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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF EFFECTS OF COMBUSTION IN RAM JET ON PERFORMANCE OF SUPERSONIC DIFFUSERS

III - NORMAL-SHOCK DIFFUSER

By Albert H. Schroeder and James F. Connors

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An experimental investigation on a 3.60-inch-diameter ram jet was conducted in the NACA Lewis 20-inch supersonic tunnel at a Mach number of 1.92 to determine the effects of combustion on the performance of a basic normal-shock diffuser. Total-pressure recovery with and without combustion was evaluated as a function of outlet-inlet area ratio and fuel flow.

A rapid decrease in peak total-pressure recovery was obtained with increasing outlet-inlet area ratio. This phenomenon is attributed to an oscillation of the diffuser normal shock initiated by pressure pulsations from an unsteady combustion process. Consequently, the peak total-pressure recovery obtainable with steady-flow conditions could not be attained in the presence of combustion. Similar results were previously reported for the shock and perforated diffusers.

Several devices were used in an attempt either to dampen the pressure pulsations or to produce a smoother combustion process. The use of cones and wire screens in the diffuser, various combustion-chamber lengths, and different flame holders resulted in little or no improvement in diffuser performance. A marked improvement in diffuser performance was obtained, however, when a powdered magnesium flare was used as the source of a smooth combustion process.

INTRODUCTION

The effect of a ram-jet combustion process on the performance of conventional supersonic diffusers has been experimentally determined from a preliminary investigation conducted at the NACA

Lewis laboratory in the 20-inch supersonic wind tunnel at a Mach number of 1.92. Previous results, presented for shock and perforated diffusers in references 1 and 2, respectively, indicated that an oscillation of the diffuser normal shock, initiated by pressure pulsations from an unsteady combustion process, caused a rapid decrease in peak total-pressure recovery with increasing outlet area. Such movement of the normal shock prevented its location at the optimum steady-state position in the diffuser and consequently the peak total-pressure recovery obtainable with steady-flow conditions could no longer be attained. The combustion process had very nearly the same effect on the performance of both the shock and perforated diffusers.

Thus the phenomenon of decreasing peak total-pressure recovery with increasing outlet area was apparently independent of the type of supersonic inlet utilizing a stream compression before the normal shock. A basic normal-shock diffuser was therefore used in the study reported herein to complete the investigation. This inlet was a simple divergent channel and produced no compression of the supersonic air stream except through the normal shock. Diffuser performance was again evaluated in terms of total-pressure recovery.

Several devices were used in an attempt either to dampen the pressure pulsations or to produce a smoother combustion process. These devices included cones and wire screens of varying densities in the subsonic diffuser, various combustion-chamber lengths, different flame holders, and another type of fuel in the form of powdered magnesium flares. No attempt was made to evaluate the combustion performance of the engine.

APPARATUS AND PROCEDURE

This investigation was made in the NACA Lewis 20-inch supersonic wind tunnel at a Mach number of 1.92 ±0.04. The inlet air was maintained at a dew point of -15 ±10° F and a total temperature of 220 ±5° F.

The experimental 3.60-inch-diameter ram jet (fig. 1) is the same as that used in references 1 and 2, except for the diffuser configuration. Unleaded 62-octane gasoline was injected in an upstream direction through a 12-gallon-per-hour diffusing spray nozzle (rated at 100 lb/sq in. gage) located in the subsonic diffuser and was ignited by means of a spark plug with an acetylene-gas pilot system.

The normal-shock diffuser consisted of a straight 5° divergent channel. In order to observe the shock pattern at the inlet, a shadowgraph was used inside the tunnel. When the normal shock was inside the engine, the calculated air flow was approximately 1100 pounds per hour. In an effort to dampen pressure fluctuations, cones and wire screens of various densities were installed perpendicular to the air stream and approximately 2 inches *upstream* of the fuel-spray nozzle.

Other modifications were designed to produce a smoother combustion process. Different combustion-chamber lengths of approximately 4.4, 6.3, and 8.5 diameters were employed. The original flame holder (fig. 1(b)) was replaced by a 28° conical spiral-gutter flame holder, which was 4.5 inches long with a 3/4-inch helical pitch. The apex of the cone and the V-gutters were upstream.

Further experiments were made in which the flame holder and the gasoline fuel system were replaced by a powdered magnesium flare. The flare was 2 inches in diameter and $7\frac{1}{2}$ inches long and had a burning duration of approximately 45 seconds. Flare tests were made at several fixed-outlet areas and the pressures were recorded on a multiple-tube mercury manometer. Total-pressure recoveries were measured before, during, and after combustion.

RESULTS AND DISCUSSION

Symbols

The following symbols are used in this discussion:

A_1 diffuser-inlet area

A_4 projected ram-jet outlet-nozzle area normal to free stream

P_0 free-stream total pressure

P_3 total pressure at combustion-chamber inlet (diffuser outlet)

W_f fuel flow, pounds per hour

Original Configuration

Total-pressure recovery without combustion. - The cold-run performance of the normal-shock diffuser at a Mach number of 1.92

is presented in figure 2. Total-pressure recovery P_3/P_0 is shown as a function of outlet-inlet area ratio A_4/A_1. Values of A_4/A_1 may deviate from the true outlet-inlet area ratio because the measured A_4 is not necessarily the true flow area. The relative values, however, should be representative and establish the trends. 1039
For the normal-shock diffuser operating under steady-flow conditions at a Mach number of 1.92, the general shape of the curve and the magnitude of the maximum P_3/P_0 would be expected. This cold-run performance curve is used as a reference to compare results obtained with combustion. It was previously ascertained (reference 1) that the injection of fuel without combustion did not altar the pressure recovery.

Combustion at constant fuel flow and constant outlet area. - The experimental variation of total-pressure recovery with outlet-inlet area ratio and fuel flow is shown in figures 3 and 4, respectively. The trends of the curves are similar to those in references 1 and 2 for the shock and perforated diffusers. The peak P_3/P_0 was less than the optimum oold-run value and decreased with increased fuel flow (fig. 3) and increased outlet-inlet area ratio (fig. 4). For constant values of A_4/A_1 of 0.63 and 0.76, the curves in figure 4 have two branches, depending upon whether the fuel flow was being increased or decreased. When the fuel flow was increased beyond the value at the peak P_3/P_0 and again decreased, the peak P_3/P_0 could not be *realized* until *the* normal shook completely reentered the diffuser and the fuel flow was again increased. This phenomenonis attributed to the increased mean fuel-air ratio resulting from air-flow spillage when the normal shook is oscillating upstream of the inlet. Rough and unsteady combustion and a blurred shock pattern at the inlet were observed for the following operating conditions: when the outlet area was decreased or the fuel flow was increased from the values at the peak P_3/P_0; and when the fuel flow was decreased from values be-that at the peak P_3/P_0 to form the lower branch of the loop for values of A_4/A_1 of 0.63 and 0.76 (fig. 4). These observations indicate that with combustion the unsteady flow process reported in reference 1 also applies to a normal-shock diffuser under similar operating conditions.

A plot of the peak P_3/P_0 from both constant-fuel-flow and constant-outlet-area runs is presented in figure 5 as a function of A_4/A_1 with the reference curve without combustion. The peak P_3/P_0 decreased from 0.74 for an A_4/A_1 of 0.51 to 0.60 for an

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A_4/A_1 of 0.92. Unsteady flow associated with normal-shock oscillations and pressure pulsations from the combustion process is believed to have caused the decrease in the peak P_3/P_0 with increasing A_4/A_1.

The unsteady flow, which produces this phenomenon, is the result of pressure fluctuations that may originate from three separate sources of flow disturbances: (1) burner vibration when the upstream flow is perfectly uniform (function of type and size of burner); (2) stream vibrations produced by the inlet (function of inlet geometry and throttling system; and (3) mutual interference between burner and inlet (function of the size and the length of the engines). The results presented herein are over-all effects. Further experiments should be made to separate the causes of normal-shock oscillations and to evaluate the effect of each on the diffuser performance.

Improvement of diffuser performance in the presence of combustion should be possible by either elimination or effective dampening of the pressure pulsations originating in the combustion process. Several methods, such as screens and cones located upstream of the fuel-spray nozzle, were used to dampen the pressure pulsations. Large total-pressure drops were experienced across the cones and the screens, but no noticeable improvement in diffuser performance with combustion was realized. These preliminary studies indicated that elimination of the pressure pulsations in the combustion process would be the most efficient method of improving the diffuser performance. Results obtained from several modifications to the combustion process are therefore presented.

Combustion-Chamber Modifications

Modifications to the combustion chamber resulted in a lateral shift of the cold-run diffuser performance curve because of variation in friction losses across the combustion chamber and pressure drop across the flame holder. At peak total-pressure recovery, the normal shock was located at the optimum position in the diffuser for the given outlet-area setting and combustion-chamber combination. In order to evaluate directly the effect of combustion-chamber modifications on diffuser performance, the peak total-pressure recovery with combustion is presented for each outlet-inlet area ratio as a function of the cold total-pressure recovery. Such a plot for the original combustion-chamber configuration is used as a reference with which to compare results obtained for the various modifications. Improved diffuser performance resulting from increased normal-shock stability is then indicated by a rise in peak total pressure above the reference curve.

Combustion-chamber length. - The length of the combustion chamber was altered to determine if its resonant frequency was such as to amplify combustion-pressure pulsations. The peak P_3/P_0 obtained for combustion-chamber length-diameter ratios of 4.4, 6.3, and 8.5 are presented in figure 6 as a function of P_3/P_0 without combustion. The data for all three combustion-chamber lengths fall approximately along one curve. This conformity in the data indicates that the resonant frequency of the original combustion chamber could not account for the rapid decrease in the peak P_3/P_0 with increasing A_4/A_1. 1039

Conical spiral-gutter-type flame holder. - Unreported results from preliminary studies of a 16-inch subsonic ram jet have indicated smooth operation over a wide range of fuel-air ratios for a conical spiral-gutter-type flame holder. This type flame holder was used to replace the original perforated conical flame holder in an attempt to dampen the pressure pulsations from the combustion process. The peak P_3/P_0 is plotted in figure 6. The data points for the conical spiral-gutter-type flame holder fall either on or slightly above the curve for the original flame holder and thus indicate a slight improvement in diffuser performance resulting from a smoother combustion process.

Powdered magnesium flare. - In order to investigate the possibility of eliminating or altering the combustion-pressure pulsations, a complete change in the combustion process was effected by replacing the flame holder and the fuel system with a magnesium flare. Because the burning rate (heat release) for the flare was nearly constant, the peak P_3/P_0 for each A_4/A_1 could not be obtained. The effect of this combustion process on the diffuser performance is shown in figure 6 in which the values of total-pressure recovery P_3/P_0 with combustion are presented as a function of the total-pressure recovery P_3/P_0 without combustion. Data points for the flares fall well above the curve for the original combustion chamber. The marked improvement in diffuser performance with the magnesium flare is attributed to a smoother combustion process. These results indicate that the attainment of the optimum cold-run total-pressure recovery may be possible, provided that the pressure pulsations from the combustion process are eliminated.

SUMMARY OF RESULTS

An experimental investigation of the effects of combustion in a 3.60-inch-diameter ram jet on the performance of a basic normal-shock diffuser gave the following results at a Mach number of 1.92:

1. An oscillation of the diffuser normal shock, initiated by pressure pulsations from an unsteady combustion process, caused a rapid decrease in peak total-pressure recovery with increasing outlet-inlet area ratio and fuel flow, similar to that previously reported for shock and perforated diffusers. The cold-run optimum total-pressure recovery was not attained with combustion.

2. Several modifications to the original combustion chamber were made in order to eliminate or to alter the pressure pulsations from the combustion process utilizing 62-octane gasoline as the main fuel. The use of cones and wire screens in the diffuser, various combustion-chamber lengths, and different flame holders had little or no effect upon the diffuser performance.

3. A smooth combustion process resulting from the use of a powdered magnesium flare produced a marked increase in total-pressure recovery above the curve of peak total-pressure recoveries established with 62-octane gasoline.

CONCLUSIONS

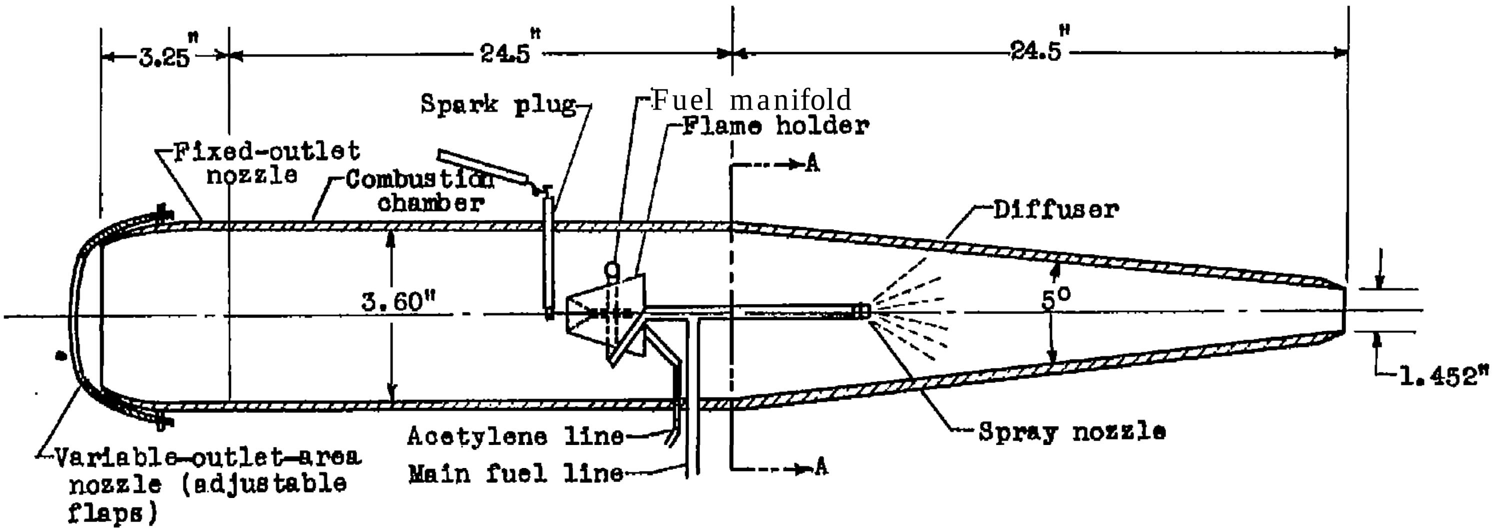
The results obtained in this preliminary investigation signify the need of further experimental studies on ram jets over the range of supersonic speeds. Cold-test performance data and one-dimensional steady-state calculations no longer seem to provide sufficient background in diffuser design for specific ram-jet application because the characteristics of the combustion and diffusion processes are so interrelated as to necessitate complete engine experiments rather than the evaluation of the various components under simulated conditions. Further corroborative evidence of the phenomenon reported must be obtained at the different flight Mach numbers and with different scale models. The possibility of utilizing other types of fuel to achieve asmoother combustion process and the feasibility of redesigning the combustion-chamber and diffuser configurations to dampen the pressure pulsations dueto combustion should also be studied.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

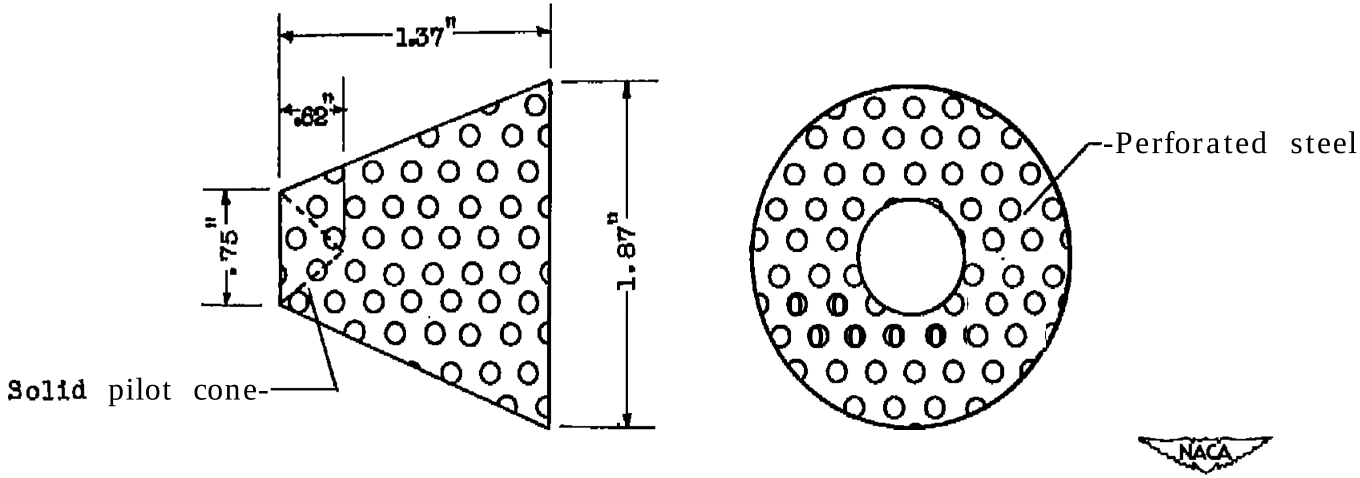
REFERENCES

1. Connors, J. F., and Schroeder, A. H.: Preliminary Investigation of Effects of Combustion in Ram Jet on Performance of Supersonic Diffusers. I - Shock Diffuser with Triple-Shock Projecting Cone. NACA RM No. E8F15, 1948.

2. Schroeder, Albert H., and Connors, James F.: Preliminary Investigation of Effects of Combustion in Ram Jet on Performance of Supersonic Diffusers. II - Perforated Supersonic Inlet. NACA RM No. E8G16, 1948.

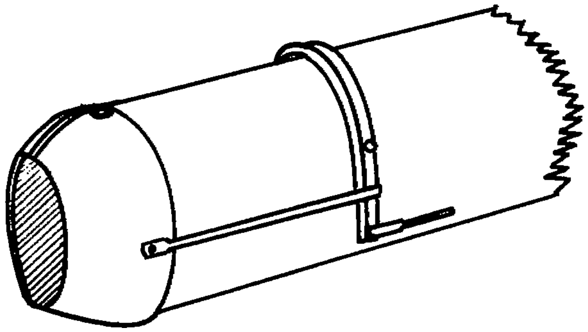


(a) Schematic diagram showing component parts.

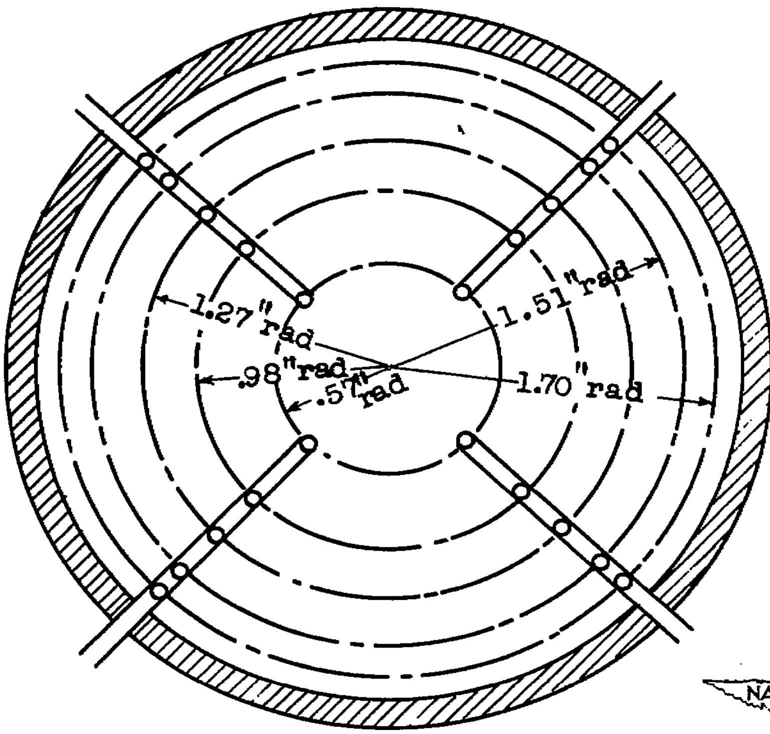


(b) Flame-holder details.

Figure 1. – Experimental ram-jet model.



(c) Variable-outlet-area nozzle.



(d) Pitot-static survey rake located at cross section A-A (fig, 1(a)).

Figure 1. - Concluded. Experimental ram-jet model.

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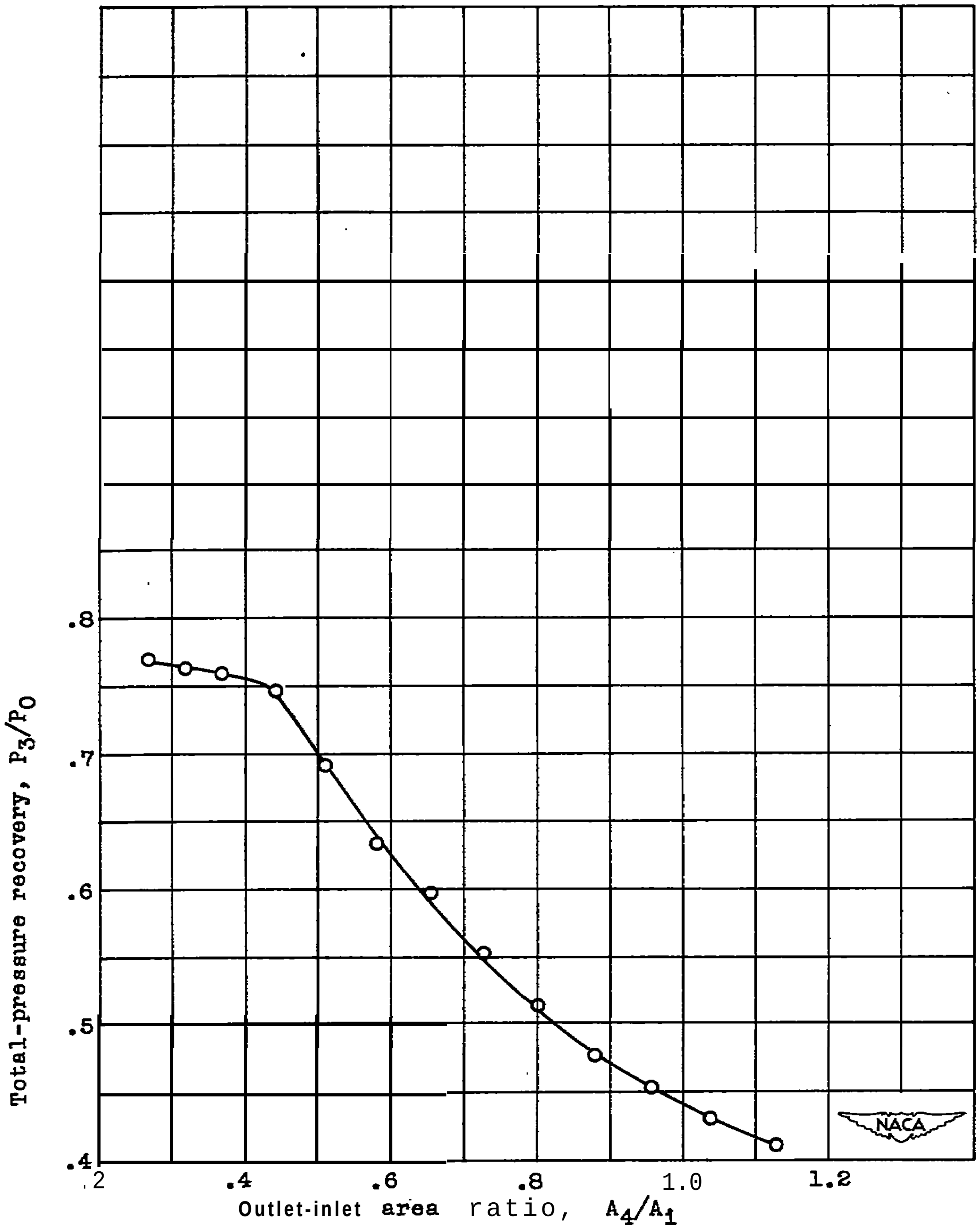

Figure 2. - Variation of total-pressure recovery with outlet-inlet area ratio without combustion.

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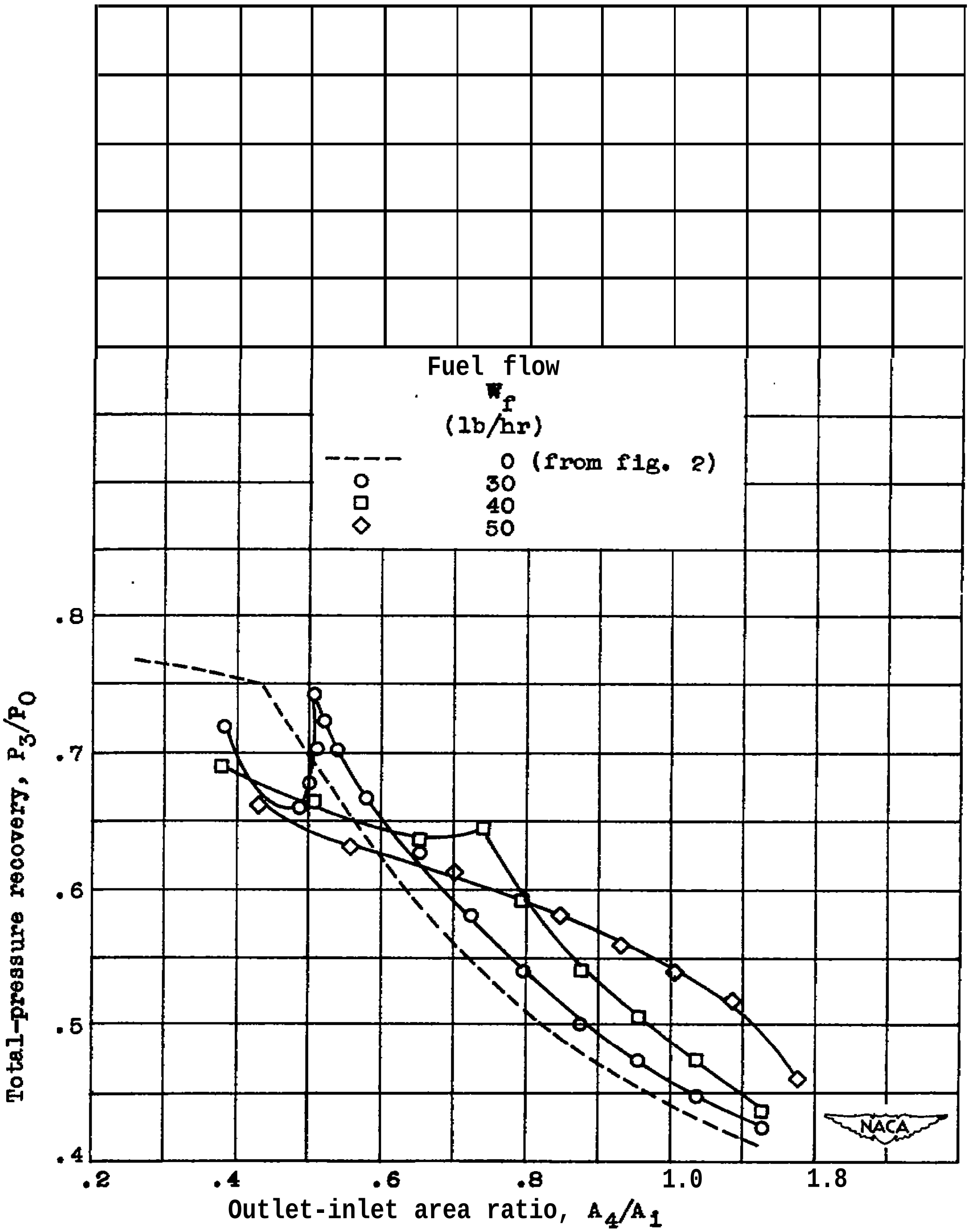

Figure 3. – Variation of total--pressure recovery with' outlet-inlet area ratio for constant fuel flows.

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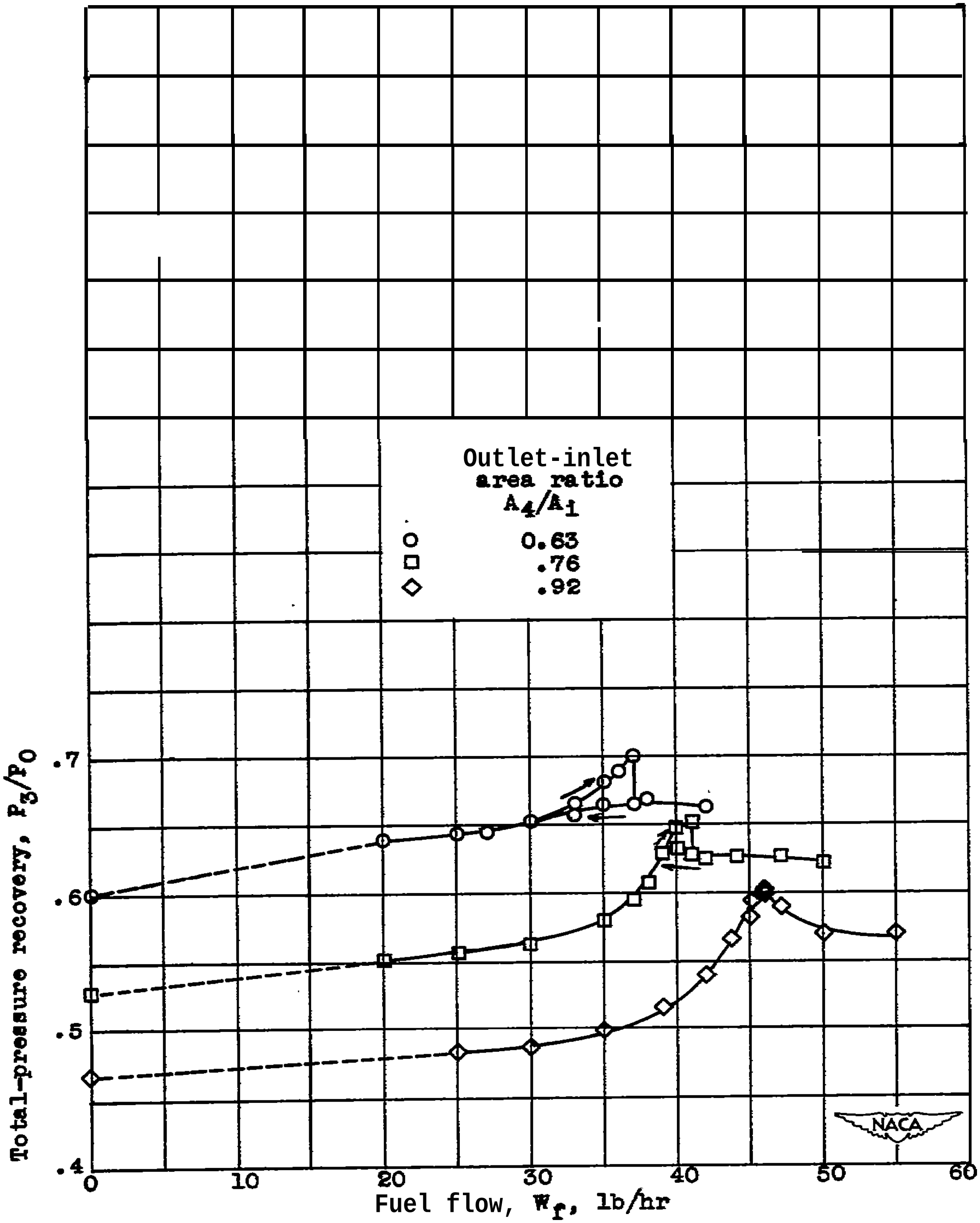

Figure 4. – Variation of total-pressure recovery with fuel flow for constant outlet-inlet area ratios.

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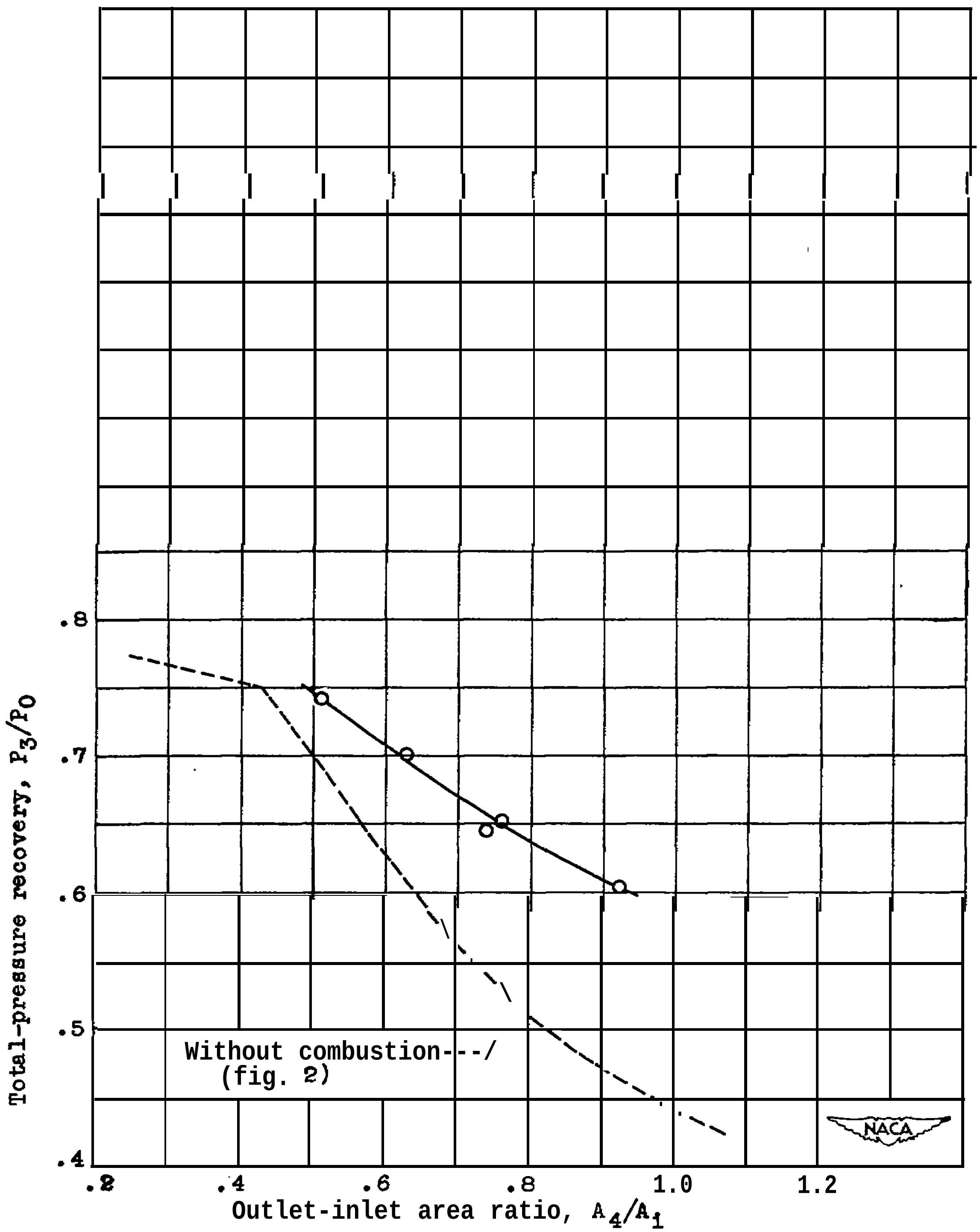

Figure 5. - Variation of peak total-pressure recovery with outlet-inlet area ratio for original combustion-chamber configuration.

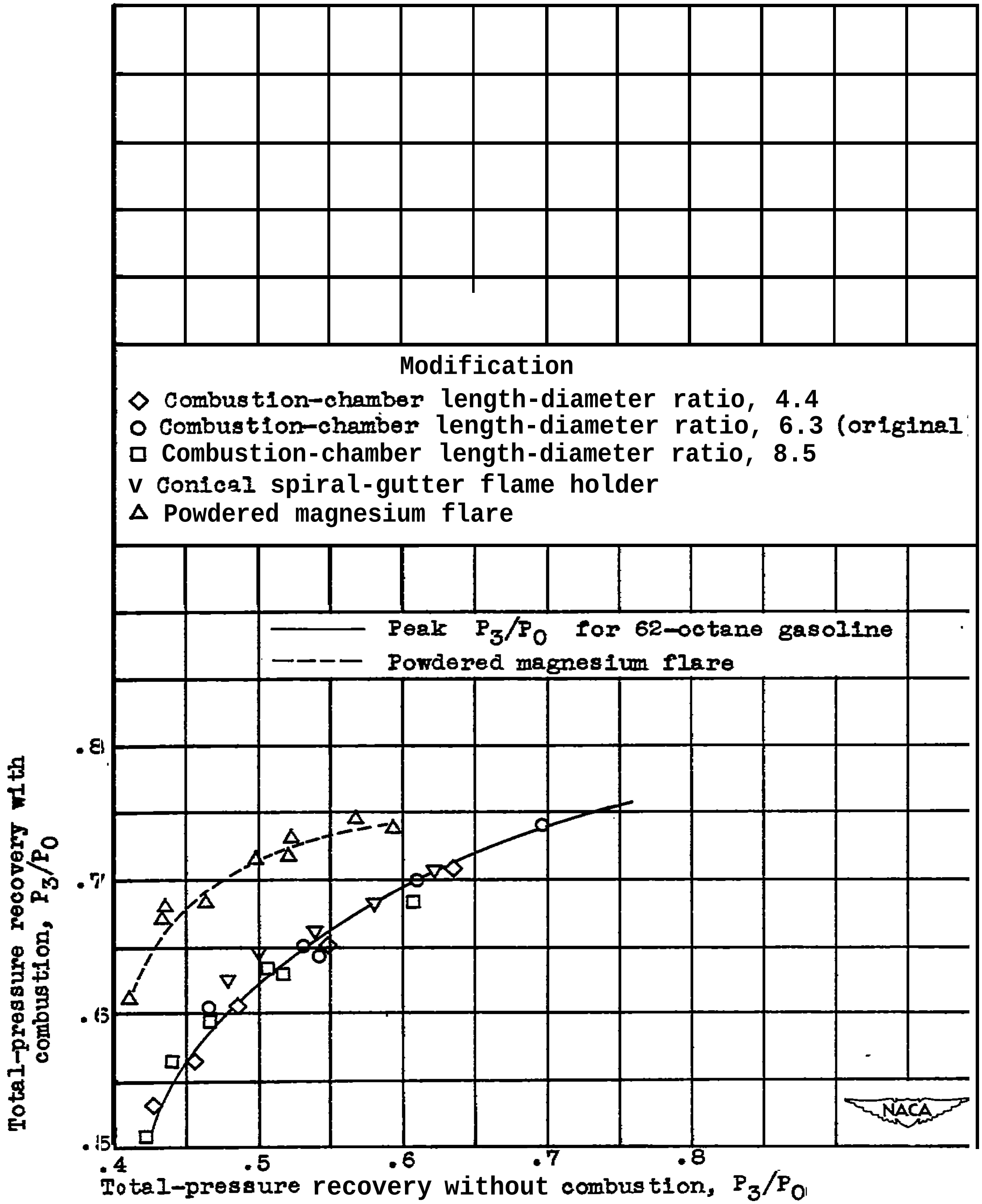

Figure 6. - Effect of several combustion-chamber modifications on total-pressure recovery.