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AIR FORCE FLIGHT DYNAMICS LABORATORY
DIRECTOR OF SCIENCE & TECHNOLOGY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE OHIO

A PRESSURE RESPONSE CALIBRATION SYSTEM FOR CHECKING RE-ENTRY PRESSURE MODELS IN THE 50 MEGAWATT RENT

OCTOBER 1976

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Mechanical Instrumentation Group
Experimental Engineering Branch
Aeromechanics Division

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This Technical Memorandum has been reviewed and is approved for publication.

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FOREWORD

This report is the result of a continued interest in calibration techniques to assure accurate test measurements. The work was performed under Project 1426 "Aerodynamic Ground Test Technology", Task 1426-02 "Development of Unique Mechanical Instrumentation Techniques to Advance Aerodynamic Ground Test Technology", and Work Unit 142602-12 "Develop A Pressure Response Calibration System for Checking Re-Entry Nose Tip Models to be Tested in the 50MW RENT". The report was prepared by Robert G. Campbell of the Experimental Engineering Branch, Aeromechanics Division, Air Force Flight Dynamics Laboratory.

Special acknowledgement is extended to Mr. Richard R. Heck, Dr. Edmund G. Brown-Edwards and Mr. Henry D. Baust for their guidance and assistance in this work unit; also for the drafting of this report, Rita L. Kibler, and the final typing, Elona Beans.

This Technical Memorandum has been reviewed and is approved.

ABSTRACT

The survivability of ballistic missile nose tips is essential and germane to the national defense. The optimum design of the nose tip shapes must be aided by simulated realistic operational ground testing, which is performed in the 50 Megawatt (MW) Re-Entry Nose Tip (RENT) Facility. Accurate and efficient pressure measurements of flight simulation in the facility require knowing the response of a pressure model before it is tested in the RENT Facility. This report is the culmination of the design and testing of a response tester which will be used for determining the response of various configurations of pressure model nose tips used in the 50MW RENT Facility.

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I. INTRODUCTION

There is an inherent problem existing in the 50MW RENT Facility, the problem being the survival of pressure instrumented models in the severe high enthalpy RENT environment.[1] To alleviate this survival difficulty the sweep speed of the carriage, to which the pressure instrumented model is attached, was increased to a point where the pressure model would survive. With this increase in sweep speed, however, a pressure model had to be developed that would respond to the pressure of the gas flow in the RENT Facility when the model is only in the flow for about 40 milliseconds. To check these fast responding pressure models before using them in the 50MW RENT Facility, a response tester was developed that would simulate the sudden surge of pressure that the nose tip experiences during a test. The response tester or "Bang Tank" is comprised of a large pressure vessel (surge tank) isolated from a small pressure vessel (test chamber) by a calibrated rupture diaphragm. The pressure model is located in the test chamber and at a predetermined calibration pressure level the diaphragm will rupture and thus exposes the pressure model to an instantaneous change in pressure. By monitoring the reference pressure and test speciman pressure and comparing the outputs a lag time or response time can be determined. The response tester is illustrated in Figure 1.

II. EQUIPMENT AND INSTRUMENTATION

The response tester was designed and fabricated in-house by Experimental Engineering Branch (FXN) instrumentation personnel. The basic configuration of the tester system (Figure 2) consists of the following:

Pressure Source
Surge Tank
Diaphragm Valve
Test Chamber
Pressure Model Base[2] and Pressure Transducers
Data Acquisition System

At present the response tester is installed in the vacuum laboratory in Building 50A, Area B, Wright-Patterson Air Force Base. A schematic of the tester system can be seen in Figure 3.

A. PRESSURE SOURCE. The pressure source used in the investigation was a standard water pumped nitrogen supply bottle. The bottle capacity was 220 cubic feet at STP when charged to 2200 psig.

B. SURGE TANK. The surge tank was used to provide a large volume of gas compared to the small volume test chamber. The volume ratio of the large tank to the small tank was 50 to 1. With this large ratio it was assumed that when the diaphragm ruptured, the small vessel would, on the order of 2-3 milliseconds, attain the pressure level of the large vessel and a uniform pressure distribution would be attained.

C. DIAPHRAGM VALVE. The diaghragm valve used was a standard 3/4 inch Frangible disc union type fitting, rated at 3000 psi rupture pressure. The valve was fitted with "Frangible Rupture Discs" which were designed to rupture at a pre-selected pressure level.

D. TEST CHAMBER. The test chamber that was used in the test, see Figure 4, was designed around the criterion that the model under test and the reference pressure transducer must occupy the same chamber, and the chamber must have a minimum volume. The reference pressure transducer was located opposite to and on the same axis as the model to be tested, and both were set equidistant from and perpendicular to the pressure inlet to the chamber. The transducer used for measuring reference pressure had a natural frequency of 12,000 Hz, and could accurately sense pressure impulses in the test chamber in approximately 3 milliseconds.

E. PRESSURE MODEL BASE AND PRESSURE TRANSDUCERS. The pressure model used in testing was designed concurrently by Mr. Richard R. Heck, AFFDL/FXN; Dr. Edmund G. Brown-Edwards, AFFDL/FXE and Mr. Park A. Doing, AFFDL/FXN. A typical pressure model base and transducer example can be seen in Figures 4 and 5.

F. DATA ACQUISITION SYSTEM. The data acquisition system used in this study was a Model 623 transducer evaluation/data acquisition system.[3] The data system can be seen in Figure 6. The system contained various signal conditioning and monitoring components. A brief description of the equipment follows:

1. Strain Gauge Bridge Conditioner. The bridge conditioner contains six strain gauge bridge conditioners to provide a six-channel capability. Each channel has an integral DC power supply for bridge excitation with span and balance controls. The acceptable bridge configuration capability is up to an eight-wire, four-arm network.

2. Operational Amplifiers. This assembly contains six independent operational amplifiers constituting an independent six-channel capability. Each amplifier is a true differential input device for common mode rejection and has excellent long term stability characteristics. The controls include six calibrated gain steps X1 to X1000 and a bandpass filter selector of 1 Hz to 10,000 Hz in four steps.

3. Visicorder Oscillograph. This visicorder oscillograph used in testing was a Honeywell Model 1508 rack-mounted direct-writing oscillograph. The visicorder can simultaneously record six-channels of data at frequencies ranging from zero to 1000 cycles per second. Paper drive speeds on the visicorder varied from 0.1-inch per second to 80-inches per second.

4. Oscilloscope and Camera. The oscilloscope used in the initial portion of the testing was a dual beam Type 551 Tektronix oscilloscope. This oscilloscope has the capability of displaying two independent horizontal and vertical traces. The horizontal input sensitivity of the Type 551 is 50 mv/cm using a Type "CA" plug-in. Sweep range was 0.1 μ sec/cm to 5 sec/cm in 24 calibrated steps. The band width is DC to 22 mHz with a rise time of 16 nanoseconds. Along with the Type 551 oscilloscope a Polaroid camera was used to acquire permanent response data.

5. 3KHz Carrier System. The AC carrier system consists of an oscillator, demodulator, and a range and balance unit properly interconnected to form the overall system. The system operates at a frequency of 3KHz and provides six independent data channels of carrier modulated information. Each data channel has independent controls for offset and linearity adjustments. In addition, each data channel has been modified so that the carrier voltage is variable in three steps. Thus, the available excitation voltage can be either 5, 10, or 20 volts rms.

III. DISCUSSION

A. GENERAL OPERATIONAL DESCRIPTION OF THE RESPONSE TESTER.

The response tester was designed to simulate the sudden pressure change that a pressure model would experience while in the flow during a 50MW RENT test. In order to simulate the pressure change, a surge tank was pressurized until a calibrated diaphragm ruptures. Upon bursting, the test chamber was filled instantaneously and was in equilibrium with the surge tank in approximately three milliseconds. During the three millisecond interim the pressure in the test chamber and the pressure impulse that was experienced by the pressure model were simultaneously monitored. The monitored data was then analyzed and a response time was determined by the difference between reference and test point time data. The upper limit for the response time was twenty percent of the model exposure time in the test Rhombus, approximately three to five milliseconds.

During the assembly of the pressure model a discrepancy was discovered between the transducer literature and the delivered pressure transducers to be used in the pressure model. There was a concave recession in the face of the diaphragm which delayed the response of the pressure model. The delay resulted in a very unacceptable response level. To alleviate the excessive time lag in the system, center hole plugs were fabricated and installed in the concaved areas to reduce the excess volume in the pressure transducers. The plugs functioned well when assembled properly; however, assembly of the plug in the proper location was rather difficult and, therefore, the model had to be tested if for no other reason than plug alignment.

The model was assembled in the 50MW RENT test configuration and analyzed in the response tester. If any of the transducers did not meet the prescribed limits (these limits were a function of sweep speed of the pressure model in the RENT Facility), the transducers would be removed, adjusted, reassembled and retested. The tuning would continue until the prescribed limits were attained.

B. <u>BASIC INVESTIGATION</u>. In the "Bang Tank" investigation there were two different recording systems used. The initial or qualitative portion of the investigation was performed with a dual trace oscilloscope and Polaroid camera and the final or quantitative portion was completed with a multi-trace oscillograph recording system.

1. <u>Initial Investigation</u>. In the initial investigation a dual trace oscilloscope in conjunction with a Polaroid camera, mounted on the oscilloscope viewing screen, was used to obtain data at the instant the disc ruptured. With that arrangement a permanent copy of the image on the oscilloscope

screen could be produced in approximately sixty seconds for immediate analysis or analysis at a future date. The oscilloscope camera data system functioned satisfactorily with respect to time resolution (2 ms/cm) however, the limited two signal simultaneous display and the amplitude resolution were unsatisfactory for testing of a multiport pressure model.

The highlights of the initial investigation can be studied by reviewing Figures 7 and 8. In Figure 7 a series of oscilloscope Polaroid pictures portray the pressure model response in the base only configuration. By analyzing the pressure model in the base only configuration any response lag that occurs can, with a high degree of reliability, be said to be in the transducer.

Figure 7a illustrates the difficulty encountered when the transducers were first purchased. With the large volume in the concave portion of the transducer the response time was approximately ten milliseconds. This response time was highly unacceptable because the model would be at the centerline of the flow before meaningful data could be obtained. By installing the center hole plug in the pressure transducer the response time decreased by about a factor of four (refer to Figure 7c). If the plug was not installed correctly, as noted earlier, the response time decreased only by a factor of two (refer to Figure 7b). Therefore, the point cannot be over-stressed that the plug must be aligned correctly. Once the plug was in place the repeatability of the base and transducer assembly was excellent. This repeatability is evident by comparing Figures 7c and 7d; the pictures were taken on two different test days.

Upon completion of the base response check, a nose tip, which would be one of many interchangeable nose tip configurations, was installed on the base and the same basic test procedure was applied. The response picture, Figure 8a, is an example of a slow responding port. The major cause of this type of lag, prior to testing in the 50MW RENT Facility, was a machining chip or some other type of machining debris restricting the flow channel which in turn caused the lag. After cleaning (Figure 8b), the response lag was no longer apparent and the pressure model assembly would be ready for testing in the 50MW RENT Facility.

The oscilloscope camera system was useful in the initial work for a qualitative analysis but fell short in the quantitative analysis needed to compare the simultaneous pressure response of a multiport pressure model at some instant of time with respect to a reference pressure. Therefore, a decision was made to improve the data acquisition system.

2. Final Investigation. To further the investigation and to acquire a quantitative tool for use in "Bang Tank" testing, a Honeywell visicorder oscillograph was selected for data acquisition. The visicorder oscillograph expanded the recording capabilities of test data from a reference pressure and one active test pressure, to a reference pressure, four active test pressures, and a 3KHz time base carrier signal.

The time and amplitude resolution were also improved by using the visicorder oscillograph. By using the carrier signal along with the maximum paper speed of 80-inches per second it was possible to attain a time resolution of 333 μ-seconds. By adjusting the operational amplifier gains, setting the bandpass filters to 10KHz, and adjusting the visicorder oscillograph variable gains, it was possible to attain an amplitude resolution of 10 psi per millimeter.

To determine the response time, with the new Data Acquisition System, the pressure model was again analysed in two ways. First, the model base was subjected to the simulated pressure change to prove or disprove the readiness for further testing with the interchangeable model tip. The on-line pressure data from the oscillograph trace was analysed for obvious pressure lags (See Figure 9); if there were no lags then an overlay plot, of all active pressure ports along with the reference pressure, was constructed (See Figure 10). The response times of the active ports were evaluated by using a pressure level midway on the positive slope and reading the respective times and subtracting the reference response time. The model tip was then installed and the same procedure was followed (Figure 11 and 12). At this point the total response time of the pressure MODEL WAS KNOWN.

A typical analysis of the oscillograph data for a pressure model that was tested in the 50MW RENT can be seen in Figure 13. The composite plot, which illustrates the base along with base nose tip data, and the data of Table I substantiate that the twenty percent upper limit for the response time was attained and that the pressure model was ready for RENT testing.

IV. CONCLUSIONS

By using this response testing method prior to 50MW RENT testing the quality of pressure data attained was increased substantially.

Plans are being made to interface the response tester "Bang Tank" into the 50MW RENT Facility where the test data conditioning equipment will be the actual equipment used in the RENT testing.

V. REFERENCES

1. AFFDL TM-75-39-FXE, "The 50 Megawatt Facility Information for Users," Thermodynamics Branch, Flight Mechanics Division, 1975.

2. AFFDL TM (To be Published), "A General Purpose Pressure Model for Use in the RENT Test Leg of the 50MW Test Facility," Brown-Edwards, Heck, Doing.

3. System Research Laboratory, "SRL Operation and Maintenance Manual for Model 623 Transducer Evaluation/Data Acquisition System," F33615-68-C-0110, October 1968.

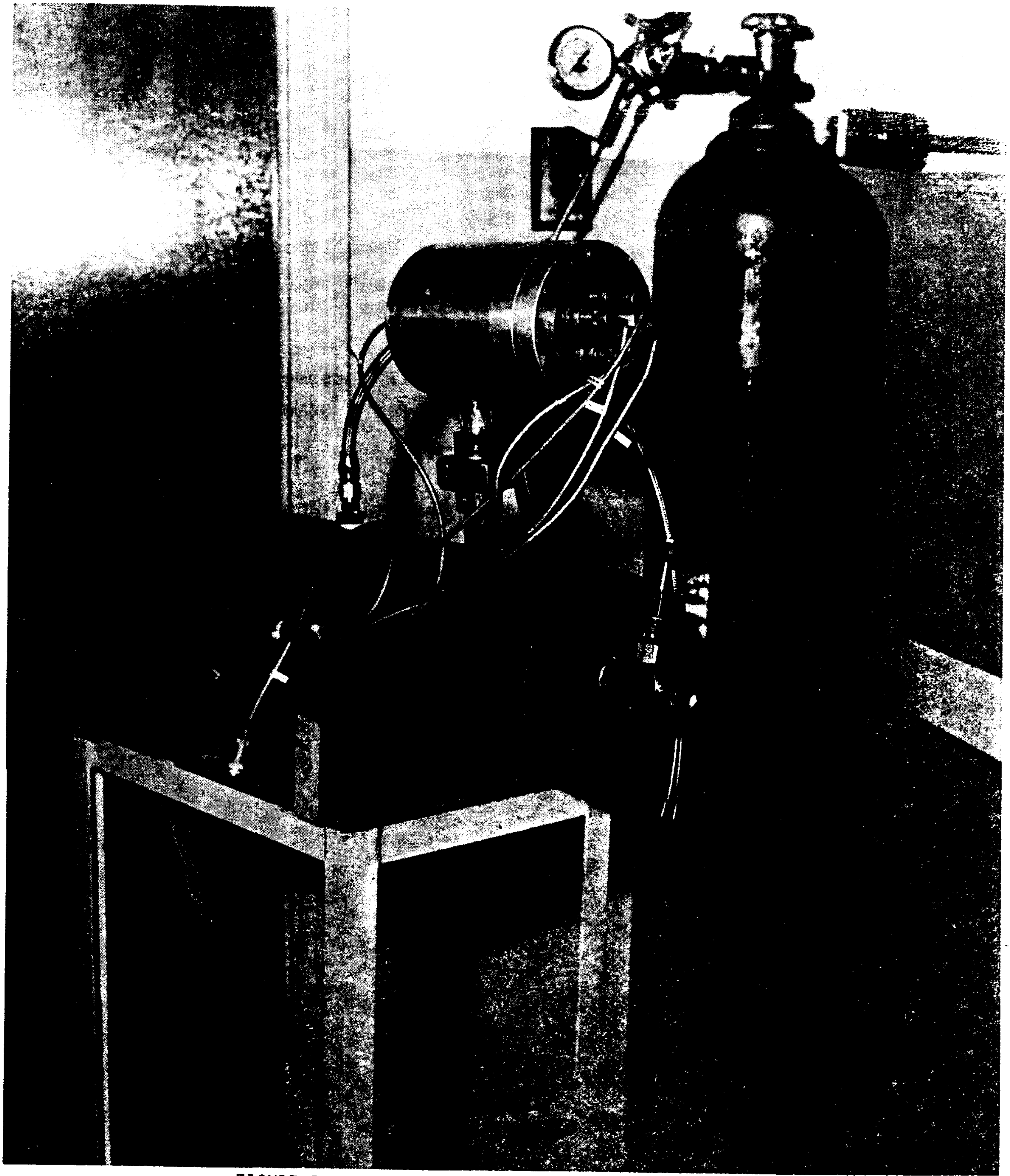


FIGURE 1. PRESSURE RESPONSE TESTER OR "BANG TANK"

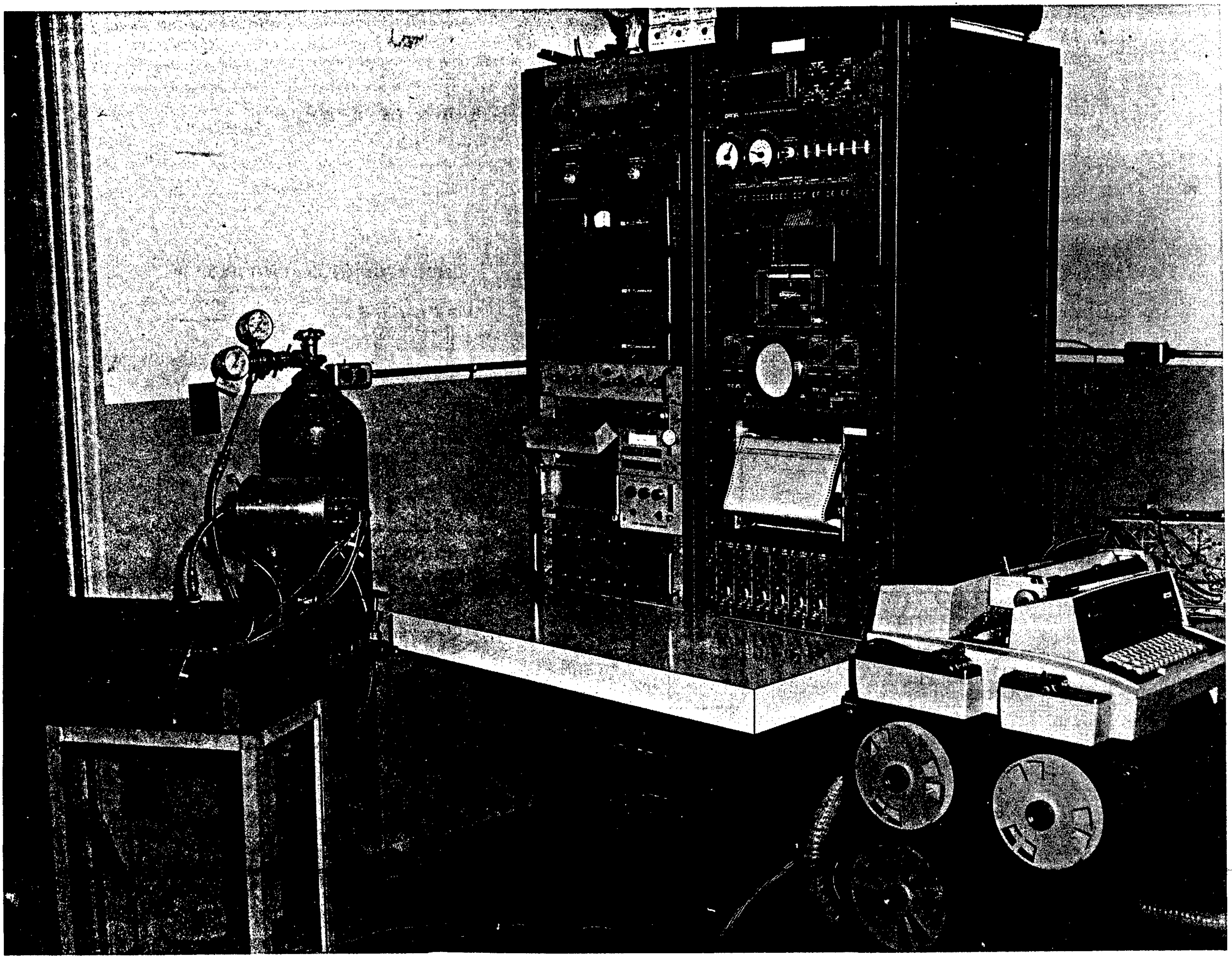
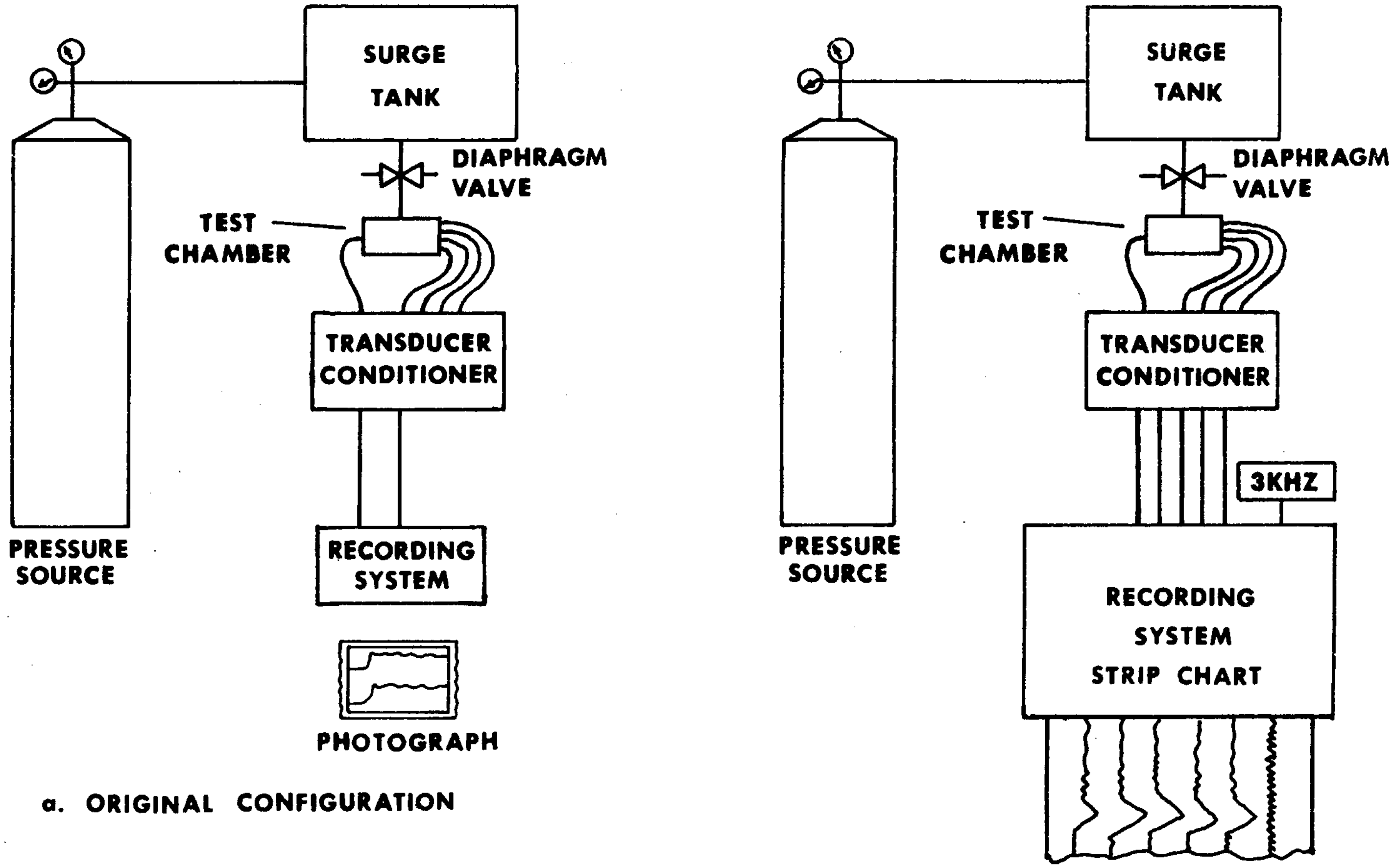


FIGURE 2. TEST APPARATUS



a. ORIGINAL CONFIGURATION

b. IMPROVED VERSION

FIGURE 3. 50 MW-RENT PRESSURE MODEL RESPONSE TESTER

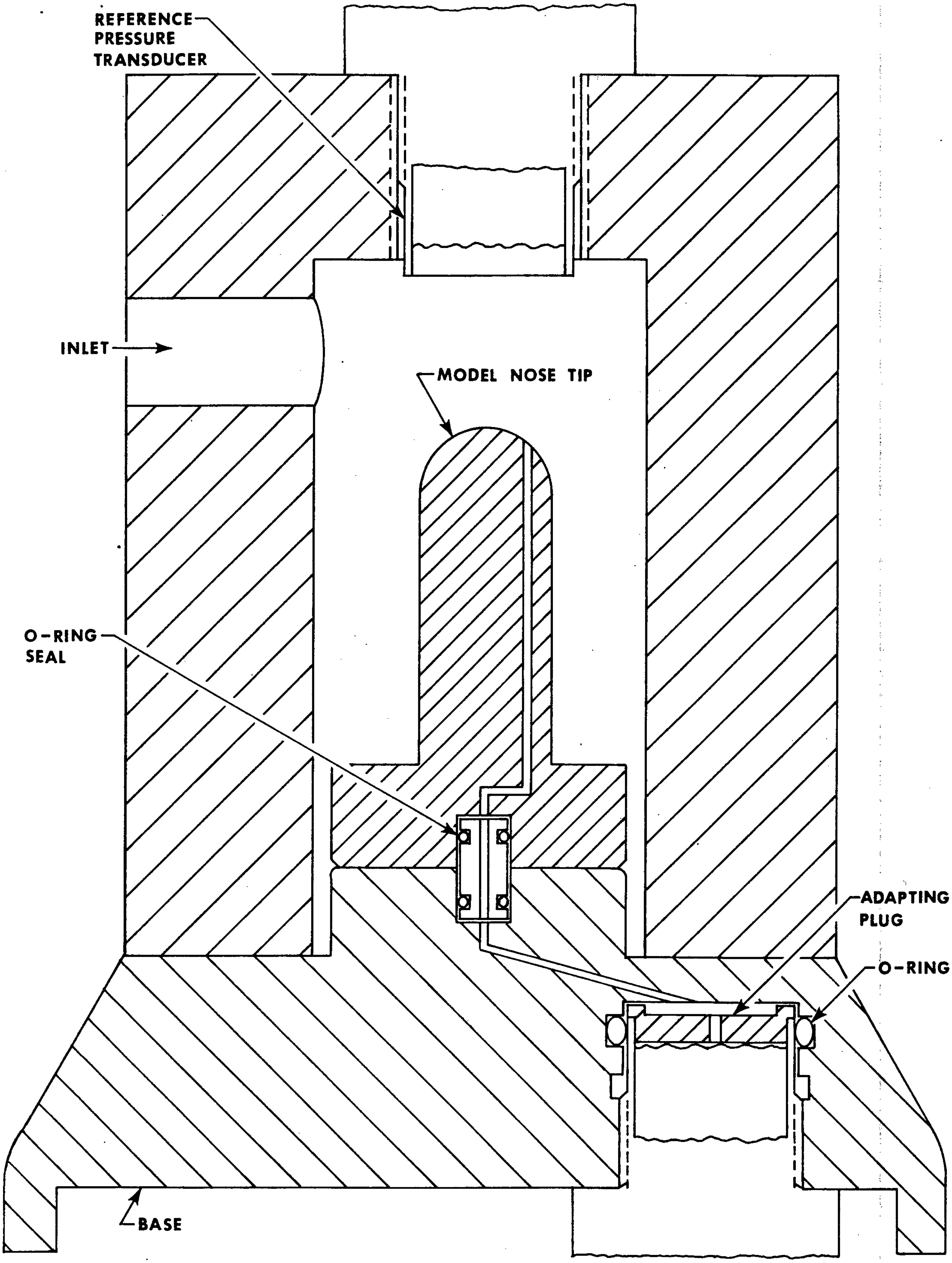


FIGURE 4. TEST CHAMBER

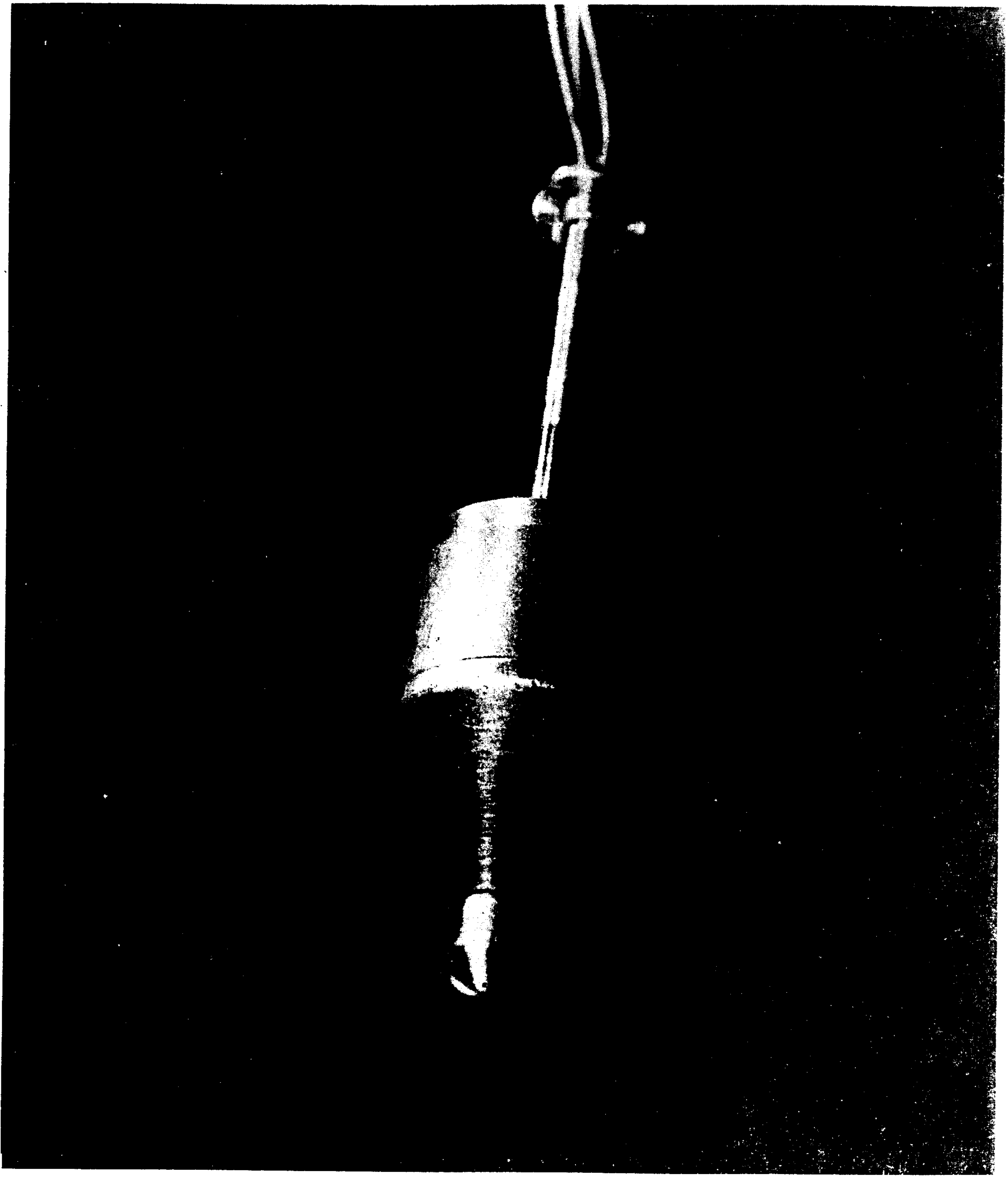


FIGURE 5. TYPICAL PRESSURE MODEL

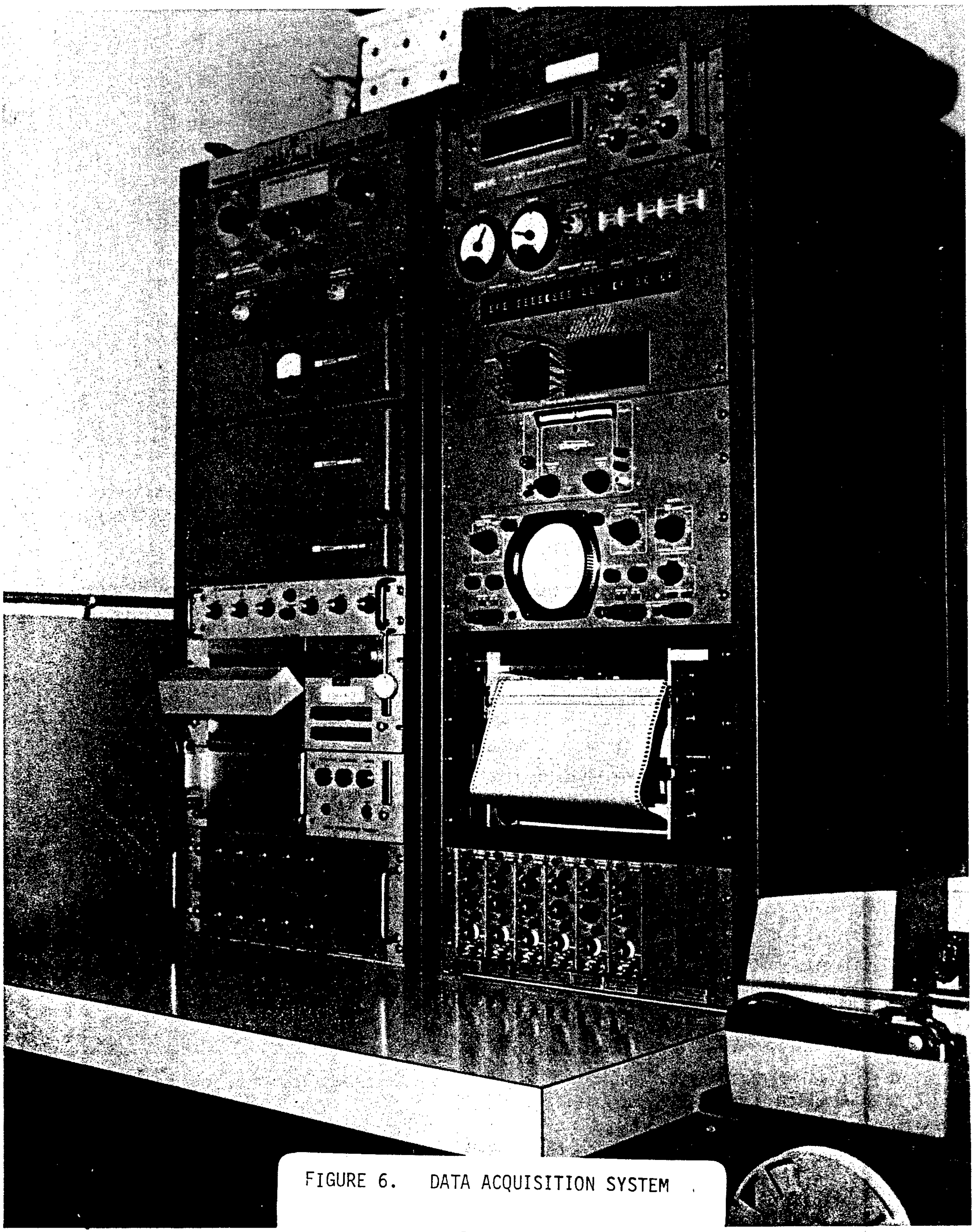
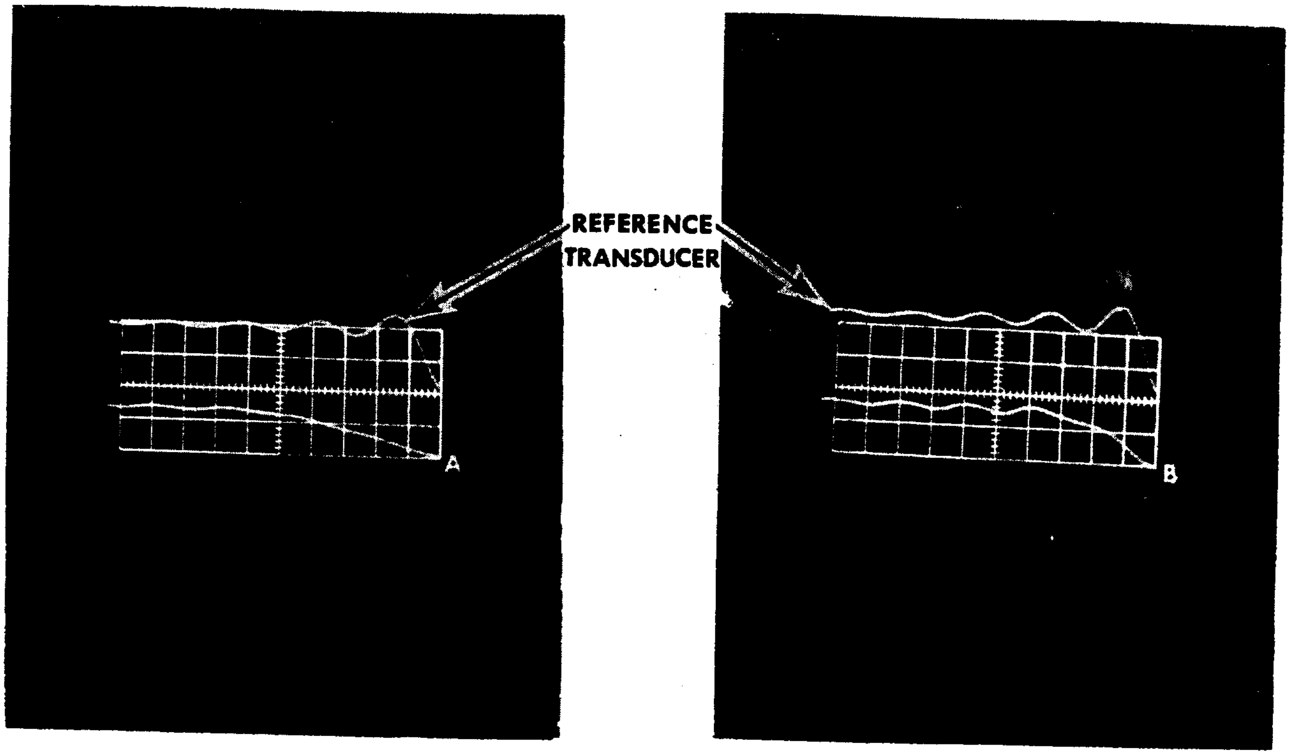
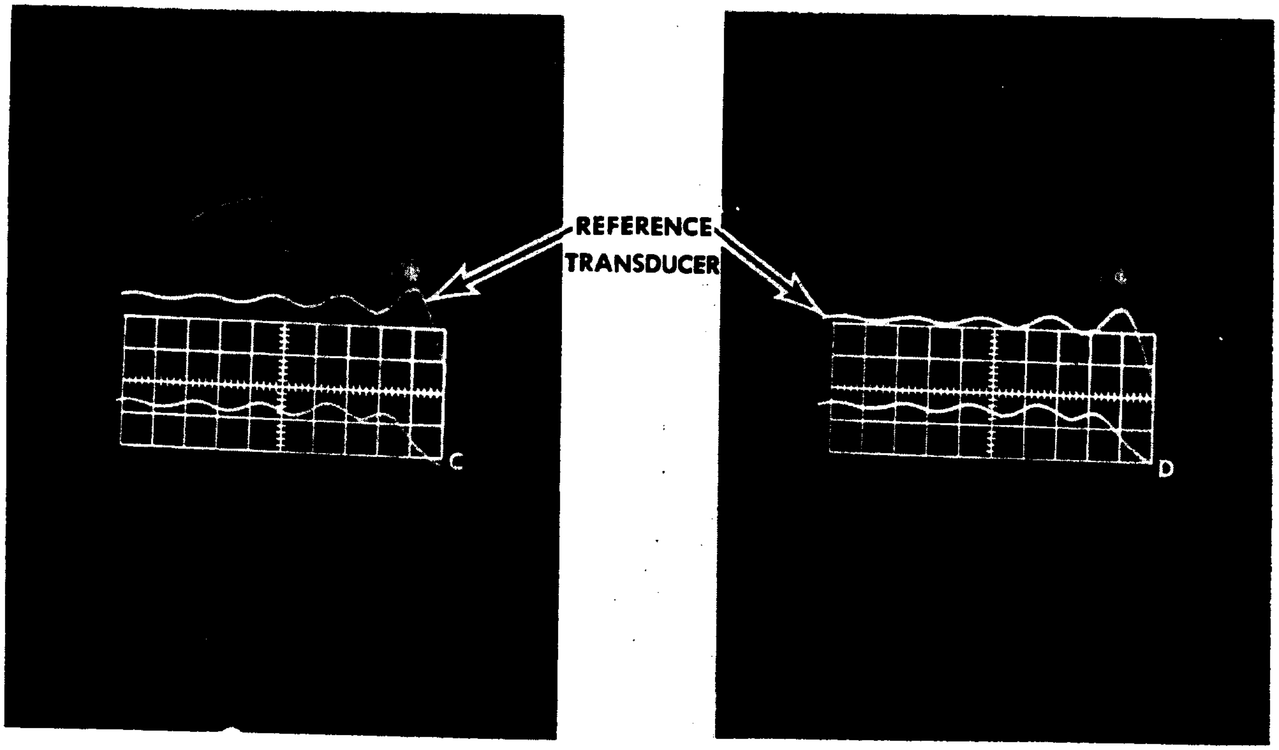


FIGURE 6. DATA ACQUISITION SYSTEM



A – OSCILLOSCOPE ANALYSIS OF A TRANSDUCER MOUNTED IN THE BASE WITH NO ADAPTING PLUG

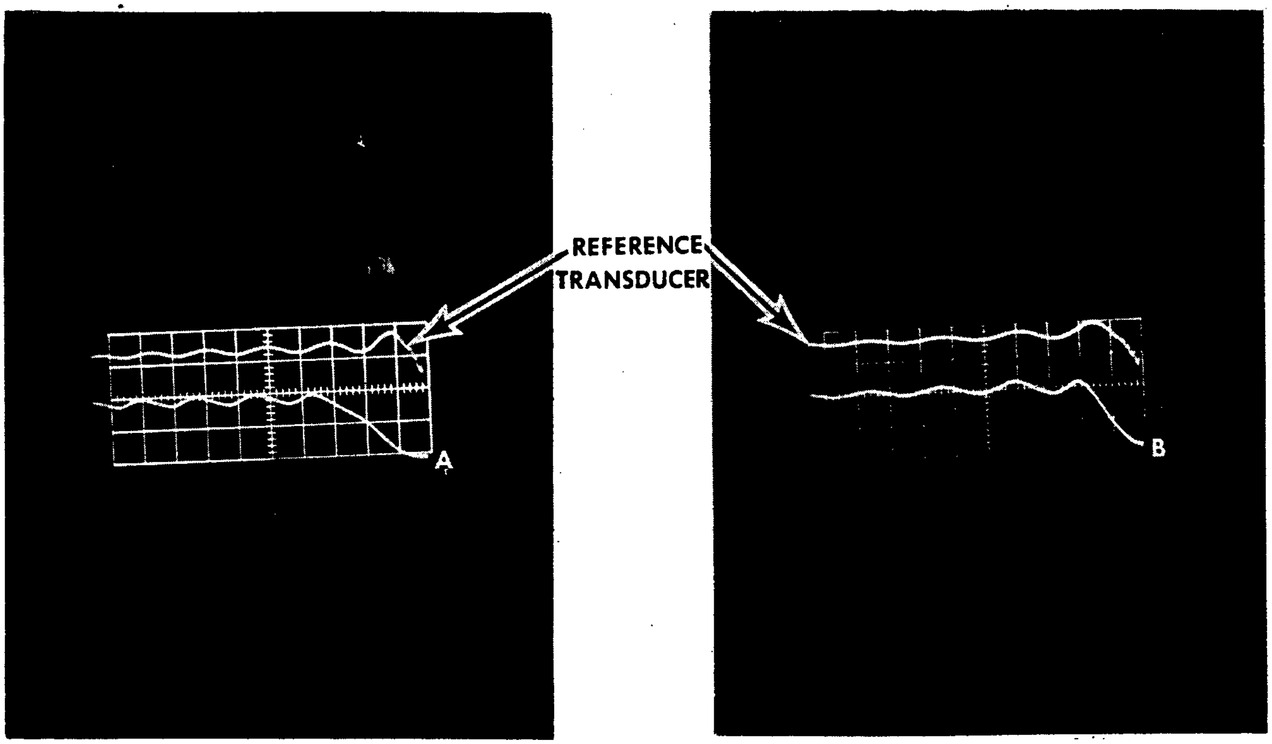
B – THE SAME TRANSDUCER INSTALLED WITH A PLUG BUT NOT ASSEMBLED EXACTLY RIGHT



C – THE SAME TRANSDUCER AND PLUG ASSEMBLED CORRECTLY AND TESTED

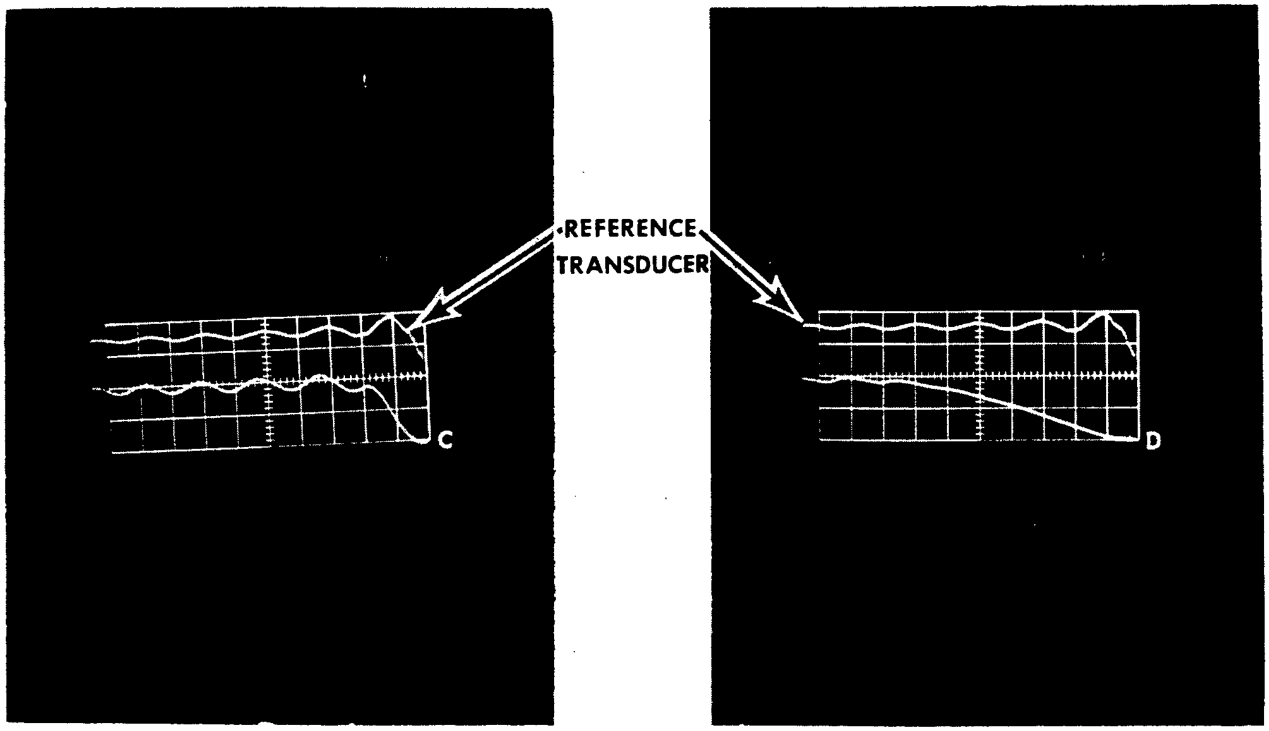
D – A REPEAT TEST RUN OF C

FIGURE 7. AN OSCILLOSCOPE ANALYSIS OF MODEL BASE TESTING



A – A TRANSDUCER AND PLUG ASSEMBLED IN THE BARE MODEL BASE IMPROPERLY

B – THE SAME COMBINATION AFTER CLEANING AND REASSEMBLY PRIOR TO TUNNEL TESTING



C – THE RESULTS OF A TANK TEST OF THE BARE BASE AFTER AN UNSUCESSFUL TUNNEL TEST

D – THE ASSEMBLED BASE WITH TRANSDUCER AND NOSE TIP AFTER THE TUNNEL RUN SHOW A LAG RESULTING FROM DEBRI ENTERING PORT

FIGURE 8. AN OSCILLOSCOPE ANALYSIS OF MODEL BASE AND NOSETIP TESTING

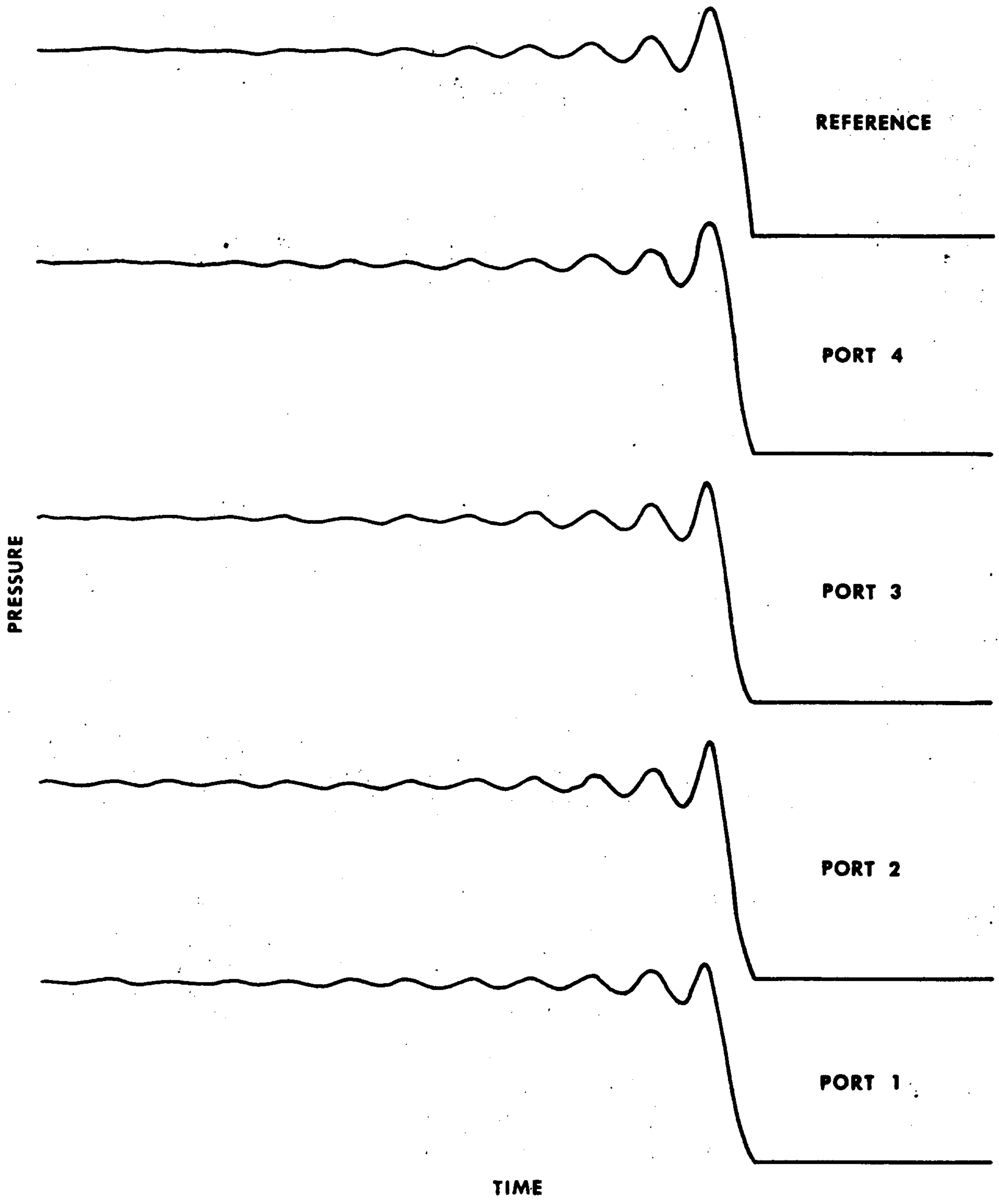


FIGURE 9. THE ORIGINAL OSCILLOSCOPE TRACE OF THE MODEL BASE CONFIGURATION

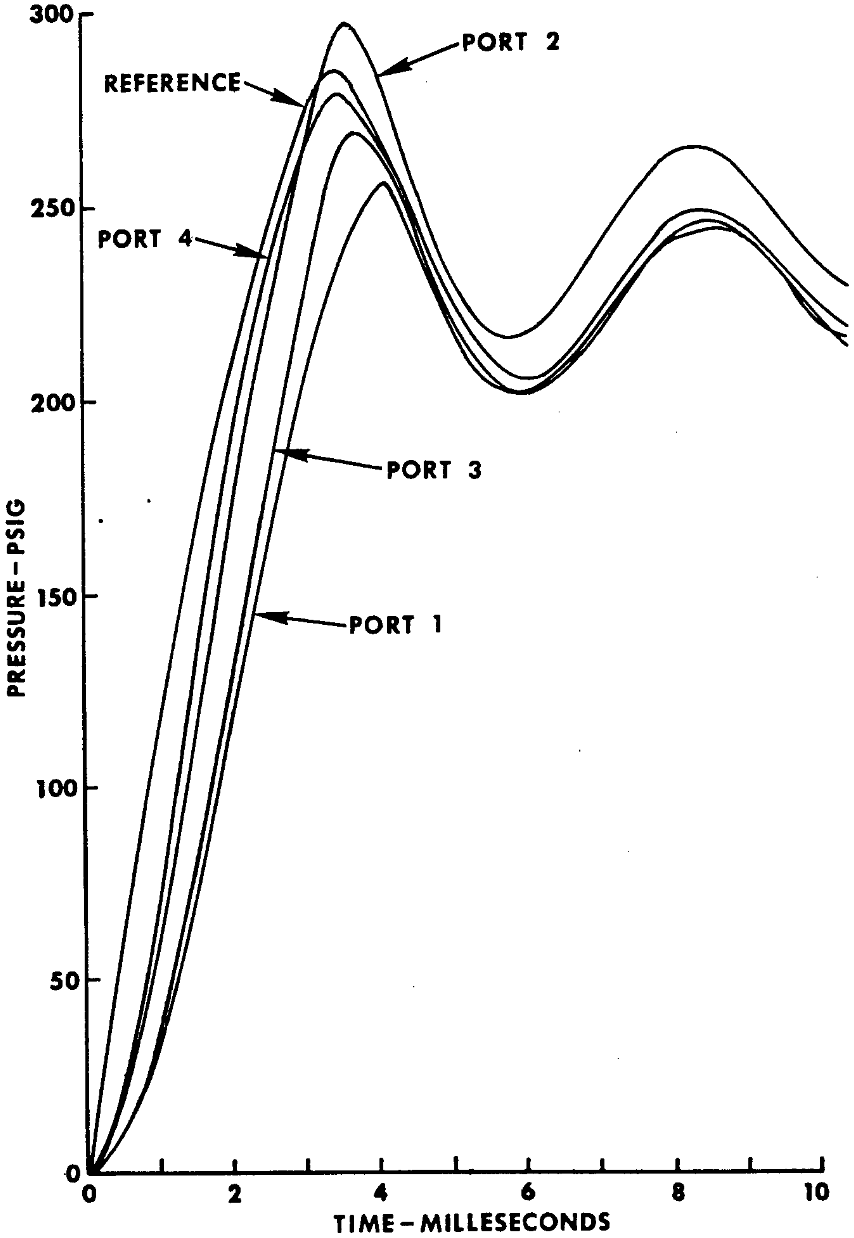


FIGURE 10. AN OVERLAY PLOT OF THE MODEL BASE CONFIGURATION

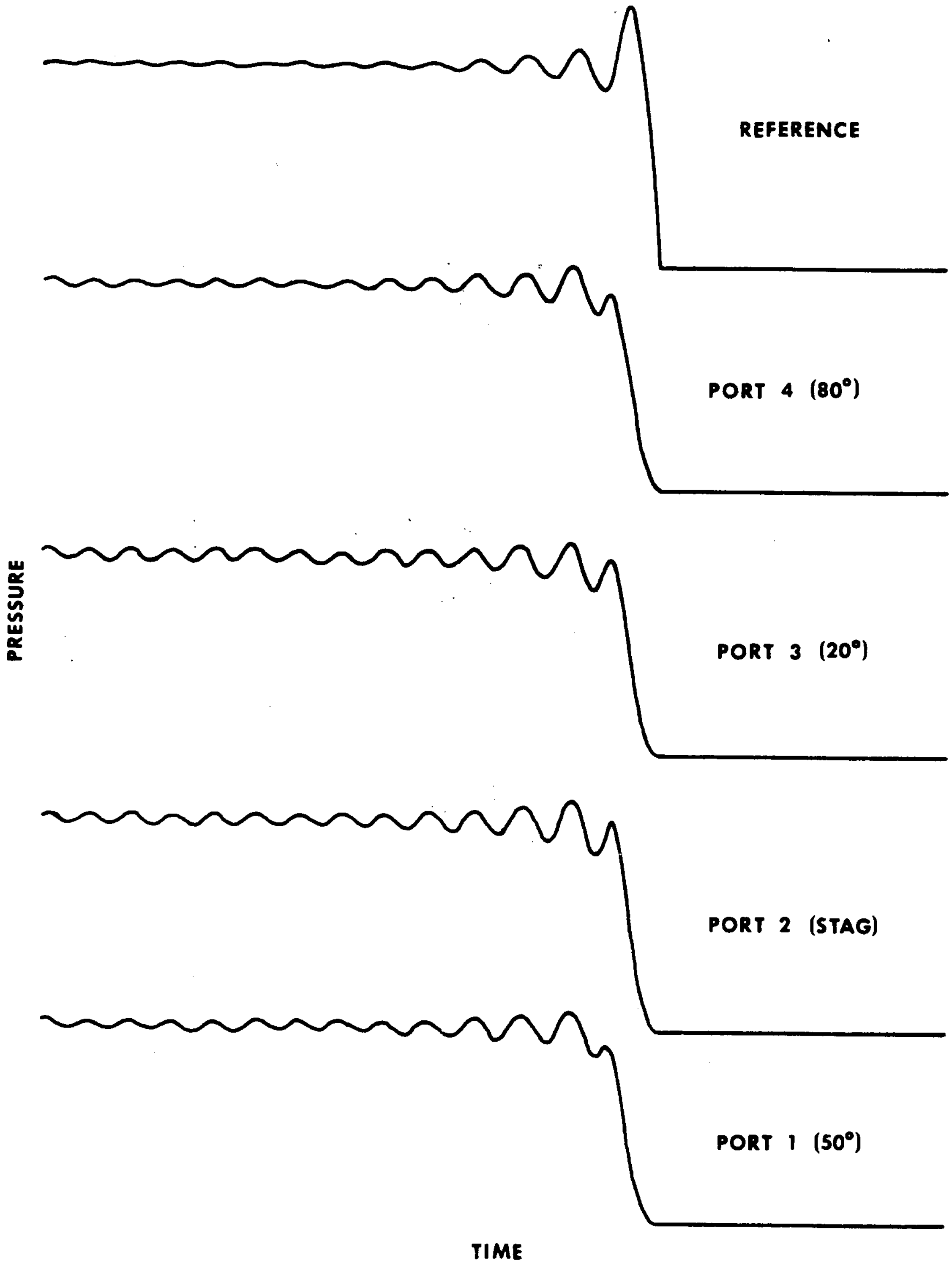


FIGURE 11. THE ORIGINAL OSCILLOGRAPH TRACE OF THE MODEL BASE AND NOSETIP CONFIGURATION

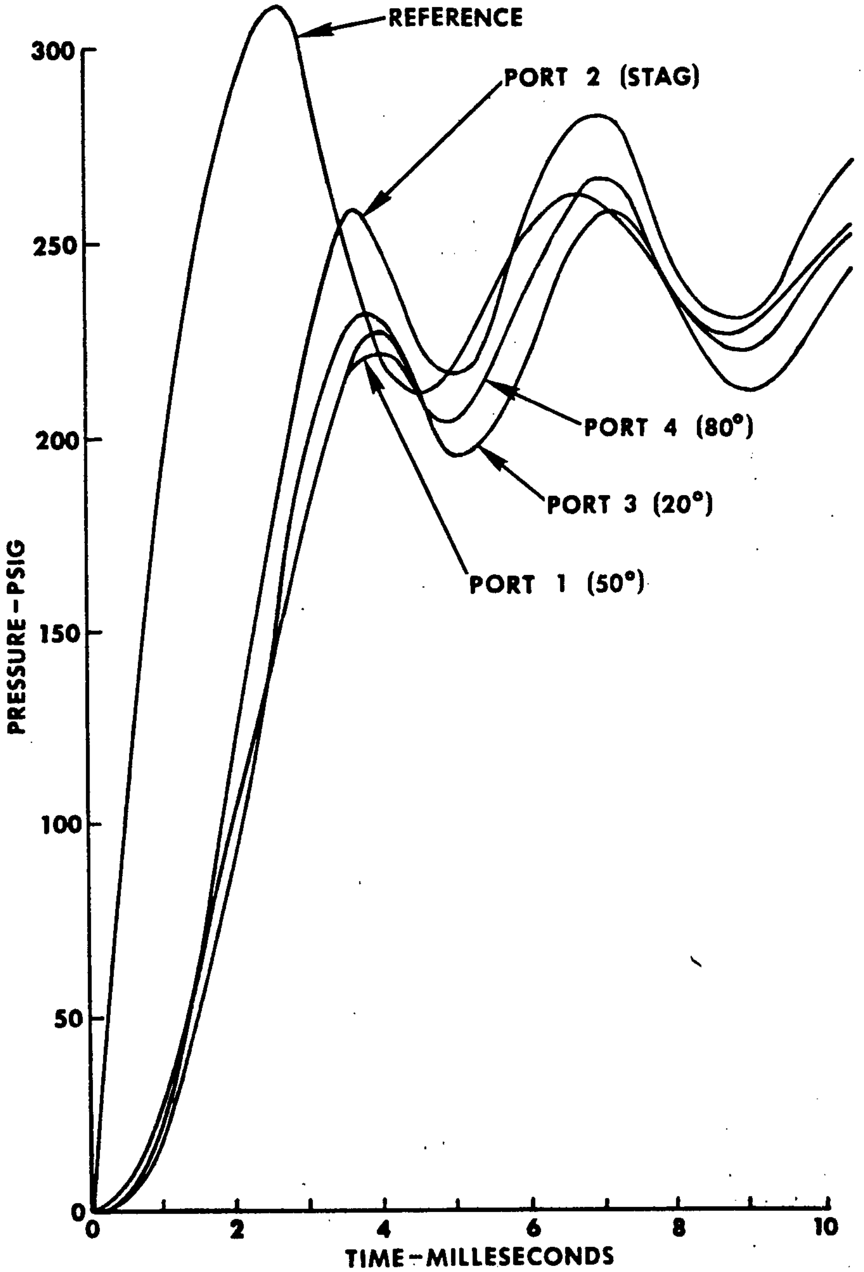


FIGURE 12. AN OVERLAY PLOT OF THE MODEL BASE AND NOSETIP CONFIGURATION