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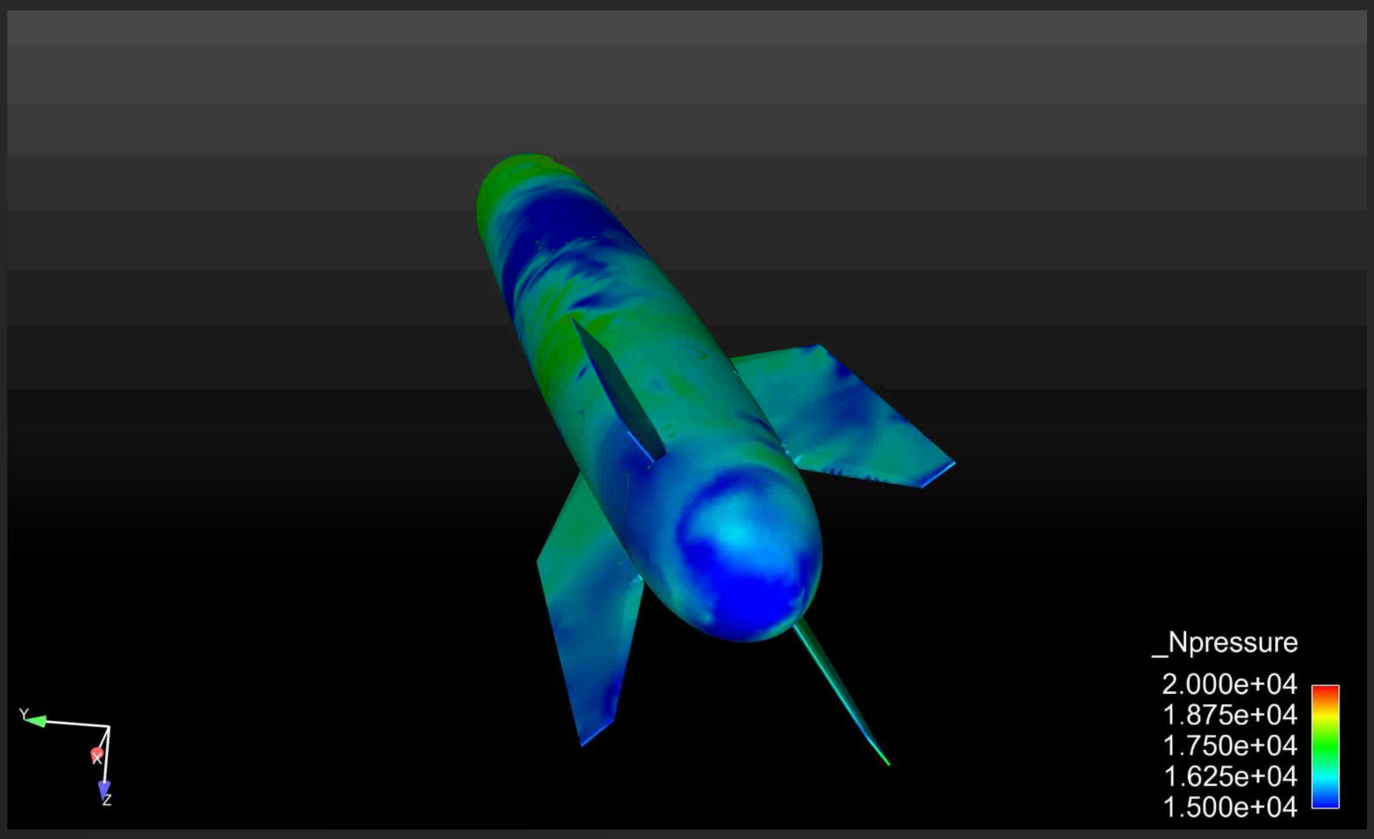
Sandia National Laboratories

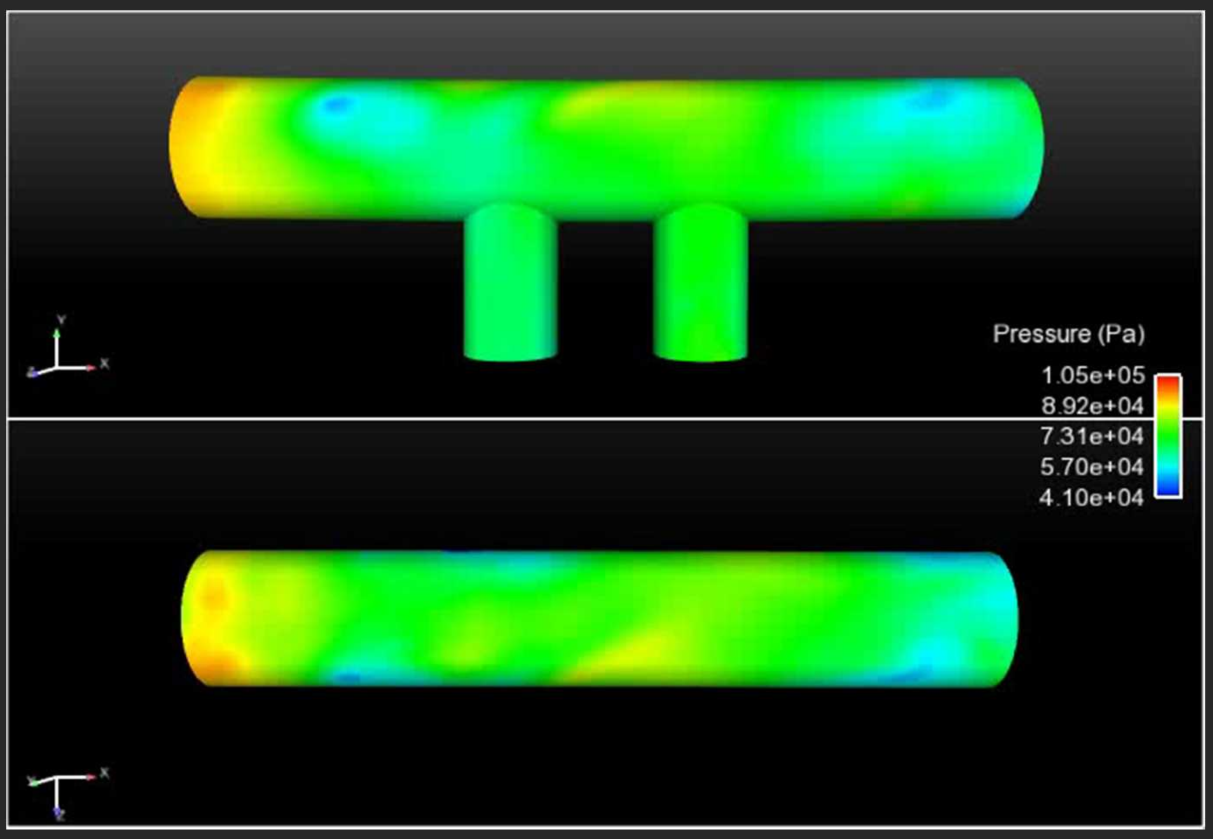
Coupled Fluid Structure Simulations Of the Captive Carriage Environment

Carriage of a stockpile system within an aircraft weapons bay is a potentially harsh vibro-acoustic environment that system components must be designed to withstand. When the weapons bay doors open during flight, air flows past and into the open bay, creating large pressure fluctuations within the bay that can excite any structures contained within it, causing potentially damaging vibrations. In cases where flight test data is scarce or unavailable, predictions of this environment using modeling and simulation play a key role. SNL has developed a coupled fluid structure analysis capability that is based on unsteady Computational Fluid Dynamics (CFD) modeling of the airflow, coupled with a finite element (FEA) structural analysis model for the weapon. The CFD code, SIGMA-CFD, is a parallel multi-block structured grid Navier-Stokes solver. SIGMA-CFD computes the flow-field and transfers surface pressures to Salinas, a parallel structural dynamics FEA code with transient analysis capability.

Development of a credible simulation capability necessarily involves extensive verification and validation efforts. In order to provide validation data for the coupled fluid-structure simulation capability, a number of validation experiments have been performed in the Sandia Tri-sonic Wind Tunnel. These have included measurements of unsteady pressure loading in rectangular cavities, with and without a model cylindrical store inside the cavity. Simulation of these validation experiments provides a means to estimate model errors and improves our understanding of model performance in the context of the full-system simulations.

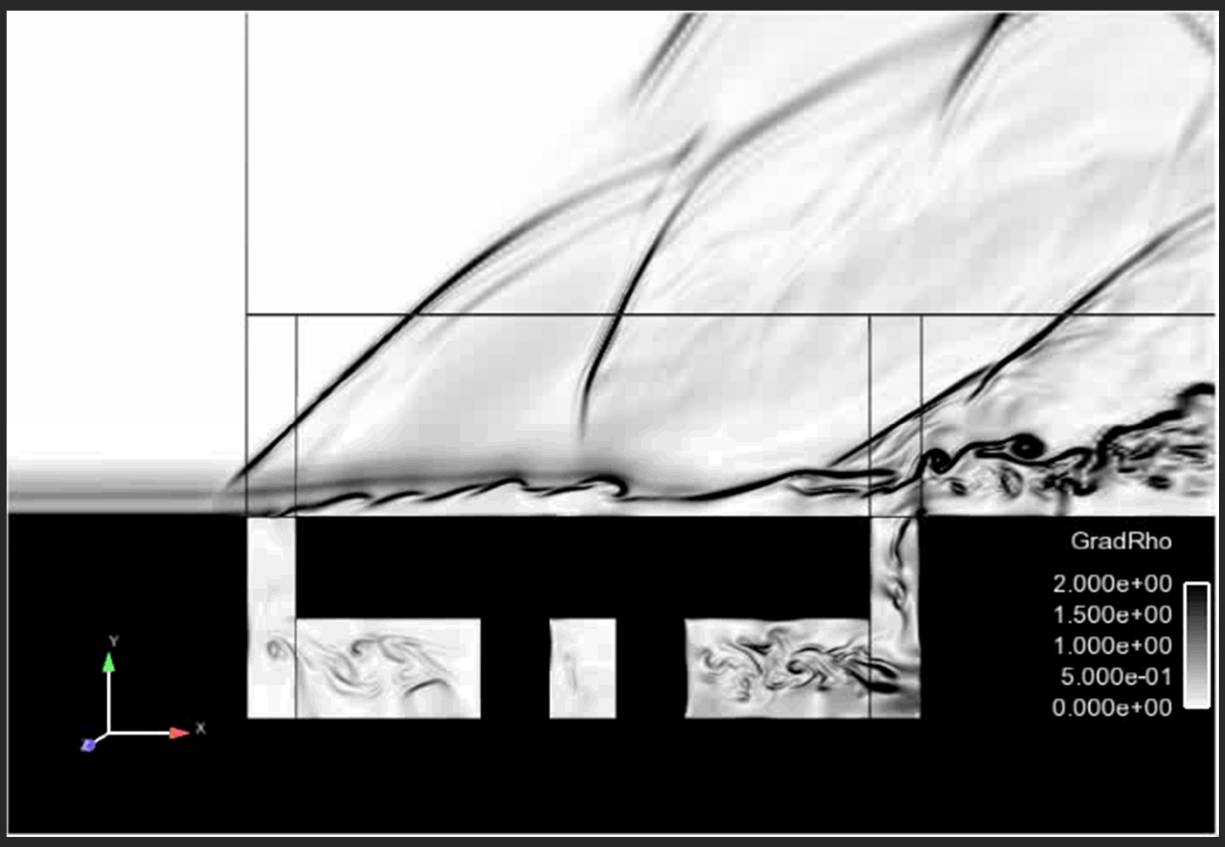


Animation in time of the fluctuating surface pressure field and resulting vibrations of a captive store carried within an aircraft weapons bay at full scale (Vibrations are magnified 10x for ease of visualization).
The results of a CFD simulation of a full scale stockpile system within the captive carriage environment are post-processed to reveal the complexity of the loading on the surface of the store. The unsteady pressures are applied as loads to a detailed finite element structural dynamics model of the store to generate store vibration predictions. The vibrations are most apparent near the trailing edge of the fins, although vibration predictions at internal component locations are also generated and help to define the design environments for those components

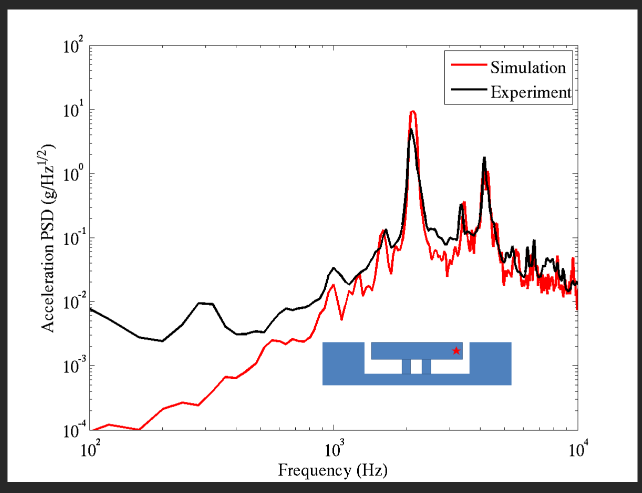


Animation of the fluctuating surface pressure field and resulting vibrations of a model store within a rectangular cavity excited by a Mach 1.5 flow (Vibrations are magnified 100x for ease of visualization).
The surface pressure loadings are seen to excite various natural modes of the model store, in particular a fore-aft rocking mode as well as a side to side twisting mode. The resulting structural response of the store is quite complex, consisting of a combination of natural mode and forced responses in various directions. This combined experimental/simulation effort has highlighted the physical mechanisms within cavity flows that give rise to vibration of captive stores.

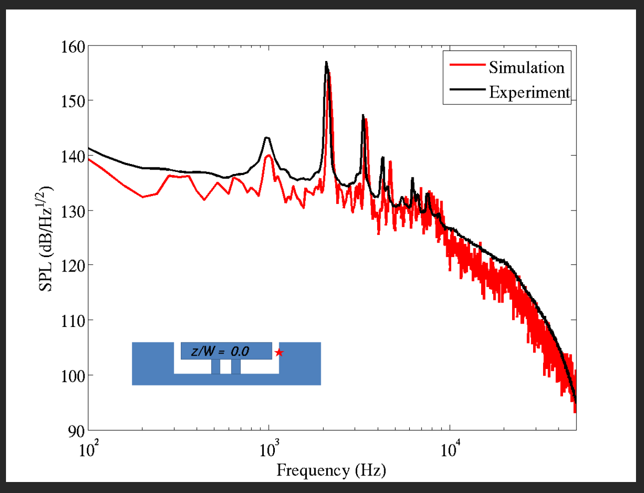
Animation of simulated density gradient field for a subsonic flow over an empty rectangular cavity (free stream flow is left to right)
The animation shows the evolution in time of the density gradient magnitude in the symmetry plane of a square (5” long by 5” wide by 1.5” deep) cavity at a free stream Mach number of 0.8. Turbulence associated with the unsteady shear layer along the edge of the cavity as well as the recirculating flow within the cavity are evident in the visualization. Acoustic waves generated by the impingement of the turbulent flow on the downstream cavity wall are also seen above the cavity. The acoustic field includes waves that are reflected from the opposite wind tunnel wall (not shown, but included in the simulation). In compressible cavity flows, the acoustic field often couples with the turbulence field to create a very loud resonant flow condition.



Animation of density gradient field for a supersonic flow past a rectangular cavity containing a model store (free stream flow is left to right)
Wind tunnel experiments were also conducted for rectangular cavities containing a model cylindrical store, supported by two cylindrical posts. This animation shows the evolution of density gradient contours in a plane cutting through the center of the model store. The cavity shear layer is seen to be lofted over the store surface, but still partially impinges on the aft wall of the cavity, resulting in acoustic waves that provide an unsteady loading on the store. Acoustic waves are also visible above the cavity; since the flow is supersonic, these acoustic waves are unable to propagate upstream against the flow.



Comparison of measured and predicted store axial acceleration spectrum, Mach 1.5



Comparison of measured and predicted wall pressure spectrum for a location on the aft wall of the rectangular cavity with model store, Mach 1.5

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