National Aeronautics and Space Administration

Analyzing the Space Launch System Debris Environment

Brandon Williams

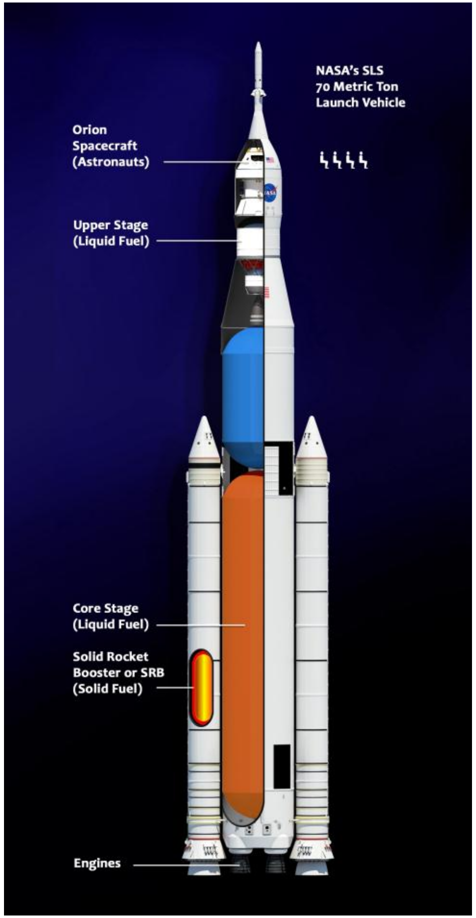
NASA Marshall / Jacobs ESSSA / CFD Research Corp.

Space Launch System

NASA's Space Launch System will be most powerful rocket ever built and enable manned and robotic missions beyond Earth orbit

The first SLS vehicle will carry the Orion spacecraft using

- 4 liquid hydrogen (LH2) / liquid oxygen (LOX) fueled RS-25 engines
- 2 RSRMV solid rocket boosters
- LH2/LOX fueled upper stage (based on Delta IV)



What is the Debris Environment?

The Debris Environment consists of all sources of debris, and the impact energies the debris may impart to the launch vehicle

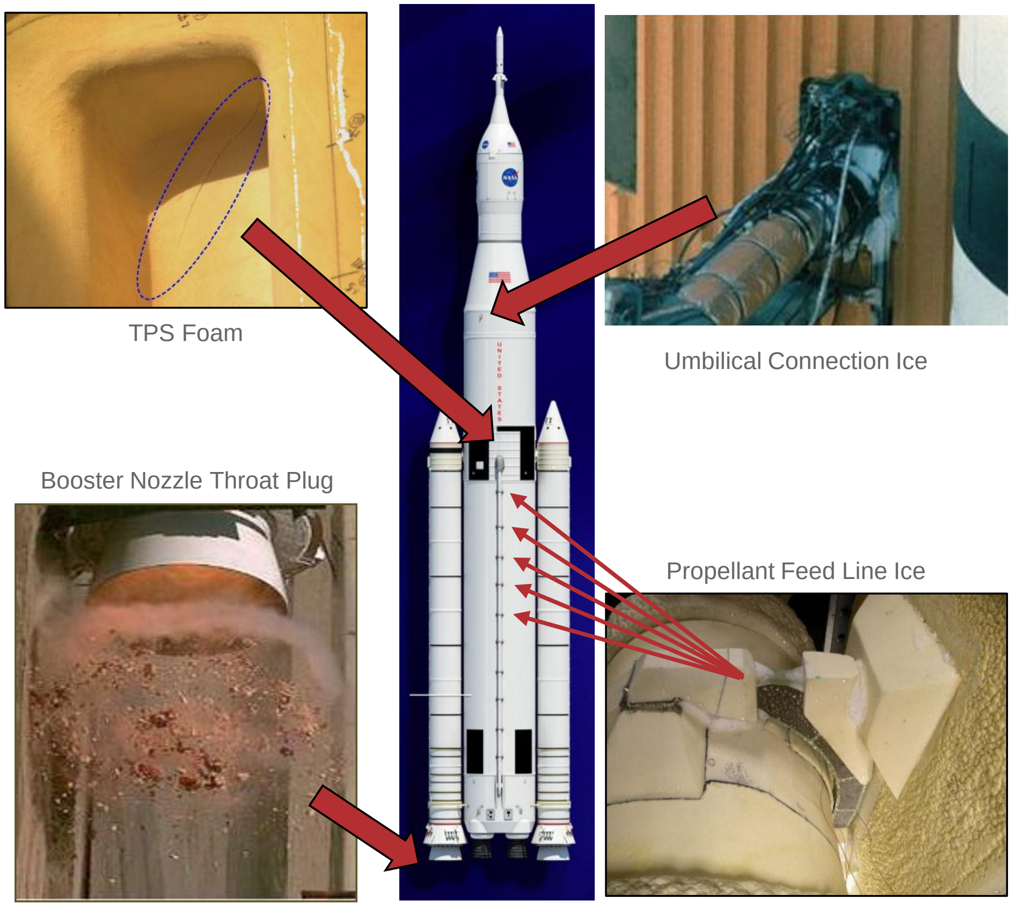
Typical Debris Sources:

Vehicle

- **Foam** from thermal protection system (TPS) on propellant tanks, Booster nozzle throat plug
- **Ice** at TPS joints, propellant feed lines, umbilical connections, vents
- Sacrificial components

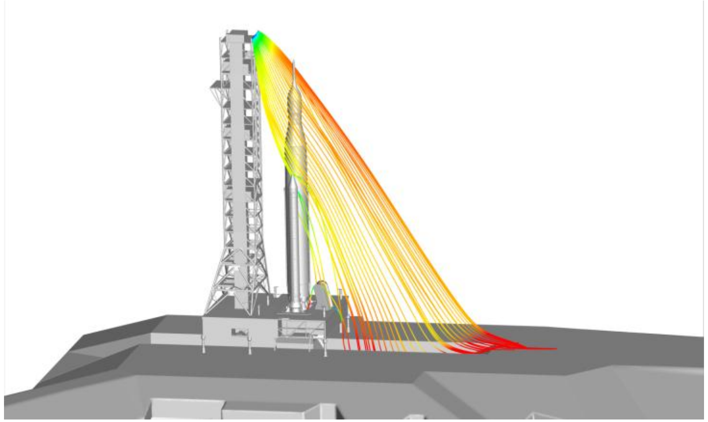
Launch Pad

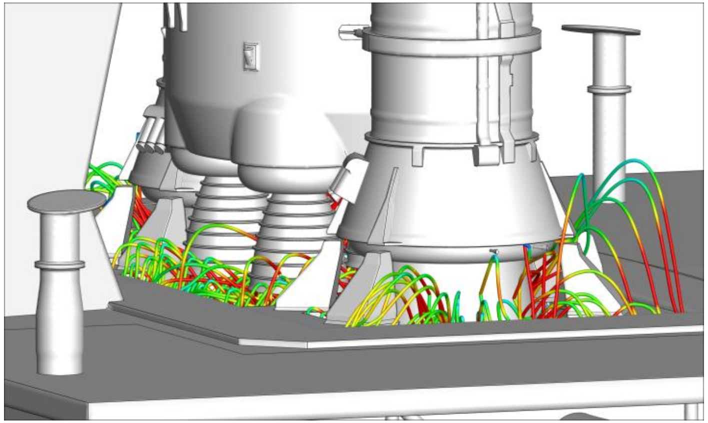
- **Rust** from launch support structures
- Sacrificial components
- Foreign Object Debris (FOD)



Debris Transport Analysis

- Debris Transport Analysis (DTA) uses high-fidelity computational fluid dynamics (CFD) simulations of the flow fields encountered by the SLS during liftoff and ascent, and couples them with models of typical debris to predict debris trajectories and the resulting impacts on the launch vehicle
- The predicted kinetic energies of the debris at impact are provided to the SLS designers to assess whether their hardware can withstand the debris environment
- Unacceptable impact energy levels can be mitigated by design changes to eliminate problematic debris sources, or strengthen affected hardware





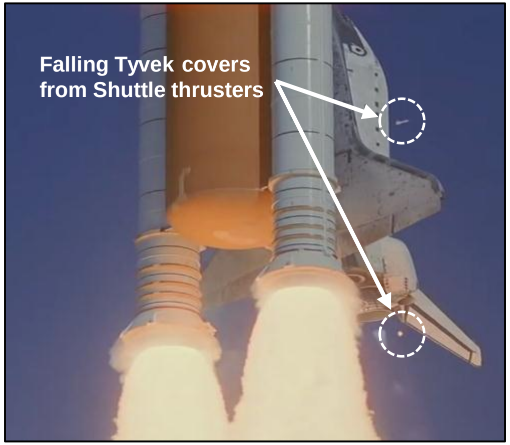
Liftoff Debris

Liftoff Debris is encountered while the vehicle is stationary, or moving (relatively) slowly

Debris transport is separated into two categories :

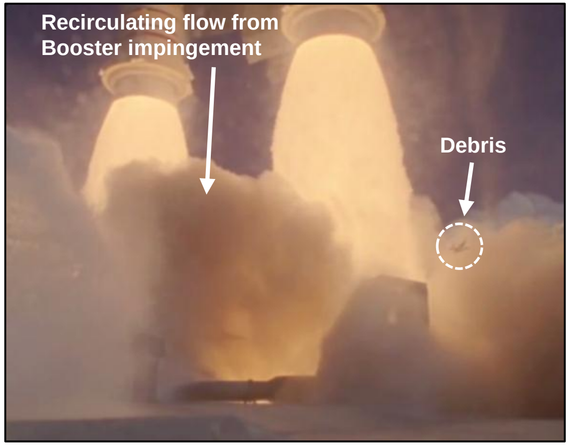
Gravity, Wind, & Plume Entrained

- Downward gravitational acceleration
- Ambient wind induces crossrange velocity
- Momentum of rocket plumes pulls debris towards aft end of vehicle



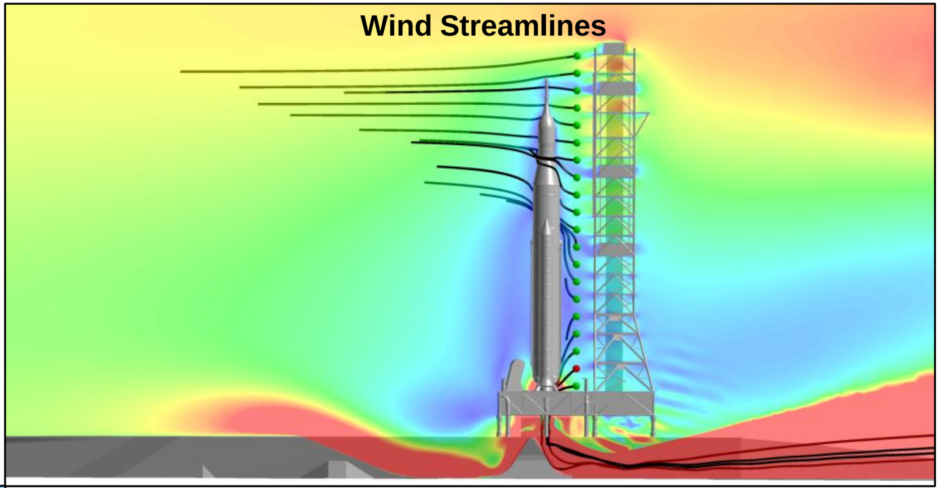
Plume Driven

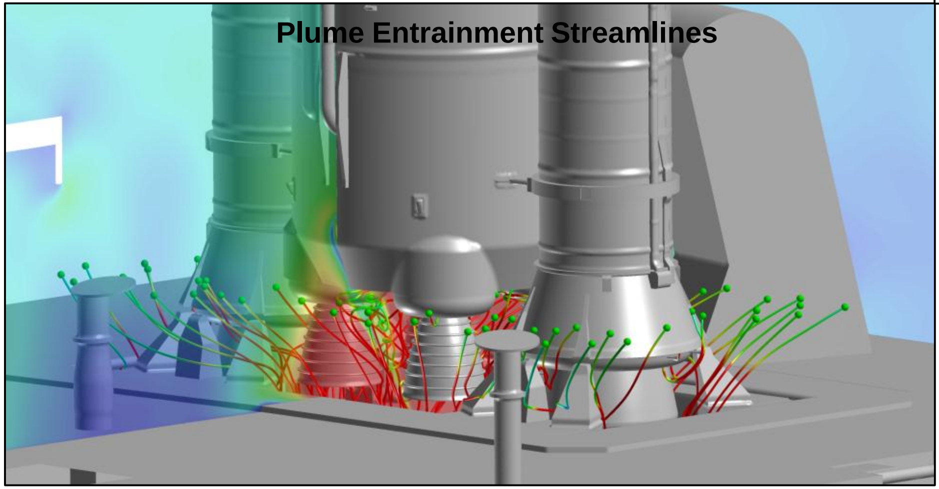
- Booster ignition overpressure (strong wave)
- Rocket plume impingement on launch structure may create recirculating flow
- Potential for much higher debris velocity



Gravity, Wind, and Plume Entrained Debris

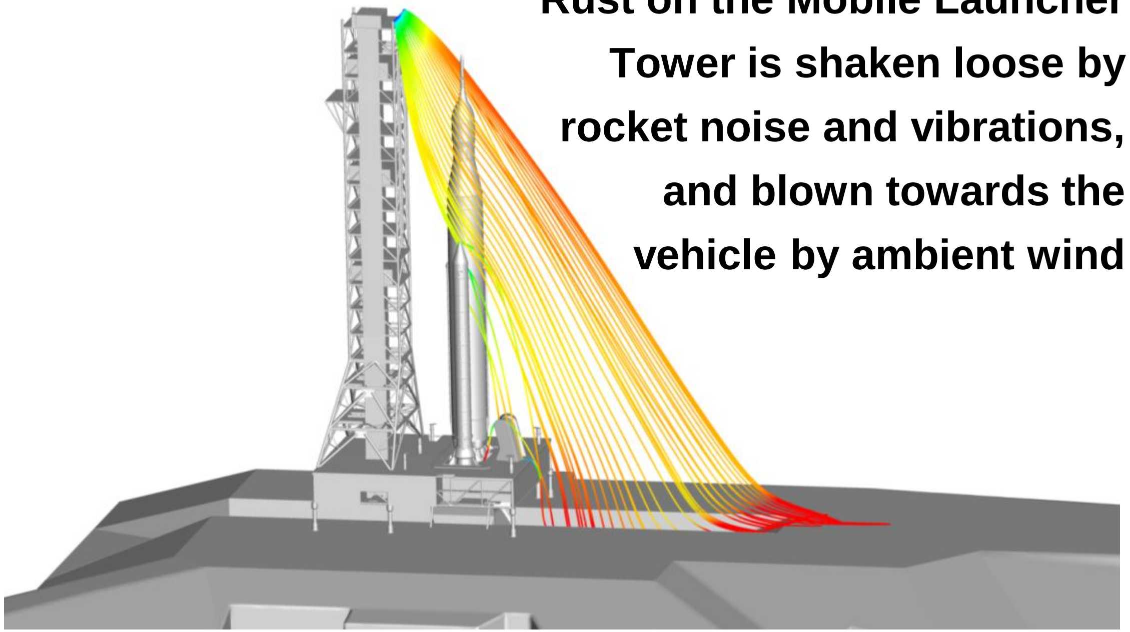
- Ambient wind has the ability to carry debris from launch support structures and the vehicle to impact a large area
- This analysis used a database of 25 static CFD simulations with various wind speed and direction combinations to try to envelope debris impact conditions





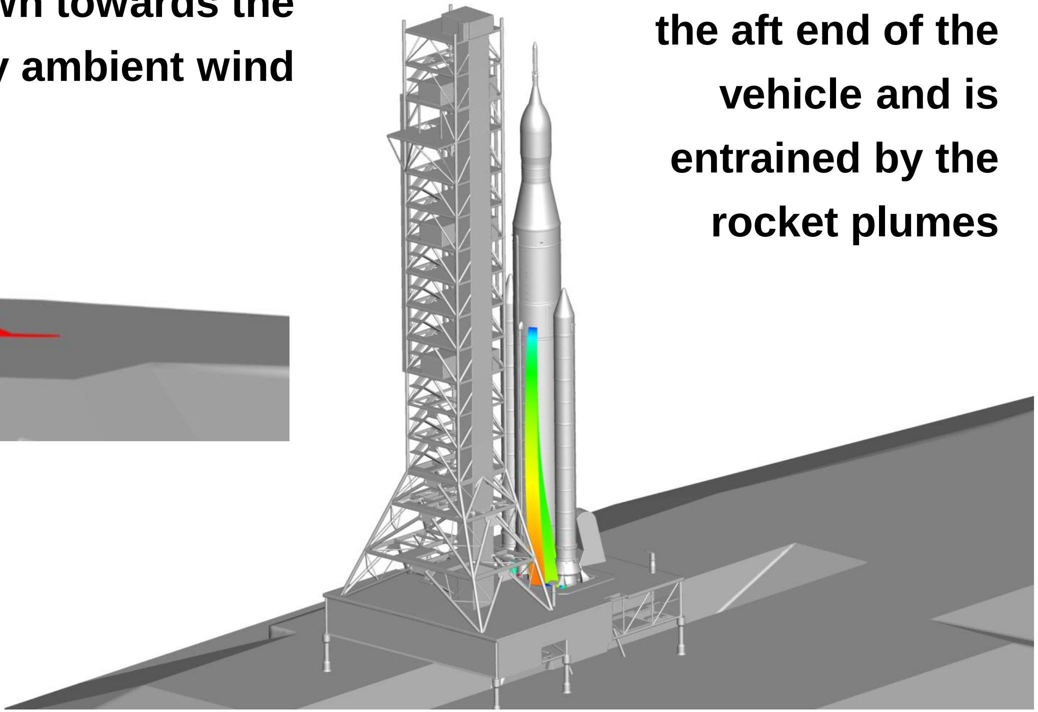
- Plume entrainment near the aft end of the vehicle dominates gravity and wind effects
- Entrainment flow accelerates debris inward towards engine nozzles

Gravity, Wind, and Plume Entrained Debris



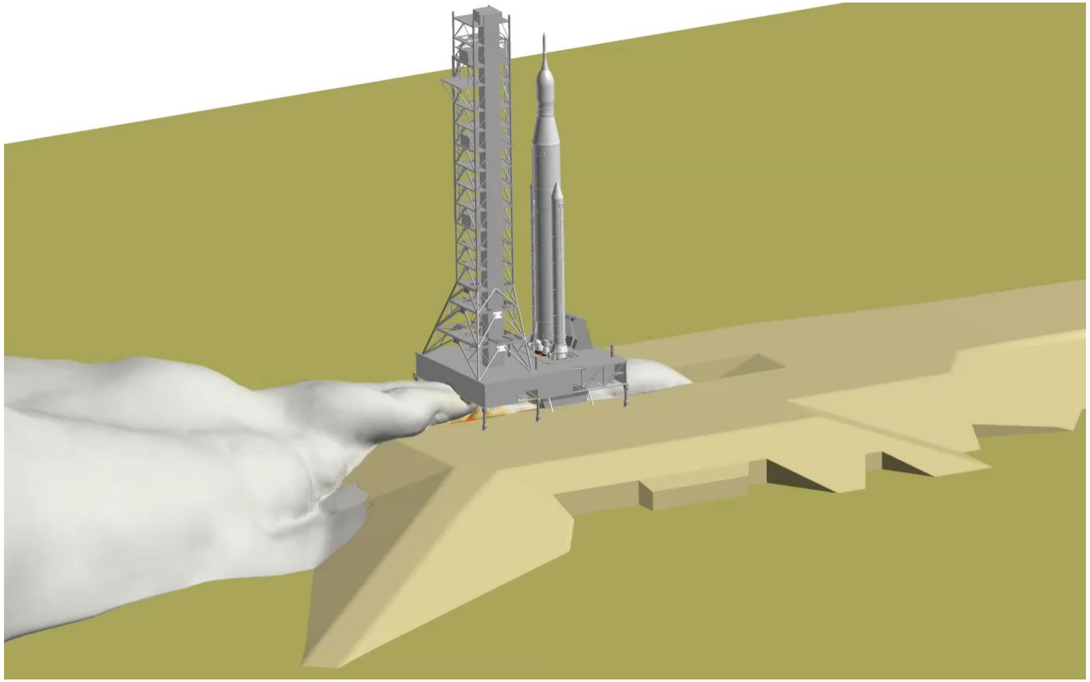
Rust on the Mobile Launcher Tower is shaken loose by rocket noise and vibrations, and blown towards the vehicle by ambient wind

Ice from an umbilical connection is released at liftoff, falls towards the aft end of the vehicle and is entrained by the rocket plumes



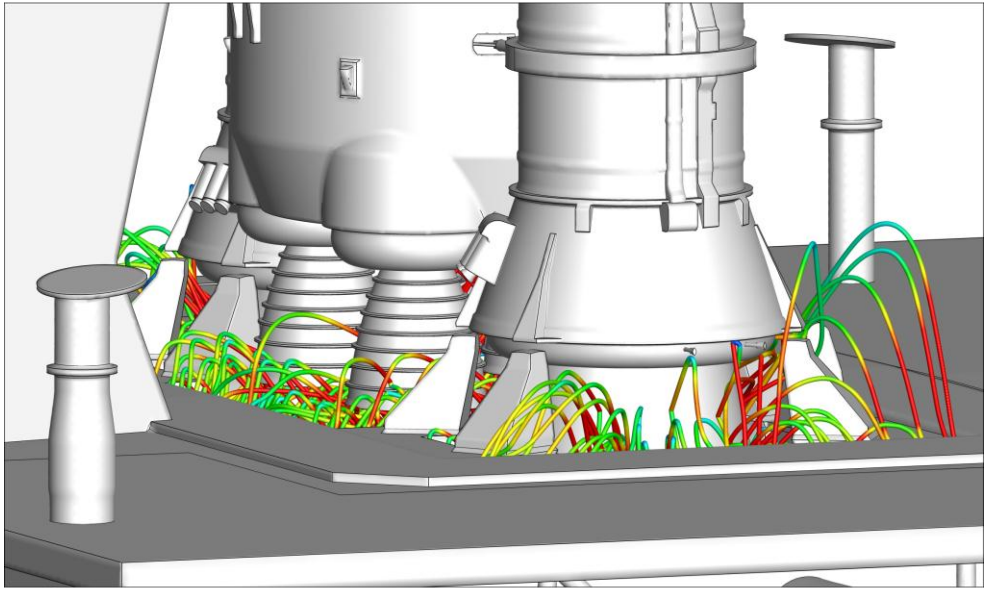
Plume Driven Debris

- Plume flow (Booster ignition overpressure, plume impingement and recirculation) has the potential to accelerate debris to much higher speeds than wind or gravity alone. These flow fields evolve as the vehicle lifts off the launch pad
- A time-accurate, moving-body CFD simulation was used to capture the transient nature of the plume-induced flow field as the vehicle travels along a prescribed launch trajectory



Plume Driven Debris

- Potential trajectories for Booster nozzle throat plug foam are predicted using time-accurate CFD
- The debris is forced upward from the plume hole by the Booster ignition overpressure wave, then is sucked back down and towards the nozzles by the plume entrainment flow



Impact of Debris Analysis

The use of high-fidelity CFD simulations for debris analysis reduced the conservatism in earlier analyses based on engineering models

Delivery of an updated debris environment was important to the successful completion of the SLS Critical Design Review this year

We continue to refine the Debris Transport Analysis as the SLS design is finalized approaching Exploration Mission 1 (EM-1) in 2018

NASA's Pleiades supercomputer is instrumental to the execution of this analysis

- The computational mesh for the SLS vehicle and launch pad is ~250 Million cells
- Each static simulation consumed 75,000 CPU-hours
- The transient, moving body simulation used nearly 4 Million CPU-hours, and would have been intractable during the Shuttle era