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PULSED MAVERICK TESTING FINAL REPORT

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FORWARD

This is the final report on the Pulsed Maverick Test Program conducted in-house by the Combustion Technology Section, Technology Division, Air Force Rocket Propulsion Laboratory. The program was conducted under Project Number: 319A04CW. This report covers the testing of production Maverick Motors for combustion stability by pulsing the motors during firing. Testing of motors was accomplished in the period Dec 75 through May 76. Data analysis was completed subsequent to the testing. Project Manager for the program was Mr. Jack E. Hewes. Assistance in the data analysis was provided by Capt. Jack J. Donn (AFRPL/DYSC) and instrumentation assistance by Mr. Richard Grove (AFRPL/TEBC).

This report has been reviewed by the Information Office/DOZ and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations. This technical report has been reviewed and is approved for publication; it is unclassified and suitable for general public release.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This program was conducted to determine the combustion stability of the Maverick motor. This report details the testing performed, the data analysis and conclusions.

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PULSED MAVERICK TESTING

I. INTRODUCTION

As early as 1963 pulse techniques were employed[1] for establishing stable operating regimes in solid propellant rocket motors. The utility of the method, however, was limited to instances where the motor was unstable to a finite amplitude excitation. The successful application of pulsing techniques to the quantitative study of linear (or incipient) stability of aluminized propellants in the T-Burner[2] suggested the possibility that similar techniques could be employed on full scale development motors (a) to establish the degree of incipient stability of the motor and (b) to determine if the motor is sensitive to pulse excitation. The first objective would allow an assessment of the relative combustion stability characteristics of several motor-propellant systems and at the same time provide data for evaluating the validity of stability prediction models. The second objective would provide a means of minimizing the risk of instability initiated by the unexpected ejection of material through the nozzle throat.

With the above goals in mind, AFRPL began a series of motor tests to evaluate the adaption of the T-Burner pulsing technology to full scale motor pulsing. A previous report[3] detailed the early results of a series of pulsed tests of 70 lb Ballistic Test and Evaluation System (BATES) motors. This report summarizes the application of the pulsing technology to a full scale Maverick tactical motor.

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1. Morris, E. P., "A Pulse Technique for the Evaluation of Combustion Instability in Solid Rocket Motors," Canadian Aero. and Space Journal, 11 (9), 1965.
2. Culick, F. E. C., "T-Burner Testing of Metallized Solid Propellants," AFRPL-TR-74-28, Oct 1974.
3. Walsh, R. K., "Pulsed BATES Testing and Analysis," Proceedings of 12th JANNAF Combustion Meeting, Aug 1975.

II. BACKGROUND

Following the success in obtaining measurable pulse decays in the BATES test series, it was decided to explore the capability of extending the pulsing techniques to the more complex Maverick motor.

For this purpose, ten production Maverick motors were obtained for use in determining the stability of the production motor. This information could then be used to establish a limit to the instability acceptable in a new generation of Maverick motors. In addition, three early development reduced-smoke Maverick motors, known to be unstable, were tested though not pulsed in this test program. Since the unstable motors would have prolonged an unstable condition during a test, a check of the instrumentation systems capability could be accomplished. In addition, correlations between pressure and accelerometer data could be made to determine if the accelerometer data could adequately depict unstable motor conditions.

III. TEST HARDWARE

The current production Maverick motors tested (Figure 1) had a sixteen point star grain of polysulfide propellant with two percent aluminum. The grain configuration gives a boost-sustain ballistic profile.

Pulsing was accomplished using a dual pulser system designed and furnished by the Thiokol Corporation. The charge weight and burst disc parameters were held constant throughout the testing. The pulser system was a modification to the igniter (Figure 2) and the Figures 3 and 4 show respectively the pulser adapter with pulsers and the end modification to the igniter which accepts the pulser adapter. Note that the pulser gases are injected into the chamber at an angle to the motor centerline which might be expected to excite transverse oscillations in the chamber cavity. The pulsers used $BKNO_3$ pellets as a source for the high pressure gas expelled into the chamber.

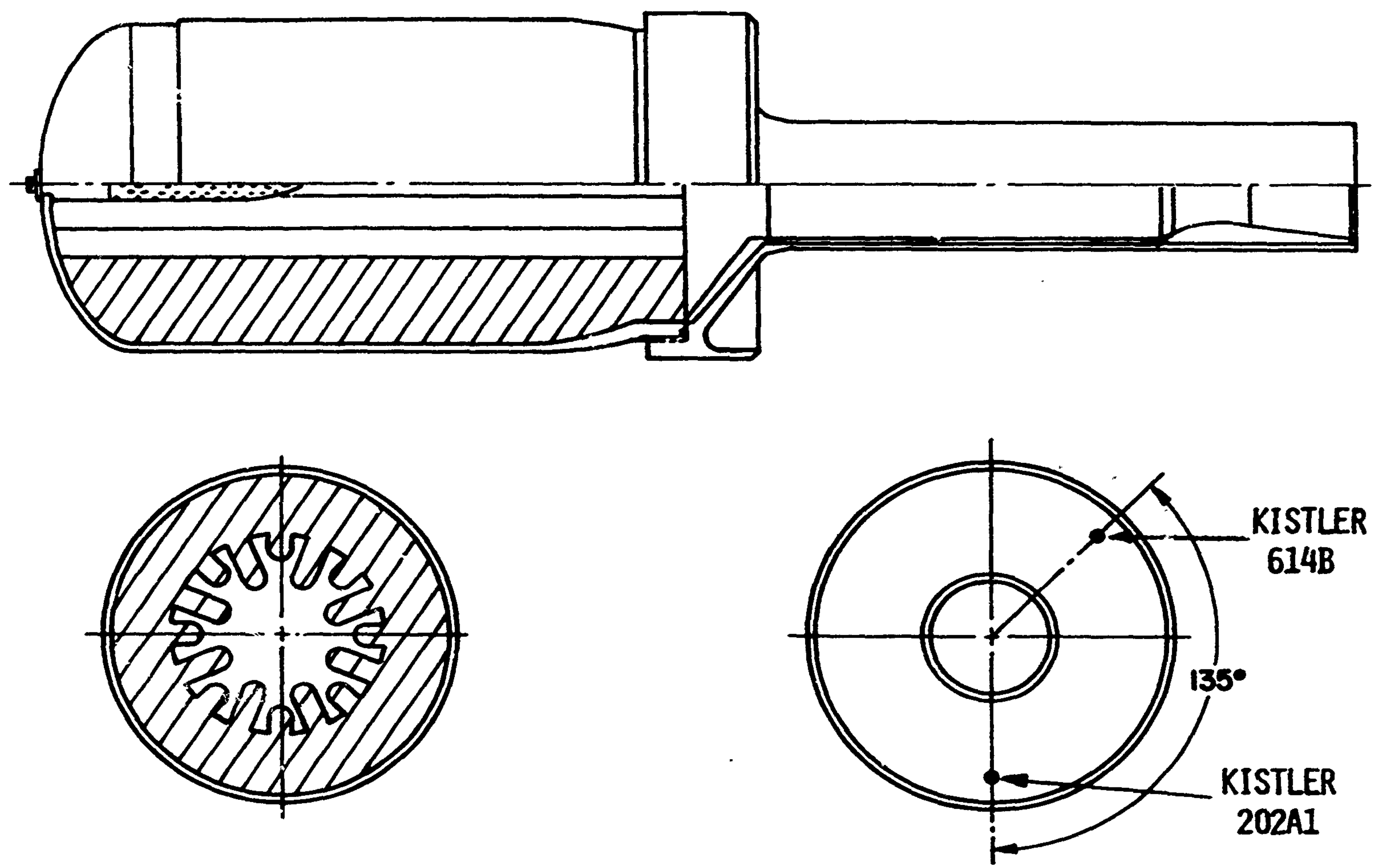

Figure 1. Pulse Maverick Motor

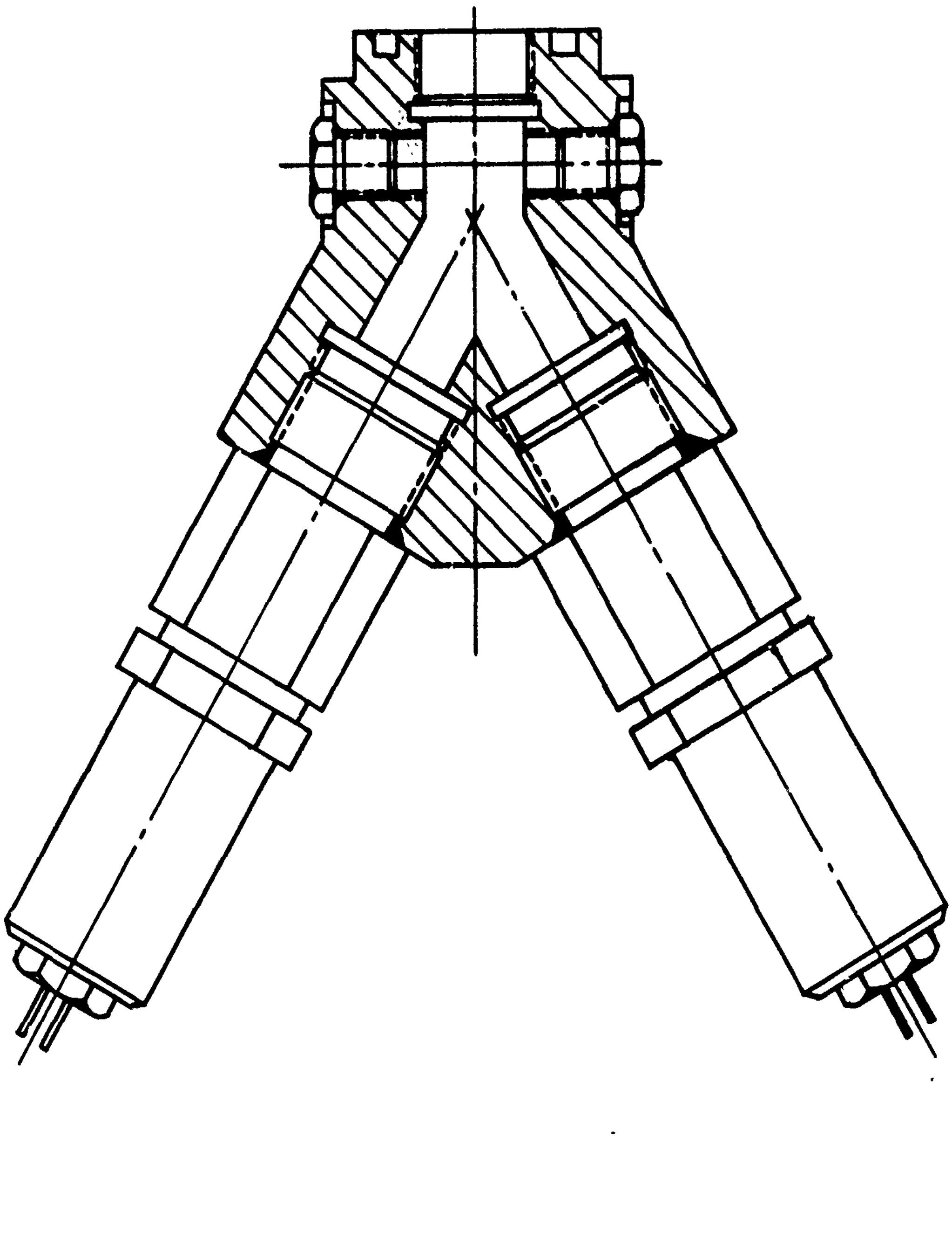

Figure 2. Pulse Maverick Pulser Adapter/Pulsers

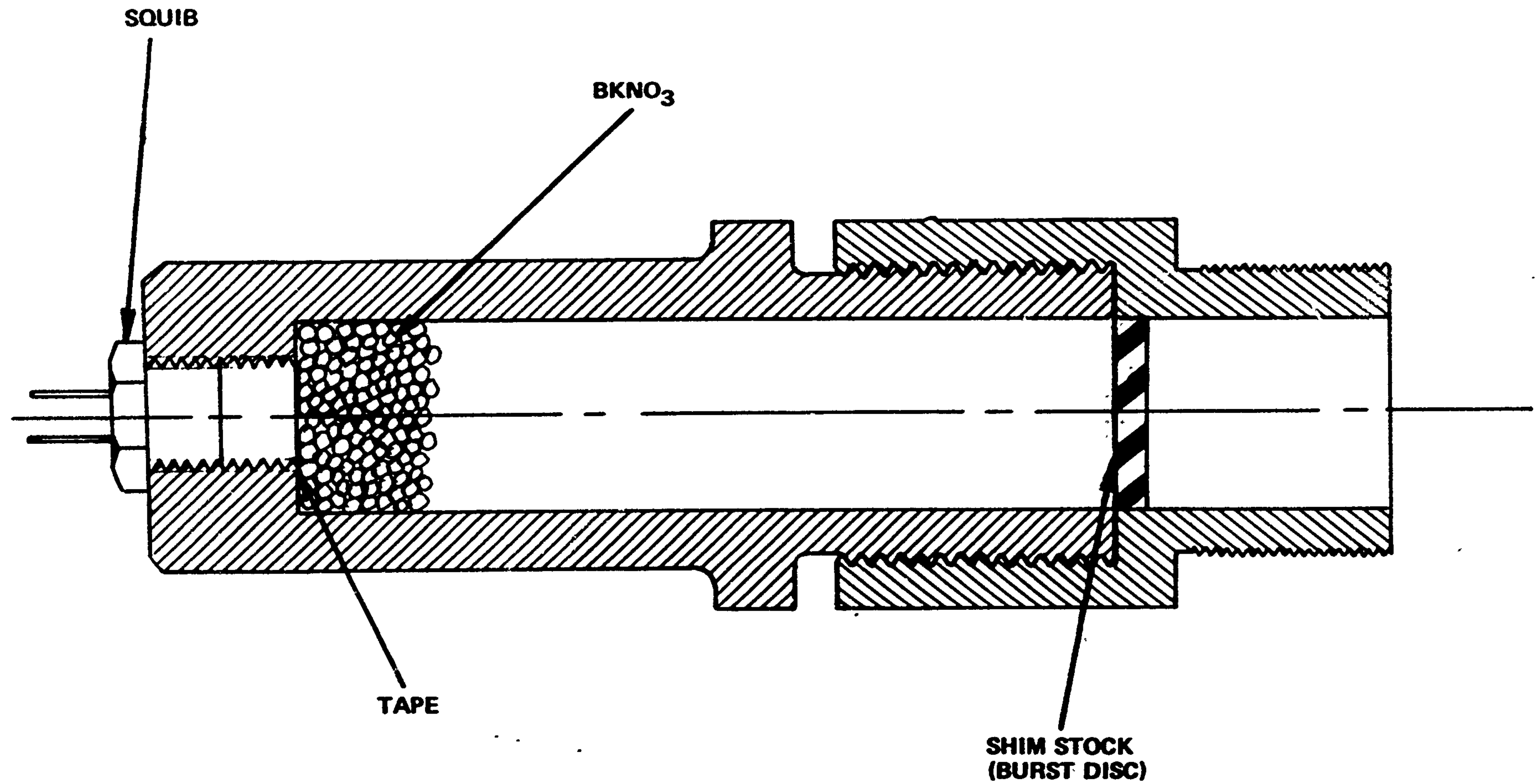

Figure 3. Pulser Assembly

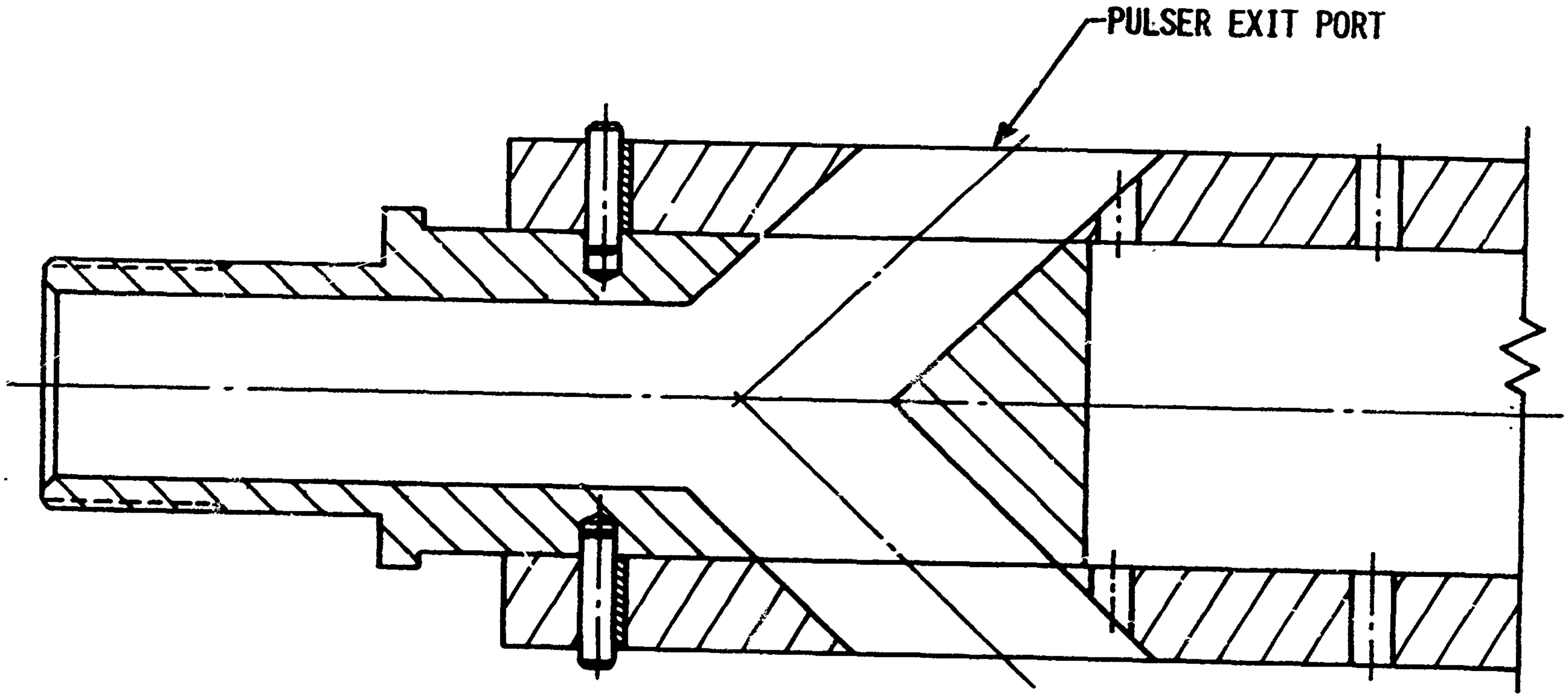

Figure 4. Pulse Maverick Modified Igniter

The three developmental reduced smoke motors were standard configuration including the igniter. No pulsers were required as these motors were known to be spontaneously unstable.

The temperature conditioning of the motors was accomplished by use of a system to vaporize liquid nitrogen or heat air and blow the gas through an insulated box which encased the motor. In this manner, the motor could be conditioned to a temperature of either -75°F or +170°F. The soak time to obtain a stable conditioned temperature was on the order of 20 hours.

The test stand, used for this series of test, was located at Test Area 1-52, Test Pad B. The test stand is a three point thrust mount designed by Ormond.

IV. TEST INSTRUMENTATION

Each motor was instrumented with two Kistler piezoelectric pressure transducers and two Taber strain gage pressure transducers and nine Kulite piezoresistive accelerometers.

Two models of Kistlers transducers (Figure 5) were employed. One was a model 614B, which is a water cooled helium bleed type and represents the AFRPL preferred method of measuring high frequency, low amplitude pressure oscillations. The other Kistler was a model 202A, which is the type used by Thiokol Chemical Corporation, Huntsville Division, in their motor testing. The Model 202A diaphragm was protected from the hot gases of the rocket motor by a 3/8 inch plug of cured RTV rubber.

During the large pressure transitions which occur at ignition and during the transition from boost to sustain mode, the pressure transducers were electrically shorted in order to avoid amplifier overload and to permit amplifier gain settings which would allow the detection of pulser induced pressure oscillations of 20 to 30 psi in the chamber.

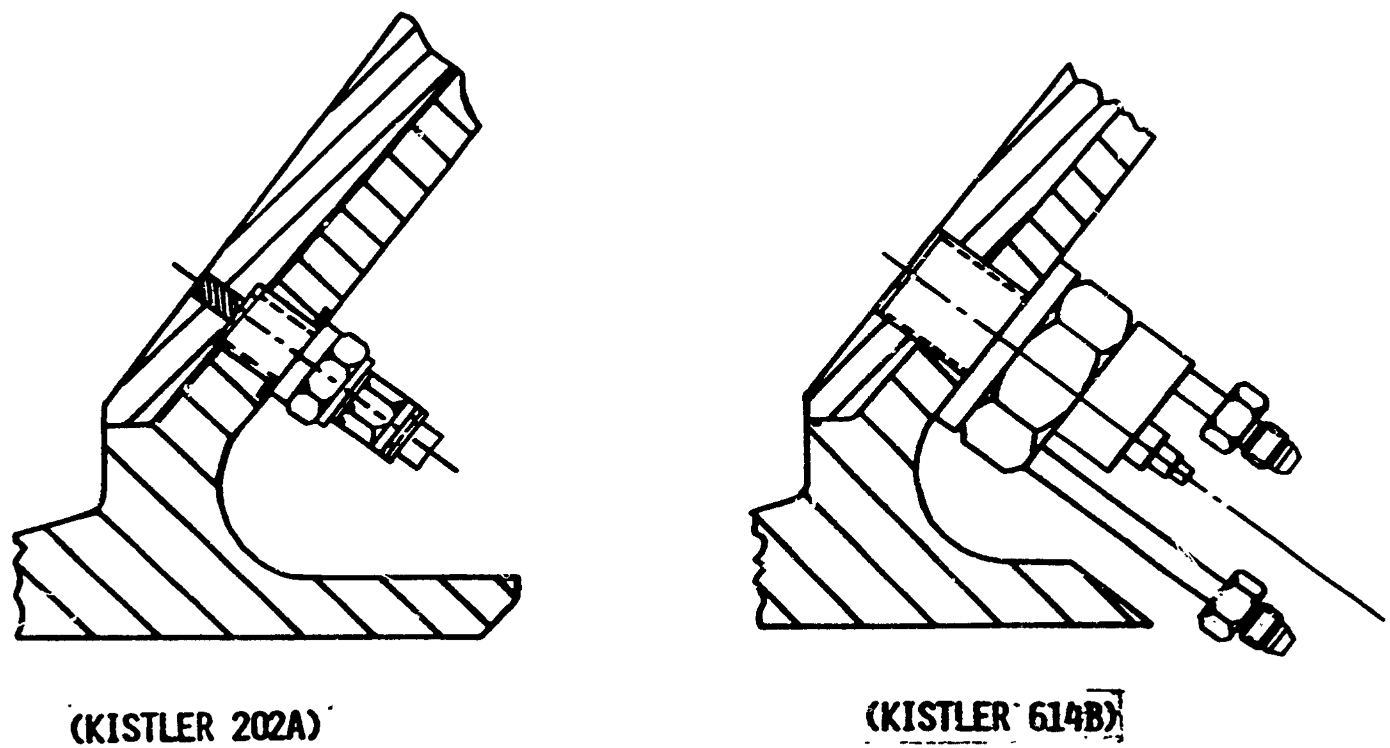

Figure 5. Pulse Maverick Pressure Transducer Installation

The data acquisition system for measuring the high frequency pressure oscillations generated by pulsing is shown in Figure 6. In this system the data is recorded on the FM tape without any filtration except whatever small amount might be inherent in the system. This method of recording permits the filtering during playback to be tailored to the various acoustical modes of the motor.

The motor case was also instrumented with nine accelerometers (Figure 7) of which one was tri-axial making a total of eleven accelerometer measurements taken on the motor. With the exception of the tri-axial accelerometer, the accelerometers were mounted with their sensitive axis in the radial direction. The tri-axial accelerometer had its axes oriented in the radial, longitudinal, and circumferential directions.

V. TEST PROGRAM

The test matrix of the 13 motors tested is presented in Table 1. The initial three motors tested on this program were standard production motors without the igniter modified for pulsing. Also, these same three motors were the baseline series with which to compare subsequent pulsed motors.

The next six production motors were supplied with the igniter modified with the pulsers. The two pulsers were used to pulse the motor once during boost and once during sustain. The tenth and final motor was pulsed only in the sustain phase and both pulsers were fired simultaneously in an attempt to force instability within the motor.

The motors were conditioned as shown in Table 1. The motor conditioning was accomplished to determine if the motor temperature had any effect on the stability characteristics of the motor.

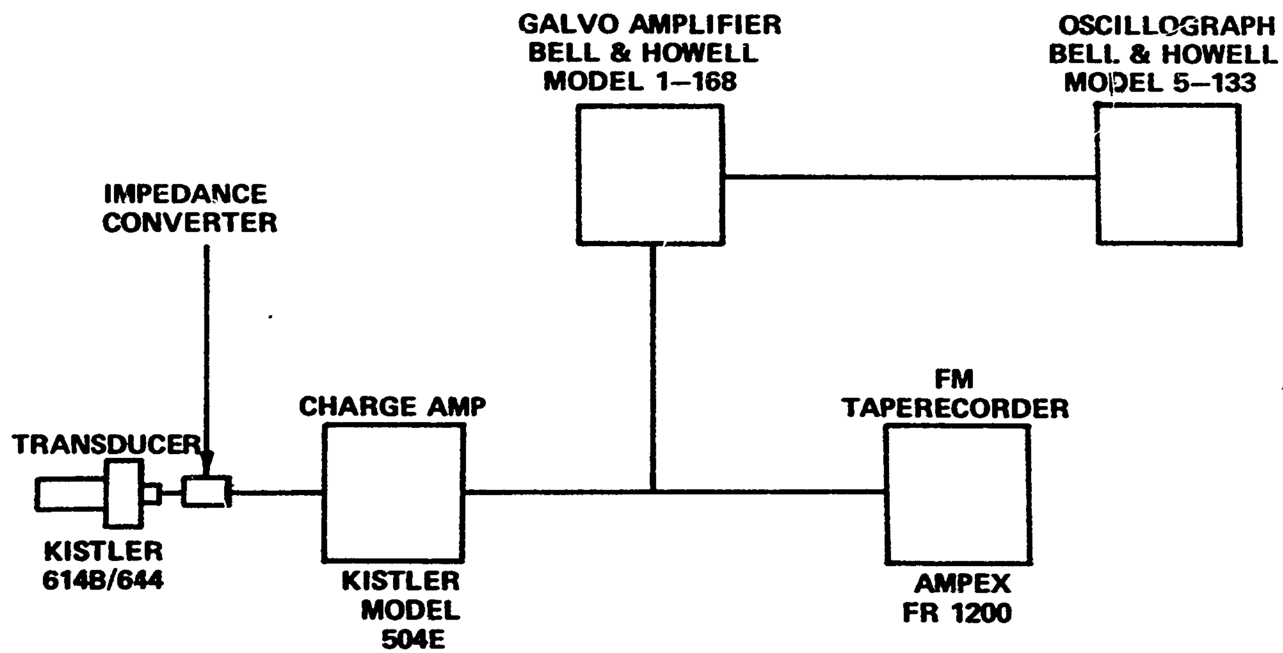

Figure 6. Typical Instrumentation System

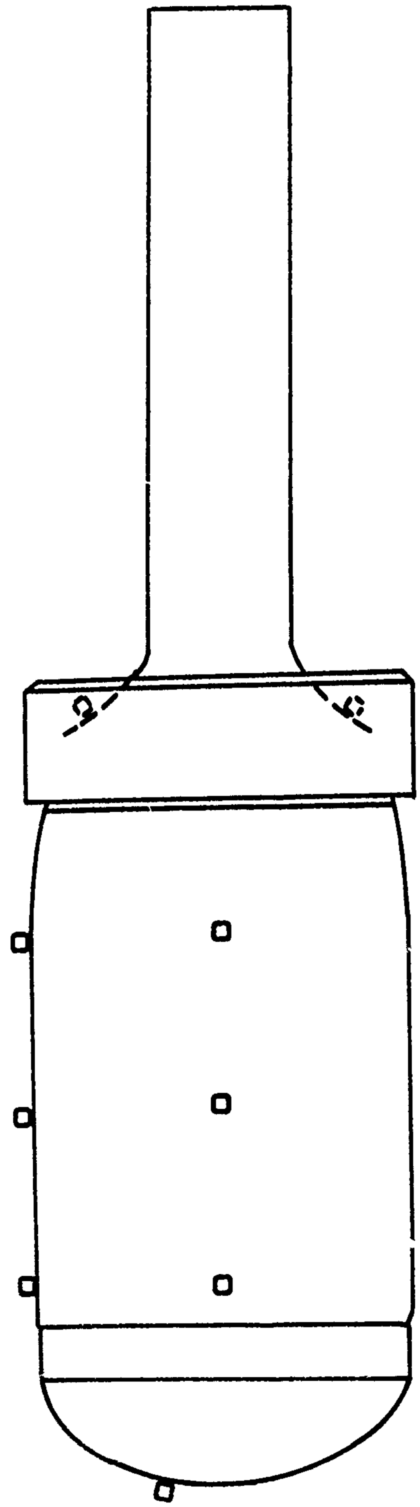

Figure 7. Accelerometer Locations

TABLE 1: Motor Test Matrix

MOTOR NO	NON-PULSED	PULSED	AMB	HOT	COLD
1	X		X		
2	X			X	
3	X				X
4	X		X		
5		X		X	
6		X		X	
7		X			X
8		X			X
9[1]	X			X	
10[1]	X			X	
11[1]	X				X
12	X	X			X
13[2]		X	X		

NOTE: (1) Motors 9, 10, and 11 were supplied with spontaneously unstable propellant.

(2) Both pulsers fired in sustain.

VI. TEST RESULTS

The three initial production motors tested exhibited no evidence of instability, and all motor performance parameters were nominal for the motors' temperature condition when tested. The six production motors which were pulsed twice demonstrated no instability in either the boost or sustain mode. A representative mean pressure trace showing the time of the two pulses is shown in Figure 8.

Figure 9 shows representative pressure and accelerometer signals from the Maverick pulse test series as well as the corresponding frequency domain spectra. The identification of the pressure signal spectral components with NASTRAN calculated acoustic mode frequencies is presented in Table 2. Of particular interest is the fact that transverse acoustic mode frequencies are observed excited by the pressure pulse. The identification of these pressure oscillations as transverse is reinforced by the significantly higher response of the radially oriented accelerometer at these frequencies as compared to the axial mode frequencies.

To evaluate the capability of obtaining quantitative measures of motor stability from the pulse data, the high frequency pressure channels were band-pass filtered for the first axial mode frequency (900-1100 Hz filter bandwidth). Figure 10 shows a representative trace of the filtered signal as well as the peak-to-peak amplitudes plotted versus cycle. A linear regression of the latter data points was used to obtain the linear decay coefficient. These results are listed in Table 3 for both pressure transducers. Not all runs yielded reducible data; the problem was one of signal-to-noise resulting from weak pulses. The data show excellent agreement between the two pressure transducers models.

The three early development reduced smoke motors (Tests 9-11) did go unstable as soon as the motor transitioned into the sustain mode. This instability persisted until burnout. A spectral analysis (Spectral Dynamics

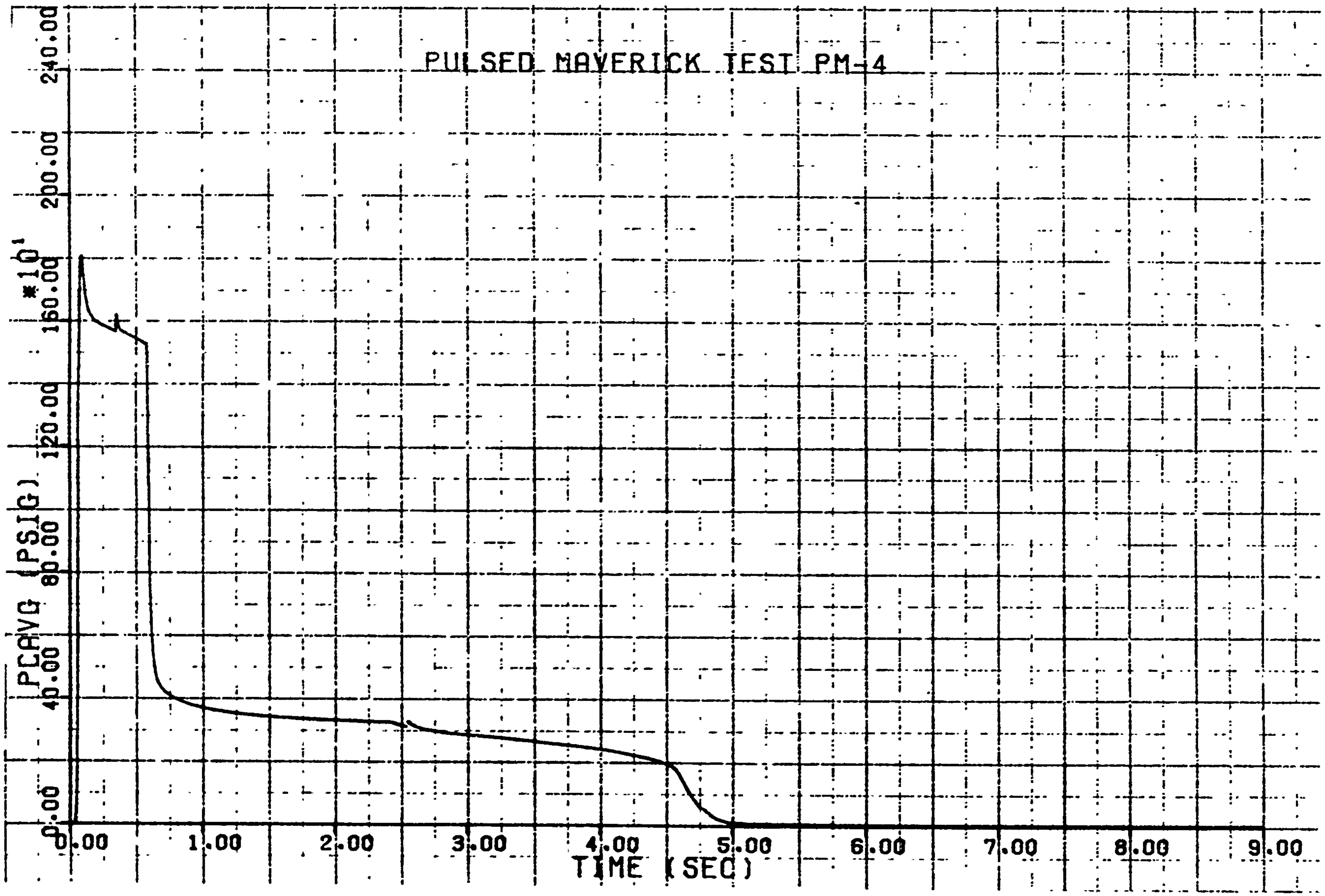

Figure 8. Motor Pressure Time History

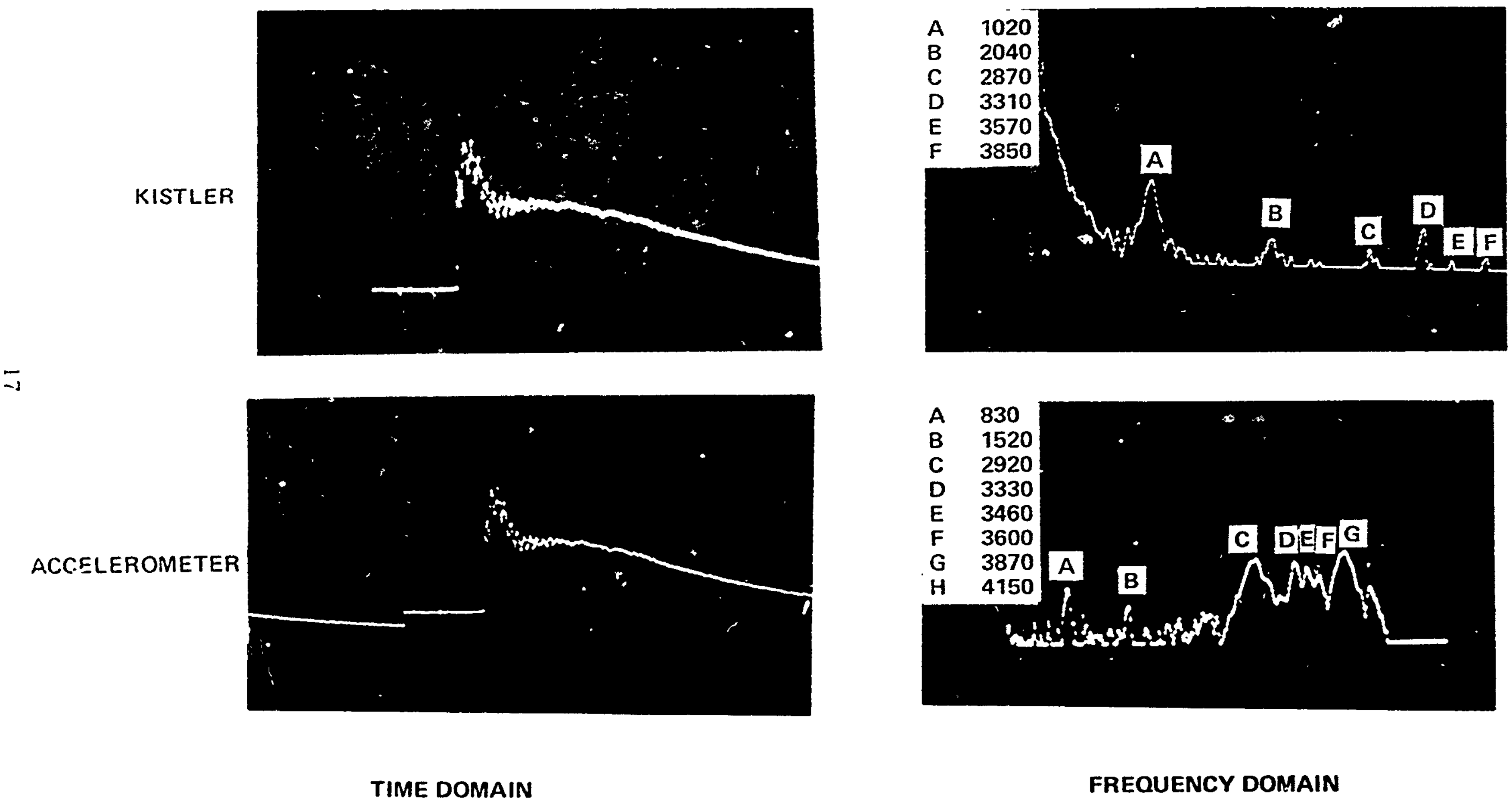

Figure 9. Pulse Maverick Run 8/Pulse 1

Table 2. Pulsed Maverick Data Run 8/Pulse 2

MEASURED FREQUENCIES FROM
KISTLER MODEL 614 PRESSURE TRANSDUCER

FREQUENCY ANALYZER (Hz)	NASTRAN CALCULATED FREQUENCIES (Hz)/ACOUSTIC MODE
1020	1040/1L
2040	2054/2L
2870	2935/1T
	3044/3L
3310	3310/1T-1L
3570	3756/1T-2L
3850	4015/4L

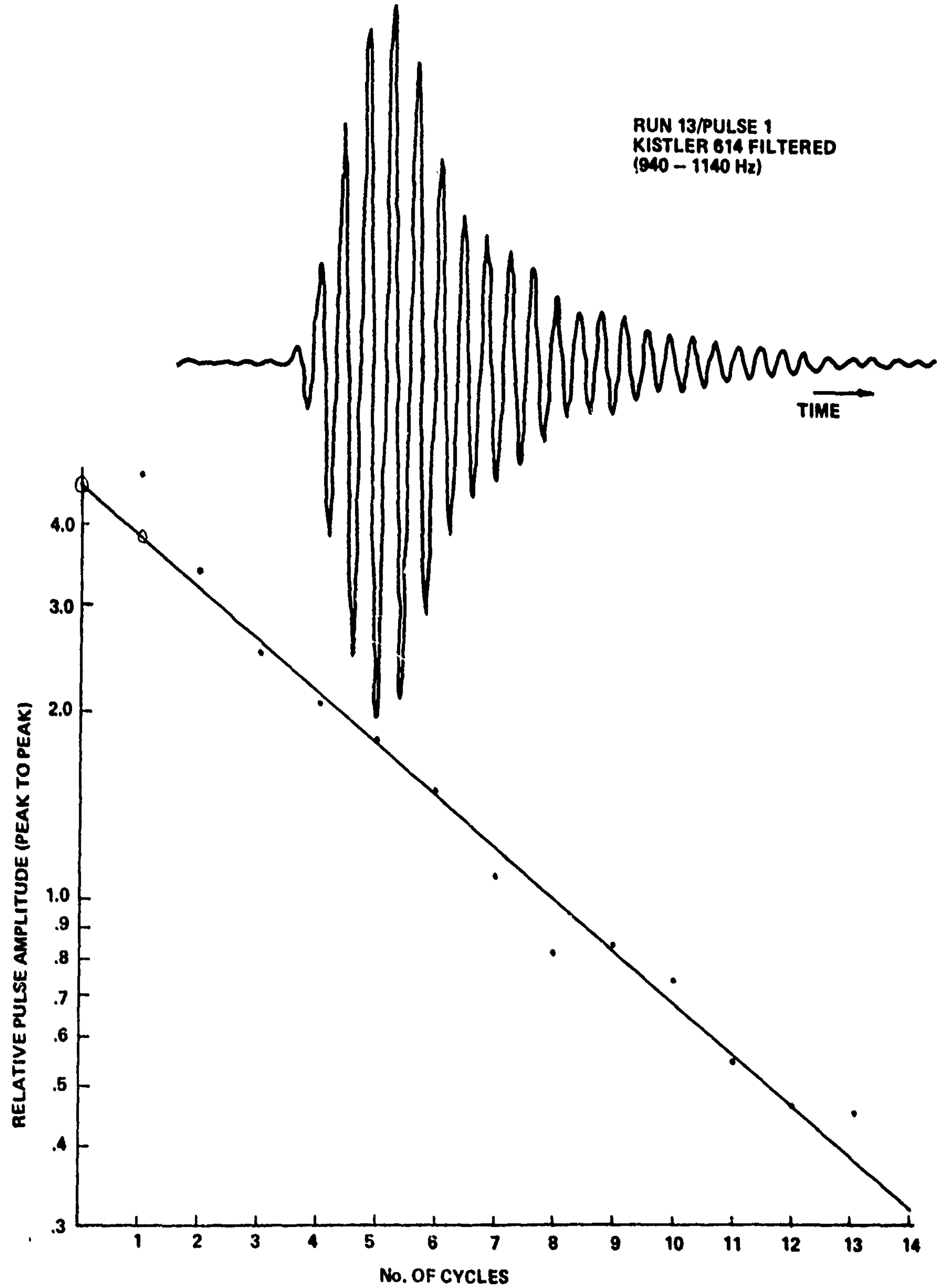

Figure 10. Linear Regression Fit of Filtered Pulse Data

TABLE 3. Measured Pulse Motor Decay Coefficients

TEST NO	PULSE NO	CONDITION TEMP (^{o}F)	% WEB	MOTOR PRESSURE (psi)	DECAY COEFFICIENT (SEC^{-1})	
					PL3	PL4
4	2	AMBIENT	.55	250	-221	-215
7	1	-75	.06	1300	-291	-289
7	2	-75	.59	225	-205	-
8	2	-75	.59	210	-248	-250
13	2	+170	.67	230	-198	-196

PL3: Kistler Model 614

PL4: Kistler Model 202

Corporation Model SD 2001-22 Digital Signal Processing System) of the data from each channel was obtained. The results of this analysis are presented in Figures 11 and 12 as "waterfall" time histories of the accelerometer or pressure transducer frequency content. Figure 11 shows the spectral time history of the pressure signal from the Kistler Model 614 pressure transducer for Run 11. In this format, the X-axis corresponds to frequency, the Y-axis to time, each line corresponding to successive 0.066 sec data slices, with the Z-axis corresponding to magnitude of the frequency component. The data clearly show the pattern of the first tangential (3000-2300 Hz) and mixed first tangential-first longitudinal (3300-3000 Hz) acoustic mode frequencies during the sustain portion of operation. Also observed at lesser amplitude are frequencies corresponding to higher order tangential modes. Figure 12 is a corresponding accelerometer spectrum. Of particular importance is the correspondence both in frequency and time between the pressure and accelerometer data.

VII. SUMMARY

While the techniques for pulsing motors and the interpretation of that pulse data are still in the early stages of development, several conclusions may be reached based on the current AFRPL work.

- It appears possible to excite and observe multiple acoustic mode frequencies through broad band pulse excitation.
- There appears to be reasonable and encouraging correlation between Kistler and accelerometer measurements in detecting and identifying acoustic modes.

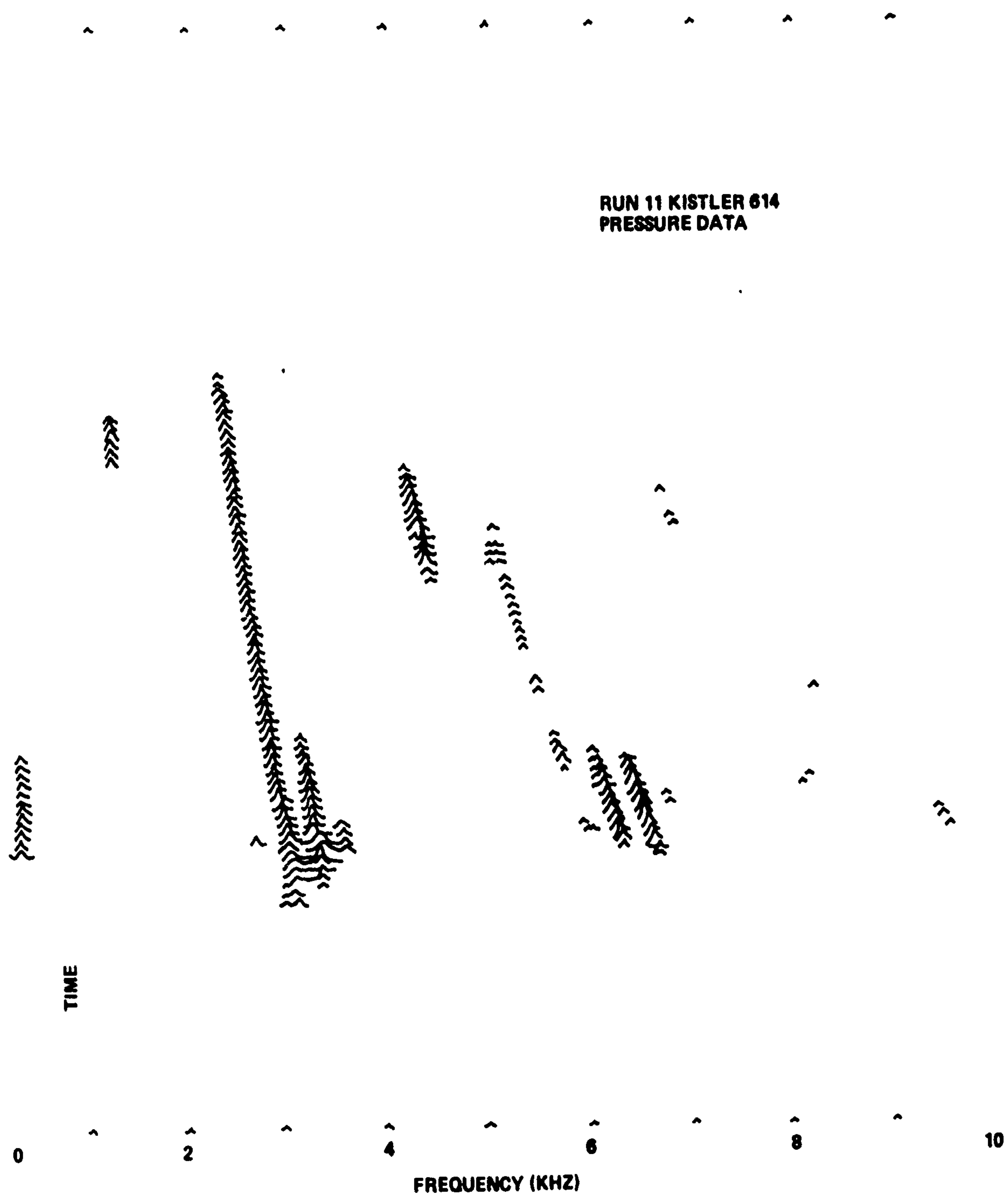

Figure 11. Waterfall Spectrum of Pressure Data

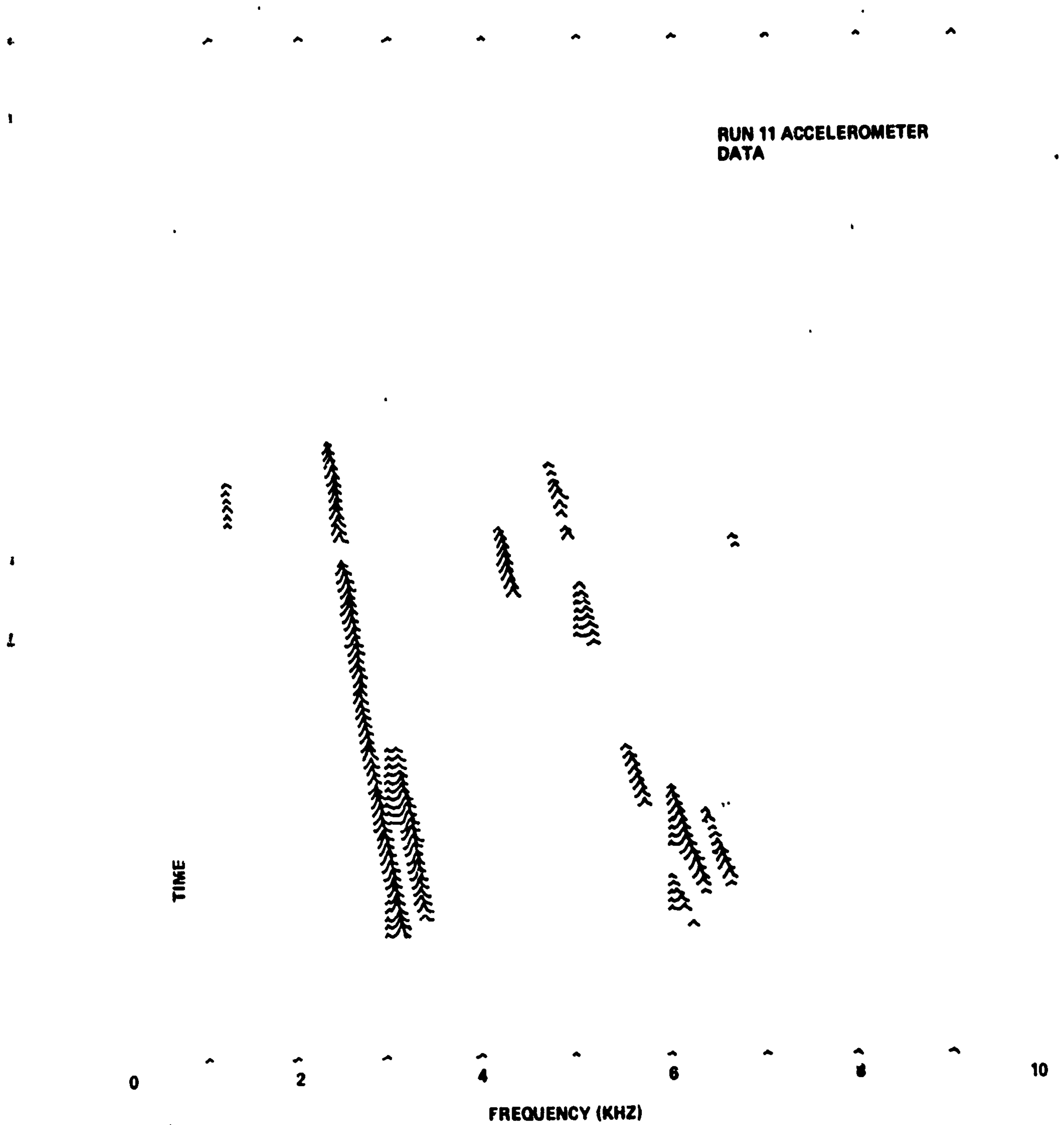

Figure 12. Waterfall Spectrum of Accelerometer Data