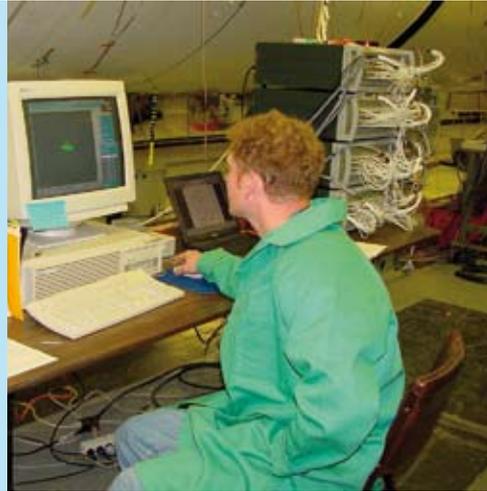


Back to the Moon, on to Mars



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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.

The 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 until now techniques were not available for accurately predicting the magnitude and frequency of the loads. 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 was 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 a very small number of 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. 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.

Value of a 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 is 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 thereby 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 such as 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 next-generation spacecraft

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 multi-million-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 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 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. ■



Vibration responses of the MSFC rocket nozzle test facility served as input for creating a structural dynamic model of the facility in LMS Virtual.Lab.



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