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BEHAVIOR OF NOZZLES AND ACOUSTIC LINERS IN THREE-DIMENSIONAL ACOUSTIC FIELDS

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I. SUMMARY OF PROGRAM OBJECTIVES

The growth or decay of a disturbance that is accidentally introduced into a propulsion device depends on the nature of its interaction with the various processes and components that are present in the system. While some processes respond by adding energy to the disturbance (e.g., the combustion process), others tend to act as energy sinks and hence cause an attenuation of the disturbance. To be able to predict whether a given disturbance will amplify or attenuate it is necessary to know the frequency response of the various processes and components with whom the disturbance is bound to interact. As long as such information is not known, a quantitative prediction of the stability of liquid propellant rocket motors will not be possible.

To obtain the desired information separate theoretical and experimental investigations aimed at the determination of the frequency responses of the various processes and components that contribute to engine stability must be conducted. These investigations should be performed under conditions that closely simulate the flow inside unstable liquid propellant rocket motors. In the present study the frequency responses of supercritical nozzles and acoustic liners are investigated.

At present, the only available investigation of the nozzle frequency response is theoretical in nature[1]. In spite of their importance in the design[2] of stable liquid propellant rocket engines these theoretical predictions have never been verified experimentally; hence their applicability and usefulness are open to question. It is one of the objectives of the present investigation to experimentally determine the frequency response of various practical nozzles. Nozzles of various shapes and area ratios will be tested and a special effort will be made to determine the dependence of the nozzle response function upon these design parameters. A comparison between the experimental data and theoretical predictions will provide a check on the validity and range of applicability of the theoretical predictions.

It is the objective of the acoustic liner study to determine the response of acoustic liners under controlled conditions that simulate, as closely as possible, the flow conditions inside unstable liquid propellant rocket motors. In this connection it should be mentioned that available data on acoustic liners response was obtained in experiments where either careful control was not possible[3] or the experimental set up did not simulate the flow conditions inside unstable liquid propellant rocket motors[4].

It is the long range objective of this program to provide propulsion engineers with reliable data about the frequency responses of typical nozzles and acoustic liners when they are subjected to flow oscillations similar to the ones that can be found in unstable liquid propellant rocket motors.

II. SUMMARY OF PROGRAM STATUS

The various tasks performed under this program involved the cooperation of three faculty members, Dr. B. T. Zinn, and Messrs. A. J. Smith, Jr. and B. R. Daniel and three graduate students, Messrs. W. A. Bell, J. M. Walsh and D. C. Kooker. These individuals were responsible for performing various design tasks as well as various theoretical and experimental investigations that had to be carried out as part of this program.

Since results obtained in the theoretical studies were used to guide the design and planning of the experiments, the results of these investigations will be discussed first. Initial theoretical studies involved the development of a three dimensional impedance tube theory that accounts for the presence of a one dimensional mean flow in the tube. The new theory represents a major extension of the classical impedance tube theory that is limited to considerations of one dimensional oscillations in tubes without mean flow. The new theory provides expressions that describe the dependence of the three dimensional wave pattern, that is generated inside the combustion chamber, upon the impedance at the tube end (e.g., the nozzle impedance) and upon the magnitude of the mean flow Mach number. It has been theoretically shown that by measuring instantaneous pressure amplitudes at various locations along the tube and then substituting the experimental data into the theoretical expressions results in a set of equations that can be used in the determination of the nozzle admittance function. As part of this investigation a special computer program capable of converting the experimental data into meaningful results (i.e., nozzle admittance functions) has been developed.

Other related analytical studies included the development of a computer program that uses Crocco's nozzle theory[1] to compute the theoretical nozzle admittance functions. The applicability of these theoretically predicted admittance functions will be checked by comparing them with the experimentally determined admittance functions. Another phase of this program was the study of acoustic liners. As part of this investigation a thorough literature search was conducted and the results were used as a guide in the design of the liners that will be tested in the program. In addition an approximate theory for investigating acoustic liner response has been developed. Other relevant theoretical investigations are in progress and they will be discussed in another section of this report.

The results of the above investigations were used to guide the design of a cold flow facility capable of simulating the flow conditions in unstable liquid propellant rocket motors. The facility uses high pressure air that is stored in a 500 cubic feet, 3000 psia storage system. During a run the air leaves the storage facility, passes through a series of control valves that reduce its pressure to a desirable level, and enters the simulated combustion chamber through a showerhead injector. Two 4000 watt electro-pneumatic drivers, that are attached to the combustion chamber walls, are used to generate the desired three dimensional pressure oscillations. The behavior of these waves is monitored by a series of pressure transducers located at various locations along the tube. The transducers' signals are recorded on tape and later processed for conversion into impedance data. A schematic of this system is presented in Fig. 1.

To be able to perform the various tasks demanded by these experiments a specialized instrumentation system had to be designed and assembled. Todate considerable amounts of money, effort and time have been invested in the purchase, installation and calibration of the various components that comprise this instrumentation system.

As part of the planning of the experimental program the various components that were to be tested (i.e., nozzles and acoustic liners) had to be designed. Two nozzles of practical shape were designed and built. These nozzles have different geometries and were chosen in a way that will enable the investigators to determine the validity of some of the assumptions used in the theoretical predictions of the nozzle admittance function. The problem of designing acoustic liners has been studied in depth. After several modifications, the present design of the acoustic liners are based on results obtained in investigations conducted at NASA Lewis[5] and Pratt & Whitney[4]. The testing of these liners is expected to produce data that will shed additional light about the applicability of available liner theory.

Considerable delays in delivery and malfunction of major system components resulted in corresponding delays in the initiation of the test program. It appears, however, that all major difficulties have been solved and preliminary testing has begun. These temporary delays will not affect the productivity and results of the overall program.

III. PROGRESS DURING REPORT PERIOD

A. Theoretical Studies

The analytical investigations concentrated in several areas. One of the investigations was concerned with the evaluation and improvement of the experimental results. To perform this investigation values of nozzle admittance function, that were determined by using Crocco's nozzle theory, were substituted into the expressions that determine the three-dimensional wave amplitude. The resulting expression could be used to calculate the pressure amplitude at any location in the chamber. The theoretically computed amplitudes were then modified by the introduction of intentional positive or negative errors. It was then assumed that the modified amplitudes had been determined experimentally and they were then used to compute the nozzle admittance functions. The computed values were then compared with the known correct values. These studies revealed that the accuracy of the experimental predictions depends upon several variables that include the magnitudes of the real and imaginary parts of the nozzle admittance, the frequency of the oscillation and the locations chosen for measurement. This investigation is in progress and various possibilities for improving the accuracy of results obtained from experimental data are being investigated.

In a recent study of lined cylindrical chambers[5] it has been shown that the inclusion of liners may have the additional effect of "detuning" the chamber. This information has been used in the design of the acoustic liners that will be tested in the present program. To obtain a better appreciation of the problem two liners having different characteristics were designed. One of these liners was designed to be a poor absorber (over the range of frequencies that will be tested) but a good "detuner", while the other liner was designed to be primarily a good absorber. The testing of these liners should help to shed light about the relative importance of these two effects as well as the applicability of the theories that guided the designs of these liners.

Two additional theoretical investigations are in progress. One of these is concerned with the investigation of three dimensional standing-wave behavior in chamber with lined walls. The second investigation is concerned with the prediction of the admittance function of nozzles with fast converging walls. Both investigations are aimed at improving existing theories and providing better theoretical approaches for the design of future liquid propellant rocket motors.

B. Test Facility

The final facility checkout phase has been completed and preliminary testing has been initiated. The main objectives of the preliminary tests were to determine the system characteristics with all control valves and instrumentation operating simultaneously, measure the background noise level that is induced in the chamber by the mean flow, and determine the limitations and characteristics of the dynamic pressure transducers that will be used to measure the sound pressure levels.

Measurements of the flow noise and its spectral analysis showed that, in the frequency range that will be used in actual experiments, there are six predominant frequencies that are contributing the major portion of the noise. The sound pressure levels recorded at these frequencies were all above 120 db (re. 2×10^{-4} DYNES/cm^2) and the highest had the level of 138 db. A detailed analysis of system characteristics showed that the major portion of the noise was being generated by the flow control valves. To alleviate this difficulty a muffler has been designed to suppress these upstream noise sources. The estimated sound pressure level of the noise generated by the valves is 160 db. Design calculations show that the addition of the muffler will decrease the sound pressure level in the chamber from 138 db to 70 db in spite of the fact that the valve noise output is 160 db. The necessary muffler has been designed and fabrication has begun. Estimated time necessary for muffler completion is approximately one month.

During the period that the muffler is being fabricated, all of the no-flow tests will be completed. The first series of tests will be conducted with an infinite impedance termination. This data will be used to provide an additional check on the operation of the computer program that has been specially formulated to reduce the experimental data. Once program verification is completed, the admittance of the nozzles, with and without steady flow, will be determined.

IV. PROGRESS DURING THE NEXT REPORT PERIOD

The admittance of the nozzles with no mean flow will be completed. The muffler will be installed and the admittance of the nozzles with mean flow will be determined. Testing of the liners will be initiated. Work on various reported theoretical investigations will continue.

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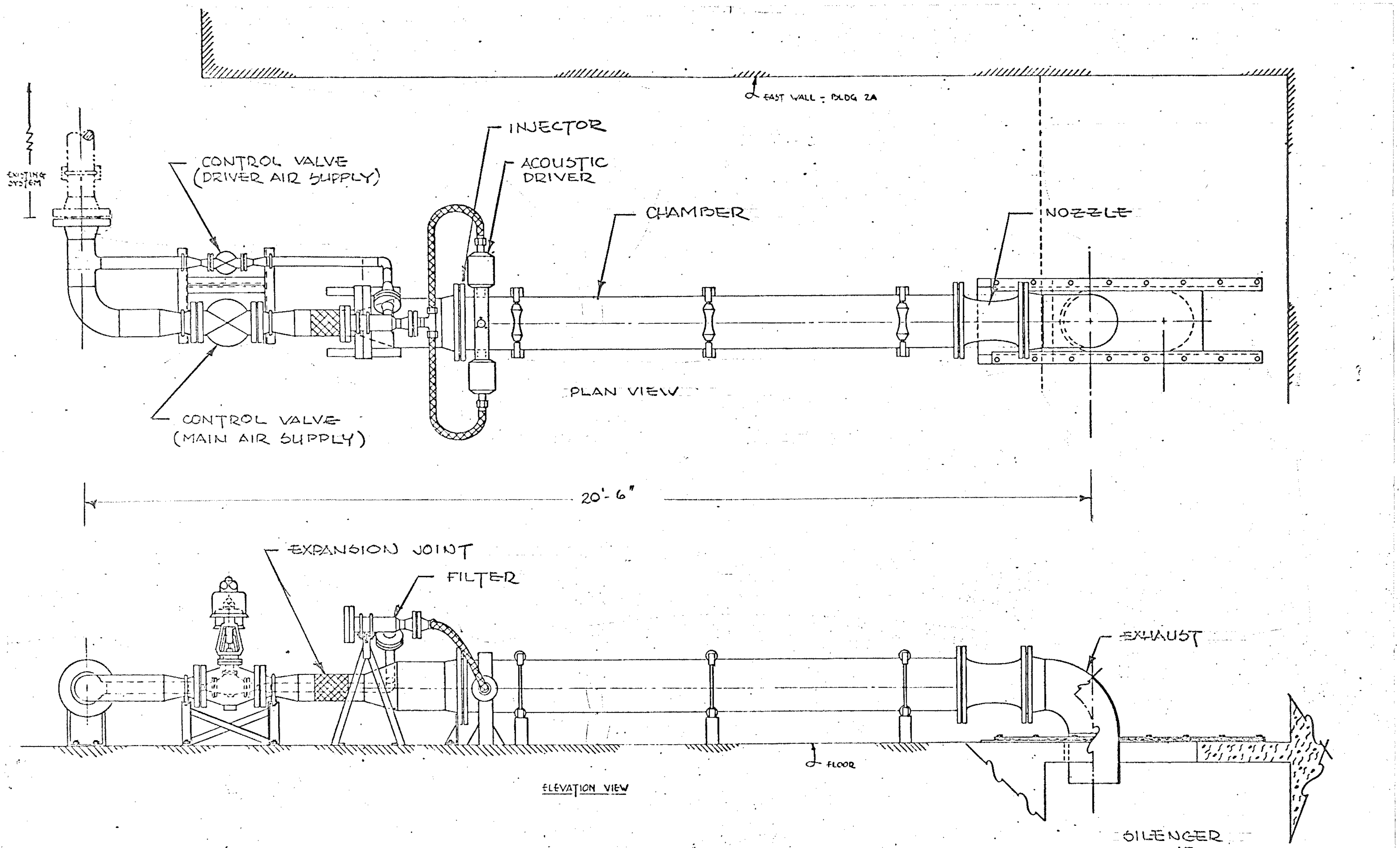

EXPERIMENT ASSEMBLY

Figure 1