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Solid Rocket Motor Acoustic Testing

Jonathan D. Rogers
Sandia National Laboratories
Albuquerque, NM

Abstract

Acoustic data are often required for the determination of launch and powered flight loads for rocket systems and payloads. Such data are usually acquired during test firings of the solid rocket motors. In the current work, these data were obtained for two tests at a remote test facility where we were visitors. This paper describes the data acquisition and the requirements for working at a remote site, interfacing with the test hosts.

Introduction

One of the important environments for rocket systems and their payloads is the acoustic environment developed during launch and powered flight. These loads are known to have caused failures and an acoustic test is routinely required for preflight system qualification [1]. Thus, it is important to accurately characterize the acoustic environment developed by the rocket motor. Meeting this requirement is the responsibility of the rocket system integrator.

This paper describes obtaining the required data to characterize the acoustic environment of the STARS first stage motor, the A3-P. The focus of the paper is not on the specific motors or the program. Rather, the focus is on the process of obtaining the required data at a remote facility that was not accustomed to making such measurements. The issues of working in an unfamiliar facility and interfacing with unfamiliar equipment make the work useful to others faced with similar challenges.

Background

The STARS motors were first developed for the Polaris program in the 1960s, with a 20,400 pound propellant load in a 54 inch diameter motor case. These original test data were no longer available. Static firings were to be conducted at NAWC/China Lake to obtain engine performance data and to identify aging effects on the 20+ year-old motors. The acoustic data acquisition was an add-on to the scheduled static firing tests.

Solid rocket motor firing tests provide some special problems for instrumentation. First, since the rockets themselves are hazardous (containing 20,400 # of type 1.3 propellant) special care must be taken to avoid static electricity discharges. In addition, the rocket motor must be located remotely from the data acquisition system and all personnel. Second, the plume from the motor is extremely hot and the radiation heating can (and will) melt wiring and other materials. Third, sometimes things go awry and there is an abundance of available energy to take a small problem and expand it dramatically.

Test Configuration

Two static firing tests were performed in this test series. The instrumentation configurations are shown in Figures 1 and 2. For each test, six microphones were used to characterize the acoustic environment. For test 2, an accelerometer was added to one of the microphone mounting locations to characterized the vibration environment of the microphone and to check for possible contamination of the acoustic data from the vibration. All microphones were low impedance output piezoelectric devices. The accelerometer used for test 2 was also a low impedance output piezoelectric device. All data obtained during the test were recorded on analog tape by NAWC/China Lake personnel.

The test item was located about one mile from the test control and data recording building due to the hazardous nature of the test. The data were routed from the test item to a buried chamber (a WWII vintage armored personnel carrier) where the signals could be amplified for transmission via underground cables to the test control and recording building. The recorded data were taken to our facility for analysis.

An overall view of test 2 is shown in Figure 3. The nozzles of the rocket motor are facing the photographer. The large cylinder on the left is an X-ray source for radiographic imaging. Figure 4 shows the instrumentation set-up for the microphone and adjacent accelerometer. The microphone is covered

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by a foam windscreen to reduce the noise signal from wind. For each test, all microphones were covered with a windscreen and mounted in a similar manner.

Transducer calibration presents some special challenges in the field-testing environment. The very long signal lines can lead to significant noise problems. Thus, it is advisable to have signal conditioning amplifiers as near the test item as possible to reduce the influence of noise on the measurements. To achieve a traceable calibration in this case, we placed a data amplifier in the remote chamber and ran calibration signals through the entire system to the tape recorder.

The microphones were calibrated using a pistonphone, a constant displacement device that delivers a known oscillatory pressure signal to the microphone. The pistonphone provides a known Sound Pressure Level (SPL) of 124 dB at two frequencies, 250 Hz and 1000 Hz. The calibrations were performed and recorded on tape just prior to the test firing for each test. In order to have the voltage levels of the calibration signals at approximately the levels expected for the tests, the voltage amplifiers were increased in gain by a factor of ten for the calibration signals. Thus, the equivalent SPL recorded on tape for the calibration signals was 144 dB. We gained confidence in the voltage amplifiers by performing several tests of the voltage gain in our lab to ensure that a true factor of ten amplification would occur.

There was concern that the vibration of the motor case could lead to erroneous SPL measurements. An accelerometer, shown in Figure 4, was mounted beside one microphone to measure the vibration environment in the direction of the sensitive axis of the microphone. The microphone manufacturer listed the acceleration sensitivity of the microphone as 0.0015 psi/g (114 dB / g). With expected SPLs on the order of 140 dB a large acceleration could contribute to the SPL measurements. The accelerometer was present only for test 2.

Test Conduct and Data Analysis

Good quality data were obtained for each test. An anomaly in the first test firing caused concern over the validity of the SPL measurements. The anomaly, associated with the failure of the old putty retaining one nozzle in an unrefurbished motor, resulted in the loss of one microphone and a very nonuniform burn. The second test firing, using a completely refurbished motor, resulted in a typical burn. The SPL measurements of the two tests were very similar up to the point on test 1 where the nozzle was ejected.

Acoustic data were required at frequencies up to 10 kHz. To achieve this, the data were sampled at about 35 kHz with anti-aliasing filters set at 15 kHz. The SPLs are routinely displayed in decibels with a reference pressure of 20 μPascals. the data analysis system was adjusted to display the autospectral densities in these units.

A typical plot of the SPL is shown in Figure 5. This SPL is from late in test 2. The SPL shows that the bulk of the acoustic energy from the rocket motor is in the frequency range of X00 to Y000 Hz.

The motor case vibration was originally measured to determine if the SPL measurements were significantly influenced by the vibration of the motor case. As noted earlier, the nominal acceleration sensitivity of the microphones is 0.0015 psi/g. Since SPL is calculated based on rms quantities, it is appropriate to consider the rms acceleration associated with the most significant vibration response. The comparison of interest is between Figures 5 and 6, the SPL and the vibration ASD at the same point in time of the test.

Each plot was calculated using the same frequency spacing so the comparison is valid. Using the nominal acceleration sensitivity of the microphones, the "Vibration SPL" at the peak in the vibration autospectral density is 113 dB. The SPL measured by the microphone at the same frequency is 122 dB. A careful calculation of the contribution of the "Vibration SPL" to the measured SPL was performed since the decibel is not an obvious unit of measure for comparison. This indicated that the "Vibration SPL" contributed only 0.6 dB to the measured SPL, and as such may be disregarded.

Summary

Testing in field environments can be a challenging experience. Innovative methods may be required to ensure that good quality data are obtained. Special care must be given to calibrating all instrumentation as the unfamiliar surroundings can lead to unexpected problems. Careful checking of the data can improve confidence in the success of the test program.

References

1. Hamberg, O., Brackin, C. A., and Tosney, W. F., "Satellite Environmental Testing Cost Benefits." Proc. 12th Aerospace Testing Seminar, IES, Manhattan Beach, CA, March 13-15, 1990.

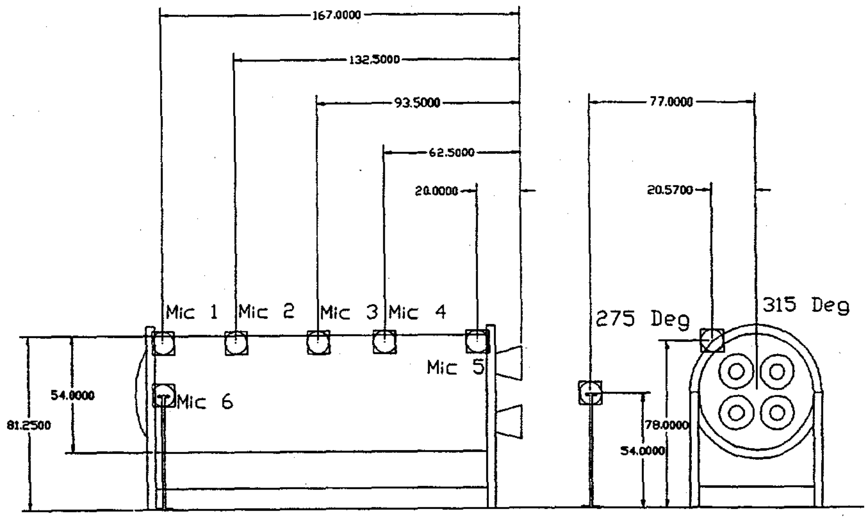

Figure 1. STARS Static Firing 1

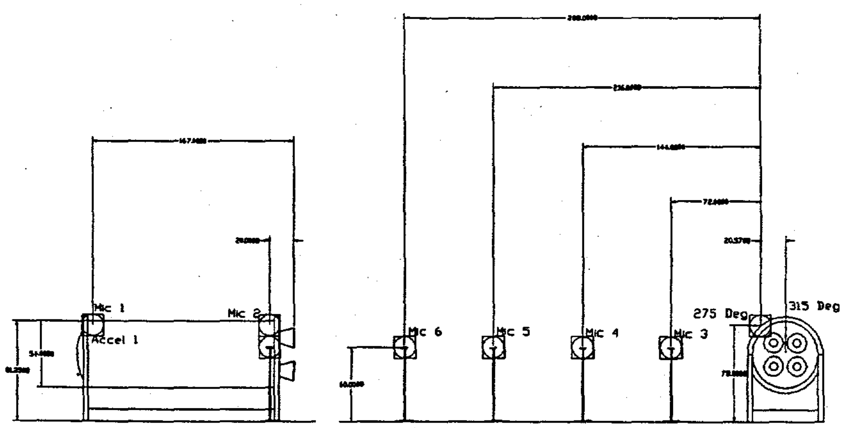

Figure 2. STARS Static Firing 2.

Figure 3. Overall view of Static Firing 2

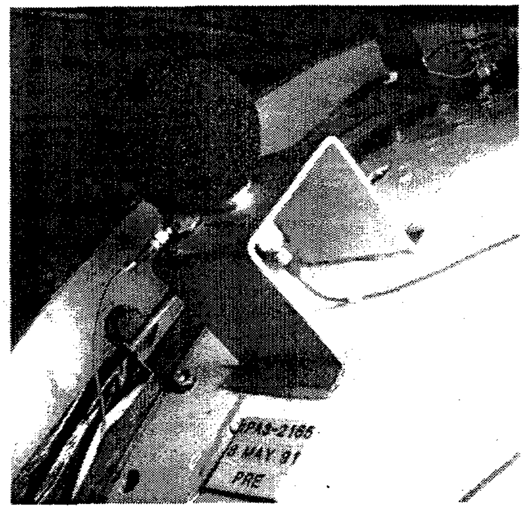

Figure 4. Instrumentation on Static Firing 2

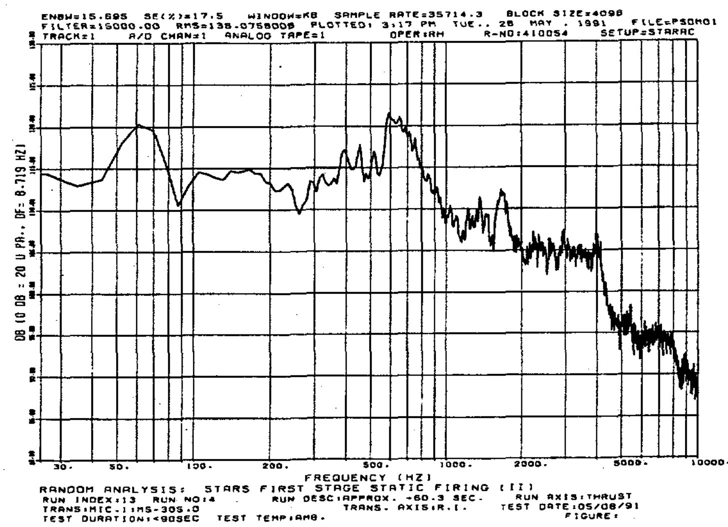

Figure 5. SPL for Microphone 1, Test 2.

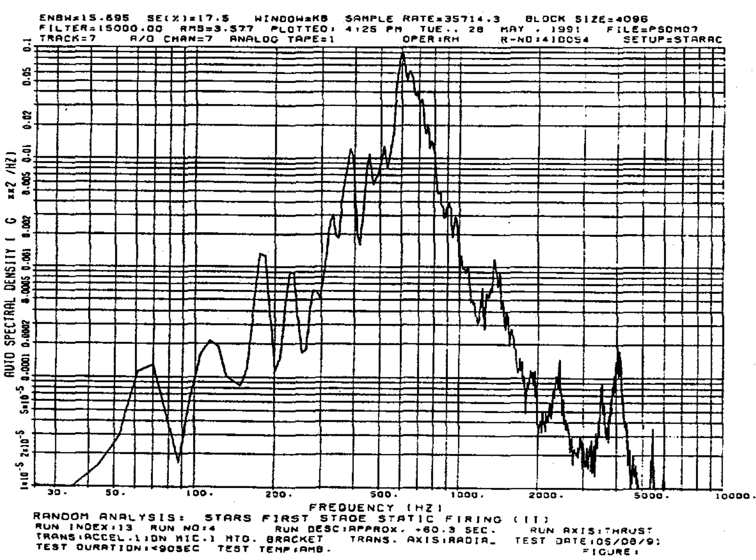

Figure 6. Autospectral Density for the accelerometer.