NASA GRANT NGL 11-002-085

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

Quarterly Report for Period 1 September 1970 to 31 November 1970

CASE FILE COPY

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PROGRESS DURING REPORT PERIOD

A. Summary of Progress

The analytical investigations associated with this program have been devoted to the development of techniques for the optimization of microphone location; the adaptation of a nonlinear regression technique to the reduction of experimental nozzle admittance data obtained at a given frequency; and the refinement of the statistical curve-fitting routine used to correlate the nozzle admittance data over a range of frequencies.

Six tests have been conducted and analyzed during this report period and the nozzle admittance results obtained in two of these tests are discussed in this report. An alternative method for determining admittances was attempted but found to be unreliable.

B. Theoretical Studies

The majority of work associated with the analytical aspects of this program has been devoted to the optimization of microphone location, the adaptation of a nonlinear regression technique to the reduction of nozzle admittance data obtained at a given frequency, and the refinement of the statistical curve-fitting routine used to correlate the nozzle admittance data over a range of frequencies. In addition the efforts associated with the prediction of the admittance values of nozzles with rapidly-converging walls have been continued.

The optimization of microphone location effort presented in Reference 1 approached this subject by conducting a computer-oriented parametric study. One significant result of that study was the observation that in order to obtain good data the sound pressure level of the transducers cannot be the same. The use of the above-mentioned parametric study to obtain additional and more

general rules has been hampered by the bookkeeping associated with the
vast quantity of computer output. Consequently, an alternate procedure
of examining the analytical expressions has been initiated. The result
of this current study is expected to provide valuable microphone loca-
tion criterion that will be incorporated into the experimental phase
of this program. Additionally, these same criterion may provide guide-
lines for the proper instrumentation of unstable rocket motors.

As a prelude to the discussion of why a nonlinear regression
technique is being employed by this program, it is necessary to review
some of the characteristics of the analytical expression that describe
the amplitude of the standing wave pressure distribution within a
chamber. This analytical expression depends on three unknown variables -
two of which describe the nozzle admittance - and numerous known vari-
ables that are determined by chamber geometry, chamber operating
conditions, frequency of the oscillation, and the location where the
pressure is measured. Consequently, the use of data obtained from
pressure measurements taken at three different chamber locations
together with the above-mentioned analytical expressions results
in the derivation of three algebraic equations that could be used to
solve for the unknown variables; that is, the nozzle admittance and
the standing wave pressure distribution over the entire length of
the chamber.

To improve the accuracy of the data five pressure measurements
are taken at each test condition instead of three measurements. This
procedure provides redundant admittance data at each of the test
conditions. That is, five transducers provide ten different combina-
tions of sets of three; consequently, each test point will yield ten
values of the nozzle admittance. If the experimental technique and
the data reduction procedure are flawless, then all ten values of the
admittance will be equal. However, due to experimental inaccuracies
some data scatter is encountered and the investigator must use a
statistical correlation technique (e.g., average, mean, or medium

value) in the presentation of his data.

It is expected that the quality of the data obtained by use of the above-mentioned technique may be improved by use of a nonlinear regression technique. The nonlinear regression technique, developed in Reference 2, has been extended to fit the objectives of this program. In this case, each set of three pressure measurements results in a standing wave pressure distribution that agrees with the measured results of the selected pressure transducers but may not necessarily agree with the other two transducers. Inasmuch as there is a possibility of producing ten different standing wave pressure distributions, the problem is to determine a pressure distribution that is a "best fit" for all of these distributions. The nonlinear regression technique employed in this program provides the "best fit" for the pressure distribution and the nozzle admittance for that test point.

The analytical effort associated with the statistical curve fit of the nozzle admittance data as a function of frequency is aimed at refining the existing curve-fitting procedure. Whereas the nonlinear regression technique determines the "best" nozzle admittance value at a given frequency, the statistical curve-fitting scheme determines the variation of the nozzle admittance over a range of frequencies. This work is still in progress.

Additional efforts associated with the analytical investigation of three-dimensional standing wave behavior in chambers with lined walls as well as the prediction of the admittance values of nozzles with rapidly-converging walls have continued during this report period; however, the studies have not progressed to the point where significant results can be reported.

C. Experimental Investigation

Six tests have been conducted and analyzed during this report period. The nozzle admittance results of two tests are discussed herein. The other four tests did not produce admittance data due to

failures associated with critical instrumentation or system components.

After the installation and checkout of the new tape recorder system, tests were conducted to measure the admittances of the two nozzles shown in Figure 1. The first nozzle has an entrance Mach number of 0.08 and a convergent half-angle of 15°. The small half-angle of this nozzle is in agreement with some of the assumptions made in existing nozzle admittance theories[3]; hence data obtained from tests conducted with this nozzle can be used to check the applicability of this theory. The second nozzle has an entrance Mach number of 0.16 and a convergent half-angle of 30°, which is more typical or rocket motor nozzles.

Figure 2 shows a typical sound pressure level trace taken from a transducer located 49 inches upstream of the nozzle. The trace represents the output of a tracking filter, which has a tuneable center frequency and a frequency bandwidth of 1.5 Hz at the -3 db point and 6.0 Hz at the -60 db point. This very narrow bandwidth permits excellent resolution of the data. For example, the first tangential mode is the first high-amplitude peak observed on the graph at approximately 670 Hertz. Two Hertz to the right is the location of the first three-dimensional wave, the combined first tangential-first longitudinal mode. These fine resolutions are not possible with standard filters such as 1/3 octave bandwidth filters.

Because of the multiplicity of admittances at each test point, "average" points have been presented on the figures that follow. Some of the points are indicated as "singular value" because multiple admittances were not available for a variety of reasons. Data scatter is indicated by vertical lines that are connected to the symbol. The absence of any external symbol marking indicates that the data scatter is within the confines of the symbol.

Figures 3 and 4 present the wave-number-dependence of the real and imaginary parts of the experimentally determined admittances for the M = 0.08 nozzle. The theoretical predictions are presented in

the upper lefthand corner of the graph. It can be seen that there is a minimum amount of data scatter. The very first point is the first tangential mode and the next point is the combined first tangential-first longitudinal mode.

The real part of the admittance is shown to agree with the theoretical predictions over most of the wave numbers. Exceptions occur in two regions, with the most serious departure at $\omega/c = 6$. This exceptionally high value indicates that a substantial portion of the acoustic energy is being transmitted out of the system. The imaginary part of the admittance is seen to be decreasing over most of the ω/c-range.

Figure 5 and 6 present the complex parts of the experimentally determined admittances for the M = 0.16 nozzle. All of these points are "singular value" points because only 3 transducers were used to monitor the dynamic pressures.

A considerable amount of effort was expended on the determination of admittances using data obtained from two pressure amplitude measurements and the phase difference between these two pressures. This is an alternate method of obtaining admittance data that could be used in addition to the technique of using three pressure measurements. After a reliable phase meter was found, it was discovered that the measurement of the phase difference was subject to much uncertainty, which is related to the fact that the frequency is not held constant during the test but is continually changing at a slow rate. Because of this uncertainty, the acquisition of admittance data by the phase difference technique has been discontinued. This technique will be reconsidered at a later date.

D. Expected Progress During the Next Report Period

The M = 0.16 nozzle will be tested using 5 pressure transducers. Previous tests will be repeated to verify data reproducibility. Three new nozzles will be designed and their fabrication phase will have

begun. Two of these nozzles will be designed for M = 0.32 and half-angles of 15 and 45 degrees. The third nozzle will be designed for M = 0.08 and a half-angle of 45 degrees. The nonlinear regression technique will be programmed and verified. All other analytical investigations will be continued.

References

1. Zinn, B. T., Smith, A. J., Jr., and Daniel, B. R., "Behavior of Nozzles and Acoustic Liners in Three-Dimensional Acoustic Fields," Quarterly Report for Period 1 June 69 to 31 Aug. 69, Georgia Institute of Technology, School of Aerospace Engineering, September, 1969.

2. Pfahl, R. C., Jr. and Mitchel, B. J., "Nonlinear Regression Methods for Simultaneous Property Measurement," AIAA Journal, Vol. 8, No. 6, June 1970, pp. 1046-1053.

3. Crocco, L., Sirignano, W. A., "Behavior of Supercritical Nozzles Under Three Dimensional Oscillatory Conditions," AGARDograph 117, 1967.
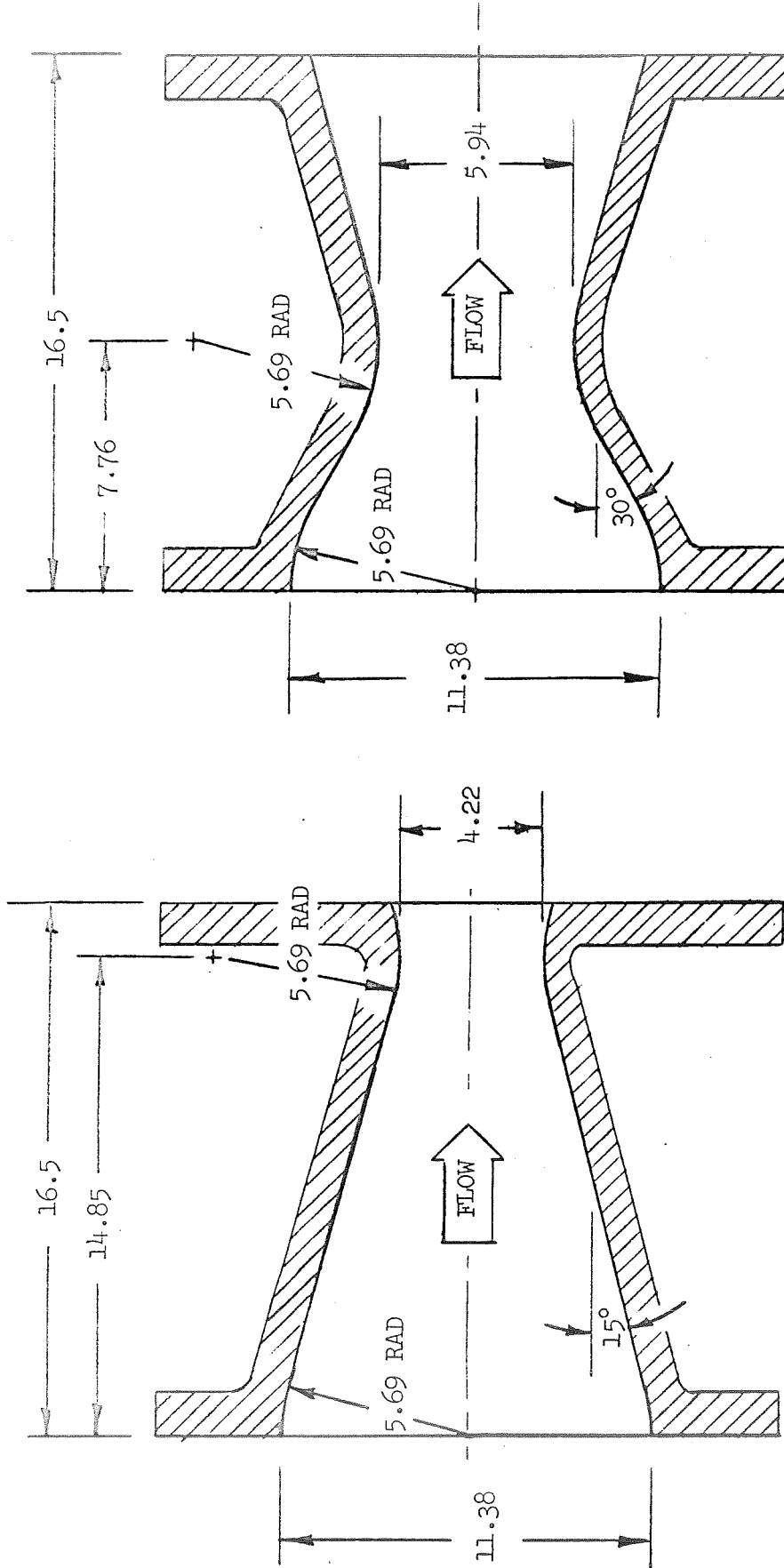
ALL DIMENSIONS IN INCHES

NOZZLE NO. 1
15-DEG HALF-ANGLE
MACH NO. = 0.08

NOZZLE NO. 2
30-DEG HALF-ANGLE
MACH NO. = 0.16

Figure 1.   Exhaust Nozzle Details
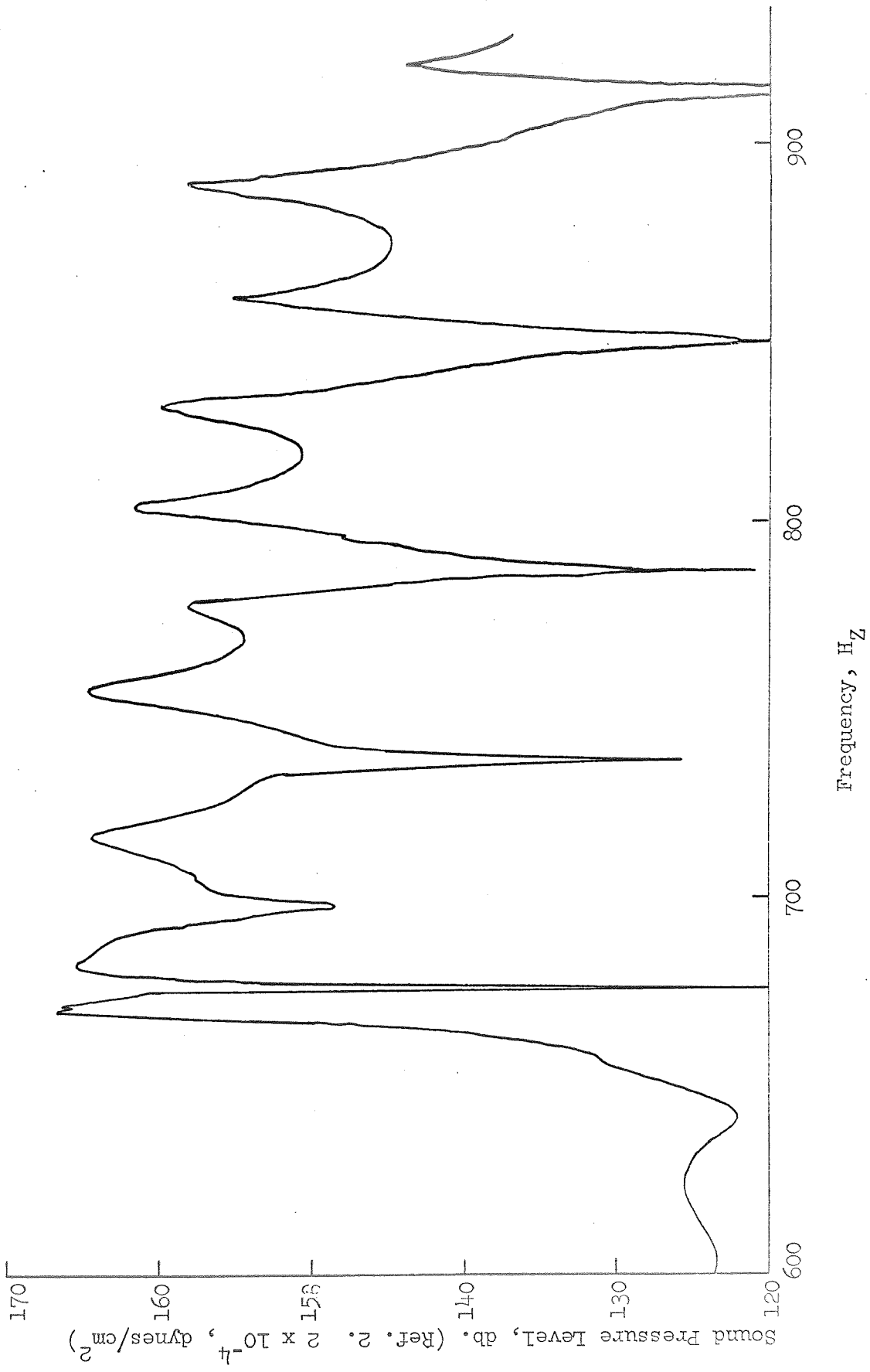
Figure 2. Typical Experimental Sound Pressure Data
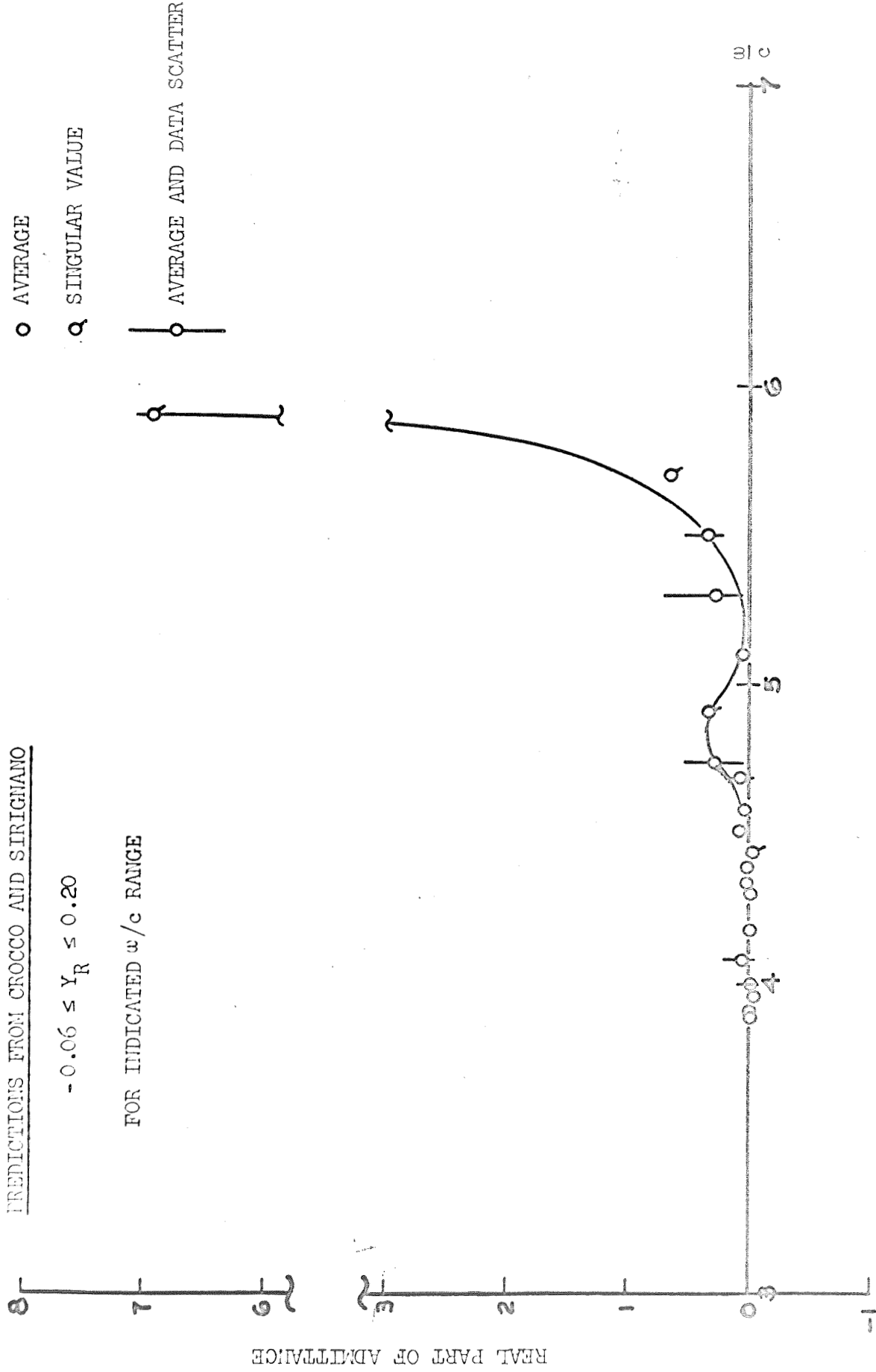
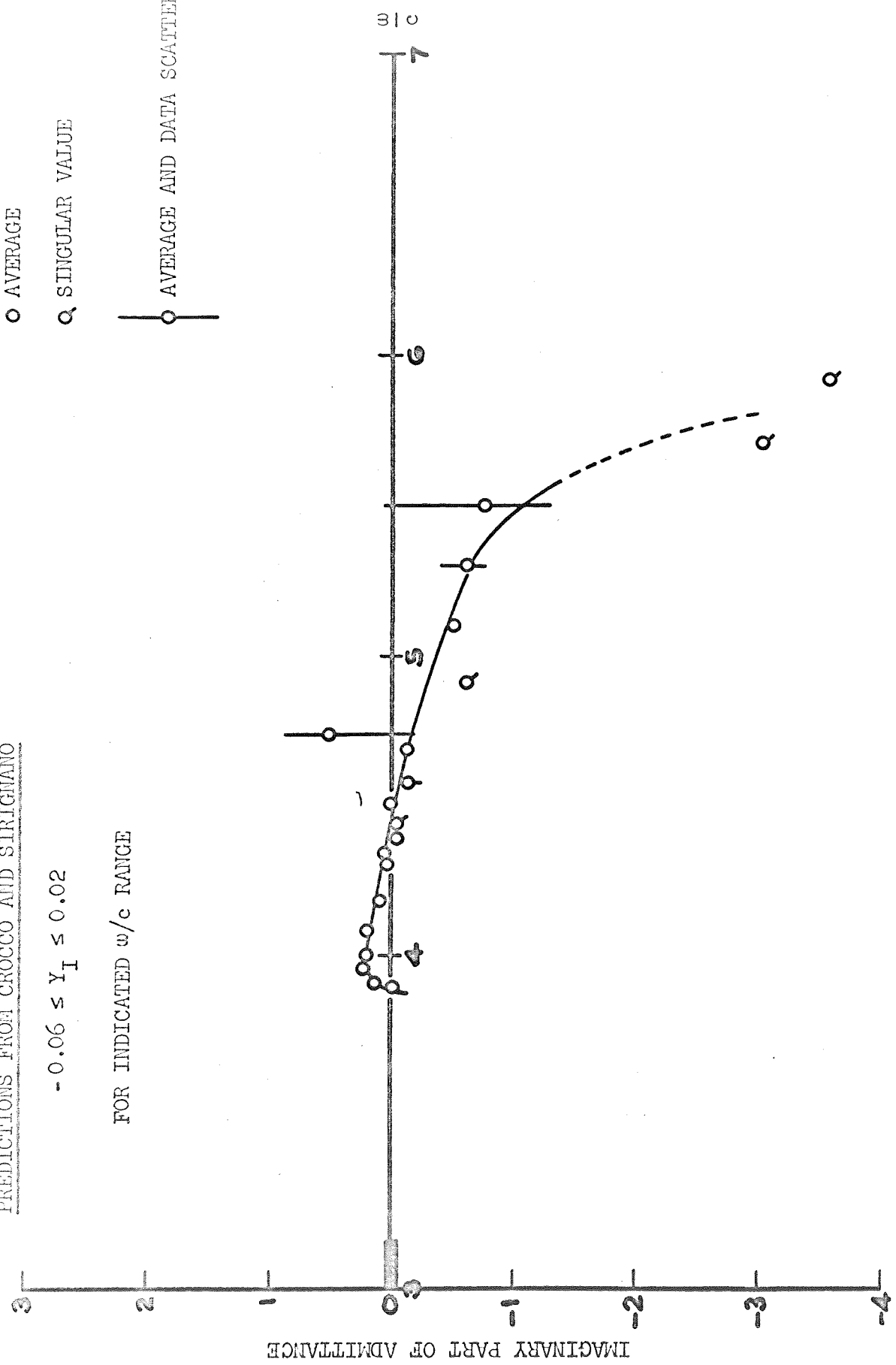Figure 3. Experimental Values of the Admittance (Real) For the M = 0.08 Nozzle

Figure 4. Experimental Values of the Admittance (Imaginary) For the M = 0.08 Nozzle
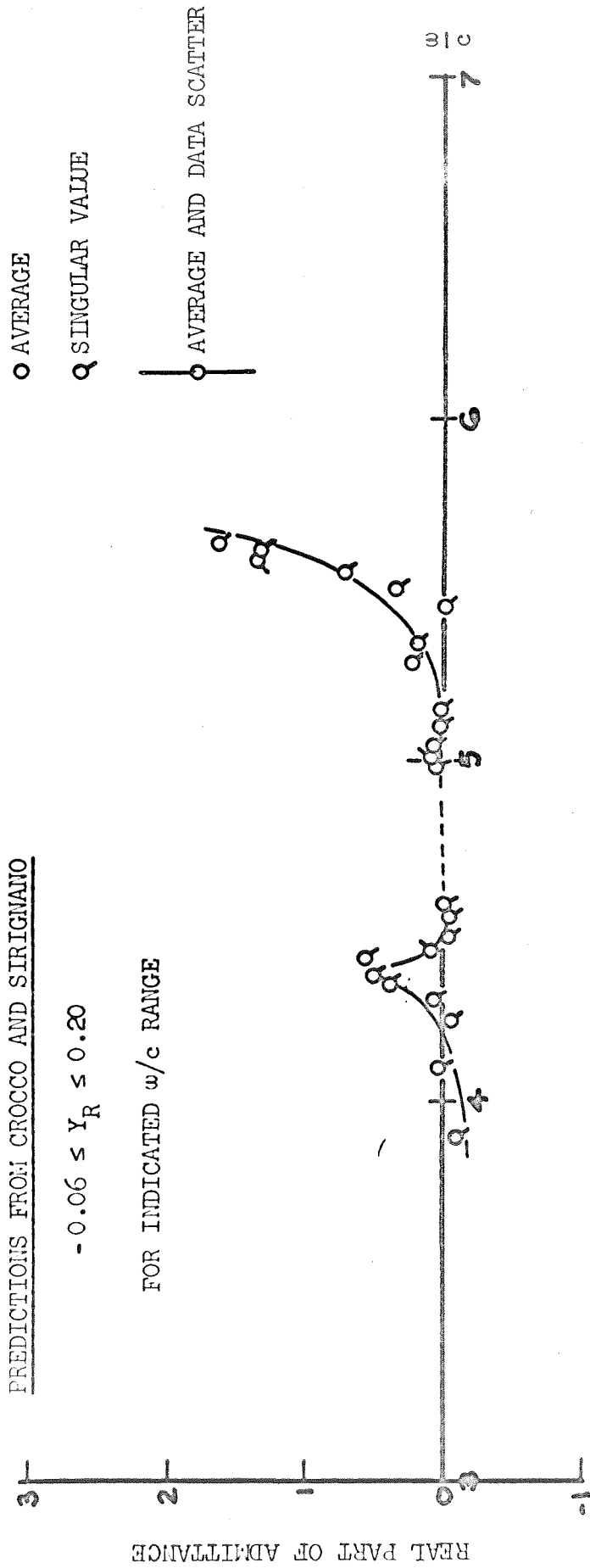
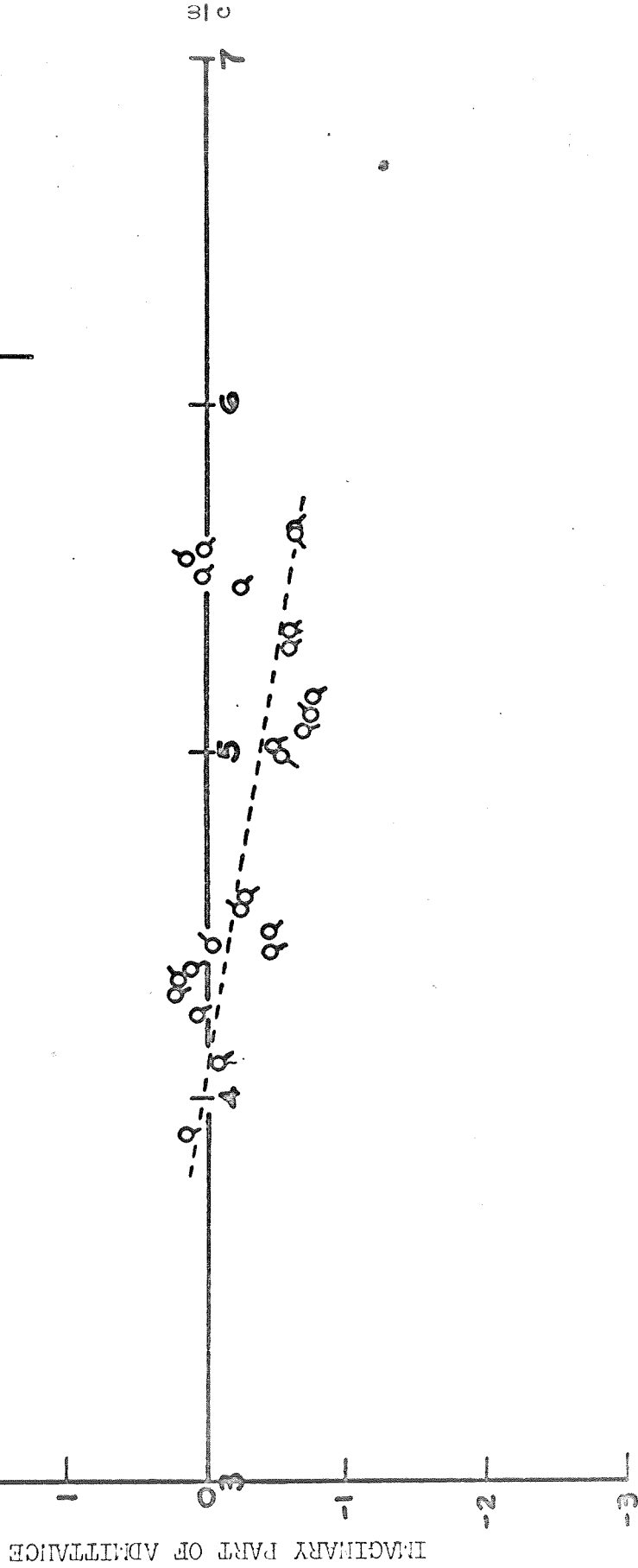Figure 5. Experimental Values of the Admittance (Real) For the M = 0.16 Nozzle

Figure 6. Experimental Values of the Admittances (Imaginary) For the M = 0.16 Nozzle