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RESEARCH MEMORANDUM

HIGH-ALTITUDE PERFORMANCE OF 9.5-INCH-DIAMETER TUBULAR EXPERIMENTAL COMBUSTOR WITH FUEL STAGING

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HIGH-ALTITUDE PERFORMANCE OF 9.5-INCH-DIAMETER TUBULAR EXPERIMENTAL COMBUSTOR WITH FUEL STAGING

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SUMMARY

As part of a general program to develop a turbojet combustor giving high combustion efficiencies at severe operating conditions, 57 experimental tubular designs embodying adjacent fuel-rich and air-rich regions and axial staging of the fuel introduction were investigated at simulated high-altitude conditions.

Axially staged fuel introduction was effective in increasing combustion efficiencies at high fuel-air ratios and high air-flow rates. At low fuel-air ratios, highest combustion efficiencies were obtained by injecting all the fuel in the first fuel-injection stage (i.e., the pilot); at high fuel-air ratios, highest combustion efficiencies were obtained by introducing one-half of the fuel in the pilot and one-half at a location downstream from the pilot. At all combustor-inlet pressures investigated, higher combustion efficiencies were obtained with the experimental combustor than with a current-production-model tubular combustor of the same diameter.

At combustor-inlet conditions simulating 85 percent rated engine speed of a 5.2-pressure-ratio reference engine at a Mach number of 0.6 and an altitude of 56,000 feet, the experimental tubular combustor operated over a range of fuel-air ratios from 0.0035 to 0.029, with a maximum combustion efficiency of 94 percent and a maximum combustor-outlet temperature of 1925° F. The maximum outlet temperature was limited by the test facility rather than by the combustor. Estimated altitude flight performance of the experimental combustor installed in the reference engine indicated that, at rated engine speed and a flight Mach number of 0.6, combustion efficiencies of 97 percent or greater would be obtained at altitudes up to 59,000 feet and of 90 percent or greater at altitudes up to 75,000 feet. The isothermal total-pressure loss of the combustor, which was somewhat greater than that of the production-model reference combustor of the same diameter, was approximately 7 percent of the inlet total pressure for a reference velocity of 100 feet per second. Individual combustor-outlet total temperatures at most operating conditions were within ±200° F of the mean outlet total temperature. No investigation was made of low-altitude operation, carbon-deposition characteristics, or durability of the combustor liner.

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INTRODUCTION

A general research program is currently in progress at the NACA Lewis laboratory to determine design criteria for improving the performance of turbojet combustors. As a part of this program, research was conducted to develop a tubular combustor capable of operating efficiently at low inlet pressures and at higher air-flow rates and fuel-air ratios than current production combustors.

Turbojet combustors must operate with a high combustion efficiency 3048
at the low combustor-inlet pressures and temperatures encountered in high altitude flight. Also, improvements in the performance of compressors (ref. 1) indicate trends toward higher air flows per unit frontal area, and developments in turbine-cooling techniques may allow increased turbine temperatures. Increased compressor air-flow rates require efficient combustor operation at high air velocities if the combustor cross-sectional area is not to exceed the area of other components. With an increase in allowable turbine temperatures, it may become desirable to operate the combustor at higher fuel-air ratios in order to provide a larger temperature rise. Past research conducted at the Lewis laboratory with fractional sectors of single-annulus combustors has indicated design criteria applicable to the improvement of combustor performance, particularly at high-altitude conditions. Reference 2 indicates the desirability of maintaining alternate fuel-rich and air-rich regions in the primary zone. Application of this design principle resulted in higher altitude operating limits, higher combustion efficiencies, and improved radial temperature distribution at the combustor outlet. It has also been found (ref. 3) that axially staged introduction of liquid fuel in the primary zone of a one-quarter sector of a single-annulus combustor resulted in increases in combustion efficiency over a wide range of fuel-air ratios, principally at air flows greater than those encountered in current combustors.

The object of the research reported herein was to develop a tubular combustor embodying the above-mentioned design principles; namely, alternate fuel-rich and air-rich regions and axial staging of the introduction of liquid fuel in the primary zone. The combustor research was aimed toward (1) efficient operation over a wide range of fuel-air ratios at low inlet pressures, (2) ability to handle greater air flows than current combustors, (3) a low over-all combustor total-pressure loss, and (4) an acceptable combustor-outlet total-temperature distribution. The investigation was conducted in a direct-connect duct with a 9.5-inch-diameter tubular combustor; liquid MIL-F-5624A grade JP-4 fuel was used. The combustor was designed to operate with alternate, concentric fuel-rich and air-rich regions and with axial staging of fuel introduction in the primary zone. Operating conditions investigated included low inlet pressures representative of high-altitude, reduced-throttle flight, and air flows per unit cross-sectional area that are (1) representative of current engine design practice and (2) 30 percent above current practice.

The performance of 57 different configurations was investigated, and performance data from selected configurations are presented herein to illustrate general trends obtained with several design variables. Performance data of the best configuration are presented and compared with similar data obtained in a current-production-model tubular combustor and in two experimental annular combustors.

APPARATUS

Installation

A diagram of the combustor test facility is shown in figure 1. Combustor-inlet and combustor-outlet ducts were connected to the laboratory air supply and altitude exhaust facilities, respectively. Air-flow rates and combustor pressures were regulated by remotely controlled valves located upstream and downstream of the combustor. Combustor-inlet air temperature was regulated by valves proportioning the amount of air passing through a steam-fed heat exchanger.

Instrumentation

Air flows were metered by a concentric-hole, sharp-edged A.S.M.E. orifice installed upstream of the inlet-air control valves. Fuel flows to each stage of the combustor were measured by separate, calibrated rotameters. Total pressures and temperatures were measured by pressure probes and bare-wire chromel-alumel thermocouples at the instrument stations indicated in figure 1 (station 1 at the combustor inlet and stations 2 and 3 at the combustor outlet). The number, type, and location of the instruments at each plane are indicated in figure 2. The inlet thermocouples and all the pressure probes were stationary. The seven outlet thermocouple probes at station 3 were moved radially by means of a chain-driven mechanism that positioned all probes simultaneously at any of four predetermined positions (fig. 2(c)); the positions represent centers of four equal areas. Details of construction of the pressure probes and thermocouples are presented in figure 3. The thermocouples were connected to a self-balancing, direct-reading potentiometer. The outlet thermocouples were connected in a parallel circuit to give an instantaneous average-temperature reading. The pressure probes were connected to absolute manometers.

Combustor

The investigation was conducted with a tubular combustor having a maximum cross-sectional area of 70.8 square inches (9.5-in. diam). Overall length of the combustor was $27\frac{1}{2}$ inches, and the distance from the first-stage fuel injector to the plane of the outlet thermocouples (station 3) was $36\frac{13}{16}$ inches. A total of 57 experimental combustor configurations were tested during the investigation. Some configurations embodied changes in combustor geometry or liner open area; other configurations, only changes in fuel nozzles. The combustor configurations are designated by numbers according to the order in which their performance was investigated.

Diagrammatic sketches of the experimental combustors are presented 3048
in figures 4 and 5. The primary zone of each configuration was composed of concentric fuel-injection stages separated by annular openings for the admission of air. The first fuel-injection stage (hereinafter referred to as the pilot) consisted of a single hollow-cone, pressure-atomizing nozzle concentrically positioned at the upstream face of the first tubular section shown in figures 4 and 5. The other fuel-injection stages were annular; each consisted of eight equally spaced nozzles of the type used in the pilot. The longitudinal axes of the nozzles in the annular stages were tilted approximately 5° toward the center line of the combustor to minimize spray impingement on the combustor liner. The different stages of the primary zone were so constructed that the combustor could be assembled with different spacings between stages of fuel injection as shown in figures 4 and 5. Secondary sleeves of different length were necessary for use with the various possible primary-zone configurations. Configurations 1 to 23 inclusive (fig. 4) contained three possible stages of fuel injection; configurations 24 to 57 inclusive (fig. 5), only two stages. In addition, the diameter of the pilot was increased in the two-stage configurations. Data relative to the geometry and the fuel-nozzle specifications of the different configurations investigated are presented in table I.

In addition to changes in the primary zone, some changes were made in the diameter of the secondary sleeve to vary the areas of primary and secondary annuli. As shown in figures 4 and 5, open area of primary annuli was considered to be the sum of the minimum annular flow areas between fuel-injector stages; open area of secondary annuli, the sum of the minimum annular flow areas between the last fuel-injection stage and the combustor housing. Sketches and descriptive data for four configurations having the same open-area pattern in the pilot but different ratios of primary to total annular area are presented in figure 6.

A photograph of configuration 57, the best configuration investigated, is presented in figure 7 together with a curve showing the longitudinal distribution of combustor open area. Dimensions of configuration 57 are presented in figure 5(c). This configuration was investigated only in the assembly shown in figure 7; that is, the performance of this configuration was not studied with a shortened secondary sleeve and an unshrouded pilot (fig. 5(b)).

Ignition was initiated within the pilots of all configurations by use of a standard turbojet-combustor spark plug with extended electrodes.

Fuel

The fuel used in this investigation was liquid MIL-F-5624A grade JP-4 fuel supplied from the laboratory distribution system. Representative inspection data for the fuel are presented in table II.

PROCEDURE

Combustion-efficiency and combustor-total-pressure-loss data were recorded with the various combustor configurations for a range of fuel-air ratios at the following combustor-inlet conditions:

Condition	Combustor-inlet total pressure, in. Hg abs	Combustor-inlet total temperature[a], $^{\circ}$F	Air-flow rate per unit combustor area[b], lb/(sec)(sq ft)	Simulated flight altitude in reference engine at 85 percent rated engine speed, ft
A	15	250	2.78	56,000
B	8	235	1.49	70,000
C	[c]6	220	.93	80,000
D	15	260	2.14	56,000
E	15	250	3.62	56,000

[a]Combustor-inlet temperature of 268° F required to simulate flight conditions listed. Temperatures listed were mean values actually used in this investigation and represent limitations of test facility.

[b]Based on maximum combustor cross-sectional area (0.492 sq ft).

[c]Pressure of 5 in. Hg abs required to simulate flight condition listed for condition C. Pressure of 6 in. Hg abs was actually used in most of this investigation, since it was minimum pressure obtainable in test facility.

These conditions simulate combustor-inlet conditions in a reference 5.2-pressure-ratio turbojet engine operating at 85 percent rated speed at a flight Mach number of 0.6. Air-flow rates at conditions A, B, and C are representative of current turbojet engines. Air-flow rates approximately

23 percent less, and 30 percent greater than those used in current turbojet engines are represented by conditions D and E, respectively.

Limited data were obtained with each combustor configuration at one or more of the above conditions in order to indicate trends in combustor performance. Data were obtained with the best configuration (57) at all conditions listed and with varying degrees of axial fuel staging.

Combustion efficiency, defined as the percentage ratio of actual to theoretical increase in enthalpy of gases flowing through the combustor, 3048
was computed by the method of reference 4. Combustor-outlet total temperatures, used to calculate the enthalpy of gas at the combustor outlet, were computed as the arithmetic mean of the temperatures indicated at the 28 outlet thermocouple positions (fig. 2(c)). Thermocouple indications were not corrected for velocity or radiation effects.

Combustor reference velocities were computed from the air-flow rate per unit combustor cross-sectional area and the combustor-inlet air density. Combustor total-pressure losses are expressed as the dimensionless ratios of (1) the combustor total-pressure loss ΔP to the reference-velocity pressure q_r $(= \rho_i V_r^2/2$ where V_r is the combustor reference velocity and ρ_i is the inlet air density) and (2) the combustor total-pressure loss ΔP to the combustor-inlet total pressure P_i.

The radial temperature distribution at the combustor outlet was determined at each test condition investigated. The temperature at each radial position was determined as the average of the indications of seven thermocouples. Circumferential temperature distribution was checked by recording individual thermocouple readings.

RESULTS AND DISCUSSION

A series of 57 combustor configurations was investigated in an effort to obtain a high-performance combustor for high-altitude turbojet-engine operation. Results obtained with a number of the configurations, selected to best illustrate the trends obtained, are discussed in the following paragraphs. Experimental data for the configurations discussed are presented in table III. The discussion is divided into three major categories: (1) the development of the pilot, (2) the development of the secondary-air admission sleeve, and (3) the development of the final configuration.

Development of Pilot

Preliminary investigations indicated that the first stage, or pilot, of the experimental combustor configuration had a predominant influence on the over-all performance of the combustor. Therefore, although it was desired that axial staging of the fuel introduction be incorporated into the combustor design, the first investigations were concerned only with the effects of pilot design on performance.

Effect of pilot fuel-nozzle capacity. - Figure 8 presents the effect of fuel-nozzle capacity on combustion efficiencies of a pilot having a representative air-entry design. A small nozzle having approximately half the capacity of a larger nozzle gave higher efficiencies at low fuel-air ratios, but resulted in locally over-rich mixture conditions and lower efficiencies at high fuel-air ratios. Similar effects have been observed in reference 3. These results may be attributed to the finer atomization obtained with the smaller nozzle. Since the pilot would be expected to operate alone at lean mixture conditions, the best pilot nozzle for fuel-staging operation would be the smallest nozzle consistent with the pilot fuel-flow requirements at rich mixtures.

3048

Effect of pilot shrouding. - Operation of the combustor was investigated with the fuel-injection stages of the combustor in different positions relative to each other (figs. 4 and 5). In a collapsed primary-zone configuration (figs. 4(b), 5(a), and (c)), the second stage shrouds the upstream portion of the pilot. In an extended primary-zone configuration (figs. 4(a), (c), and 5(b)), the unshrouded upstream portion of the pilot would be expected to receive a larger percentage of the air flow. The results obtained with a pilot configuration operated at inlet conditions A, B, and C with the pilot shrouded and unshrouded are presented in figure 9. Secondary sleeves of the same diameter and the same number and size of openings but 3 inches different in length were used with the two primary-zone configurations. The larger quantity of air introduced into the unshrouded pilot chamber (configuration 37) resulted in lower combustion efficiencies at lean fuel-air ratio conditions, and higher combustion efficiencies at rich fuel-air ratio conditions. These results may be attributed to fuel-air-mixture conditions in the primary zone. At low fuel-air ratios, the larger amount of air admitted by the unshrouded pilot resulted in an over-lean primary zone; at rich fuel-air ratios, the increased amount of air resulted in improved fuel-air mixtures.

Effect of pilot-air admission. - Air was admitted into the pilot either through small circular holes or through a combination of small circular holes and longitudinal slots. With each method of air admission, the size, spacing, and number of openings were varied over a wide range to determine the optimum design. In all, 30 different pilot configurations were investigated, 15 embodying small circular holes and 15 embodying a combination of small circular holes and longitudinal slots for air admission. Figure 10 shows the longitudinal open-area distribution of small circular holes and longitudinal slots in five representative configurations; combustion efficiencies for these configurations are presented in figure 11. Increases in pilot open area of these configurations resulted in increased efficiencies at rich fuel-air ratios. The same general trends in combustion efficiencies were found with pilots embodying only small circular holes for air admission. These trends may be attributed to greater penetration and mixing of air with fuel with increases in pilot open area.

Effect of method of pilot-air admission. - The longitudinal distributions of open area of two pilots, one having small circular holes for air admission and the other, a combination of small circular holes and longitudinal slots, are shown in figure 12. The total open area at any 3048 longitudinal position was approximately the same for each pilot. Combustion efficiencies for the two configurations are presented in figure 13. The pilot having a combination of small circular holes and longitudinal slots for air admission operated more efficiently over most of the range of fuel-air ratios than did the pilot having small circular holes alone. The lower combustion efficiencies of the slotted configuration at lean fuel-air ratios may be due to greater penetration of air jets into the pilot zone with longitudinal slots; this would create an over-lean pilot zone. Longitudinal distribution of open area of the best pilot configurations embodying each method of air admission are presented in figure 14. Combustion efficiencies for the two configurations are presented in figure 15. Even with optimized pilot open areas, the configuration having a combination of small circular holes and longitudinal slots for air admission operated more efficiently than did the configuration having small circular holes alone.

Effect of pilot diameter. - Curves showing the longitudinal distribution of open area of several pilots varying both in length and diameter are presented in figure 16. Combustion efficiencies of the various pilots, operated at inlet conditions B and C, are presented in figure 17. Combustion efficiencies obtained with the various pilot configurations increased with increases in pilot diameter. This trend was noted with pilots of both the same and different lengths. Although air-distribution factors were present in the comparisons, the data obtained indicated that high combustion efficiencies were more easily obtained with larger pilots. Other investigators have found similar trends in combustion efficiencies; for example, references 5 and 6 indicate increased combustion efficiencies with combustors of increasing hydraulic radii.

Variations in the diameter of pilots resulted in changes in the size of the open flow annuli around the pilots and accompanying changes in the ratios of primary to total open annular area. As a result of these changes, a variation in the air-flow distribution between the primary and secondary zones of the combustor might occur. The two larger pilots (configurations 30 and 32) of figure 17 differed mainly in diameter; they had approximately the same type and spacing of openings and total open area for pilot-air admission. The combustion efficiencies of configuration 32, which had a diameter of $5\frac{13}{16}$ inches and a ratio of primary to total open annular area of 0.171, were higher than those of configuration 30, which had a diameter of $5\frac{1}{4}$ inches and an area ratio of 0.333. The higher efficiencies obtained with configuration 32 are probably due to increases in the combustion volume as well as decreases in open annular area ratio. The open area ratio of configuration 32 is typical of many current production combustors, which have approximately 20 percent of the total open area in the upstream half, or the primary zone, of the combustor liner.

3048

Development of Secondary-Air Admission Sleeve

The secondary zone of a combustor serves, by mixing the products of combustion with additional air, to cool the exhaust-gas mixture to a temperature suitable for entry into the turbine. Since a large portion of air must be added in this zone, pressure loss is an important consideration. Modifications to the secondary zone may affect not only combustor total-pressure losses and outlet temperature distribution but also the proportioning of the air to the primary zone and thus the combustion efficiency. The effect of modifications to the secondary zone were studied with a number of configurations.

CK-2

<u>Effect of secondary-sleeve diameter</u>. - The effect of secondary-sleeve diameter on the performance of a pilot is shown in figure 18. Two secondary sleeves, one $8\frac{1}{2}$ inches in diameter (fig. 5(a)) and one $8\frac{1}{4}$ inches in diameter (fig. 5(c)), were installed in the combustor during operation of the same pilot. Number, size, shape, and spacing of openings were the same in each sleeve. Performance of the pilot operated with the $8\frac{1}{2}$-inch-diameter sleeve was generally superior to that of the pilot operated with the $8\frac{1}{4}$-inch-diameter sleeve. However, over-all isothermal $\Delta P/q_r$ of the combustor was approximately 27.5 with the $8\frac{1}{2}$-inch-diameter sleeve compared to 17.5 with the sleeve of smaller diameter. Superior performance of the pilot with the $8\frac{1}{2}$-inch-diameter secondary sleeve may be attributable to a larger combustion volume as mentioned previously in the section describing the effect of pilot diameter on pilot performance. Also, the superior performance may be due to differences in the ratios of primary to total open annular area. The slightly lower open-area ratio with the $8\frac{1}{4}$-inch-diameter sleeve could account for the superior performance of this configuration at lean fuel-air ratios, since less air probably would be entering the pilot.

<u>Effect of secondary-air-entry design</u>. A limited number of tests were conducted to investigate the effect of secondary-air-entry design on the performance of the experimental combustor configurations. A comparison of the performance of the combustor with a single pilot and three different $8\frac{1}{4}$-inch-diameter secondary sleeves is presented in figure 19. One configuration (54) embodied the secondary sleeve used with the best configuration; the others differed in air-entry design and had total open areas approximately 25 percent greater. Decreases in performance of the pilot at rich fuel-air ratio conditions with the secondary sleeves having 3048
larger open areas may have been the result of a redistribution of air flow which created an over-rich primary zone. Performance was impaired most by increases in secondary-sleeve open area near the pilot. Lower performance with the best sleeve (configuration 54) at lean fuel-air ratios may be due to greater penetration and mixing of air jets entering near the pilot through four large slots. Air entered near the pilot through 12 small slots in configuration 55 and through 8 large slots in configuration 56.

Combustor-outlet total temperatures were higher and lower at the center and wall, respectively, during operation with the secondary sleeve having the greatest open area near the downstream end (configuration 55). Little change in outlet-temperature distribution was observed with the greatest open area near the pilot (configuration 56).

Development of Final Configuration

The final configuration (57), which produced better performance than any other configuration, embodied a pilot having small circular holes and longitudinal slots for air admission. Higher combustion efficiencies were attained with such pilots than with other models over a wide range of fuel-air ratios. A fuel nozzle rated at 10.5 gallons per hour with a spray cone angle of 60° at a pressure differential of 100 pounds per square inch was selected for use in the pilot. The combustion efficiencies attained with pilots using nozzles of this capacity were superior at lean fuel-air ratios to those attained with nozzles of larger capacities. The capacity of the 10.5-gallon-per-hour nozzle was consistent with the fuel-flow requirements for fuel staging at rich fuel-air ratios.

The two-stage design of the combustor was chosen in an effort to obtain as large a pilot as possible. A general trend toward increasing combustion efficiencies had been noted with increases in pilot diameter. Satisfactory distribution of fuel from the second stage at the low-nozzle-pressure differentials associated with small flows necessitated the use of nozzles rated at 2.5 gallons per hour with a spray cone angle of 30°.

A lower over-all combustor-total-pressure loss was the criterion for selection of the $8\frac{1}{4}$-inch-diameter secondary sleeve; superior performance of the combustor and acceptable combustor-outlet temperature distribution over most of the range of fuel-air ratios governed the selection of the air-admission pattern in the secondary sleeve.

Performance of Best Configuration

<u>Effect of fuel staging</u>. - Combustion efficiencies of the best configuration (57) with various degrees of fuel staging are presented in figure 20 for five combustor-inlet conditions. Axial fuel staging improved the performance of the combustor at medium and rich fuel-air ratios. Highest combustion efficiencies at lean fuel-air ratios were obtained with all the fuel injected in the pilot. At very rich fuel-air ratios, highest efficiencies were obtained with approximately 50 percent of the total fuel flow through the pilot. Fuel staging with 25 percent of the total fuel flow injected in the pilot was inferior to other modes of operation; operation was not possible with the second stage alone. The fuel-air ratio at which staging became desirable increased with (1) decreasing combustor-inlet pressures at the same combustor reference velocity (figs. 20(a) and (b)) and (2) decreasing air flows at the same inlet pressure (figs. 20(a), (d), and (e)). The data show that fuel staging is more effective at higher air-flow rates; similar results were found in the investigations of reference 3.

The results indicate that the fuel-air mixtures resulting from introduction of all the fuel in the pilot became over-rich with increasing fuel-air ratios and caused lower combustion efficiencies. Increased fuel staging with increasing fuel-air ratios alleviated this condition by introducing larger percentages of the fuel farther downstream. Introduction of too large a percentage of fuel in the second stage also caused a reduction in combustion efficiencies; this result may be attributed to (1) lean fuel-air mixture conditions in the pilot zone, (2) over-rich mixtures in the combustion zone of the second stage, or (3) too low a residence time for the fuel injected in the second stage.

<u>Range of combustor operation</u>. - Desired combustor performance characteristics included operation over a wide range of fuel-air ratios and combustor-outlet temperatures. At inlet condition A (corresponding to operation of a 5.2-pressure-ratio reference engine at 85 percent rated speed, an altitude of 56,000 feet, and a flight Mach number of 0.6), the best configuration (57) operated over a range of fuel-air ratios from 0.0035 to 0.029 with a maximum combustion efficiency of 94 percent and a maximum combustor-outlet temperature of 1925° F (fig. 20(a)). Data at higher values of fuel-air ratio were not obtainable at condition A because of exhaust-system limitations. At a fuel-air ratio of 0.037, a combustion efficiency of 83.5 percent was obtained at the air flow and inlet temperature of condition A and a slightly higher inlet pressure of 16 inches mercury absolute. The corresponding outlet total temperature was 2200° F, a temperature rise of approximately 1950°.

<u>Comparison of performance with other combustors</u>. - Combustion efficiencies of the best configuration (57) are presented for combustor temperature rises of 680° and 1180° F in figure 21 as a function of the reciprocal of the combustion parameter P_iT_i/V_r which is given in reference 7. V_r represents a combustor reference velocity based on maximum open cross-sectional area of the combustor and density of combustor-inlet air, and P_i and T_i are combustor-inlet pressure and temperature, respectively. The curve shown for configuration 57 represents the best over-all degree of fuel staging, 75 percent of the total fuel injected in the pilot. For comparison, the combustion efficiencies of a refer- 3048
ence current production tubular combustor of the same diameter (ref. 8) and two experimental annular combustors (refs. 5 and 9) are also included. The tubular and annular combustors are compared on the basis of the same mass flows of air per unit engine frontal area. Because of the unused space between tubular combustors, the reference velocity in the tubular combustor would be approximately 1.3 times the reference velocity in the annular combustors for the same flight conditions. Accordingly, the actual values of V_r/P_iT_i for the tubular combustors in figure 21 have been reduced by a factor of 1.3. Temperature-rise values of 680° and 1180° F correspond to engine requirements for 85 percent rated speed and rated speed operation, respectively, of a current production turbojet engine at a flight Mach number of 0.6 in the stratosphere.

At both values of temperature rise, the experimental tubular combustor gave higher combustion efficiencies than did the reference tubular combustor of the same diameter. It should be noted, however, that the reference tubular combustor was designed on the basis of many factors not considered in the present investigation, for example, low altitude operation, starting, liner durability, and carbon-deposition characteristics.

At a temperature rise of 680° F, the experimental tubular combustor gave lower efficiencies than the annular combustors of references 5 and 9 in which liquid fuel and propane, respectively, were used. At a temperature rise of 1180° F, the experimental tubular combustor gave higher combustion efficiencies than the liquid-fueled annular combustor at values of V_r/P_iT_i greater than 160×10^{-6}.

<u>Estimated flight performance</u>. - Estimated altitude flight performance of the experimental tubular combustor in a 5.2-pressure-ratio reference engine at a flight Mach number of 0.6 is presented in figure 22 in terms of maximum combustion efficiencies attainable at various engine speeds and altitudes. Data for the constant efficiency curves were obtained by the method of reference 10. This method requires a knowledge of the sea-level, static operating characteristics of the reference engine. The square data points on figure 22 denote actual experimental data where

test conditions accurately simulated flight operation at the conditions indicated. Agreement of the combustion efficiencies of these experimental data points with the calculated curves is good. The curves of figure 22 indicate that the experimental tubular combustor could operate at rated engine speed with combustion efficiencies of 97 percent or greater up to an altitude of 59,000 feet or 90 percent or greater up to 75,000 feet.

Combustor total-pressure losses. - Combustor total-pressure losses
3048 are presented in figure 23 in terms of $\Delta P/q_r$ and $\Delta P/P_1$; the data are plotted against the ratio of combustor inlet to outlet gas density. The faired curves of figure 23(a) were determined by the method of least mean squares. Isothermal $\Delta P/q_r$ of the experimental combustor was approximately 17. Increased fuel flow in the second stage resulted in slight decreases in $\Delta P/q_r$. Lower pressure losses with increases in second-stage fuel flow may be due to decreased mixing of combustion products in the secondary zone and, hence, a lowering of mixing pressure loss. This supposition is supported by increasing uneven distributions of combustor-outlet total temperature with increases in second-stage fuel flow. Combustor total-pressure-loss ratio $\Delta P/P_1$ varied from 0.07 at isothermal conditions to 0.10 at a ratio of combustor inlet to outlet gas density of 3.2 for a reference velocity of approximately 100 feet per second.

Combustor-outlet total-temperature distribution. - Combustor-outlet total-temperature distributions that are representative of data obtained with the best configuration (57) are presented in figure 24. In all cases in which 50 percent or greater of the total fuel was injected in the pilot, individual combustor-outlet total temperatures were within $\pm 200^\circ$ F of the mean temperature. The distribution of combustor-outlet total temperature became more uneven as larger percentages of fuel were injected in the second stage.

SUMMARY OF RESULTS

An investigation was conducted to develop a high-performance tubular turbojet combustor embodying previously evolved principles of alternate fuel-rich and air-rich regions and axial fuel staging in the primary combustion zone. The desired operating characteristics included efficient operation over a wide range of combustor temperature rise at low combustor-inlet pressures and high air-flow rates, low over-all combustor total-pressure loss, and an acceptable combustor-outlet temperature distribution. The performance obtained with the best of 57 configurations investigated is described below; simulated flight performance references are for the experimental tubular combustor installed in a 5.2-pressure-ratio engine at a flight Mach number of 0.6.

1. Axially staged fuel introduction was generally more effective in increasing combustion efficiencies at high fuel-air ratios and high air-flow rates. Highest combustion efficiencies were obtained with the experimental configuration operating with 100 percent and 50 percent of the total fuel injected in the pilot at lean and at rich fuel-air ratios, respectively. For a fixed proportion of fuel injected into the pilot, the best over-all performance was obtained with 75 percent of the fuel being injected in the pilot and 25 percent in the second stage.

2. At the low-inlet-pressure conditions investigated, higher combustion efficiencies were obtained with the experimental combustor than with a current production tubular combustor of the same diameter.

3. At combustor-inlet conditions simulating 85 percent rated engine speed at an altitude of 56,000 feet, the experimental combustor operated over a range of fuel-air ratios from 0.0035 to 0.029. Maximum combustion efficiency was 94 percent and maximum combustor outlet temperature was 1925° F; this temperature maximum was determined by capacity of the test facility and not by the combustor.

4. Estimated altitude flight performance of the experimental tubular combustor installed in the reference engine at rated engine speed indicated a combustion efficiency of 97 percent or greater at altitudes up to 59,000 feet and 90 percent or greater up to 75,000 feet.

5. Isothermal combustor-total-pressure loss of the experimental combustor was approximately 17 times the reference velocity pressure. The ratio of combustor total-pressure loss to combustor-inlet total pressure varied from 0.07 at isothermal conditions to 0.10 at a ratio of combustor inlet to outlet gas density of 3.2 at a reference velocity of approximately 100 feet per second.

6. Individual combustor-outlet total temperatures at most operating conditions were within ±200° F of the mean temperature.

7. Low-altitude performance of the combustor was not investigated; therefore, little is known regarding its durability or carbon deposition characteristics.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, January 8, 1954

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TABLE I. - SUMMARY OF CONFIGURATIONS INVESTIGATED

Configuration	Pilot		Secondary sleeve		Ratio of primary to total open annular area	Pilot			Second stage			Third stage			Additional variable
	Diameter, in.	Length, in.	Diameter, in.	Length, in.		Nozzles per stage	Nozzle capacity, gal/hr (a)	Nozzle spray angle, deg (a)	Nozzles per stage	Nozzle capacity, gal/hr (a)	Nozzle spray angle, deg (a)	Nozzles per stage	Nozzle capacity, gal/hr (a)	Nozzle spray angle, deg (a)	
1	2.75	3.06	8.5	10.88	0.419	1	10.5	45	8	6.0	30	8	3.5	30	
2	2.75	3.06	8.5	10.88	0.413	1	6.0	80	8	6.0	30	8	3.5	30	
3-5, 7	2.75	3.06	8.5	10.88	0.413	1	6.0	80	8	3.5	30	8	3.5	30	Pilot open area
6	2.75	3.06	8.5	10.88	0.413	1	4.5	80	6	3.5	30	8	3.5	30	
8	2.75	4.56	8.5	10.88	0.413	1	6.0	60	8	3.5	30	8	3.5	30	
9-10	2.75	4.56	8.5	10.88	0.413	1	10.5	80	8	2.5	30	8	3.5	30	Pilot open area
11	3.43	4.19	8.5	10.88	0.342	1	10.5	60	8	2.5	30	8	3.5	30	
12-13	2.75	4.56	8.5	16.88	0.413	1	10.5	80	8	2.5	30	8	3.5	30	Pilot shrouding
14	2.75	8.06	8.5	16.88	0.413	1	10.5	60	8	2.5	30	8	3.5	30	
15	2.75	6.13	8.5	16.88	0.413	1	10.5	60	8	2.5	30	8	3.5	30	
16-20	2.75	4.56	8.5	16.88	0.413	1	10.5	60	8	2.5	30	8	3.5	30	Pilot open area
21	2.75	4.56	8.5	16.88	0.413	1	6.0	30	8	2.5	30	8	3.5	30	
22-23	3	4.56	8.5	16.88	0.368	1	10.5	60	8	2.5	30	8	3.5	30	Pilot open area
24-26	5.25	6	8.5	19.88	0.348	1	10.5	60	8	2.5	30	-	---	---	Secondary-sleeve open area, pilot open area
27-28	5.25	6	8.5	19.88	0.333	1	10.5	80	8	2.5	30	-	---	--	Pilot open area, secondary-sleeve open area
29	5.25	4.25	8.5	19.88	0.333	1	10.5	60	8	2.5	30	-	---	---	
30	5.25	6	8.5	19.88	0.333	1	10.5	60	8	2.5	30	-	---	---	
31-32	5.81	6	8.5	19.88	0.171	1	10.5	60	8	2.5	30	-	---	---	Pilot open area
33	5.81	6	8.5	19.88	0.210	1	10.5	80	8	2.5	30	-	---	--	
34-35	5.81	6	8.25	19.88	0.177	1	10.5	80	8	2.5	30	-	---	--	Pilot open area and method of air introduction
36, 38, 40-41	5.81	6	8.25	19.88	0.177	1	15.3	80	8	2.5	30	-	---	--	Pilot open area and method of air introduction
37	5.81	6	8.25	16.88	0.177	1	15.3	80	8	2.5	30	-	---	---	
39	5.81	6	8.25	19.88	0.177	1	20.5	80	8	2.5	30	-	---	--	
42	5.81	5.25	8.25	19.88	0.177	1	15.3	80	8	2.5	30	-	---	--	
43-54	5.81	6	8.25	19.88	0.201	1	15.3	80	8	2.5	30	-	---	--	Pilot open area and method of air introduction
55-56	5.81	6	8.25	19.88	0.201	1	15.3, 10.5	80	8	2.5	30	-	---	---	Secondary-sleeve open area
57	5.81	6	8.25	19.88	0.201	1	10.5	60	8	2.5	30	-	---	--	

[a]Rated at 100 lb/sq in. pressure differential.

CK-3 3048

TABLE II. - FUEL ANALYSIS

Fuel properties	MIL-F-5624A (JP-4) (NACA fuel 52-53)
A.S.T.M. distillation D86-46, °F	
Initial boiling point	136
Percentage evaporated	
5	183
10	200
20	225
30	244
40	263
50	278
60	301
70	321
80	347
90	400
Final boiling point	498
Residue, percent	1.2
Loss, percent	0.7
Aromatics, percent by volume	
A.S.T.M. D-875-46T	8.5
Silica gel	10.7
Specific gravity	0.757
Viscosity, centistokes at 100° F	0.762
Reid vapor pressure, lb/sq in.	2.9
Hydrogen-carbon ratio	0.170
Net heat of combustion, Btu/lb	18,700

TABLE III. - EXPERIMENTAL RESULTS

Run	Combustor-inlet total pressure, P_i, in. Hg abs	Combustor-inlet total temperature, T_i, °F	Air-flow rate, lb/sec	Air-flow rate per unit area, lb/(sec)(sq ft)	Combustor reference velocity, V_r, ft/sec	Fuel-flow rate, 1st stage, lb/sec	Fuel-flow rate, 2nd stage, lb/sec	Fuel-manifold pressure, 1st stage (above combustor-inlet pressure), lb/sq in.	Fuel-manifold pressure, 2nd stage (above combustor-inlet pressure), lb/sq in.	Fuel-air ratio	Mean combustor outlet total temperature, °F	Mean combustor temperature rise, °F	Combustion efficiency, percent	Total pressure loss through combustor, ΔP, in. Hg	Combustion parameter, V_r/P_iT_i, ft, lb, sec, °R units	Fuel injected in 1st stage, percent of total
								Configuration 18								
1	8.0	255	0.731	1.486	97.58	7.55×10^{-3}	——	21	——	0.01052	545	306	40.3	——	247.7×10^{-6}	100
2	8.0	255	.731	1.496	97.39	10.57	——	39	——	.01419	694	439	44.6	——	247.7	100
3	8.0	255	.730	1.484	97.25	13.12	——	62	——	.01800	824	569	45.8	——	247.3	100
4	8.0	255	.735	1.490	97.65	15.89	——	92	——	.02164	989	734	46.3	——	248.3	100
5	8.0	255	.735	1.490	97.45	18.80	——	125	——	.02539	1063	898	47.2	——	246.3	100
6	8.0	255	.729	1.482	97.12	21.60	——	184	——	.02961	1181	926	45.9	——	247.0	100
7	5.0	226	.453	.921	95.18	5.61	——	——	——	.01240	Blow-out		——	——	393.0	100
8	5.0	217	.454	.925	94.26	6.16	——	12	——	.01359	494	207	20.8	——	393.8	100
9	5.0	225	.455	.921	95.18	7.58	——	20	——	.01668	530	306	25.2	——	393.0	100
10	5.0	227	.453	.921	95.48	10.57	——	57	——	.02285	751	504	31.0	——	393.0	100
11	5.1	226	.454	.925	93.52	13.12	——	80	——	.02690	806	581	29.0	——	378.3	100
12	5.3	220	.457	.929	89.91	15.10	——	89	——	.03306	Blow-out		——	——	352.8	100
								Configuration 22								
13	8.0	255	0.730	1.484	97.26	7.58×10^{-3}	——	18.4	——	0.01065	571	336	44.0	——	247.3×10^{-6}	100
14	8.0	255	.730	1.484	97.67	10.57	——	36.4	——	.01430	729	491	47.5	——	247.3	100
15	8.0	255	.724	1.472	96.47	13.12	——	57.4	——	.01814	871	636	49.1	——	245.3	100
16	8.0	255	.722	1.467	96.14	15.89	——	88.4	——	.02200	1048	810	52.7	——	244.3	100
17	8.0	255	.727	1.478	96.86	18.80	——	116.4	——	.02540	1143	906	51.5	——	246.3	100
18	8.2	255	.738	1.494	95.52	22.05	——	148.3	——	.03000	1300	1065	52.6	——	257.0	100
19	5.0	218	.454	.925	94.41	4.60	——	——	——	.00992	Blow-out		——	——	393.8	100
20	5.0	218	.454	.925	94.41	4.78	——	——	——	.01053	416	188	26.3	——	393.8	100
21	5.2	220	.454	.925	91.05	7.58	——	19.8	——	.01663	603	383	31.8	——	364.1	100
22	5.0	223	.454	.925	95.11	10.57	——	56.9	——	.02260	808	585	39.2	——	393.4	100
23	5.0	218	.454	.925	94.41	13.12	——	58.9	——	.02690	830	612	30.4	——	393.8	100
24	5.0	220	.454	.925	94.69	14.79	——	75.9	——	.03290	788	568	25.2	——	393.8	100
								Configuration 30								
25	8.0	256	0.731	1.486	97.39	5.89×10^{-3}	——	10.6	——	0.00606	Blow-out		——	——	247.7×10^{-6}	100
26	8.0	255	.738	1.494	97.91	6.45	——	——	——	.00679	551	296	45.3	——	249.0	100
27	8.0	255	.731	1.488	97.38	7.56	——	19.6	——	.01033	625	370	48.5	——	247.7	100
28	8.0	255	.730	1.484	97.25	10.57	——	33.6	——	.01420	714	479	46.5	——	247.3	100
29	8.0	235	.728	1.480	96.99	13.12	——	59.6	——	.01805	845	610	47.9	——	246.7	100
30	8.0	237	.752	1.488	97.80	15.89	——	89.5	——	.02170	1029	792	50.1	——	248.0	100
31	8.0	235	.729	1.482	97.12	18.60	——	114.5	——	.02551	1158	923	52.5	——	247.0	100
32	8.0	235	.727	1.478	96.86	21.40	——	180.8	——	.02941	1309	1074	54.0	——	248.3	100
33	5.0	218	.449	.913	93.59	4.78	——	——	——	.01066	Blow-out		——	——	389.8	100
34	5.0	218	.453	.921	94.21	5.89	——	12.0	——	.01326	556	338	30.3	——	393.0	100
35	5.0	220	.450	.918	93.87	7.58	——	21.0	——	.01679	655	435	35.4	——	390.4	100
36	5.0	225	.451	.917	94.77	10.57	——	33.0	——	.02500	836	611	37.4	——	391.3	100
								Configuration 32								
37	15.0	256	1.370	2.785	100.26	4.78×10^{-3}	——	——	——	0.00348	448	185	75.1	1.21	132.0×10^{-6}	100
38	15.0	256	1.370	2.785	100.26	7.58	——	17.1	——	.00580	579	323	78.5	1.26	132.0	100
39	15.0	256	1.369	2.782	100.17	10.57	——	32.1	——	.00757	675	419	74.8	1.27	131.9	100
40	15.0	260	1.368	2.780	100.64	13.12	——	54.1	——	.00938	771	511	75.0	1.28	131.8	100
41	15.1	258	1.372	2.789	100.04	15.89	——	85.0	——	.01154	883	625	75.0	1.30	130.8	100
42	15.0	260	1.372	2.789	100.99	18.60	——	112.1	——	.01352	981	721	74.5	1.32	132.2	100
43	15.0	260	1.364	2.780	100.66	21.40	——	147.1	——	.01582	1071	811	73.4	1.35	131.8	100
44	8.0	255	.728	1.482	97.12	3.66	——	——	——	.00502	516	261	74.5	.66	247.0	100
45	8.0	256	.728	1.480	97.41	4.78	——	——	——	.00656	581	325	65.9	.67	248.7	100
46	8.0	240	.728	1.480	97.59	7.65	——	18.5	——	.01033	715	475	62.5	.69	248.7	100
47	8.0	250	.730	1.484	98.35	10.57	——	35.8	——	.01416	908	658	62.8	.72	247.3	100
48	8.0	232	.729	1.482	97.54	13.12	——	53.6	——	.01800	990	758	68.0	.72	247.0	100
49	8.0	238	.728	1.480	97.41	15.89	——	85.8	——	.02180	1148	910	60.0	.75	248.7	100
50	8.0	239	.728	1.480	97.41	18.60	——	111.8	——	.02538	1206	967	55.1	.75	248.7	100
51	8.0	238	.728	1.480	97.41	21.40	——	147.8	——	.02940	1250	992	49.8	.75	248.7	100
52	5.0	225	.456	.927	96.52	7.56	——	——	——	.01851	734	511	42.8	.42	396.8	100
53	5.0	225	.456	.927	95.80	10.57	——	32.0	——	.02270	864	639	41.2	.45	395.5	100
54	5.0	220	.456	.927	98.30	13.12	——	54.0	——	.02660	864	644	31.7	.43	393.5	100
55	5.0	215	.456	.927	94.40	14.73	——	70.0	——	.03250	789	574	25.7	.41	395.5	100
56	5.0	215	.456	.927	94.40	15.89	——	74.0	——	.03342	Blow-out		——	.41	398.8	100

CK-3 back 3048

TABLE III. - Continued. EXPERIMENTAL RESULTS

Run	Combustor-inlet total pressure, P_1, in. Hg abs	Combustor-inlet total temperature, T_1, °F	Air-flow rate, lb/sec	Air-flow rate per unit area, lb/(sec)(sq ft)	Combustor reference velocity, V_r, ft/sec	Fuel-flow rate, 1st stage, lb/sec	Fuel-flow rate, 2nd stage, lb/sec	Fuel-manifold pressure, 1st stage (above combustor-inlet pressure), lb/sq in.	Fuel-manifold pressure, 2nd stage (above combustor-inlet pressure), lb/sq in.	Fuel-air ratio	Mean combustor outlet total temperature, °F	Mean combustor temperature rise, °F	Combustion efficiency, percent	Total pressure loss through combustor, ΔP, in. Hg	Combustion parameter, V_r/P_1T_1, ft, lb, sec, °R units	Fuel injected in 1st stage, percent of total
Configuration 33																
57	15.0	252	1.376	2.797	100.15	4.78×10^{-3}	—	—	—	0.00347	427	175	68.7	1.87	132.6×10^{-6}	100
58	15.1	250	1.377	2.789	99.28	7.55	—	19.1	—	.00546	598	346	64.5	1.92	130.9	100
59	15.1	250	1.375	2.785	99.14	10.37	—	35.1	—	.00753	726	476	65.7	1.93	130.8	100
60	15.0	255	1.369	2.782	100.05	13.12	—	54.2	—	.00958	875	620	89.0	1.95	131.9	100
61	15.1	255	1.369	2.782	99.37	15.56	—	79.1	—	.01159	1020	765	92.0	2.00	130.1	100
62	15.0	256	1.369	2.782	100.17	18.80	—	108.2	—	.01359	1124	868	90.0	2.05	131.9	100
63	15.0	256	1.369	2.762	100.17	21.40	—	129.2	—	.01561	1225	969	88.2	2.01	131.9	100
64	8.0	238	.757	1.496	96.60	4.78	—	—	—	.00649	616	378	78.2	1.05	249.7	100
65	8.0	240	.755	1.494	96.61	7.55	—	18.7	—	.01027	881	641	85.8	1.09	249.0	100
66	8.0	245	.740	1.504	93.96	10.37	—	33.7	—	.01400	1065	820	82.3	1.14	250.7	100
67	8.1	235	.758	1.500	97.09	13.12	—	55.6	—	.01778	1200	965	77.5	1.11	245.9	100
68	6.0	228	.455	.925	80.01	7.55	—	18.6	—	.01698	1130	902	75.4	.55	274.1	100
69	6.0	225	.454	.925	79.56	10.37	—	35.6	—	.02330	1360	1135	71.0	.55	273.6	100
70	6.1	225	.455	.925	78.40	13.12	—	54.6	—	.02948	1519	1294	65.6	.57	265.2	100
71	15.0	255	1.370	2.785	97.39	—	—	—	—	—	—	—	—	1.67	132.1	—
Configuration 34																
72	15.0	260	1.372	2.787	101.00	4.78×10^{-3}	—	—	—	0.00346	455	195	74.14	1.22	132.6×10^{-6}	100
73	15.0	260	1.370	2.783	100.80	7.57	—	18.0	—	.00553	603	343	83.20	1.26	132.1	100
74	15.1	260	1.370	2.783	100.10	10.36	—	32.0	—	.00756	729	469	84.16	1.29	130.2	100
75	15.1	260	1.369	2.781	100.10	15.65	—	78.0	—	.01156	968	708	84.99	1.33	130.2	100
76	15.0	260	1.368	2.779	100.70	18.58	—	105.0	—	.01358	1065	825	85.25	1.35	132.0	100
77	15.0	260	1.368	2.779	100.70	21.39	—	134.0	—	.01584	1193	933	84.89	1.38	132.0	100
78	8.0	240	.732	1.487	98.16	4.78	—	—	—	.00653	598	358	73.55	.69	248.0	100
79	8.0	240	.732	1.487	98.18	7.57	—	17.5	—	.01034	764	524	69.25	.72	248.0	100
80	8.0	245	.731	1.486	98.75	10.36	—	33.5	—	.01417	988	743	73.36	.75	247.8	100
81	8.0	260	.752	1.487	99.56	13.10	—	52.5	—	.01790	1151	901	71.83	.77	248.0	100
82	8.0	240	.732	1.487	98.18	15.65	—	79.5	—	.02166	1161	941	62.66	.77	248.0	100
83	8.0	240	.732	1.487	98.18	18.58	—	106.5	—	.02638	1205	965	55.33	.76	248.0	100
84	8.0	240	.732	1.487	98.18	21.39	—	140.5	—	.02922	1179	939	47.25	.75	248.0	100
85	6.0	225	.445	.904	77.68	7.57	—	17.5	—	.01701	1054	829	68.61	.36	268.1	100
86	6.0	225	.445	.904	77.68	10.36	—	31.5	—	.02528	1179	954	59.22	.39	268.1	100
87	6.0	225	.454	.922	79.45	13.10	—	51.5	—	.02885	1200	975	49.60	.36	273.5	100
88	15.1	228	.445	.904	91.62	—	—	—	—	—	—	—	—	.36	380.5	—
Configuration 37																
89	14.9	255	1.360	2.763	100.00	15.10×10^{-3}	—	26.3	—	0.00963	675	420	69.36	0.88	132.9×10^{-6}	100
90	15.1	254	1.360	2.763	98.85	15.85	—	39.2	—	.01168	864	606	72.05	.91	129.3	100
91	15.0	257	1.356	2.755	99.36	18.58	—	53.2	—	.01370	981	724	73.83	.94	130.7	100
92	15.0	256	1.350	2.743	99.06	21.39	—	71.2	—	.01584	1095	837	74.61	.95	130.2	100
93	15.0	260	1.361	2.765	100.10	24.12	—	91.2	—	.01772	1209	949	76.70	.98	131.2	100
94	15.1	260	1.361	2.765	99.48	26.86	—	114.2	—	.01974	1328	1068	76.43	1.01	128.5	100
95	14.9	260	1.361	2.765	100.80	29.56	—	137.3	—	.02172	1426	1166	78.66	1.10	133.0	100
96	15.1	262	1.344	2.730	98.51	32.28	—	158.2	—	.02402	1514	1252	77.20	1.15	127.9	100
97	8.0	235	.726	1.479	96.95	4.78	—	—	—	.00656	Blow-out		—	—	247.0	100
98	8.0	235	.735	1.495	97.86	7.58	—	—	—	.01030	496	261	34.29	.47	249.1	100
99	8.1	235	.739	1.501	97.20	10.36	—	10.7	—	.01402	771	536	52.78	.51	244.7	100
100	8.0	236	.738	1.499	98.42	13.10	—	20.7	—	.01775	888	652	51.56	.54	250.0	100
101	8.1	255	.735	1.493	96.97	15.85	—	36.6	—	.02158	1134	899	59.90	.55	245.1	100
102	8.0	235	.729	1.481	96.80	18.58	—	50.7	—	.02549	1250	1017	58.30	.55	247.0	100
103	8.0	238	.728	1.481	97.08	19.42	—	—	—	.02664	Blow-out		—	—	247.0	100
104	6.0	218	.454	.922	78.64	8.67	—	—	—	.01909	Blow-out		—	—	273.6	100
105	6.0	220	.454	.922	78.87	10.36	—	11.6	—	.02262	1010	790	49.47	.27	273.6	100
106	6.1	222	.454	.922	77.81	13.10	—	24.6	—	.02885	1284	1062	54.29	—	265.0	100[a]
107	15.0	256	1.358	2.758	99.37	—	—	—	—	—	—	—	—	.77	130.8	—
Configuration 38																
108	15.0	266	1.376	2.795	100.80	18.58×10^{-3}	—	59.1	—	0.01350	1024	769	79.79	1.48	130.5×10^{-6}	100
109	8.0	240	.756	1.495	96.72	4.78	—	—	—	.00649	Blow-out		—	—	246.5	100
110	8.0	245	.734	1.491	98.87	7.57	—	10.5	—	.01031	750	507	67.17	.76	248.9	100
111	8.0	248	.730	1.483	99.05	10.36	—	18.5	—	.01419	876	628	61.53	.78	247.5	100
112	8.0	248	.734	1.491	99.58	13.10	—	28.5	—	.01785	1008	760	60.25	.79	249.0	100
113	8.0	257	.733	1.489	97.90	15.65	—	42.5	—	.02162	1073	836	56.38	.77	248.6	100
114	8.0	238	.725	1.473	96.97	18.58	—	56.5	—	.02563	1135	897	50.80	.75	245.8	100
115	8.1	240	.726	1.475	96.18	21.39	—	72.5	—	.02946	1129	889	44.27	.76	240.1	100
116	8.0	257	.737	1.497	98.43	22.75	—	—	—	.03067	Blow-out		—	—	249.8	100
117	6.1	222	.457	.928	78.32	4.78	—	—	—	.01046	609	387	50.14	.38	266.1	100
118	6.1	225	.456	.924	78.06	7.67	—	11.4	—	.01664	913	690	58.00	.41	265.4	100
119	6.1	226	.456	.924	78.32	10.36	—	17.4	—	.02277	1034	809	50.67	.40	265.4	100
120	6.0	228	.440	.894	77.34	13.10	—	28.5	—	.02977	1118	890	43.81	.38	265.3	100
121	6.0	222	.457	.928	79.63	14.47	—	—	—	.05168	Blow-out		—	—	275.5	100
122	15.1	266	1.372	2.787	99.72	—	—	—	—	—	—	—	—	1.11	130.5	100

[a]Blow-out.

3048

TABLE III. - Continued. EXPERIMENTAL RESULTS

Run	Combustor-inlet total pressure, P_1, in. Hg abs	Combustor-inlet total temperature, T_1, °F	Air-flow rate, lb/sec	Air-flow rate per unit area, lb/(sec)(sq ft)	Combustor reference velocity, V_r, ft/sec	Fuel-flow rate, 1st stage, lb/sec	Fuel-flow rate, 2nd stage, lb/sec	Fuel-manifold pressure, 1st stage (above combustor-inlet pressure), lb/sq in.	Fuel-manifold pressure, 2nd stage (above combustor-inlet pressure), lb/sq in.	Fuel-air ratio	Mean combustor outlet total temperature, °F	Mean combustor temperature rise, °F	Combustion efficiency, percent	Total pressure loss through combustor, ΔP, in. Hg	Combustion parameter, V_r/P_1T_1, ft, lb, sec, °R units	Fuel injected in 1st stage, percent of total
Configuration 39																
123	15.0	258	1.365	2.789	101.60	8.11×10^{-3}	—	—	—	0.00585	Blow-out		—	—	133.4×10^{-6}	100
124	15.1	255	1.370	2.783	99.44	10.36	—	6.9	—	.00756	685	430	78.84	1.33	130.2	100
125	15.1	256	1.373	2.789	100.10	13.10	—	12.9	—	.00954	812	554	79.54	1.35	130.5	100
126	15.1	259	1.373	2.789	100.20	15.85	—	20.9	—	.01184	925	666	79.98	1.37	130.4	100
127	15.1	260	1.373	2.789	100.40	18.58	—	27.9	—	.01353	1036	776	80.27	1.45	130.5	100
128	15.1	261	1.368	2.775	100.10	21.59	—	37.9	—	.01584	1149	888	80.59	1.46	130.1	100
129	15.0	262	1.374	2.791	101.40	24.12	—	50.0	—	.01756	1263	1021	83.67	1.50	132.5	100
130	15.1	262	1.375	2.793	100.80	26.86	—	61.9	—	.01953	1393	1131	84.26	1.51	130.8	100
131	15.0	262	1.383	2.810	102.00	29.58	—	75.0	—	.02137	1460	1198	82.25	1.53	133.2	100
132	15.0	260	1.380	2.803	101.50	32.28	—	87.0	—	.02339	1537	1277	80.82	1.53	133.0	100
133	8.0	240	.740	1.503	99.26	7.57	—	—	—	.01023	674	434	57.76	.75	251.0	100
134	8.0	242	.735	1.493	98.87	10.36	—	—	—	.01410	875	633	62.31	.77	249.1	100
135	8.0	250	.730	1.483	99.31	13.11	—	10.4	—	.01796	1056	806	63.86	.79	247.4	100
136	8.0	256	.735	1.493	98.02	15.85	—	21.4	—	.02156	1121	865	58.95	.77	248.1	100
137	8.0	257	.727	1.477	97.09	18.58	—	29.4	—	.02556	1203	946	56.10	.77	246.8	100
138	8.0	256	.723	1.469	96.42	21.39	—	36.4	—	.02958	1251	1015	50.66	.76	246.0	100
139	8.0	256	.722	1.467	96.15	23.85	—	—	—	.03301	Blow-out		—	—	244.9	100
140	6.0	218	.449	.912	77.77	4.77	—	—	—	.01064	530	312	38.64	—	270.5	100
141	6.0	220	.460	.935	79.92	7.57	—	—	—	.01645	821	601	50.85	.38	277.0	100
142	6.1	220	.460	.935	78.61	10.36	—	—	—	.02252	1073	853	54.29	.38	268.1	100
143	6.0	225	.461	.937	80.66	13.11	—	11.4	—	.02844	1203	978	50.45	.41	277.9	100
144	6.0	218	.449	.912	77.77	15.85	—	—	—	.03530	Blow-out		—	—	270.5	100
Configuration 44																
145	6.0	236	0.728	1.478	97.09	4.78×10^{-3}	—	—	—	0.00656	479	243	42.49	0.66	247.0×10^{-6}	100
146	6.0	240	.740	1.503	99.25	7.57	—	—	—	.01023	646	406	53.29	.68	251.0	100
147	6.0	240	.735	1.493	98.58	10.36	—	—	—	.01410	786	546	53.51	.70	249.1	100
148	6.2	246	.734	1.491	96.75	13.10	—	—	—	.01785	913	668	52.67	.69	236.8	100
149	6.1	234	.733	1.489	96.15	15.86	—	41.5	—	.02182	953	717	47.22	.69	249.8	100
150	6.0	235	.732	1.487	97.45	18.58	—	56.5	—	.02538	941	706	39.95	.70	247.9	100
151	6.0	236	.732	1.487	97.48	21.39	—	76.8	—	.02922	963	734	36.51	.71	247.9	100
152	6.0	235	.732	1.487	97.46	21.67	—	—	—	.02960	Blow-out		—	—	247.9	100
153	6.0	220	.466	.930	78.57	7.57	—	—	—	.01653	775	556	46.89	.37	276.0	100
154	6.0	228	.457	.928	79.96	10.36	—	17.5	—	.02267	933	714	44.87	.38	273.4	100
155	6.1	218	.462	.939	78.71	13.10	—	28.4	—	.02835	994	776	39.55	.37	268.1	100
156	15.1	258	1.370	2.783	100.20	—	—	—	—	—	—	—	—	1.08	131.3	—
Configuration 48																
157	15.0	256	1.366	2.776	99.95	4.67×10^{-3}	—	—	—	0.00342	Blow-out		—	—	131.8×10^{-6}	100
158	15.0	255	1.364	2.772	99.67	7.16	—	7.1	—	.00524	565	300	76.42	1.12	131.8	100
159	15.1	254	1.366	2.776	99.01	9.92	—	17.0	—	.00726	676	422	78.50	1.15	130.0	100
160	15.0	257	1.367	2.778	100.20	12.64	—	27.1	—	.00926	781	524	77.38	1.15	131.8	100
161	15.0	260	1.369	2.782	100.70	15.35	—	40.1	—	.01121	897	637	78.55	1.17	132.0	100
162	15.0	259	1.364	2.772	100.20	18.07	—	54.1	—	.01325	973	714	75.26	—	131.8	100
163	15.1	260	1.365	2.774	99.77	20.85	—	71.0	—	.01527	1055	795	73.45	1.21	129.9	100
164	15.1	260	1.365	2.774	99.77	23.61	—	90.0	—	.01730	1133	873	71.87	1.22	129.9	100
165	15.0	260	1.363	2.770	100.30	26.31	—	112.1	—	.01930	1201	941	70.10	1.26	131.4	100
166	15.1	260	1.364	2.772	100.00	28.85	—	154.0	—	.02114	1276	1016	69.87	1.27	130.4	100
167	15.0	260	1.364	2.772	100.70	31.26	—	160.1	—	.02289	1370	1110	70.95	1.31	132.4	100
168	8.0	257	.737	1.498	98.43	4.54	—	—	—	.00671	Blow-out		—	—	248.5	100
169	8.0	240	.734	1.492	96.45	7.17	—	—	—	.00976	685	445	61.99	.63	248.9	100
170	8.0	244	.739	1.502	99.69	9.92	—	17.5	—	.01342	821	577	58.51	.64	250.6	100
171	8.0	246	.738	1.498	97.56	12.64	—	27.5	—	.01717	906	660	53.27	.67	249.5	100
172	8.0	257	.739	1.502	98.70	15.36	—	40.5	—	.02079	912	675	46.00	.66	249.6	100
173	8.1	236	.739	1.502	97.94	18.08	—	56.5	—	.02447	990	754	44.26	.67	247.8	100
174	8.0	236	.740	1.504	92.31	20.86	—	71.5	—	.02818	1023	787	40.56	.66	253.9	100
175	8.0	235	.740	1.504	96.55	23.61	—	—	—	.03191	Blow-out		—	—	251.0	100
176	6.0	220	.455	.925	79.05	7.17	—	—	—	.01675	815	595	52.44	.31	274.0	100
177	6.0	226	.460	.935	80.50	9.92	—	18.5	—	.02156	892	674	44.27	.35	277.1	100
178	6.0	226	.460	.935	80.50	12.64	—	26.5	—	.02748	995	770	40.54	.36	277.1	100
Configuration 50																
179	15.0	256	1.357	2.758	99.29	7.17×10^{-3}	—	7.0	—	0.00528	576	320	81.01	1.08	130.8×10^{-6}	100
180	15.0	255	1.364	2.772	99.67	9.92	—	17.0	—	.00727	700	445	82.79	1.08	131.5	100
181	15.0	255	1.363	2.770	99.59	12.64	—	27.0	—	.00927	809	554	81.72	1.10	131.4	100
182	15.1	257	1.370	2.785	99.72	15.36	—	37.9	—	.01121	918	661	81.85	1.11	130.2	100
183	15.1	258	1.362	2.768	99.27	18.06	—	53.9	—	.01326	1011	753	79.37	1.15	128.4	100
184	15.1	260	1.362	2.768	99.88	20.86	—	71.9	—	.01532	1084	824	76.01	1.14	130.5	100
185	15.1	260	1.359	2.762	99.33	23.61	—	92.2	—	.01737	1168	908	74.61	1.17	129.1	100
186	15.0	260	1.360	2.764	100.10	26.31	—	115.0	—	.01935	1236	976	72.84	1.18	131.2	100
187	15.0	260	1.360	2.764	100.10	28.88	—	137.0	—	.02122	1334	1074	73.69	1.21	131.2	100
188	8.0	240	.738	1.500	98.99	4.42	—	—	—	.00598	471	231	51.52	.61	250.0	100
189	8.0	241	.735	1.494	98.73	7.17	—	—	—	.00975	729	488	68.18	.63	249.0	100
190	8.0	244	.735	1.494	99.15	9.92	—	16.4	—	.01349	886	642	66.03	.63	249.0	100
191	8.0	246	.735	1.494	99.43	12.64	—	26.4	—	.01720	1001	755	61.27	.64	249.0	100
192	8.0	239	.738	1.500	98.65	15.36	—	40.4	—	.02081	970	731	49.85	.64	250.0	100
193	8.0	239	.738	1.500	98.85	18.08	—	55.4	—	.02455	1024	785	46.15	.66	250.0	100
194	8.0	239	.738	1.500	98.85	20.86	—	74.4	—	.02627	1113	874	45.16	.66	250.0	100
195	8.0	239	.738	1.500	98.85	24.69	—	—	—	.03346	Blow-out		—	—	250.0	100
196	6.0	225	.456	.927	79.80	7.17	—	—	—	.01572	854	629	55.70	.32	274.7	100
197	6.0	225	.456	.927	79.80	9.92	—	11.4	—	.02175	896	671	43.69	.33	274.7	100
198	6.0	227	.456	.927	80.04	12.64	—	25.4	—	.02772	1101	874	45.90	.34	274.7	100

3048

TABLE III. - Continued. EXPERIMENTAL RESULTS

Run	Combustor-inlet total pressure, P_i, in. Hg abs	Combustor-inlet total temperature, T_i, °F	Air-flow rate, lb/sec	Air-flow rate per unit area, lb/(sec)(sq ft)	Combustor reference velocity, V_r, ft/sec	Fuel-flow rate, 1st stage, lb/sec	Fuel-flow rate, 2nd stage, lb/sec	Fuel-manifold pressure, 1st stage (above combustor-inlet pressure), lb/sq in.	Fuel-manifold pressure, 2nd stage (above combustor-inlet pressure), lb/sq in.	Fuel-air ratio	Mean combustor outlet total temperature, °F	Mean combustor temperature rise, °F	Combustion efficiency, percent	Total pressure loss through combustor, ΔP, in. Hg	Combustion parameter, V_r/P_iT_i, ft, lb, sec, °R units	Fuel injected in 1st stage, percent of total
Configuration 52																
199	15.0	256	1.367	2.778	100.00	7.17×10^{-3}	—	7.2	—	0.00524	545	289	73.60	1.07	131.7×10^{-6}	100
200	15.1	255	1.367	2.778	99.22	9.92	—	17.1	—	.00726	658	403	75.02	—	130.1	100
201	15.0	255	1.367	2.778	99.88	12.64	—	27.2	—	.00826	755	500	73.74	1.11	131.7	100
202	15.0	256	1.373	2.791	100.50	15.35	—	40.2	—	.01180	881	625	73.22	1.13	132.4	100
203	15.0	257	1.373	2.791	100.80	18.07	—	54.2	—	.01318	999	742	78.83	1.14	132.4	100
204	15.1	257	1.384	2.813	101.10	20.85	—	71.1	—	.01507	1094	837	78.48	1.14	132.7	100
205	15.0	257	1.367	2.778	100.20	23.61	—	92.2	—	.01727	1201	944	78.14	1.16	131.8	100
206	15.0	257	1.367	2.778	100.20	26.31	—	114.2	—	.01926	1313	1056	79.33	1.20	131.8	100
207	15.0	258	1.367	2.778	100.30	28.85	—	137.2	—	.02110	1404	1146	79.35	1.19	131.7	100
208	15.1	258	1.367	2.778	99.64	31.28	—	161.1	—	.02288	1475	1217	76.34	1.23	130.1	100
209	8.0	236	.736	1.494	96.02	5.22	—	—	—	.00711	Blow-out		—	—	249.2	100
210	8.1	236	.735	1.494	96.81	7.17	—	—	—	.00975	678	442	61.60	.58	243.0	100
211	8.0	240	.735	1.494	96.56	9.92	—	17.6	—	.01349	853	613	62.94	.60	249.1	100
212	8.0	240	.732	1.486	98.18	12.64	—	26.6	—	.01727	976	736	60.06	.62	248.2	100
213	8.0	235	.736	1.494	97.88	15.36	—	40.6	—	.02068	1041	806	55.06	.62	249.2	100
214	8.1	235	.736	1.494	96.67	18.07	—	55.5	—	.02459	1126	891	52.46	.61	243.0	100
215	8.1	235	.736	1.494	96.67	20.85	—	71.5	—	.02637	1176	941	48.61	.65	243.0	100
216	8.0	235	.736	1.494	97.88	23.33	—	—	—	.03174	Blow-out		—	—	249.2	100
217	8.0	231	.731	1.486	96.79	—	—	—	—	—	—	—	—	.52	247.9	—
Configuration 54																
218	15.0	255	1.375	2.795	100.80	7.17×10^{-3}	—	7.0	—	0.00554	559	284	68.51	1.17	133.8×10^{-6}	100
219	15.0	258	1.375	2.795	100.50	9.92	—	17.0	—	.00721	670	415	77.70	1.22	132.7	100
220	15.0	255	1.370	2.785	100.10	12.64	—	27.0	—	.00923	796	541	80.14	1.25	132.0	100
221	15.0	256	1.370	2.785	100.20	15.33	—	38.0	—	.01115	946	690	85.43	1.27	131.9	100
222	15.0	256	1.370	2.785	100.20	18.08	—	52.0	—	.01320	1070	814	86.53	1.29	131.9	100
223	15.0	260	1.365	2.774	100.40	20.83	—	80.0	—	.01526	1188	928	86.42	1.30	131.5	100
224	15.0	260	1.365	2.774	100.40	23.61	—	104.0	—	.01730	1298	1039	86.36	1.33	131.5	100
225	15.1	260	1.368	2.774	100.10	26.31	—	129.9	—	.01927	1404	1144	86.34	1.35	130.6	100
226	15.0	260	1.365	2.774	100.40	28.86	—	157.0	—	.02114	1491	1231	85.46	1.36	131.5	100
227	8.0	235	.727	1.478	96.81	5.94	—	—	—	.00818	Blow-out		—	—	246.8	100
228	8.0	235	.727	1.478	96.81	7.17	—	—	—	.00986	656	421	58.00	.63	246.8	100
229	8.0	235	.727	1.478	96.81	9.92	—	—	—	.01364	943	708	72.26	.67	246.8	100
230	8.0	237	.727	1.478	97.09	12.64	—	—	—	.01739	1152	915	74.86	.72	246.6	100
231	8.0	235	.728	1.480	96.95	15.33	—	—	—	.02106	1286	1061	72.95	.70	247.0	100
232	8.0	235	.728	1.480	96.95	18.06	—	—	—	.02483	1344	1109	65.50	.72	247.0	100
233	8.1	235	.727	1.478	95.62	20.83	—	—	—	.02865	1388	1153	59.77	.69	240.5	100
234	6.0	215	.454	.923	78.29	7.17	—	—	—	.01579	876	661	58.24	.34	273.5	100
235	6.0	217	.454	.923	78.52	9.92	—	—	—	.02184	1250	1033	88.34	.35	273.5	100
236	6.0	216	.454	.923	78.64	12.64	—	—	—	.02784	1375	1157	61.41	.38	273.5	100
237	5.0	211	.454	.923	83.39	—	—	—	—	—	—	—	—	.34	394.0	—
Configuration 55																
238	15.1	252	1.375	2.795	99.71	7.17×10^{-3}	—	6.8	—	0.00521	561	309	79.17	1.14	131.6×10^{-6}	100
239	15.0	250	1.368	2.780	99.26	9.92	—	16.9	—	.00725	706	456	65.04	1.17	131.8	100
240	15.1	249	1.370	2.785	98.93	12.64	—	27.8	—	.00923	803	554	82.06	1.20	131.1	100
241	15.1	255	1.375	2.795	100.10	15.35	—	41.6	—	.01116	929	674	83.61	1.20	130.8	100
242	15.0	255	1.362	2.768	99.52	18.07	—	56.9	—	.01327	1046	791	83.56	1.25	131.2	100
243	15.1	256	1.374	2.793	98.73	20.85	—	73.8	—	.01517	1160	905	84.60	1.28	130.5	100
244	15.0	256	1.380	2.805	100.60	23.61	—	93.8	—	.01711	1269	1014	86.00	1.29	132.9	100
245	8.0	236	.736	1.494	97.88	7.17	—	—	—	.00976	731	496	69.28	.66	249.2	100
246	8.0	237	.732	1.488	97.76	9.92	—	10.3	—	.01355	891	654	66.97	.70	247.9	100
247	8.0	242	.732	1.488	98.46	12.64	—	—	—	.01727	1018	776	63.49	—	247.9	100
248	8.0	240	.733	1.490	98.32	15.36	—	42.3	—	.02094	1010	770	52.42	.68	248.7	100
249	8.0	232	.736	1.494	98.05	—	—	—	—	—	—	—	—	.55	252.1	—
Configuration 56																
250	15.0	260	1.354	2.752	98.24	7.17×10^{-3}	—	—	—	0.00529	545	315	79.80	1.08	130.4×10^{-6}	100
251	15.0	250	1.354	2.752	96.24	9.92	—	—	—	.00732	683	433	79.85	1.09	130.4	100
252	15.0	253	1.358	2.760	98.95	12.64	—	—	—	.00951	794	541	79.44	1.12	130.9	100
253	15.0	256	1.352	2.748	98.79	15.38	—	—	—	.01136	918	663	80.57	1.13	130.2	100
254	15.1	255	1.365	2.774	99.06	18.07	—	—	—	.01324	1024	769	81.30	1.19	129.9	100
255	15.1	255	1.365	2.774	99.41	20.85	—	—	—	.01527	1156	901	83.66	1.24	130.6	100
256	15.0	252	1.366	2.780	99.41	—	—	—	—	—	—	—	—	.87	131.7	—
Configuration 58																
257	8.0	242	0.732	1.488	98.46	12.64×10^{-3}	—	50.6	—	0.01727	1036	793	64.94	—	248.0×10^{-6}	100
258	8.0	239	.732	1.488	96.04	15.35	—	70.6	—	.02097	1138	899	61.57	0.69	248.0	100
259	8.0	240	.732	1.488	98.18	18.08	—	82.6	—	.02470	1066	826	48.28	.68	248.0	100
Configuration 57																
260	15.0	256	1.375	2.795	100.80	4.69×10^{-3}	—	7.0	—	0.00341	Blow-out		—	—	132.5×10^{-6}	100
261	15.0	255	1.375	2.795	100.60	7.18	—	16.0	—	.00522	590	335	85.79	1.17	132.6	100
262	15.0	249	1.366	2.780	99.12	7.17	—	20.2	—	.00524	591	342	87.26	—	131.8	100
263	15.0	257	1.375	2.795	100.70	9.92	—	37.0	—	.00721	715	458	85.99	1.22	132.5	100
264	15.0	258	1.362	2.768	99.94	9.92	—	33.0	—	.00728	725	467	86.86	—	131.3	100
265	15.0	250	1.362	2.768	98.82	9.92	—	37.2	—	.00726	718	468	87.00	—	131.3	100
266	15.0	251	1.367	2.778	99.33	9.92	—	38.0	—	.00726	724	473	88.21	1.20	131.8	100
267	15.0	256	1.367	2.778	100.00	12.64	—	49.1	—	.00926	848	593	87.91	1.26	131.6	100
268	15.0	259	1.362	2.768	100.10	12.64	—	58.0	—	.00926	860	601	88.88	1.32	131.5	100
269	15.0	253	1.370	2.785	99.82	12.64	—	—	—	.00923	851	598	88.61	—	132.0	100
270	15.1	250	1.367	2.778	98.86	12.64	—	61.9	—	.00925	854	604	89.53	1.22	130.9	100
271	15.0	255	1.367	2.778	99.88	15.35	—	74.1	—	.01123	981	726	89.78	1.28	131.9	100
272	15.0	258	1.375	2.795	100.90	15.35	—	82.0	—	.01116	994	736	91.66	1.35	132.7	100
273	15.0	251	1.365	2.774	99.18	15.36	—	87.1	—	.01125	994	743	91.75	1.26	131.6	100
274	15.0	250	1.369	2.782	99.35	15.36	—	90.2	—	.01121	984	734	90.94	—	131.9	100

3048

TABLE III. - Continued. EXPERIMENTAL RESULTS

Run	Combustor-inlet total pressure, P_1, in. Hg abs	Combustor-inlet total temperature, T_1, °F	Air-flow rate, lb/sec	Air-flow rate per unit area, lb/(sec)(sq ft)	Combustor reference velocity, V_r, ft/sec	Fuel-flow rate, 1st stage, lb/sec	Fuel-flow rate, 2nd stage, lb/sec	Fuel-manifold pressure, 1st stage (above combustor-inlet pressure), lb/sq in.	Fuel-manifold pressure, 2nd stage (above combustor-inlet pressure), lb/sq in.	Fuel-air ratio	Mean combustor outlet total temperature, °F	Mean combustor temperature rise, °F	Combustion efficiency, percent	Total pressure loss through combustor, ΔP, in. Hg	Combustion parameter, V_r/P_1T_1, ft, lb, sec, °R units	Fuel injected in 1st stage, percent of total
								Configuration 37								
275	15.0	255	1.367	2.778	99.88	18.08×10^{-3}	—	96.1	—	0.01323	1103	848	90.11	1.28	131.9×10^{-6}	100.00
276	15.0	265	1.365	2.774	99.74	18.08	—	112.1	—	.01325	1111	856	90.64	1.28	131.6	100.00
277	15.0	260	1.372	2.789	99.55	18.08	—	122.0	—	.01318	1116	856	92.37	—	132.1	100.00
278	15.0	249	1.365	2.774	98.90	18.08	—	122.1	—	.01328	1118	869	92.21	—	131.8	100.00
279	15.0	252	1.360	2.764	98.96	18.08	—	127.1	—	.01329	1115	863	91.35	—	131.1	100.00
280	15.0	256	1.377	2.799	100.80	20.85	—	152.1	—	.01514	1221	965	90.67	1.36	132.9	100.00
281	15.0	250	1.370	2.785	99.40	20.85	—	155.2	—	.01522	1217	967	90.34	1.31	132.0	100.00
282	15.0	252	1.375	2.795	100.00	20.85	—	167.1	—	.01518	1221	969	90.90	1.31	132.5	100.00
283	15.0	254	1.375	2.795	100.30	23.60	—	212.1	—	.01716	1319	1065	89.25	1.33	132.5	100.00
284	15.0	254	1.370	2.785	99.96	24.89	—	235.1	—	.01817	1361	1107	88.02	—	131.9	100.00
285	15.0	259	1.363	2.774	100.30	9.46	3.19×10^{-3}	32.0	—	.00927	881	622	92.15	1.33	131.6	74.77
286	15.1	260	1.367	2.778	98.53	9.47	3.22	34.9	—	.00928	873	613	92.05	1.25	130.1	74.64
287	15.0	260	1.375	2.795	101.20	11.47	3.89	47.0	—	.01117	1009	749	93.30	1.31	132.7	74.67
288	15.0	256	1.370	2.785	100.20	13.56	4.50	65.1	—	.01318	1129	873	93.27	1.29	131.9	75.08
289	15.0	257	1.373	2.791	100.60	15.65	5.22	92.1	—	.01520	1259	1002	94.02	1.34	132.5	74.99
290	15.1	257	1.382	2.809	100.60	17.69	5.86	135.0	—	.01704	1361	1104	93.38	1.35	131.5	75.12
291	15.0	250	1.370	2.785	99.40	17.69	5.86	115.2	—	.01719	1349	1099	92.07	1.39	132.0	75.12
292	15.0	250	1.372	2.789	99.55	17.69	5.86	—	—	.01718	1376	1126	94.61	—	132.1	75.12
293	15.3	257	1.374	2.793	98.38	19.69	6.61	—	—	.01914	1465	1208	92.01	—	126.4	74.87
294	15.2	249	1.370	2.785	97.96	19.69	6.63	149.1	—	.01921	1451	1202	91.09	—	128.6	74.81
295	15.0	251	1.372	2.789	99.89	19.69	6.63	—	—	.01918	1478	1227	93.28	—	132.1	74.81
296	15.1	250	1.360	2.764	98.02	21.61	7.22	175.1	—	.02120	1578	1328	92.33	1.39	129.2	74.96
297	15.0	251	1.370	2.785	99.54	23.50	7.88	202.1	—	.02289	1670	1419	92.22	1.45	132.0	74.94
298	15.0	251	1.370	2.785	99.54	25.11	8.39	232.1	—	.02445	1739	1488	91.23	1.45	132.0	74.96
299	15.0	260	1.375	2.795	101.20	6.33	6.31	16.0	—	.00919	853	593	88.42	1.26	132.7	50.10
300	15.1	251	1.367	2.778	99.00	6.33	6.31	16.9	—	.00925	835	584	86.52	—	130.9	50.10
301	15.0	260	1.375	2.795	101.20	7.64	7.87	22.0	—	.01115	963	703	87.88	1.29	132.5	49.26
302	15.0	255	1.365	2.774	99.74	9.03	8.97	30.0	—	.01319	1094	839	89.34	1.26	131.6	50.16
303	15.0	257	1.377	2.799	100.90	10.46	10.42	41.1	—	.01518	1225	968	90.84	1.33	132.8	50.10
304	15.1	258	1.376	2.797	99.96	11.81	11.82	—	—	.01717	1349	1091	91.84	1.55	130.1	49.98
305	15.0	251	1.372	2.789	99.69	11.82	11.83	58.0	—	.01724	1298	1047	87.22	—	132.2	49.98
306	15.3	257	1.375	2.795	98.77	13.19	13.12	62.9	—	.01913	1498	1241	94.74	1.32	127.9	50.13
307	15.0	252	1.372	2.789	99.83	13.18	13.11	67.0	17.0	.01916	1414	1162	88.14	—	132.2	50.13
308	15.0	252	1.372	2.789	99.83	14.43	14.44	82.0	20.0	.02104	1535	1283	88.63	—	132.2	49.98
309	15.0	252	1.366	2.780	99.54	14.43	14.44	82.1	—	.02110	1529	1277	88.98	1.42	131.9	49.98
310	15.0	265	1.376	2.801	100.70	14.43	14.44	85.0	20.0	.02095	1503	1248	87.42	1.39	132.9	49.98
311	15.0	252	1.372	2.789	99.85	15.61	15.67	97.0	24.0	.02280	1641	1389	90.45	—	132.2	49.90
312	15.1	255	1.365	2.774	99.06	15.61	15.67	100.0	—	.02292	1624	1369	88.68	—	129.9	49.90
313	15.0	253	1.372	2.789	99.97	16.76	16.78	106.0	29.0	.02448	1719	1466	89.83	—	132.2	49.97
314	15.0	255	1.380	2.805	100.80	16.76	16.78	112.0	22.0	.02430	1684	1429	87.90	—	133.0	49.97
315	15.0	255	1.364	2.772	99.66	16.76	16.78	112.0	—	.02458	1704	1449	88.26	1.45	131.5	49.97
316	15.0	253	1.372	2.789	99.97	17.79	17.76	120.0	30.0	.02591	1776	1523	88.63	—	132.2	50.04
317	15.0	255	1.364	2.772	99.66	17.79	17.76	123.0	—	.02606	1775	1520	88.00	1.45	131.6	50.04
318	15.0	253	1.372	2.789	99.97	18.92	18.90	135.0	33.0	.02757	1859	1606	88.56	—	132.2	50.03
319	15.0	252	1.368	2.780	99.54	18.92	18.90	135.2	—	.02765	1866	1614	88.76	1.50	131.9	50.03
320	15.1	255	1.362	2.768	98.86	18.92	18.90	140.0	—	.02777	1864	1609	88.16	1.48	129.5	50.03
321	15.1	255	1.368	2.780	99.30	18.92	18.90	139.0	—	.02765	1853	1598	87.87	—	130.2	50.03
322	15.0	252	1.372	2.789	99.83	20.03	19.99	149.0	37.0	.02917	1933	1681	88.32	—	132.2	50.05
323	15.1	255	1.362	2.768	98.86	20.03	19.99	155.0	—	.02938	1930	1675	87.42	1.48	129.4	50.05
324	15.1	255	1.364	2.772	99.00	20.05	19.99	—	—	.02934	1925	1670	87.24	—	129.8	50.05
325	15.4	255	1.362	2.768	96.93	21.12	21.08	171.9	—	.03098	2003	1748	87.19	—	124.6	50.05
326	15.6	255	1.368	2.780	96.11	22.22	22.22	181.8	—	.03249	2044	1789	85.57	—	122.0	50.00
327	15.8	256	1.368	2.780	95.03	23.33	23.33	—	—	.03411	2103	1847	84.72	—	118.9	50.00
328	15.9	256	1.363	2.774	94.22	24.47	24.50	—	—	.03588	2160	1904	83.64	—	117.1	49.97
329	16.2	256	1.365	2.774	92.48	24.42	26.11	226.5	—	.03702	2203	1947	83.30	—	112.9	48.33
330	15.0	258	1.375	2.795	100.90	3.19	9.47	—	—	.00922	733	475	70.28	1.13	132.8	25.21
331	15.0	257	1.370	2.785	100.40	3.86	11.53	—	—	.01123	870	613	75.33	1.17	132.0	25.08
332	15.0	258	1.375	2.791	100.70	4.51	13.53	—	—	.01314	986	728	77.41	1.21	132.8	25.02
333	8.0	251	.732	1.488	96.92	4.42	—	—	—	.00603	Blow-out		—	—	248.0	100.00
334	8.0	255	.733	1.490	97.61	7.18	17.7	—	—	.00980	780	545	75.83	.69	246.8	100.00
335	8.0	232	.732	1.488	97.08	7.18	20.4	—	—	.00981	791	559	77.61	.68	246.0	100.00
336	8.0	235	.735	1.490	97.61	9.92	31.7	—	—	.01353	1000	765	78.95	.72	246.8	100.00
337	8.0	232	.732	1.488	97.06	9.92	35.8	—	—	.01355	1020	788	81.25	—	246.0	100.00
338	8.0	235	.726	1.480	96.95	12.64	52.7	—	—	.01738	1134	859	76.70	.72	247.0	100.00
339	8.0	232	.732	1.488	97.06	12.64	56.4	—	—	.01727	1214	982	81.17	.76	248.0	100.00
340	8.0	236	.733	1.490	97.78	15.36	77.7	—	—	.02094	1348	1112	77.12	.78	248.7	100.00
341	8.0	233	.726	1.474	96.27	15.35	—	85.4	—	.02117	1371	1138	78.16	.75	245.4	100.00
342	8.0	231	.732	1.488	98.92	18.08	—	115.4	—	.02470	1384	1153	68.56	.78	247.9	100.00
343	8.0	229	.730	1.484	96.36	18.08	—	120.6	—	.02477	1341	1112	65.78	—	247.4	100.00
344	8.0	230	.730	1.484	96.52	20.85	—	157.8	—	.02856	1378	1143	59.51	—	247.4	100.00
345	8.0	230	.729	1.462	94.03	7.26	2.61	—	—	.01356	1011	781	80.40	.69	241.0	75.60
346	8.0	232	.735	1.494	97.46	9.48	3.19	32.4	—	.01721	1276	1044	86.84	.75	249.1	74.77
347	8.0	232	.730	1.484	96.79	11.47	3.89	49.4	—	.02104	1453	1221	84.77	.77	247.3	74.67
348	8.0	232	.730	1.484	96.79	13.56	4.50	—	—	.02474	1545	1313	76.86	—	247.3	75.08
349	8.0	234	.730	1.484	97.07	15.64	5.22	81.4	—	.02858	1470	1236	64.46	.77	247.3	74.98
350	8.0	234	.732	1.488	97.34	4.96	5.03	10.4	—	.01364	1001	767	78.62	—	246.0	49.65
351	8.0	236	.733	1.490	97.75	6.33	6.31	10.7	—	.01724	1180	924	78.27	.74	248.6	50.10
352	8.0	237	.733	1.490	97.90	7.64	7.87	19.7	—	.02089	1350	1115	77.38	.76	248.4	49.90
353	8.0	234	.730	1.484	97.07	9.03	9.03	30.4	—	.02474	1455	1221	72.61	—	247.4	50.00
354	8.2	230	.729	1.452	94.03	10.47	10.42	—	—	.02866	1653	1423	74.77	—	235.1	50.12
355	8.0	235	.733	1.490	97.61	3.19	9.47	—	—	.01729	888	653	52.92	.66	246.5	25.21
356	8.0	237	.733	1.490	97.90	3.86	11.53	—	—	.02100	1151	914	62.52	.72	248.5	25.09
357	8.1	237	.727	1.478	95.88	4.53	13.53	—	—	.02484	1333	1096	64.69	.74	240.5	25.07
358	8.0	230	.724	1.460	96.25	5.22	15.64	—	—	.02885	1246	1016	52.20	—	246.9	25.03
359	6.0	206	.455	.925	77.65	2.74	—	—	—	.00601	Blow-out		—	—	274.0	100.00
360	6.0	208	.456	.927	77.82	4.40	—	—	—	.00964	693	485	68.05	.38	274.9	100.00
361	6.0	208	.455	.925	77.65	7.17	—	—	—	.01575	1016	808	71.92	.38	274.0	100.00
362	6.0	210	.454	.923	77.71	9.92	—	—	—	.02184	1236	1025	67.70	.38	273.6	100.00
363	6.0	211	.456	.927	78.17	9.92	—	37.8	—	.02175	1231	1020	67.62	.38	274.9	100.00
364	6.0	206	.457	.929	77.64	9.92	—	37.8	—	.02170	1256	1050	69.64	.38	275.7	100.00

3048

TABLE III. - Concluded. EXPERIMENTAL RESULTS

Run	Combustor-inlet total pressure, P_1, in. Hg abs	Combustor-inlet total temperature, T_1, °F	Air-flow rate, lb/sec	Air-flow rate per unit area, lb/(sec)(sq ft)	Combustor reference velocity, V_r, ft/sec	Fuel-flow rate, 1st stage, lb/sec	Fuel-flow rate, 2nd stage, lb/sec	Fuel-manifold pressure, 1st stage (above combustor-inlet pressure), lb/sq in.	Fuel-manifold pressure, 2nd stage (above combustor-inlet pressure), lb/sq in.	Fuel-air ratio	Mean combustor outlet total temperature, °F	Mean combustor temperature rise, °F	Combustion efficiency, percent	Total pressure loss through combustor, ΔP, in. Hg	Combustion parameter, V_r/P_1T_1, ft, lb, sec, °R units	Fuel injected in 1st stage, percent of total
Configuration 57																
365	6.0	211	0.457	0.929	78.34	9.92×10⁻³	—	38.3	—	0.02170	1247	1036	68.90	0.38	275.7×10⁻⁶	100.00
366	6.0	205	.457	.928	77.64	9.92	—	—	—	.02170	1249	1044	69.39	.38	275.7	100.00
367	6.0	205	.456	.927	77.47	9.92	—	36.6	—	.02174	1257	1052	69.84	.38	274.9	100.00
368	6.0	212	.456	.927	78.29	12.64	—	—	—	.02772	1281	1069	56.64	—	274.8	100.00
369	6.0	208	.457	.929	77.99	12.64	—	59.5	—	.02766	1321	1113	59.18	—	275.5	100.00
370	6.0	210	.457	.929	78.23	12.64	—	65.3	—	.02766	1280	1070	56.79	.38	275.5	100.00
371	6.0	206	.456	.927	77.47	12.64	—	—	—	.02772	1309	1104	58.55	—	274.8	100.00
372	6.0	207	.454	.923	77.36	12.64	—	56.7	—	.02784	1273	1066	56.19	.37	273.5	100.00
373	6.0	206	.457	.929	77.91	15.06	—	—	—	.03300	Blow-out		—	—	275.5	100.00
374	6.0	212	.452	.919	77.60	7.26	2.61×10⁻³	25.5	—	.02188	1274	1062	70.21	—	272.5	73.80
375	6.0	206	.457	.928	77.76	7.26	2.61	—	—	.02164	1258	1052	70.15	—	275.5	73.80
376	6.0	211	.457	.929	78.34	7.26	2.61	—	—	.02164	1255	1044	69.66	—	275.5	73.80
377	6.0	206	.456	.927	77.59	7.26	2.61	—	—	.02169	1260	1054	70.17	.38	274.8	73.80
378	6.0	214	.452	.919	77.83	9.47	3.22	—	—	.02806	1464	1250	66.12	—	272.7	74.64
379	6.0	211	.457	.929	78.34	9.47	3.22	—	—	.02777	1483	1272	68.03	.38	275.5	74.64
380	6.0	211	.457	.929	78.34	9.47	3.22	34.5	—	.02777	1503	1292	69.19	—	275.5	74.64
381	6.0	207	.456	.927	77.70	9.47	3.22	—	—	.02783	1483	1276	68.06	.41	274.8	74.64
382	6.0	206	.457	.928	77.76	4.96	5.00	—	—	.02179	1221	1015	67.08	—	275.5	49.79
383	6.0	210	.457	.929	78.23	4.96	5.00	—	—	.02179	1208	998	65.36	—	275.5	49.79
384	6.0	210	.457	.929	78.23	6.33	6.31	11.6	—	.02766	1523	1313	70.67	.41	275.5	50.10
385	6.0	212	.457	.928	78.46	6.33	6.31	—	—	.02766	1490	1278	68.64	—	275.5	50.10
386	6.0	207	.456	.927	77.70	6.33	6.31	—	—	.02772	1469	1262	67.53	—	274.6	50.10
387	6.0	208	.457	.929	77.89	1.81	5.33	—	—	.01562	974	766	69.57	.36	275.5	25.30
388	6.0	210	.456	.927	78.06	2.47	7.47	—	—	.02181	1155	945	62.21	.38	274.8	24.84
389	6.0	211	.457	.929	78.34	3.19	9.50	—	—	.02777	1231	1020	53.76	.37	275.5	25.17
390	15.0	237	1.062	2.138	74.93	4.40	—	7.1	—	.00419	Blow-out		—	—	101.4	100.00
391	15.0	240	1.046	2.130	74.97	7.17	—	20.1	—	.00624	691	451	86.90	.67	101.0	100.00
392	15.0	242	1.055	2.144	75.66	9.92	—	37.1	—	.00940	876	634	92.49	.70	101.6	100.00
393	15.0	245	1.052	2.138	75.79	9.92	—	39.1	—	.00943	875	630	91.72	.70	101.4	100.00
394	15.0	242	1.050	2.134	75.33	9.92	—	43.0	—	.00945	877	635	82.24	—	101.2	100.00
395	15.0	257	1.051	2.136	74.86	12.64	—	58.1	—	.01203	1033	786	92.16	.74	101.3	100.00
396	15.0	239	1.053	2.140	75.22	15.35	—	90.1	—	.01456	1208	969	94.20	.74	101.5	100.00
397	15.0	250	1.045	2.124	75.82	15.35	—	95.0	—	.01469	1216	966	93.37	—	100.7	100.00
398	15.0	242	1.048	2.130	75.18	15.35	—	100.0	—	.01465	1213	971	94.01	.73	101.0	100.00
399	15.0	248	1.049	2.132	75.90	18.08	—	127.0	—	.01724	1346	1098	91.69	.77	101.1	100.00
400	15.0	249	1.045	2.124	75.72	20.53	—	163.0	—	.01965	1459	1210	89.80	.78	100.7	100.00
401	15.0	237	1.049	2.132	74.72	9.47	3.19	35.1	—	.01206	1073	836	96.64	.78	101.1	74.76
402	15.0	245	1.060	2.154	75.65	9.47	3.22	47.0	—	.01209	1079	834	96.42	—	101.2	74.64
403	15.0	240	1.060	2.154	75.11	11.47	3.86	51.1	—	.01460	1238	998	97.07	.75	101.2	74.82
404	15.0	245	1.057	2.148	76.15	13.56	4.51	74.0	—	.01713	1380	1135	95.68	.80	101.8	75.04
405	15.0	249	1.043	2.120	75.57	16.64	5.24	100.0	—	.02002	1534	1285	94.07	.82	100.5	74.90
406	15.0	249	1.048	2.130	75.95	17.69	5.86	123.0	—	.02247	1646	1397	92.24	.83	101.0	75.12
407	15.0	249	1.045	2.124	75.72	19.69	6.63	152.0	—	.02518	1769	1520	90.75	—	100.7	74.81
408	15.0	245	1.049	2.132	75.56	3.58	3.60	—	—	.00685	Blow-out		—	—	101.1	49.90
409	15.0	238	1.053	2.140	75.11	4.96	5.00	12.1	—	.00948	835	597	86.42	.70	101.5	49.79
410	15.0	243	1.048	2.130	75.29	4.96	5.00	—	—	.00950	839	596	85.88	—	101.0	49.79
411	15.0	238	1.051	2.136	74.97	6.33	6.29	17.1	—	.01201	1024	786	91.14	.73	101.3	50.16
412	15.0	245	1.043	2.120	75.14	6.33	6.31	—	—	.01212	1028	783	90.11	—	100.8	50.10
413	15.0	240	1.048	2.130	74.97	7.65	7.67	23.1	—	.01462	1201	961	93.12	.75	101.0	49.95
414	15.0	246	1.049	2.132	75.68	9.03	9.01	—	—	.01720	1350	1104	92.41	.80	101.1	50.04
415	15.0	249	1.045	2.124	75.72	10.47	10.42	45.0	—	.01999	1503	1254	91.79	.80	100.7	50.12
416	15.0	248	1.042	2.118	75.50	11.82	11.83	57.0	—	.02270	1635	1386	90.58	.83	100.4	49.98
417	15.0	245	1.049	2.132	75.56	1.81	5.33	—	—	.00681	Blow-out		—	—	101.1	25.30
418	15.0	235	1.054	2.142	74.86	2.47	7.44	—	—	.00941	775	540	78.23	.64	101.5	24.93
419	15.0	245	1.049	2.132	75.56	2.47	7.46	—	—	.00948	771	526	75.69	—	101.1	24.88
420	15.0	238	1.051	2.136	74.97	3.19	9.50	—	—	.01207	944	706	81.12	—	101.3	25.17
421	15.0	243	1.045	2.124	75.07	3.19	9.50	—	—	.01214	975	732	83.83	—	100.7	25.17
422	15.0	238	1.049	2.132	74.93	3.85	11.53	—	—	.01466	1146	908	87.80	.69	101.1	25.01
423	15.0	246	1.049	2.132	75.68	4.51	13.53	7.0	—	.01720	1304	1058	88.34	.77	101.1	25.02
424	15.0	258	1.777	3.612	130.40	5.50	—	—	—	.00310	Blow-out		—	—	171.2	100.00
425	15.0	257	1.780	3.616	130.40	7.17	—	21.0	—	.00403	499	242	79.80	2.01	171.5	100.00
426	15.0	256	1.780	3.616	130.20	7.17	—	20.1	—	.00403	506	250	82.45	2.07	171.5	100.00
427	15.0	256	1.781	3.620	130.70	9.92	—	38.0	—	.00557	593	335	80.80	—	171.8	100.00
428	15.0	252	1.784	3.626	129.81	9.92	—	37.1	—	.00556	581	329	79.13	2.09	171.8	100.00
429	15.0	262	1.782	3.622	131.50	12.64	—	62.1	—	.00708	684	422	80.47	2.18	171.7	100.00
430	15.0	256	1.782	3.622	130.80	12.64	—	61.0	—	.00709	677	419	79.78	2.15	171.7	100.00
431	15.0	256	1.790	3.638	131.30	15.35	—	88.0	—	.00858	776	518	82.29	2.18	172.5	100.00
432	15.0	262	1.781	3.620	131.40	15.35	—	92.1	—	.00862	785	523	82.75	2.20	171.6	100.00
433	15.2	262	1.780	3.618	129.80	18.06	—	124.0	—	.01016	879	617	83.63	2.21	167.0	100.00
434	15.1	260	1.788	3.634	130.70	18.03	—	116.0	—	.01011	860	600	81.60	2.15	170.0	100.00
435	15.2	259	1.790	3.638	129.80	20.85	—	152.0	—	.01165	948	689	82.10	—	166.0	100.00
436	15.0	258	1.781	3.620	130.70	6.89	2.61	—	—	.00533	Blow-out		—	—	171.6	72.52
437	15.0	258	1.786	3.630	131.20	9.47	3.22	34.0	—	.00711	677	418	79.46	2.12	172.1	74.64
438	15.0	259	1.793	3.644	131.70	11.49	3.89	48.0	—	.00858	782	523	83.10	2.15	172.6	74.71
439	15.0	260	1.798	3.654	132.30	13.56	4.61	68.0	—	.01005	880	620	84.94	2.23	173.2	75.04
440	15.0	259	1.782	3.622	130.90	5.22	5.00	—	—	.00576	Blow-out		—	—	171.7	51.10
441	15.0	258	1.780	3.618	130.60	4.96	5.00	—	—	.00558	Blow-out		—	—	171.5	49.79
442	15.0	256	1.790	3.636	131.20	6.33	6.31	17.0	—	.00706	534	276	52.55	—	172.5	50.10
443	15.0	261	1.780	3.618	131.20	6.33	6.29	16.1	—	.00709	559	298	54.55	—	171.5	50.18
444	15.0	257	1.786	3.630	131.20	7.65	[illegible]	22.0	—	.00858	653	394	62.26	—	172.1	49.92
445	15.0	260	1.800	3.658	132.40	9.03	9.01	30.0	7.0	.01002	741	481	65.64	2.16	173.4	50.04
446	15.0	256	1.810	3.679	132.80	10.47	10.42	40.0	7.0	.01154	827	569	67.88	—	174.4	50.12
447	15.0	260	1.780	3.618	131.00	2.46	7.44	—	—	.00572	Blow-out		—	—	171.5	25.01
448	15.0	261	1.783	3.624	131.40	3.14	9.50	—	—	.00709	Blow-out		—	—	171.6	24.83
449	15.0	257	1.791	3.640	131.30	3.19	9.50	—	—	.00709	Blow-out		—	—	172.6	25.17
450	15.0	258	1.790	3.638	131.50	3.86	11.54	—	—	.00880	Blow-out		—	—	172.5	25.07
451	15.0	262	1.779	3.616	131.30	3.86	11.53	—	—	.00852	Blow-out		—	—	171.4	25.10
452	15.0	260	1.782	3.622	131.10	4.61	13.53	—	—	.01012	Blow-out		—	—	171.7	25.02

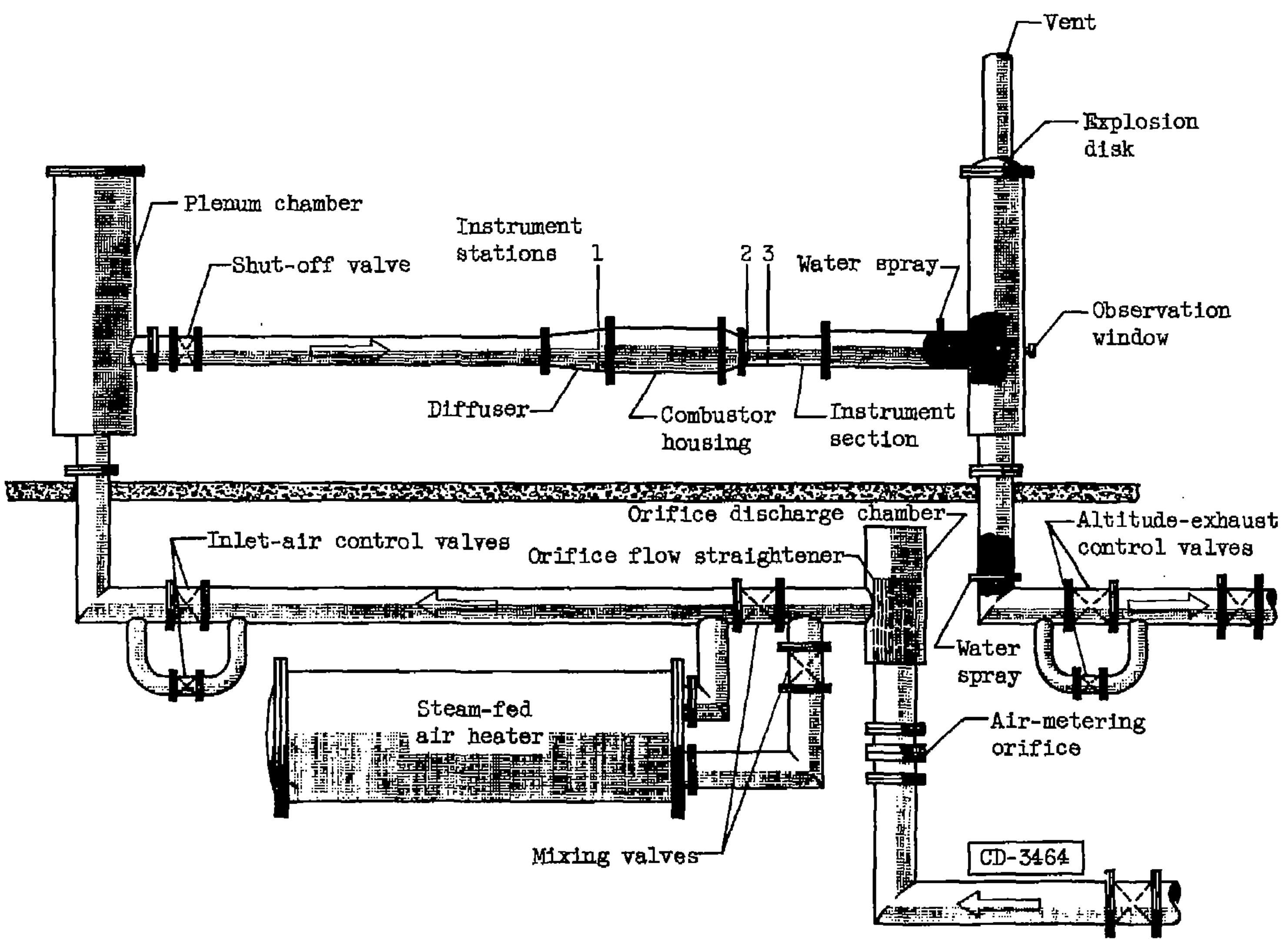
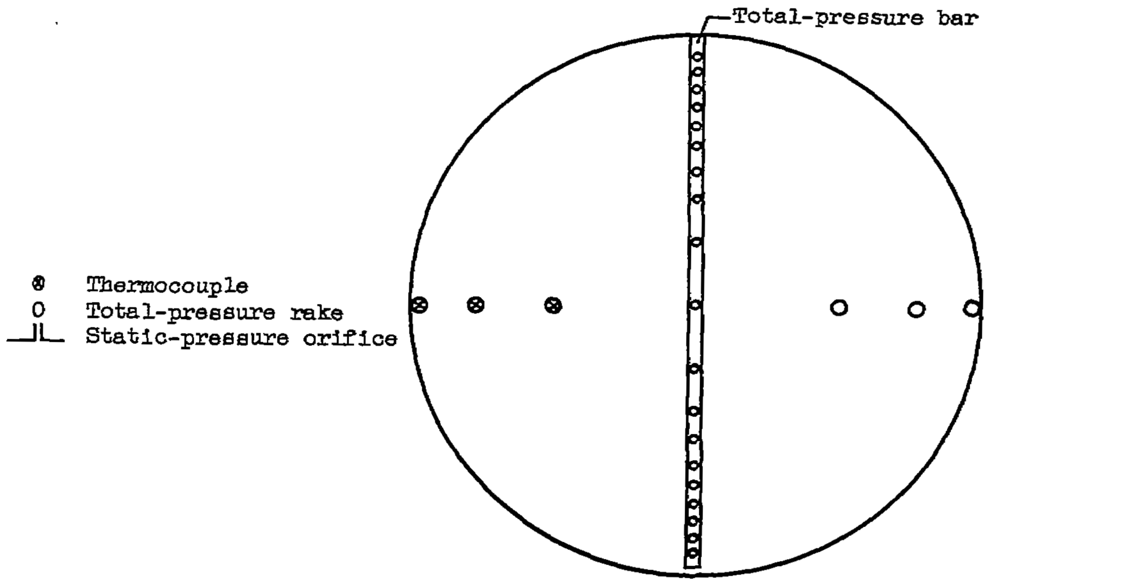
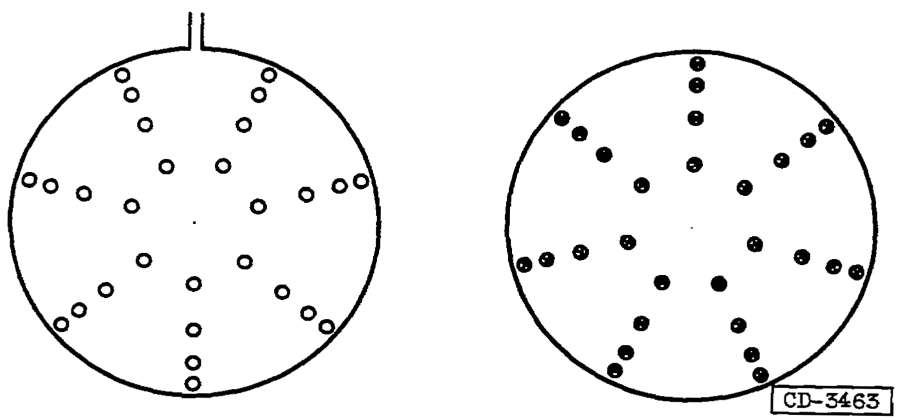


Figure 1. - Installation of $9\frac{1}{2}$-inch-diameter experimental tubular combustor.



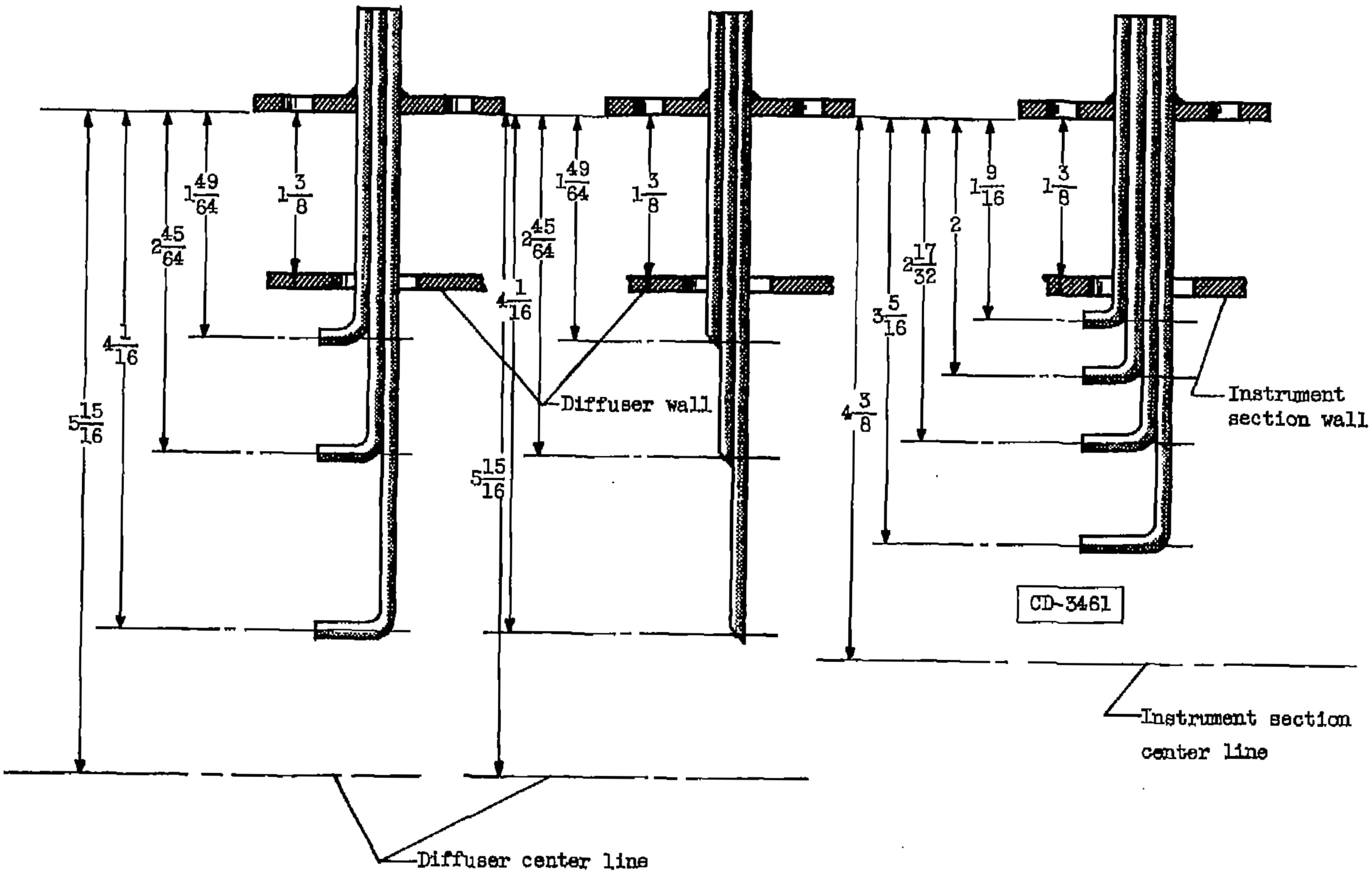
(a) Inlet thermocouples (chromel-alumel) and inlet total-pressure rake and bar in plane at station 1.



(b) Outlet total-pressure rakes in plane at station 2.

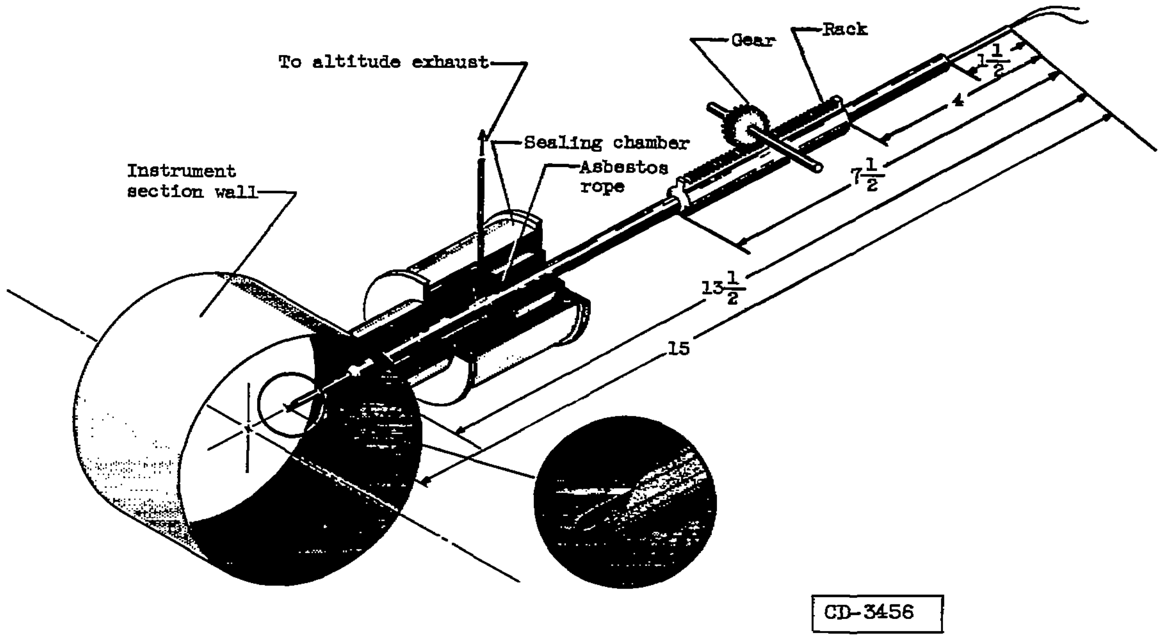
(c) Temperature recording positions of movable outlet thermocouples (chromel-alumel) in plane at station 3.

Figure 2. - Combustor pressure and temperature instrumentation.

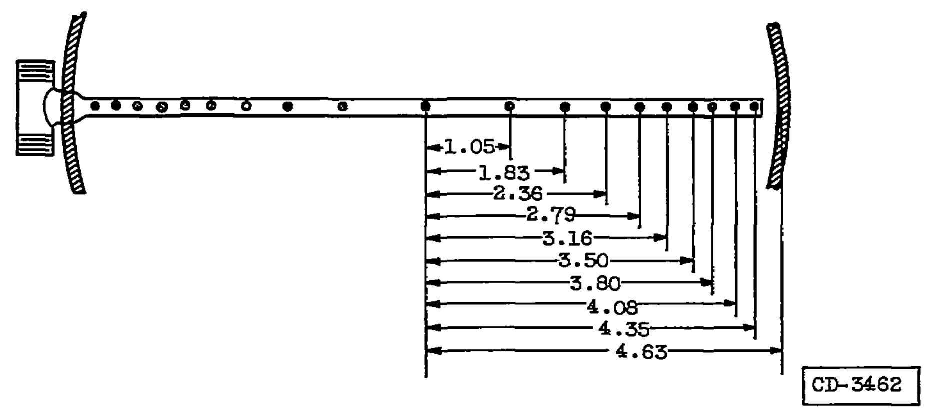


(a) Inlet total-pressure rake. (b) Inlet thermocouple. (c) Outlet total-pressure rake.

Figure 3. - Details of combustor instrumentation. (Dimensions are in inches.)

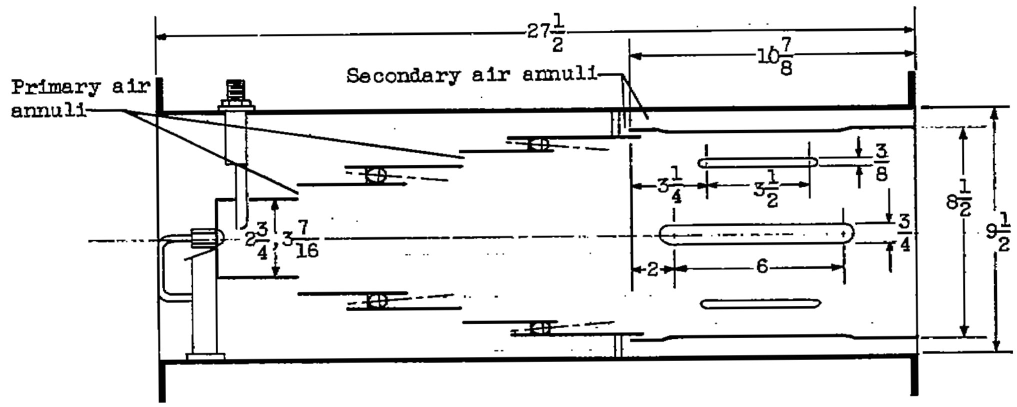


(d) Movable outlet thermocouple.

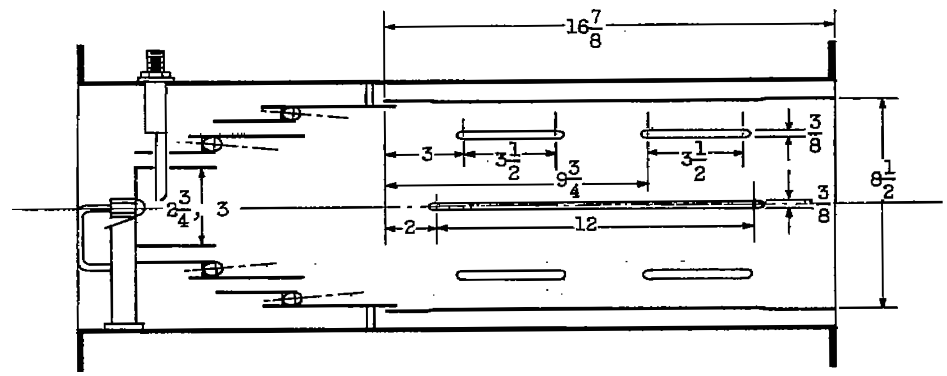


(e) Inlet total-pressure bar.

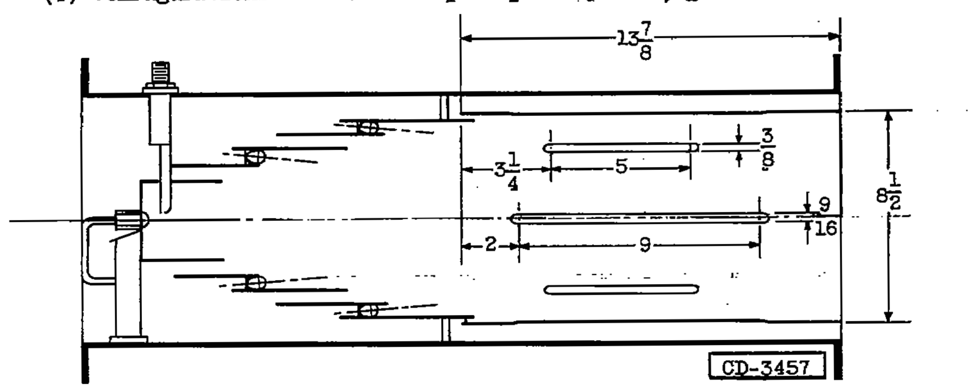
Figure 3. - Concluded. Details of combustor instrumentation. (Dimensions are in inches.)



(a) Configurations 1-11. Extended primary zone, pilot unshrouded.



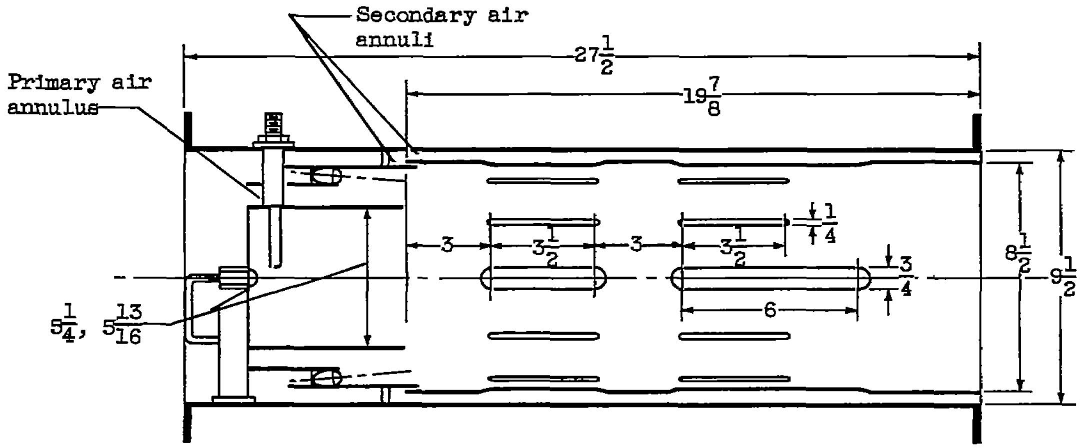
(b) Configurations 12-23. Collapsed primary zone, pilot shrouded.



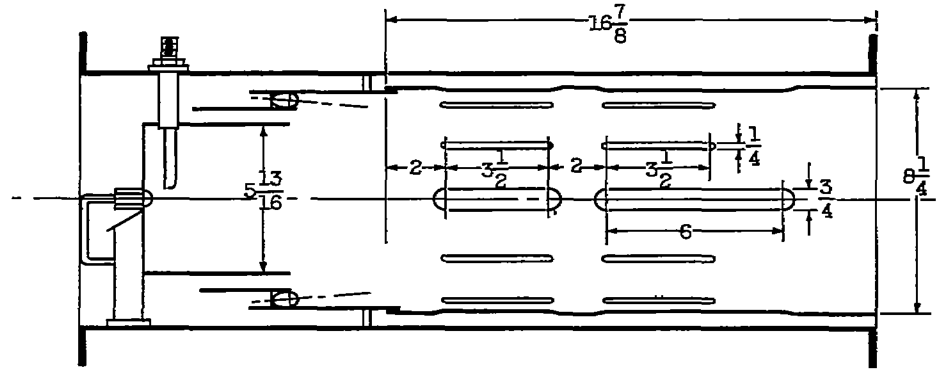
(c) Half-extended primary zone, pilot unshrouded.

Figure 4. - Diagrammatic sketches of experimental combustors employing three possible stages of fuel injection. Configurations 1 to 23. (Dimensions are in inches.)

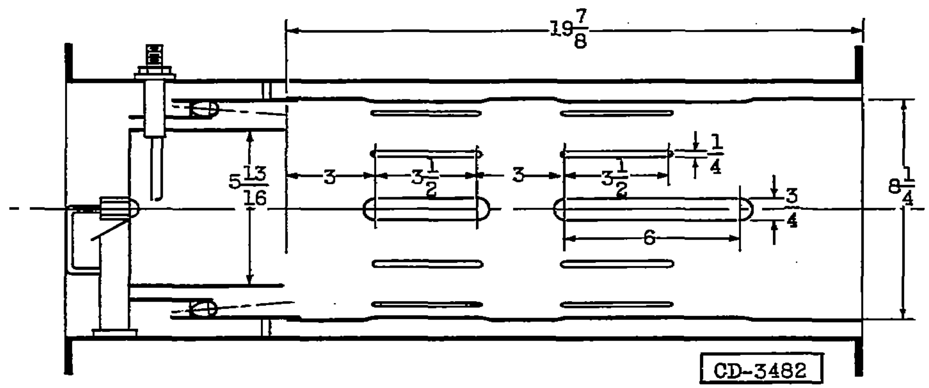
3048



(a) Configurations 24-33. Collapsed primary zone, pilot shrouded.



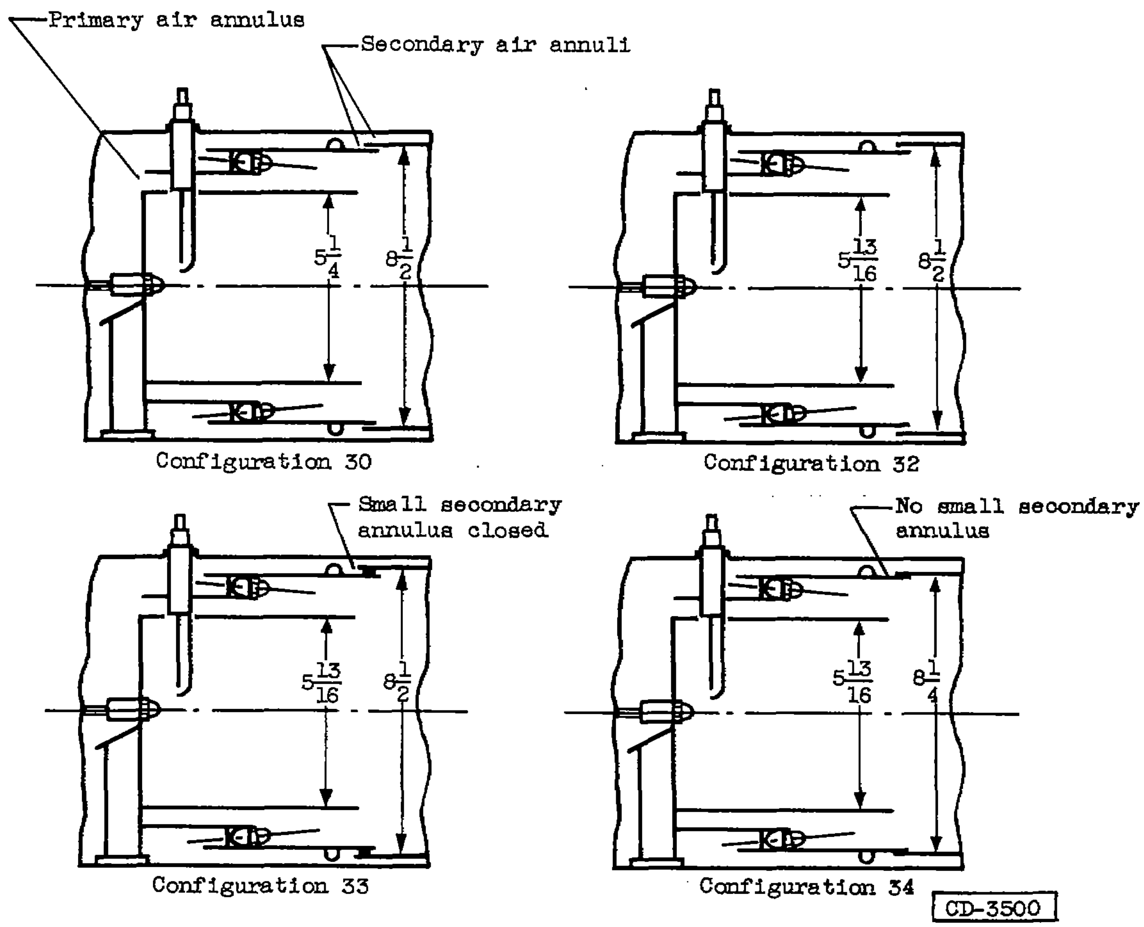
(b) Configuration 37. Extended primary zone, pilot unshrouded.



(c) Configurations 34-36, 38-57. Collapsed primary zone, pilot shrouded.

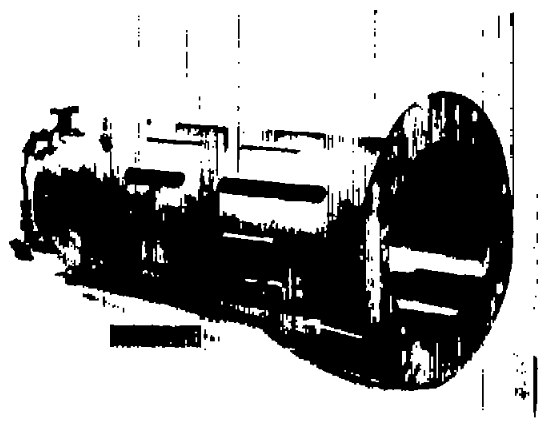
Figure 5. - Diagrammatic sketches of experimental combustors employing two possible stages of fuel injection. Configurations 24-57. (Dimensions are in inches.)

3048



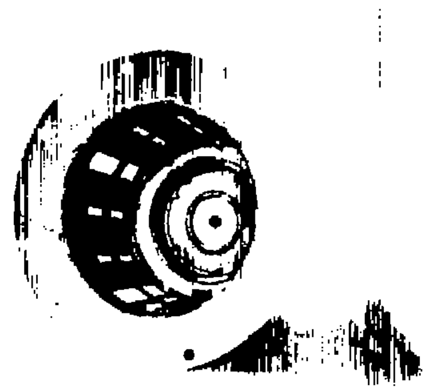
Configuration	Small secondary annulus	Primary annulus, area, sq in.	Secondary annuli, area, sq in.	Ratio of primary to total open annular area
30	Open	8.55	16.39	0.333
32	Open	3.61	16.39	.171
33	Closed	3.61	12.47	.210
34	None	3.61	15.84	.177

Figure 6. - Diagrammatic sketches of four secondary-sleeve - pilot combinations. Pilot open-area pattern same in each configuration.



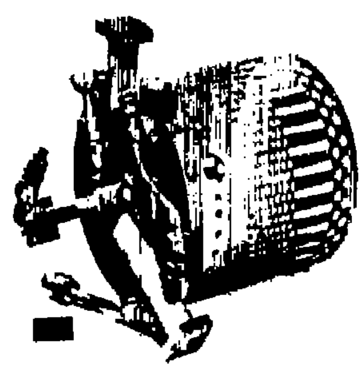
C-34180

Side view, assembly



C-34179

End view, assembly



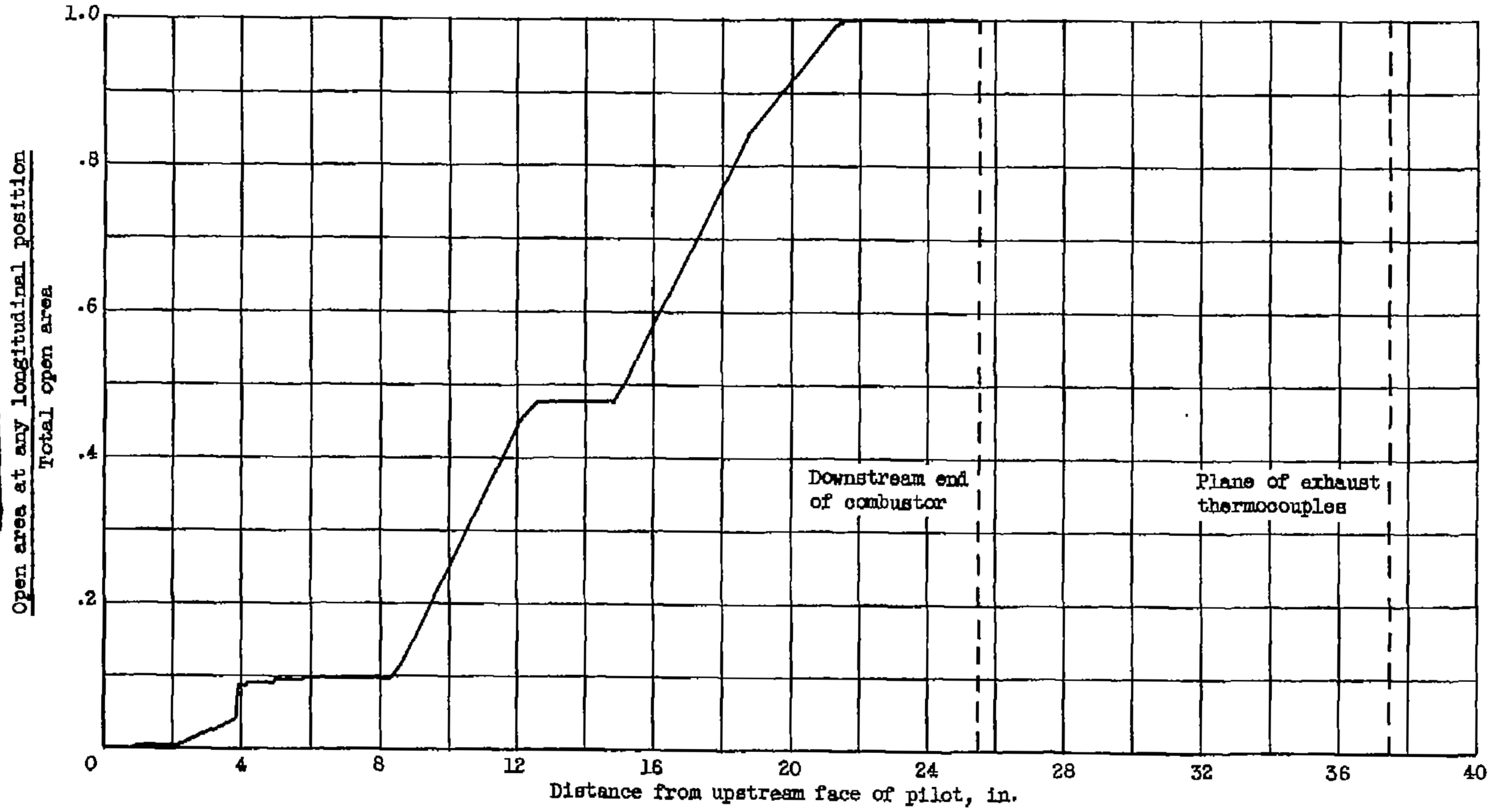
C-34178

Pilot

(a) Assembly and pilot.

Figure 7. - Configuration 57.

[redacted]



[redacted]

(b) Longitudinal distribution of combustor open area.

Figure 7. - Concluded. Configuration 57.

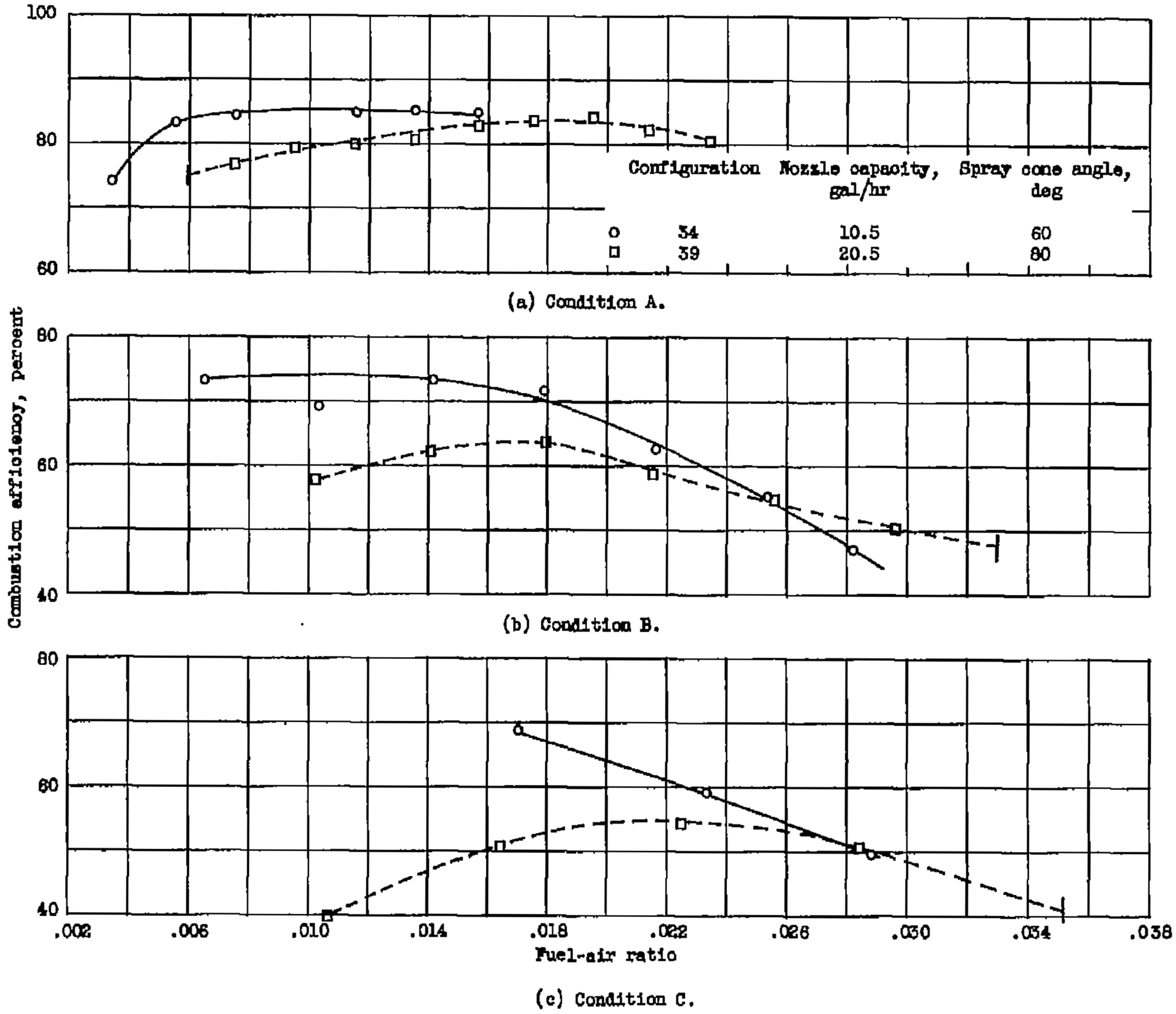
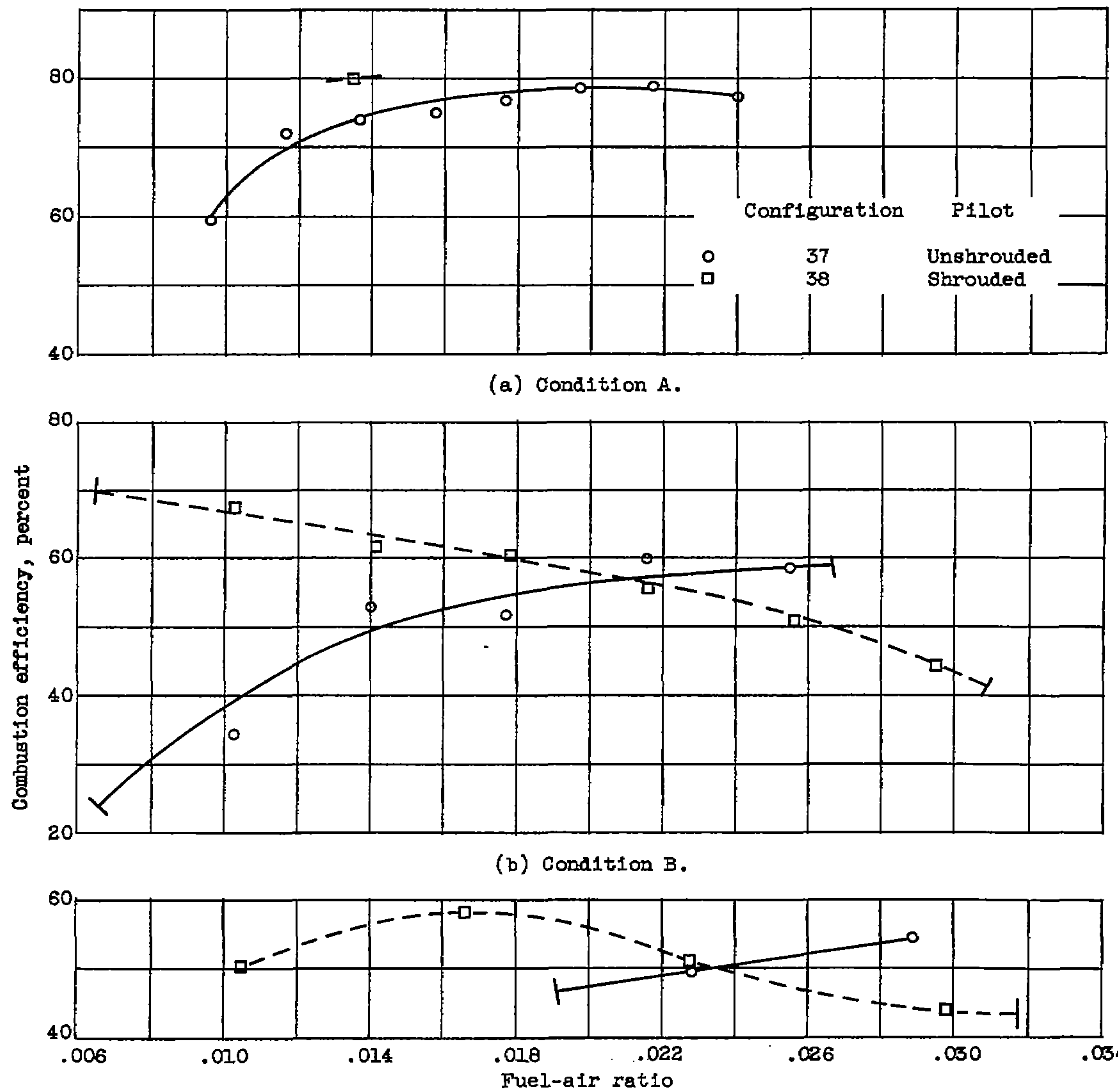


Figure 8. - Effect of pilot fuel-nozzle capacity on combustion efficiencies of one pilot-air admission design. (Nozzles rated at 100 lb/sq in. pressure differential.)

3048



(a) Condition A.

(b) Condition B.

(c) Condition C.

Figure 9. - Effect of pilot shrouding on combustion efficiencies of one pilot-air admission design.

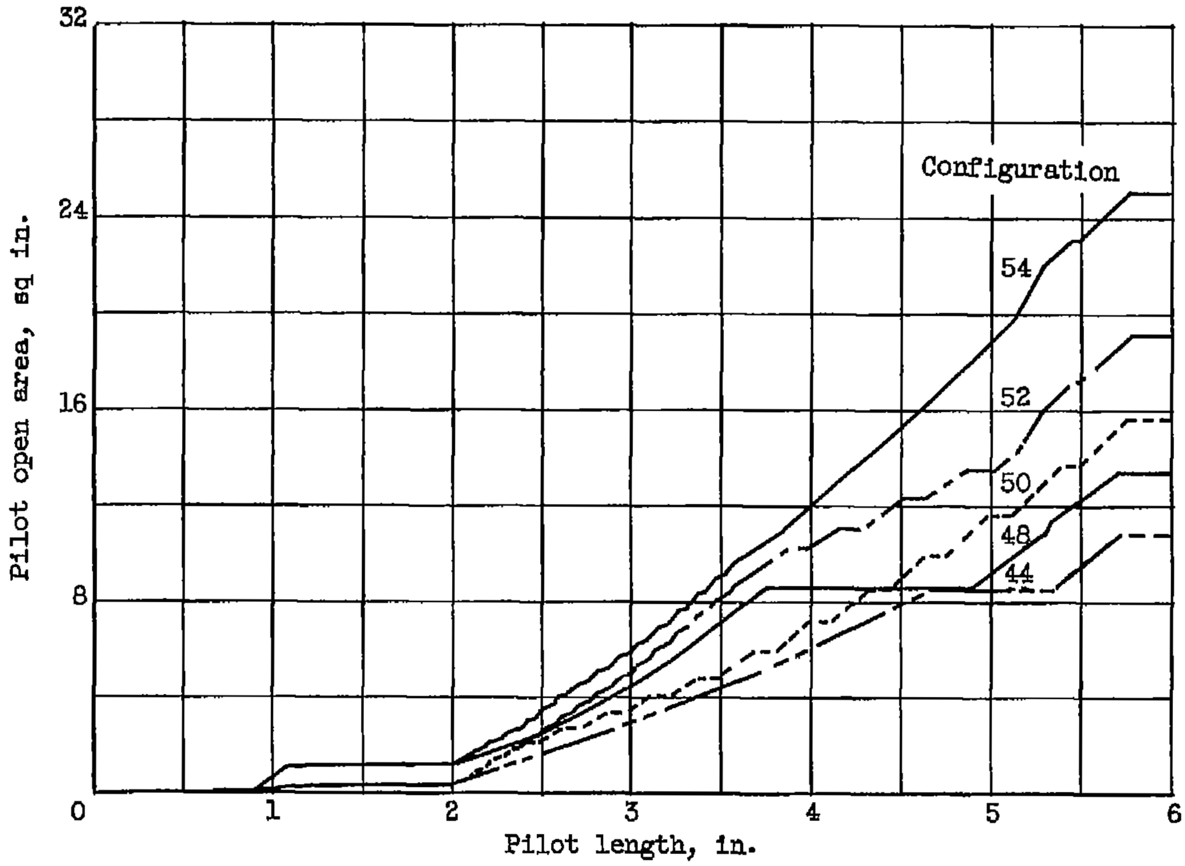


Figure 10. - Pilot open-area distribution of five configurations using small circular holes and longitudinal slots for air admission.

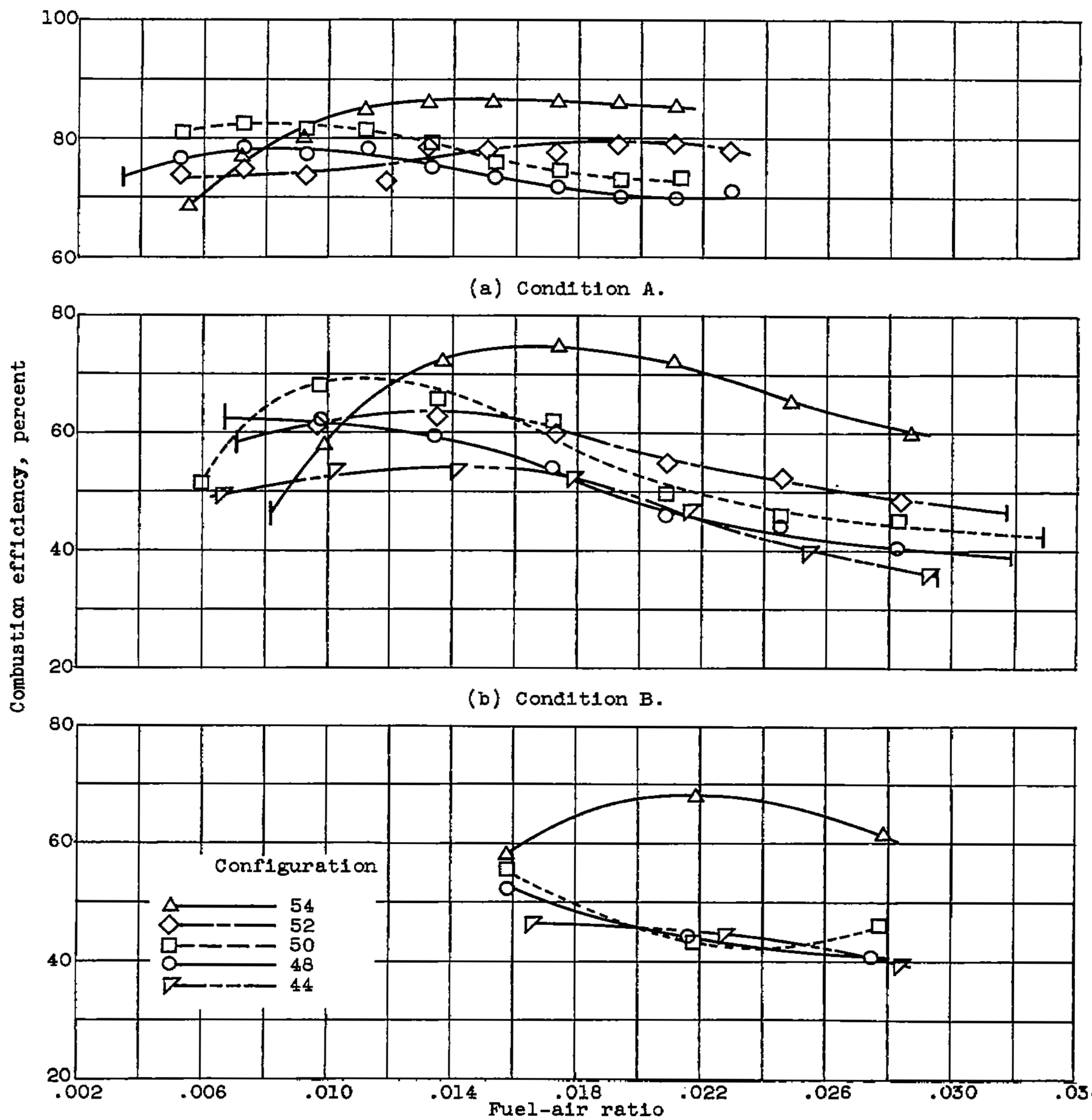


Figure 11. - Effect of pilot-air distribution on combustion efficiencies of five configurations having small circular holes and longitudinal slots for air admission.

3048

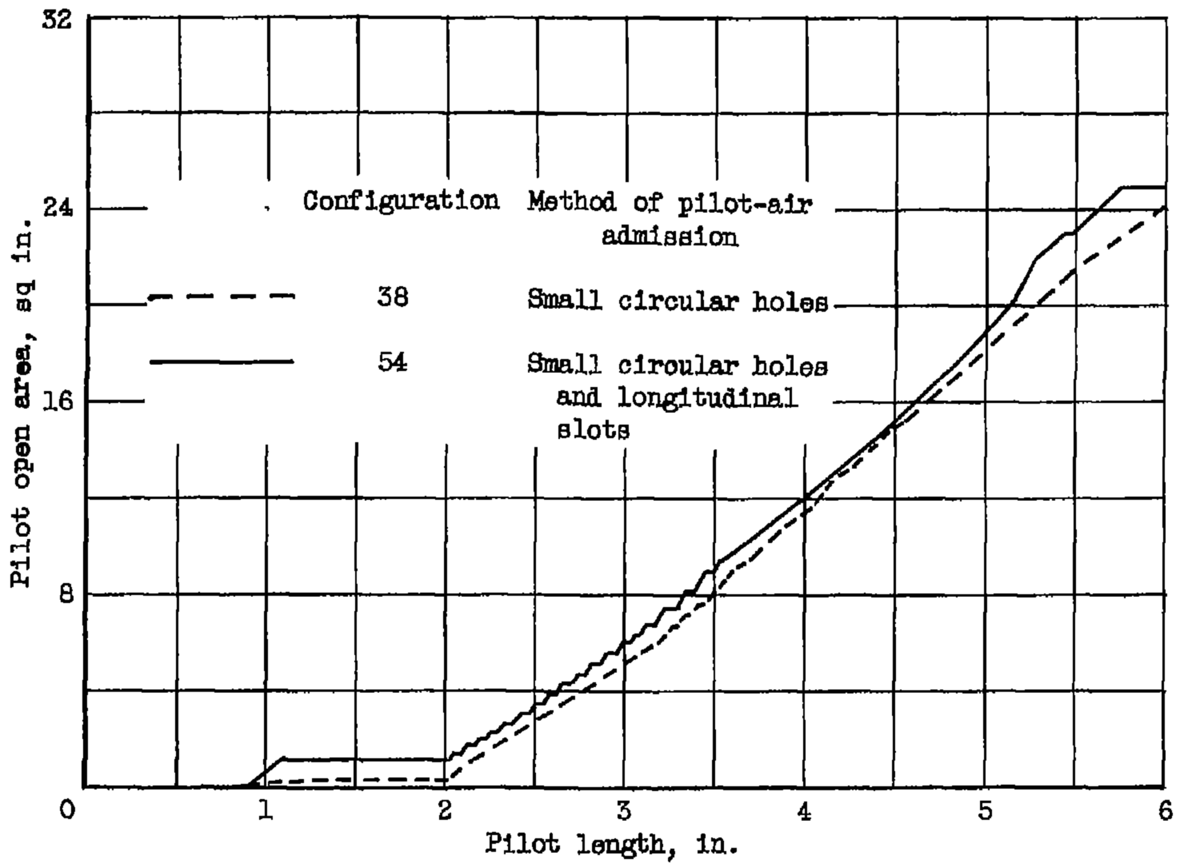
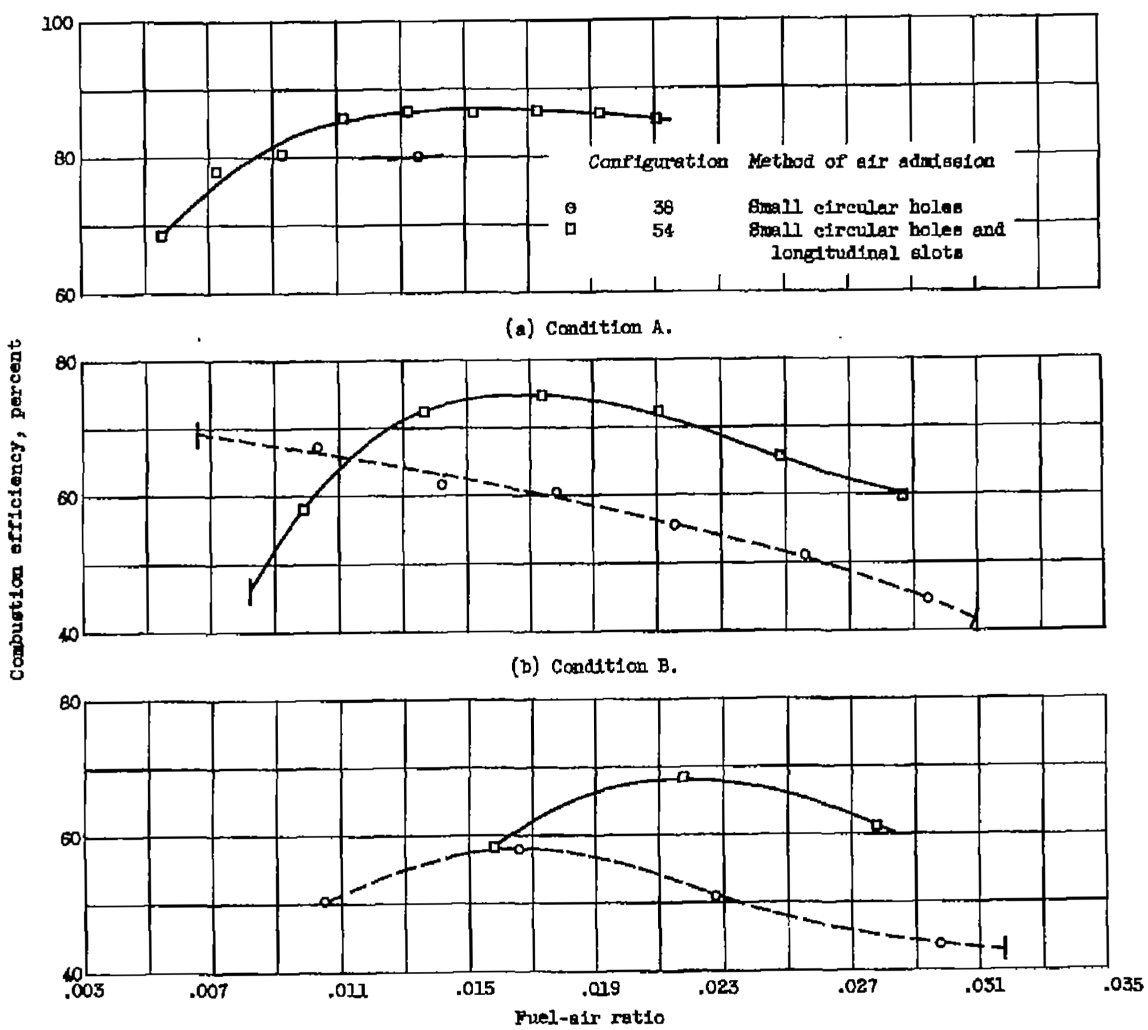


Figure 12. - Pilot open-area distribution of two configurations with two methods of pilot-air admission. Total open-area approximately the same at any longitudinal position.



(a) Condition A.

(b) Condition B.

(c) Condition C.

Figure 13. - Effect of method of pilot-air admission on combustion efficiencies of two configurations having approximately same total open area at any longitudinal position.

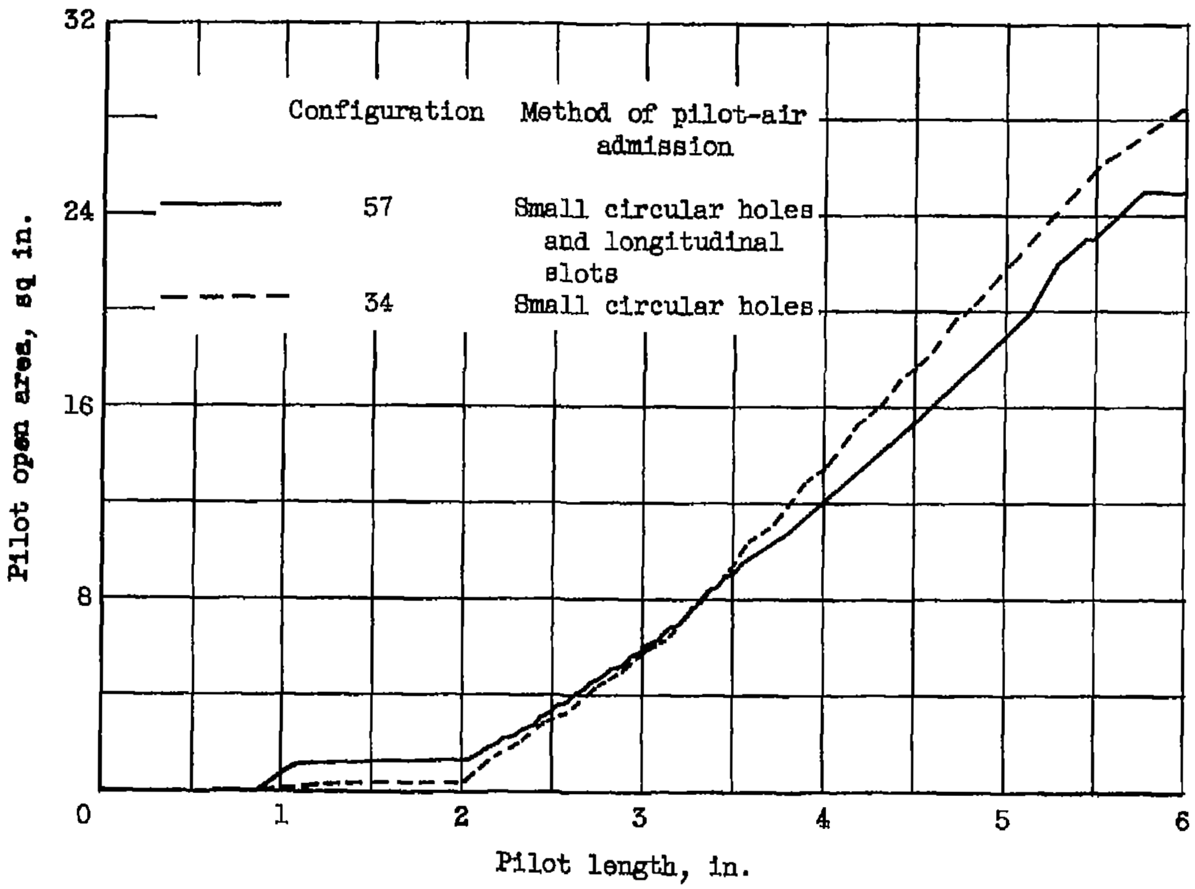


Figure 14. - Pilot open-area distribution for best configurations embodying two methods of pilot-air admission.

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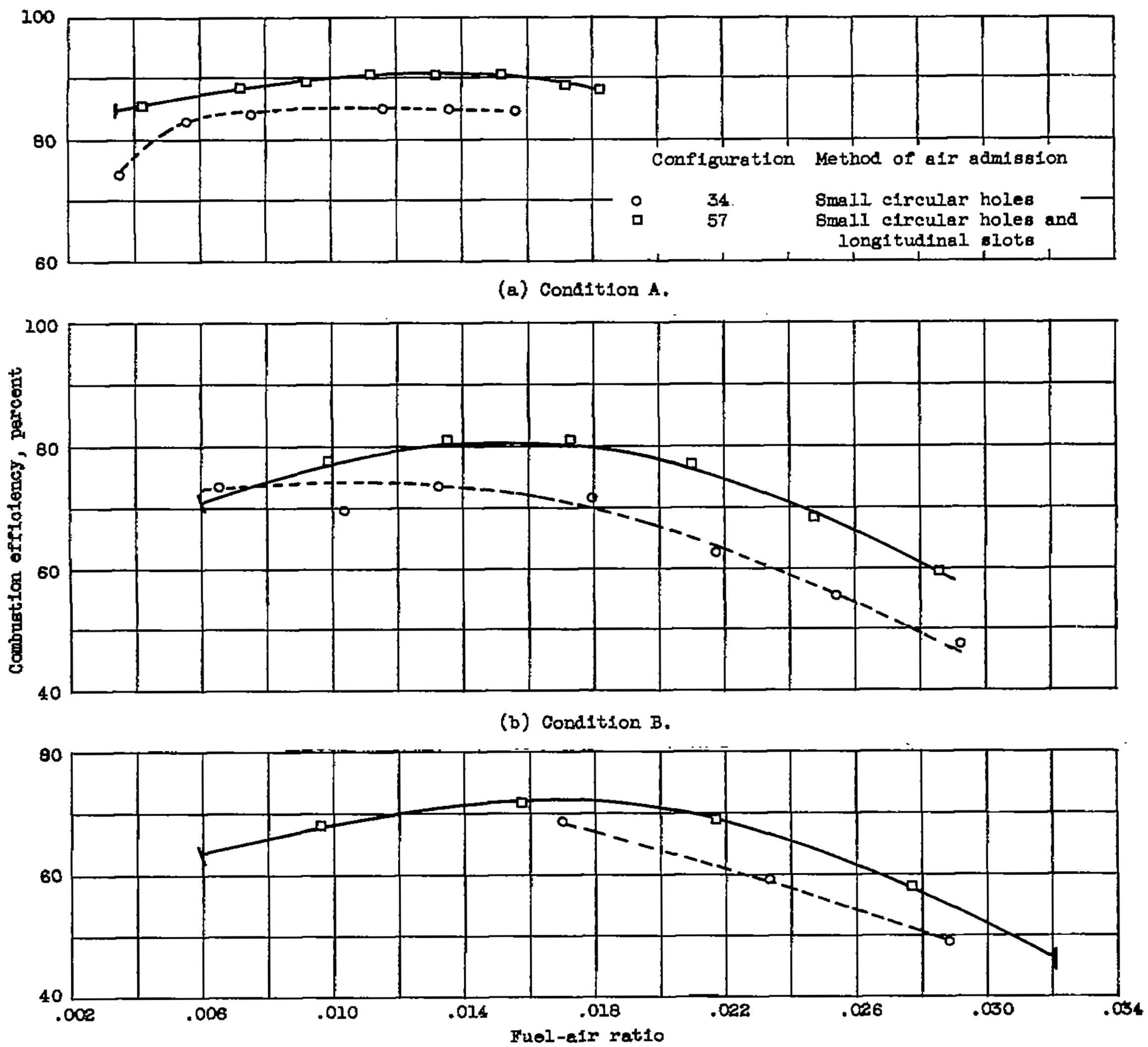


(c) Condition C.

Figure 15. - Combustion efficiencies of best configurations embodying two methods of pilot-air admission.

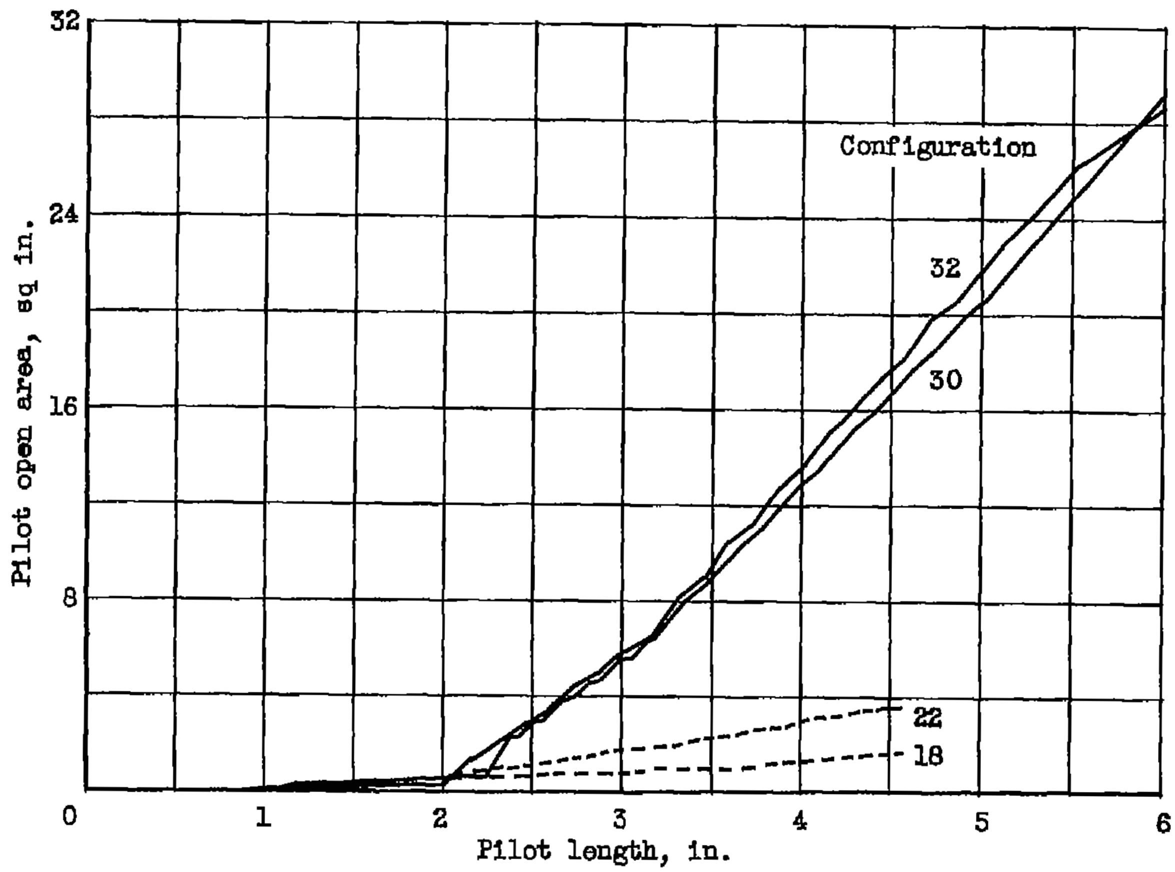


Figure 16. - Pilot open-area distribution for several pilots of various diameters and lengths.

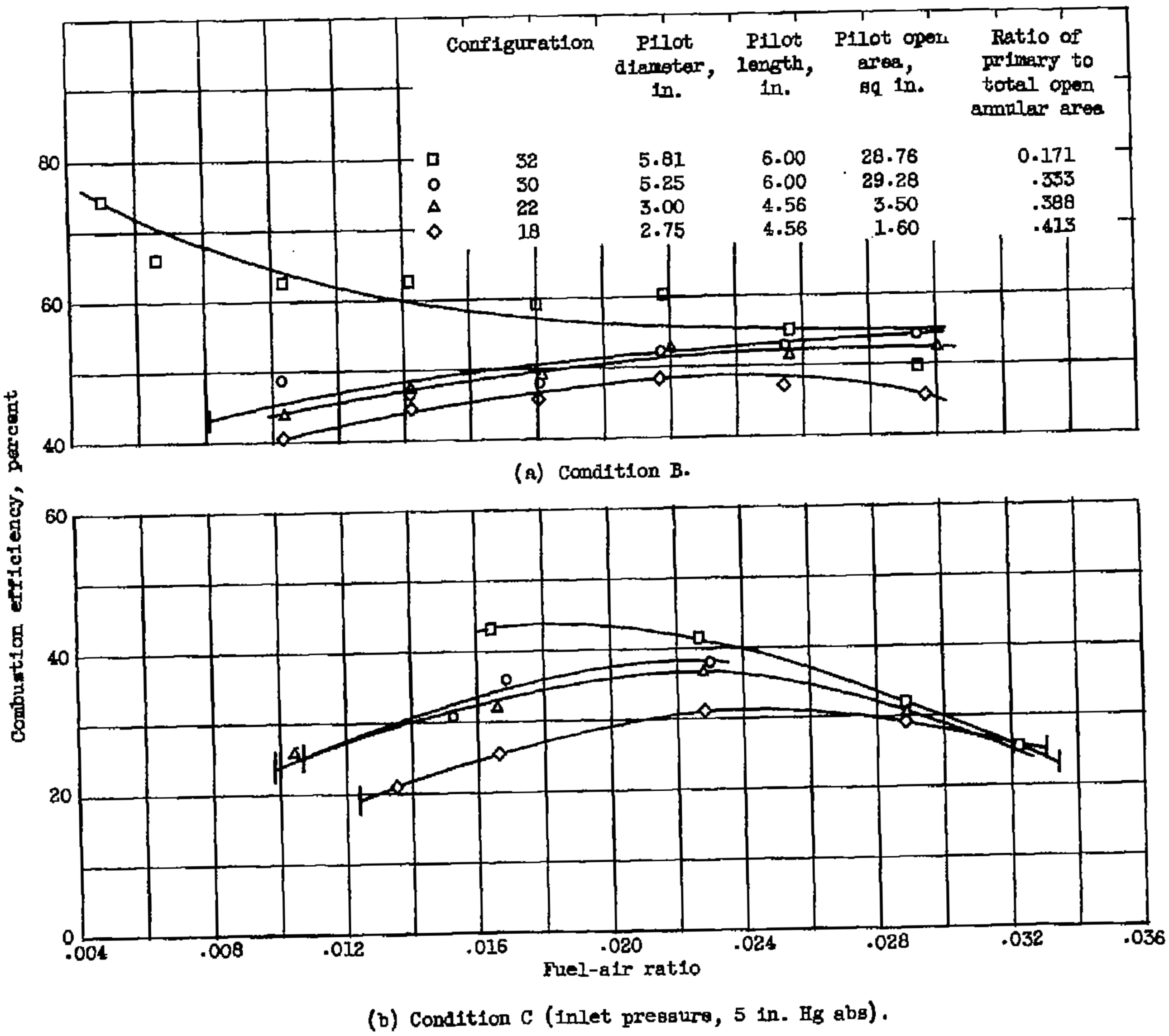
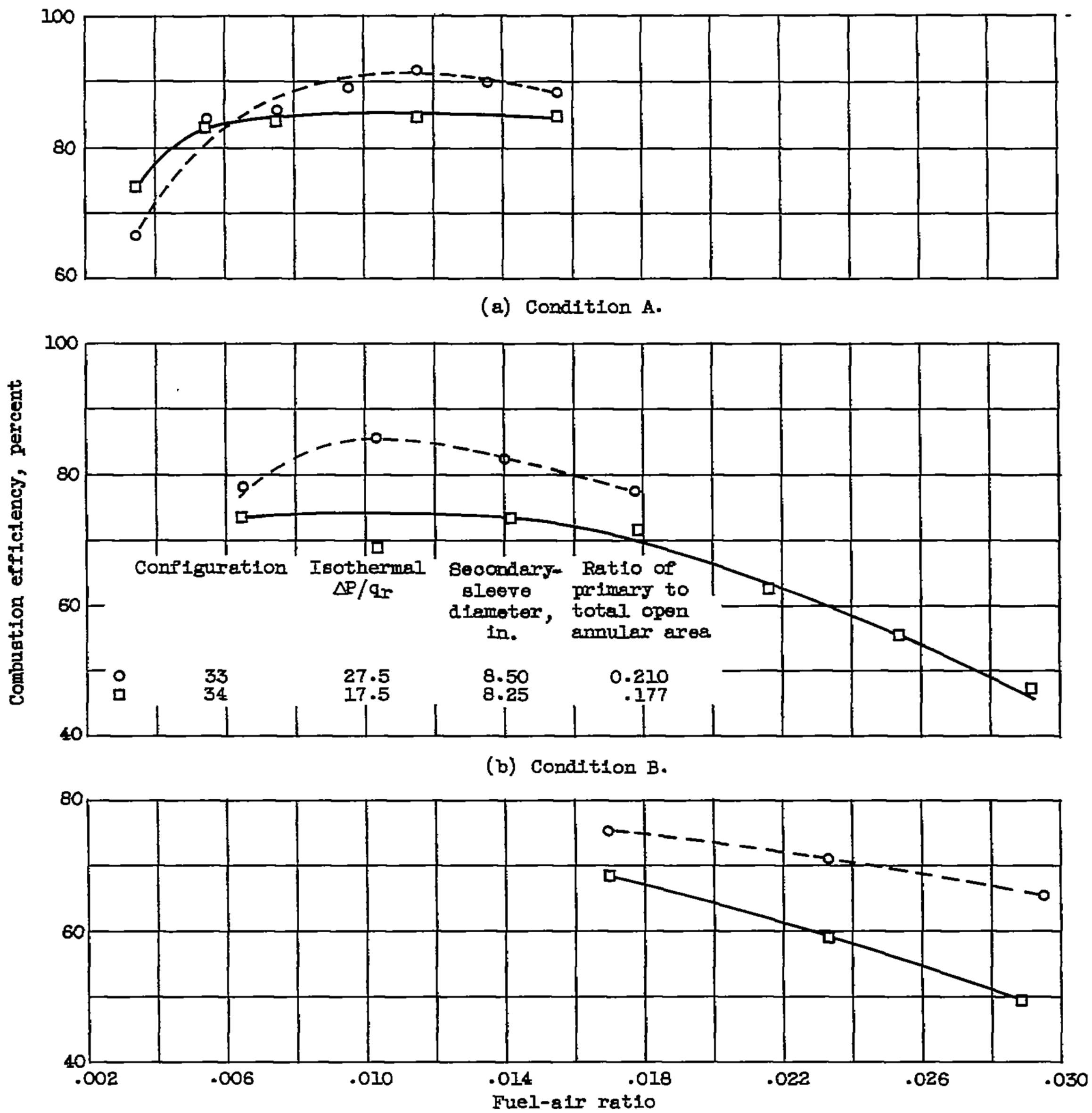


Figure 17. - Effect of pilot diameter on combustion efficiencies of four pilots having different lengths.



(c) Condition C.

Figure 18. - Effect of secondary-sleeve diameter on combustion efficiencies of a single pilot.

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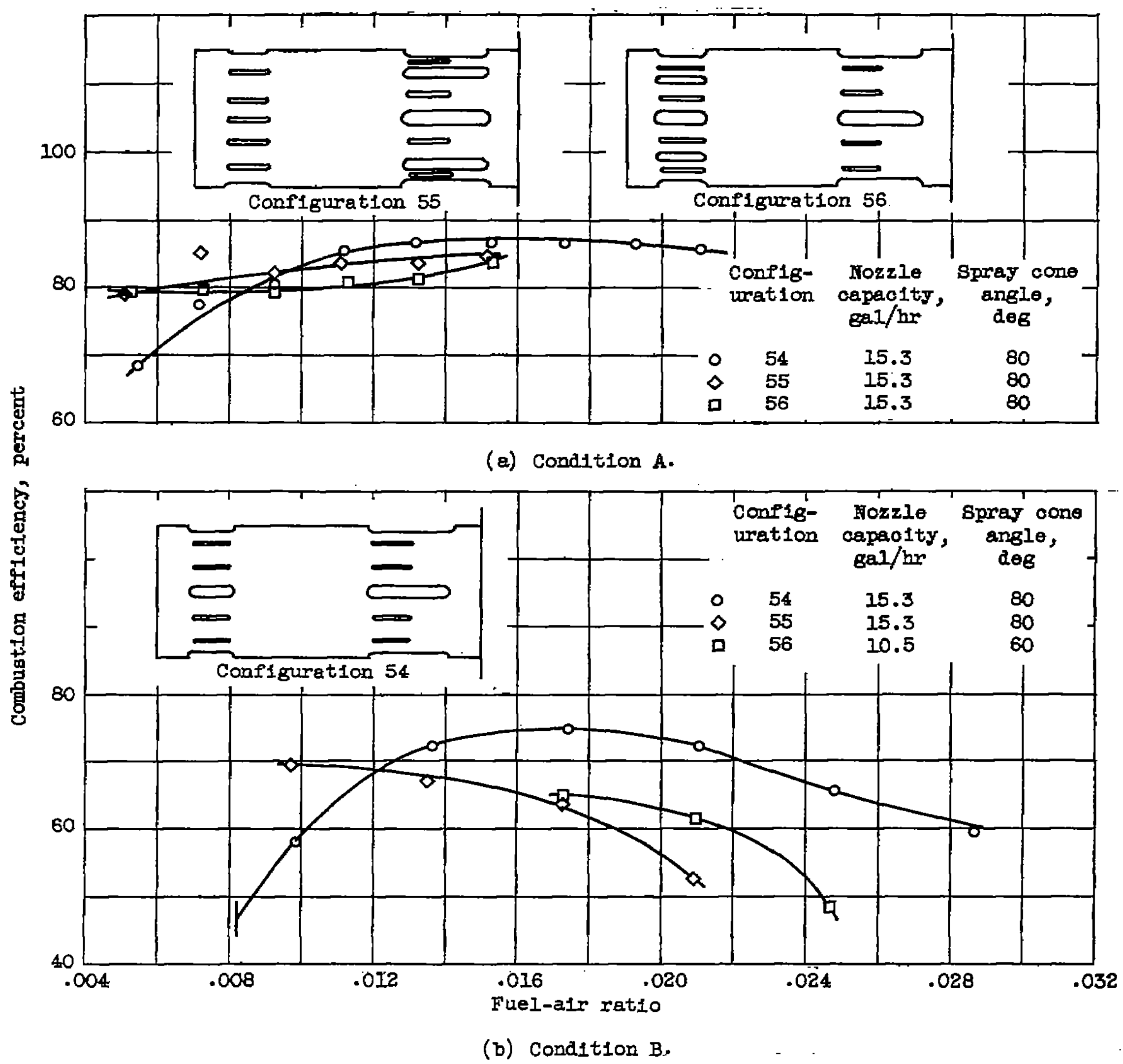
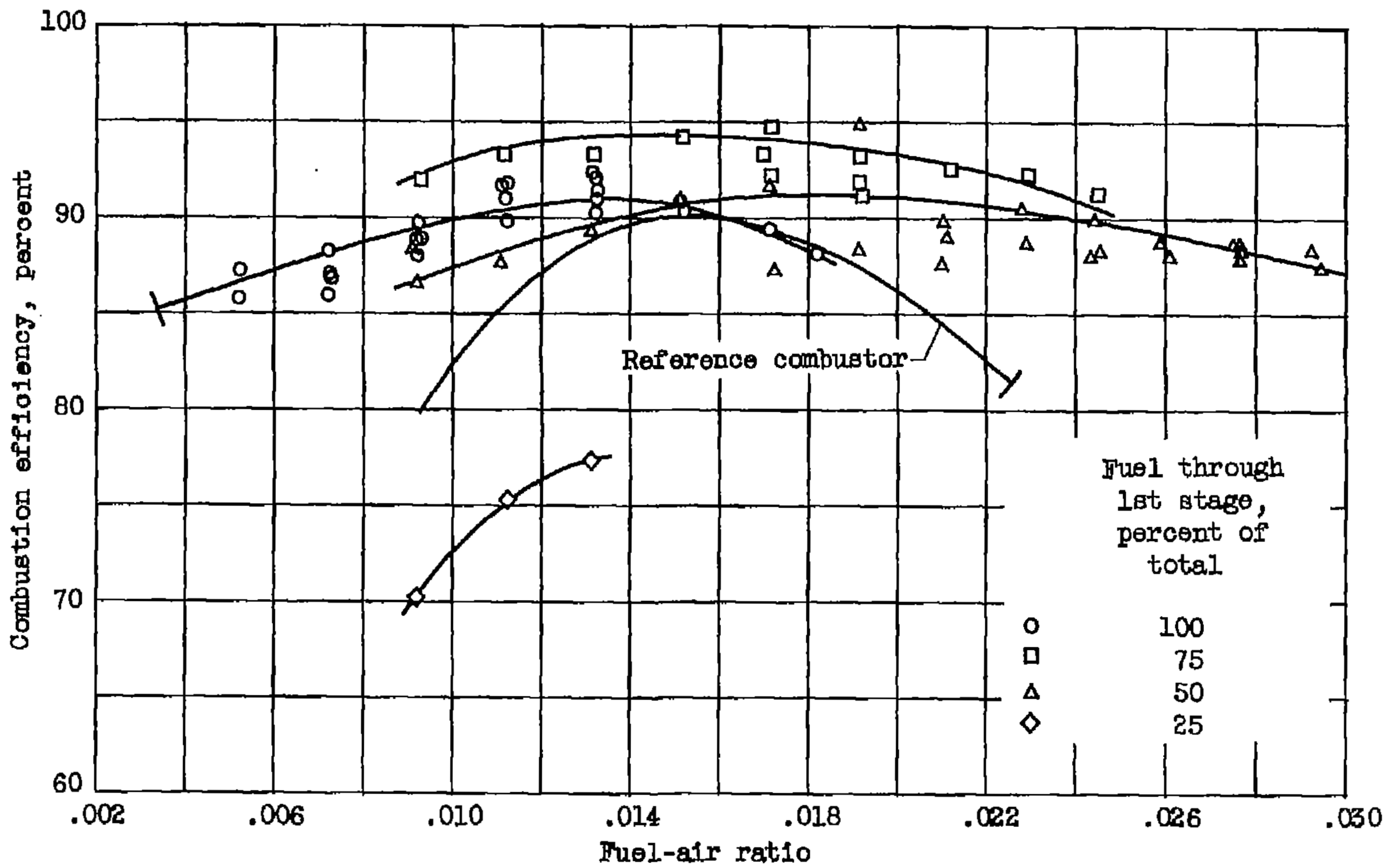


Figure 19. - Effect of changes in secondary-sleeve air-entry design on combustion efficiencies of same pilot.

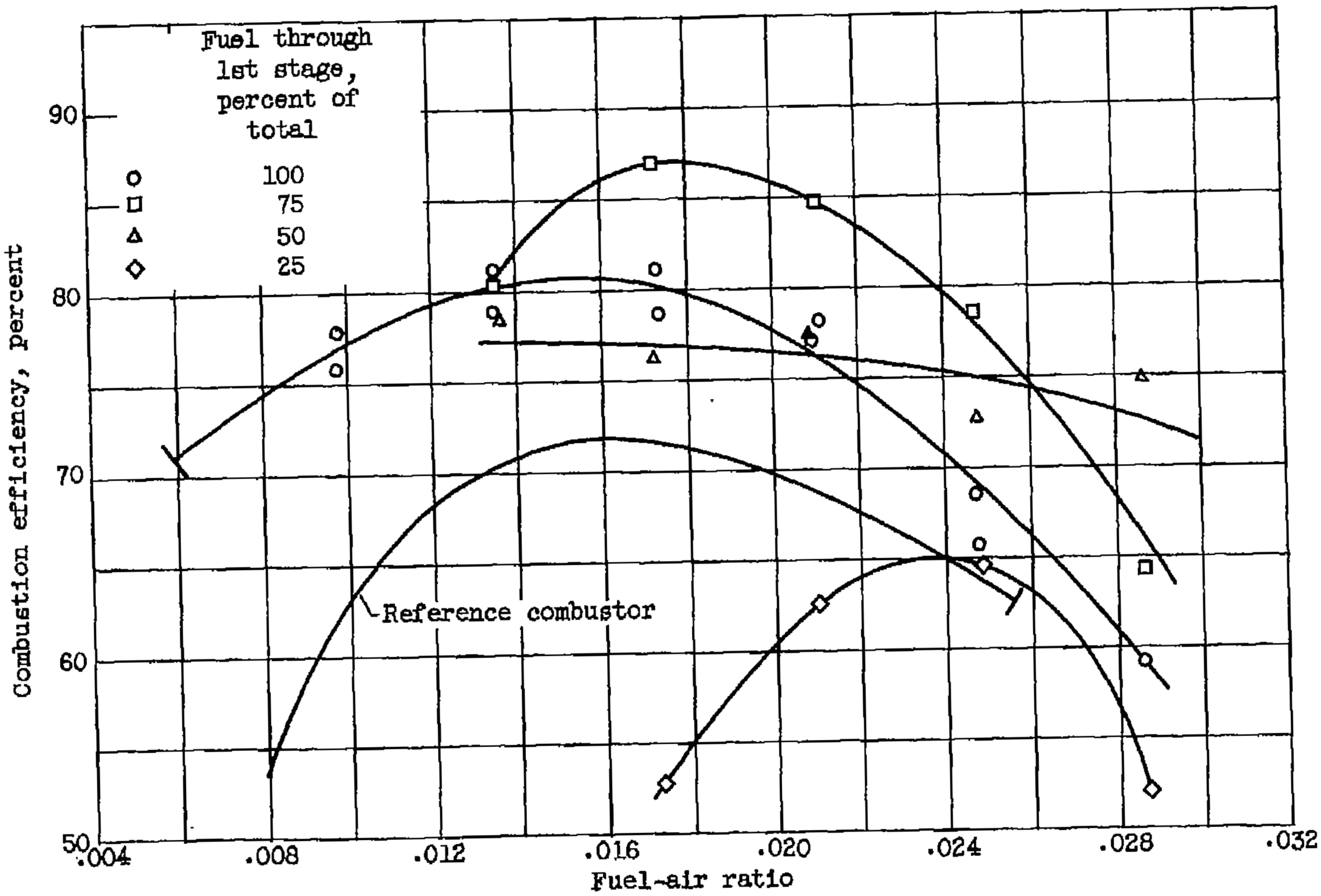
[redacted]



(a) Inlet condition A. (Reference combustor data from ref. 8)

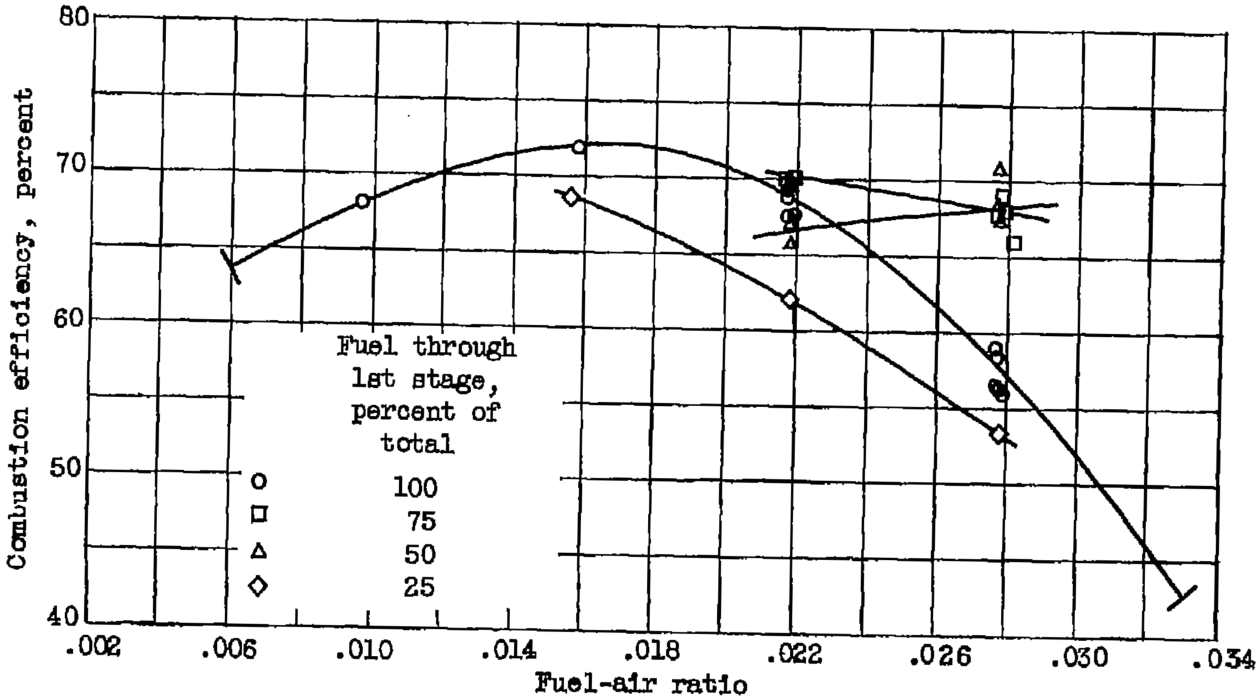
Figure 20. - Combustion efficiencies of best configuration (57).

[redacted]



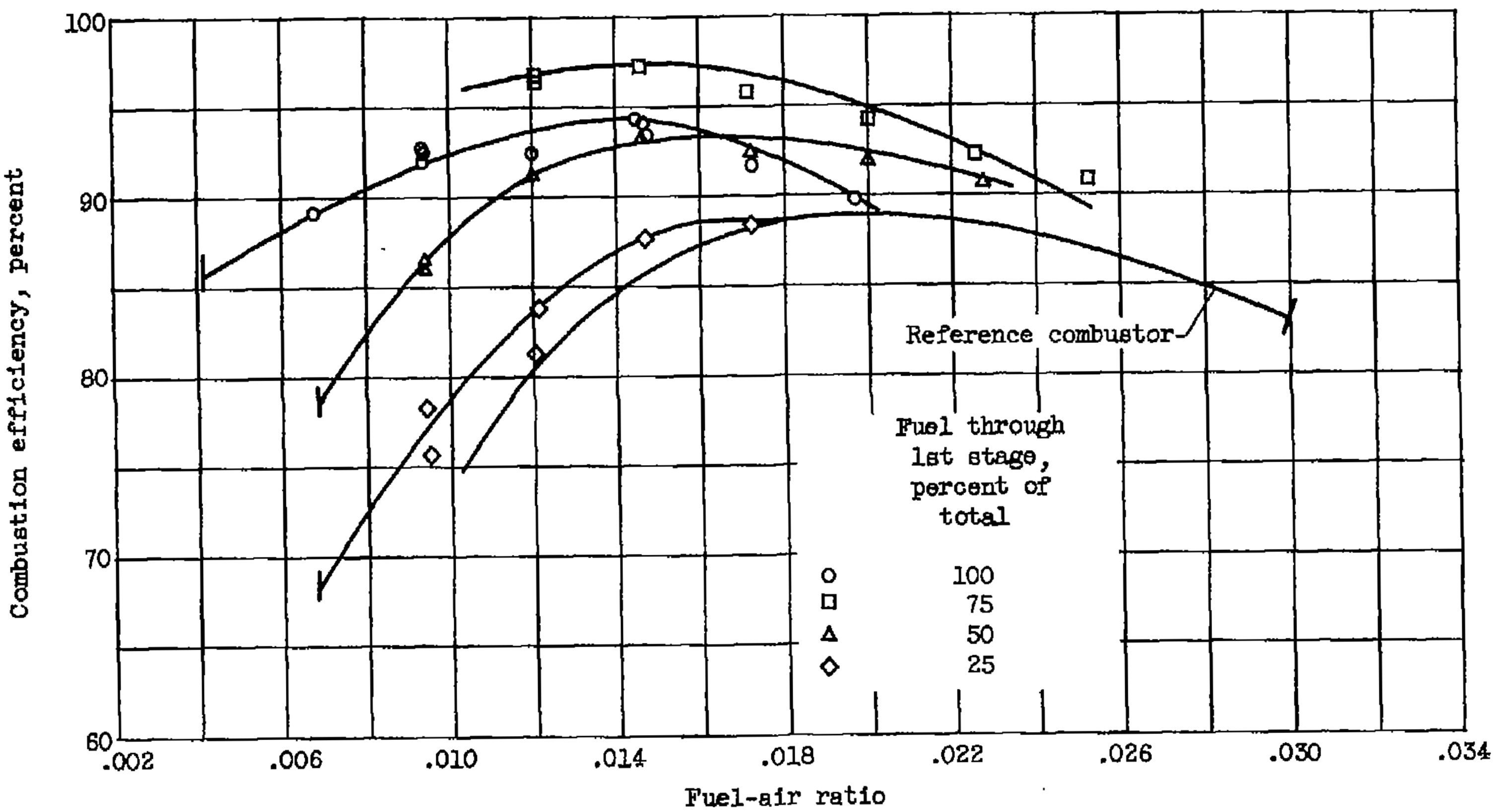
(b) Inlet condition B. (Reference combustor data from ref. 8.)

Figure 20. - Continued. Combustion efficiencies of best configuration (57).



(c) Inlet condition C.

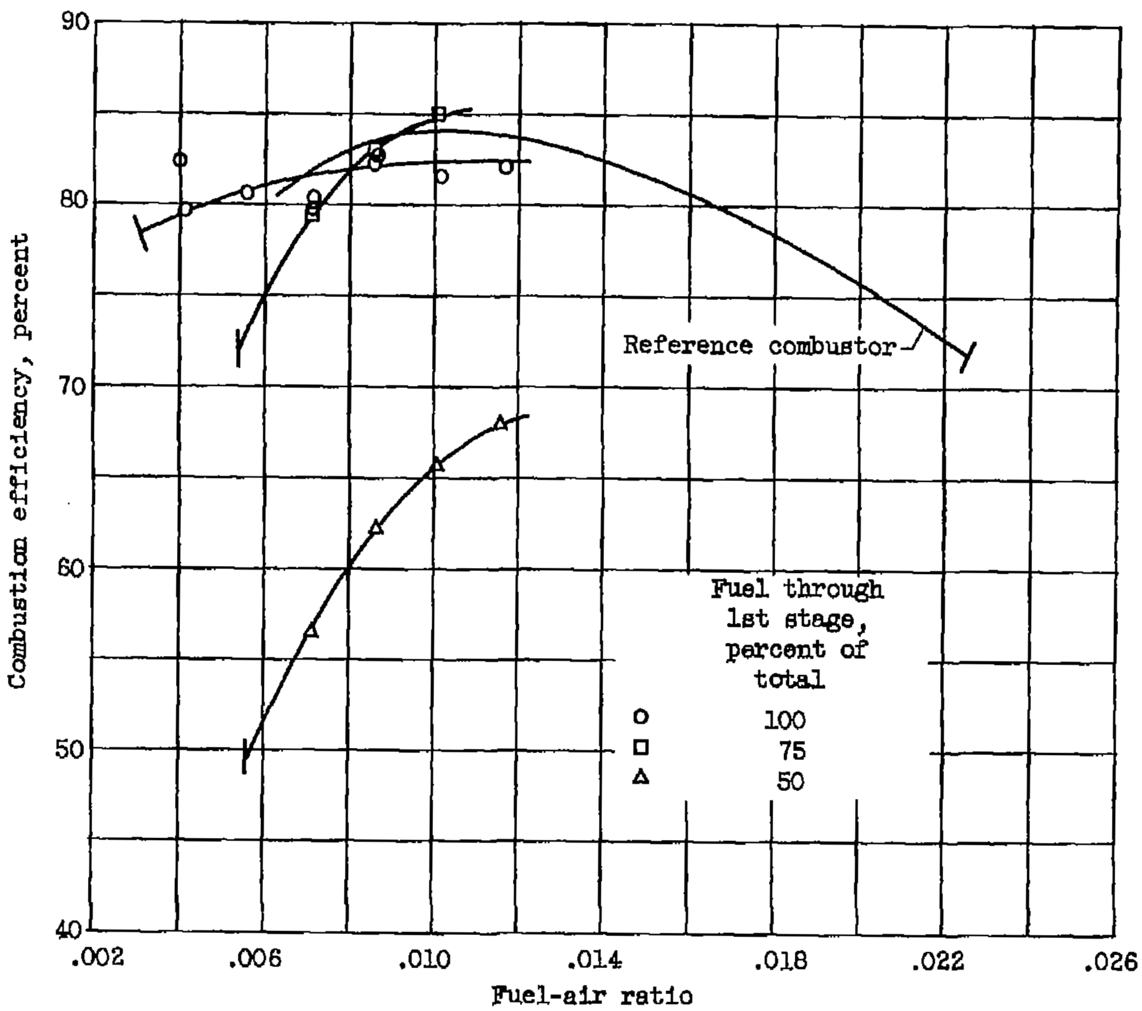
Figure 20. - Continued. Combustion efficiencies of best configuration (57).



(d) Inlet condition D. (Reference combustor data from ref. 8).

Figure 20. - Continued. Combustion efficiencies of best configuration (57).

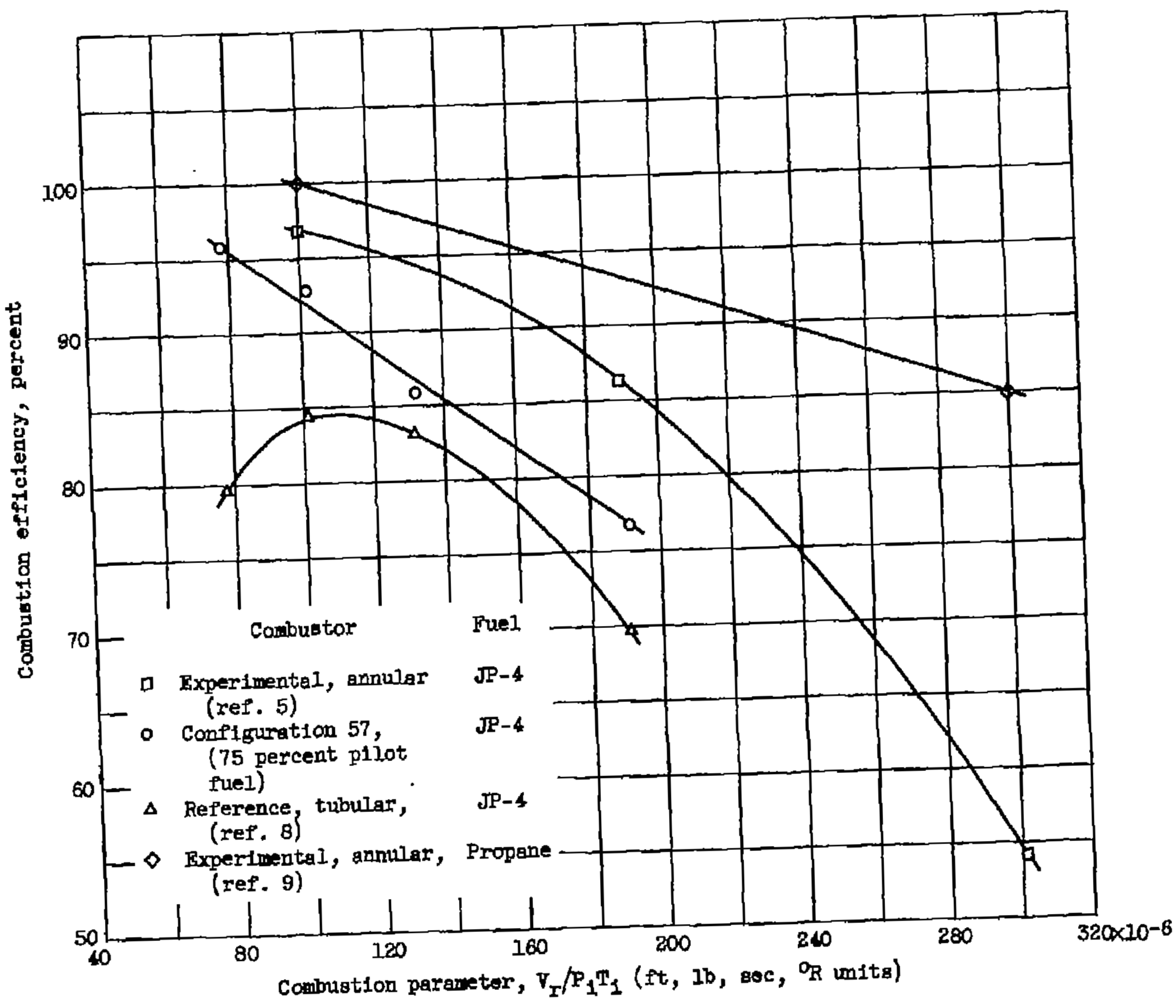
[redacted]



(e) Inlet condition E. (Reference combustor data from ref. 8).

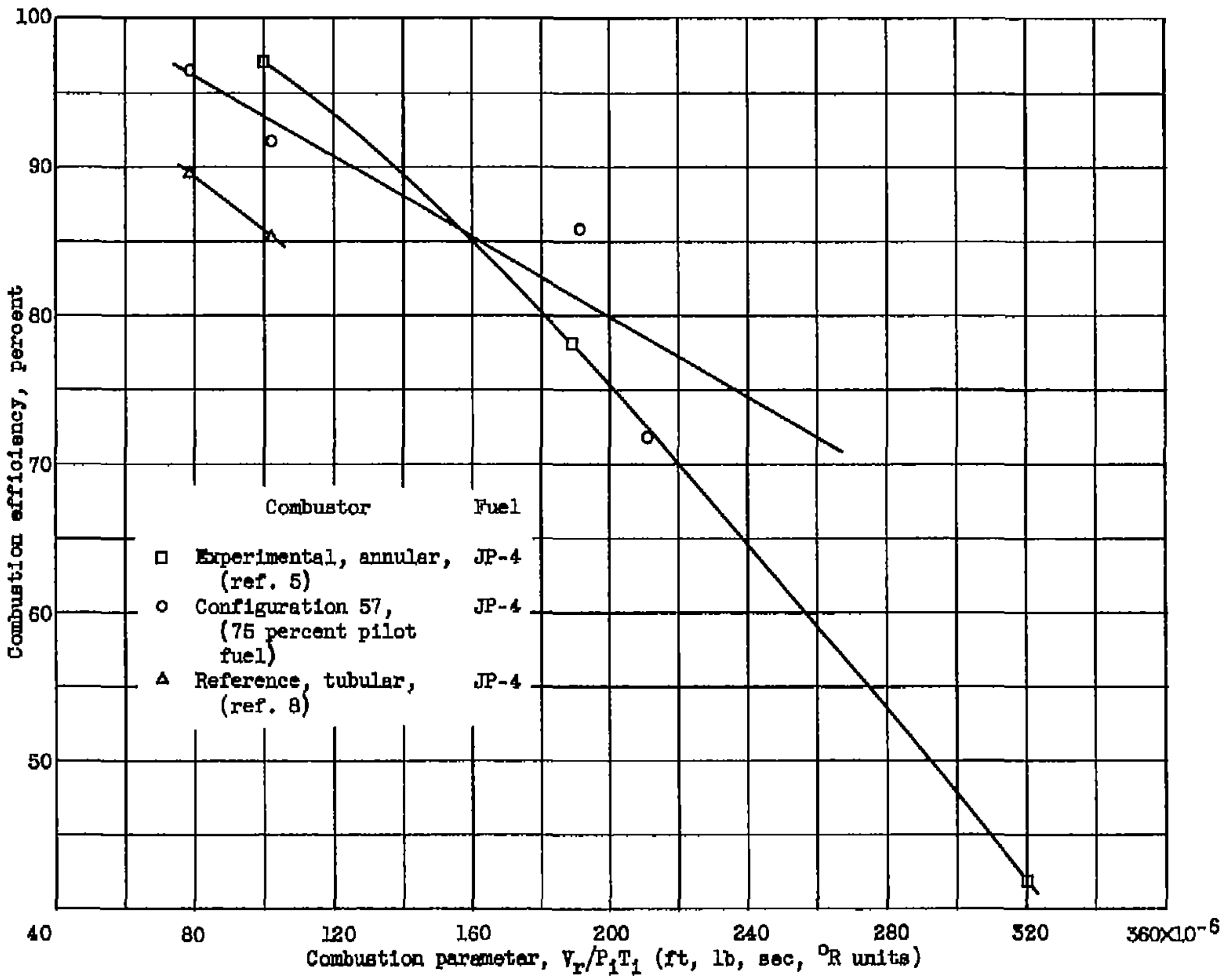
Figure 20. - Concluded. Combustion efficiencies of best configuration (57).

[redacted]



(a) Combustor temperature rise, 680° F.

Figure 21. - Correlation and comparison of combustion efficiency data of figure 20. $V_r/1.3$ used for tubular combustors.



(b) Combustor temperature rise, 1180° F.

Figure 21. - Concluded. Correlation and comparison of combustion efficiency data of figure 20. $V_r/1.3$ used for tubular combustors.

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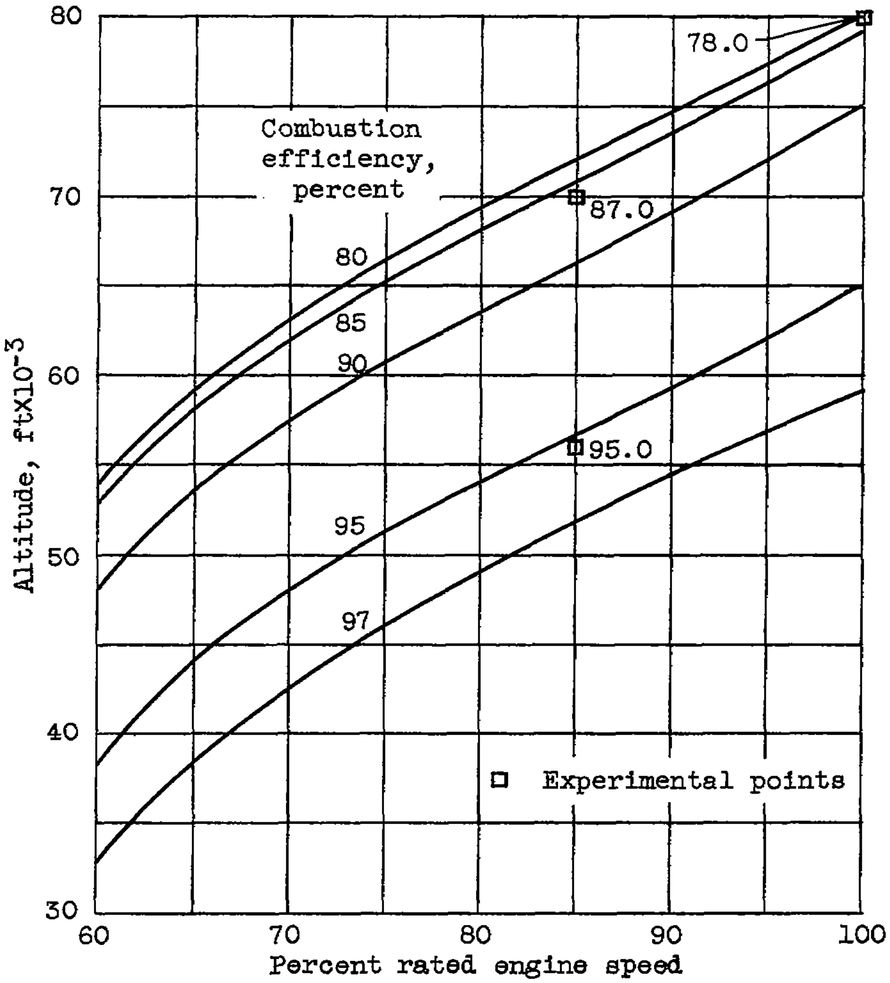
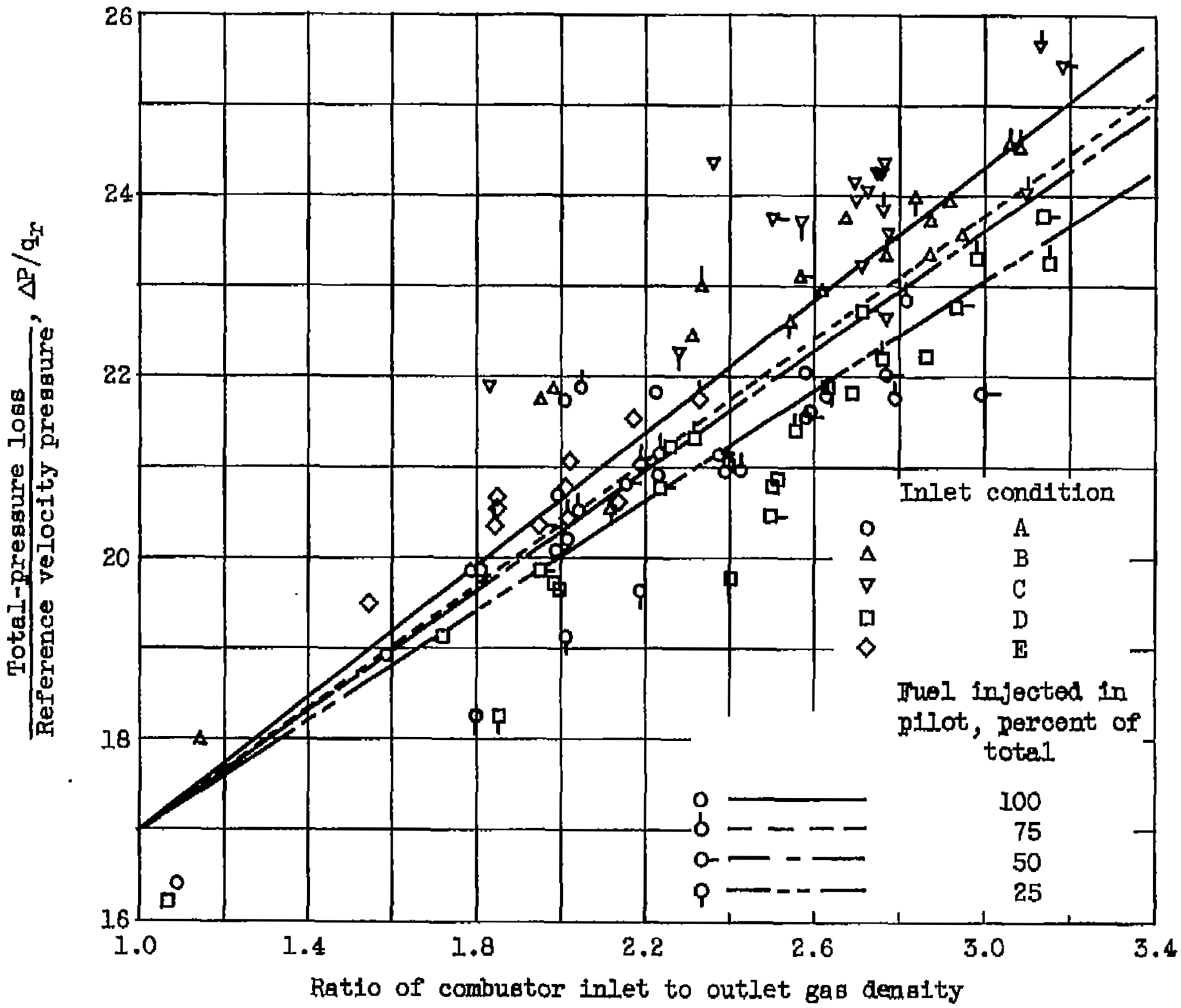


Figure 22. - Estimated altitude flight performance of best configuration (57) in 5.2-pressure-ratio engine at flight Mach number of 0.6.



(a) As function of reference velocity pressure.

Figure 23. - Pressure losses of best configuration (57).

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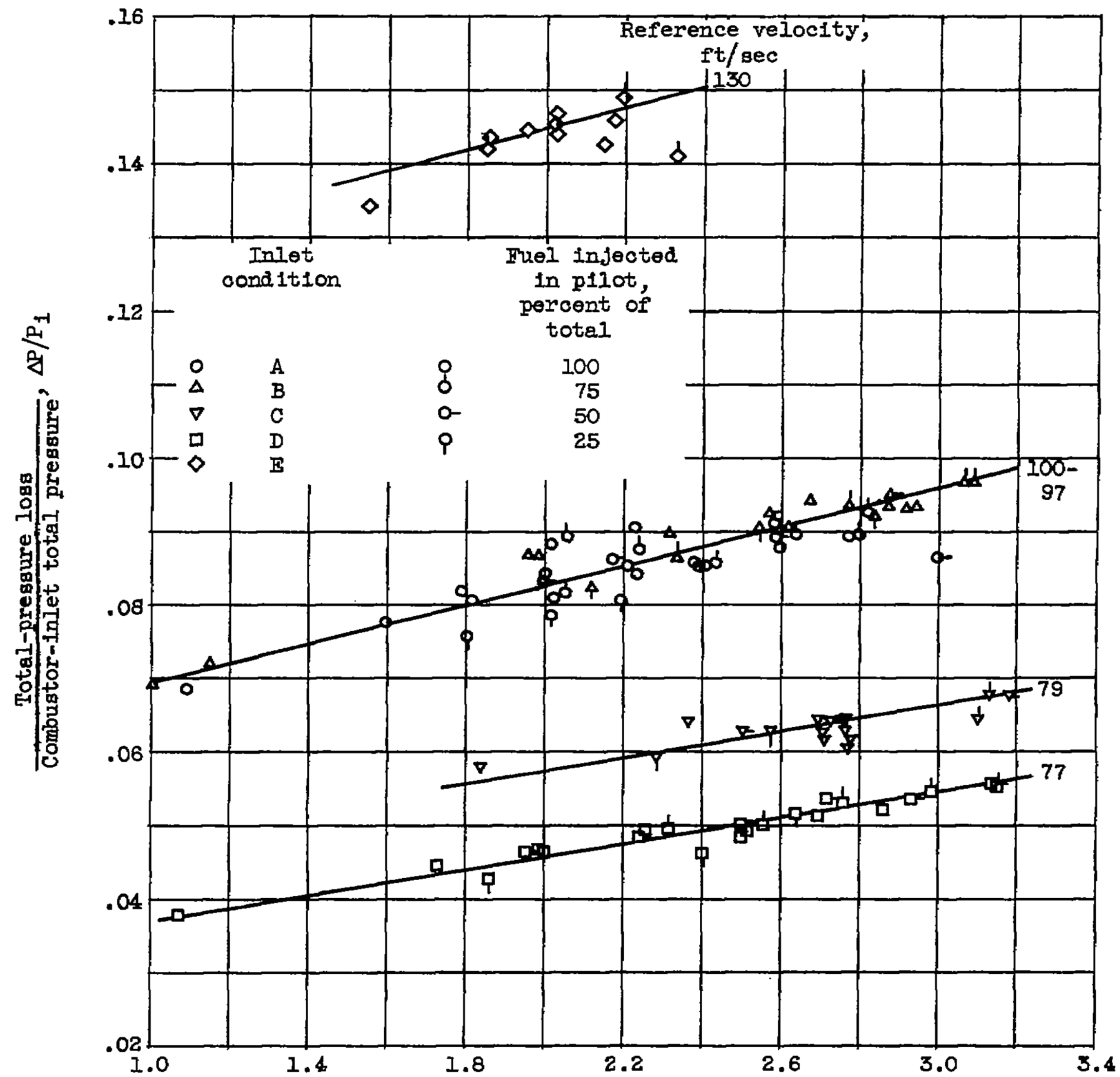

(b) As function of combustor-inlet total pressure.

Figure 23. - Concluded. Pressure losses of best configuration (57).

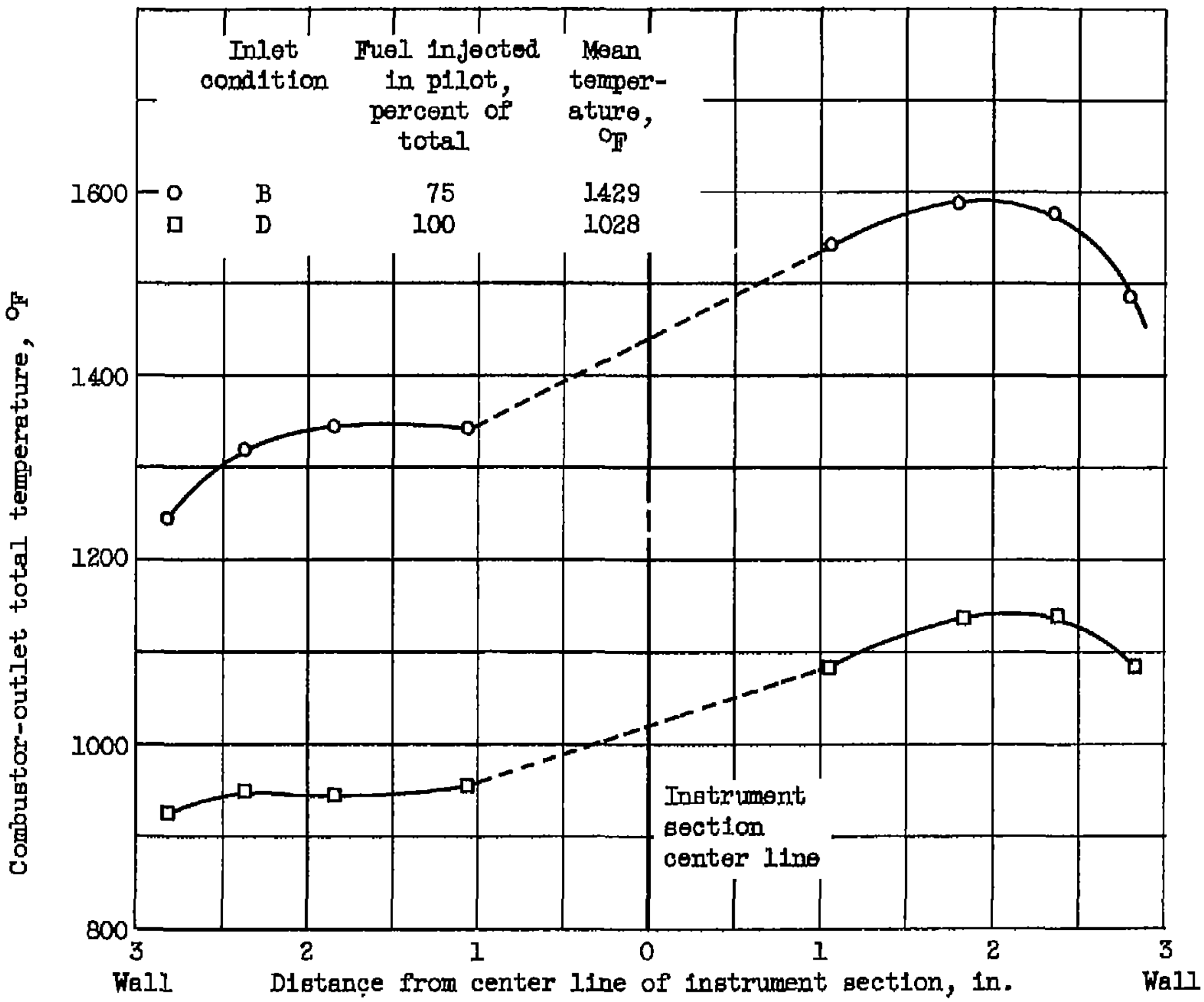

Figure 24. - Representative combustor-outlet total-temperature distributions of best configuration (57).