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RESEARCH MEMORANDUM

A PRELIMINARY INVESTIGATION OF STATIC-PRESSURE CHANGES ASSOCIATED WITH COMBUSTION OF ALUMINUM BOROHYDRIDE IN A SUPERSONIC WIND TUNNEL

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

A PRELIMINARY INVESTIGATION OF STATIC-PRESSURE CHANGES ASSOCIATED WITH COMBUSTION OF ALUMINUM BOROHYDRIDE IN A SUPERSONIC WIND TUNNEL

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SUMMARY

Static-pressure changes resulting from steady combustion of aluminum borohydride in a supersonic wind tunnel were studied. Static pressures were measured along the top wall of a 3.84- by 10-inch tunnel adjacent to the flame that filled the upper portion of the test section.

Pressure increases of the order of 20 to 40 percent of the initial static pressure were measured during combustion. The magnitude of the pressure changes suggests that further use of aluminum borohydride to study the effects of heat addition on supersonic flow is warranted.

INTRODUCTION

Theoretical studies of heat addition to supersonic flow (refs. 1 to 4) predict that the static pressure of a supersonic gas stream will increase if heat is added to the stream. Applications of this effect were considered in references 5 to 8. Reference 5 shows theoretically that significant improvements in the lift coefficient and in the lift-drag ratio result if heat is added directly to the supersonic stream adjacent to the lower surface of an airfoil.

Until recently, combustion had not been stabilized in a supersonic stream; there are little or no experimental data on pressure changes associated with direct heat addition. Consequently, it has not been possible to compare the theoretical results with experimental data.

A method of adding heat to a supersonic stream was recently demonstrated in reference 9, which showed that aluminum borohydride could be burned stably in a supersonic airstream. Liquid aluminum borohydride injected through an orifice in the top wall of a wind-tunnel test section burned in the adjacent supersonic stream. No flameholders were needed to prevent blow-out.

This report extends the work reported in reference 9. Static-pressure changes were measured along the top wall of the tunnel adjacent to the flame in the supersonic stream at Mach numbers of 2 and 3. The research reported herein was done at the NACA Lewis laboratory.

APPARATUS AND PROCEDURE

A 3.84- by 10-inch supersonic wind tunnel operating at nominal Mach numbers of 2 and 3 was used. Tunnel stagnation pressure was held between 44 and 47 inches of mercury. The tunnel air had a dewpoint of approximately -20° F and was preheated to 85° to 105° F. The side walls of the tunnel were made of 1-inch-thick plate glass, which permitted convenient visual and schlieren observation or photography of flow phenomena associated with combustion. 3755

Static-pressure changes were measured along the centerline of the top wall of the test section. Statham strain-gage pressure transducers were connected by short tubes to static taps in the top wall of the test section at stations 14.25, 18.25, and 32.25 inches downstream of the fuel-injection point. The signal output from each strain-gage pressure-transducer bridge was amplified and recorded by an oscillograph. Additional static taps in the top wall were connected to a small mercury manometer board, which was sequentially photographed with an Air Force K-24 (aerial) camera at the rate of 2 to 3 pictures per second.

The fuel was injected for a 1- to 2-second period through a single orifice 1/64 inch in diameter which was flush with the top wall of the tunnel. The orifice was located at the upstream end of the test section on the centerline of the top wall. Helium usually pressurized to 38 pounds per square inch gage was used to inject the fuel. The injection rate could be changed by varying the helium pressure. The fuel-injection apparatus is shown in figure 1. A spark plug (1 joule, 5 sparks/sec) or a capsule fuel ignitor (ref. 9) was located 25.25 inches downstream of the fuel-injection point. After ignition, the flame rapidly traveled upstream to the injection region and remained seated there until all the fuel was injected. A photograph of the flame seated in the injection region is shown in figure 2.

RESULTS AND DISCUSSION

Static-pressure increases of the order of 20 to 40 percent of the initial static pressure were measured at the top wall of the tunnel adjacent to the flame in the supersonic stream. Typical static-pressure pulse traces from the oscillograph are shown in figure 3 for Mach numbers 1.95 and 2.9 at the three pressure-transducer stations. These traces show that the actual pressure pulses due to heat addition were essentially rectangular in form with respect to time and that the combustion was fairly steady during the runs. As discussed in reference 9, the flow in the portion of the tunnel stream below the flame was supersonic throughout the runs.

The change in static pressure at various stations downstream of the fuel orifice is shown in figure 4. The pressure changes at the three pressure-transducer stations are connected by a smooth dashed curve that gives static-pressure changes indicated by the sequential photographs of the manometer board. Because of incomplete response of the manometer board in many of the runs, the pressure changes indicated by the manometer board were normalized with respect to the value given by the Statham at the 18.25-inch position. Figure 4(a) shows the results of two runs at Mach 1.95. In each run, the change in static pressure increased with distance downstream of the injection point until a plateau of fairly constant pressure change was reached at 14 to 18 inches. The sharp rise in the pressure-change curves between 25 and 31 inches indicated by the manometer board was probably due to the effect of the spark plug or the ignitor capsule on the flame and pressure field. The ignitor position is indicated in the figure.

Figure 4(a) also shows that a change in fuel-injection rate from 3 to 10 cc per second caused a considerable increase in the pressure change. The equivalence ratios assuming that combustion occurred in the upper third of the tunnel volume were 0.012 and 0.038. From the average depth of the flame and the average width of the ash pattern on the top wall, these appear to be reasonable estimates.

The pressure-change curves for two runs at Mach 2.9 are shown in figure 4(b). Both runs at Mach 2.9 were with fuel-injection rates of 3 cc per second (equivalence ratio, 0.028) and gave quite similar pressure changes. In addition, the runs at Mach 2.9 are similar in form to the runs at Mach 1.95. They differ primarily in the amplitude of the pressure changes.

An appreciation of the magnitude of the effect of combustion on the static pressure can be seen from figures 5 and 6. The static-pressure distribution along the top wall of the test section before combustion is shown in figure 5. The ratio of the change in static pressure resulting from combustion to the static pressure before combustion is shown in figure 6. This figure shows that, for the same fuel-flow rate (3 cc/sec), the ratio of $\Delta p/p_i$ is larger for the higher Mach number. Increasing the fuel-flow rate to 10 cc per second at Mach 1.95 gave a greater percentage effect than the 3-cc-per-second rate at either Mach number.

Some difficulty was encountered in controlling the fuel-injection rates because of partial plugging of the orifice during the runs. This may have been caused by the ash deposits around the edges of the fuel orifice. In addition, the ash deposits occasionally plugged the first few static-pressure holes.

The effect of the tunnel boundary layer on the character of the heat-addition region and consequently the static pressure is not known. The boundary layer of this tunnel and its possible effects on combustion were discussed in reference 9. It would be desirable to investigate the effect of the boundary layer on the pressure change resulting from heat addition. 3755

CONCLUDING REMARKS

Static pressure increases significantly when aluminum borohydride burns in a supersonic stream. The order of magnitude of this pressure increase further substantiates the suggestion of reference 9 that aluminum borohydride may be useful in the study of the effects of heat addition on supersonic flow.

On the basis of the work reported in reference 9 and herein, it appears possible to establish a steady flame adjacent to a model located in the center of the stream of a supersonic tunnel. The associated pressure changes in the heated stream adjacent to the model could then be studied. A detailed study of the associated pressure changes would permit an evaluation of suggested practical applications such as improvement in the lift coefficient of a wing (ref. 5).

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, June 7, 1955

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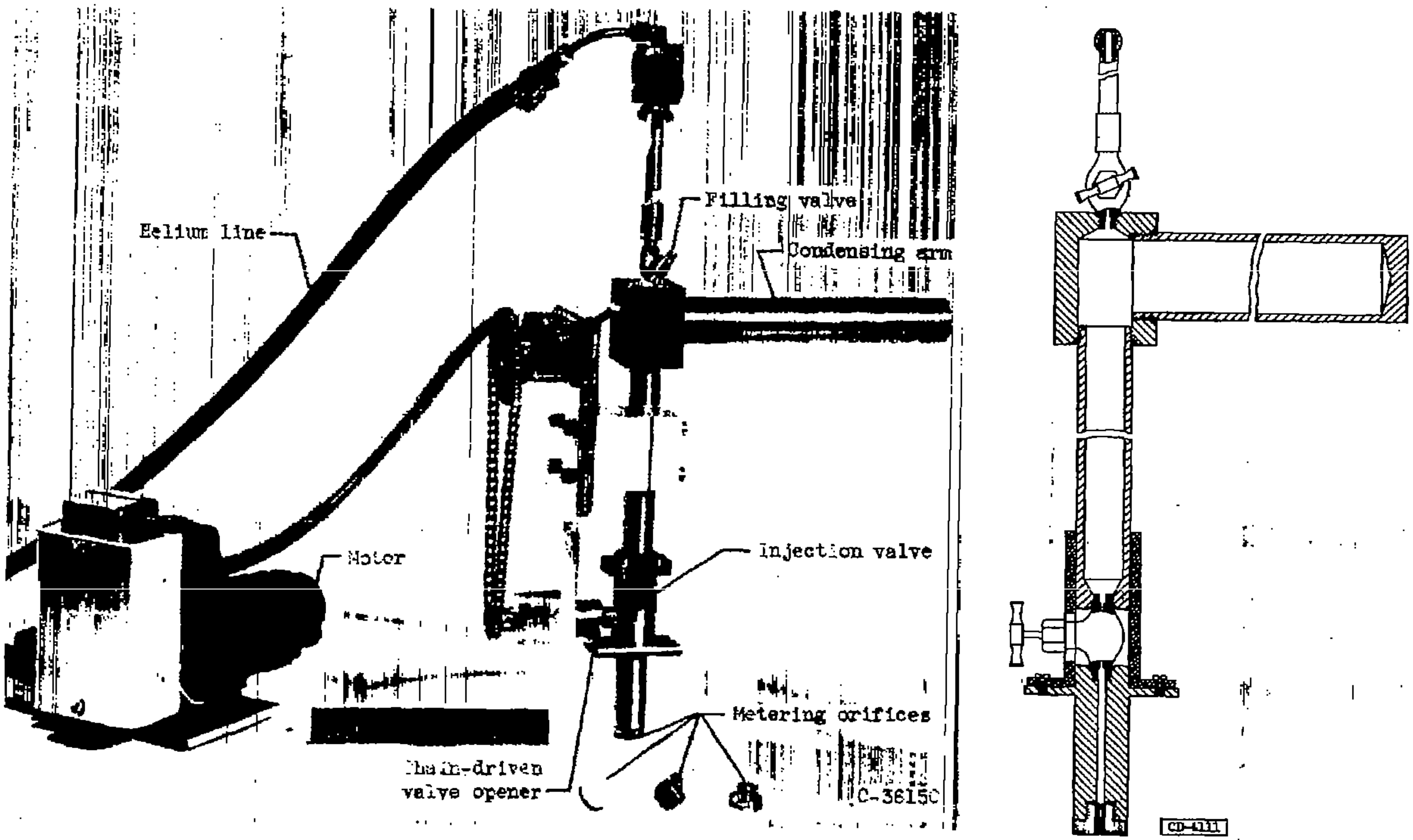


Figure 1. - Fuel injector, showing auxiliary remote-control opening equipment and helium line.

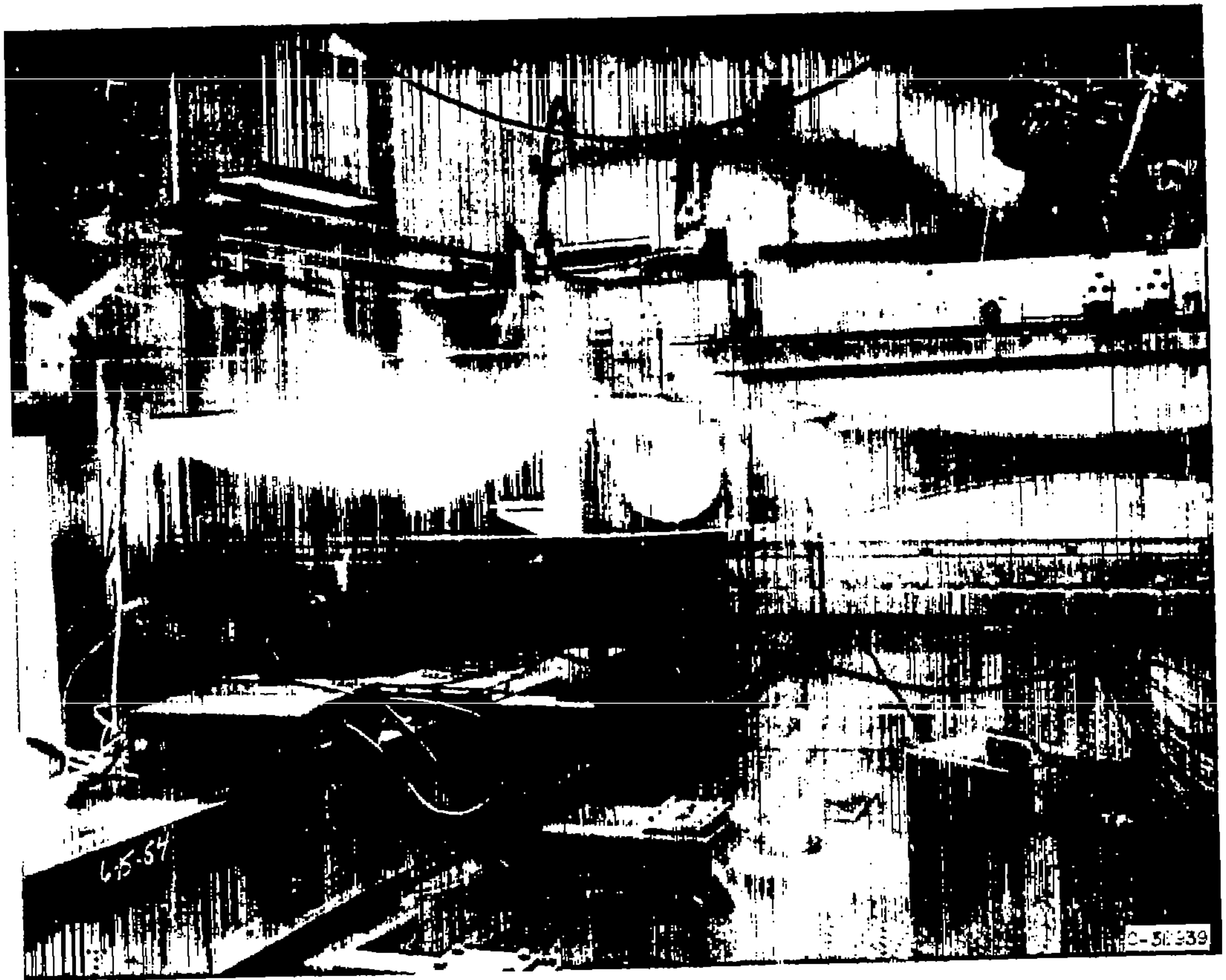
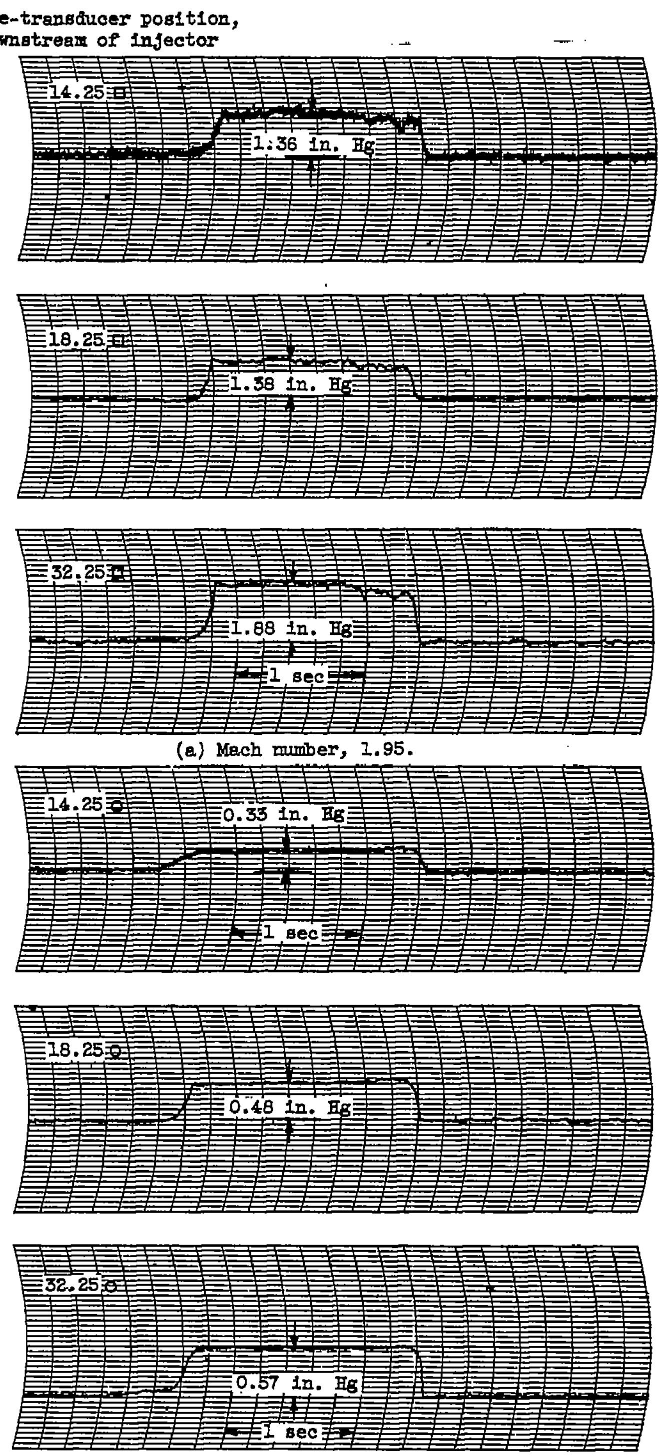


Figure 2. - Photograph of flame in supersonic stream.



(a) Mach number, 1.95.

(b) Mach number, 2.9.

Figure 3. - Typical pressure pulses observed with oscillograph.

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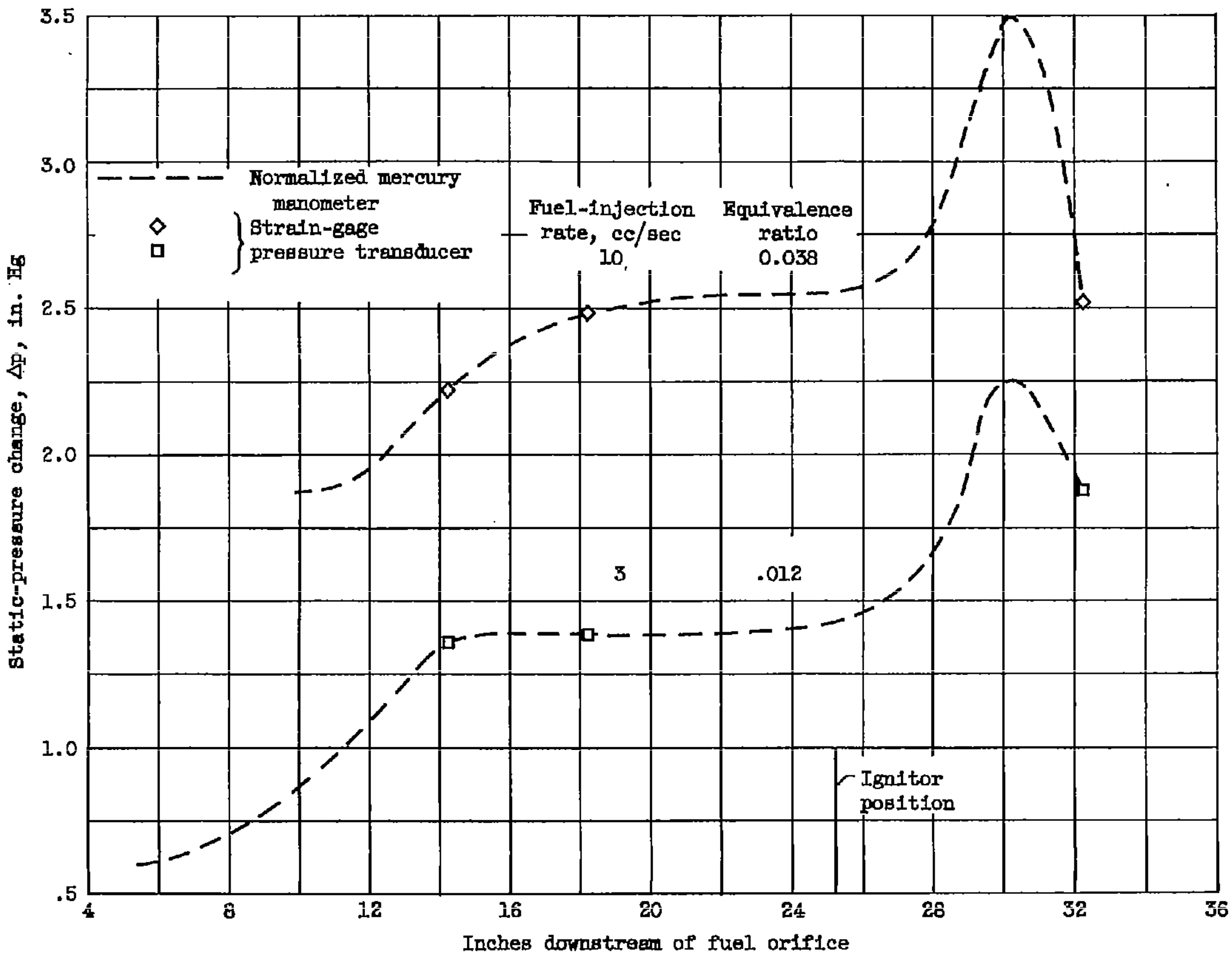
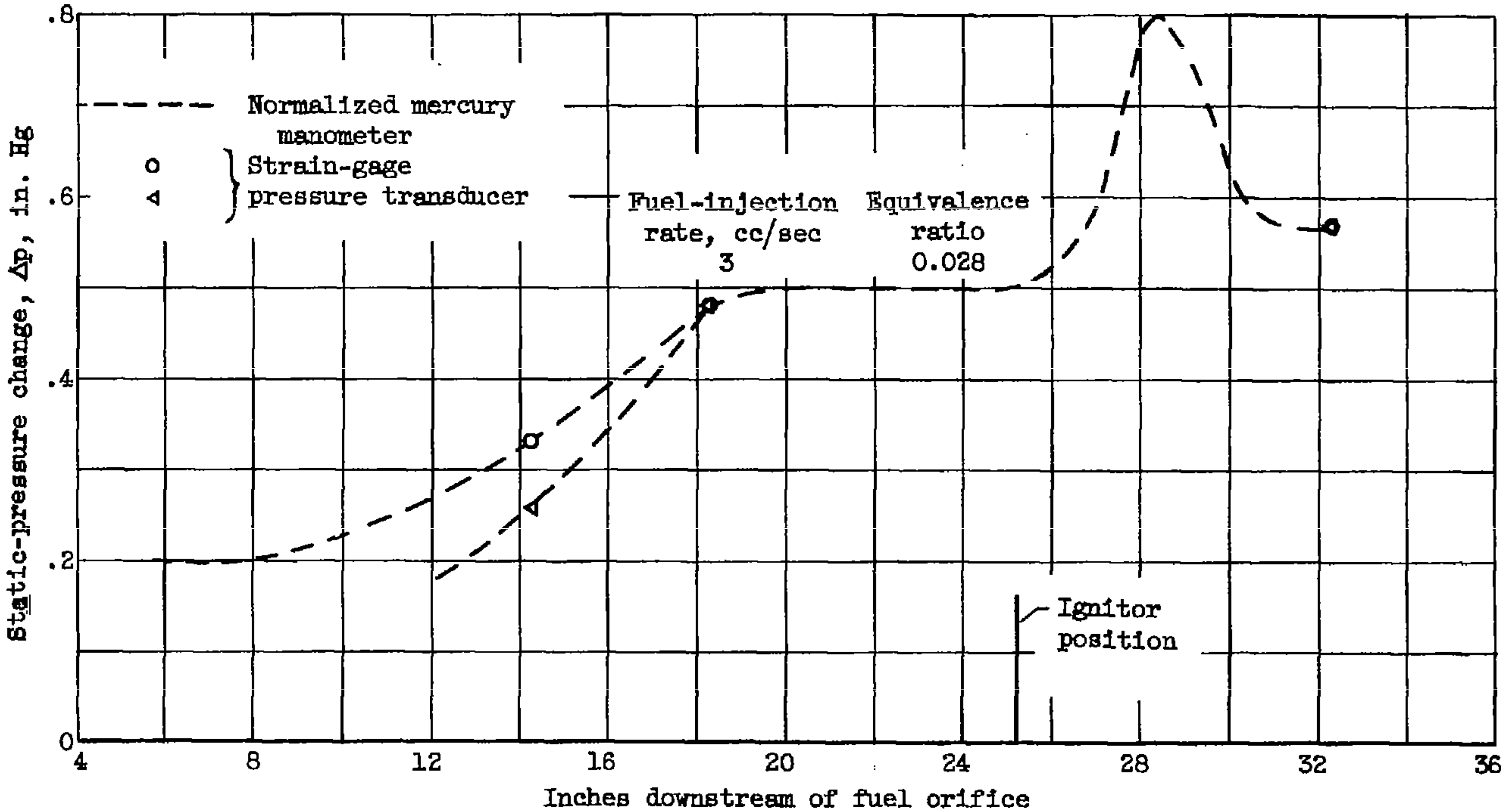


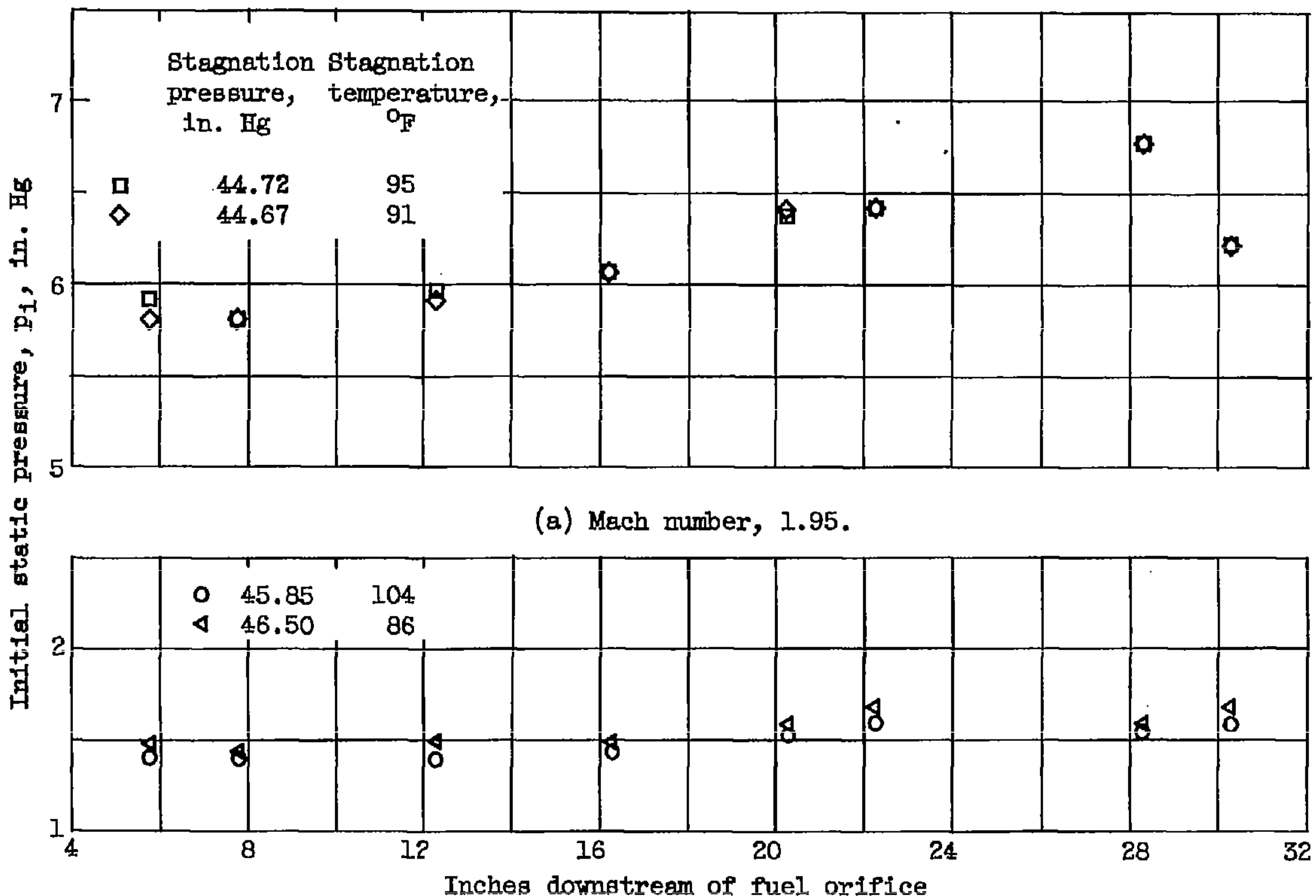
(a) Mach number, 1.95.

Figure 4. - Variation of wall static-pressure change resulting from combustion with distance from fuel-injection orifice.



(b) Mach number, 2.9.

Figure 4. - Concluded. Variation of wall static-pressure change resulting from combustion with distance from fuel-injection orifice.



(b) Mach number, 2.9.

Figure 5. - Static-pressure distribution along top wall of test section before combustion.

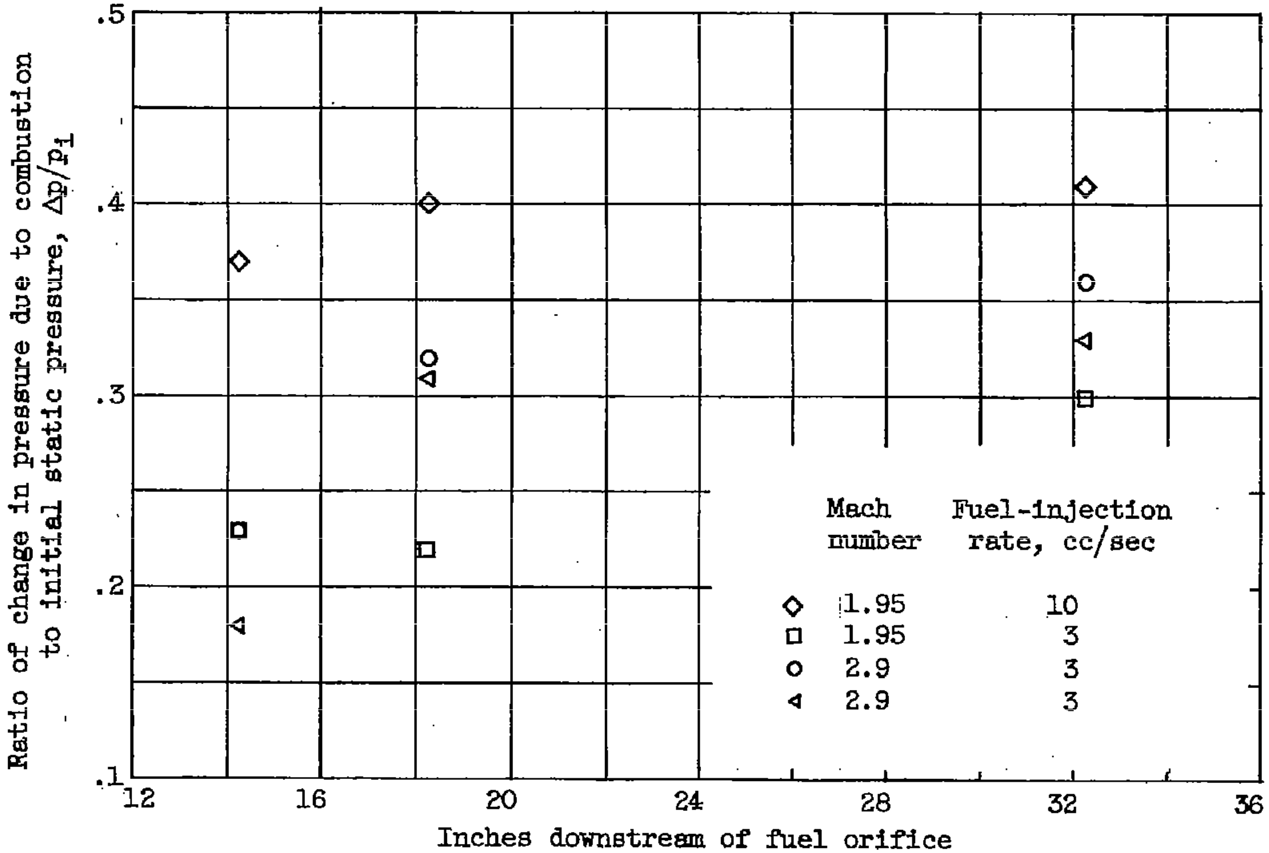


Figure 6. - Ratio of change in pressure due to combustion to initial static pressure.

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