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A Shock Tube for Producing Subsonic, Transonic, and Supersonic Flows for Aerodynamic Testing

18 FEBRUARY 1963

Prepared by R. L. VARWIG
Aerodynamics and Propulsion Research Laboratory

Prepared for COMMANDER SPACE SYSTEMS DIVISION
UNITED STATES AIR FORCE
Inglewood, California

LABORATORIES DIVISION • AEROSPACE CORPORATION
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ABSTRACT

A shock tube is proposed in which the flow conditions between the shock wave and advancing interface are expected to range from low subsonic to moderate supersonic speeds. Furthermore, testing times of 10 msec or more are predicted, a time quite adequate for aerodynamic force measurements. The driven section in the proposed facility is large enough to accomodate large scale models. To test the feasibility of the proposed tube, a shock tube was assembled using a surplus 7-foot diameter vacuum tank as a driven section and 12-inch flanged pipe for the driver. A series of tests were performed to determine shock formation time and experimental testing time. The results of these tests are reported.

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I. INTRODUCTION

An examination of the flow conditions in a shock tube behind a normal well-formed shock wave shows that (1) the pressure, temperature, and velocity are constant between the shock wave and the interface separating the driver from the driven gas, and (2) for varying shock speeds the range of flow Mach number (M_2), defined as u_2/a_2, includes subsonic flow for weak shocks ($M_s < 1.5$), transonic flow for $1.5 < M_s < 2.2$, and supersonic flow for $M_s > 2.2$ up to a maximum theoretical value of 1.89. Further, the time interval between the arrival at any point of the shock wave and the interface may be varied, within limits, by varying the point location and the length of the shock tube, including the driver. Hence, it is possible in concept to design a shock tube with a testing time that is adequate for aerodynamic measurements by using equipment which had been developed for shock tunnel research.

A shock tube study of this type was reported in 1949 by Geiger, Mautz, and Hollyer (Ref. 1). They worked with a shock tube of constant 2-by 7-inch rectangular cross-section. The maximum testing time for this facility was about 400 μsec at a flow Mach number of about 1.2 corresponding to a shock Mach number of 2.6. This testing time is just under one-half the ideally computed value. The short testing time together with the small tube dimensions limited the model size, although two-dimensionality was maintained.

The writer proposed to devise a shock tube of such size and testing time that models designed to be tested in the hypersonic shock tunnel could also be inserted into the shock tube for subsonic, transonic, and supersonic aerodynamic measurements. The maximum diameter of the nozzle cone in the existing shock tunnel is not quite 67 inches. Hence, the mimimum i.d. of the proposed shock tube was set at 6 feet. The x - t curves for ideal shock tubes and the practical size limitation were examined and a length of 35 feet for the driven section was selected. The examined shock Mach number range extends from $M_s = 1.2$ to 3.2. The x - t curves for these conditions are shown in Fig. 1, 2, and 3 from which testing times of 12, 13, and 1.5 msec, respectively, were determined. A compromise of model location was made because the maximum testing time was obtained at different locations for varying shock Mach numbers. The maximum testing time was determined by the intersection of either the contact interface or the reflected rarefaction with the reflected shock wave.

Finally, the driven section was to be contained in a thin high pressure cylinder. It was expected that the shock could be driven to a satisfactorily high Mach number by trading off high driver pressure for driver cross-sectional area. A series of calculations worked out by Lamb (Ref. 2) yielded the data shown in Fig. 4. The calculations were based on an unsteady expansion of a driver gas from a driver with a cross-sectional area smaller than the driven section. From this curve, the maximum working pressure can be determined for which the driver, as a vessel, must be designed for a specific area ration between the driver and driven section.

A feasibility experiment was conducted (1) to confirm the pressure calculations, (2) to determine whether, with the above configuration, the slim driver with the driver gas expanding into the large driven section produces a diffuse mixing region for the interface which reduces the testing time to substantially nothing, and (3) to determine the amount of time it takes for the shock wave to become "reasonably well formed" in the driven section.

II. EXPERIMENTAL EQUIPMENT AND PROCEDURE

With the use of a surplus vacuum dump tank and vacuum equipment from a small dismantled wind tunnel as the driven section and the 3 inch diameter driver the shock tube was assembled as shown in Fig. 5. The driven section was 7 feet in diameter and approximately 17 feet in length. An observation section of 12 in. windows was installed 11.7 feet from the diaphragm. A blunt model was inserted from the end of the tank to the observation area.

A Schlieren camera system was installed with pressure gauges in the wall and at the stagnation point of a hemispheric-cylindrical model. After a shake-down period during which the nonfunctional equipment was repaired or replaced, pressure records and Schlieren photographs of the shock were obtained for shock Mach numbers up to 2.0. The shock Mach number was obtained by measuring the time of passage of the shock from one pressure gauge position to another.

From Schlieren observations of the shock wave, it seemed that several shocks occurred which were suspected to have originated from the diffraction occurring at the expansion point where the driver entered the driven section. To relieve this situation, a conical transition section was added between the driver and driven section and, finally, a driver section 12-in. in diameter was adopted. This configuration, a 12-inch i.d. by 5-feet long driver, a 38-degree conical transition section and a 7-foot i.d. by 17-foot driven section, served as the prototype shock tube from which the data reported in the following section were obtained.

III. EXPERIMENTAL RESULTS

At a shock Mach number of 1.12 corresponding to a flow Mach number of 0.15 which was obtained for $P_4/p_1 \sim 6$. Schlieren photographs of the passage of a shock wave are shown in Fig. 6. The presence of two shocks is confirmed by pressure records made at the same time. An x - t curve for this shock Mach number with N_2 as the driver gas is shown in Fig. 7. The points in the figure represent the experimentally observed arrival times of the reflected shock and rarefaction waves obtained from the pressure histories. It should be emphasized that these results are for very weak shock waves obtained in a non-ideal shock tube and barely one or two diameters from the diaphragm section. In addition, there are numerous ports and protuberances in the tank or driven section which tend to disturb the flow. As a result, a smooth testing region is not obtained.

An x - t diagram for $M_s = 1.6$ is shown in Fig. 8 with the experimental arrival times for the reflected shock and rarefaction waves. Schlieren photographs (Fig. 9) show again the two shocks but in this case they are much closer and not resolvable in the pressure records. The testing time is about 3.6 msec as compared with about 4 predicted from the x - t curve. The diaphragm pressure ratio for $M_s = 1.6$ is 325 with $p_1 = 0.0167$ atm. $M_f = 0.68$.

In the Fig. 9 the shock Mach number is 2.0. Because of the high noise level it is difficult to identify the reflected rarefaction wave on the pressure records. The noise level caused by the tank vibration is proportional to the driver pressure which remains the same while the signal level is proportional to the driven section pressure which is reduced by a factor of five. One point is obtained which results in a testing time of 70 percent of the predicted time as shown in the x - t curve for $M_s = 2$ (Fig. 10). Since the flanges on the driver and driven sections which held the diaphragm had a rating of 250 psi, it was not possible to produce values of M_s beyond about 2. The driver pressure could not be increased beyond this value.

From the test results it is concluded that (1) the diaphragm pressure ratio is higher than that predicted by the theory, and (2) the testing time as indicated by the arrival of reflected shocks and rarefaction is reasonably close to the predicted time when reflected shock and rarefaction waves can be determined. The arrival of the contact interface was not detected. Hence, no definite conclusion about the testing time can be made. Test data are being reduced on flow duration from a low density shock tube which is appropriate to this problem. We have committed our plans for fabrication as indicated below.

IV. PROPOSED FACILITY

Design of the new shock tube is in progress. A rough preliminary layout of the facility and the location of the facility in its allocated space are shown in

Fig. 11. Sections of the existing tank will be used in the new facility. All objectionable ports and projections will be removed or modified. The windows will be installed flush to the walls of the round tank.

Completion date for the driver and driven sections is set for 1 March and the first operational test is scheduled for 15 March 1963.

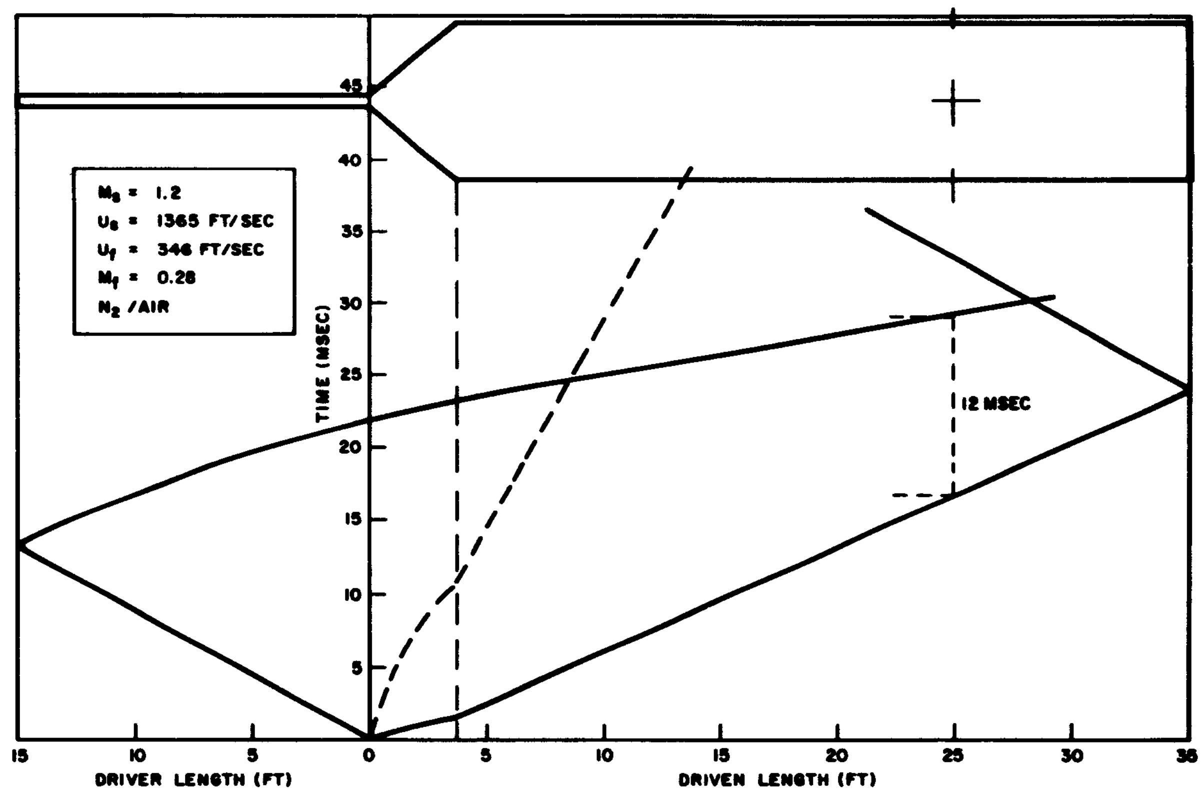


Figure 1. Wave Diagram for Proposed Aerodynamic Shock Tube.
$M_s = 1.2$

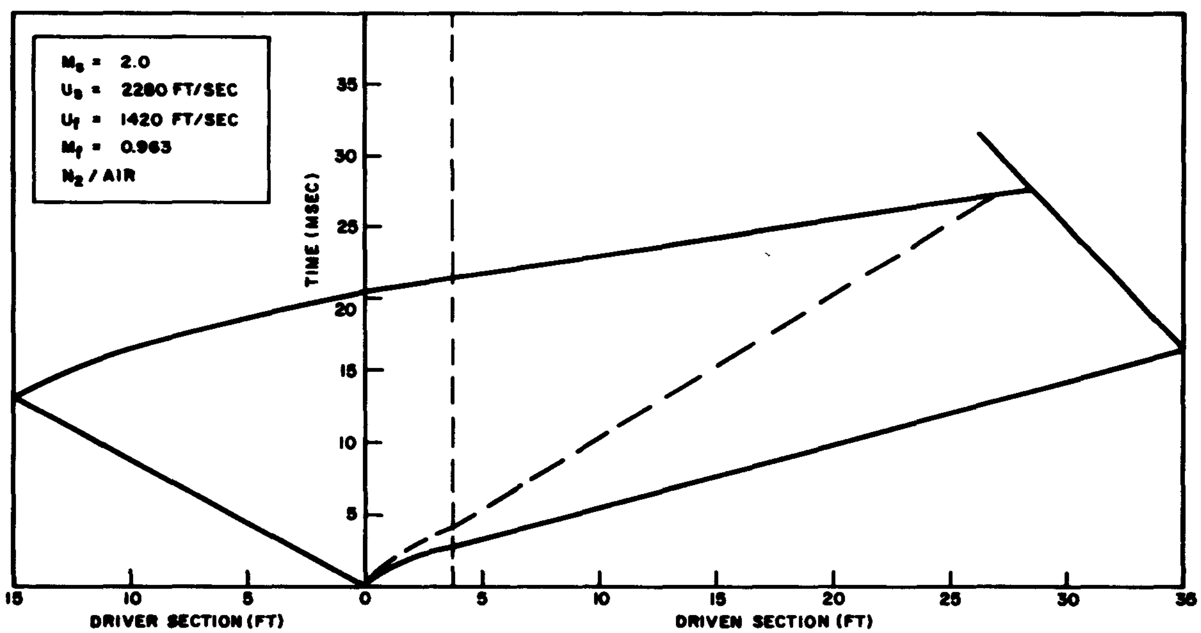


Figure 2. Wave Diagram for Proposed Aerodynamic Shock Tube.
$M_s = 2.0$

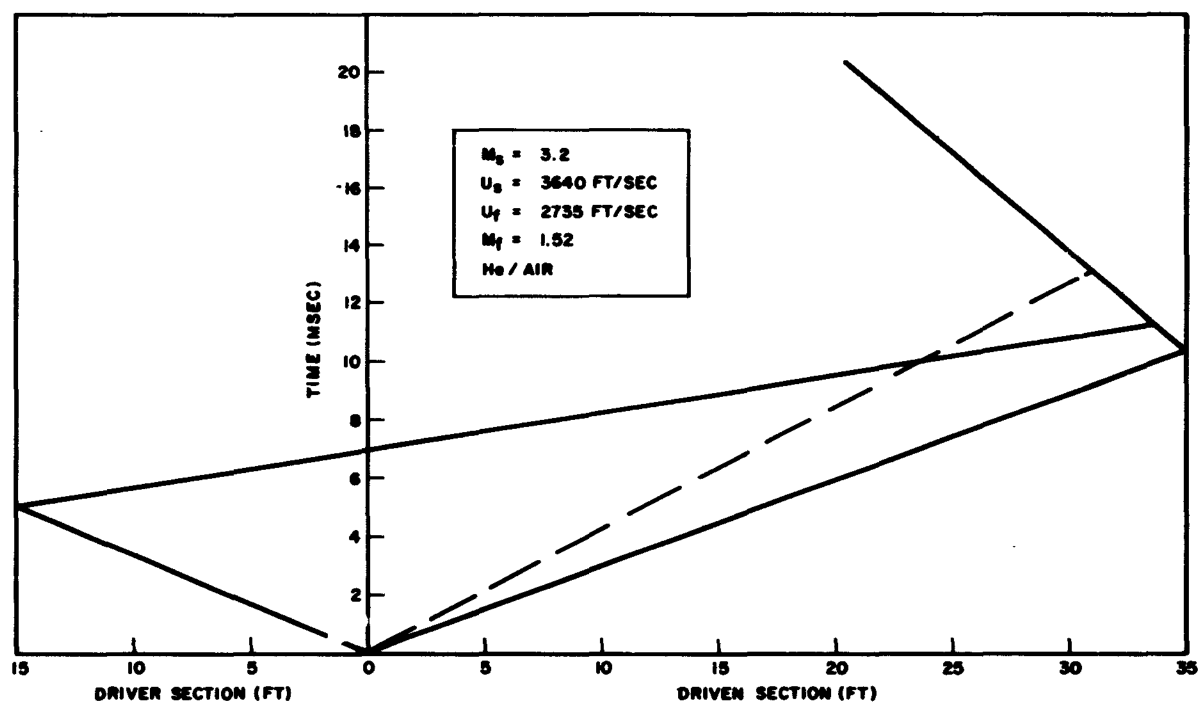


Figure 3. Wave Diagram for Proposed Aerodynamic Shock Tube.
$M_s = 3.2$

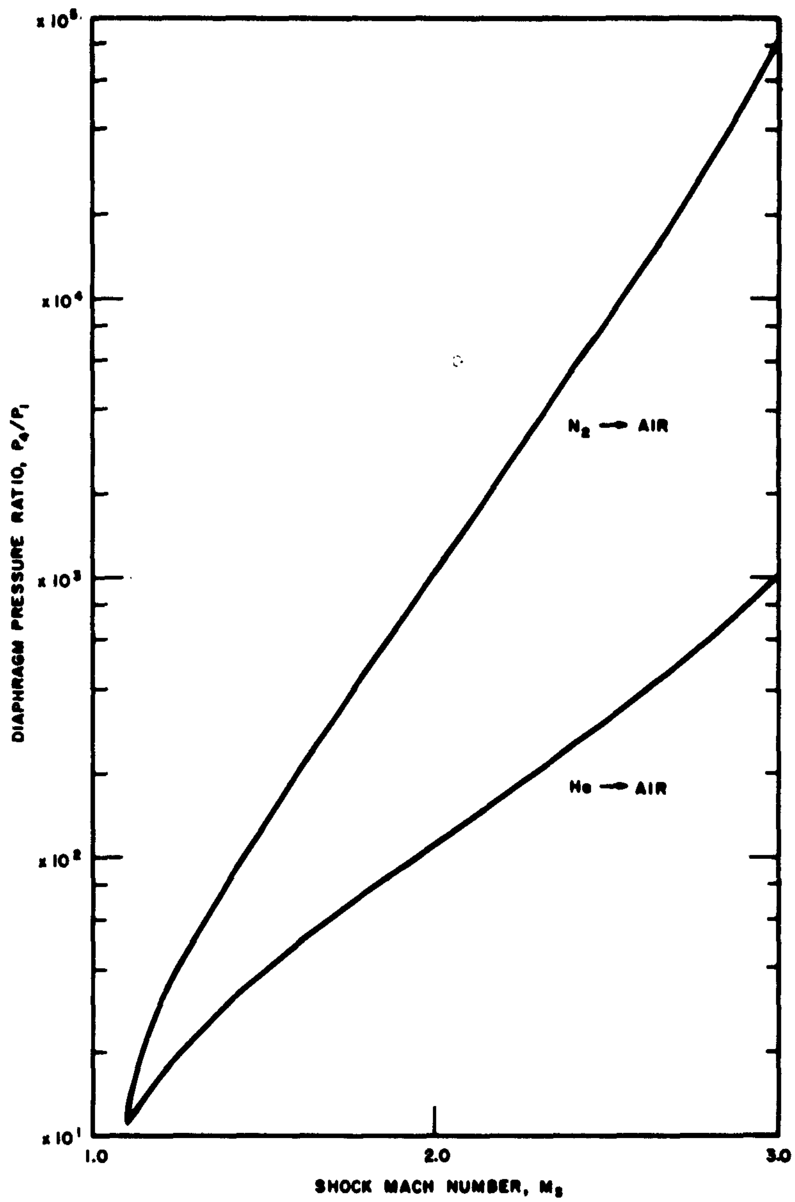


Figure 4. Diaphragm Pressure Ratio Versus Shock Mach Number for N_2 + He Driving Gas. $A_4/A_1 = 1/196$

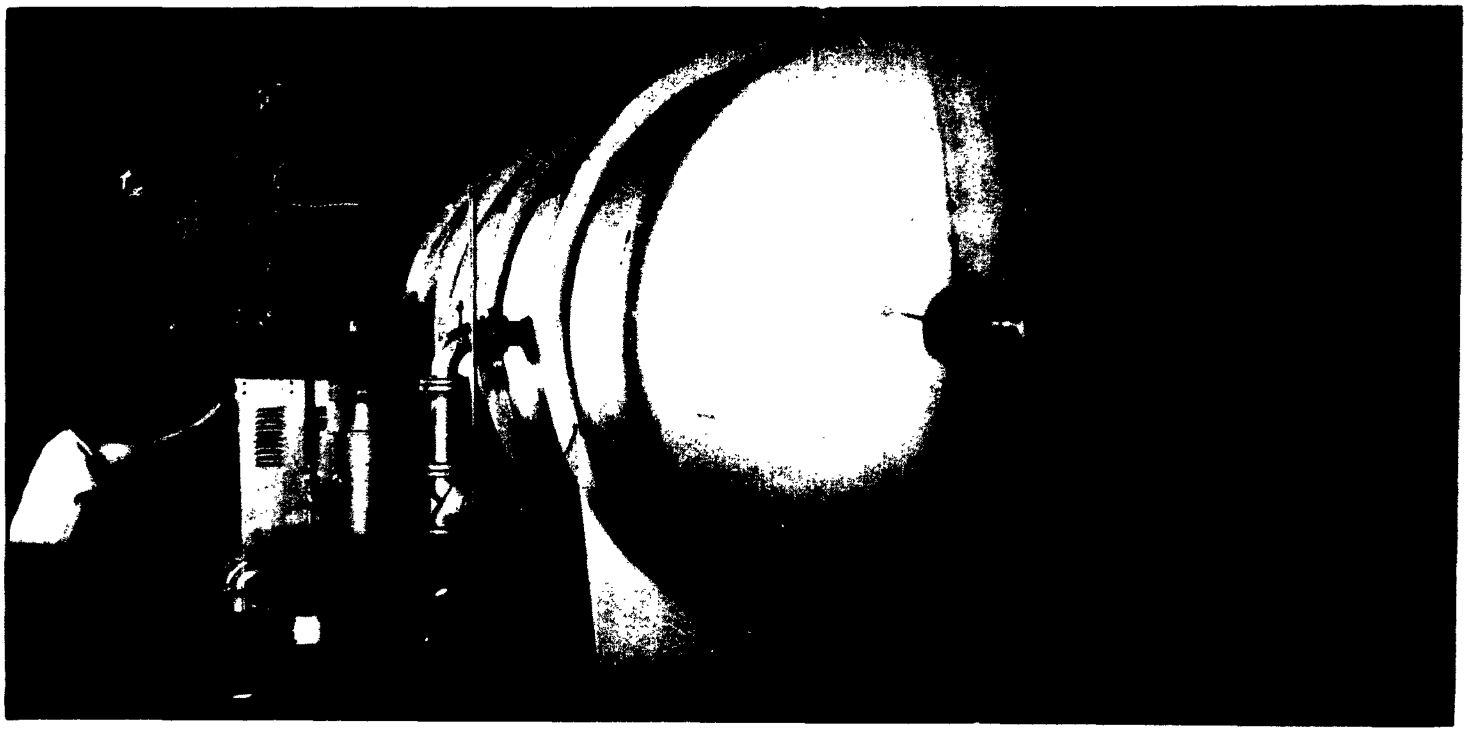
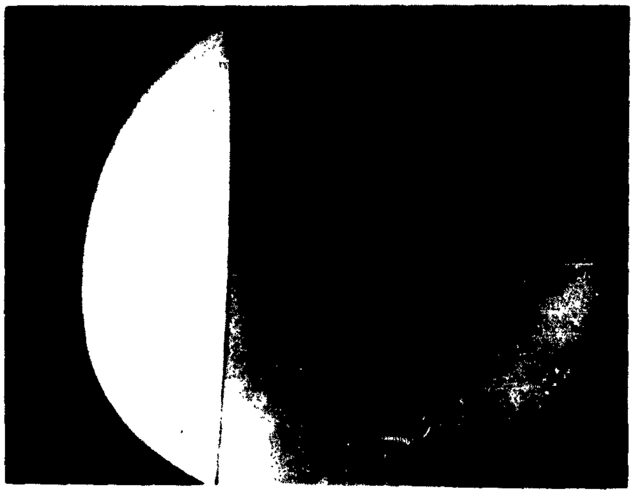
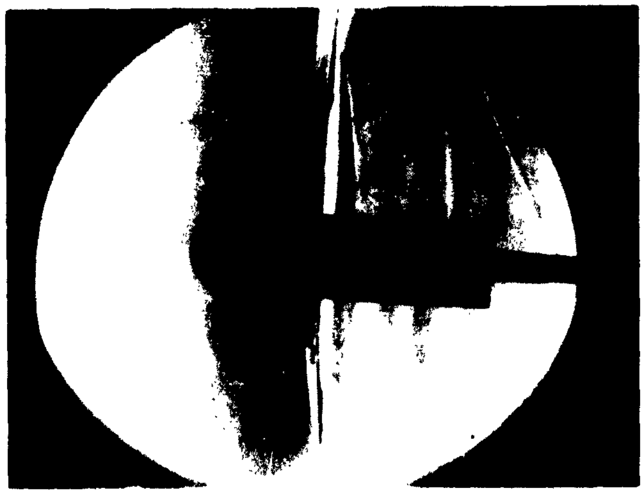


Figure 5. Prototype Shock Tube for Aerodynamic Studies



a



b

Figure 6. Shock Wave Passage Over Blunt Body. $M_s = 1.12$. (a) First Shock Approaching Body. (b) Second Shock Passing Over Body. First Shock has Passed and Portions of It near the Wall Are Reflecting from the Recessed Window Mounts

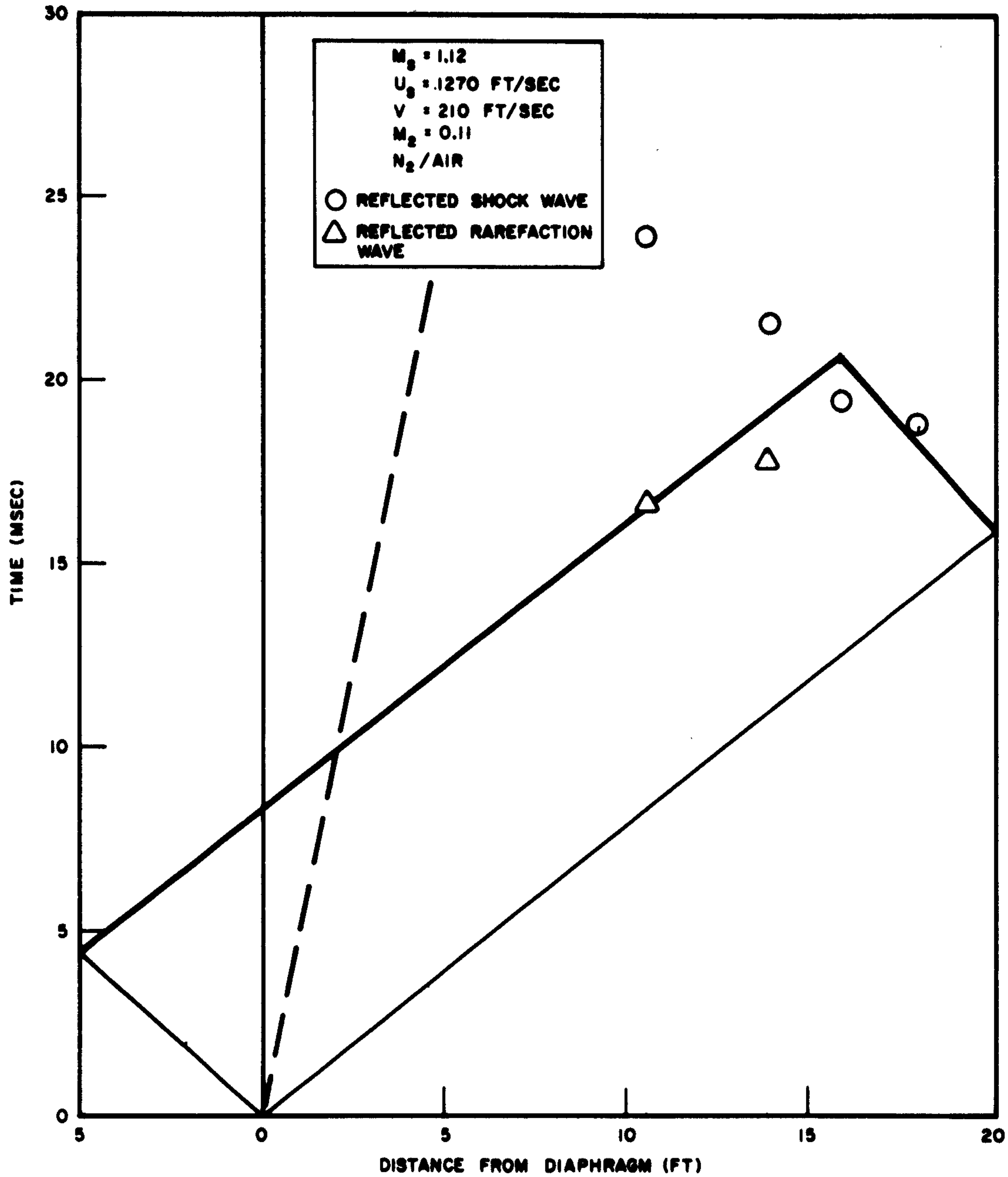


Figure 7. Wave Diagram and Experimentally Observed Arrivals of Reflected Shock Wave and Rarefaction Wave for M_s = 1.12

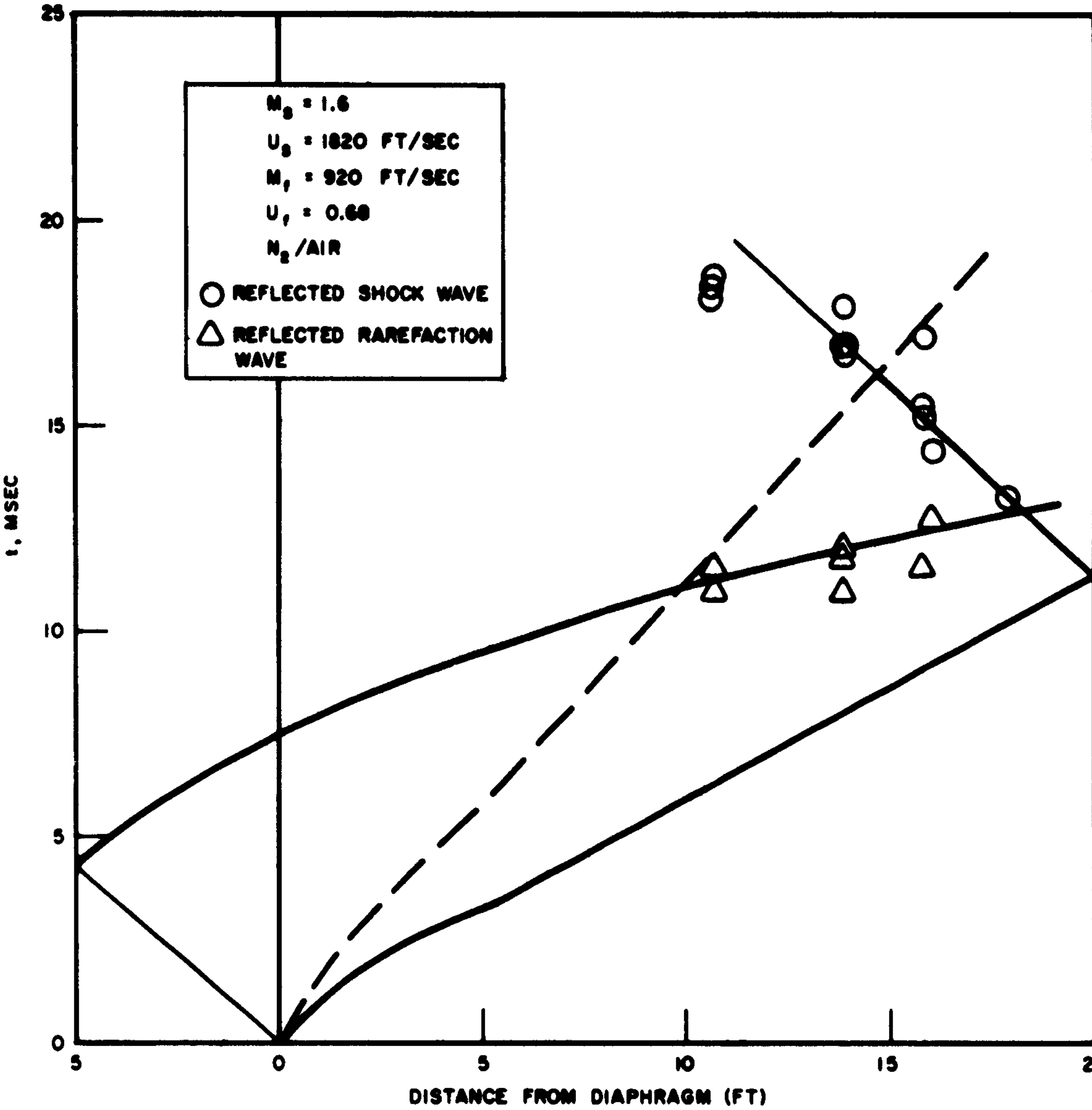


Figure 8. Wave Diagram Showing Experimentally Observed Arrival of Reflected Shock and Rarefaction Waves

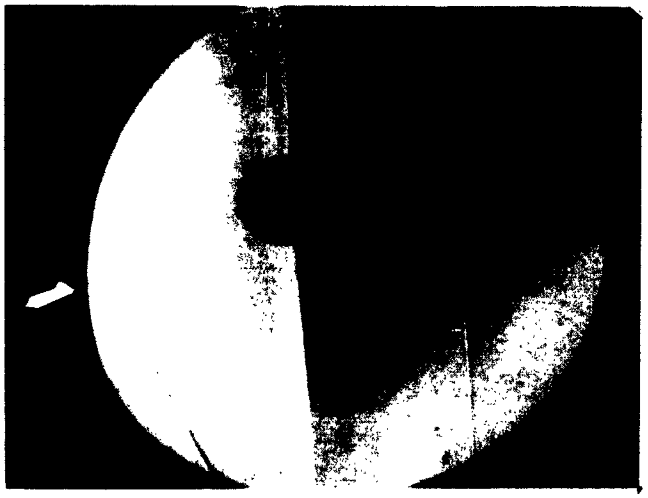


Figure 9. Schlieren Observation of Shock Waves in Aerodynamic Shock Tube at $M_s = 1.6$

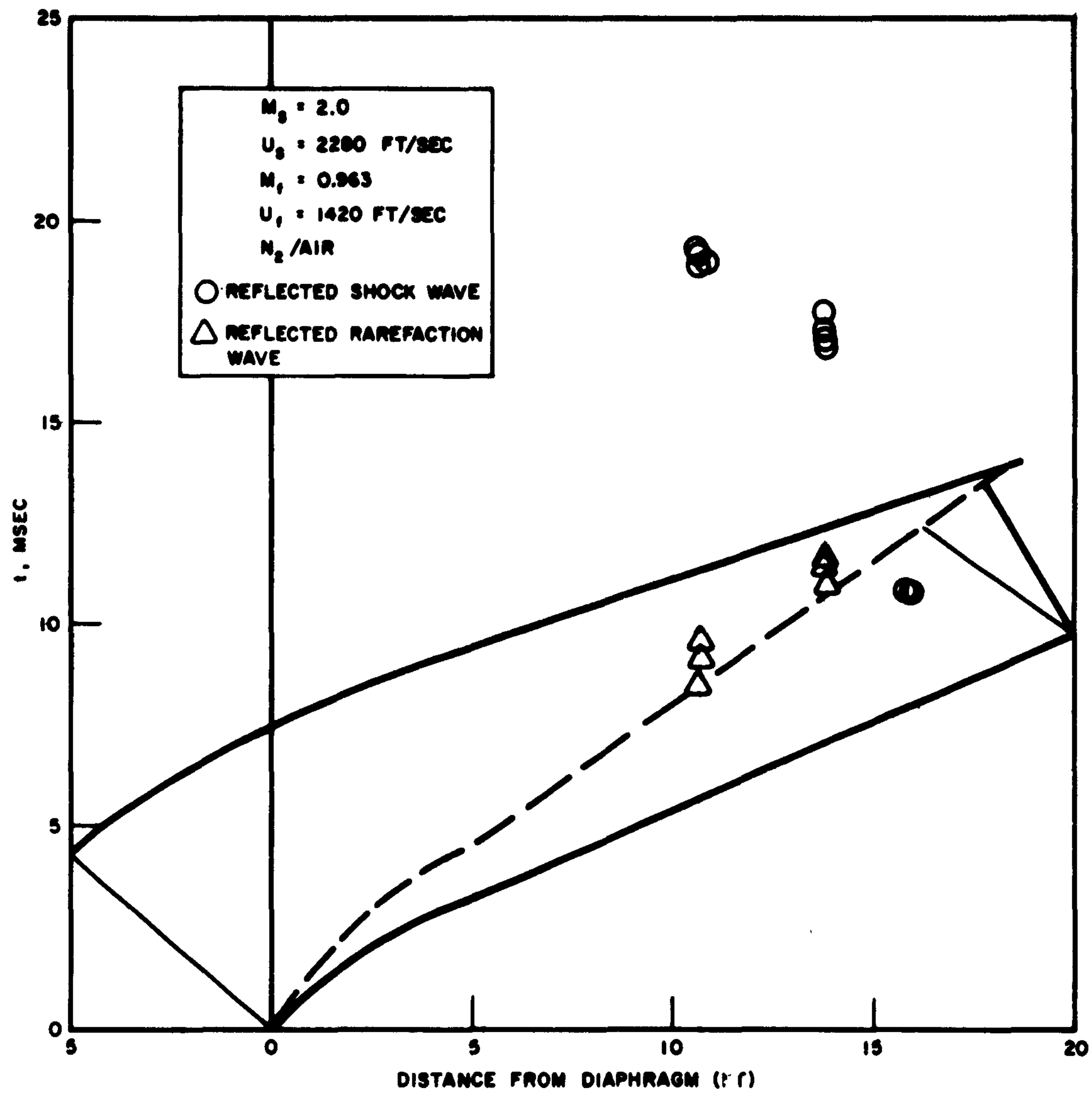
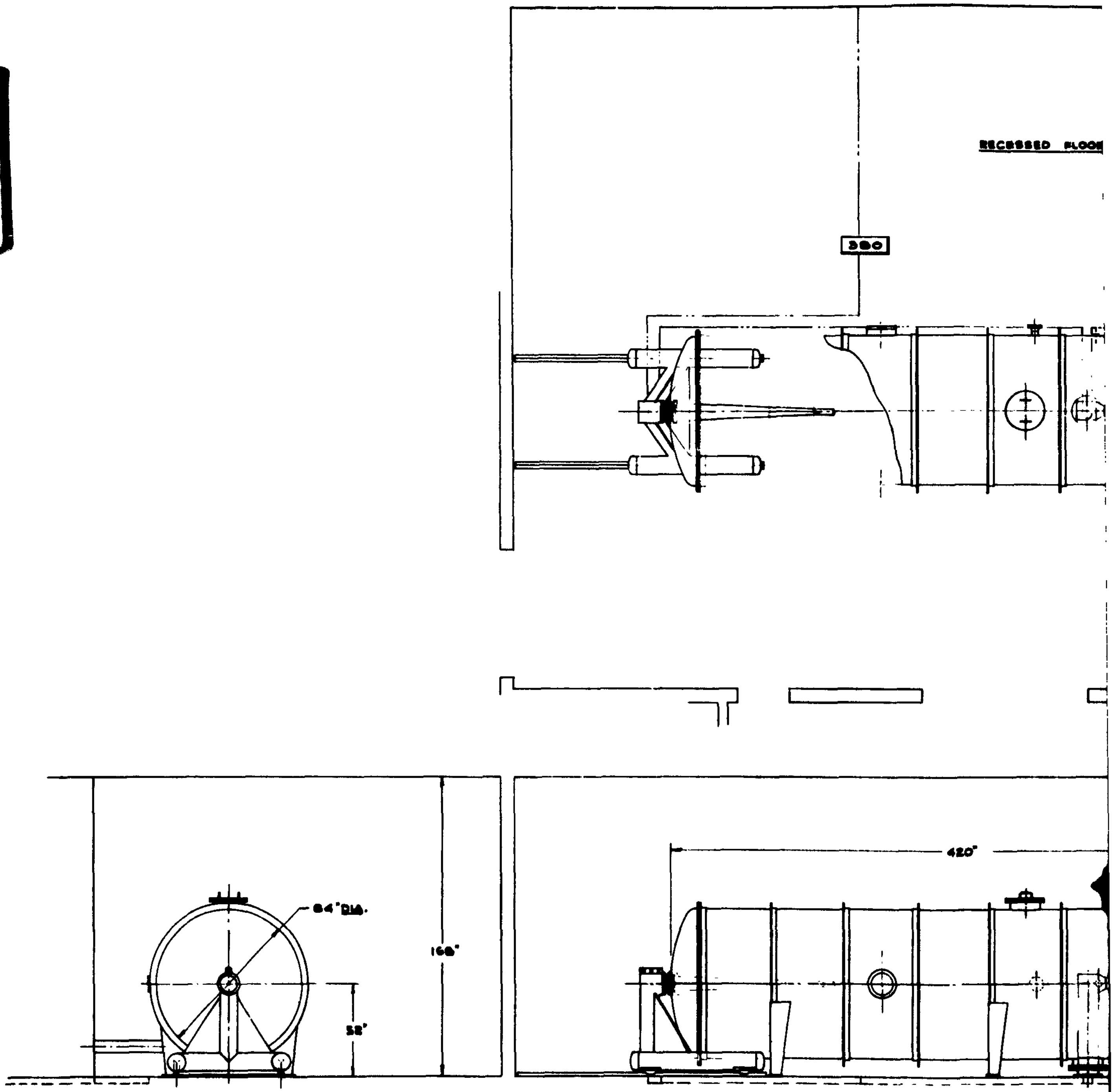
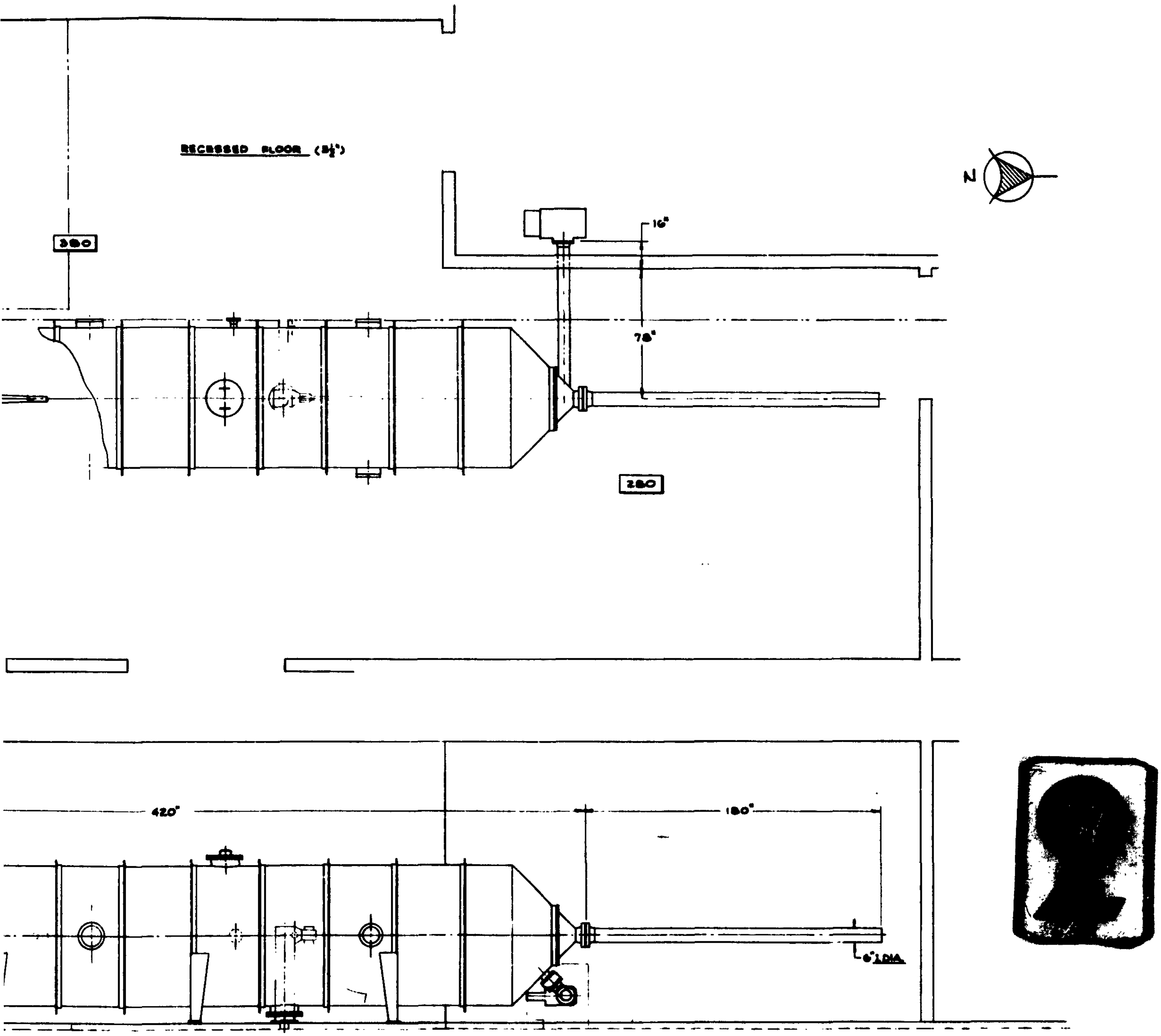


Figure 10. Wave Diagram for M_s = 2.0

Figure 11. Schematic View of Aerodynamic Shock Tube and Housing Facility




RECESSED FLOOR (3½")
380
N
16"
78"
280
420"
180"
6" I.DIA.

REFERENCES

1. Geiger, F. W., C. M. Mautz, and R. N. Hollyer, Jr., "The Shock Tube as an Instrument for the Investigation of Transonic and Super-Sonic Flow Patterns" Engineering Research Institute, University of Michigan Report, Project M720-4 (June 1949).

2 Lamb, L. Y., Private Communication, Aerospace Corporation, El Segundo, California.

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Aerospace Corporation, El Segundo, California.
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