Back to the Moon, then on to Mars

Using modal data from LMS Test.Lab, researchers at the Marshall Space Flight Center created hybrid models with LMS Virtual.Lab to determine critical loading on giant rocket nozzles of NASA's next-generation Ares launch vehicle. As part of its responsibility for many of the modal tests within the U.S. space agency, Marshall's Structural Dynamics Test Branch also will use LMS Test.Lab for ground vibration tests of the new vehicles. In these and other projects, NASA engineers and researchers rely on LMS technologies in designing and testing advanced spacecraft that will travel the solar system in the coming decades.

If all goes according to plan, NASA astronauts will return to the moon as early as 2015 and establish a lunar base from which six-month flights to Mars would be launched by 2030. Explorers will fly to these and other extraterrestrial destinations using a next-generation Ares launch vehicle powered by the J-2X propulsion system with the world's largest rocket nozzles. System-response models for calculating critical side-wall loads on these huge nozzles have been developed in LMS Virtual.Lab based on modal data on nozzle replicas from LMS Test.Lab. Tests were conducted by the Marshall Space Flight Center (MSFC) Structural Dynamics Test Branch, which uses LMS Test.Lab to perform modal testing for the U.S. space program in a wide range of projects – including an upcoming ground vibration test (GVT) of the complete Ares vehicle.

Earthshaking Thrust. With a core propulsion stage of five RS-68 engines – the largest liquid hydrogen/liquid oxygen rocket motor in existence – the massive Ares V cargo ship will stand 360 feet tall and lift over 286,000 pounds to low Earth orbit: almost five times the shuttle payload weight. Its sister craft, the Ares I, will serve as the crew launch vehicle carrying astronauts on space missions.

The upper stages of both vehicles will be driven by a highly efficient and powerful J-2X main liquid engine designed to deliver required levels of thrust while conserving fuel on long space flights. Over 15 feet long and 10 feet in diameter, the nozzle for the J-2X will be the world's largest rocket nozzle ever made.

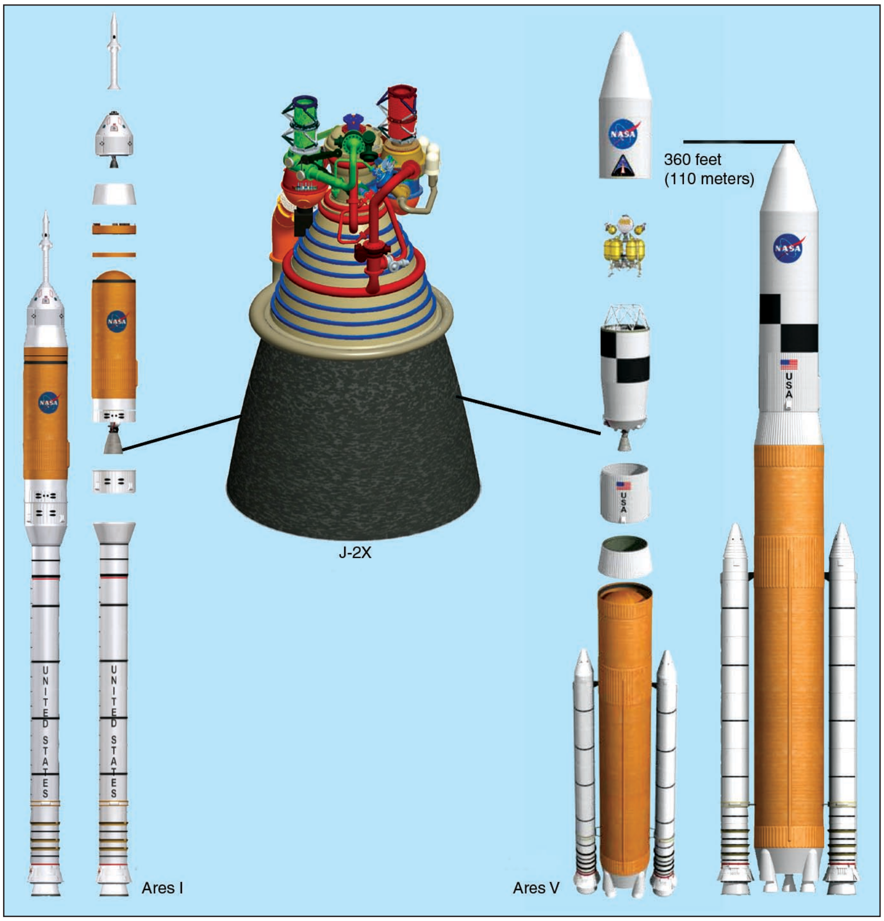
Risk of Large Side-Wall Loads. One of the conditions that engineers carefully consider in designing rocket nozzles, particularly large ones such as the J-2X, is called separation phenomenon. This occurs when outside ambient air is sucked into the nozzle rim by the relatively low pressures of rapidly expanding exhaust gases. This separation of exhaust gases from the side wall imparts large asymmetric transverse loads on the nozzle, deforming the shape and thus perturbing exhaust flow to cause even greater separation. The resulting fluid-structure interaction can set up 10 g resonant vibrations with several inches of side-wall deflection – enough to potentially crack the nozzle or break actuator arms that control thrust direction.

Because of these risks, side-wall loads represent an important parameter in the design of rocket nozzles. These forces are extremely difficult to measure directly, and techniques were not available for accurately predicting the magnitude and frequency of the loads until now. In developing such a method, NASA researchers studied separation phenomenon in an MSFC test cell that shoots compressed air through 5:1 scale-model rocket nozzles. The goal was to use measured vibration on these nozzle replicas to calculate the unknown force causing the vibrations. Key to this approach was the creation of a computer model accurately representing the nozzle as well as the test cell.

Building a System-Response Model. Structural dynamic models of these complex configurations would have been difficult to prepare. Therefore, unique system-response models were created based on modal test data from LMS Test.Lab, which combines multi-channel data acquisition with a suite of integrated testing, analysis and display capabilities. The modal data were used in LMS Virtual.Lab, where system-level response analysis technology was applied to construct the overall representation. Assembly definition tools specified the various connections between individual parts and a component representation manager kept track of properties for each component.

The system response model defined the overall dynamics of the structure in terms of resonant frequencies, mode shapes and damping. One of the main advantages of the method is that very few key physical points of interest require testing. The sets of modes used in creating the system response model must all be independent. For this determination, LMS PolyMAX was used in quantifying the amplitude and frequency of each mode, and LMS Modal Assurance Criterion (MAC) 3D plots were used to check these levels so modes that most accurately represent the dynamics of the structure could be selected.

Next, LMS Test.Lab was used to acquire vibration responses from a measured input force applied by electromagnetic shakers. Measurements were then compared to predictions for checking the validity of the system response model, with discrepancies corrected by scaling factors. Nozzle side loads were then computed in an inverse force determination in which nozzle power spectral density (PSD) responses were obtained for various inputs, with amplitudes and frequencies iterated until a good comparison between measurements and prediction was achieved.



Upper stages of Ares V cargo ship and Ares I crew launch vehicle will be powered by the J-2X main liquid engine with world's largest rocket nozzle ever made.

Using an LMS test system, NASA engineers at the Marshall Space Flight Center conduct a modal test of the five-segment, solid-rocket motor, the most powerful rocket motor ever fired.

With the process validated, the system response model can be used to readily compute side-wall forces from measured vibration of any rocket nozzle. This process will be applied in particular to the J-2X using modal test measurements on nozzle scale replicas.

Tight Interface. The use of LMS Virtual. Lab in creating the system model and in quickly performing the FRF iterations for determining scaling factors was key in developing the process. Because of close integration between LMS Test.Lab and LMS Virtual.Lab, data are readily available between the two systems instead of having to go through universal file conversions that often fail to fully represent critical data such as frequency response functions. Utilizing test data in combination with modeling and predictive tools in this type of hybrid approach will enable engineers to more accurately determine transverse separation forces and have the information to design nozzles for better withstanding operational loads.

The approach has the potential for application to all rocket nozzles, particularly the large types like the J-2X, for liquid fuel engines in future spacecraft. More broadly, the system response approach of creating system models based on modal test data should prove useful in R&D studies of similar structures that are difficult to model and whose dynamic behavior is of primary interest. In this way, this project helps to develop tomorrow's rocket propulsion systems and also can be used for engineering applications in a wide range of other industries.

GVTs for the Next-Generation. The nozzle side-wall load prediction project is an example of the work done with LMS Test.Lab by NASA's Structural Dynamics Test Branch at MSFC. This branch is responsible for many of the modal tests conducted within the space agency for a wide range of projects, including telescope systems, on-board equipment, robotic arms, turbine blades and rocket nozzles.

Preparations are underway for ground vibration testing (GVT) of the complete Ares I craft to be conducted in 2011 using the dynamic test stand at MSFC. Tests will be performed on the "full stack," including the first- and second-stage motors, fuel tanks and crew capsule. Structural vibrations will be induced using up to six hydraulic or electrodynamic shakers delivering random and sine excitations. LMS Test.Lab can provide engineers with critical test data, including frequency response functions (FRFs), natural frequencies, damping values and mode shapes to evaluate how the structure will likely vibrate during liftoff, stage separation and subsequent phases of the flight.

The LMS SCADAS 260-channel front-end is one of NASA's large modal data-acquisition systems. The high channel count enables the modal test measurements in fewer test runs. Measuring multiple functions simultaneously allows them to obtain FRFs as well as associated cross spectrums, auto powers and time data in parallel instead of having to run separate tests.

The modal test team will probably complete the Ares GVT in only three test sets versus up to eight runs needed for comparable tests on the Saturn and Shuttle vehicles using a system with far fewer channels. Reducing the number of runs saves time and expense while reducing errors in recombining and interpreting separate data files.

Testing Big-Dollar Prototypes. Vibration monitoring and control software in LMS Test.Lab precisely regulates shaker excitation and automatically checks peak structural response on selected channels. This ensures that vibration amplitude does not exceed a preset limit in the GVT project. To avoid damage to the Ares prototype – worth hundreds of millions of dollars – the system has automated alarms and abort features for shutting down the test when excessive vibration is detected.

Exhaustive vibration tests must be completed without damage to the structure or to the test system. Automated features provide a significant level of safety in tracking channels for delicate parts of the vehicle and safely aborting the test if potentially damaging structural responses are detected.

The team also makes extensive use of LMS PolyMAX software that automatically highlights resonances. The tool also provides more consistent results that otherwise can vary according to subjective interpretation of data. In addition, animated operational deflection shape (ODS) features show how the structure may bend and twist at various frequencies so engineers have deeper insight into dynamic structural behavior. In using such technology, engineers leverage their professional dedication and decades of experience in working with the most complex vehicles ever built.

For more information, please visit: www.lmsintl.com.

NASA to Perform Ares GVT on Historic Test Stand

Using LMS Test.Lab, ground vibration testing of the full Ares I launch system will be performed in 2011 in the dynamic test stand at NASA's Marshall Space Flight Center, Huntsville, Alabama. A soft suspension system allows space vehicles to 'float' in an unconstrained environment for the large-scale vibration tests.

The facility was built in 1964 for vibration tests of the Saturn V rocket as part of the Apollo manned lunar missions. Later it was used in testing the Skylab Space Station and the Space Shuttle. After subsequent microgravity experiments, the facility was 95% mothballed and is now undergoing major refurbishment for the Ares tests. The tower is 360 feet high with a 64-foot overhead derrick, for a total height of 425 feet. For its unique role in the U.S. space program, the facility has been added to the National Register of Historic Places.