

Keeping Astronauts Safe

Predicting Vibrations on the Launch Abort Vehicle

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ORION

Launch Abort System (LAS)

NASAfacts

Ensuring Astronaut Safety
NASA is developing technologies that will enable humans to explore new destinations in the solar system. America will use the Orion spacecraft, launched atop the Space Launch System rocket, to send a new generation of astronauts beyond low-Earth orbit to places like an asteroid and eventually Mars. In order to keep astronauts safe in such difficult, yet exciting missions, NASA and Lockheed Martin collaborated to design and build the Launch Abort System.

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Launch Abort System Configuration

The Launch Abort System, or LAS, is positioned atop the Orion crew module. It is designed to protect astronauts if a problem arises during launch by pulling the spacecraft away from a failing rocket. Weighing approximately 16,000 pounds, the LAS can activate within milliseconds to pull the vehicle to safety and position the module for a safe landing. The LAS is comprised of three solid propellant rocket motors: the abort motor, an attitude control motor, and a jettison motor.

JETTISON MOTOR - The jettison motor will pull the LAS away from the crew module, allowing Orion's parachutes to deploy and the spacecraft to land in the Pacific Ocean.

ATTITUDE CONTROL MOTOR - The attitude control motor, consists of a solid propellant gas generator, with eight proportional valves equally spaced around the outside of the three-foot diameter motor. Together, the valves can exert up to 7,000 pounds of steering force to the vehicle in any direction upon command from the Orion crew module.

ABORT MOTOR - In the worst-case scenario the abort motor is capable of producing about 400,000 pounds of thrust to propel the crew module away from the launch pad.

FAIRING ASSEMBLY - The fairing assembly is a lightweight composite structure that protects the capsule from the environment around it, whether it's heat, wind or acoustics.

FUN FACTS

- The Launch Abort System can activate within milliseconds to carry the crew to a peak height of approximately one mile at 42 times the speed of a drag race car.
- The Launch Abort System's abort motor generates enough thrust to lift 26 elephants off the ground.
- The Launch Abort System's abort motor produces the same power as five and a half F-22 Raptors combined.
- The Launch Abort System can move at transonic speeds that are nearly three times faster than the top speed of a fast sports car.
- The jettison motor can safely pull the Launch Abort System away from the crew module to a height of 240 Empire State Buildings stacked on top of each other.

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ST1 Launch Abort Motor Test

Picture of ST1 test at Orbital ATK facility in Utah for comparison

Pole for mounting far-field mics

High-speed imaging & BOS

Near-field plume acoustics tower (NFTA)

Aero-thermo plate (PLAT)

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QM1 Launch Abort Motor Test



Qualify LAS solid rocket motors for flight

Performed turbulence-resolving computational fluid dynamics (CFD) simulations

Slow motion video from ignition to 0.3 seconds



Rendering of QM1 test simulation with isosurfaces of Q-criterion colored by gauge pressure

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Using HPC To Keep Astronauts Safe



Perform time-resolved CFD simulations to predict transient pressure loads on heat shield and crane ahead of QM1 test to ensure test safety

Use comparison to ST1 and QM1 measurements to validate Launch, Ascent and Vehicle Aerodynamics (LAVA) simulation software

Simulation details:

- LAVA solves full non-linear Navier-Stokes coupled partial differential equations
- 350 million degrees of freedom in space, clustered automatically in most important regions
- Integrated in time ~1 microsecond at a time from ignition to 0.3 seconds
- Massively parallel simulations on 50-80 Intel Broadwell nodes for a total of 2000+ cores
- Completed in ~40 days on NASA's Pleiades Supercomputer
- Generates ~100 Terabytes of data

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QM1 Launch Abort Motor Test



Slow motion video from ignition to 0.3 seconds



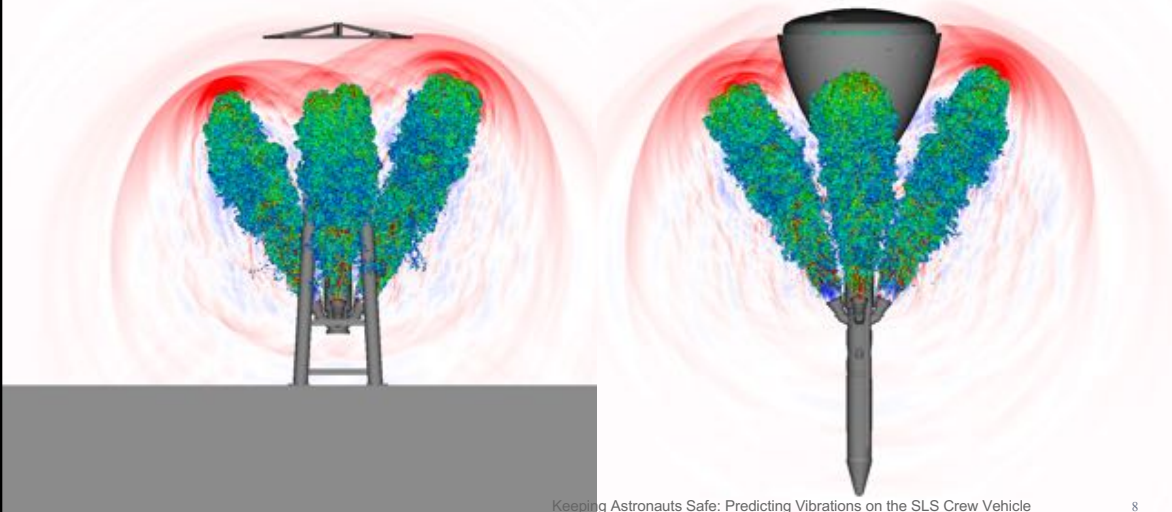
Rendering of QM1 test simulation with passive particles seeded at the nozzles colored by Mach number and gauge pressure on the vertical plane

Launch Abort Vehicle Simulations



LAV was missing from QM1 test
Use CFD to account for its presence

Renderings of QM1 test and LAV pad abort simulations with isosurfaces of Q-criterion colored by Mach number and gauge pressure on the vertical plane



Launch Abort Scenario



Rendering of LAV launch abort simulation with isosurfaces of Q-criterion colored by gauge pressure

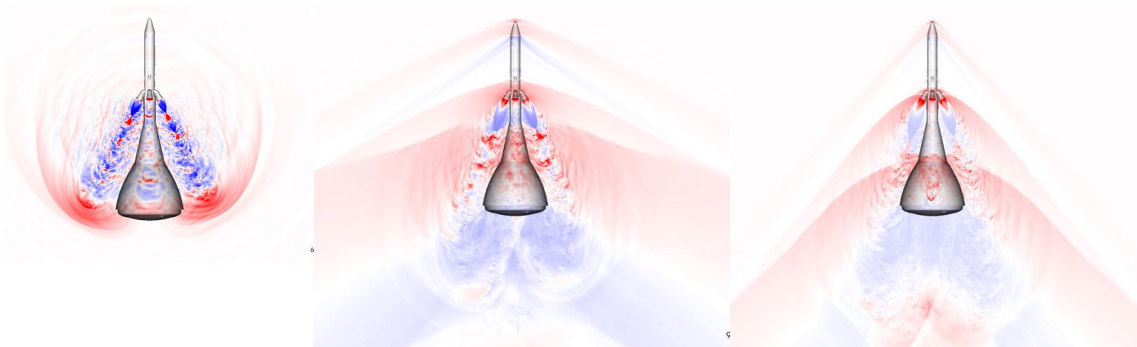
Slow motion video from ignition to 0.3 seconds

Ascent Abort Scenarios



Launch abort can also happen during ascent

Use CFD to identify differences in transient loads, hot spot locations

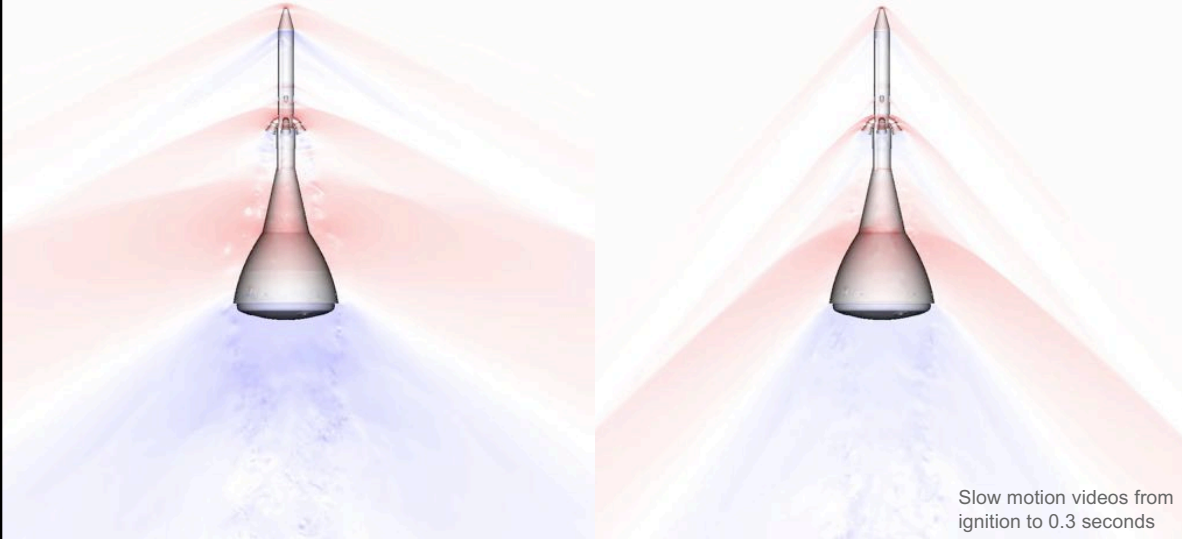


Gauge pressure on the vertical plane and on the LAV surface for launch (left), transonic (middle), and supersonic (right) abort scenarios

Ascent Abort Scenarios



Gauge pressure on the vertical plane and on the LAV surface transonic (left), and supersonic (right) ascent abort scenarios



Slow motion videos from ignition to 0.3 seconds

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Ascent Abort Scenarios



Rendering of LAV transonic ascent abort simulation with isosurfaces of Q-criterion colored by gauge pressure



Slow motion video from ignition to 0.3 seconds

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Ascent Abort Scenarios



Rendering of LAV supersonic ascent abort simulation with isosurfaces of Q-criterion colored by gauge pressure



Slow motion video from ignition to 0.3 seconds

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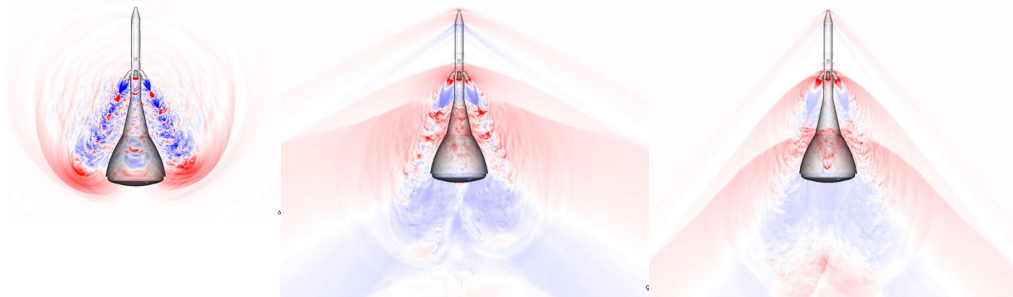
Results & Impact



Validated computational aero-acoustic prediction capabilities for LAVA software

Discovered that pressure doubling on the surface only occurs near the nozzle due to the change in incidence angle → vibrations are not as strong as expected on LAV

Showed how vibration hot spots move and overall vibration levels are reduced on ascent abort cases because of convection and interactions with attached shocks



Why HPC Matters



The availability of the rich dataset from our many simulations directly impacts the final design for the SLS launch abort vehicle

NASA Advanced Supercomputing (NAS) facility's visualization experts provided passive particle renderings that helped enrich our understanding of the fluid dynamics in the plume of the launch abort motors

Ongoing effort to reduce uncertainty in transient loads on LAV by simulating cases outside of nominal operations

Resources



For more information on the LAVA computational framework, please refer to this paper:

Kiris, Cetin C., et al. "Computational framework for launch, ascent, and vehicle aerodynamics (LAVA)." *Aerospace Science and Technology* 55 (2016): 189-219.

For more information on the Space Launch System:

<https://www.nasa.gov/exploration/systems/sls/index.html>

For the official Orbital ATK video of the QM1 launch abort motor test, please follow this

link: <https://www.youtube.com/watch?v=B-1qajOvEI4>