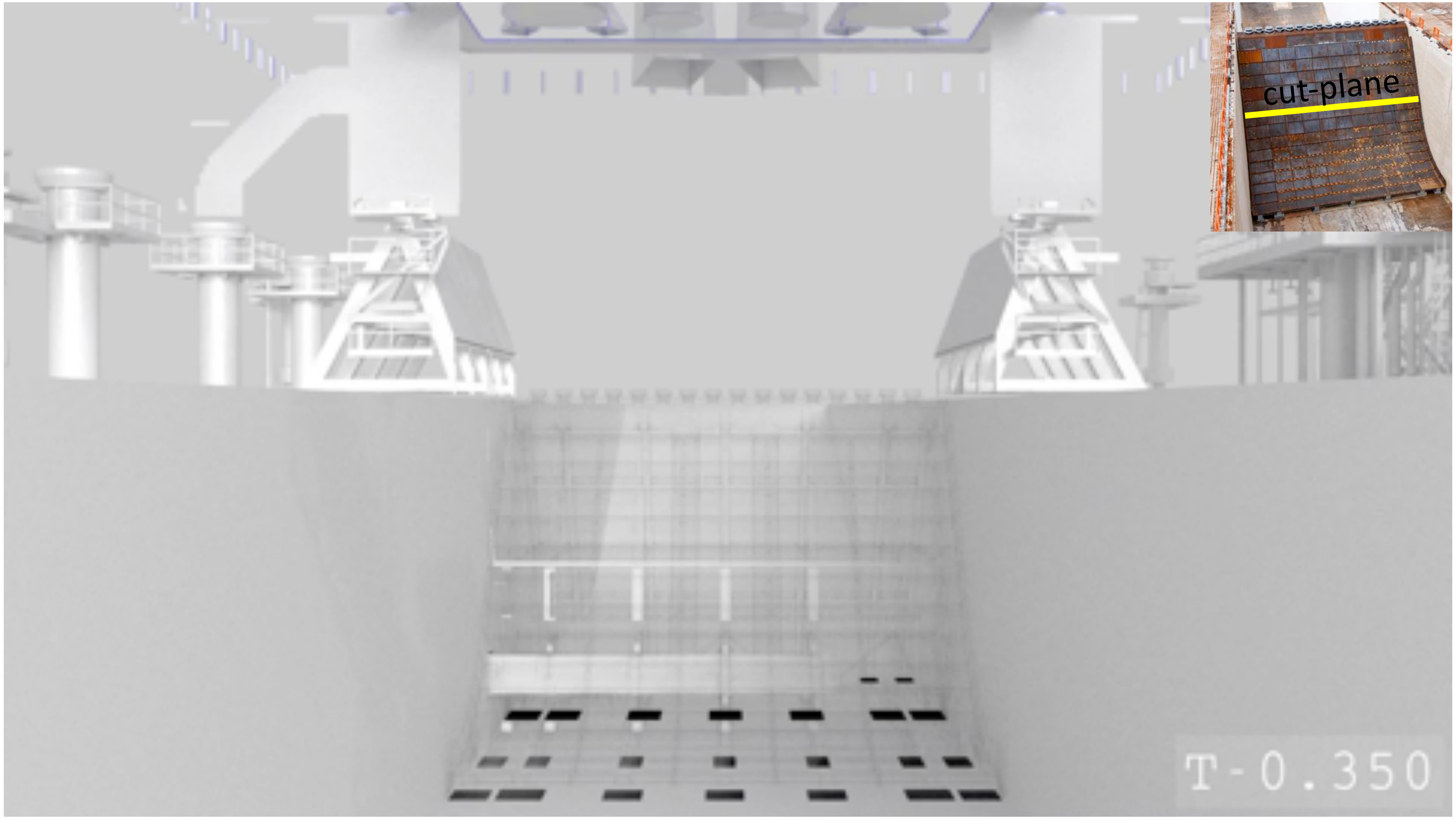
Cartesian Grid IOP Simulations: Flow Visualizations



Pressure cutting plane passing through the SRB centerlines. Plume is clipped.

Note: Viscous/thermal boundary layers, combustion, conjugate heat transfer, water, and other effects are not included for the Cartesian simulation.

Cartesian Grid IOP Simulations: Flow Visualizations



Temperature cutting plane passing through the SRB centerlines. Plume is clipped.

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Cartesian Grid IOP Simulations: Flow Visualizations

Temperature cutting plane passing through an SRB centerline. Plume is clipped. Green people shown for scale.

Note: Viscous/thermal boundary layers, combustion, conjugate heat transfer, water, and other effects are not included for the Cartesian simulation. Temperatures are shown to indicate trends.