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FINAL REPORT

April 22 - July 21, 1986

To

George C. Marshall Space Flight Center
Environmental Analysis Branch
Propulsion Test Division
Marshall Space Flight Center, Al. 35812

SSME MAIN INJECTOR 4000 HERTZ PHENOMENON

NASA Purchase Order H-85081B

By

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Principal Investigator

Aug 21, 1986

SSME MAIN INJECTOR 4000 HERTZ PHENOMENON

Introduction

Several Space Shuttle Main Engines have experienced very high acceleration responses measured in the main injector of the powerhead during static firings. This unusual response has been noted to occur very prominently on about four engines in particular. The responses are centered around 4000 hertz, and as fatigue sets in, the frequency shifts downward.

This purchase order (H-85081B) was issued to enlist additional help from the principal investigator, G. D. Johnston, to monitor flow tests on a powerhead installed at Test Stand 116 for water flow experiments designed to re-create this "4000 Hertz" high Q response. The principal investigator was to study the test setup, assist with instrumentation problems to assure good data, witness the tests and assist in the data analysis review.

Figures 1 and 2 show the location and number of accelerometer, pressure and strain gages used to record data during the various flow tests. These sketches show the basic structure used in the test setup; however, the overall setup was more involved.

Data from previous hot fire SSME tests relating to the 4000 hertz phenomenon were reviewed to provide a better understanding of the nature of this structural response. The objective was to technically understand the way this phenomenon works, recommend a fix and test the fix.

Work Performed

The period of this work effort officially began on April 22, 1986, and was necessarily stopped on July 21, 1986, when the amount of time applied to the effort exhausted the available funds. The work covered exactly a three months period. Considerable work remains to be performed on the overall program, and it is with a great deal of regret that we must stop our effort since we had just begun to get a 'feel' for the nature of the problem.

To get the work started, a large package of data including time histories and spectral plots were reviewed from past engine firings. This data was a compilation of plots seclected from over 200 tests covering SSME units 2025, 2116, 0110F, 0005, 2026, 2011, 0010, 2024 and 2012. In addition to this review of data, the author met with Mr. Bill Smith and Mr. Wayne Swanson to discuss other data related to the 4000 hertz problem. This served to provide the author with an up-to-date status on the severity of the problem.

The modal test data performed prior to the start of the water flow tests on the Main Injector #0008 was reviewed. The test could have been enhanced had more data points been obtained, particularly on the 'hot dog' and Lox Inlet Tee. The data does show at least three potential modes which could be related to this phenomenon. These modes show very little damping which definitely fits the criteria for the 'buzz' frequency.

Mode 8 (3850 Hz) of test TSS-001 shows the type of structural response that could provide the necessary phasing for the splitter vanes to have a high 'Q' response. The damping is very low in this mode, but not enough data points are available to really pinpoint it as the strongest possibility. In test TSS-002, mode 2 (4107 Hz, .24% damping) is another strong candidate; however, the limited amount of data on the 'hot dog' doesn't allow one to see the precise movement. In fact, the data tends to show less 'hot dog' action than in the 3850 hertz mode. The effect of water mass loading the injector to cause these frequencies to be lowered will probably be offset by the internal pressure which will tend to stiffen the structure and increase the frequencies. The modal test proves that this test setup has lightly damped modes in the range of 3700 to 4200 hertz where the problems have been observed.

Regardless of whether #0008 is proven to be a 'buzzer' in this setup or not a 'buzzer', it is recommended that this main injector be removed from this setup as soon as practical and subjected to a very detailed modal analysis test in a free-free condition. If data can be obtained from the splitter vanes, it should be of a high priority.

Instrumentation problems developed during the early low-level flow tests. The author assisted in acquiring replacement pressure transducers for damaged ones following the flow tests on April 15. The accelerometers located on the 'hot dog' near the splitter vanes (particularly A4) were being shaken off. One accelerometer was literally shook apart. The author was requested to provide an expert in epoxy bonding to reattach the accelerometers. Vibration and Acoustics, Inc., paid Mr. Bill White to install the accels on four occasions. The author ordered a large supply of the epoxy that Rocketdyne uses (Kalex D-85) and also obtained some Normco 7343, a proven epoxy for this type application even at cryogenic temperatures. The instrumentation attachment is very important because without a continuously rigid attach point the data is not reliable or is lost altogether. The author ordered pressure transducer adapters from PCB Industries (#62 PCB adapters). A recommendation was made that lighter mass accelerometers be used (Endevco 2226) to reduce the stress on the epoxy bond. Also, it was recommended that Endevco 2225 shock accels be used where stud mounting was acceptable.

On April 15 two tests were run. One at 2000 psi supply pressure and the other at 2500 psi. The accelerometer bonding was better, but the violent environment eventually shook the bonded accels off and backed the stud-mounted accels out to where they were loose. We continued to experiment with Kalex D-85 and Normco 7343 until we got the accels to stay on through some of the 4000 psi tests. It should be pointed out that above 4000 psi supply pressure the violent environment not only debonded the accels it literally destroyed the pressure sensors.

The author made arrangements with the Dynamics Test Branch to run vibration tests on the pressures transducers (PCB 113A23, Kistler and Kulite) used to obtain pressure data to determine their sensitivity to mechanical excitation. The vibration test did not show an excessive response to mechanical excitation in the frequency range that it was driven. This tends to prove that the signal from the pressure transducers is the fluctuation of the fluid pressure in the line. We know that the spectral content of the pressure measurements were very much like the mechanical response of the accels. This all seems to say that the fluid is the source of energy that is driving the injector structure.

The author followed the flow test through the highest supply pressures (4750 psi) and the subsequent valve throttling tests. A limited amount of data was reviewed.

On April 29, the author attended a meeting to discuss the test setup for the plastic model water flow test. A shaker (model UD 6) was recommended to support this test. The author later went to Bldg. 4650 with Mr. Tomas Nesman to identify the shakers to be used for this test.

Following the final water flow test on #0008, the author assisted with the instrumentation on the 6.4% model acoustic setup for the WTR configuration. A vibration test procedure was written to cover an evaluation of the Larson-Davis microphone preamplifier. The purpose of the test was to determine its sensitivity to mechanical vibration much like the previous test of the pressure transducers, but the test had to be delayed when several on-line microphone preamplifiers failed. The two complete channels to be used for the vibration test had to be carried back to the blockhouse and installed to Test Stand 116. The author compiled a list of acoustic instrumentation needed to support this program and filled out a procurement request for acquisition.

Summary

Several Space Shuttle Main Engines had exhibited a high level of vibration in the main injector during hot firings. The high 'Q' response is usually centered around 4000 hertz. Vibration and Acoustics, Inc., received a purchase order (H-85081B) to monitor water flow tests on injector #0008 at Test Stand 116.

The author reviewed data from past hot firings and data from the water flow tests. The data from the main injector modal test was also reviewed.

It is rather obvious to state, but a very thorough examination of the injectors known to have the most severe responses (S/N's 0110F, 2116, 2025 & 2026) would problably reveal some structural feature that is causing the problem. In the absence of that hardware, it is recommended that S/N 0008 be removed and thoroughly examined (using dye penetrant). A very detailed modal test should be performed in the free-free condition and then reinstalled with boundary conditions for retest.

This purchase order only had sufficient funds to cover a three month period. The author regrets that he could not spend more time on the test results because the 'feel' for the problem was just being attained when the funds ran out. The original funding only allowed for an expenditure of 114 manhours. It is our desire to continue work on this problem in the future if funds are ever available to do so.

Financial Report

During the three months period (Apr 22 - Jul 21, 1986) 114 manhours were expended. Given the negotiated rates for labor, overhead and fee, the hours stated will utilize the total funds available as shown in the enclosed invoice.

Signed

G. D. Johnston

G. D. Johnston P. I.

Date: 8-22-86

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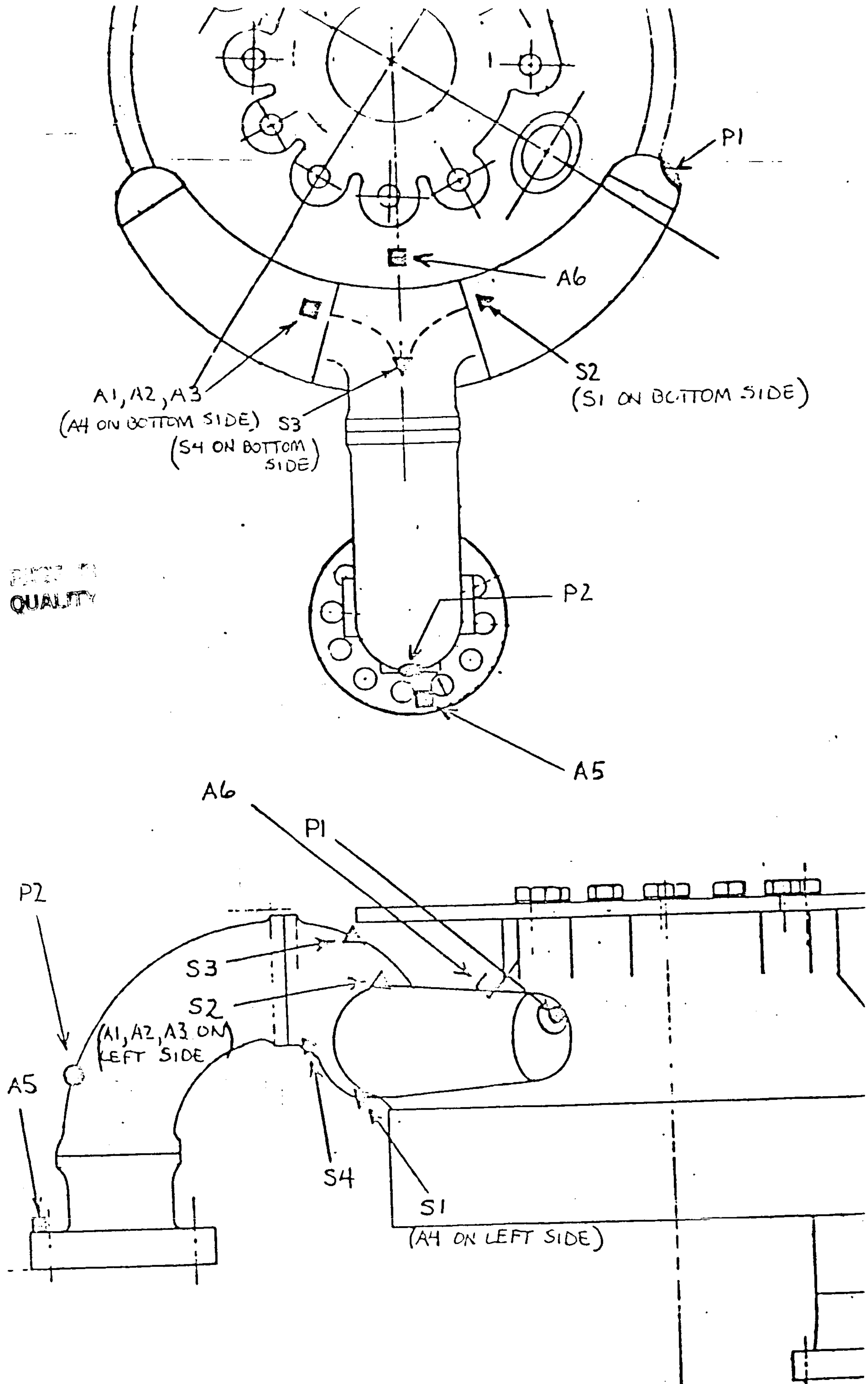
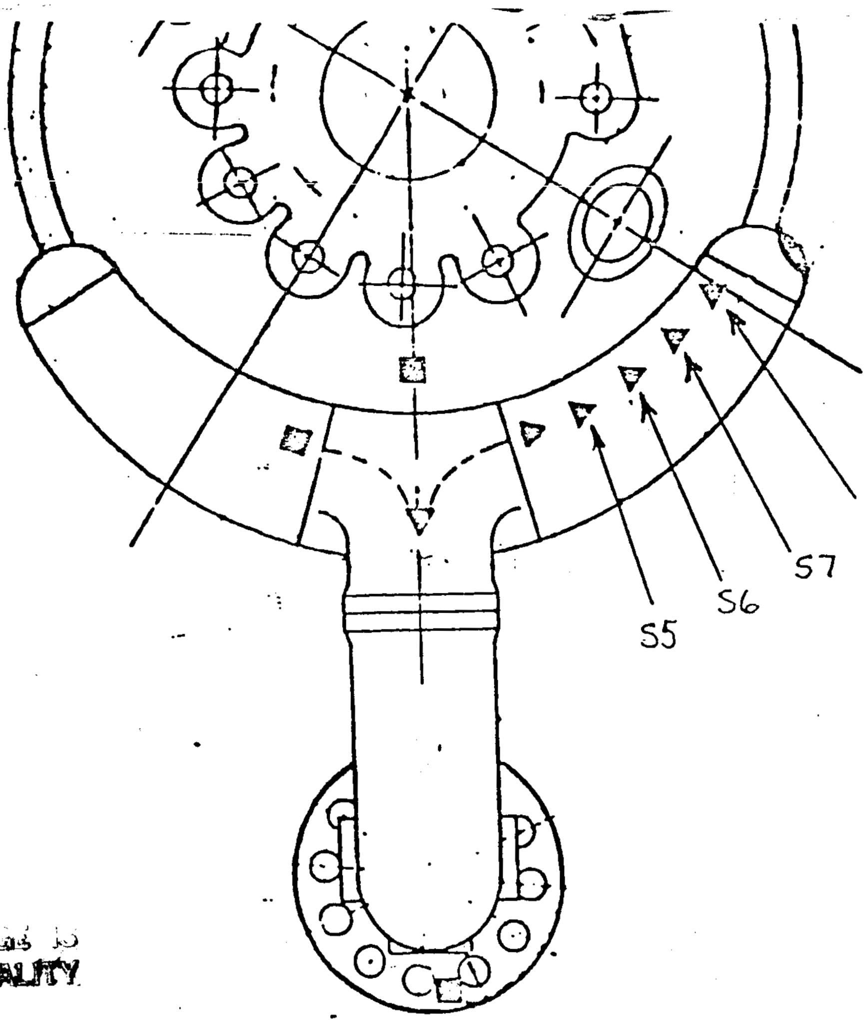


FIGURE 1. POWERHEAD ASSEMBLY MODEL AND INSTRUMENTATION LOCATIONS



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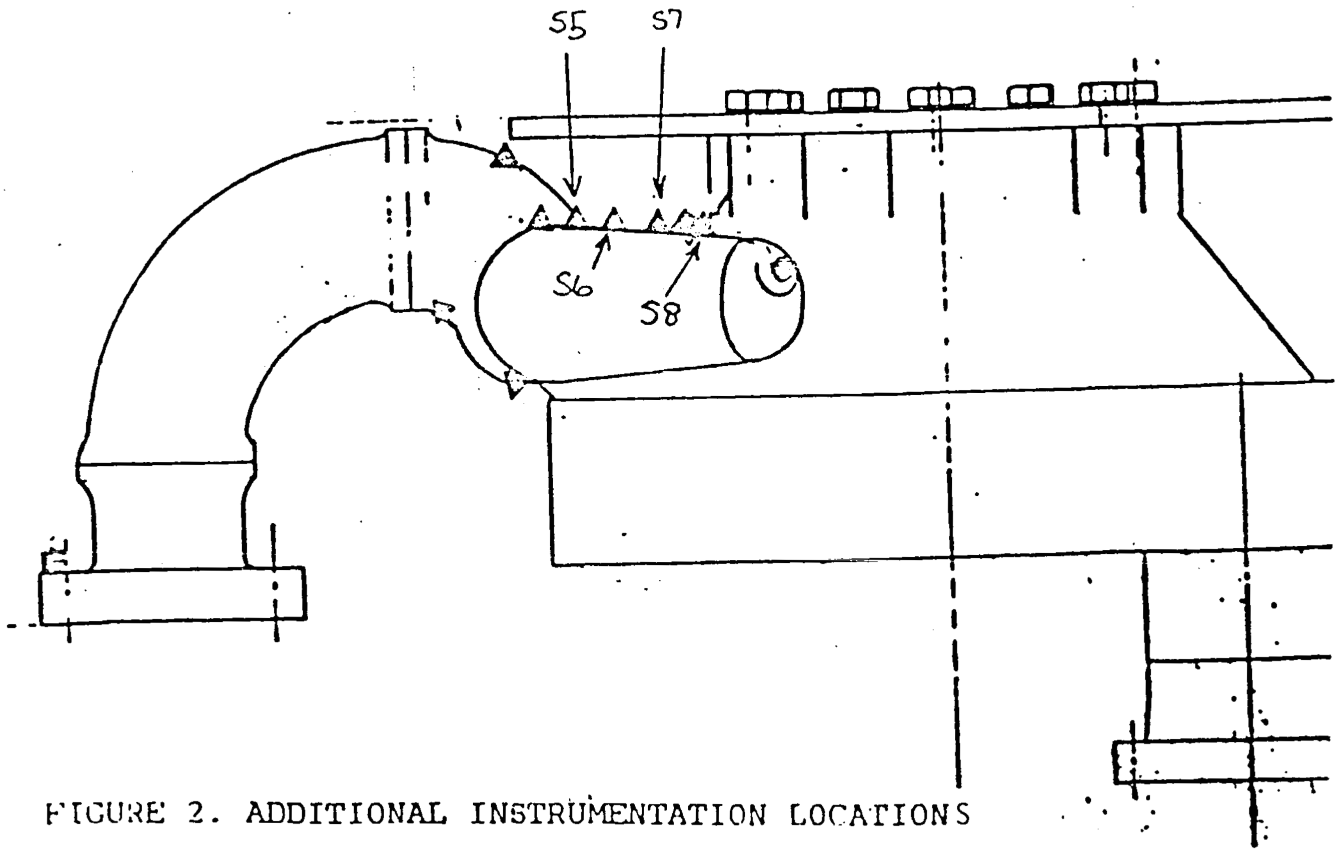

FIGURE 2. ADDITIONAL INSTRUMENTATION LOCATIONS