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RESEARCH MEMORANDUM

COMBUSTION-CHAMBER PERFORMANCE WITH FOUR FUELS IN BUMBLEBEE 18-INCH RAM JET INCORPORATING VARIOUS RAKE- OR GUTTER-TYPE FLAME HOLDERS

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and David T. Dupree

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RESEARCH MEMORANDUM

COMBUSTION-CHAMBER PERFORMANCE WITH FOUR FUELS IN BUMBLEBEE 18-INCH RAM JET INCORPORATING VARIOUS RAKE- OR GUTTER-TYPE FLAME HOLDERS

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SUMMARY

The effects of using various fuels and several rake- or gutter-type flame-holder configurations in a Bumblebee 18-inch ram jet are presented and discussed. Studies were made in the Lewis altitude wind tunnel at pressure altitudes from 10,000 to 35,000 feet and at ram-pressure ratios equivalent to free-stream Mach numbers from 0.49 to 1.46.

Beet performance was obtained with a rake-type flame holder, which has alternate rakes connected to the pilot combustion-chamber outlet by gutters. The three rakes that were connected by gutters to the pilot-combustion-chamber outlet appear to have been more effective as flame holders than the other three rakes.

Use of propylene oxide or a blend of 25-percent propylene oxide and 75-percent kerosene rather than kerosene as fuel resulted in increased combustion efficiency and better stability of combustion. When propylene oxide was used, ignition at higher values of combustion-chamber-inlet velocity and a wider range of operable fuel-air ratio were obtained than with kerosene. At a fuel-air ratio of about 0.070, the combustion efficiency was raised from an approximate value of 59 percent to 85 percent when the fuel was changed from kerosene to propylene oxide in the configuration, which included the rake-type flame holder described above.

The combustion efficiency increased as the combustion-chamber-inlet static temperature was raised from a value of 35° to 130° F.

INTRODUCTION

In order to determine the altitude performance and operating range of a Bumblebee 18-inch ram jet, a detailed investigation under controlled conditions of pressure altitude and equivalent free-stream Mach number was conducted in the NACA Lewis altitude wind tunnel.

An extensive study was conducted to determine the performance with rake-, gutter-, and can-type flame holders with several fuels. The burners, each consisting of a fuel-injection system, flame holder, and a combustion chamber, were developed as a part of the Bumblebee project conducted by the Applied Physics Laboratory, Johns Hopkins University, and have satisfactorily performed in sea-level investigations (unpublished). Operational data for the ram jet under choking conditions with the best can- and rake-type flame holders are presented in references 1 and 2, respectively.

The results presented herein were obtained from an analysis of combustion-chamber performance with 3 rake- and 5 gutter-type flame holders and four fuels. Combustion-chamber performance data are presented in terms of combustion efficiency and gas total-temperature ratio across the engine. Operable ranges of fuel-air ratio, pressure surveys at three stations, and effects of combustion-chamber-inlet conditions on operation and efficiency are included. Comparisons are made between operation with AN-F-32, hereinafter called kerosene, gasoline, propylene oxide, and a mixture of 75-percent kerosene and 25-percent propylene oxide.

APPARATUS AND PROCEDURE

The Bumblebee 18-inch ram jet used in this investigation was mounted above a wing that extended across the 20-foot-diameter test section of the NACA Lewis altitude wind tunnel (fig. 1). Diffuser-inlet pressures corresponding to those encountered in flight were obtained by introducing, from the tunnel make-up air system, air that was throttled from approximately sea-level pressure to the desired pressure at the engine inlet. Various ram-pressure ratios across the engine were obtained either by changing the pressure altitude in the tunnel or by varying the total pressure of inlet air. The temperature of the inlet air was controlled between 32° and 150° F according to the conditions desired. Measurement of thrust with the wind-tunnel balance system was made possible by incorporation of a sealed slip joint between the make-up air duct and the ram-jet diffuser inlet. In order to permit visual observation of the combustion-chamber interior during operation, a periscope was mounted in the tunnel test section downstream of the ram jet.

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The main components of the ram jet, which is described in detail in reference 1, are a subsonic diffuser containing a center body and a burner consisting of a fuel-injection system and a flame holder, and a combustion chamber. The diameter of the diffuser at the inlet is 11.5 inches, the over-all length is 9.54 feet, and the diffuser ratio is 1.64. The 18-inch-diameter combustion chamber has several sections. A 1.33-foot uncooled section was used between the combustion-chamber inlet and the flame holder and a 4.29-foot water-cooled section was mounted downstream. When two-stage flame holders were used, the combustion chamber could be varied in length from 5.62 to 7.12 feet by means of 0.75-, 1.25-, and 1.50-foot sections inserted between stages. For the long combustion chamber, an uncooled 4-foot section was inserted between the flame holder and the water-cooled section to give an over-all length of 9.62 feet. For most of the data presented, the combustion-chamber-outlet diameter was 17.50 inches; however, for some configurations a plate with a 14.75-inch-diameter orifice was mounted at the combustion-chamber outlet.

A low-pressure fuel-distribution system, described in reference 3, was located in the rear section of the diffuser center body approximately 1.1 feet ahead of the combustion-chamber inlet (fig. 2). This system was designed to distribute the fuel evenly to a number of fuel-injection tubes over a wide range of fuel flows with small changes in fuel-injection pressure. Forty fuel-injection tubes were mounted in eight removable groups of five tubes; each group is designated a fuel pattern. Fuel patterns 1, 4, and 3P, which are described in references 1 and 2, were used. Numerical designations for the fuel-injection patterns and flame holders conform to those used by the Applied Physics Laboratory of John Hopkins University. Schematic diagrams are shown for fuel patterns 1 and 4 and fuel patterns 4 and 3P in figure 3.

Ignition was obtained by a vortex-type pilot burner attached to the downstream end of the diffuser center body. Two ducts built into the diffuser center body supplied the pilot burner with air. This air was discharged into the pilot burner through two 45° pipe elbows, which gave a vortex motion to the air (reference 2). The combustion chamber of the vortex-type pilot consists of a truncated cone 16 inches long that expands in diameter from 6 inches at the upstream end to 7 inches at the downstream end. Fuel is supplied to the pilot burner through a commercial spray nozzle that operates at approximately its rated delivery of 21.5 gallons per hour at a pressure drop of 100 pounds per square inch. The fuel-air mixture in the pilot burner is ignited by a spark plug and the pilot burner was continuously operated during the investigation. A tube through which hydrogen was injected was included to aid ignition when necessary (reference 2).

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The flame holders are shown in figures 4 to 7. The rake-type flame holders are shown in figures 4 and 5. Single-stage flame holder 71-7 (fig. 4) is described in reference 2. This configuration has three gutters, inclined at an angle of about 45°, which connect three alternate rakes to a center ring that fits over the end of the pilot combustion chamber. Similar flameholders used only in the second stage of two-stage flame holders are shown in figure 5. Flame holder 71-a (fig. 5(a)), which is a modification of the configuration described in reference 4, has six flared-tube rakes alternately connected by gutters and bars. The bars are of solid metal 1.25 inches thick to lessen the danger of burning away in the flames originating upstream. The modified 71-4.B flame holder (fig. 5(b)) has two 0.5-inch plates welded on each of the three bars to increase the blocking area.

The gutter-type flame holders used in the investigation are shown in figures 6 and 7. The flame holders shown in figure 6 were used either alone or as the first stage of two-stage flame holders. Flame holder 80 (fig. 6(a)) consists of three 1.75-inch gutters connected to a center ring that fits over the pilot combustion chamber. Flame holder 80-1 (fig. 6(b)) is the same basic type with three 4.25-inch gutters. The flame holder of figure 6(c) has six 2.75-inch gutters connected to a center ring. The flame holders shown in figure 7 were used only as downstream stages of two-stage flame holders. Flame holder 79 (fig. 7(a)) consists of three 4.25-inch gutters arranged in a Y shape. The flame holder shown in figure 7(b) is made of six scoops mounted on the combustion-chamber wall, which project about halfway to the center of the combustion chamber.

The fuels investigated for use in the main burner were AN-F-32 (hereinafter called kerosene), AN-F-22 (which is a 62-octane gasoline), propylene oxide, and a mixture of 25-percent propylene oxide and 75-percent kerosene. Inasmuch as several batches of kerosene were used, the ranges of properties of this fuel and some properties of each fuel are listed in the following table:

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Fuel	Heating value (Btu/lb)	Approximate stoichiometric fuel-air ratio	Specific gravity	Boiling point (°F)	Approximate flash point (°F)
Kerosene (AN-F-32)	18,500	0.068	0.792-0.835	[a]362-382	110
Gasoline (AN-F-22)	19,000	0.067	0.704	[a]184	-10
Propylene oxide	13,075	0.105	0.831	93	-35
25-percent propylene oxide plus 75-percent kerosene	17,144	0.077	0.802-0.834	[a]351-374	--------

[a]50-percent point.

In order to obtain better starting characteristics and a wider range of pilot stability than afforded by kerosene, propylene oxide was used as the pilot fuel.

Air flow through the engine was calculated from measurements of total and static pressures and indicated temperatures obtained with survey rakes mounted in the diffuser inlet. The air flow and wall static pressures measured at the combustion-chamber inlet were used to compute combustion-chamber-inlet velocities. As an alternate to the wind-tunnel balance system, a water-cooled combustion-chamber-outlet rake of total- and static-pressure tubes was also used to determine the jet thrust.

A rotameter was used to measure fuel flow to the main burner and fuel flow to the pilot burner was determined from the pressure drop across the pilot fuel nozzle. The fuel flows used in all computations included pilot as well as main-burner fuel.

Combustion efficiency and gas total-temperature ratio were computed by methods outlined in references 5 and 6 and included the heat lost to the combustion-chamber cooling water. This heat loss was determined from measurements of water flow and temperature rise of the water. The sum of the pressure loss that would occur across a normal shock at the throat of a convergent-divergent diffuser of optimum contraction ratio and the measured diffuser-inlet total pressure was used as the equivalent free-stream total pressure in the computation of equivalent free-stream Mach number.

Total-pressure losses across the burner were determined from total pressures measured with rakes behind the fuel injector and at the combustion-chamber outlet. A rake ahead of the fuel injector was used to determine the distribution of pressures at that location.

Data were obtained at approximate pressure altitudes from 10,000 to 35,000 feet and equivalent free-stream Mach numbers from 0.49 to 1.46 over a range of combustion-chamber-inlet static temperatures, static pressures, and operable fuel-air ratios. When possible, lean and rich blow-out points were determined. 1022

SYMBOLS

The following symbols are used in this report:

f/a fuel-air ratio

M Mach number

ΔP total pressure drop, pounds per square foot

p static pressure, pounds per square foot absolute

q dynamic pressure, pounds per square foot

T total temperature, $^{\circ}R$

t static temperature, $^{\circ}F$

V velocity, feet per second

η_b combustion efficiency, percent

τ ratio of gas total temperature at combustion-chamber outlet to gas total temperature at diffuser inlet, T_4/T_1

Subscripts:

0 equivalent free-stream conditions

1 subsonic-diffuser inlet

2 combustion-chamber inlet

4 combustion-chamber outlet

RESULTS AND DISCUSSION

Combustion-chamber performance data for a Bumblebee 18-inch ram jet with various configurations operated over ranges of fuel-air ratio are presented and discussed. Comparisons are made to show effects of operation with four fuels and with several combustion-chamber-inlet conditions of static temperature, static pressure, velocity, and fuel-air ratio. Ranges of combustion-chamber-inlet variables over which the engine was operated with some of the flame holders investigated are shown in table I. Also shown are the fuel-air ratios at the lean and rich blow-out conditions and the concomitant combustion-chamber-inlet variables.

Operation of Various Burner Configurations

Best performance was obtained with the configuration in which rake-type flame holder 71-7 and fuel patterns 1 and 4 were used. Stable combustion, as defined by regularity or steadiness of operation without tendency to blow out within the operable range of fuel-air ratio, as well as smoothness and high efficiency, were obtained with kerosene as fuel. When fuel patterns 4 and 3P were substituted, however, unstable and rough burning and a narrow operable range of fuel-air ratio resulted. The three rakes connected by gutters to the center ring were apparently subjected to higher temperatures than the other three rakes and were burned (fig. 4(b)); the other rakes were only lightly sooted, which indicates less complete burning of the fuel and concomitant lower rake temperatures. Visual observations made with the periscope installation also showed that sometimes only the three rakes connected to the center ring held flames. The use of a gutter to connect each rake to the pilot combustion chamber when rake-type flame holders are used thus appears desirable.

Rake-type flame holders 71-4B and modified 71-4B (fig. 5) were also investigated. Each of these flame holders was used as a secondary stage or downstream flame holder in conjunction with a gutter-type flame holder used upstream. Unstable operation was obtained with either 80 and 71-4B or 80 and modified 71-4B flame holders. Inappreciable differences were noted in combustion stability or gas total-temperature ratio when gasoline was used as fuel with flame holders 80 and 71-4B. With gasoline, however, the minimum operable fuel-air ratio was lower than with kerosene. No operation was obtained with flame holders 80 and 71-4B without combustion-chamber-outlet restriction. Operation was obtained when the values of combustion-chamber-inlet velocity were reduced by restriction of the combustion-chamber-outlet diameter to 14.75 inches.

by means of the orifice plate, which was used when the gasoline and kerosene were being compared, but combustion was rough and unstable (table I).

Operation was somewhat improved when the 4.25-inch-gutter flame holder 80-1 was substituted for the 1.75-inch-gutter flame holder 80 upstream of 71-4B. Burning was still rough, however, and there was some tendency for the flames to be held only on the upstream or first stage. The belief that some of the instability was caused by the secondary stage being inoperative was confirmed by visual observation. Installation of orifices in the fuel-injector tubes to raise the fuel-discharge pressure to about 50 pounds per square inch gage produced no appreciable effect other than a slight increase in combustion stability. Changing the distance between flame-holder stages from 9 to 15 inches and then to 18 inches also made no appreciable difference in stability of combustion. Substitution of fuel patterns 4 and 3P for 1 and 4 did not change stability of combustion, but did increase the range of operable fuel-air ratio. When the fuel was changed from kerosene to a blend of 25-percent propylene oxide and 75-percent kerosene, however, both stability and smoothness of burning were greatly improved.

Low combustion efficiency resulted when 4.25-inch-gutter flame holders 80-1 and 79 were concurrently used with fuel patterns 1 and 4. Experiments made to determine the effect of changing relative orientations of the two flame holders showed inappreciable differences in operation. Positions investigated were: the gutters of 79 directly behind those of 80-1, the gutters of 79 rotated 30° from the first position, and the gutters of 79 bisecting the angles formed by those of 80-1.

The use of the configuration with 80-1 and six scoops resulted in very rough operation and low combustion efficiency. The use of flame holder 80-1 as a single-stage flame holder resulted in smooth operation over a wide range of fuel-air ratios, but combustion efficiency was low (15 to 21 percent) over the entire range. Use of the six-radial-gutter flame holder as a single-stage flame holder yielded similar results and combustion efficiency varied from values of 20 to 35 percent over the range of operable fuel-air ratio.

Effects of Combustion-Chamber-Inlet Conditions

on Combustion-Chamber Performance

Relations between the combustion-chamber-inlet variables, combustion efficiency η_b, combustion-chamber-inlet static temperature t_2, combustion-chamber-inlet velocity V_2, fuel-air ratio f/a, and gas total-temperature ratio τ are presented in figures 8 to 10 for flame holder 71-7 with fuel patterns 1 and 4. Inasmuch as changes in the combustion-chamber-inlet static pressure p_2 have been shown to have negligible effect on η_b for most of the range of p_2 investigated herein (references 2 and 7), p_2 is not considered as one of the variables that influence η_b.

Static temperature. - The effect of combustion-chamber-inlet static temperature t_2 on η_b at approximately constant values of f/a and V_2 is shown in figure 8. These data indicate that η_b increases as t_2 is raised from a value of approximately 35° to 130° F at constant conditions of V_2 and f/a, and the rate of increase appears to be different for various values of V_2 and f/a. This trend of η_b with increasing t_2 is similar to trends shown in reference 8. At an approximate V_2 of 213 feet per second and f/a of 0.040, η_b was increased from a value of 60 to 77 percent as t_2 was raised from 32° to 125° F. Combustion-chamber stability decreased and the maximum V_2 at which combustion could be maintained was lowered from 265 to 213 feet per second as t_2 was lowered from 130° to 35° F with kerosene as fuel.

Fuel-air ratio and velocity. - The relations between τ, and f/a, and V_2 and η_b are presented in figures 9 and 10, respectively. At constant t_2 and V_2, η_b decreased as f/a was raised over the range investigated. For t_2 of 130° ± 20° F and V_2 about 260 feet per second, η_b was reduced from a value of about 71 percent to 56 percent as f/a was raised from 0.045 to 0.059 (fig. 9(a)). Over the same range of f/a and at the same value of V_2, τ appeared to increase slightly as f/a was raised, inasmuch as the greater heat input counterbalanced the reduced combustion efficiency (fig. 9(b)).

In order to determine the effect of increasing the time available for combustion, an experiment was conducted using the 9.62-foot combustion chamber, hereinafter referred to as the "long combustion chamber", in which the length was increased by a factor of 1.71. An improvement in performance was obtained with this configuration. At an approximate f/a of 0.060 and V_2 equal to 225 feet per second, η_b was raised from a value of about 69 percent to 82 percent when the long combustion chamber was used in lieu of the 5.62-foot combustion chamber (fig. 10).

Data in figure 9 were cross-plotted, as shown in figure 10, to show more clearly the relation between η_b and V_2. Over the range investigated, η_b decreased as V_2 was increased above a value of 228 feet per second.

Fuels

The effects of four fuels on combustion-chamber performance are shown in figures 9, 11, and 12. A comparison of performance with kerosene and with propylene oxide in the configuration with flame holder 71-7 and fuel patterns 1 and 4 is presented in figure 9. Effects of the blend of propylene oxide and kerosene are shown in figure 11 for the burner with flame holders 80-1 and 71-4B and fuel patterns 4 and 3P. Effects of gasoline and kerosene for the configuration with flame holders 80 and 71-4B, fuel patterns 1 and 4, and the 14.75-inch-diameter orifice plate are shown in figure 12. Use of either propylene oxide or the blend of 25-percent propylene oxide and 75-percent kerosene resulted in increased η_b, better stability, and smoothness of combustion. Use of propylene oxide also resulted in ignition at higher values of V_2 and a wider operable range of f/a. At a pressure altitude of 30,000 feet, the maximum V_2 at which ignition could be obtained with flame holder 71-7 was raised from 350 to 500 feet per second when propylene oxide was substituted for kerosene in the configuration with flame holder 71-7 and fuel patterns 1 and 4. When the fuel was changed from kerosene to propylene oxide, η_b was raised from a value of 59 to 85 percent at f/a of 0.070 and the same t_2 and V_2 (fig. 9(a)). At fuel-air ratios of 0.78 of stoichiometric for the two fuels, η_b was raised from a value of 72 to about 84 percent when the fuel was changed from kerosene to propylene oxide. The use of gasoline, however, resulted in inappreciable differences (fig. 12).

Inasmuch as the heating value of propylene oxide is much lower than that of kerosene, τ obtained at an f/a of 0.070 with both fuels is approximately the same, despite the higher η_b obtained with propylene oxide (fig. 9(b)). Higher values of τ were obtained when the blend of propylene oxide and kerosene was substituted for kerosene (fig. 11(b)). This increase in τ might be attributed to the addition of propylene oxide to kerosene, which sufficiently increased the volatility and chemical activity to improve η_b without materially decreasing the heating value. Use of either propylene oxide or the blend of propylene oxide and kerosene enabled attainment of burning with good η_b at higher f/a, however, and higher maximum values of τ were therefore obtained with these fuels than with kerosene.

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Burning with Inoperative Stage

Performance of the configuration with flame holders 80-1 and 71-4B and fuel patterns 1 and 4 is presented in figure 13 with both stages operating and with the second stage inoperative. When very rough operation was obtained, visual observations confirmed the belief that flames were clinging only to the primary stage (80-1) and the secondary stage was inoperative. The value of η_b was reduced from a value of about 54 to 47 percent when the secondary flame holder became inoperative at an approximate f/a of 0.053 and V_2 of about 275 feet per second.

Pressure and Velocity Surveys

Total-pressure-drop coefficients across the combustion chamber for each flame-holder configuration investigated are presented as functions of the combustion-chamber-inlet Mach number M_2 in figure 14. Values of the total-pressure-drop coefficient across the various flame holders varied from about 0.95 to 2.76 over the range of M_2 from 0.08 to 0.32. Each burner had an essentially constant pressure-drop coefficient, except the configuration with flame holders 80 and 79, for which the coefficient changed from 1.55 at M_2 of 0.10 to 1.86 at M_2 of 0.29. For the configuration with flame holder 71-7, the coefficient had a constant value of about 1.45.

Profiles of dynamic pressure q and air flow per square foot per second upstream of the fuel injectors and at the combustion-chamber inlet are presented in figures 15 and 16, respectively. The dynamic pressures and the radial location of fuel-injector tubes are shown in figures 15(a) and 16(a). Maximum values of q ahead of the fuel injector near the approximate mean fuel radius (fig. 15(a)) indicate favorable conditions for good fuel-air mixing. Profiles of q obtained for the choked and unchoked conditions at the combustion-chamber outlet or with and without burning differed very little. Among the causes of changes in profiles on both sides of the fuel injector are the added diffusion of the air and injection of fuel, as well as turbulence induced by the fuel injector. The air-flow profiles presented in figures 15(b) and 16(b) for the conditions corresponding to those in figures 15(a) and 16(a) indicate little difference in the profiles behind the fuel injector obtained for choked and unchoked conditions or with and without burning.

Values of static and total pressures at the combustion-chamber outlet at conditions corresponding to those of the previous figures are presented in figure 17. Data for the unchoked condition with burning are unavailable. For the condition without burning, the distribution of total and static pressures is relatively flat; when burning occurs, the values of total and static pressure change but the distribution remains relatively flat.

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SUMMARY OF RESULTS

From an investigation of a Bumblebee 18-inch ram jet in the NACA Lewis altitude wind tunnel under controlled conditions of pressure altitude and equivalent free-stream Mach number, the following results of combustion-chamber performance were obtained wing several rake- or gutter-type flame holders and four different fuels:

1. Best performance was obtained with the configuration that consisted of rake-type flame holder 71-7 and fuel patterns 1 and 4. The three rake8 connected by gutters to the pilot-canbustion-chamber outlet appeared to be more effective as flame holder8 than the other three rakes.

2. Uae of either propylene oxide or a blend of 25-percent propylene oxide and 75-percent kerosene instead of kerosene as fuel resulted in higher combustion efficiencies and better stability of combustion. When propylene oxide was used, ignition at higher value8 of combustion-chamber-inlet velocity and wider operable range of fuel-air ratio8 were obtained than with kerosene. At 8 fuel-air ratio of about 0.070, the combustion efficiency was raised from an approximate value of 59 percent to 85 percent when the fuel was changed from kerosene to propylene oxide.

3. Over the range investigated, the combustion efficiency increased as the combustion-chamber-inlet static temperature was raised from 35° to 130° F at constant conditions of inlet velocity and fuel-air ratio. At a combustion-chamber-inlet velocity of about 213 feet per second and an approximate fuel-air ratio of 0.040, the combustion efficiency was increased from 8 value of 60 to 77 percent as the combustion-chamber-inlet static temperature was raised from 32° to 125° F.

4. At the same combustion-chamber-inlet conditions of fuel air ratio, velocity, static temperature, and static pressure, approximately equal values of gas total-temperature ratio were obtained with either kerosene or propylene oxide. Use of the blend of 25-percent propylene oxide and 75-percent kerosene instead of kerosene resulted in generally higher values of gas total-temperature ratio.

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5. Higher values of fuel-air ratio and combustion efficiency attained with either propylene oxide or the blend of propylene oxide and kerosene resulted in higher maximum values of gas total-temperature ratio across the engine than those obtained with kerosene.

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REFERENCES

1. Sterbentz, W. H., and Nussdorfer, T. J.: Investigation of Performance of Bumblebee 18-Inch Ram Jet with a Can-Type Flame Holder. NACA RM No. E8E21, 1948.

2. Wilcox, Fred A., and Howard, Ephraim M.: Comparison of Two Fuels in Bumblebee 18-Inch Ram Jet Incorporating Rake-Type Flame Holder. NACA RM No. E8F11, 1948.

3. Anon.: Bumblebee Equipment Manual. Bumblebee Series Rep. No. 62, Appl. Physics Lab., Johns Hopkins Univ., Nov. 1947. (U. S. Navy Contract NOrd 7386.)

4. Anon.: Survey of the Bumblebee. Bumblebee Rep. No. 31, Appl. Physics Lab., Johns Hopkins Univ., Feb. 1946. (U. S. Navy Contract NOrd 7386.)

5. Perchonok, Eugene, Wilcox, Fred A., and Sterbentz, William H.: Preliminary Development and Performance Investigation of a 20-Inch Steady-Flow Ram Jet. NACA ACR No. E6D05, 1946.

6. Perchonok, Eugene, Sterbentz, William H., and Wilcox, Fred A.: Performance of a 20-Inch Steady-Flow Ram Jet at High Altitudes and Ram-Pressure Ratios. NACA RM No. E6L06, 1947.

7. Sterbentz, W. H., Perchonok, E., and Wilcox, F. A.: Investigation of Effects of Several Fuel-Injection Locations on Operational Performance of a 20-Inch Ram Jet. NACA RM No. E7L02, 1948.

8. Cervenka, A. J., and Miller, R. C.: Effect of Inlet-Air Parameters on Combustion Limit and Flame Length in 8-Inch-Diameter Ram-Jet Combustion Chamber. NACA RM No. E8C09, 1948.

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TABLE I - RANGE OF ENGINE OPERATION FOR VARIOUS BURNER CONFIGURATIONS

Burner configuration			Operating conditions				Range of fuel-air ratio f/a and combustion-chamber-inlet velocity V_2 (ft/sec) at blow-out (Fuel-air ratio, f/a: .02, .04, .06, .08, .10, .12)	Remarks
Flame holder	Combustion-chamber length (ft) (outlet diameter, 17.5 in. except as noted)	Fuel pattern	Fuel	Combustion-chamber-inlet static temperature t_2	Inlet pressure (lb/sq ft abs)	Equivalent free-stream Mach number		
71-7	5.62	1 and 4	Kerosene	130 ± 20	1700-1900	0.50-0.72	235 ├─┤ 151	
	5.62	1 and 4	do.	130 ± 20	1800-1900	1.00-1.43	265 ├─┤ 229	
	5.62	1 and 4	do.	130 ± 20	1000		H	
	5.62	1 and 4	Propylene oxide	130 ± 20	1400-1900	1.00-1.45	├─┤ 236	Smooth stable burning. Rich blow-out not determined for p_2 of 1900 (See reference 2.)
	5.62	1 and 4	Kerosene	85 ± 10	1900	0.50-0.74	210 ├─┤ 190	Operation could not be maintained at V_2 above 241 ft/s
	5.62	1 and 4	do.	85 ± 10	1900	1.00-1.18	241 ├─┤ 231	Smoothness and stability of combustion decrease as t_2 is lowered
	5.62	1 and 4	do.	85 ± 10	1200		180 ├─┤ 175	
	5.62	1 and 4	do.	35 ± 10	1700-1900	0.49-0.73	213 ├─┤ 157	Operation could not be maintained at V_2 above 213 ft/sec
	9.62	1 and 4	do.	130 ± 20	1788	1.03	H 223	Blow-out limits not determined, only one point obtained
	5.62	4 and 3P	do.	130 ± 20	1140	0.53	├─┤ 166	Unstable rough burning
80 and 71-4B, 9 inches apart	6.37	1 and 4	Kerosene	130 ± 20	1950	0.79-1.36	190 ├─┤ 150	Unstable burning
	14.75-inch-diameter outlet	1 and 4	Gasoline	130 ± 20	1950	0.90-1.46	195 ├─┤ 150	No improvement in stability over that obtained with kerosene
80-1 and 71-4B, 18 inches apart	7.12	1 and 4	Kerosene	130 ± 20	2000		245 ├─┤ 250	Unstable rough burning
	7.12	4 and 3P	do.	130 ± 20	2000	0.74-0.75	225 ├─┤ 180	Unstable burning
	7.12	4 and 3P	do.	130 ± 20	1700	1.10	244 ├─┤	
	7.12	4 and 3P	25-percent propylene oxide and 75-percent kerosene	130 ± 20	2000	0.66-0.74	195 ├─┤ 175	Burning stable and more smooth than with kerosene
80-1 and 71-4B, 9 inches apart	6.37	1 and 4	Kerosene	130 ± 20	1400-1800	1.16-1.35	324 ├─┤ 245	Second stage intermittently inoperative
80-1 and 79, 15 inches apart, gutters directly behind each other	6.87	1 and 4	Kerosene	130 ± 20	1900	1.10-1.32	310 ├─┤ 290	Smooth stable burning, η_b from 19 to 38 percent
	6.87	1 and 4	do.	130 ± 20	850	1.30	H	
80-1	5.62	1 and 4	Kerosene	130 ± 20	1450-1620	0.91-1.20	415 ├─┤ 380	Smooth stable burning, η_b from 15 to 21 percent
	5.62	1 and 4	do.	130 ± 20	930-1080		380 ├─┤ 336	
Six gutter	5.62	1 and 4	Kerosene	130 ± 20	1550-1870	.96-1.45	369 ├─┤ 311	Smooth stable burning, η_b from 20 to 35 percent

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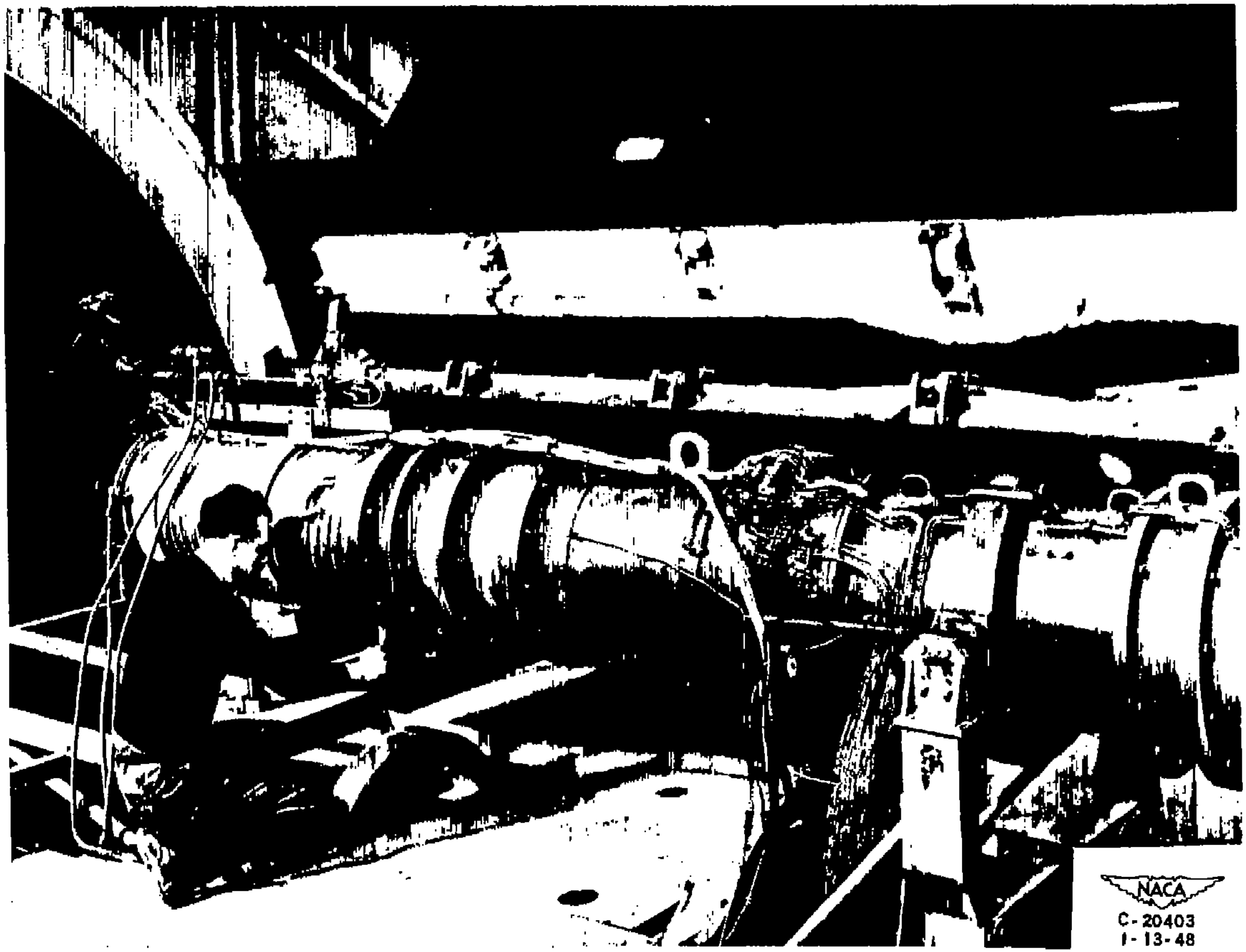


Figure 1. - Installation of Bumblebee 18-inch ram jet in NACA Lewis altitude wind tunnel.

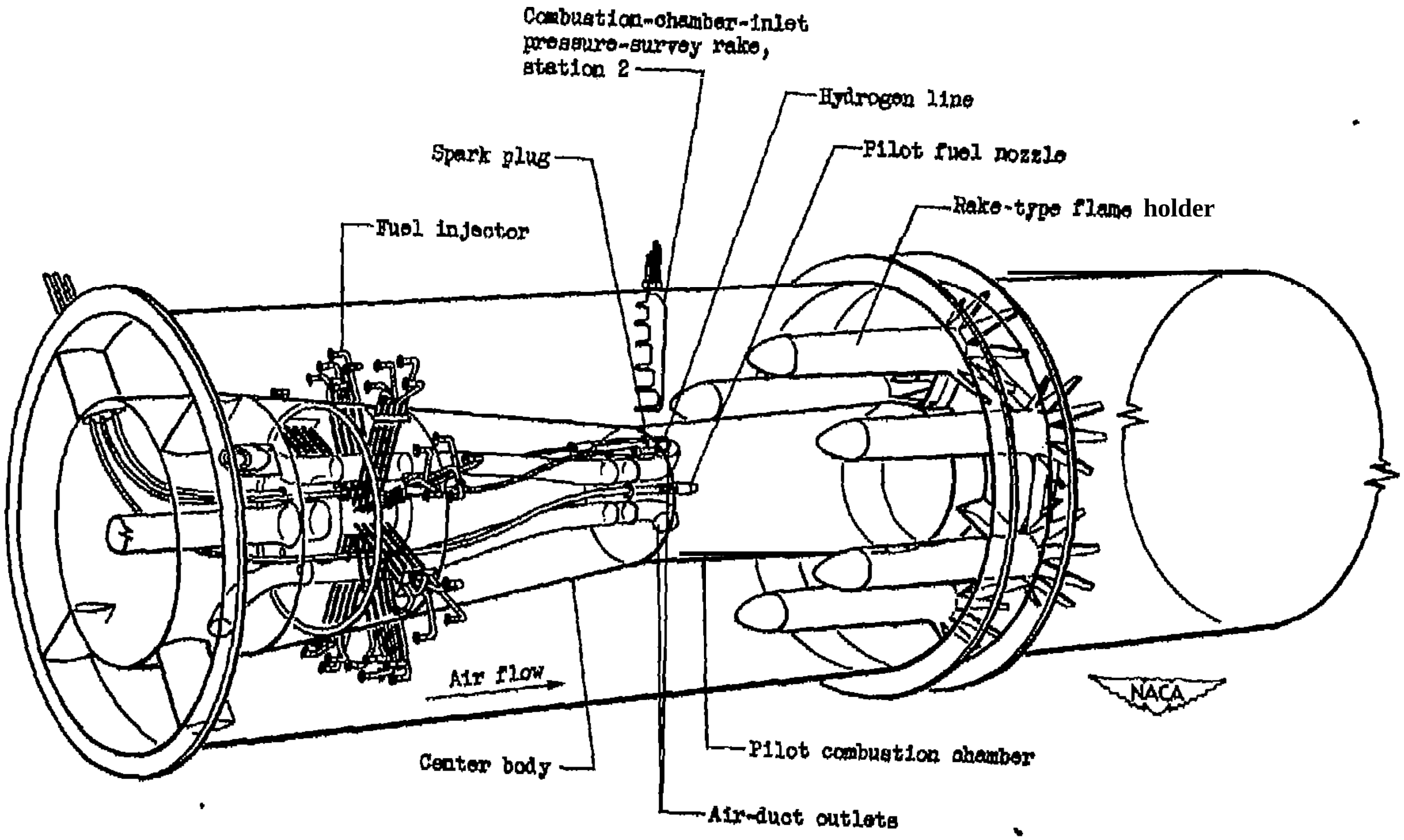
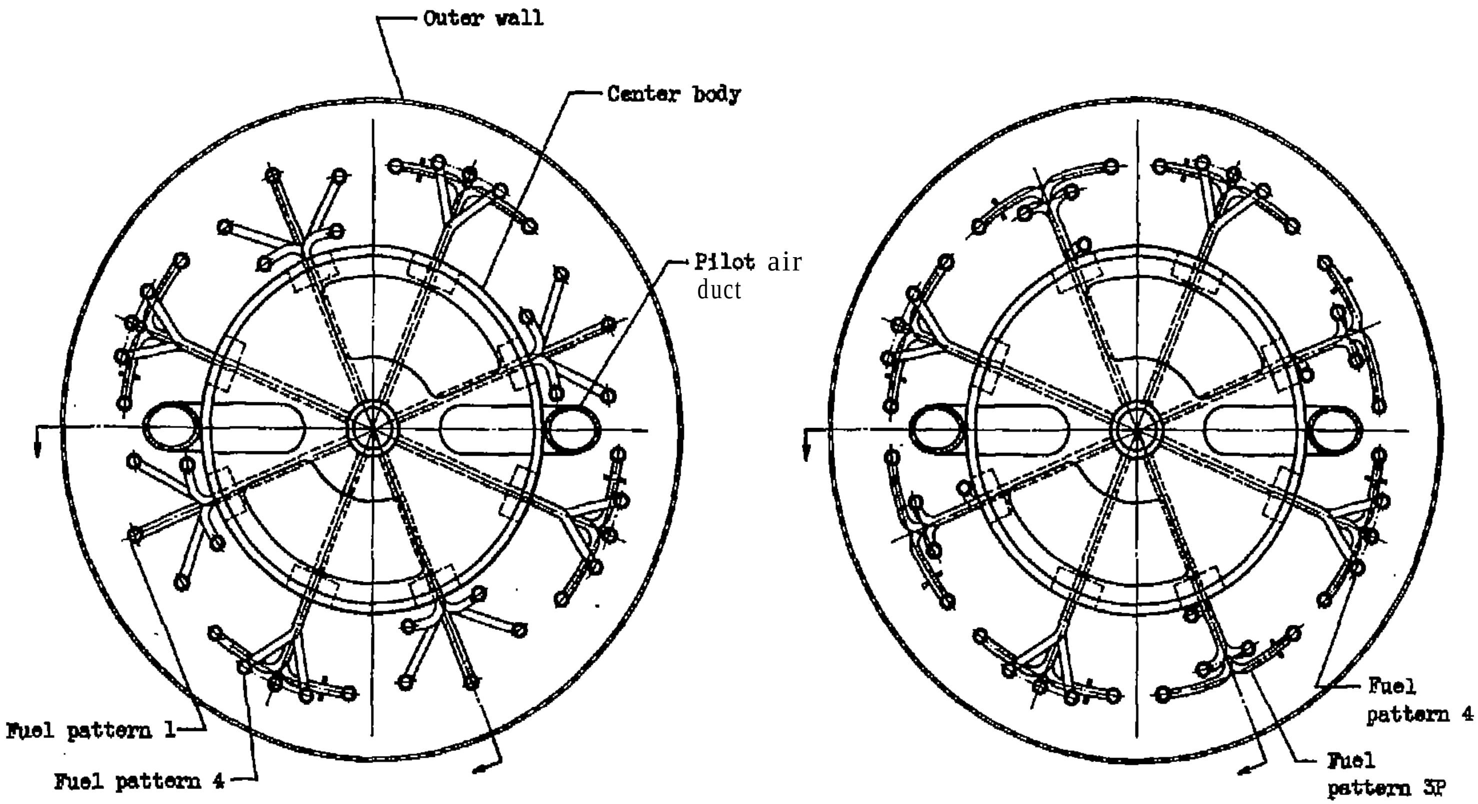


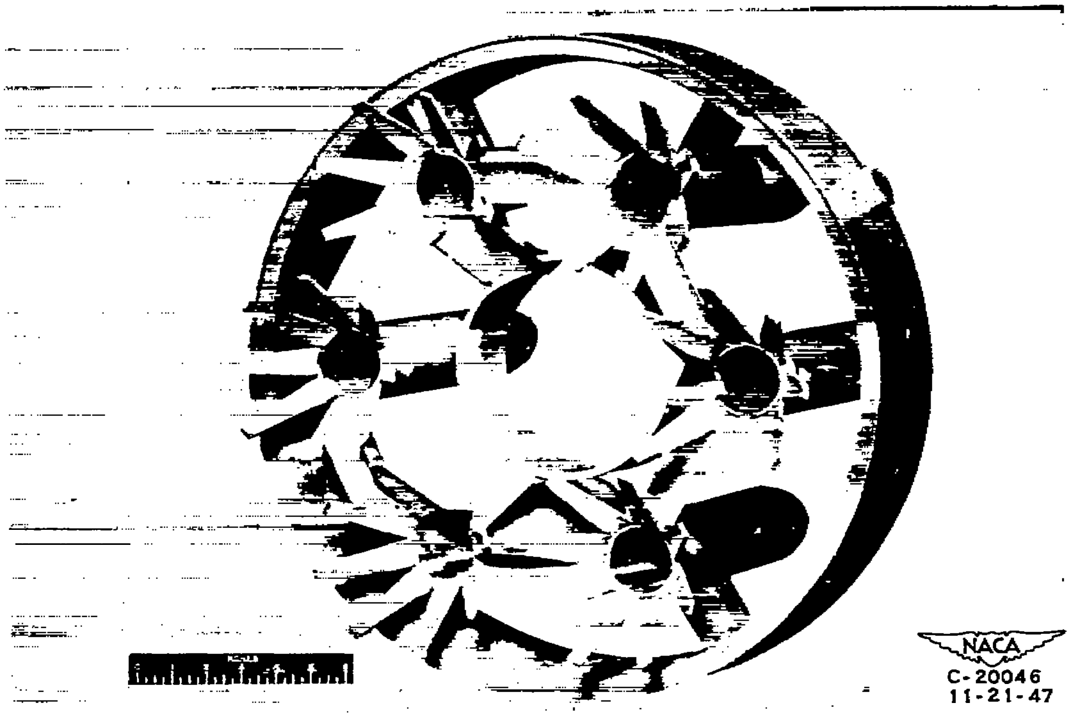
Figure 2. - Schematic diagram or burner for Bumblebee 18-inch ram jet showing rake-type flame holder installed.



(a) Fuel patterns 1 and 4.

(b) Fuel patterns 4 and 3P.

Figure 3. - Schematic diagram of multiple-orifice fuel-injection system showing fuel-injection points.



(a) Before operation.

(b) After operation.

Figure 4. - Photographs of rake-type flame holder 71-7.

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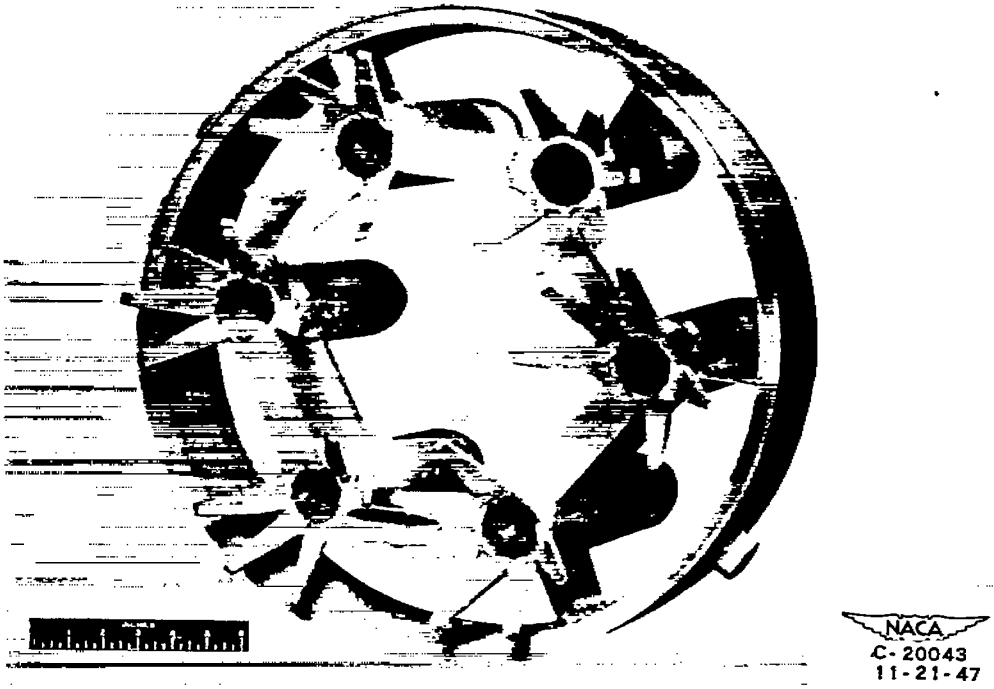
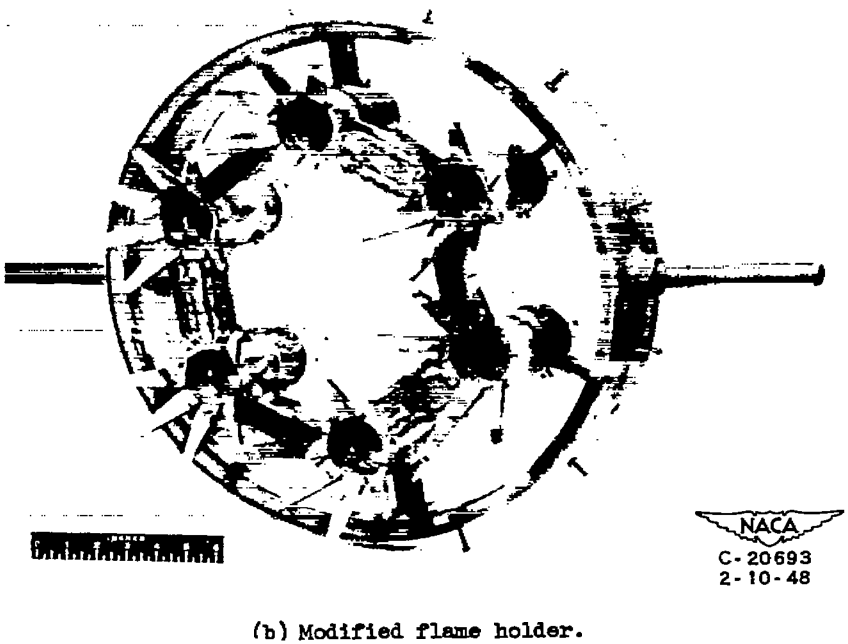


(a) Original flame holder.



(b) Modified flame holder.

Figure 5. - Photographs of original and modified rake-type flame holders 71-4B.

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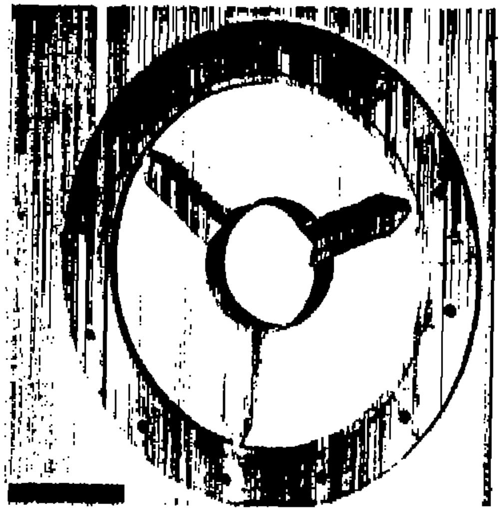

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(a) Flame holder 80 with 1.75-inch-wide gutters.

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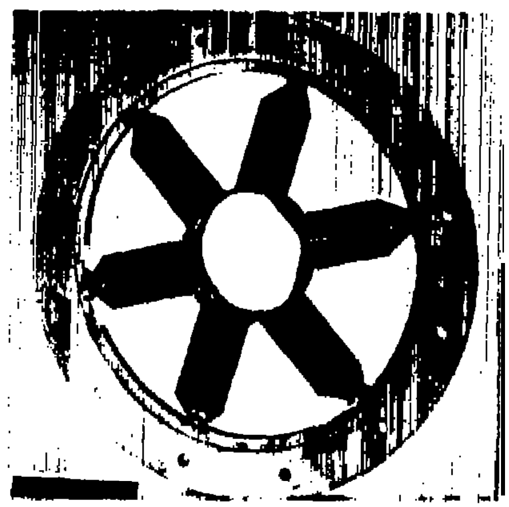
(b) Flame holder 80-1 with 4.25-inch-wide gutters.



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(c) Flame holder with six 2.75-inch-wide gutters.

Figure 6. - Primary-stage gutter-type flame holders.

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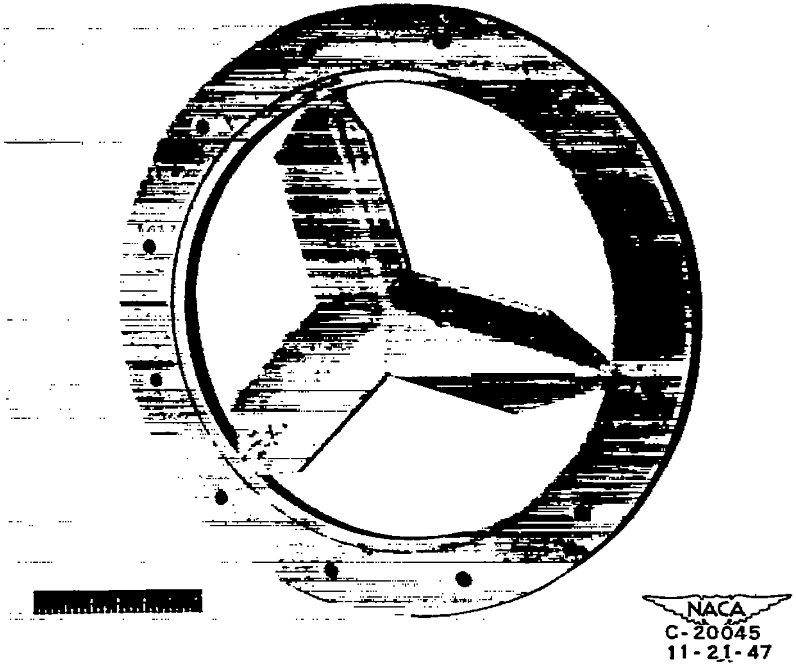
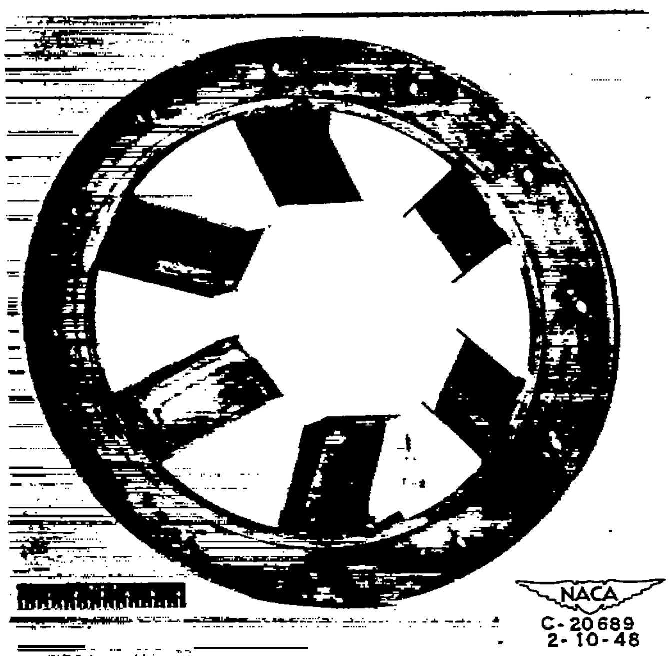


(a) Flame holder 79 with 4.25-inch-wide gutters.



(b) Six-scoop flame holder.

Figure 7. - Secondary-stage flame holders.

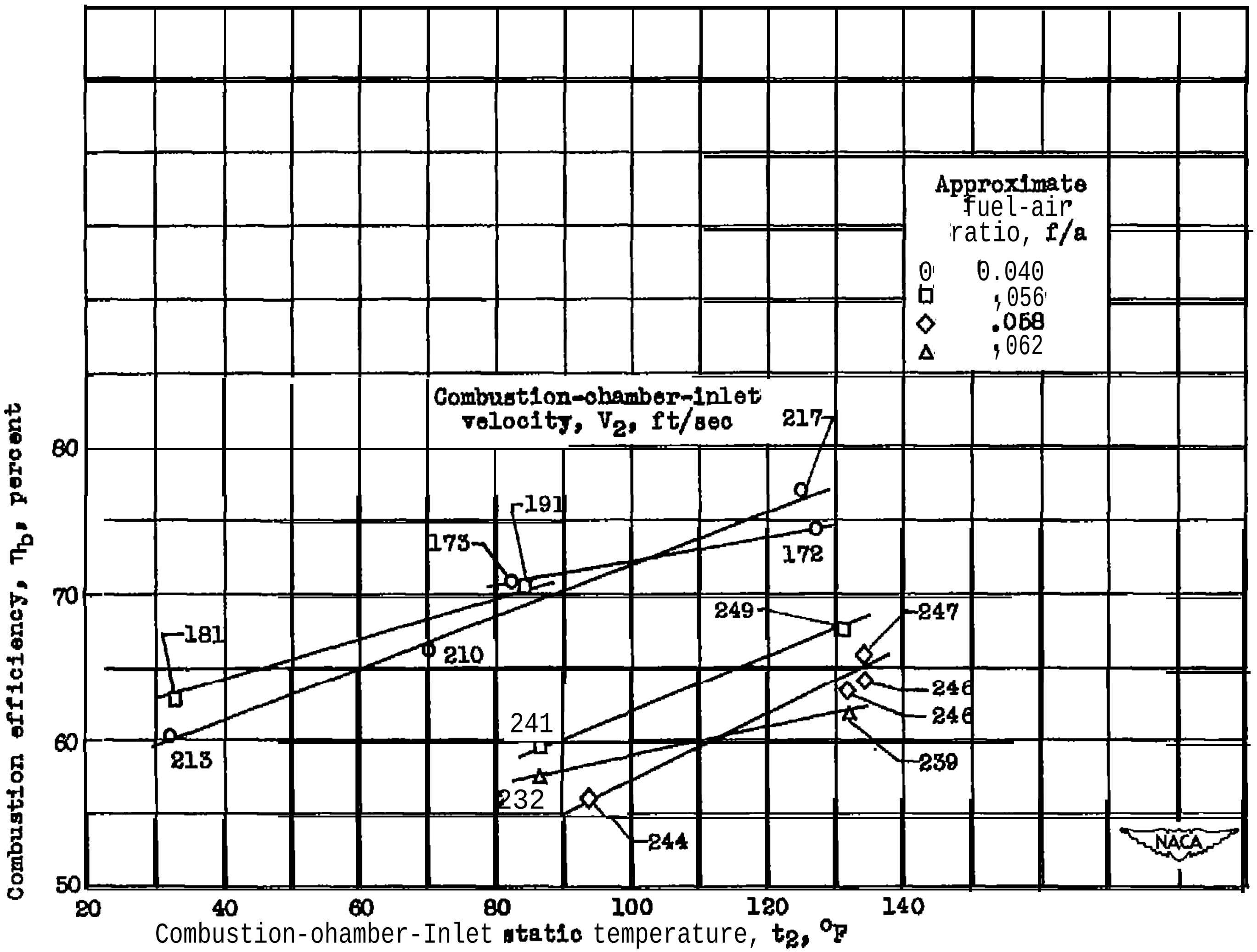
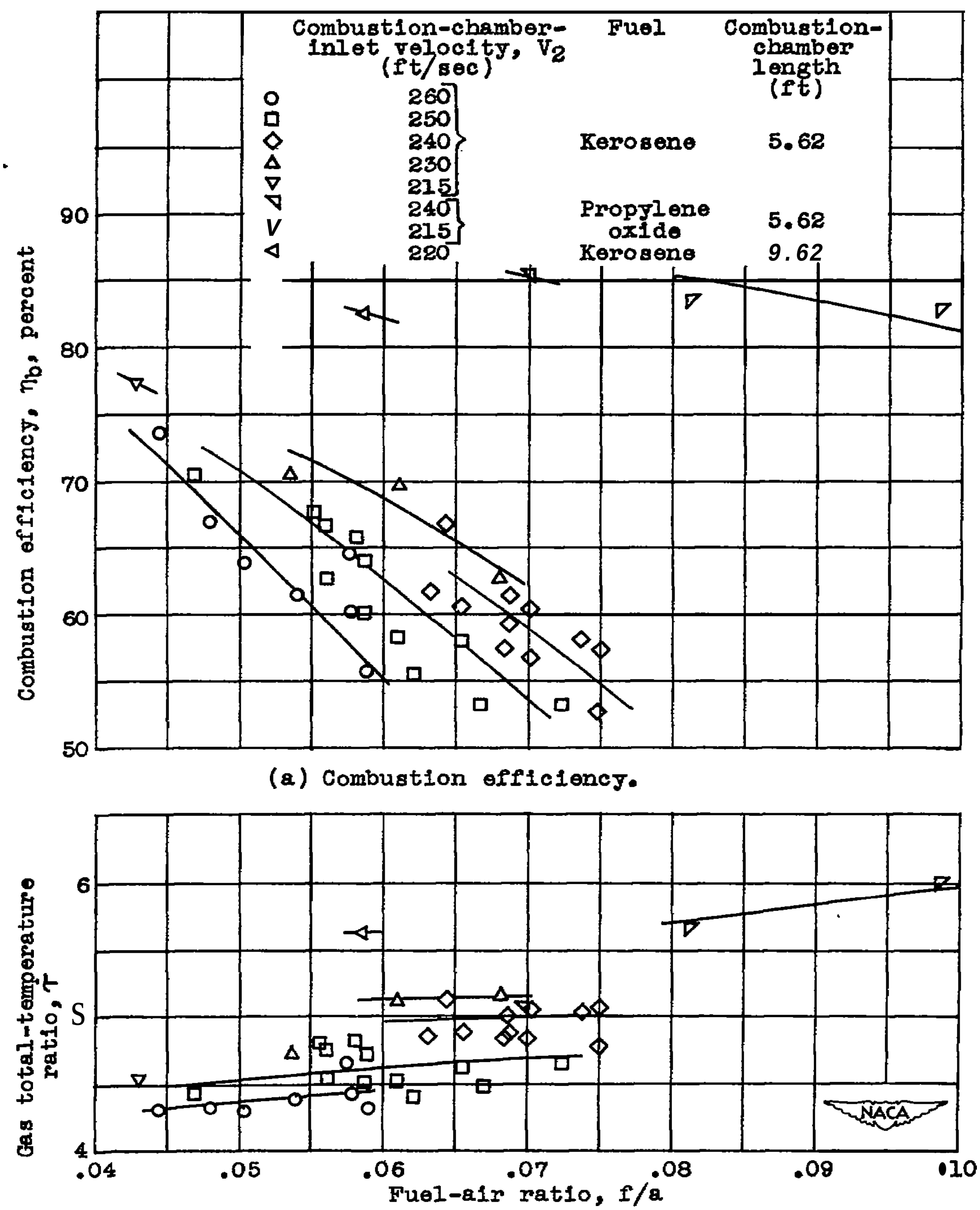


Figure 8. - Effects of combustion-chamber-inlet static temperature on combustion efficiency for various values of fuel-air ratio and combustion-chamber-inlet velocity. Flame holder 71-7 and fuel patterns 1 and 4 with kerosene as fuel.



(a) Combustion efficiency.

(b) Gas total-temperature ratio.

Figure 9. - Effects of fuel-air ratio, combustion-chamber-inlet velocity, fuel, and combustion-chamber length on combustion-chamber performance. Flame holder 71-7 and fuel patterns 1 and 4; combustion-chamber-inlet static temperature t_2, 130° ± 20° F.

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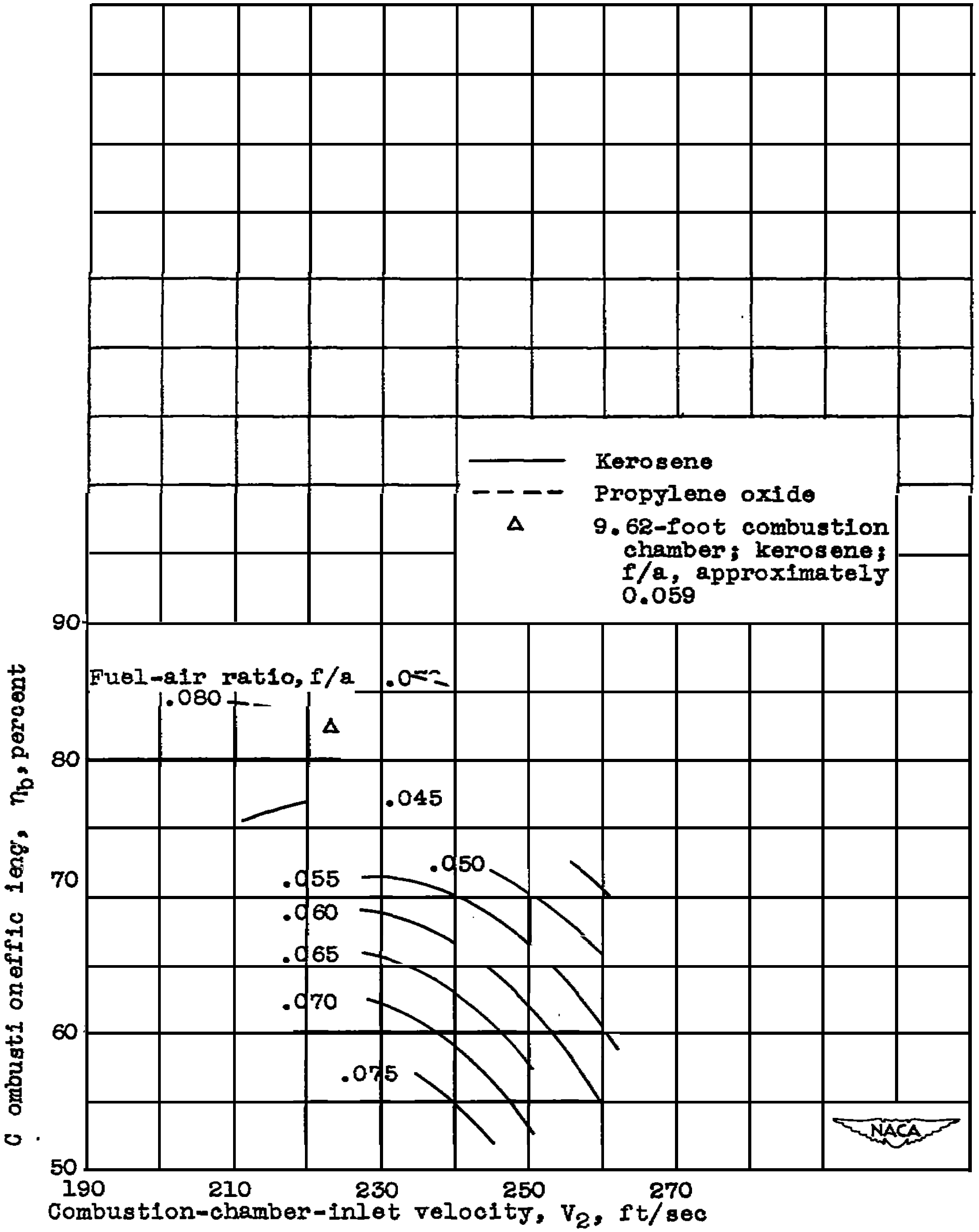
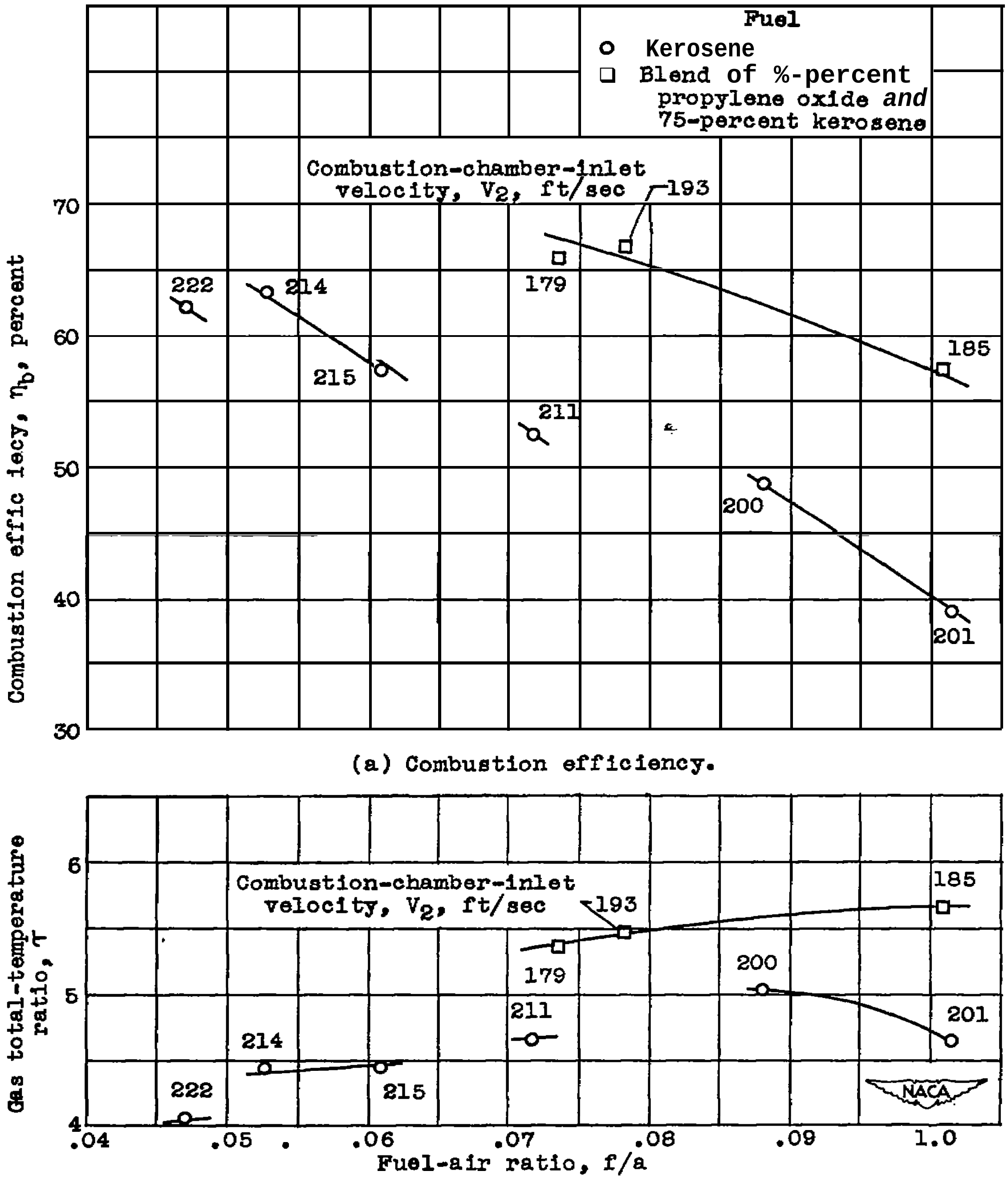


Figure 10. - Relation between combustion-chamber-inlet velocity and combustion efficiency for various values of fuel-air ratio and two fuels. Flame holder 71-7 and fuel patterns 1 and 4; combustion-chamber-inlet static temperature t_2, 130° ± 20° F. (Cross plot of fig. 9.)



(a) Combustion efficiency.

(b) Gas total-temperature ratio.

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Figure 11. - Effects of operation with kerosene or a blend of 25-percent propylene oxide and 75-percent kerosene on combustion-chamber performance. Flame holders 80-1 and 71-4B and fuel patterns 4 and 3P; combustion-chamber-inlet static temperature t_2, 130° ± 20° F.

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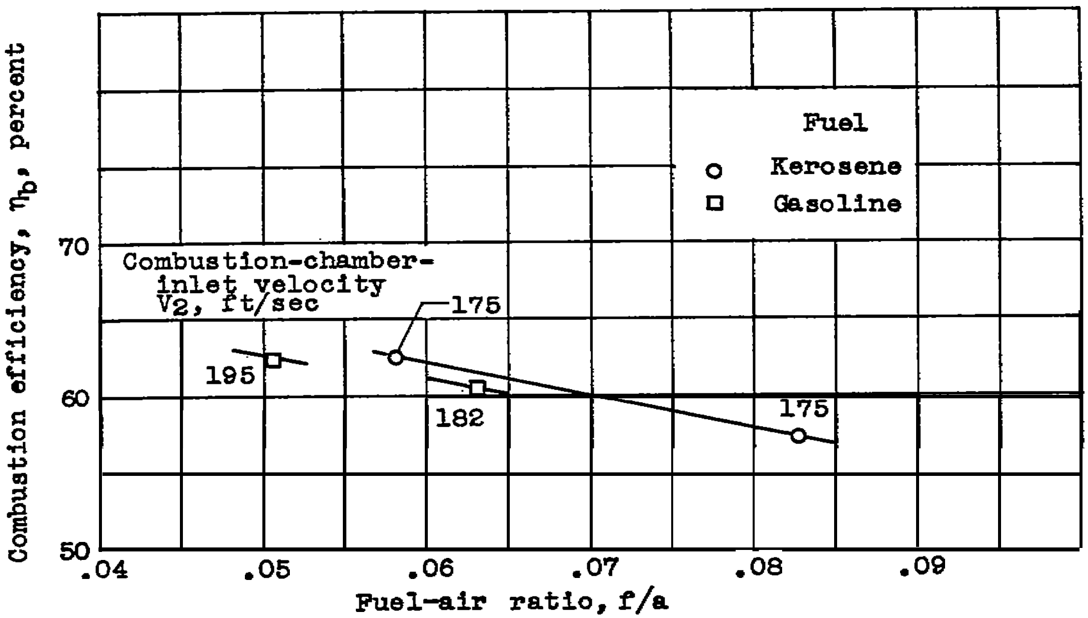

Figure 12. - Effects of operation with kerosene and gasoline on combustion efficiency for flame holders 80 and 71-4B with fuel patterns 1 and 4 and 14.75-inch-diameter orifice plate at combustion-chamber outlet. Combustion-chamber-inlet static temperature t_2, 130° ± 20° F.

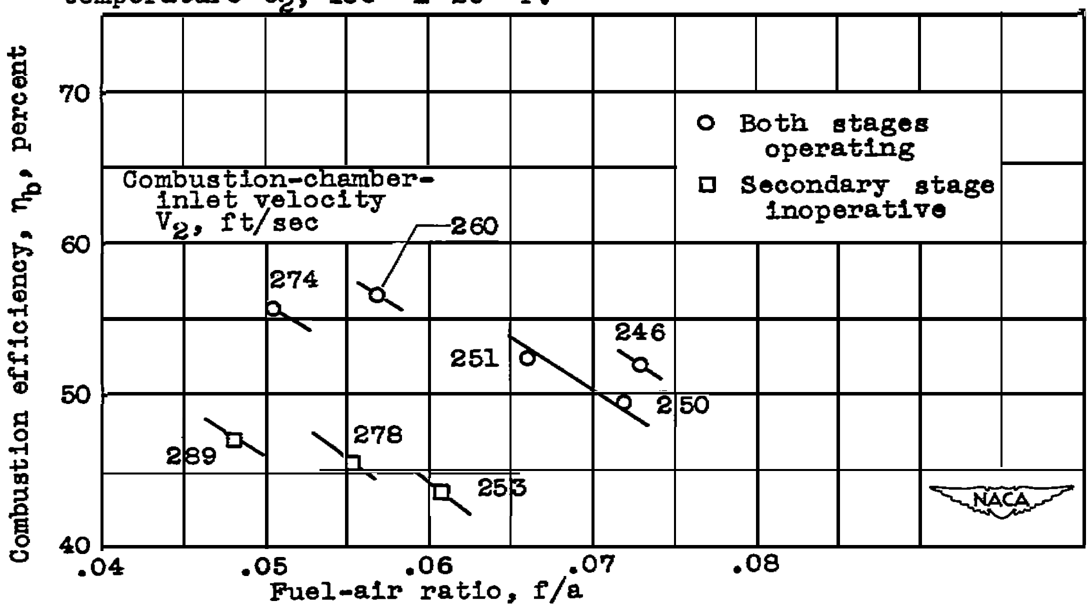

Figure 13. - Relation between fuel-air ratio and combustion efficiency for two-stage flame holder with both stages operative or with secondary stage inoperative with kerosene as fuel. Flame holder 80-1 and 71-4B and fuel patterns 1 and 4; combustion-chamber-inlet static temperature t_2, 130° ± 20° F.

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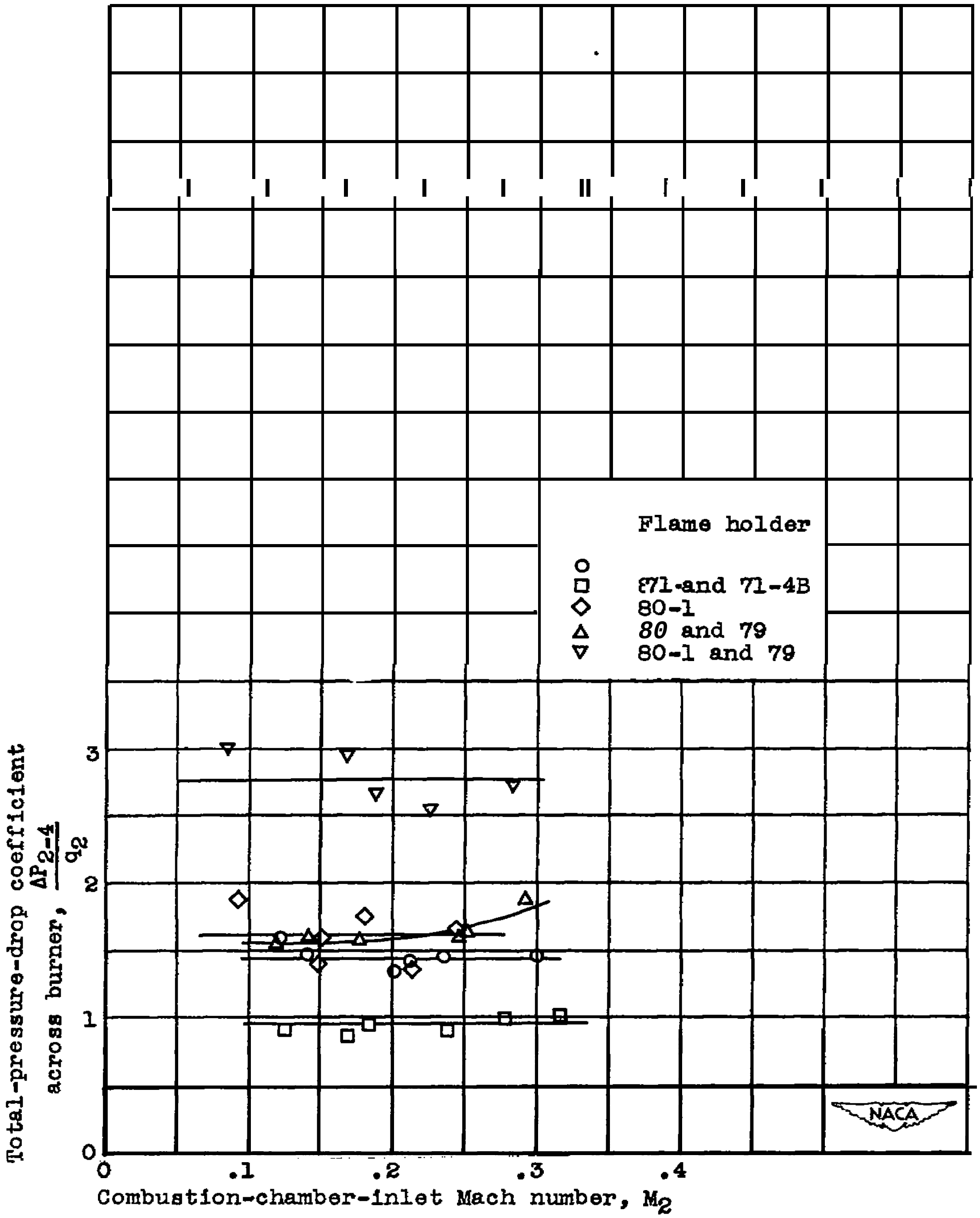
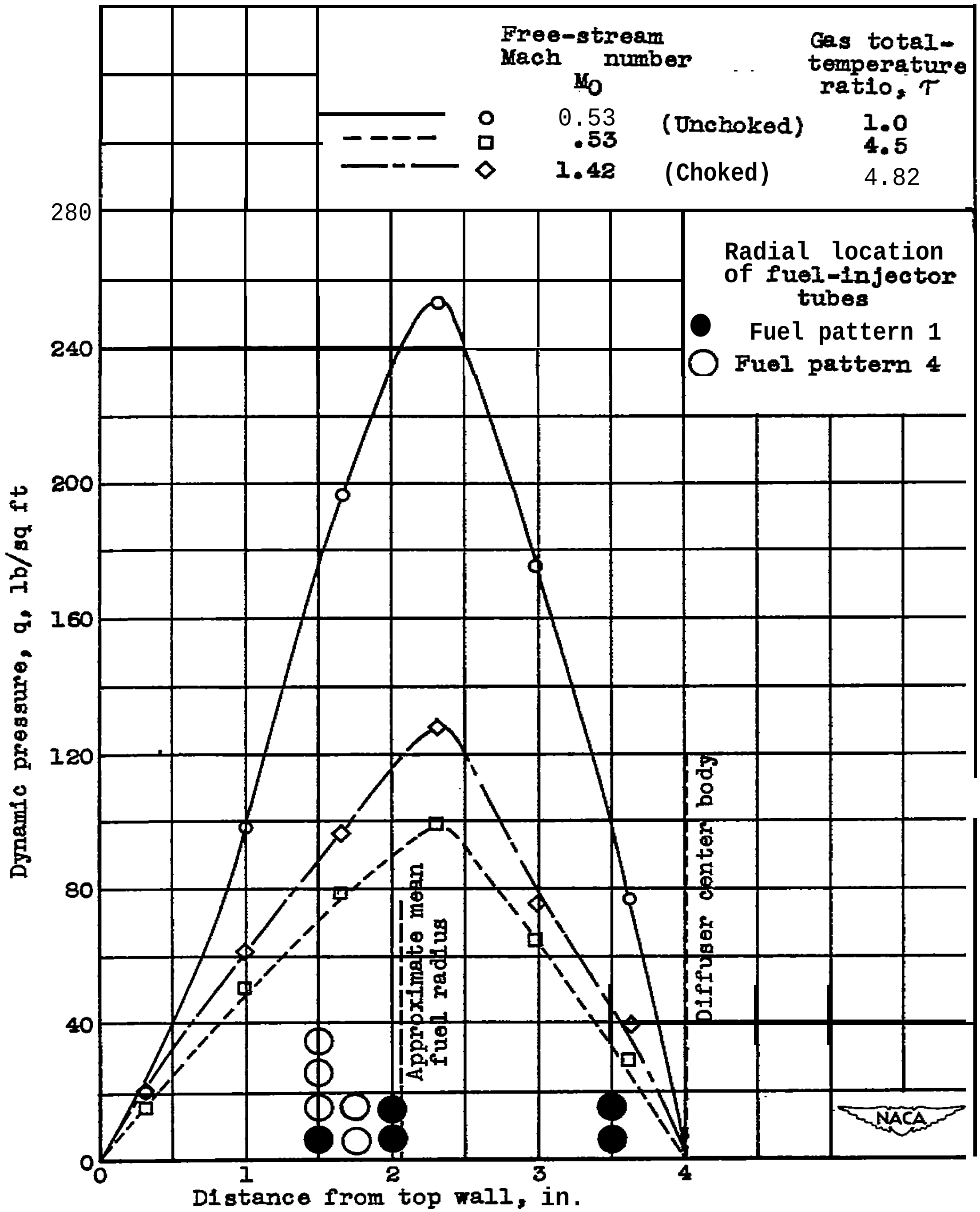
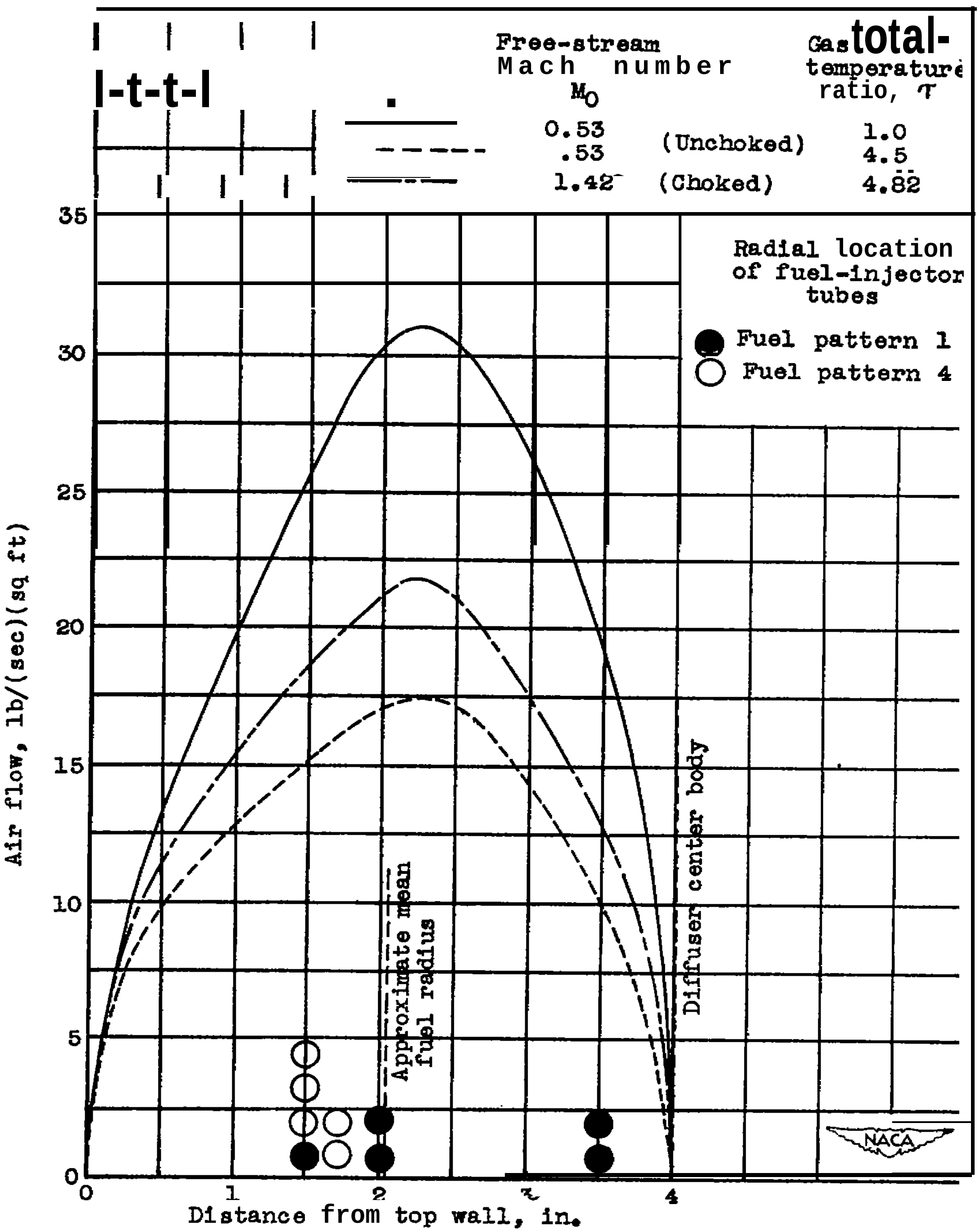


Figure 14. - Relation between combustion-chamber-inlet Mach number and total-pressure-drop coefficient across burner for several rake-type and gutter-type flame holders.



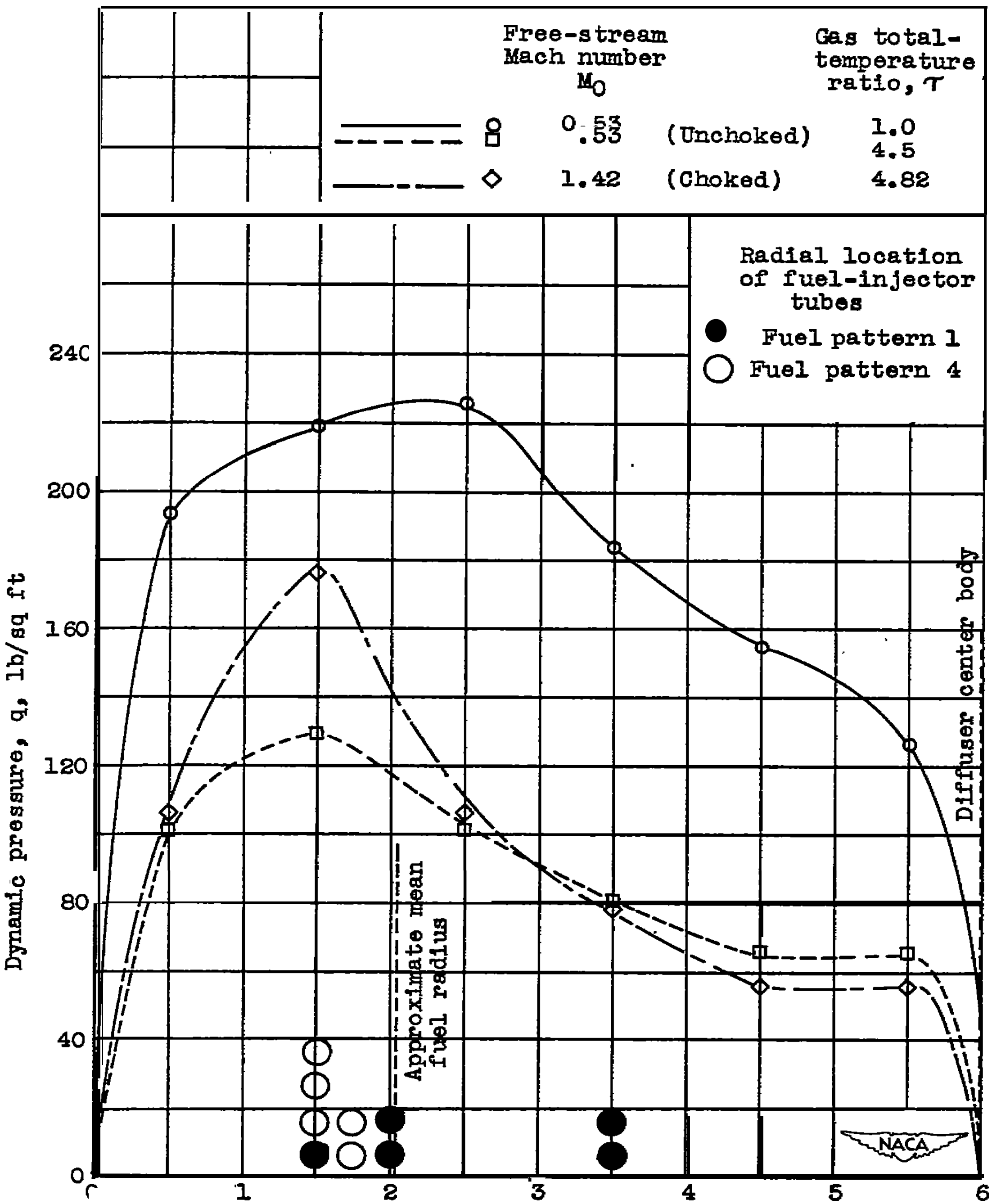
(a) Dynamic pressures.

Figure 15. - Profile of dynamic pressure and air flow upstream of fuel-injector tubes. Flame holder 71-7 and fuel patterns 1 and 4; combustion-chamber-inlet static temperature t_2, 130° ± 20° F.



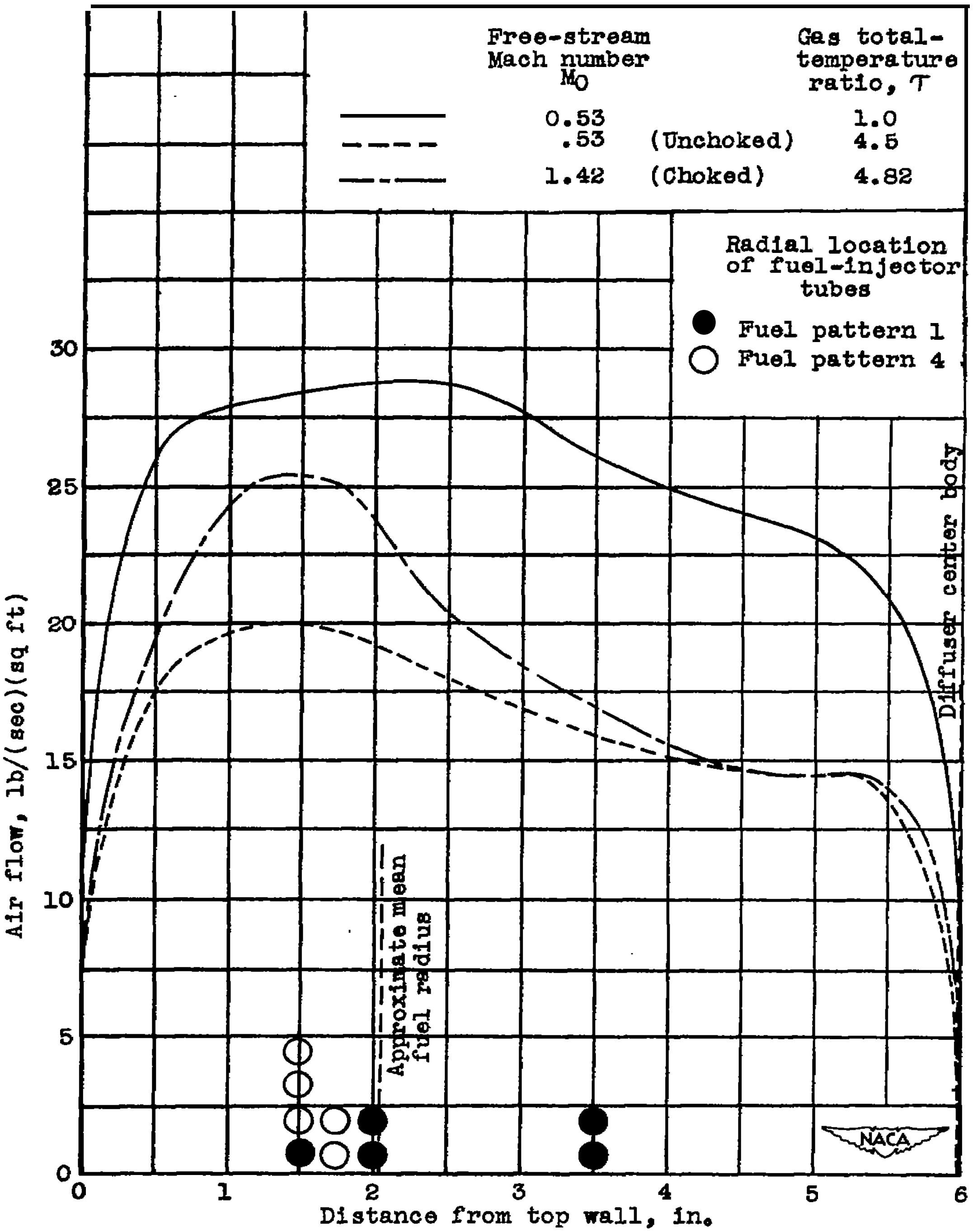
(b) Air flow.

Figure 15.- Concluded. Profile of dynamic pressure and air flow upstream of fuel-injector tubes. Flame holder 71-7 and fuel patterns 1 and 4; combustion-chamber-inlet static temperature t_2, 130° ± 20° F.



(a) Dynamic pressures.

Figure 16. - Profile of dynamic pressure and air flow downstream of fuel-injector tubes. Flame holder 71-7 and fuel patterns 1 and 4; combustion-chamber-inlet static temperature t_2, 130° ± 20° F.



(b) Air flow.

Figure 16.- Concluded. Profile of dynamic pressure and air flow downstream of fuel-injector tubes. Flame holder 71-7 and fuel patterns 1 and 4; combustion-chamber-inlet static temperature t_2, 130° ± 20° F.

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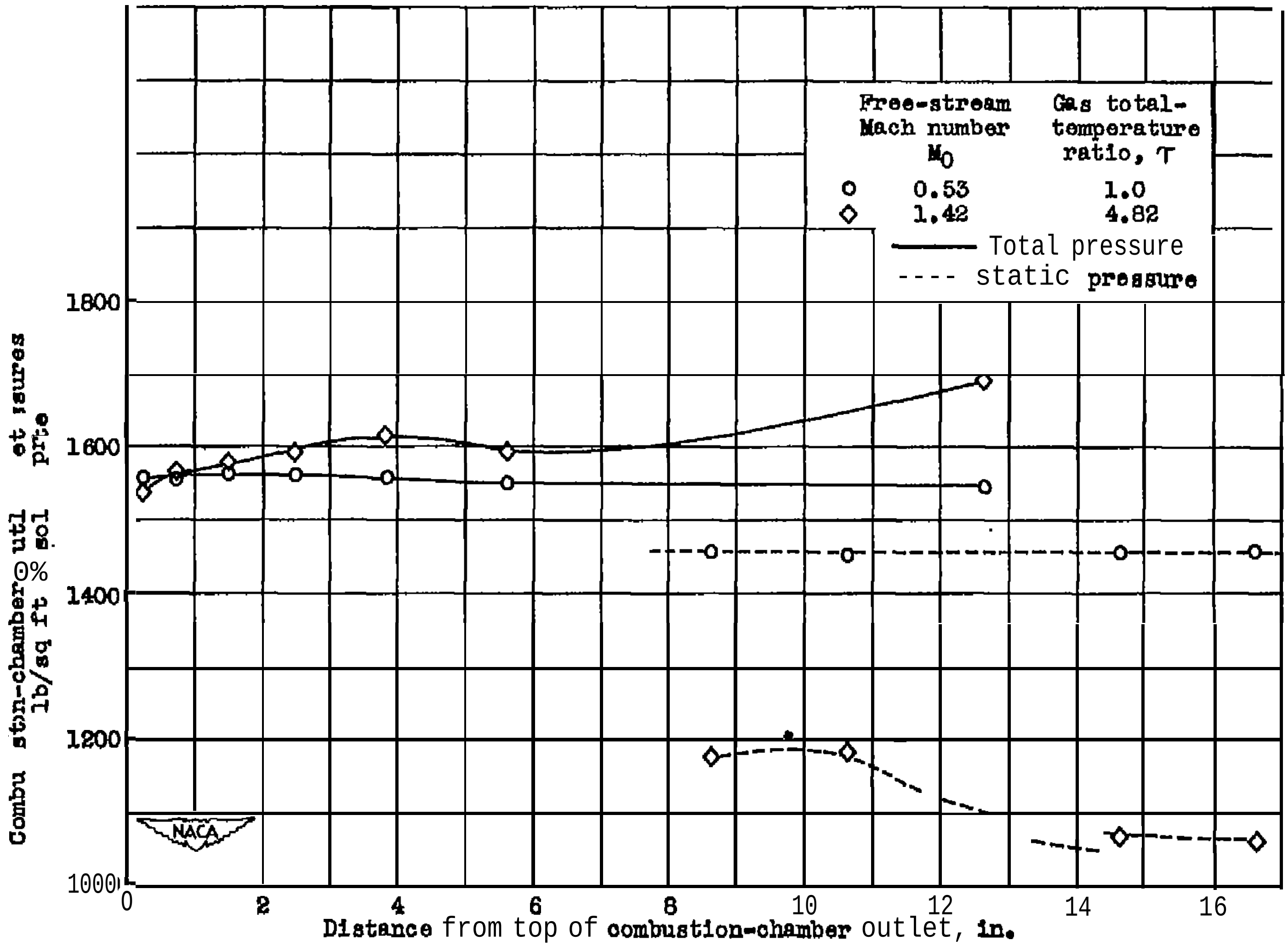

Figure 17. - Survey of pressures across combustion-chamber outlet. Flame holder 71-7 and fuel patterns 1 and 4; combustion-chamber-inlet static temperature t_2, 130° ± 20° F.

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