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RESEARCH MEMORANDUM

PERFORMANCE OF A VAPORIZING ANNULAR TURBOJET COMBUSTOR AT SIMULATED HIGH ALTITUDES

By Carl T. Norgren

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY

As part of a general program to determine design criteria for turbojet combustors, an experimental vaporizing annular combustor was evolved from a high-performance annular combustor developed for vapor-fuel injection. The combustor consisted of a one-quarter sector of a single-annulus combustor designed to fit in a housing with an outside diameter of 25.5 inches, an inside diameter of 10.6 inches, and a combustor length of approximately 23 inches. Liquid fuel was supplied to three heat-exchanging coils located in the region between the primary and secondary combustion zones. The prevaporized fuel was then injected into the combustion chamber from the upstream end of the combustor. The combustor was designed to operate with liquid fuel at low altitudes and sea-level operation.

The combustor was investigated at simulated high-altitude flight conditions corresponding to operation in a 5.2-pressure-ratio engine at a flight Mach number of 0.6 at cruise speed. Combustion efficiencies of 98, 90, and 82 percent were obtained at 56,000, 70,000, and 80,000 feet, respectively, at a temperature-rise level of 1180° F (temperature requirement at rated speed). Increasing the air flow to 69 percent above current practice at an altitude of 56,000 feet gave a combustion efficiency of 82 percent; however, the use of larger fuel atomizers and an external fuel preheat to 150° F at this condition increased combustion efficiency to 98 percent. Since the fuel is used as a coolant in present-day aircraft, external fuel preheat to 150° F would be available.

The combustor pressure losses were comparable to those of current production-model combustors. A total-pressure loss of 4 to 6 percent at a combustor reference velocity of 80 feet per second was obtained. Installation of the prevaporizing system in the combustor resulted in negligible over-all pressure loss. The combustor exhaust-temperature profile followed the pattern generally desired at the turbine position.

INTRODUCTION

Research at the NACA Lewis laboratory has shown that high-altitude operating characteristics of an annular turbojet combustor can be improved if the fuel is prevaporized (ref. 1). A quarter-sector annular combustor was developed (ref. 2) to operate under simulated flight conditions at 70,000 feet with over 92-percent combustion efficiency using gaseous propane in lieu of liquid fuel. The investigation reported herein was conducted to develop a combustor with vapor fuel supplied from 3237
liquid fuel by means of a heat exchanger within the combustor. A combustor similar to that of model 28I, reported in reference 2, was modified to accommodate installation of the fuel prevaporizer; suitable changes in the primary air-entry pattern were incorporated to maintain performance characteristics.

The heat-exchanging surface of the fuel prevaporizer was designed to vaporize most of the fuel at high-altitude conditions without heating the fuel to temperatures that would cause a rapid decomposition of the fuel within the prevaporizer. The prevaporizer was located near the downstream end of the primary combustor zone to minimize any deleterious quenching effect of cold heat-exchanger walls on combustion. At the same time, advantage was taken of the high gas temperatures available in this region, thus reducing the heat-transfer area and the size of the prevaporizer required. The combustor was designed to operate with liquid fuel at sea level and low altitudes, with an increasing vapor content up to a simulated altitude of 56,000 feet, at which point the liquid fuel would be approximately 100 percent vaporized. The heat exchanger was incorporated into a series of radial struts that served as shields for the secondary jets. The secondary air jets were admitted through large slots that have been found desirable for control of the outlet-temperature profile (ref. 1). The shields were located in a region of low-velocity flow, thereby incurring low pressure losses.

The combustor used in this investigation was a one-quarter segment of a 25.5-inch-diameter annular turbojet installed in a direct-connect duct. Data are presented to compare performance at a flight Mach number of 0.6 in a 5.2-pressure-ratio turbojet engine operating at 85 percent rated rotor speed at 56,000, 70,000, and 80,000 feet. In addition, one condition representing 69 percent increased air flow at 56,000 feet was investigated. Data including combustion efficiency, outlet radial-temperature profile, combustor pressure losses, and specific fuel consumption are shown.

APPARATUS

Installation

The combustor installation (fig. 1) was similar to that of reference 1. The combustor-inlet and -outlet ducts were connected to the laboratory air supply and low-pressure exhaust systems, respectively. Airflow rates and combustor pressures were regulated by remote-controlled valves located upstream and downstream of the combustor. The desired combustor-inlet air and fuel temperatures were obtained by means of electric preheaters.

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Instrumentation

Air flow was metered by a sharp-edged orifice installed according to A.S.M.E. specifications. The liquid fuel-flow rate was metered with a calibrated rotameter, and the vapor fuel-flow rate with a calibrated sharp-edged orifice. Thermocouples and pressure tubes were located at the combustor-inlet and -outlet instrument stations indicated in figure 1. The number, type, and position of these instruments at each of the four stations are indicated in figure 2. The combustor-outlet thermocouples (stations 2 and 4) and pressure probes (station 3) were located at centers of equal area in the duct. Manifolded upstream total-pressure probes (station 1) and downstream static-pressure probes (station 3) were connected to absolute manometers; individual downstream total- and static-pressure probes were connected to banks of differential manometers. The chromel-alumel thermocouples (stations 2 and 4) were connected to a self-balancing, recording potentiometer.

Combustors

Final configuration. - Design principles evolved in the series of combustor modifications of references 1 and 2 were used in the present investigation to develop the final combustor air-entry hole configuration. The combustor consisted of a one-quarter segment (90°) of a single annulus having an outside diameter of 25.5 inches, inside diameter of 10.6 inches, and a length from fuel injectors to combustor-outlet thermocouples (station 2) of approximately 25 inches. The maximum combustor cross-sectional area was 105 square inches (corresponding to 420 sq in. for the complete combustor). Five fuel atomizers (corresponding to 20 atomizers in the complete combustor) injected fuel in the downstream direction from the upstream end of the combustor. Three prevaporizing coils (corresponding to 12 coils in the complete combustor) vaporized the liquid fuel prior to injection into the combustion zone. A three-quarter cutaway view of the final combustor configuration with the internal fuel prevaporizer installed is shown in figure 3. A longitudinal cross-sectional view of the combustor is shown in figure 4.

Development. - Combustor model 28 of reference 2 was used as the basic combustor configuration for the investigation reported herein. As a first step toward incorporating prevaporizing coils into the model 28 combustor, three large slots in the inner and outer walls with radial shields (see fig. 3) were designed to admit secondary air, to accomodate future prevaporizing coils (not installed in this model), and to provide adequate mixing of the secondary air and the hot primary combustion gases. The combustor modified in this way will be referred to hereinafter as model 29. The inlet air-entry hole geometry of model 29 was subsequently modified somewhat in order to improve the combustion efficiency performance. Developmental tests of model 29 were conducted with gaseous propane fuel. This fuel was injected downstream into the combustion chamber through sharp-edged orifice-type nozzles which had previously been developed for propane injection (ref. 3).

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The final air-entry configuration (model 30) is shown as a developed view in figure 5(a). The ratio of the total progressive open-hole area along the combustor length is shown in figure 5(b) for combustor model 30. Also included in figure 5(b), for reference, is the open-air distribution of the original combustor model 28. The increased primary-zone open area of model 30 is readily apparent; for example, at a combustor length 5 inches from the fuel manifold, 41 percent more area is opened in model 30 than in model 28.

Fuels and Fuel System

Liquid MIL-F-5624A grade JP-4 fuel was supplied to the combustor for most of the tests. The inspection data for this fuel are presented in table I. The vapor fuel used for development and comparison tests was commercial propane.

Preliminary tests were conducted in model 30 with propane fuel. The final evaluation of combustor model 30 was conducted with the liquid-fuel prevaporizing coils installed in the combustor as shown in figure 3. The fuel-prevaporizing system is shown in figure 6. Preliminary calculations indicated that a heat-transfer surface area of 60 square inches would be required to vaporize the fuel required for operation at 56,000 feet, which corresponds approximately to 6.5 percent of the maximum sea-level fuel requirements in the reference turbojet engine. The heat-transfer surface was incorporated into three prevaporizing coils of the type shown in figure 6. Liquid fuel was supplied to the prevaporizing coils by means of tubing located internally as shown in figure 6. The three prevaporizing coils were connected in series, and the vapor fuel returned internally to the fuel manifold, where it was distributed to five fuel nozzles. The total heat-transfer surface area in model 30 was 70.7 square inches, which included the coils and associated connecting tubing.

The fuel nozzles as shown in figure 6 were used during the investigation of model 30 combustor. Simple sharp-edged orifices were selected on the basis of previous performance (ref. 3), and simple swirl generators were installed to break up and distribute partially vaporized fuel. These nozzles will be referred to hereinafter by their letter designation which will follow the model designation (e.g., model 30I). The fuel nozzles are described in the following table:

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Fuel nozzle	Description
I	Simple sharp-edged orifice, 7/64-in. diam.
J	Simple sharp-edged orifice, 7/64-in. diam., 0.026-in. hole through swirl generator
L	Simple sharp-edged orifice, 1/8-in. diam., simple swirl generator
M	Simple sharp-edged orifice, 5/32-in. diam., simple swirl generator

PROCEDURE

The test conditions investigated are given in the following table:

Test condition	Combustor-inlet total pressure, P_i, in. Hg abs	Combustor-inlet total temperature, T_i, °F	Air-flow rate per unit area,[a] W_a/A_r, lb/(sec)(sq ft)	Simulated flight altitude in reference engine at cruise speed, ft
A	15	268	2.14	56,000
B	8	268	1.14	70,000
C	5	268	.714	80,000
E	15	268	3.62	56,000

[a]Based on maximum combustor cross-sectional area of 0.73 square foot.

The combustor was operated at three simulated flight conditions, test conditions A, B, and C, for a reference turbojet engine with a 5.2-pressure ratio at a flight Mach number of 0.6. Cruise speed was taken as 85 percent of the rated rotor speed. One additional condition, test condition E, was selected to represent an air-flow rate 69 percent above 3237
that required in the reference engine. At each test condition, combustion efficiencies and pressure-loss data were recorded for a range of fuel-air ratios.

Combustion efficiency was computed by the method of reference 4 as the percentage ratio of the actual to the theoretical increase in enthalpy from the combustor-inlet to the combustor-outlet instrumentation plane (stations 1 and 2). In preliminary tests, the arithmetic mean of the 30 outlet thermocouple indications was used to obtain the value of combustor-outlet enthalpy for the experimental combustor configuration. In a number of tests, correction was made for variations in mass flow past each thermocouple of station 2.

For most of the data presented herein, combustion efficiency was computed using the arithmetic mean of 30 chromel-alumel thermocouples located at station 3 (fig. 1). For these tests, the thermocouples at station 2 and the total-pressure probes at station 3 were removed, and an Inconel exhaust-gas mixer (fig. 7) was installed upstream of station 2 at the exhaust end of the combustor. Gases flowing along the inner wall of the mixer tend to be displaced toward the outer wall and vice versa; in addition, turning is imparted by the guide vanes. An erratic temperature profile was obtained 2 inches downstream of the mixer; however, as the mixing length was increased to 8 inches (station 3), a uniform exhaust-gas temperature was obtained. Since the average outlet temperature indications at stations 2 and 3 were the same, it was assumed no afterburning had taken place, and that the actual combustion performance was not affected by the installation of the mixer.

The radial-temperature distribution at the combustor outlet, station 2, was determined for a temperature rise across the combustor of approximately 1180° F, which corresponds to the required value at 100 percent of rated engine speed in the reference turbojet engine at altitudes above the tropopause. The radial temperature indications were obtained from four thermocouple rakes. The thermocouple rake at each side wall of the combustor was not included in these average temperatures (fig. 2(b)), since the side walls exert an influence on the flow pattern and temperature profile that would not be present in a complete annulus.

RESULTS AND DISCUSSION

Performance of Model 29I Combustor

The experimental data obtained in the investigation of a one-quarter sector prevaporizing combustor are presented in table II.

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Combustion efficiency. - The combustion efficiencies obtained with propane in model 29I combustor are presented in figure 8 for a range of fuel-air ratios at one test condition. Combustor model 28I is included for comparison, since it represents the highest combustion efficiencies obtained previously with vapor (propane) fuel in a near-optimum combustor unit. Curves obtained with model 29I are shown for (1) the vaporizer shield installed, and (2) the shields removed. The presence of the shields appeared to aid combustion efficiency, particularly at the high fuel-air ratios. Combustor model 29I (with the vaporizer shields) operates with efficiencies 7 to 8 percent lower than model 28I. This decrease in efficiency is attributed to a shift in air distribution resulting from the introduction of the large secondary air slots in model 29I. Each combustor had identical primary hole patterns; however, model 29I had approximately 9.5 percent more open area in the secondary zone than model 28I. Combustion efficiency data obtained for model 29I combustor (without shields) were the same at test condition C when based on temperatures measured at station 2 or when based on temperatures measured at station 3 with the mixer installed.

Pressure loss. - The pressure losses of combustor model 29I are shown in figure 9. The pressure loss is presented as the ratio of the total-pressure loss to the combustor-inlet total pressure for a range of inlet-to-outlet gas density ratios. The installation of the shields reduced the pressure losses approximately 15 percent below combustor model 29I without shields (combustor reference velocity of 80 ft/sec). The shields blocked approximately 45 percent of the annular passage; however, this blocked area was located near the end of the primary combustion zone, at which position only about 30 percent of the combustion air had been admitted. The entrance and mixing losses of the secondary air stream were apparently reduced sufficiently by the shields to result in reduced over-all pressure losses with the shields in place.

Performance of Model 30

Combustor model 30 was developed from model 29I by a series of design changes directed toward improving the combustion efficiency of model 29, and incorporating fuel-prevaporizing coils for use with liquid MIL-F-5624A grade JP-4 fuel. The performance was determined at the high-altitude test conditions A, B, C, and E with fuel injector L (1/8-in. orifice).

The combustion-efficiency curves are presented in figure 10 for efficiencies computed from the indicated outlet thermocouple readings with no correction, with correction for mass-flow distribution, and with a mixer installed in the exhaust gas. Correcting for mass-flow distribution reduced the computed combustion efficiency. Previous experience has indicated that uneven temperature profiles generally cause erroneously high arithmetically averaged temperature readings (ref. 1). Even though the efficiency data were reduced, the curves indicated a combustion efficiency over 100 percent for several conditions. This would indicate insufficient instrumentation; however, because of the physical limitations of the exhaust section, additional instrumentation was impractical.

The combustion efficiencies of model 30L (fig. 10) with the mixer shown in figure 7 installed in the exhaust stream are from 7 to 13 percent lower than the uncorrected efficiencies, and from 2 to 10 percent lower than the efficiencies corrected for mass-flow distribution. With the mixer installed, the outlet thermocouple indications at station 3 were relatively uniform; therefore, errors due to mass distribution would be negligible. Additional data were obtained from temperature indications approximately 7 feet downstream (station 4) in the 20-inch-diameter exhaust duct. In this length, the exhaust gas had mixed such that both flow and temperature indications were uniform. Combustion efficiencies were computed from thermocouple indications in the exhaust duct (water sprays shown in fig. 1 were shut off), and allowance was made for laminar-flow free-convection heat losses from the duct. Agreement within $1\frac{1}{2}$ percent was obtained with the efficiencies computed at station 3. It was assumed that the efficiency measurements obtained with the exhaust-gas mixer installed and the thermocouple indications at station 3 were reliable; all subsequent combustion efficiencies reported were obtained in this manner.

Combustion-efficiency data are shown in figure 11 for three different sets of fuel nozzles at test conditions A, B, C, and E. The three nozzle configurations J, L, and M represent increasing fuel-orifice diameters of 7/64, 1/8, and 5/32 inch, respectively. The nozzles had simple swirl generators installed. Nozzle modification J, however, had a hole 0.026 inch in diameter axially through the swirl generator to allow a portion of the fuel to squirt directly into the combustion zone, thus increasing the fuel penetration, which has previously been found desirable in a combustor of this type (ref. 3). These curves indicate that for a test condition such as C (fig. 11(c)), where the total fuel flow required is small, the smaller capacity atomizer (model J) produces the best over-all combustion efficiency. As the fuel requirements increase (test conditions A and B (figs. 11(a) and (b)), the larger capacity atomizer (model L) produces a better over-all combustion efficiency. At high air flows, such as test condition E (fig. 11(d)), the efficiency is maintained uniformly high by a still larger fuel atomizer (model M). This trend falls within general agreement with previously reported work on the effect of fuel-injector design (ref. 5).

The effect of fuel preheating external to the combustor on the combustion efficiency of model 30M is presented in figure 12. The test condition investigated, E, required the highest fuel-flow rates of the conditions considered; hence, insufficient prevaporizing capacity of the coils would be most apparent at this condition. It is shown (fig. 12) that as additional heat was supplied by increasing the initial fuel temperature to 150° or 190° F, combustion efficiencies were improved as much as 8 percent at the higher fuel-air ratios. As anticipated, additional data obtained at test conditions B and C (see table II) indicated that either minor or no improvements were experienced with similar fuel preheat.

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The additional fuel preheat required for test condition E could be obtained by increasing the surface area of the prevaporizer, except that this increased capacity is not considered to be required for test conditions A, B, and C. Fuel in present-day aircraft is used as a coolant in the oil-cooler heat exchanger. If advantage is taken of this initial temperature rise in the fuel, the prevaporizing coils in this combustor would be of adequate capacity to supply the vapor fuel required to maintain high combustion efficiencies for fuel flows 69 percent higher (test condition E) than those in current practice.

The heat-exchanging coils used during the investigation accumulated approximately 50 hours of running. No difficulty was experienced with internal deposits during this time. Fuel-manifold pressure drop was approximately the same at the beginning and the end of the investigation. Additional development would be required, however, to determine the reliability of the heat-exchanger design used.

Performance of Best Combustor Configuration

Combustion efficiencies. - Comparison of combustion efficiencies obtained with combustor model 30I using propane fuel and model 30 with various fuel nozzles and JP-4 fuel are presented in figure 13. The best nozzle configuration investigated for propane fuel (model I from ref. 3) and combustor model 30 with shields installed at the prevaporizer station were used in obtaining the propane data. The best combustion-efficiency data for JP-4 fuel operation of model 30 at test conditions A, B, C, and E were selected, regardless of injector design, from figures 11 and 12. Comparison of the propane and JP-4 fuel curves indicate (1) since maximum efficiencies were obtained by varying the nozzle size with air flow, a variable-area nozzle would be desirable for JP-4 fuel operation and (2) vaporized JP-4 operation is comparable with propane (100-percent vapor fuel) operation.

Figure 14 presents the correlation of the combustion-efficiency data of the prevaporizing combustor models 30J, 30L, and 30M with the combustion parameter $V_r/p_i T_i$ (ref. 6), where V_r is the combustor reference velocity based on the maximum cross-sectional area; p_i is the inlet total pressure, and T_i is the inlet-air temperature. The values of combustion efficiency were obtained from the efficiency curves of figures 10 and 11 at a temperature-rise level of 1180° F (required temperature rise for rated speed). The combustion efficiencies obtained with propane fuel in model 28I (ref. 2) are included for comparison. At a combustor reference velocity of 80 feet per second (test conditions A to C at combustion efficiencies of 98, 90, and 82 percent, respectively), model 30L (1/8-in. orifice) operated within 2 percent of model 28I. At a combustor reference velocity of 140 feet per second (test condition E), the efficiency was 82 percent with model 30L; however, this efficiency was increased to 98 percent with model 30M (5/32-in. orifice) and an external fuel preheat temperature of 150° F. Combustor models 30J and 30M operated at lower efficiencies than model 30L at the basic combustor reference velocity of 80 feet per second.

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Temperature profile without mixer. - The outlet-radial-temperature profile of combustor model 30 and the desired temperature profile are shown in figure 15. The desired temperature profile represents an approximate average of those profiles required or desired in various turbojet engines. The isothermal temperature-contour patterns obtained at the combustor-exhaust section at test condition A are shown in figure 16. These patterns were obtained for model 30L combustor configuration and were recorded for an average indicated outlet temperature of approximately 1450° F. The prevaporizing coil shields and the fuel atomizer locations are indicated in figure 16, for they should be expected to influence the temperature profiles. The outlet-temperature profiles and contour patterns do not indicate wide variations in outlet temperature that were assumed responsible for the abnormally high combustion efficiencies obtained in earlier tests at these conditions (fig. 10). However, more complete instrumentation of the exhaust gas may reveal strong temperature gradients or mass-flow variations to which the abnormally high combustion efficiencies may be attributed.

Pressure losses. - The combustor pressure losses of the model 30 combustor are shown in figure 17. In figure 17(a), the pressure losses are plotted as a ratio of the total-pressure loss to the reference dynamic pressure. The pressure losses of model 28I (ref. 2) are included for comparison. The development of an internal fuel-prevaporizing system from the vapor fuel combustor model 28I did not necessitate an increase in pressure loss. No attempt was made to decrease the pressure losses in this program other than by the initial choice of a low-pressure-loss configuration. In figure 17(b), the pressure losses are presented as the ratio of total-pressure loss to combustor-inlet total pressure. Pressure losses from 4 to 6 percent at a combustor reference velocity of 79 feet per second are obtained for the model 30 combustor, which compare favorably with current production model combustors. At the higher air-flow rate (condition E), pressure losses range from 11 to 14 percent of the total pressure at a combustor reference velocity of 140 feet per second.

Effect on specific fuel consumption. - Figure 18 presents a comparison of the ratio of actual to ideal specific fuel consumption for combustor model 30M and for a current turbojet combustor. The specific-fuel-consumption ratio was computed, assuming for the ideal case: (1) 100 percent combustion efficiency, and (2) no pressure loss. The specific fuel consumption for simulated flight operation was computed using the cycle-efficiency method described in reference 7. Basic assumptions are listed as follows:

Ambient temperature, $^{\circ}R$	392.4
Ambient pressure, in. Hg	2.14
Compressor efficiency, percent	70.3
Diffusor recovery factor, percent	95.0
Turbine efficiency, percent	90.0
Nozzle coefficient	0.96
Turbine-inlet temperature, $^{\circ}R$	2010
Flight Mach number	0.6

The data point at a combustor reference velocity of 106 feet per second was obtained from unpublished data. Since trends toward higher flight speeds result in higher air-flow rates per unit combustor frontal area, the fuel-consumption ratio is plotted against reference velocity. As shown in figure 18, model 30M combustor would operate with a specific-fuel-consumption ratio of 1.057 at an altitude of 56,000 feet and a combustor reference velocity of 80 feet per second, whereas the reference turbojet engine requires a specific-fuel-consumption ratio of 1.242 to produce an equivalent thrust at these conditions. The vaporizing combustor will operate over a comparatively wide range of inlet velocities; however, the reference turbojet engine operates over a range of combustor reference velocities limited at 90 feet per second.

SUMMARY OF RESULTS

The application of an internal fuel prevaporizing system to a turbojet combustor previously developed for vapor-fuel operation was investigated. The following results were obtained with the prevaporizing combustor design for simulated high-altitude flight in a 5.2-pressure-ratio engine at a flight Mach number of 0.6:

1. The best prevaporizing combustor, model 30L, operated with combustion efficiencies of 98, 90, and 82 percent at 56,000, 70,000, and 80,000 feet, respectively, at a temperature rise of 1180° F and a combustor reference velocity of 80 feet per second.

2. Combustor model 30L, at an air-flow rate 69 percent above current practice and altitude of 56,000 feet, gave a combustion efficiency of 82 percent for a temperature rise of 1180° F; however, the use of larger fuel atomizers (model 30M) and external fuel preheat to 150° F at this condition increased combustion efficiency to 98 percent. At the lowest air-flow rates (an altitude of 80,000 ft), combustion efficiency could be improved, particularly at the lean fuel-air ratios, by a smaller atomizer (model J).

3. Installation of radial shields to house the fuel preheating coils resulted in a small decrease in combustor total-pressure loss. The pressure losses of the final prevaporizing combustor were approximately the same (4 to 6 percent at the inlet air velocity of 80 ft/sec) as those of the best combustor designed previously for operation with propane fuel.

4. The combustor-outlet temperature profile was generally satisfactory for the final combustor design.

CONCLUDING REMARKS

Present information indicates that a variable-area nozzle would be desirable over the range of operation investigated for this combustor; however, the combustor would operate at high efficiencies with a fixed-area nozzle at reference velocities of 80 feet per second. Low altitudes and sea-level operating conditions have not been investigated. The combustor was designed to operate as a liquid-fuel-injection combustor in this region; sufficient fuel would flow through the heat-exchanging coils to keep them intact. Additional work would be required to determine the reliability of the heat-exchanger design used in this investigation.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, July 19, 1954

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TABLE I. - FUEL ANALYSIS

Fuel properties	MIL-F-5624A grade JP-4
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	
A.S.T.M. D-875-46T, percent by volume	8.5
Silica gel, percent by volume	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	18,700

[redacted]

[redacted]

[redacted]

TABLE II. - COMBUSTOR TEST DATA

Combustor-inlet total pressure, P_1, in. Hg	Combustor-inlet total temperature, T_1, °R	Air-flow rate, W_a, lb/sec	Air-flow rate per unit area, W_a/A_r, lb/(sec)(sq ft)	Combustor reference velocity, V_r, ft/sec	Fuel-flow rate, W_f, lb/hr	Fuel-air ratio, f	Mean combustor-outlet temperature, T_O, °R	Mean temperature rise through combustor, ΔT, °F	Combustion efficiency, η_b, percent	Inlet fuel temperature, T_{fi}, °F	Fuel temperature after prevaporizing, T_{fv}, °F	Fuel manifold pressure, lb/(sq in.) gage	Total pressure drop through combustor, ΔP, in. Hg	Combustion parameter, V_r/P_1T_1, ft. lb, sec, °R units
Model 29I; propane														
5.0	733	0.524	0.718	----	17.0	0.0090	1280	547	78.4	--	---	----	----	---
4.97	732	.521	.714	80.9	23.1	.0123	1440	708	75.9	--	---	----	0.28	320
5.0	730	.523	.717	----	26.9	.0137	1550	820	79.5	--	---	----	----	---
5.0	721	.522	.718	----	29.4	.0156	1650	934	80.3	--	---	----	----	---
5.0	724	.521	.714	----	32:2	.0172	1770	998	78.6	--	---	----	----	---
5.0	728	.520	.713	----	39.4	.0210	1840	1114	73.2	--	---	----	----	---
5.01	726	.520	.712	79.4	45.3	.0242	1850	1124	64.8	--	---	----	.33	314
15.1	722	2.66	3.65	139.6	----	----	----	----	----	--	---	----	1.80	181
15.0	732	2.64	3.61	----	64.7	.0068	1195	463	86.8	--	---	----	----	---
15.1	720	2.63	3.61	----	81.1	.0086	1525	605	91.4	--	---	----	----	---
15.2	726	2.67	3.66	139.4	94.3	.0098	1450	724	98.3	--	---	----	2.53	188
15.0	718	2.66	3.65	----	107.0	.0112	1560	846	99.2	--	---	----	----	---
15.0	729	2.66	3.64	----	135.0	.0139	1770	1039	101.0	--	---	----	----	---
15.3	726	2.65	3.64	138.2	157.0	.0165	1915	1189	98.7	--	---	----	2.84	186
15.0	728	2.65	3.64	----	170.0	.0178	1980	1252	98.9	--	---	----	----	---
15.0	720	2.64	3.62	----	191.0	.0201	2070	1350	95.6	--	---	----	----	---
Model 29I; propane; without shields														
5.1	729	0.529	0.724	79.9	19.2	0.0101	1330	601	77.6	--	---	----	0.30	310
5.0	720	.532	.728	----	22.9	.0120	1420	700	76.9	--	---	----	----	---
	727	.532	.728	----	26.1	.0137	1515	788	76.7	--	---	----	----	---
	723	.533	.730	----	35.0	.0172	1830	907	71.2	--	---	----	----	---
	722	.527	.722	----	41.0	.0216	1670	946	60.2	--	---	----	----	---
	728	.526	.721	80.8	48.5	.0255	1650	902	49.0	--	---	----	.38	319
15.2	728	2.65	3.64	138.7	----	----	----	----	----	--	---	----	2.19	167
15.1	718	2.65	3.64	138.1	73.5	.0077	1270	552	92.2	--	---	----	2.46	190
15.0	726	2.65	3.62	----	88.0	.0092	1595	869	94.1	--	---	----	----	---
	726	2.64	3.62	----	103.0	.0108	1525	799	97.1	--	---	----	----	---
	717	2.64	3.62	----	118.0	.0124	1630	913	97.9	--	---	----	----	---
	718	2.65	3.63	----	139.0	.0146	1760	1042	95.4	--	---	----	----	---
	727	2.65	3.63	140.3	165.0	.0174	1870	1145	90.1	--	---	----	2.82	192
	726	2.65	3.63	----	199.0	.0209	1910	1184	78.5	--	---	----	----	---
Model 29I; propane; without shields; mixer														
5.0	718	0.521	0.713	----	17.2	0.0092	1280	562	79.0	--	---	----	----	---
5.3	724	.521	.713	73.9	25.2	.0134	1480	756	74.6	--	---	----	0.44	273
5.0	720	.521	.715	----	29.2	.0156	1590	870	74.9	--	---	----	----	---
5.0	728	.519	.711	----	33.1	.0177	1660	932	71.3	--	---	----	----	---
5.0	728	.519	.711	----	40.7	.0218	1740	1012	64.0	--	---	----	----	---
5.1	718	.520	.713	77.7	48.6	.0259	1680	962	51.5	--	---	----	.59	306
15.0	722	2.64	3.61	----	69.0	.0073	1240	518	91.2	--	---	----	----	---
15.2	722	2.63	3.60	129.6	82.9	.0088	1360	638	94.4	--	---	----	3.89	167
15.0	725	2.66	3.66	----	102.0	.0107	1485	760	93.3	--	---	----	----	---
	723	2.65	3.63	----	122.0	.0128	1610	887	92.0	--	---	----	----	---
	720	2.64	3.62	----	131.3	.0138	1665	945	91.5	--	---	----	----	---
15.3	724	2.63	3.61	----	150.0	.0158	1770	1046	90.0	--	---	----	----	---
15.[illegible]	727	2.64	3.62	125.5	178.0	.0185	1900	1173	87.5	--	---	----	5.34	154

Model 30L; JP-4														
15.0	729	2.84	3.83	140.0	-----	------	----	----	-----	--	---	----	1.83	192
15.0	731	2.01	2.74	105.0	-----	------	----	----	-----	--	---	----	.77	139
8.0	734	.84	1.15	81.5	-----	------	----	----	-----	--	---	----	.33	200
5.0	729	.52	.71	79.5	-----	------	----	----	-----	--	---	----	.20	291
15.0	728	1.56	2.14	80.0	-----	------	----	----	-----	--	---	----	.51	107
15.0	730	2.80	3.57	-----	88.0	0.0072	1270	540	102.0	80	458	27.0	----	---
	734	2.80	3.57	139.0	78.0	.0084	1370	636	104.5	80	465	34.0	1.85	189
	716	2.61	3.50	-----	92.0	.0098	1460	744	106.0	82	448	40.0	----	---
	724			-----	109.0	.0116	1610	886	107.0		418	45.0	----	---
	724			-----	123.0	.0131	1715	991	107.0		396	50.0	----	---
	725			-----	137.0	.0146	1790	1065	104.0		392	53.0	----	---
	726			138.0	154.0	.0164	1870	1144	101.0	84	364	65.0	2.33	185
5.0	728	.533	.732	-----	21.8	.0114	1355	627	78.4	82	500	3.0	----	---
	732	.527	.724	79.8	23.2	.0122	1435	703	80.2			4.5	----	294
	734	.526	.723	-----	27.9	.0148	1610	876	84.2			6.5	----	---
	738	.527	.724	-----	30.0	.0158	1690	954	88.2			9.0	----	---
	738	.526	.725	-----	34.2	.0181	1800	1064	85.2	88		11.0	----	---
	728	.526	.725	78.7	40.5	.0214	1825	1197	82.4	90		13.0	.31	293
	724	.525	.721	-----	46.0	.0244	1875	1261	78.2	93	465	15.5	----	---
8.0	729	.830	1.14	-----	24.9	.0083	1300	571	93.7	93	500	6.0	----	---
	738	.828	1.14	78.2	29.1	.0097	1410	674	95.8	94		9.0	----	198
	723	.831	1.14	-----	35.2	.0118	1560	837	99.7	95		13.0	----	---
	720	.831	1.14	-----	40.2	.0134	1670	950	100.1	96		19.0	----	---
	724	.827	1.13	-----	44.0	.0148	1770	1046	101.2	96		18.0	----	---
	728	.825	1.13	78.0	50.2	.0169	1900	1172	100.2	99		22.0	.40	197
	725	.830	1.14	-----	55.5	.0188	2020	1295	102.1	99		24.0	----	---
15.0	728	1.56	2.14	-----	41.0	.0073	1295	457	104.0	74		15.0	----	---
	726	1.57	2.18	79.0	49.2	.0087	1410	684	108.0	78		20.0	.68	108
	728	1.56	2.14	-----	55.5	.0099	1500	772	108.7	81		25.0	----	---
		1.56		-----	65.5	.0117	1670	842	113.7	82		33.0	----	---
		1.56		-----	77.0	.0137	1780	1052	109.3	83		35.0	----	---
	730	1.56		79.5	87.5	.0156	1900	1170	108.1	83		40.0	.79	107
	731	1.55	2.13	-----	103.0	.0184	2060	1329	105.8	81	470	42.0	----	---
5.0	725	.527	.724	82.4	20.7	.0110	1410	685	80.7	81	500	2.7	----	254
	720	.527	.724	-----	26.3	.0140	1560	860	88.4	83	500	5.0	----	---
	725	.529	.726	-----	29.5	.0157	1665	842	85.5	83	499	8.0	----	---
	728	.531	.728	-----	34.6	.0184	1820	1092	88.1	88	496	10.7	----	---
	727	.526	.723	82.0	39.0	.0209	1885	1156	81.0	90	490	11.5	----	293
	724	.530	.727	-----	43.5	.0229	1920	1196	75.9	92	490	14.7	----	---
	723	.528	.728	-----	41.2	.0220	1810	1167	79.2	94	430	13.2	----	---
15.0	721	1.57	2.16	-----	42.5	.0075	1310	589	105.9	92	500	19.0	----	---
	726	1.56	2.14	-----	50.5	.0089	1440	714	109.8	94	430	24.0	----	---
	726	1.56		80.1	57.5	.0102	1560	834	114.0	96	440	30.0	----	107
	725	1.58		-----	69.4	.0123	1710	985	113.0		420	38.0	----	---
	725	1.58		-----	70.5	.0141	1820	1095	111.5		410	40.0	----	---
	724	1.58	2.17	-----	87.0	.0153	1890	1166	109.7		410	40.0	----	---
	724	1.59	2.18	-----	101.9	.0178	2060	1324	108.8		400	45.0	----	---

TABLE II. - Concluded. COMBUSTOR TEST DATA

Combustor-inlet total pressure, P_1, in. Hg	Combustor-inlet total temperature, T_1, ^oR	Air-flow rate, W_a, lb/sec	Air-flow rate per unit area, W_a/A_r, $\frac{lb}{(sec)(sq\ ft)}$	Combustor reference velocity, V_r, ft/sec	Fuel-flow rate, W_f, lb/hr	Fuel-air ratio, f	Mean combustor-outlet temperature, T_0, ^oR	Mean temperature rise through combustor, ΔT, ^oF	Combustion efficiency, η_b, percent	Inlet fuel temperature, T_{fi}, ^oF	Fuel temperature after prevaporizing, T_{fv}, ^oF	Fuel manifold pressure, lb/(sq in.) gage	Total pressure drop through combustor, ΔP, in. Hg	Combustion parameter, V_r/p_1T_1, ft, lb, sec, ^oR units
Model 30L; JP-4; mixer														
15.0	718	2.63	3.61	-----	88.8	0.0092	1370	652	97.8	74	456	34.0	----	---
	722	2.64	3.62	-----	99.9	.0105	1460	728	100.0	79	444	40.0	----	---
	716	2.66	3.66	-----	117.0	.0123	1558	859	96.0	86	408	45.0	----	---
	715	2.65	3.64	-----	142.0	.0149	1680	985	92.0	79	403	50.0	----	---
15.1	715	2.64	3.62	-----	179.0	.0188	1790	1075	82.5	77	396	50.0	----	
15.0	720	1.58	2.17	-----	50.0	.0088	1380	660	102.0	76	510	20.0	----	---
	722	1.56	2.14	-----	55.0	.0098	1445	723	100.1	82	510	24.0	----	---
	730	1.55	2.14	-----	63.7	.0114	1550	820	101.0	85	500	30.0	----	---
	720	1.57	2.15	-----	79.0	.0140	1705	985	99.5	88	500	40.0	----	---
	728	1.57	2.15	-----	85.8	.0152	1770	1042	98.3	88	500	39.0	----	---
	724	1.55	2.14	-----	106.5	.0190	2000	1276	98.5	86	464	40.0	----	---
8.0	726	.838	1.15	-----	23.9	.0079	1226	499	86.0	81	525	3.5	----	---
	715	.836	1.15	-----	33.2	.0110	1425	712	89.4	81		10.0	----	---
	720	.837	1.15	-----	39.7	.0132	1570	850	90.7	83		16.0	----	---
	728	.765	1.05	-----	47.8	.0174	1820	1092	90.8			20.0	----	---
	730	.836	1.15	-----	59.3	.0197	1925	1195	88.6			22.0	----	---
15.0	738	1.57	2.16	-----	54.7	.0097	1410	684	97.3	73	520	21.0	----	---
	730	1.56	2.14	-----	63.5	.0113	1530	800	96.8	83	520	30.0	----	---
	730	1.56		-----	77.0	.0137	1680	950	96.8	82	520	33.0	----	---
	732	1.56		-----	84.5	.0150	1760	1028	97.8	84	500	40.0	----	---
	732	1.56		-----	99.0	.0178	1925	1193	98.5	82	480	40.0	----	---
5.0	724	.525	.720	-----	30.0	.0158	1505	781	69.3	80	529	8.5	----	---
	725	5518	.712	-----	33.8	.0180	1760	1037	81.9	81	525	10.0	----	---
	726	.523	.720	-----	37.8	.0201	1865	1139	82.6	83	525	10.0	----	---
	728	.523	.720	-----	41.3	.0225	1975	1247	80.1	86	510	12.0	----	---
Model 30J; JP-4; mixer														
8.0	732	0.835	1.145	-----	33.0	0.0110	1400	668	85.8	78	500+	18.0	----	---
	738	.835	1.148	-----	40.0	.0133	1530	794	85.3	80		25.0	----	---
	732	.836	1.145	-----	40.8	.0136	1530	798	83.0	86		25.0	----	---
	733	.808	1.11	-----	45.4	.0156	1660	927	86.0	88		30.0	----	---
	732	.835	1.145	-----	53.0	.0177	1775	1043	85.8	92		35.0	----	---
	732	.828	1.14	-----	65.9	.0221	1920	1188	79.3	93		40.0	----	---
	732	.835	1.145	-----	34.8	.0115	1360	628	76.0	133		25.0	----	---
	733	.835	1.145	-----	41.0	.0138	1545	812	85.0	123		31.0	----	---
	735	.827	1.13	-----	46.0	.0153	1675	940	89.0	136		37.0	----	---
	735	.828	1.14	-----	51.7	.0173	1780	1045	89.0	154		43.0	----	---
	733	.833	1.145	-----	61.6	.0210	1980	1147	89.0	156		48.0	----	---
5.0	734	.528	.74	-----	24.4	.0130	1430	696	78.0	108		14.0	----	---
	736	.523	.72	-----	30.8	.0165	1640	904	80.0	104		22.0	----	---
	734	.523	.72	-----	35.7	.0191	1795	1061	83.0	103		27.0	----	---
	736	.523	.72	-----	42.7	.0230	1960	1236	82.0	103		30.0	----	---
15.0	724	2.64	3.63	-----	78.8	.0083	1260	536	90.0	85	428	40.0	----	---
	728	2.64	3.63	-----	131.0	.0138	1570	844	88.0	89	403	55.0	----	---
	724	2.64	3.63	-----	174.0	.0183	1840	1116	90.0	89	385	50.0	----	---

[redacted]

Model 30M; JP-4; mixer														
15.0	724	2.65	3.64	-----	73.3	0.0077	1250	526	93.7	78	441	28.0	----	---
	728	2.64	3.63	-----	88.0	.0093	1345	617	92.3	80	445	35.0	----	---
	724	2.65	3.64	-----	104.2	.0109	1460	736	94.3	81	426	41.0	----	---
15.1	732	2.64	3.63	-----	124.2	.0131	1580	848	92.3	80	405	48.0	----	---
15.2	722	2.63	3.61	-----	161.2	.0171	1790	1066	90.5	79	385	50.0	----	---
15.0	729	1.57	2.16	-----	50.0	.0088	1350	821	97.3	92	500+	22.0	----	---
	728	1.57	2.16	-----	66.5	.0118	1535	807	96.7	92	500+	32.0	----	---
	727	1.57	2.16	-----	90.0	.0160	1800	1073	97.0	92	500	40.0	----	---
8.0	720	.845	1.16	-----	32.0	.0104	1340	820	82.8	75	500+	11.0	----	---
	736	.835	1.15	-----	37.6	.0125	1490	784	85.0	77		15.0	----	---
	732	.835	1.15	-----	42.7	.0142	1580	848	86.0	81		20.0	----	---
	724	.840	1.15	-----	53.5	.0175	1786	1061	87.7	84		24.0	----	---
	730	.834	1.15	-----	62.0	.0206	1920	1190	85.1	85		27.0	----	---
5.0	723	.521	.72	-----	23.0	.0123	1360	637	72.5	87		5.0	----	---
	728	.520	.71	-----	30.0	.0160	1545	818	72.7	88		10.0	----	---
	730	.520	.71	-----	34.5	.0185	1670	940	73.2	86		12.0	----	---
	728	.520	.71	-----	41.8	.0223	1850	1122	74.0	87		13.0	----	---
15.0	730	2.64	3.63	-----	73.7	.0078	1275	545	86.5	150	475	30.0	----	---
	722	2.64	3.63	-----	87.8	.0093	1340	618	92.5	150	476	40.0	----	---
	728	2.64	3.63	-----	105.0	.0111	1480	732	92.5	144	469	50.0	----	---
15.2	722	2.62	3.60	-----	160.5	.0170	1870	1148	98.5	150	405	58.0	----	---
15.4	721	2.64	3.63	-----	185.6	.0196	2040	1219	99.4	150	397	58.0	----	---
15.0	728	2.64	3.63	-----	74.0	.0078	1260	532	93.5	193	500	33.0	----	---
15.0	720	2.64	3.63	-----	103.7	.0109	1450	730	93.5	196	487	40.0	----	---
15.1	726	2.64	3.63	-----	131.6	.0138	1640	914	94.0	185	433	57.0	----	---
15.3	726	2.63	3.61	-----	161.7	.0170	1850	1122	95.8	186	415	61.0	----	---
5.0	723	.515	.71	-----	22.8	.0123	1335	612	69.2	142	500+	5.0	----	---
	728	.515	.71	-----	34.0	.0183	1665	937	73.8	132		12.0	----	---
	730	.520	.71	-----	42.0	.0225	1860	1130	74.5	151		15.0	----	---
Model 30I; propane; mixer														
5.0	730	0.521	0.72	-----	18.7	0.0100	1365	635	82.8	---	---	----	----	---
	723	.521		-----	22.8	.0122	1500	777	84.3	---	---	----	----	---
	725	.525		-----	27.5	.0145	1640	915	84.3	---	---	----	----	---
	723			-----	31.7	.0168	1760	1037	84.1	---	---	----	----	---
	723			-----	36.7	.0194	1865	1142	81.3	---	---	----	----	---
	722			-----	41.3	.0218	2010	1288	82.5	---	---	----	----	---
8.0	740	.836	1.15	-----	30.7	.0100	1400	660	88.9	---	---	----	----	---
	748	.836		-----	34.6	.0115	1500	752	90.0	---	---	----	----	---
	714	.836		-----	39.2	.0130	1600	886	90.6	---	---	----	----	---
	715	.838		-----	48.6	.0161	1810	1095	92.0	---	---	----	----	---
	717	.836		-----	53.5	.0177	1900	1185	91.5	---	---	----	----	---
15.0	728	1.57	----	-----	63.8	.0113	1580	852	99.0	---	---	----	----	---
	730	1.56	----	-----	75.9	.0135	1730	1000	99.0	---	---	----	----	---
	729	1.56	----	-----	85.0	.0151	1830	1101	98.9	---	---	----	----	---
	728	1.56	----	-----	98.9	.0176	1985	1257	98.7	---	---	----	----	---
	731	2.64	3.63	-----	78.0	.0082	1335	604	97.8	---	---	----	----	---
	740			-----	91.3	.0096	1460	720	97.8	---	---	----	----	---
	729			-----	104.0	.0110	1540	811	98.3	---	---	----	----	---
	726			-----	118.0	.0124	1660	934	99.6	---	---	----	----	---
	728			-----	133.0	.0140	1760	1032	99.4	---	---	----	----	---
	722			-----	147.0	.0158	1840	1118	98.5	---	---	----	----	---
15.1	728			-----	160.0	.0168	1905	1177	98.0	---	---	----	----	---
15.2	732			-----	168.0	.0177	2000	1268	98.3	---	---	----	----	---

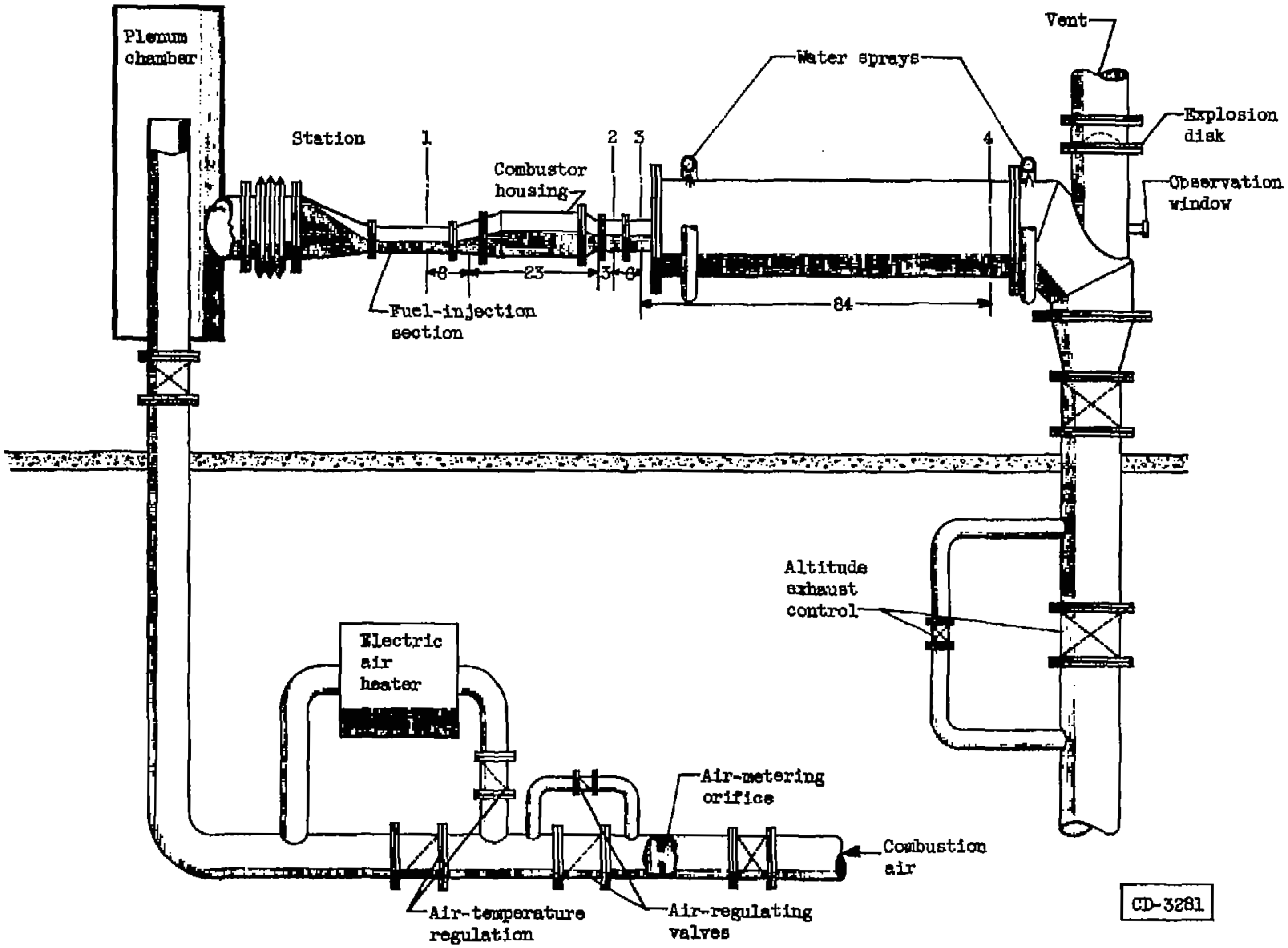
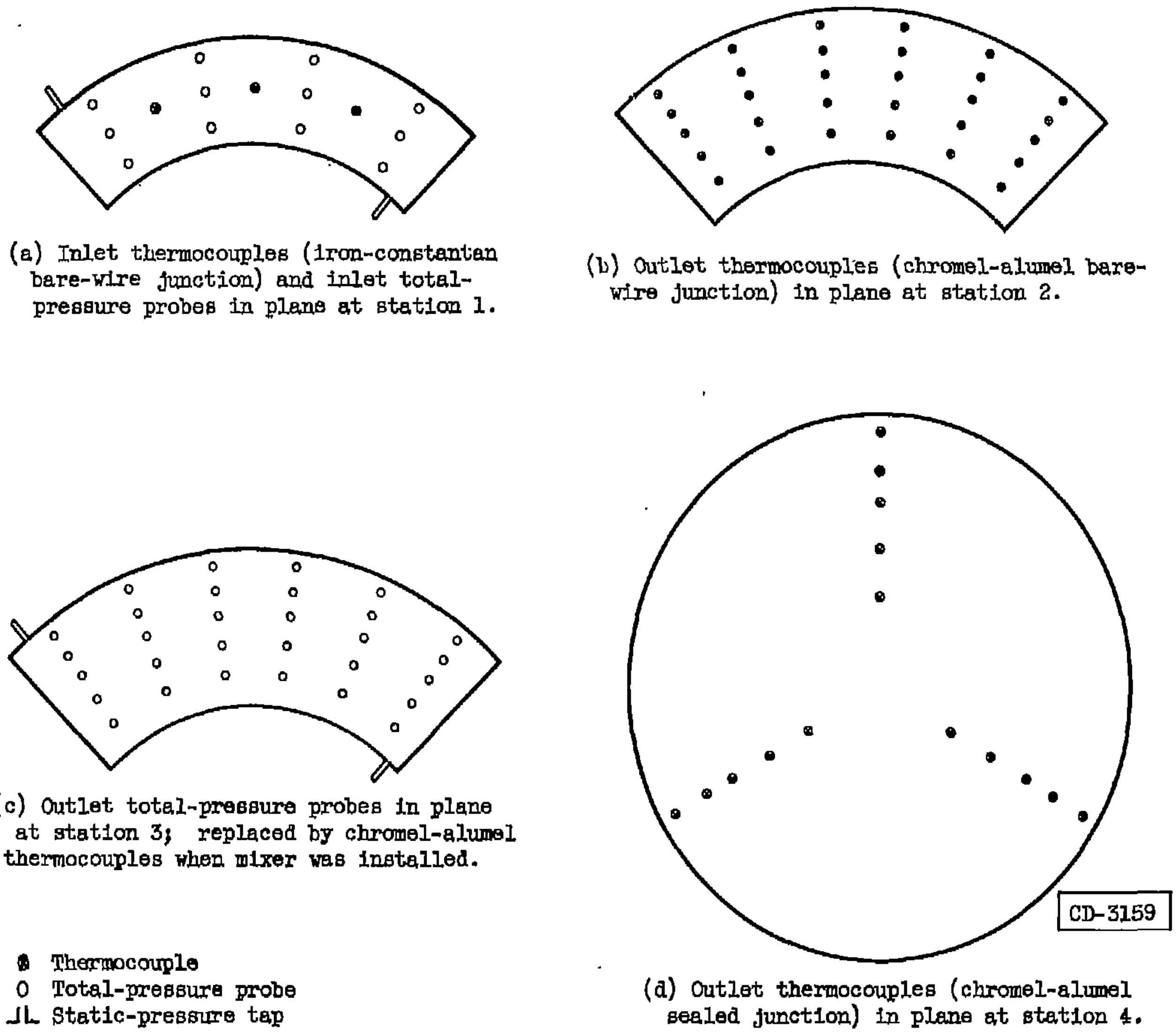


Figure 1. - Installation of one-quarter sector of $25\frac{1}{2}$-inch-diameter annular combustor. (Dimensions are in inches.)



(a) Inlet thermocouples (iron-constantan bare-wire junction) and inlet total-pressure probes in plane at station 1.

(b) Outlet thermocouples (chromel-alumel bare-wire junction) in plane at station 2.

(c) Outlet total-pressure probes in plane at station 3; replaced by chromel-alumel thermocouples when mixer was installed.

● Thermocouple
O Total-pressure probe
⅃L Static-pressure tap

(d) Outlet thermocouples (chromel-alumel sealed junction) in plane at station 4.

Figure 2. Experimental combustor instrumentation.

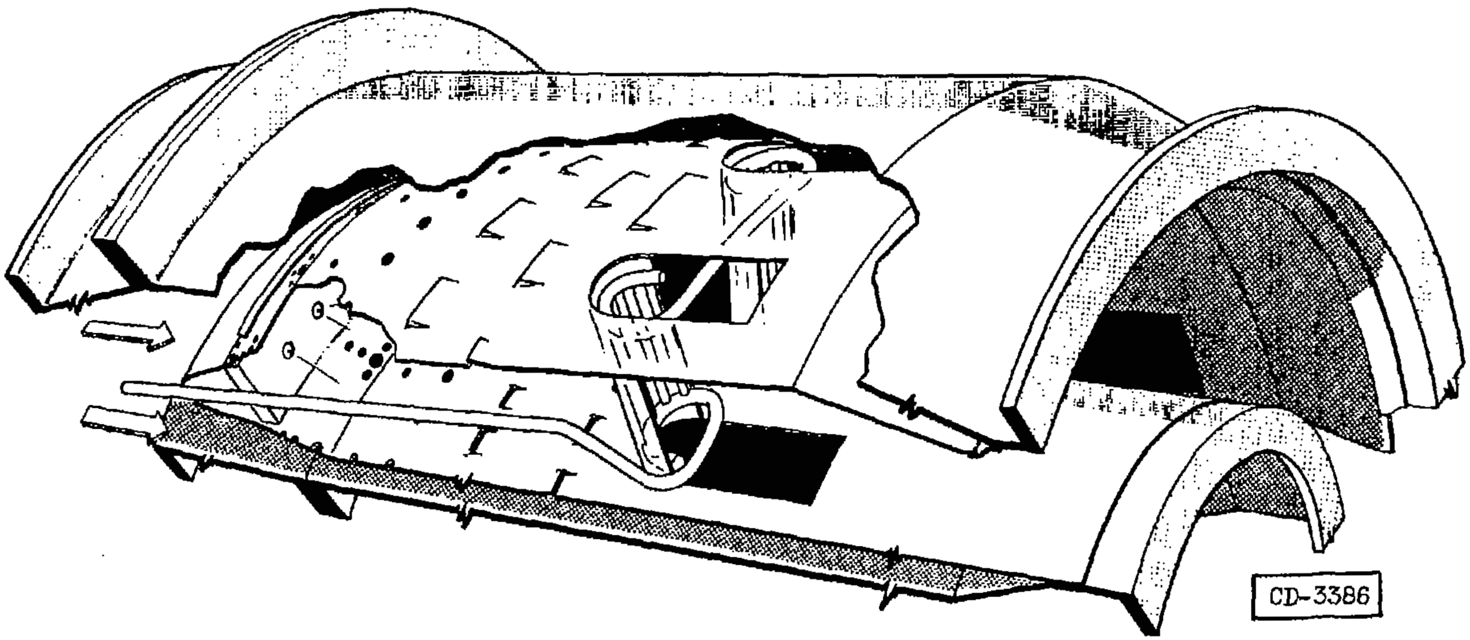


Figure 3. - One-quarter sector of annular prevaporizing combustor model 30 assembled in test ducting.

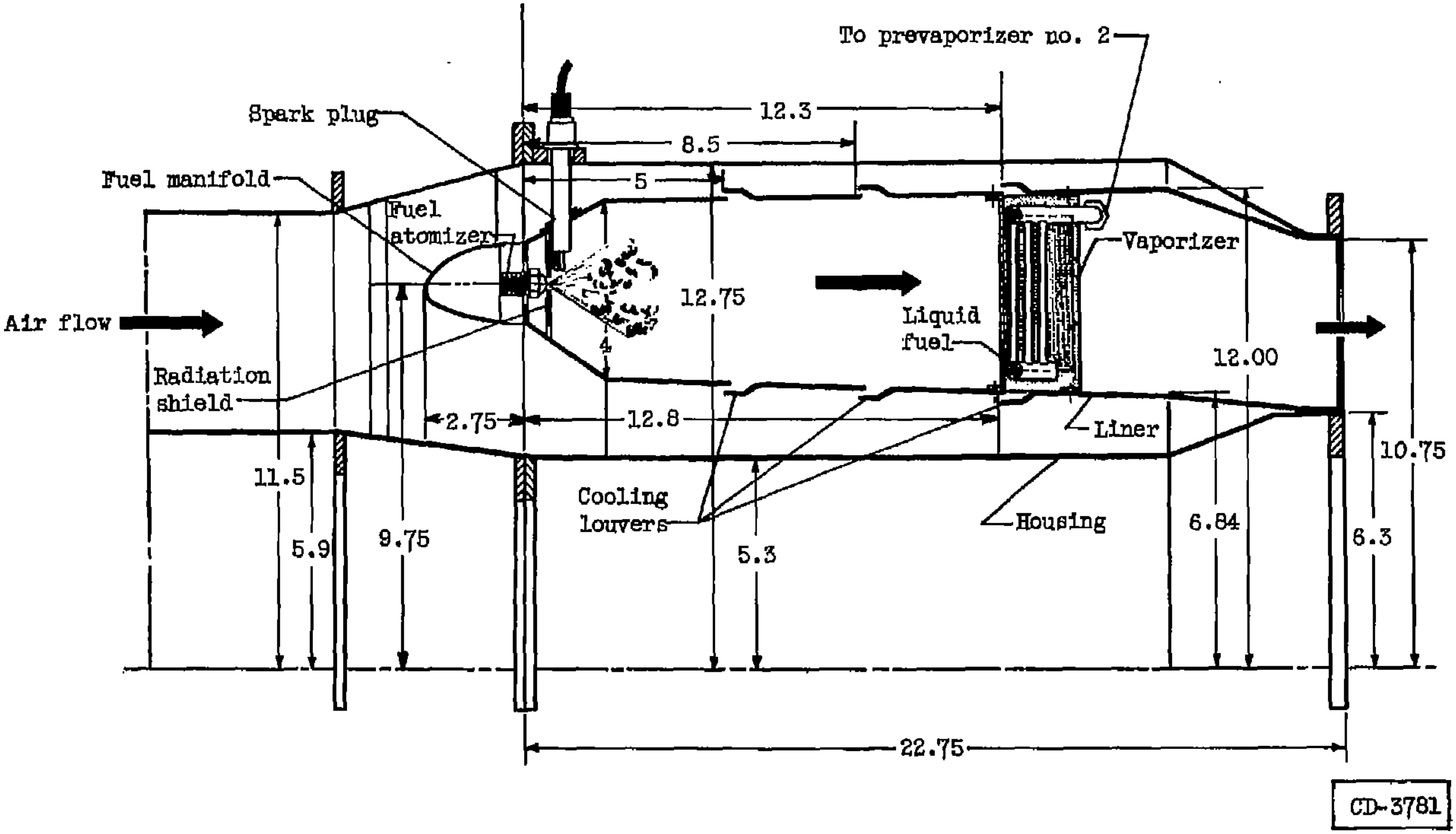
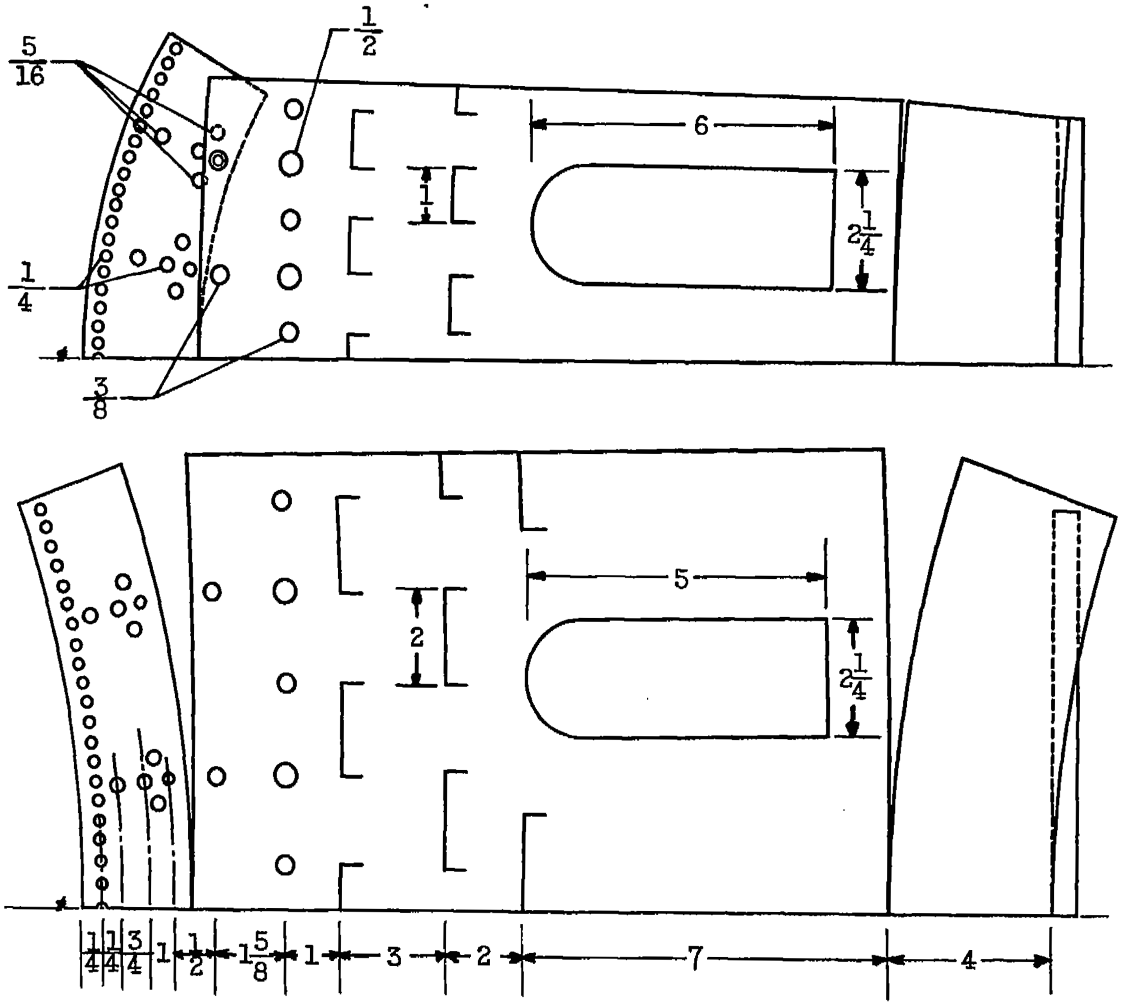


Figure 4. - Longitudinal cross-sectional view of annular prevaporizing combustor model 30. (Dimensions are in inches.)



(a) Air-entry hole pattern.

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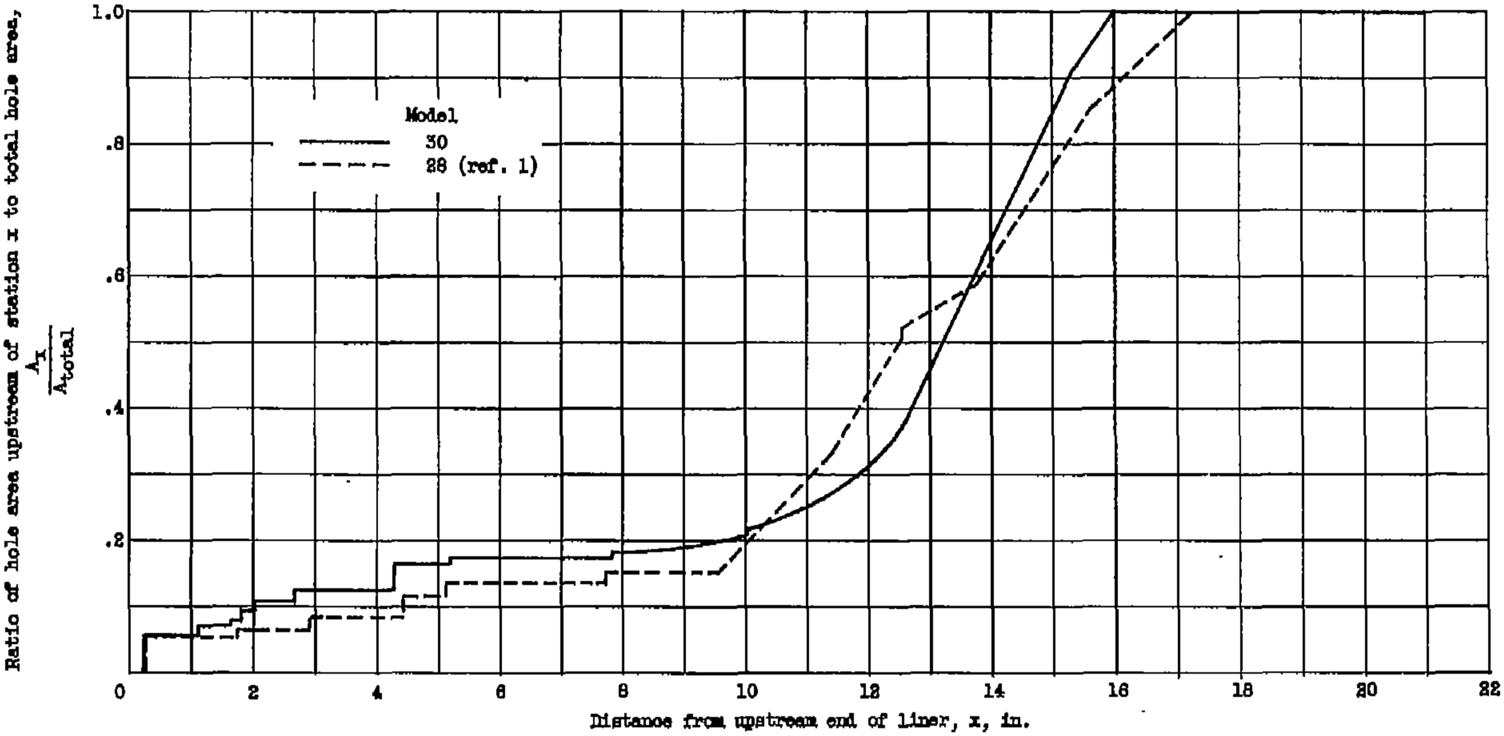
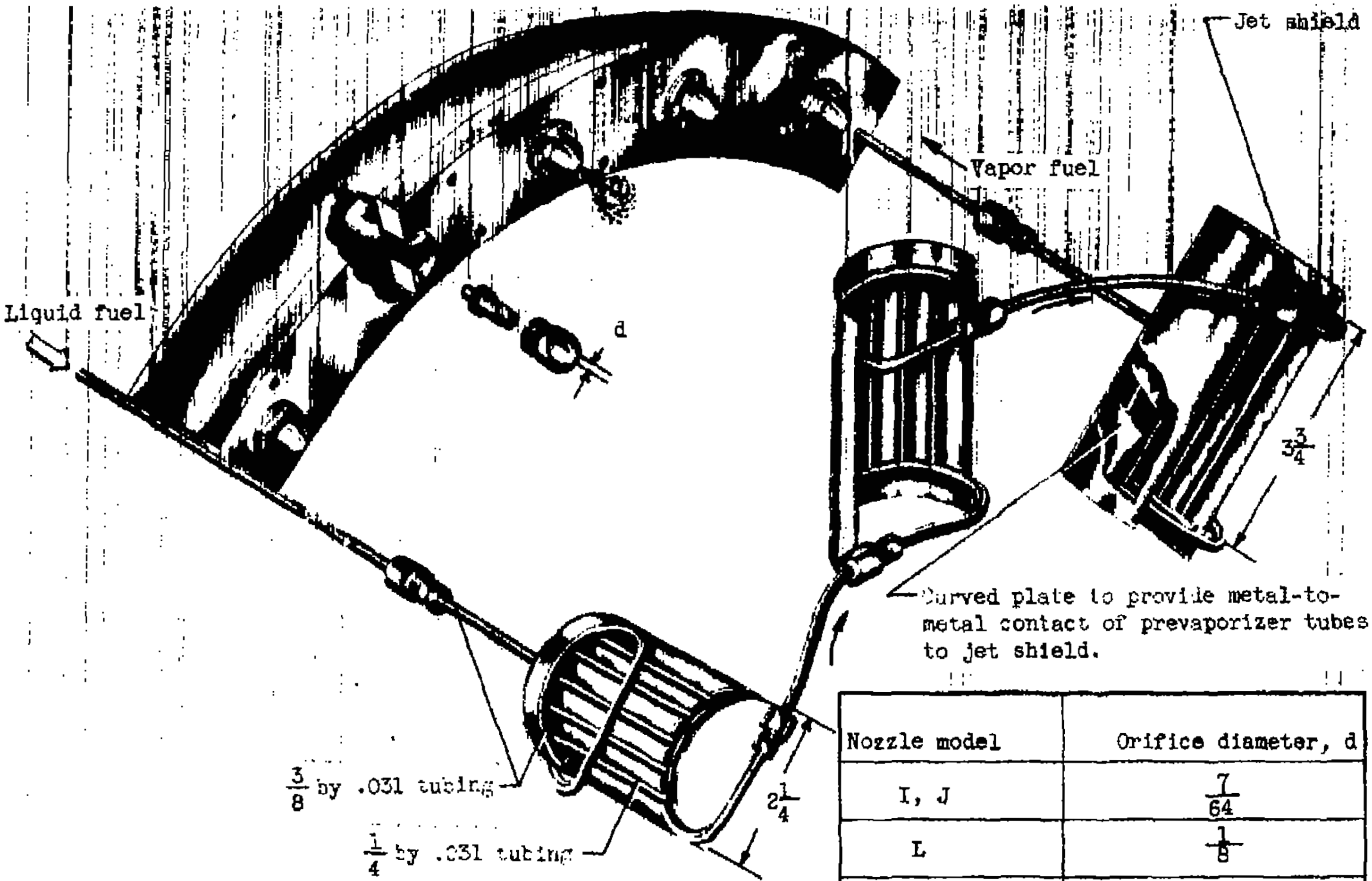
Figure 5. - Annular prevaporizing combustor model 30 air-entry configurations.



(b) Comparison of air-entry open-hole area distribution of model 30 with model 28.

Figure 5. - Concluded. Annular prevaporizing combustor model 30 air-entry configurations.



Nozzle model	Orifice diameter, d
I, J	$\frac{7}{64}$
L	$\frac{1}{8}$
M	$\frac{5}{32}$

Figure 6. - Fuel prevaporizing system in combustor model 30. (Dimensions are in inches.)

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Figure 7. - Exhaust-gas mixer.

[redacted]

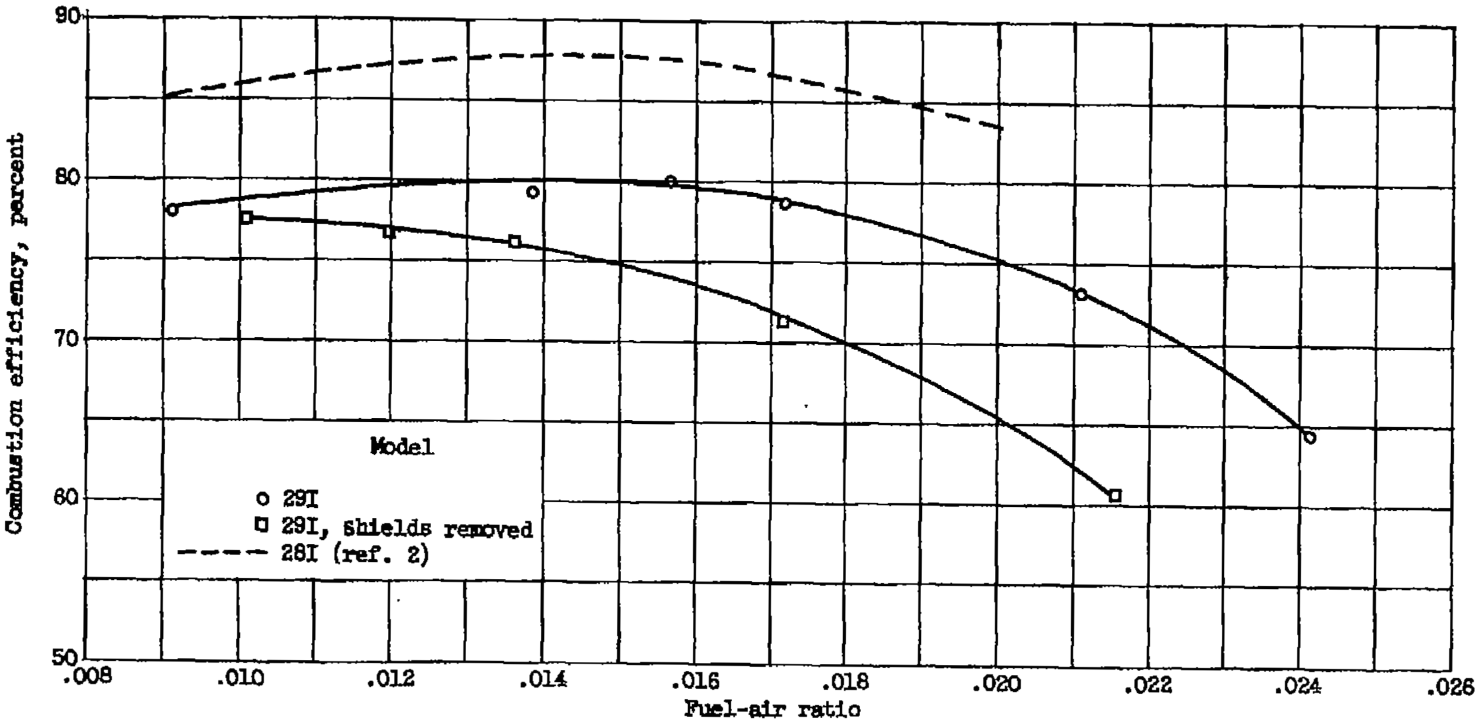


Figure 8. - Comparison of model 29I combustor with and without shields, and model 28I combustor at test condition C; propane fuel operation.

[redacted]

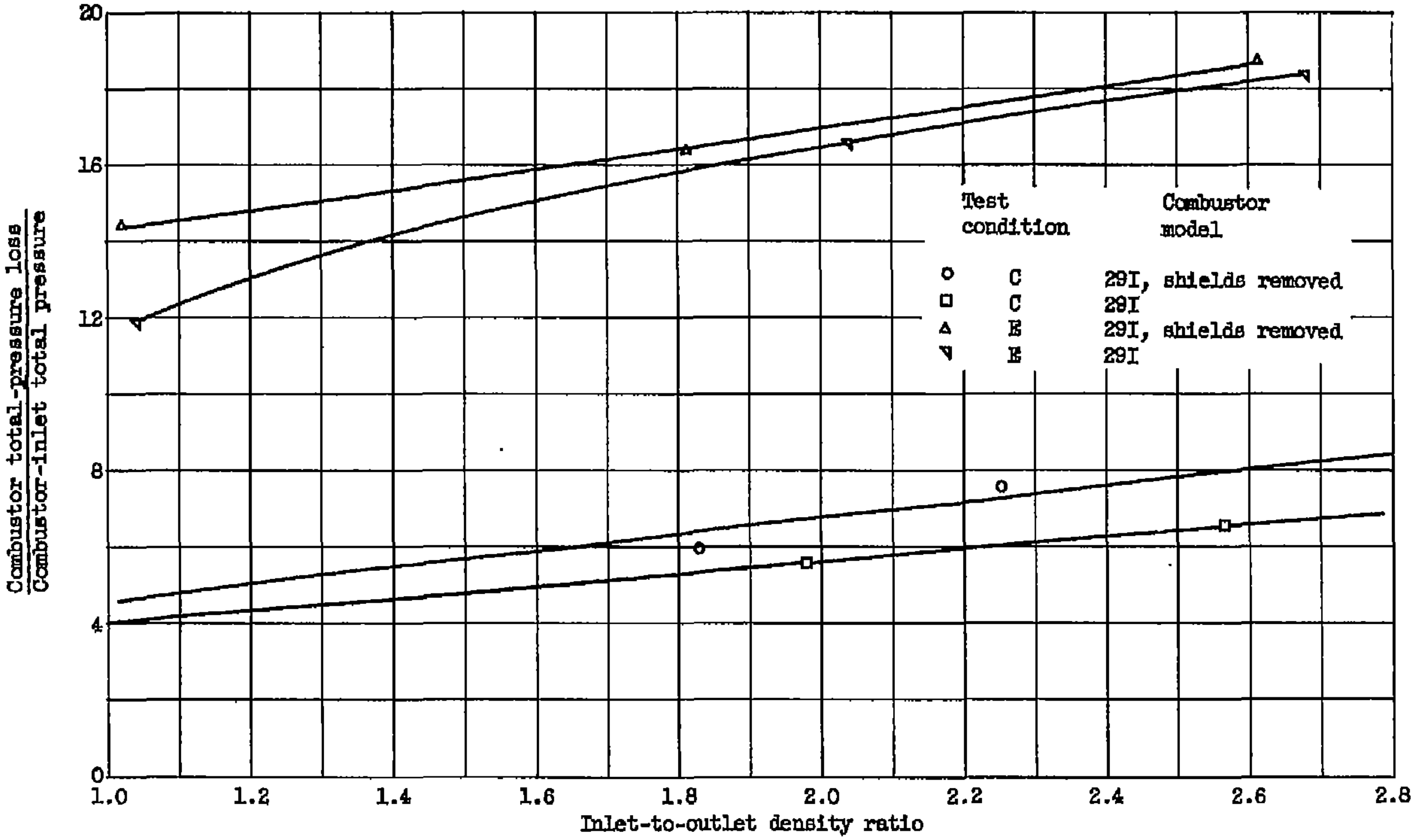
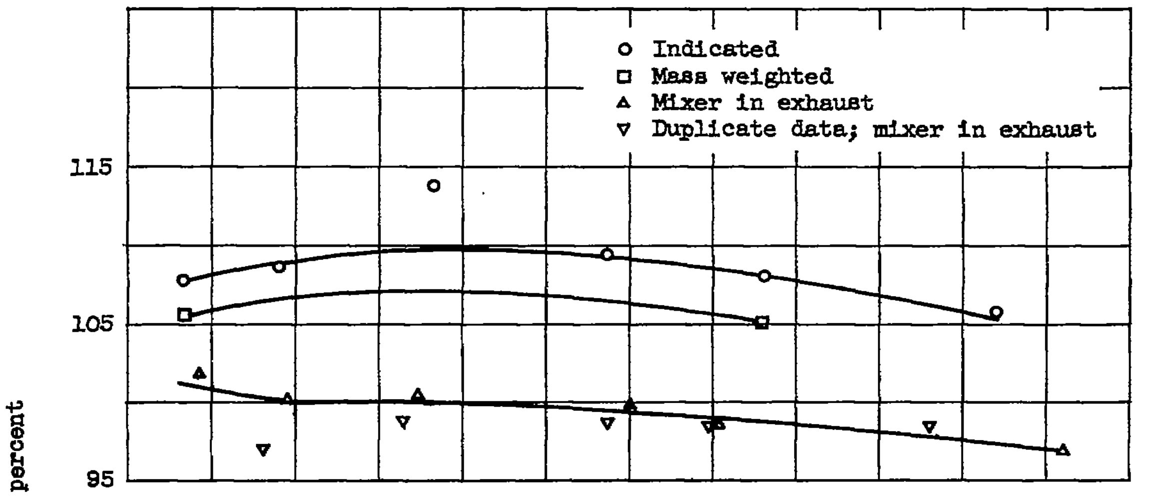
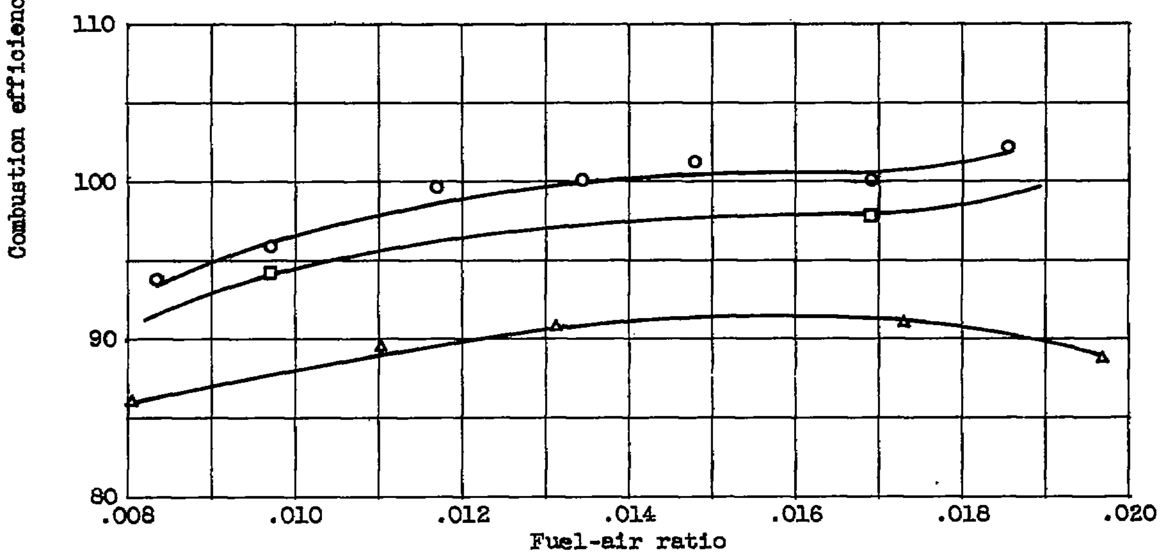


Figure 9. - Pressure losses of model 29I combustor.

3237



(a) Test condition A.



(b) Test condition B.

Figure 10. - Combustion efficiencies of prevaporizing combustor model 30L with liquid MIL-F-5624A grade JP-4 fuel.

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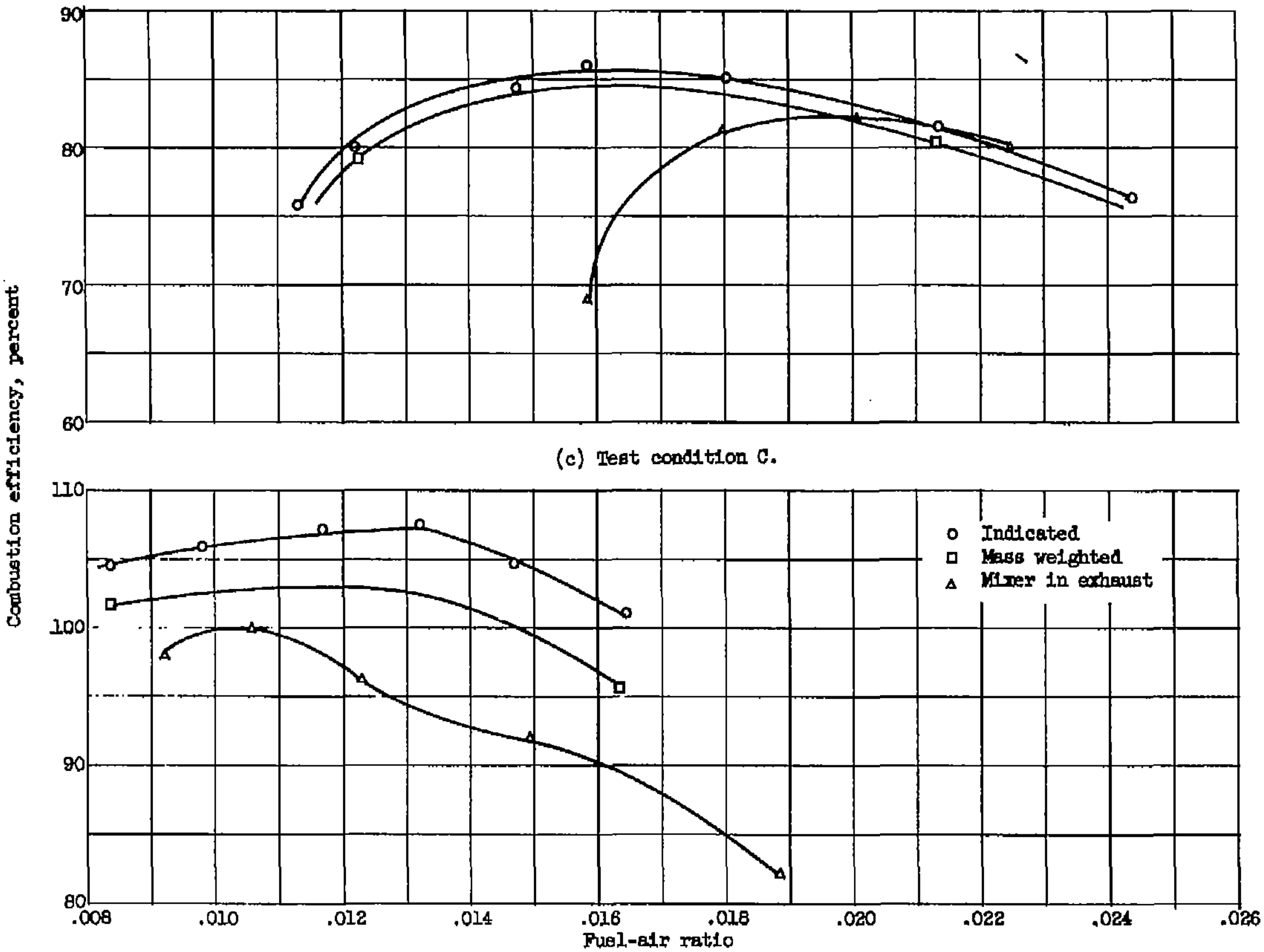
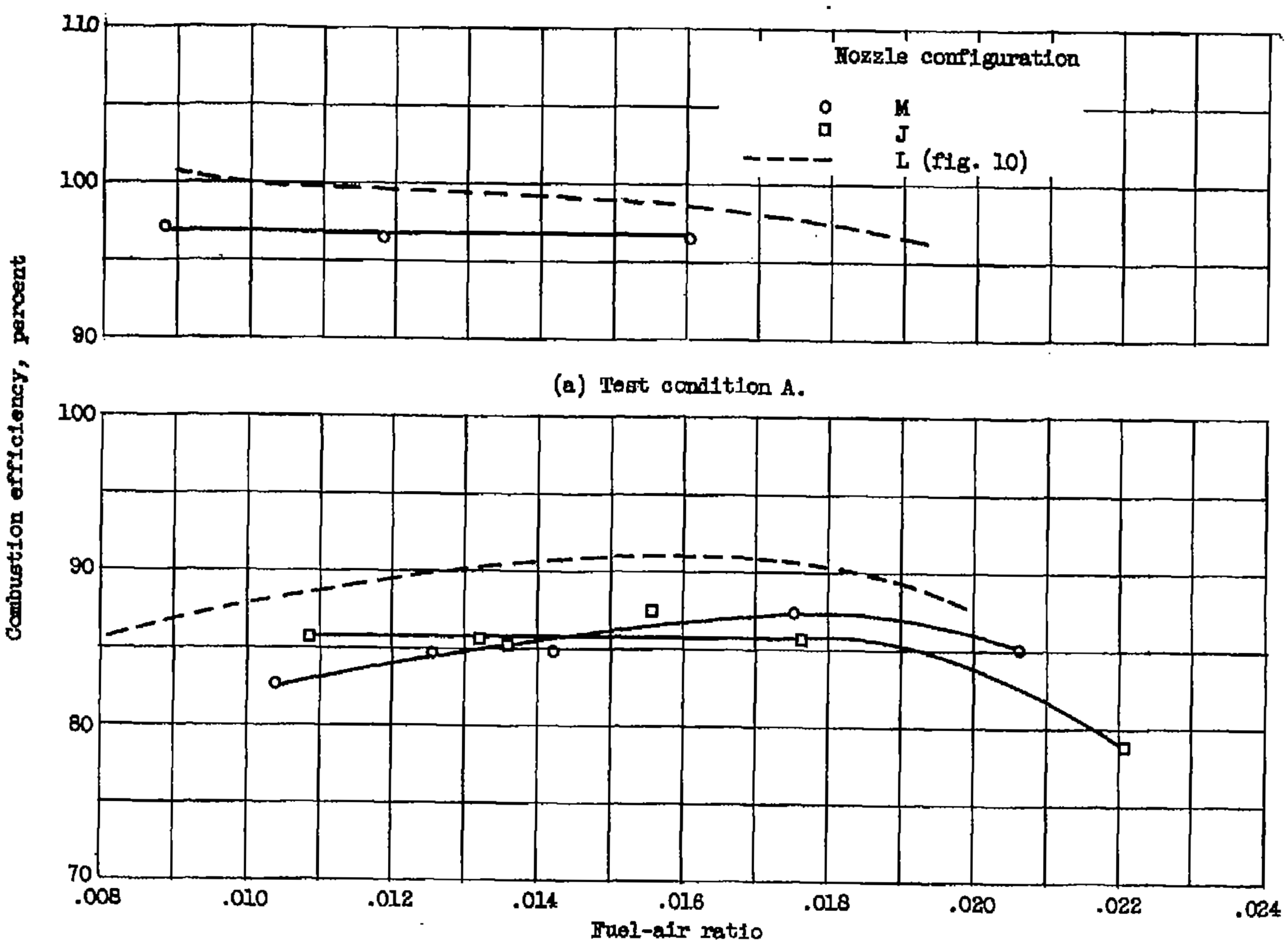
[redacted]



(c) Test condition C.

(d) Test condition E.

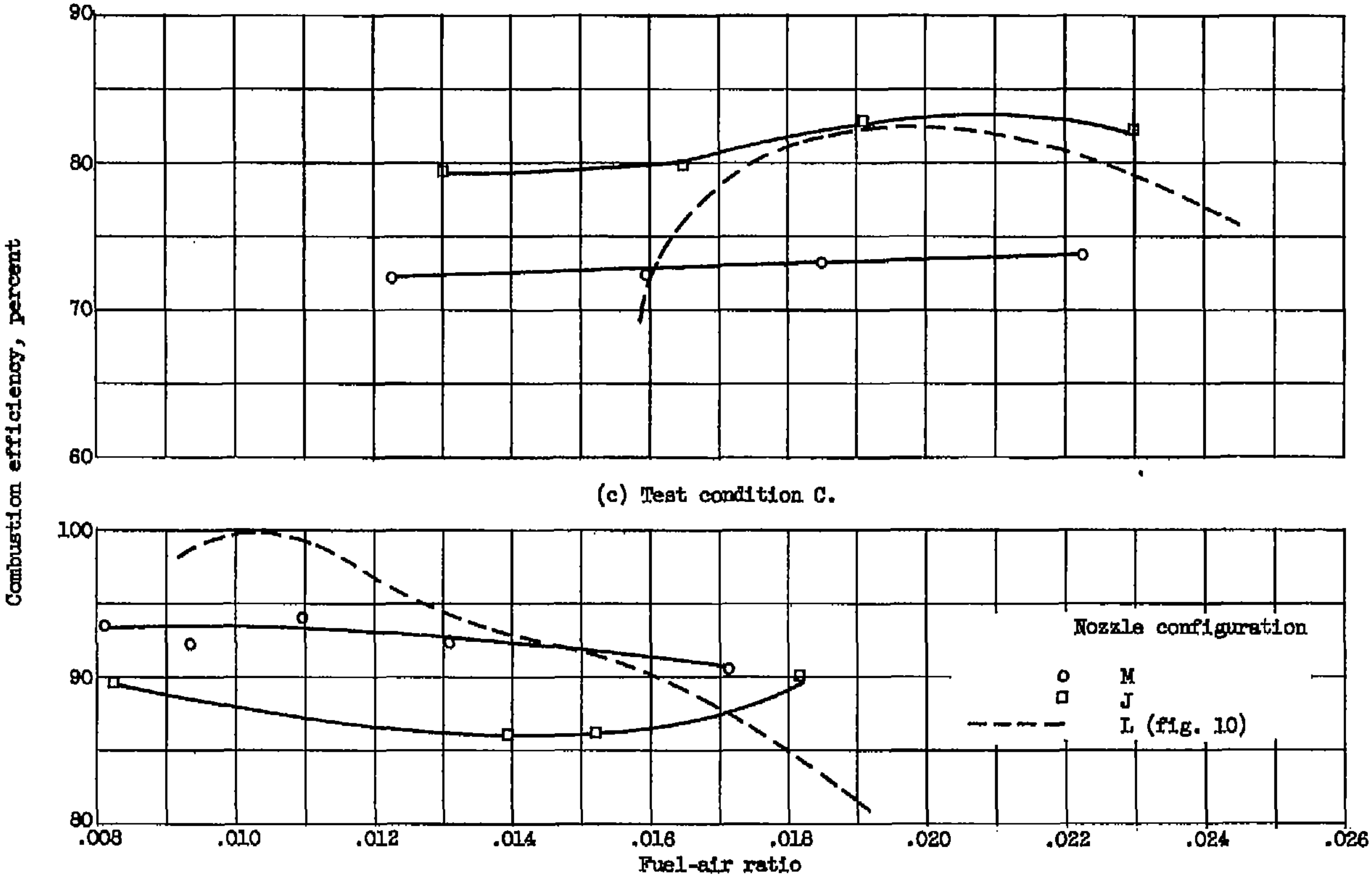
Figure 10. - Concluded. Combustion efficiencies of prevaporizing combustor model 30L with liquid MIL-F-5624A grade JP-4 fuel.



(a) Test condition A.

(b) Test condition B.

Figure 11. - Combustion efficiencies of prevaporizing combustor model 30 for various nozzle configurations with liquid MIL-F-5624A grade JP-4 fuel.



(c) Test condition C.

(d) Test condition E.

Figure 11. - Concluded. Combustion efficiencies of prevaporizing combustor model 30 for various nozzle configurations with liquid MIL-F-5624A grade JP-4 fuel.

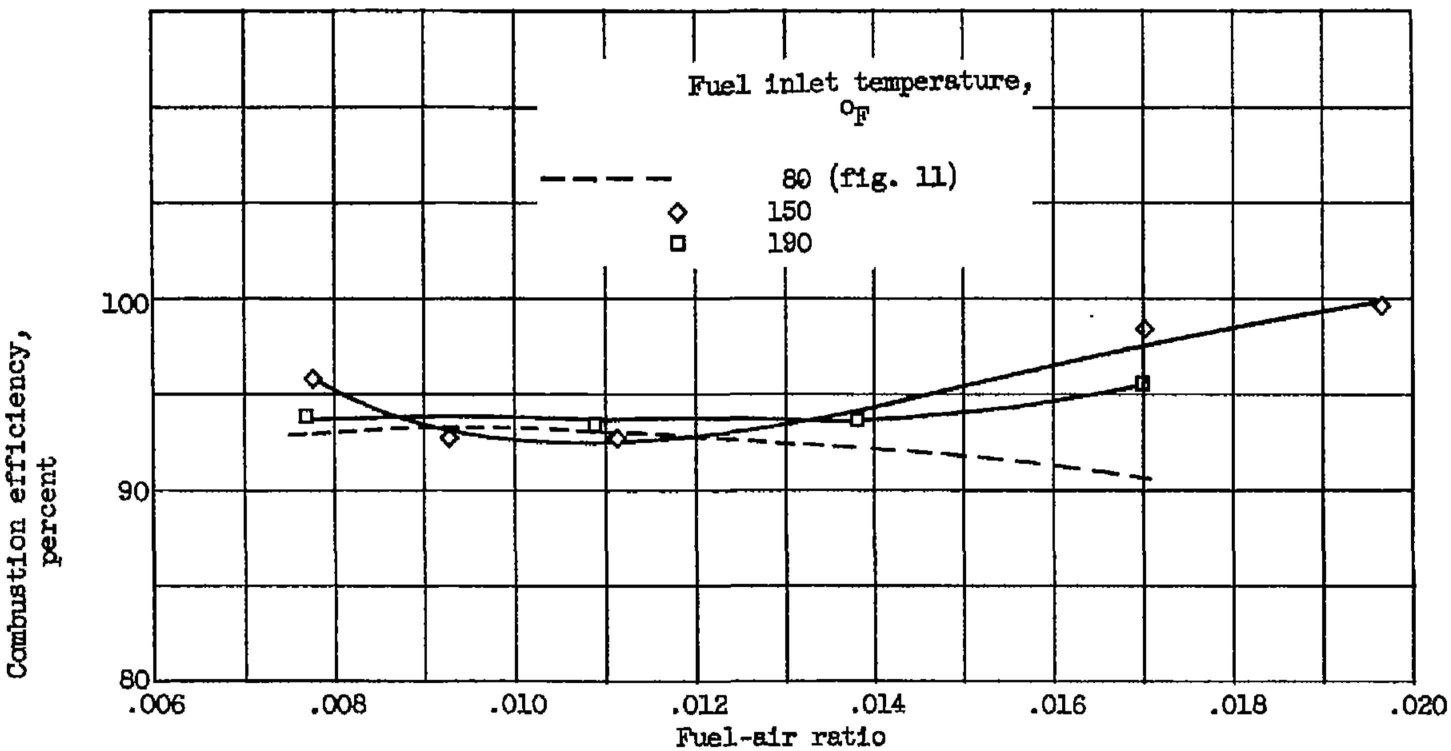


Figure 12. - Combustion efficiencies of prevaporizing combustor model 30M at test condition E; operation with externally preheated MIL-F-5624A grade JP-4 and mixer in exhaust.

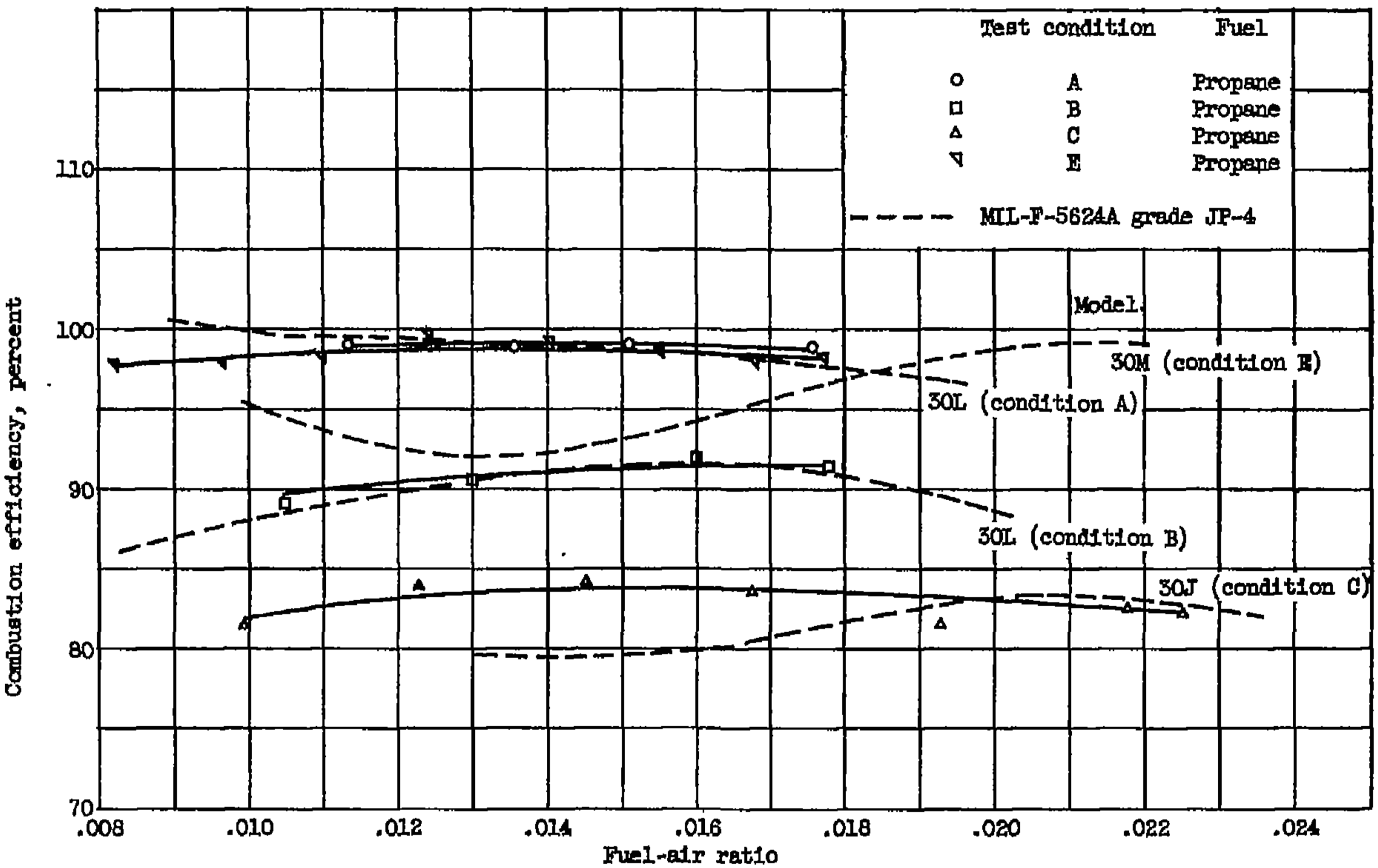


Figure 13. - Comparison of combustor model 30 with vapor fuel (propane) and vaporized MIL-F-5624A grade JP-4 fuel operation with various fuel nozzles. Mixer installed in the exhaust.

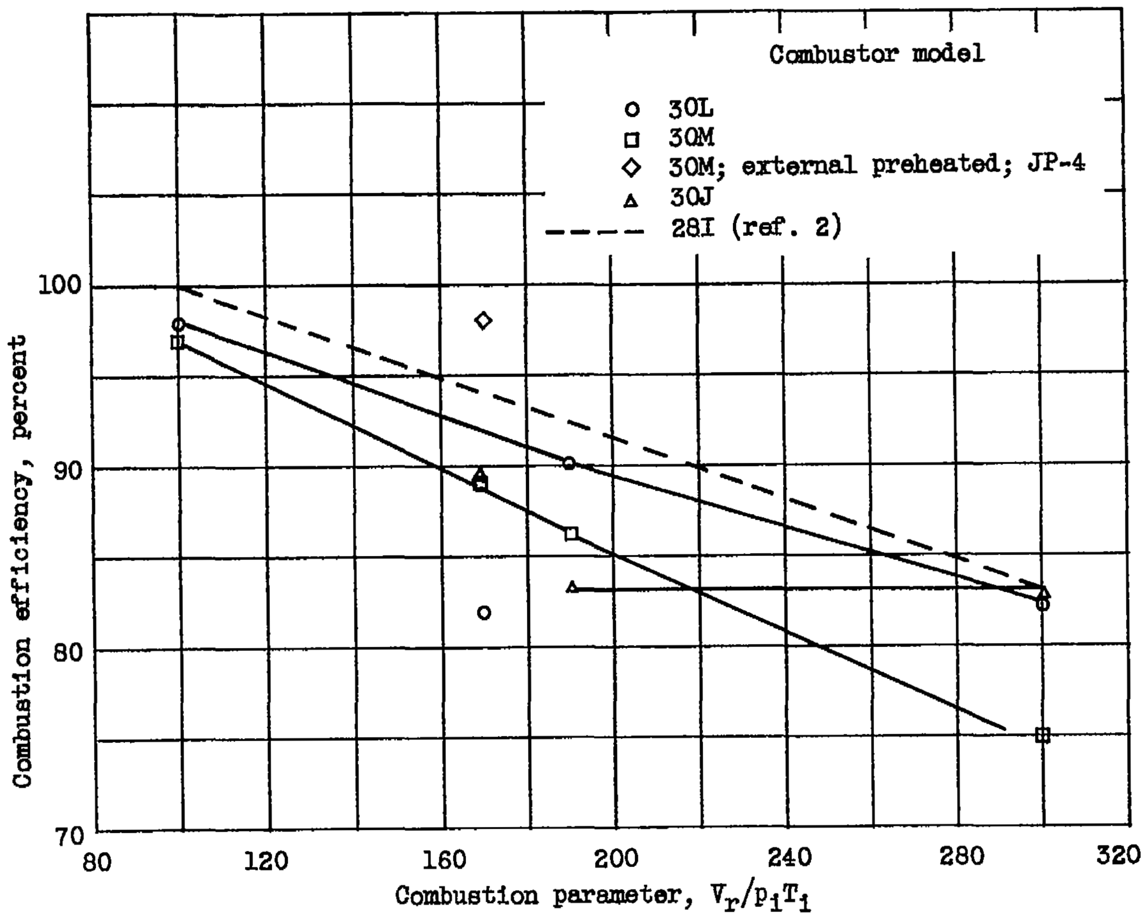


Figure 14. - Correlation of combustion efficiency data of model 30 combustor and comparison with model 28I combustor with combustion parameter V_r/p_1T_1 at a temperature-rise level through the combustor of 1180° F with MIL-F-5624A grade JP-4 fuel. (Values of V_r/p_1T_1 are obtained at combustor reference velocity of 80 ft/sec, except at $V_r/p_1T_1 = 170\times10^{-6}$, which represents a combustor reference velocity of 140 ft/sec.)

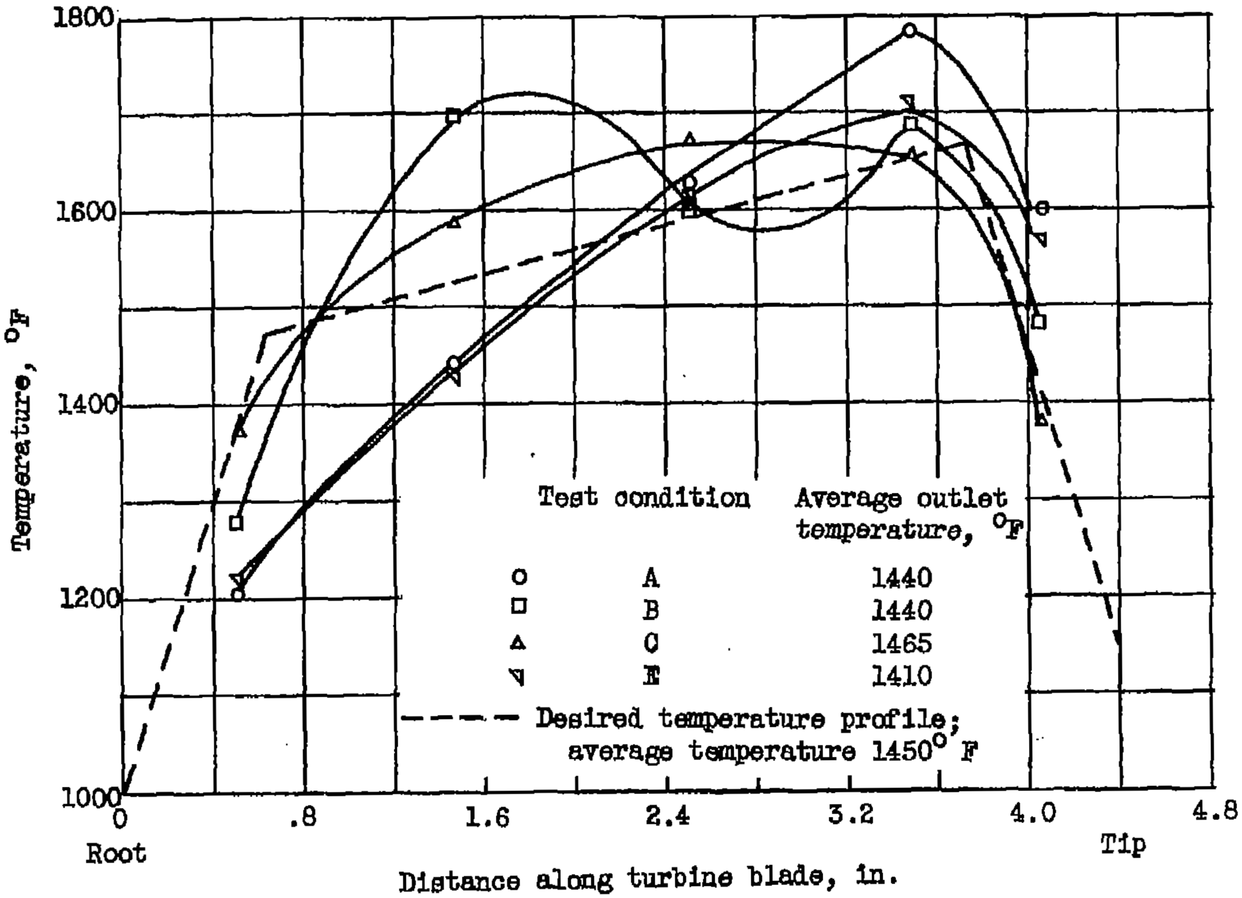


Figure 15. - Prevaporizing combustor model 30L outlet-radial-temperature profiles.

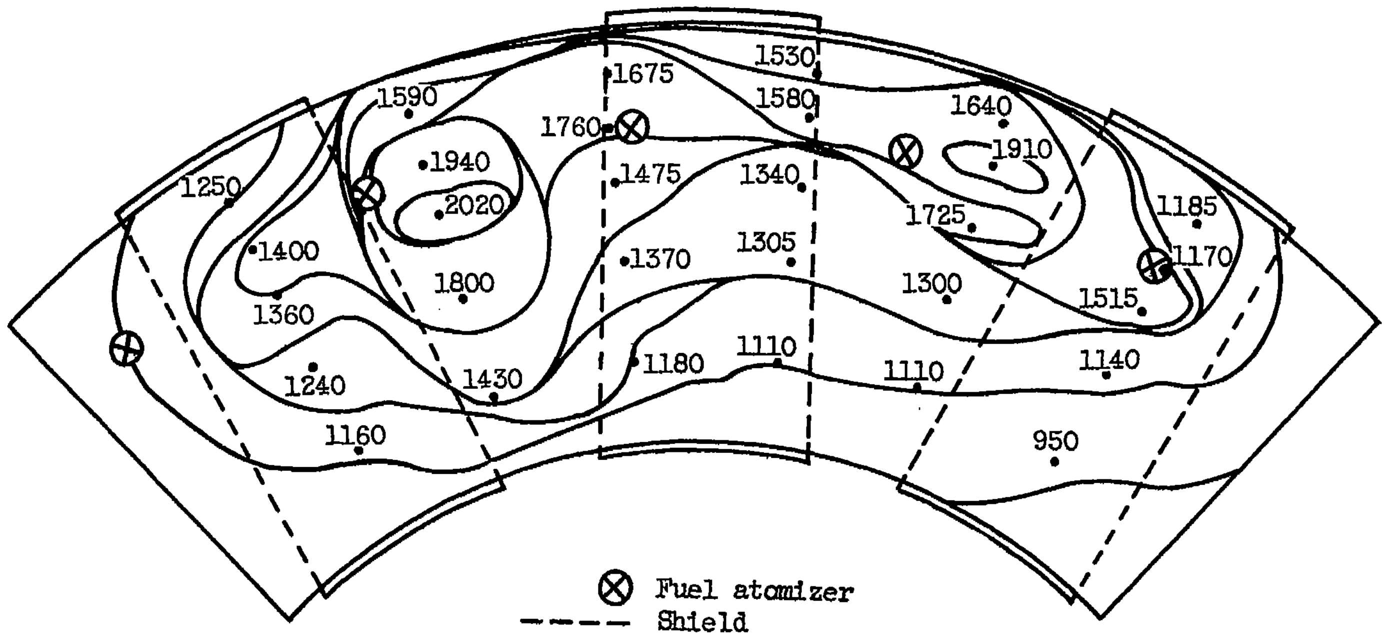
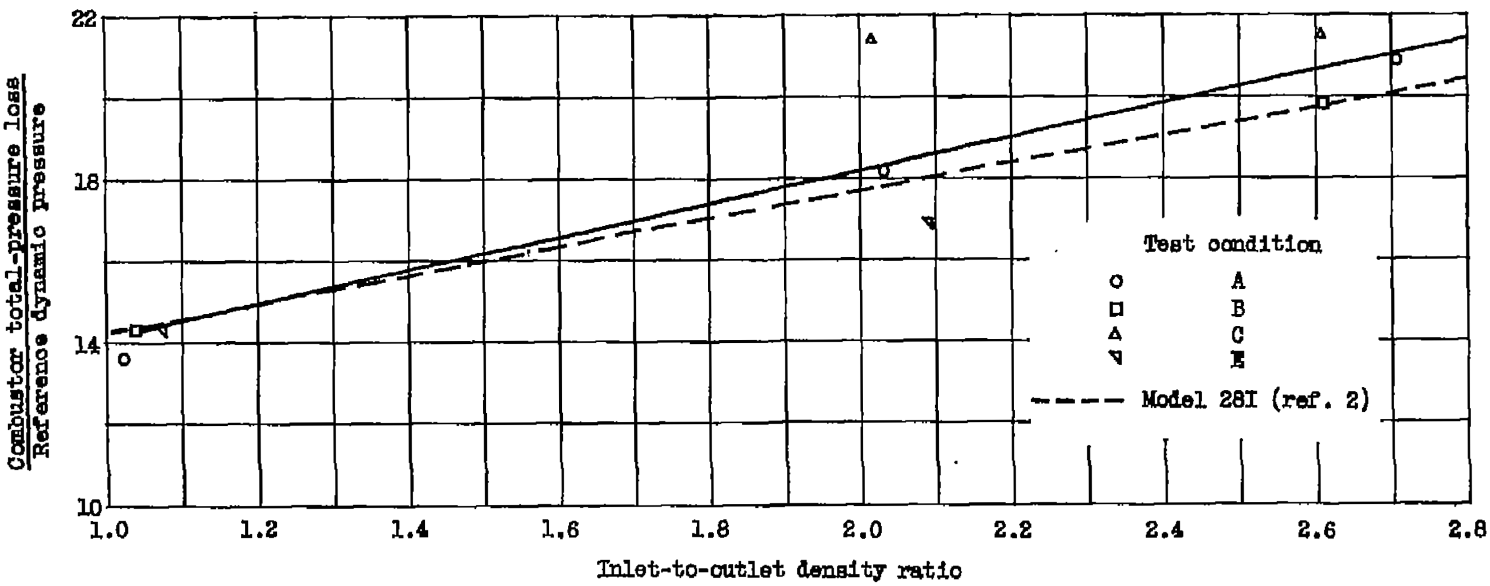
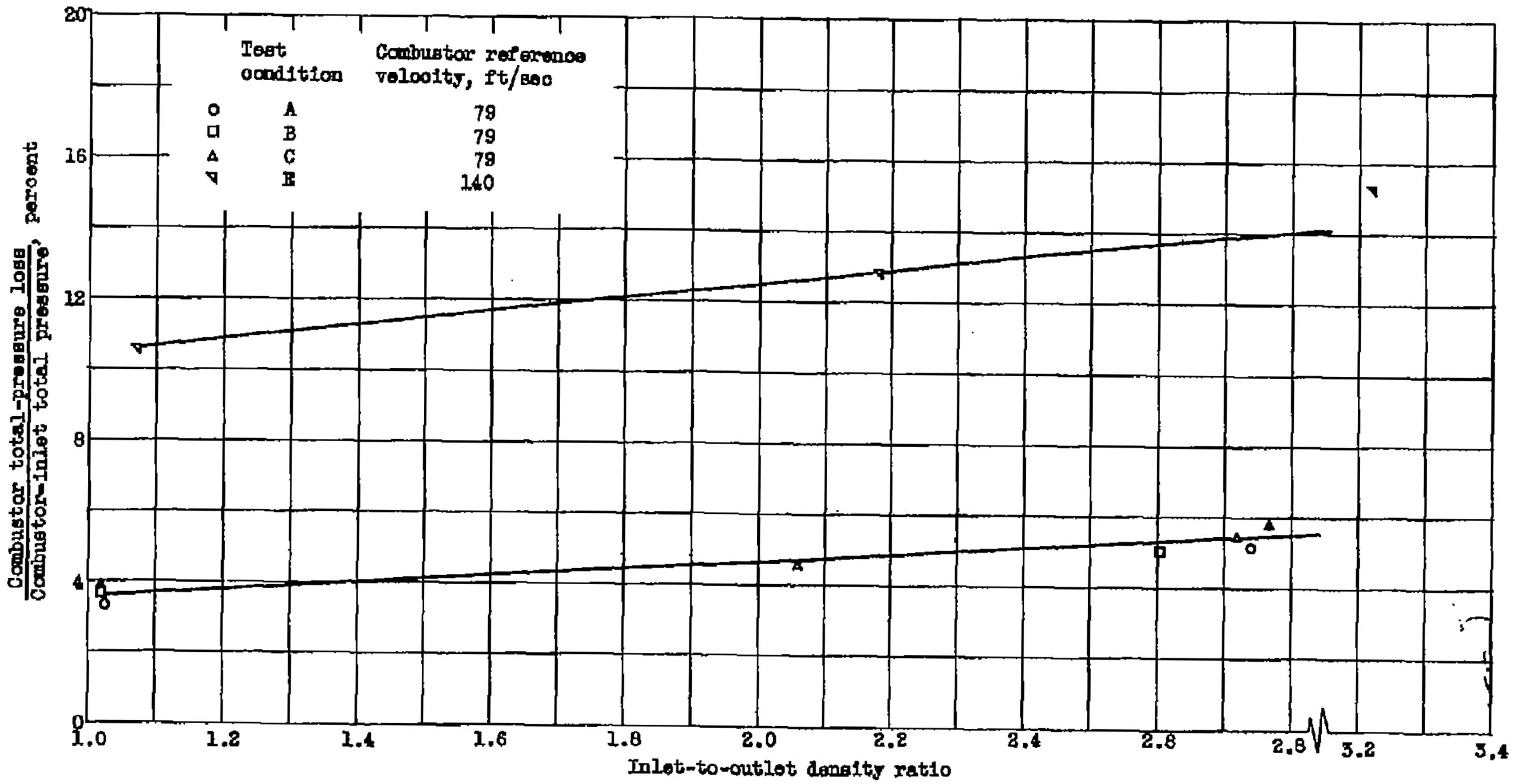


Figure 16. - Isothermal contour patterns at combustor outlet of experimental prevaporizing combustor model 30L. Test condition A; average temperature, 1439° F.



(a) Ratio of total-pressure loss to reference dynamic pressure loss.

Figure 17. - Combustor pressure losses of model 30 prevaporizing combustor.



(b) Ratio of total-pressure loss to total inlet pressure.

Figure 17. - Concluded. Combustor pressure losses of model 30 prevaporizing combustor.

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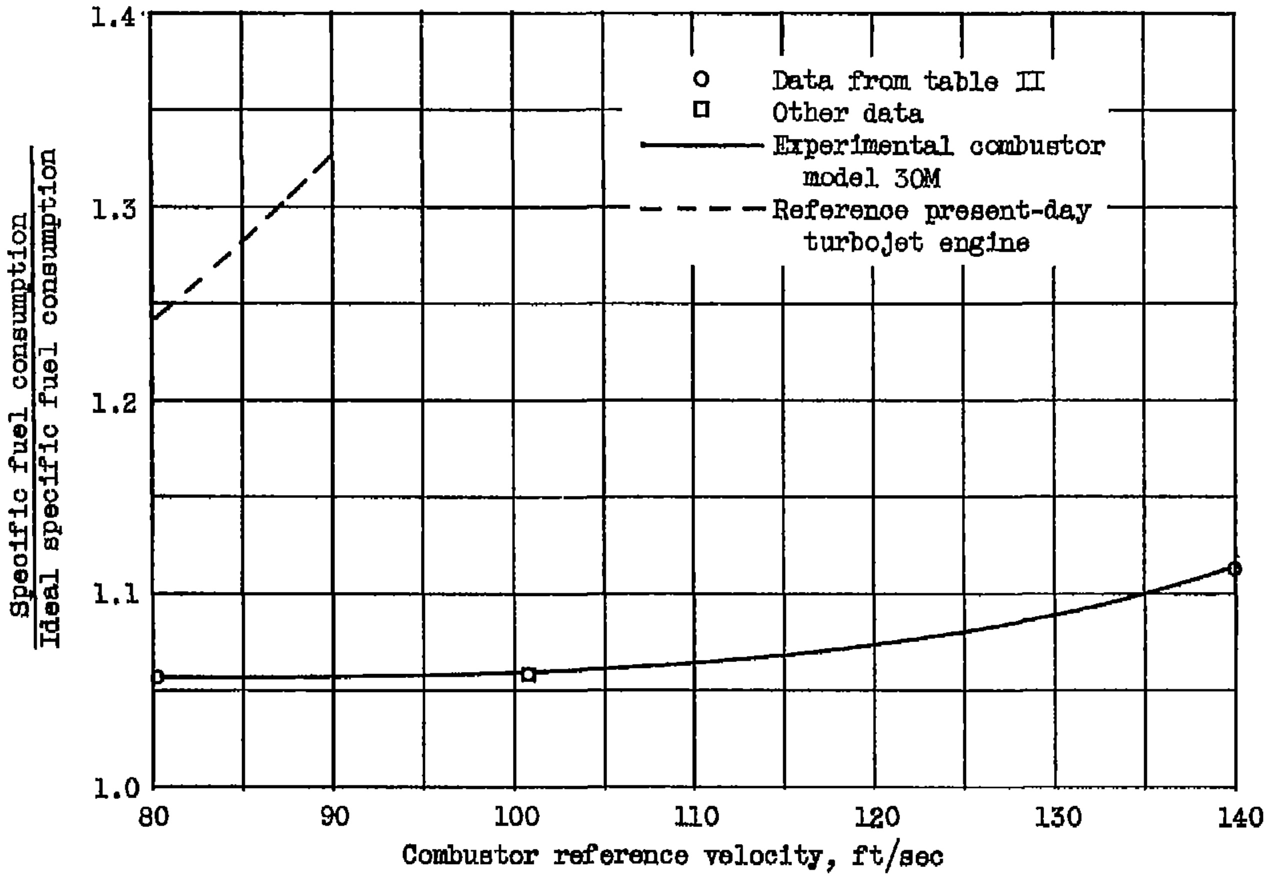

Figure 18. - Estimated specific fuel consumption increase due to combustion efficiency and pressure loss. Combustor pressure, 15 inches of mercury absolute; inlet temperature, 268° F.

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