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Title: Time Accurate CFD Simulations of the Orion Launch Abort Vehicle in the Transonic Regime

Abstract: Significant asymmetries in the fluid dynamics were calculated for some cases in the CFD simulations of the Orion Launch Abort Vehicle through its abort trajectories. The CFD simulations were performed steady state and in three dimensions with symmetric geometries, no freestream sideslip angle, and motors firing. The trajectory points at issue were in the transonic regime, at 0° and ±5° angles of attack with the Abort Motors with and without the Attitude Control Motors (ACM) firing. In some of the cases the asymmetric fluid dynamics resulted in aerodynamic side forces that were large enough that would overcome the control authority of the ACMs. MSFC's Fluid Dynamics Group supported the investigation into the cause of the flow asymmetries with time accurate CFD simulations, utilizing a hybrid RANS-LES turbulence model. The results show that the flow over the vehicle and the subsequent interaction with the AB and ACM motor plumes were unsteady. The resulting instantaneous aerodynamic forces were oscillatory with fairly large magnitudes. Time averaged aerodynamic forces were essentially symmetric.

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Time-Accurate CFD Simulations of the Orion Launch Abort Vehicle in the Transonic Regime

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Motivation for Analysis

- Steady state computational fluid dynamic (CFD) simulations of the Orion Launch Abort Vehicle (LAV) have predicted asymmetric flow in the transonic regime ($0.8 < M < 1.2$)

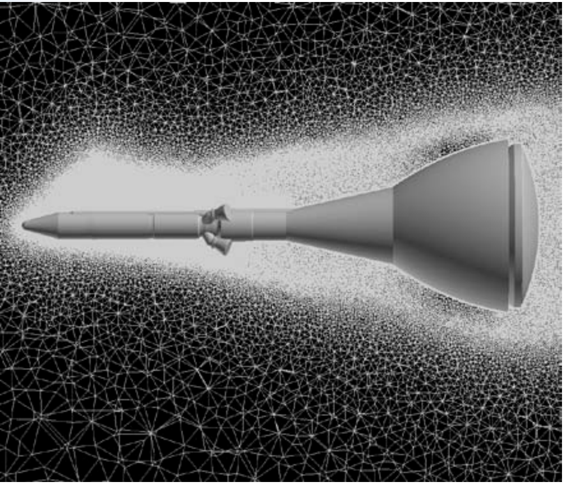
- The asymmetries present in the steady simulations were large enough to prevent Orion's Attitude Control Motors (ACM) from controlling the vehicle

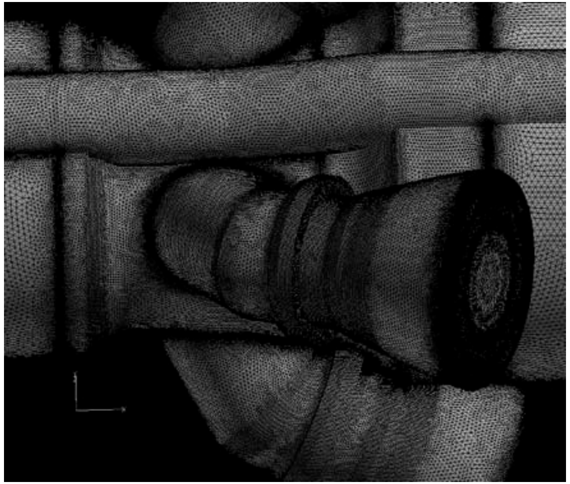
- It was expected that the interactions of the Abort Motor (AM) plumes and ACM plumes with each other and with the Orion LAV would be unsteady, requiring time accurate CFD simulations to resolve the unsteadiness

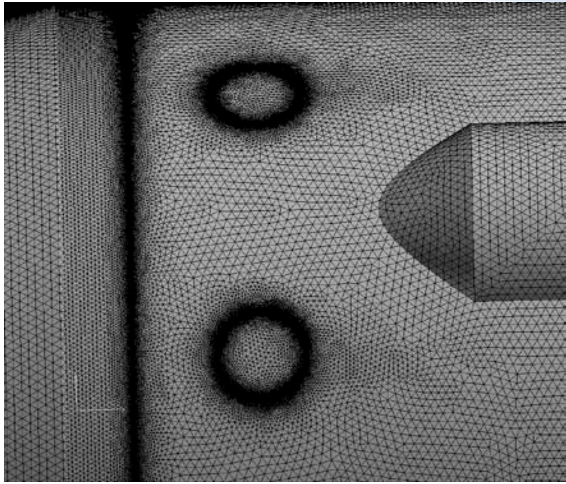
- The Propulsion Fluid Dynamics Branch at Marshall Space Flight Center was asked to investigate

Mesh Generation and Analysis Approach

- **An unstructured mesh methodology was used for this analysis**







- **The unstructured CFD analysis tool Loci-Chem was used for the time accurate simulations at a freestream Mach number of 1.1 with AM Coefficient of Thrust=3 and ACM Thrust Ratio=0.1**

Simulation Parameters

- Time accurate simulations were performed at angles of attack of -5° , 0° , and 5°

- A multi-scale hybrid RANS/LES turbulence model was used with Menter's SST model for the RANS equations. Simulations were started from a stationary URANS simulation

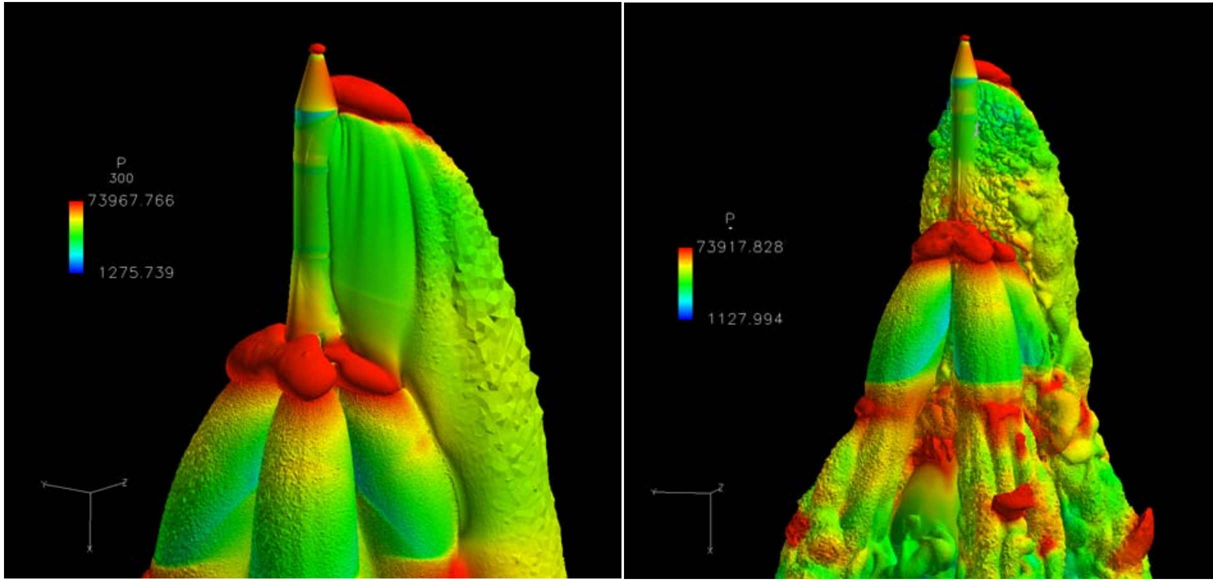
- In a hybrid RANS/LES turbulence formulation, the eddy viscosity is a function of two turbulent length scales as opposed to one. The larger turbulent scales are resolved by the computational mesh, while the smaller scales are modeled.

- Simulations were run at a maximum time step of 2×10^{-6} seconds, but the time step was also limited by the maximum change in a flow variable of 50%

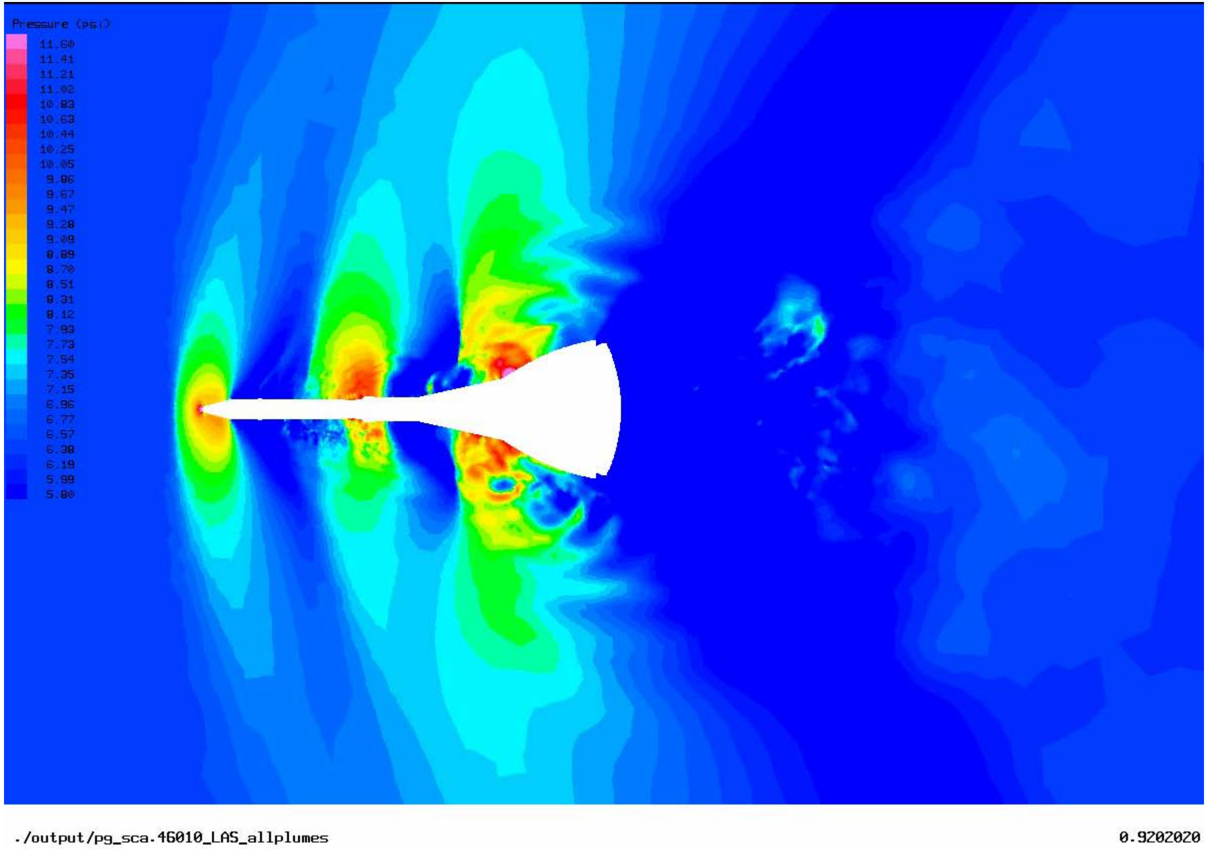
Steady vs. Unsteady Simulation Results

- The image on the left shows a temperature iso-surface at 300K extracted from a steady simulation. There is no vortex shedding from the tower or unsteady interaction between the ACM plume and the AM plume

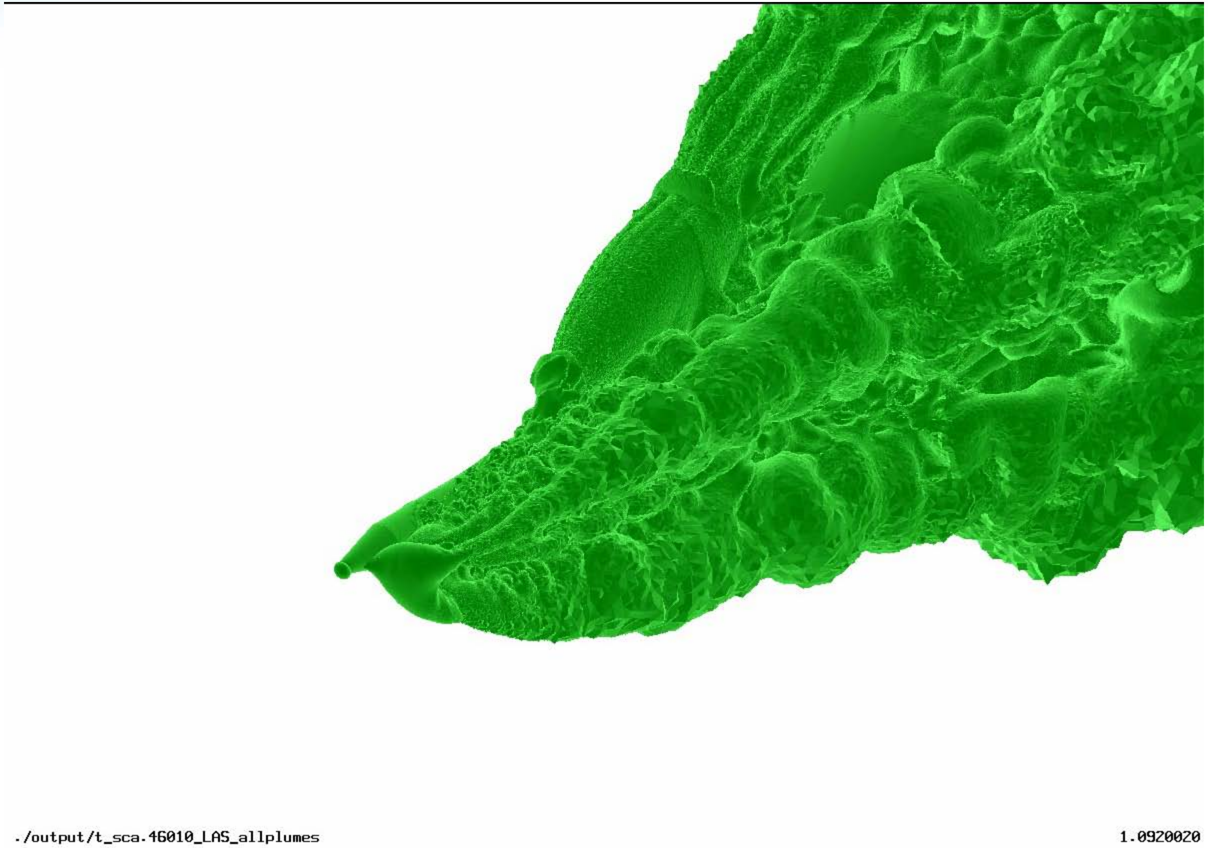
- The iso-surface taken from the unsteady simulation is shown on the right. There is vortex shedding from the tower, and unsteady features are present between the AM plumes and near the Orion capsule.



Z-Cut Pressure Animation

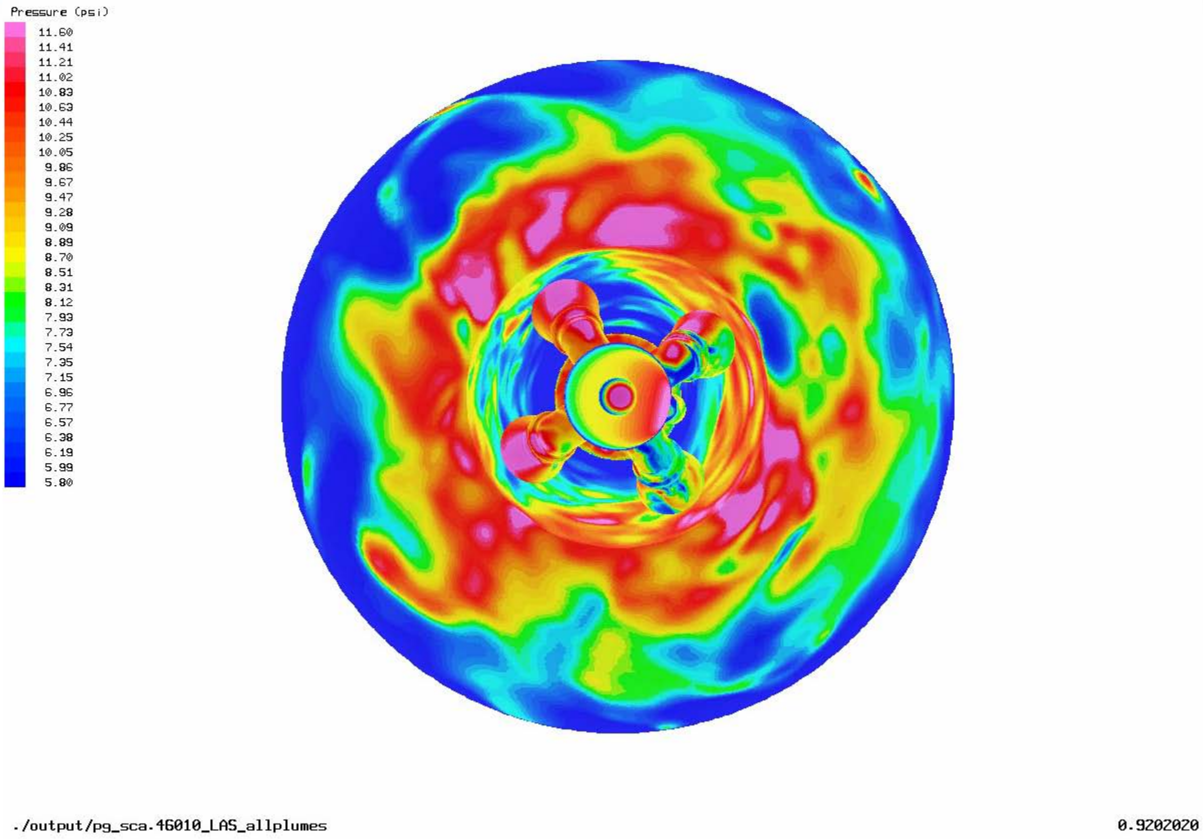


Temperature Iso-Surface Animation Isometric



Temperature Iso-Surface Animation Front

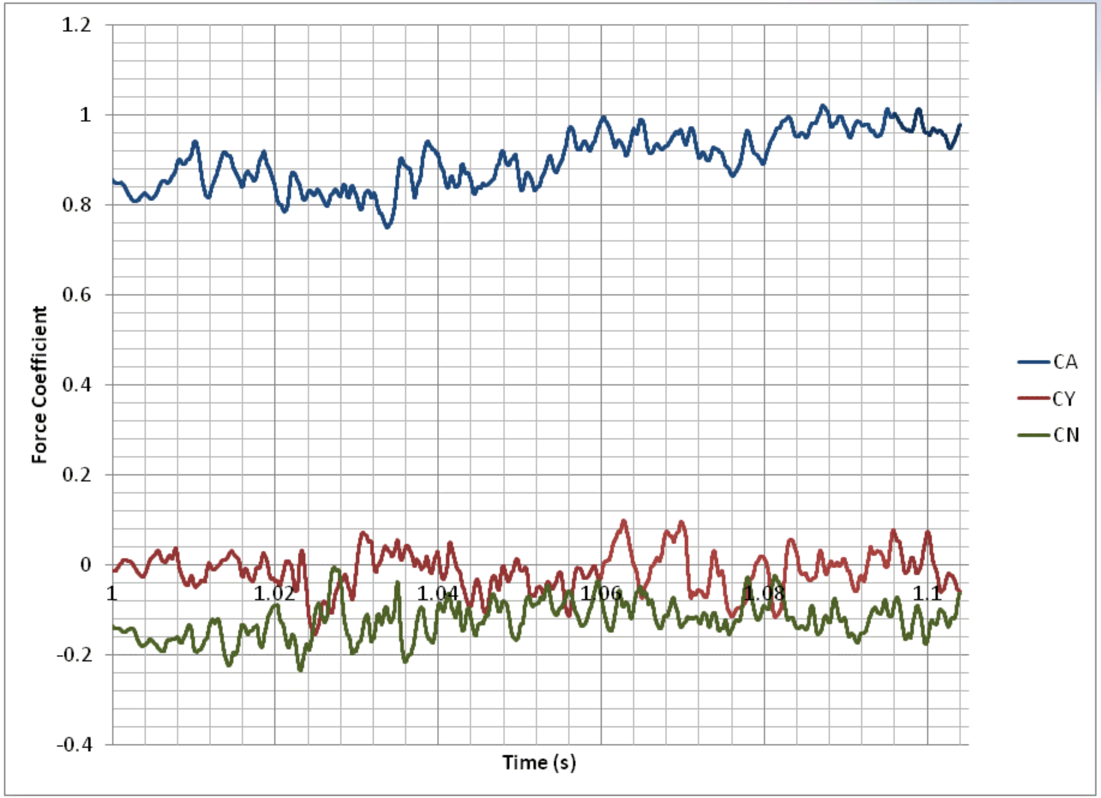
Surface Pressure Animation



Integrated Force Coefficients

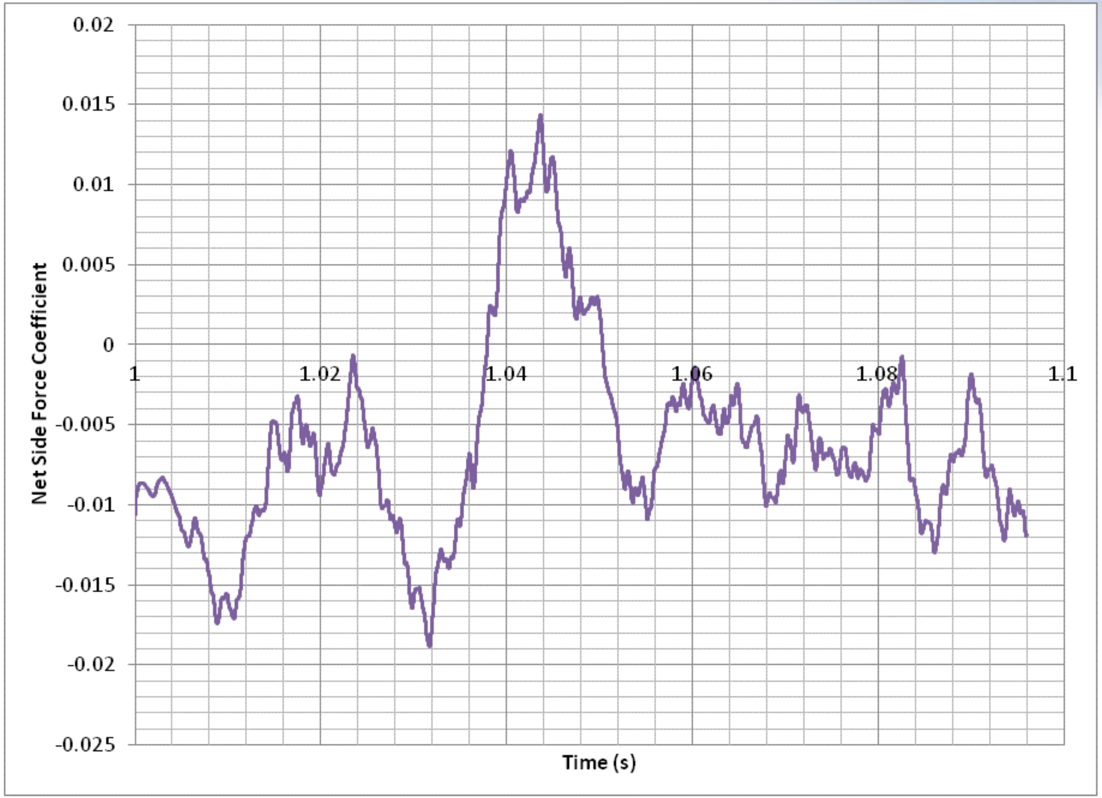
- **Peak-to-peak oscillation in side and normal force coefficients has a magnitude of ~0.2 as seen on plot**

- **Side force coefficient periodically changes signs and is large enough, at points in the simulation, to overcome the control authority of the Launch Abort Vehicle**



Side Force Components

- **This plot shows the side force coefficient acting on LAV surfaces other than the Orion capsule**
- **Peak-to-peak oscillation magnitude of ~0.035**
- **The Orion capsule component accounts for more than 80% of the total peak-to-peak oscillation**



Conclusions and Future Work

- **Oscillations of this magnitude were not expected and are considered to be very large. The oscillations are large enough that the LAV will intermittently be unable to control itself in flight under these conditions**

- **A rigorous validation effort should be completed in order to better understand these results and to clarify uncertainty**

- **Additional simulations are being performed in which the LAV "flies" through its abort trajectory, better reflecting its environment in an actual flight**