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RESEARCH MEMORANDUM

SIMULATED ALTITUDE PERFORMANCE OF TWO ANNULAR COMBUSTORS WITH CONTINUOUS AXIAL OPENINGS FOR ADMISSION OF PRIMARY AIR

By Eugene V. Zettle and Herman Mark

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Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Methods of introducing and distributing air and fuel into the combustor of turbojet engines were evaluated by investigating the performance of two single-annulus liners in a one-quarter sector (90° annulus) of a $25\frac{1}{2}$-inch-diameter turbojet combustor. The investigations covered a range of simulated altitudes and engine speeds, and the required conditions at the combustor inlet were obtained from data for an existing $25\frac{1}{2}$-inch-diameter turbojet engine operating over a range of altitude and engine speeds at a ram pressure ratio of 1.04. The altitude performance data for the two combustors investigated are compared with existing performance data for a production-model double-annulus combustor that has the same combustor-housing dimensions, but the performance of which was obtained in a complete combustor (360° annulus).

The performance of one of the two combustors investigated indicated that the altitude operating limits for the single-annulus combustors were as much as 11,000 feet higher than for a production-model double-annulus design at rated engine speed. At maximum rated engine speed and altitudes between 40,000 and 50,000 feet, both single-annulus combustors operated with combustion efficiencies about 30 percent higher than those of the double-annulus combustor. The combustion efficiencies were insensitive to changes in fuel-air ratio over the range of fuel-air ratios investigated (0.007 to 0.024). The temperature profiles at each condition investigated showed temperatures higher near the outer wall than near the inner wall. The generally desirable radial temperature distribution with higher temperatures near the tips of the turbine blades was thus attained.

The total-pressure losses for both combustors were slightly more than twice the pressure losses for the existing double-annulus design and were probably due to a decrease in open-hole area in the combustor liner as well as an increase in the percentage of the inlet area blocked by the upstream face of the combustor.

INTRODUCTION

The altitude at which an aircraft is required to operate can seriously affect combustion in a turbojet engine. Early investigations indicated that combustion efficiency decreased with increased altitude and that for any turbojet combustor at each engine speed an altitude existed above which the combustor would not supply sufficient energy to the turbine to operate the engine at the particular conditions, no matter how much fuel was injected. Because for some engines these altitude operational limits are seriously low, a general research program directed at the analysis and the improvement of the altitude performance of turbojet combustors was initiated at the NACA Lewis laboratory.

The cause of the reduced efficiency and the altitude limits is indicated in reference 1. Systematic investigations of the distribution of the air entering the combustor (unavailable publication) and similar studies on the effect of the volatility and the degree of atomization of the fuel (reference 2) indicated specific remedial measures that led to appreciably improved altitude limits and efficiencies. In these studies it was recognized that other combustor problems, such as the distribution of turbine-inlet gas temperatures, required solution simultaneously with the altitude-limit and efficiency problems. A study (reference 3) was therefore made to determine the possibilities of maintaining high altitude operational limits and efficiencies and of obtaining, at the same time, the preferred turbine-inlet-gas-temperature distribution.

The initial results of research in which the work prior to and including reference 3 is continued are presented herein. As part of this continued study of the effect of combustor design on performance, two single-annulus combustors were designed and their altitude performance investigated. Results obtained with these two combustors are described. Each of the combustors consisted of a one-quarter section of a $25\frac{1}{2}$-inch annular-combustor housing. Two particular ideas, or techniques, were investigated, namely: (1) an extension of a technique that had previously been investigated in a smaller-diameter combustor (reference 3) for producing alternate longitudinal sectors of fuel-rich and air-rich zones in the primary combustion region; and (2) the use of an internal baffling arrangement for increasing the uniformity of the fuel distribution and possibly the fuel-residence time in the primary combustion zone. The operating conditions selected were the same as those used for a previous unreported investigation of an entire $25\frac{1}{2}$-inch-diameter annular combustor; a more direct comparison of the results obtained in these two investigations was thus made possible.

The investigation of altitude performance consisted in determining the altitude operating limits, the combustion efficiency, the total-pressure loss through the combustor, and the radial temperature distribution of the combustor exhaust gases. The improvement of any one of these characteristics without deleterious effects on the remaining performance characteristics constitutes an improvement in the overall performance of the combustor.

APPARATUS

Combustor Installation

A schematic diagram of the installation is shown in figure 1. Air of desired quantity, pressure, and temperature was drawn from the laboratory air-supply system and exhausted into the altitude exhaust system, which permitted operation in the test chamber at pressures as low as 5 inches of mercury absolute. Combustor-inlet temperatures were controlled by using a gasoline-fired air preheater located in a bypass line upstream of the combustor. The quantity of air flowing through the bypass, the total air flow, and the combustion-chamber static pressure were regulated by three remote-control valves. Two observation windows were installed in the test section in order to permit visual observation of combustion.

Instrumentation

Total temperature and pressure were measured at the three stations indicated in figure 1: station 1, combustor inlet; station 2, combustor outlet (corresponding to turbine inlet); and station 3, exhaust section where thermocouples were installed in order to check the results measured at the combustor outlet and to indicate any burning beyond the combustor outlet. The position of the instruments in each of the three planes is shown in figure 2.

Combustor-inlet total temperatures were measured with three bare-junction, unshielded iron-constantan thermocouples at station 1, as shown in figure 2(a). Slightly upstream of station 1 were located 12 total-pressure tubes, three in each of four rakes as shown in figure 2(a). Combustor-outlet total temperatures were measured with 30 bare-junction unshielded chromel-alumel thermocouples; five thermocouples in each of six rakes were located across the duct at station 2, as shown in figure 2(b). At station 3 were 15 total-pressure tubes in three rakes of five pressure tubes each and 15 bare-junction chromel-alumel thermocouples in three rakes of five thermocouples each (fig. 2(c)). All instruments were located at approximate centers of equal areas. Static-pressure taps were installed at the walls, as shown in figure 2.

Instrument construction details are shown in figure 3. The thermocouples were connected to calibrated self-balancing indicating potentiometers. The total-pressure tubes and wall static-pressure taps were connected to common-well manometers. Mercury manometers were used for measuring the gage static chamber pressure. Fuel flow was metered through calibrated rotameters and air flow, through a concentric-hole, sharp-edged orifice.

Description of Combustors

Each of the two combustors investigated consisted of a single-annulus liner or basket designed to fit into a one-quarter sector of a combustor housing. The combustor housing was $25\frac{1}{2}$ inches in diameter and the distance in the assembled combustor from the fuel nozzles to the turbine-nozzle inlet was approximately 23 inches.

A longitudinal cross section of the liner for the first combustor design is shown in figure 4(a). The liner was so constructed as to be divisible into two pieces at a section approximately 5 inches downstream of the fuel-inlet section. The two pieces are shown separated in figure 4(b).

The assembled liner had diagonal internal baffles (figs. 4(a) and 4(b)), which appear in figure 4(c) as the perforated convergent portions of the liner walls. Views of the inner and outer walls of the assembled liner showing the distribution of open-hole area are presented in figure 4(d). Air was admitted into the combustion zone upstream of the internal baffles through small circular holes. Downstream of the internal baffles, additional primary air was admitted through long, thin triangular slots running axially along the liner. Shorter rectangular slots were cut for admission of secondary air. Louvers, as shown, were punched in the walls between the rows of slots to admit cooling air and thereby reduce liner-wall warping. No attempt was made to alter the type or location of the internal baffles.

The second combustor investigated consisted of a similar liner from which the internal baffles were removed.

The fuel manifold used for each combustor was fitted with 10 equally spaced fuel-injection nozzles that produced hollow-cone fuel sprays. These nozzles were rated at 10.3 gallons per hour (at a pressure differential of 100 lb/sq in.) with a 60° spray angle. The same fuel nozzles were used for the entire investigation.

PROCEDURE

The altitude performance of the two combustors was investigated with the combustor-inlet air conditions of air weight flow, pressure, and temperature simulating operation of the $25\frac{1}{2}$-inch-diameter 4:1 pressure ratio turbojet engine at altitudes varying from 35,000 to 60,000 feet and over a range of corrected engine speeds from 54 to 100 percent of maximum rated speed (7000 to 13,000 corrected rpm). The combustor-inlet air conditions and the values of the estimated combustor-outlet temperatures required to operate the reference engine over the range of interest were calculated from data obtained in an altitude-wind-tunnel investigation of the complete engine. Conditions were chosen at the ram pressure ratio nearest static conditions for which wind-tunnel data were available (1.04). Curves for combustor-inlet conditions and for the estimated values of combustor-outlet gas temperatures at a ram pressure ratio of 1.04 are given in figure 5. Altitude performance was determined for both combustors with two fuels, AN-F-32 and AN-F-58.

Altitude Operating Limits

The altitude operating limits were determined over a range of corrected engine speeds from 54 to 100 percent of maximum rated speed (7000 to 13,000 corrected rpm) in the following manner: At a given simulated condition of altitude and engine speed, all inlet-air conditions were kept constant and the fuel flow was increased until either the required temperature rise was attained, the combustor-outlet temperature decreased with further increase in fuel flow, or combustion blow-out occurred. If the temperature rise was attained, the point was considered in the operating region for the engine; if either of the other two conditions was encountered, the point was considered in the nonoperating region for the engine. This procedure was repeated for sufficient engine operating points to determine the limiting altitude for engine operation at each engine speed; the altitude operating limits were thus established.

Combustion efficiency. - The effect of variations in simulated altitude and engine speed on the combustion efficiency was determined at values of temperature rise through the combustor slightly exceeding the temperature rise required to operate the engine at each given altitude and engine speed.

The effect of variation of fuel-air ratio on combustion efficiency was determined over a range of fuel-air ratios (0.007 to 0.024) at the following simulated flight conditions chosen to cover a range of combustor-inlet air variables:

Altitude (ft)	Maximum rated engine speed (percent)	Combustor-inlet air			
		Flow (lb/sec)	Pressure (in. Hg abs.)	Temperature (°F)	Required combustor-outlet temperature (°F)
40,000	100	3.31	24.7	192	1274
40,000	77	2.30	14.9	89	773
50,000	100	1.80	15.1	192	1502

Radial temperature distribution. - The combustor-outlet radial temperature distribution was determined at values of temperature rise through the combustor slightly exceeding the temperature rise required to operate the engine at the simulated flight conditions tabulated.

Total-pressure loss. - Simultaneously with the determination of combustion efficiency and combustor-outlet radial temperature distribution, the total pressures at the combustor inlet and outlet were recorded. The differences between the inlet and outlet total pressures are given in terms of a dimensionless parameter involving a reference dynamic pressure q_r.

METHODS OF CALCULATION

Average temperatures and pressures were taken as the arithmetic average of all the readings at each section. The temperature averages were not weighted for mass-flow profiles. All temperatures were considered as total temperatures, because maximum errors due to incomplete impact recovery were of the order of 1 percent of the total temperature. The combustion efficiency is the ratio of the average gas-temperature rise through the combustor to the temperature rise theoretically obtainable with the given over-all fuel-air ratio. The reference dynamic pressure q_r was calculated from the air flow, the average inlet-air temperature and static pressure, and the maximum cross-sectional area of the combustor housing (105 sq in.).

RESULTS AND DISCUSSION

Altitude Operating Limits

The altitude operating limits for the two combustors and two fuels used are shown in figure 6, where simulated altitude is plotted against simulated corrected engine speed. In each plot the altitude operating limits are defined by a curve that separates the operating conditions for which the combustor can produce the required combustor-outlet temperatures from the operating conditions for which it cannot produce this temperature. The combustor-outlet temperatures required for steady-state engine operation and the combustor-outlet temperatures obtained exceeding the required values are included beside each data point on figure 6. At altitudes below the operating limits, higher values of combustor-outlet temperature were attainable; the values tabulated are the particular values at which the combustion efficiency and other data were recorded.

When AN-F-32 fuel was used, the altitude operating limits of the combustor with internal baffles were about 63,000 feet if extrapolated to maximum rated engine speed and 40,000 feet at 54 percent of maximum rated engine speed (fig. 6(a)). The operating limits of the combustor without internal baffles were about 64,000 feet if extrapolated to maximum rated engine speed and 37,000 feet at 54 percent of maximum rated engine speed (fig. 6(c)). Both combustors had operating limits about 4000 feet lower in the range of 70 to 100 percent of maximum rated engine speed when operated with AN-F-58 fuel.

In figure 7, the altitude operating limits of the two combustors are compared for each of the two fuels investigated. The altitude operating limits of the combustor without internal baffles were 2000 to 4000 feet higher than those of the combustor with internal baffles in the range of 75 to 100 percent of maximum rated engine speed.

The altitude operating limits obtained with a production-model double-annulus combustor designed to fit into the same $25\frac{1}{2}$-inch-outside-diameter combustor housing are also shown in figure 7. These altitude operating limits of the double-annulus combustor were obtained in an investigation of the full-annulus (360°) combustor operating with AN-F-58 fuel at conditions simulating flight in the same reference engine as that used in this investigation. This curve can therefore be compared directly with the curves for operation of the two current designs with AN-F-58 fuel. The altitude operating limits of the single-annulus combustor without internal baffles were about 11,000 and 5000 feet above those of the double-annulus production model at 100 and 70 percent, respectively, of maximum rated engine speed.

Combustion Efficiency

The combustion efficiencies at various simulated flight conditions are shown in figure 8 for the two combustors operating with each of the two fuels investigated. The curves of figure 8 were obtained by interpolating between the values of efficiency obtained at each of the data points indicated on figure 6. The curves representing the altitude limits of the combustors do not necessarily represent a constant-efficiency line; the combustion efficiency decreases rapidly near the altitude operating limits of the combustors. The combustion efficiencies of the combustor with internal baffles were about 3 percent higher than those of the combustor without internal baffles throughout most of the range of altitudes and engine speeds investigated. The combustion efficiency of the two single-annulus combustors with AN-F-32 fuel at maximum rated engine speed and various altitudes is shown in the following table:

Altitude (ft)	Combustion efficiency (percent)	
	Combustor with internal baffles	Combustor without internal baffles
Below 40,000	Over 99	Over 99
45,000	98	97
50,000	96	93
55,000	88	85
60,000	82	75

For both combustors, the efficiencies obtained were approximately 2 percent higher for AN-F-32 fuel than for AN-F-58 fuel. The combustion efficiencies of both combustors approach 100 percent as altitude is decreased and engine speed is increased. Both single-annulus combustors investigated operated with efficiencies about 30 percent higher than those of the production-model double-annulus combustor in the range of altitudes from 40,000 to 50,000 feet at maximum rated engine speed.

The variation of combustion efficiency with fuel-air ratio for simulated altitudes of 40,000 and 50,000 feet at maximum rated engine speed (13,000 corrected rpm) and 40,000 feet at 77 percent of maximum rated speed is illustrated in figure 9. The combustion efficiency remained essentially constant with increases in fuel-air ratio over the entire range investigated (0.007 to 0.024) for both combustors and both fuels.

A comparison is made in figure 10 between typical data for a double-annulus production-model combustor and typical data for a single-annulus combustor taken from figure 9. The efficiency of the double-annulus combustor was quite sensitive to changes in fuel-air ratio and increased with increasing fuel-air ratio.

Temperature Distribution

Radial temperature distributions at the combustor outlet for the two combustors are shown in figure 11. The temperature distributions were approximately the same for both combustors and for both fuels investigated. The fuel-air ratio at which these temperature distributions are shown was in each case just sufficient to produce the combustor-outlet temperatures required to operate the engine for the simulated-flight conditions. Each of the data points in figure 11 is the average of six circumferential temperature readings at the given radial distance from the turbine root section in the engine. The temperature profiles at each condition investigated showed temperatures higher near the outer wall than near the inner wall. No attempt was made, by modifications in the combustor as in reference 3, to alter the temperature distributions at the combustor outlet. For the conditions investigated, the deviation from the average temperature increases as altitude is increased at constant engine speed and also the deviation from the average temperatures increases as the engine speed is increased at constant altitude conditions; however, the general radial pattern of the outlet-temperature distribution did not change with operating conditions within the range investigated.

Combustor Total-Pressure Loss

The ratio of the combustor total-pressure loss ΔP_T to the calculated reference dynamic pressure q_r is plotted as a function of the inlet- to outlet-gas density ratio ρ_1/ρ_2 in figure 12. The pressure losses for the two combustors were the same within experimental accuracy, as shown by a comparison of figures 12(a) and 12(b). The value of $\Delta P_T/q_r$ increased linearly from approximately 26 with isothermal (no-burning) flow to approximately 36 at $\rho_1/\rho_2 = 3$. A comparison with the original production-model double-annulus combustor reveals $\Delta P_T/q_r$ values for the two combustor designs reported herein about $2\frac{1}{3}$ times the values for the double-annulus combustor. The percentage of inlet-air-passage area blocked by the upstream face of the single-annulus combustor is greater than the percentage blocked by the faces of the double-annulus design because the upstream end of the single-annulus liner was extended $1\frac{1}{2}$ inches farther upstream into the compressor-outlet diffuser. A portion of the increase in total-pressure loss is thereby accounted for; some of the increase in pressure loss, however, must be due to the somewhat lower total-open-hole area in the single-annulus combustor liner (210 sq in. compared to 330 sq in. in the production-model double-annulus liner).

Character of Flames

At simulated conditions of altitude and engine speed below the altitude limit of the engine, combustion changed with increasing fuel-air ratio from the steady combustion to that characterized by a steady flickering, which increased in magnitude up to the point of flame blow-out. The flame remained seated well toward the upstream end of the combustor at all conditions of operation. No rough combustion was witnessed at any of the operating conditions investigated.

SUMMARY OF RESULTS

The following results were obtained from the experimental investigation of the simulated-altitude performance of two single-annulus combustors designed for a one-quarter sector of a $25\frac{1}{2}$-inch-diameter combustor housing:

1. When operated with AN-F-32 fuel, the altitude operating limits of the combustor with internal baffles were 63,000 and 40,000 feet at 100 percent and 54 percent of rated engine speed, respectively. The operating limits of the combustor with no internal baffles were 64,000 and 38,000 feet at 100 percent and 54 percent of rated engine speed, respectively. When operated with AN-F-58 fuel both single-

annulus combustors had operating limits about 4000 feet lower in the range of 70 to 100 percent rated speed than when operated with AN-F-32 fuel.

2. The combustion efficiency of the two single-annulus combustors with AN-F-32 fuel at rated engine speed and various altitudes is shown in the following table:

Altitude (ft)	Combustion efficiency (percent)	
	Combustor with internal baffles	Combustor without internal baffles
Below 40,000	Over 99	Over 99
45,000	98	97
50,000	96	93
55,000	88	85
60,000	82	75

The combustion efficiencies for the two combustor configurations were about 2 percent lower when operated with AN-F-58 fuel.

3. The efficiencies of both these single-annulus combustors were about 30 percent higher than those of a double-annulus production-model combustor in the range of altitudes from 40,000 to 50,000 feet at rated engine speed.

4. In contrast to the increase in combustion efficiency with increase in fuel-air ratio noted for the double-annulus production-model combustor, the combustion efficiency of the single-annulus combustors did not vary appreciably with fuel-air ratio in the range investigated (0.007 to 0.024).

5. The exhaust-gas radial temperature distributions at each condition and for each combustor and fuel investigated showed temperatures higher near the outer wall than near the inner wall; the generally desirable radial distribution with higher temperatures near the tips of the turbine blades was thus attained. In addition, the general radial pattern of the outlet-temperature distribution did not change with operating conditions within the range investigated.

6. The total-pressure losses for both combustors were almost the same over the entire range of inlet- to outlet-density ratios. For isothermal conditions (no combustion), the total-pressure loss was approximately 26. At an inlet- to outlet-density ratio of 3.0 the value of total-pressure loss for both combustors was 36. These

pressure losses were slightly more than twice the pressure losses for the existing double-annulus design and were probably due to a decrease in open-hole area in the combustor liner as well as an increase in the percentage of the inlet area blocked by the upstream face of the combustor, which extended farther upstream into the compressor-outlet diffuser than did the upstream face of the existing double-annulus design.

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2. McCafferty, Richard J.: Effect of Fuels and Fuel-Nozzle Characteristics on Performance of an Annular Combustor at Simulated Altitude Conditions. NACA RM E8C02a, 1948.

3. Mark, Herman, and Zettle, Eugene V.: Effect of Air Distribution on Radial Temperature Distribution on One-Sixth Sector of Annular Turbojet Combustor. NACA RM E9I22, 1949.

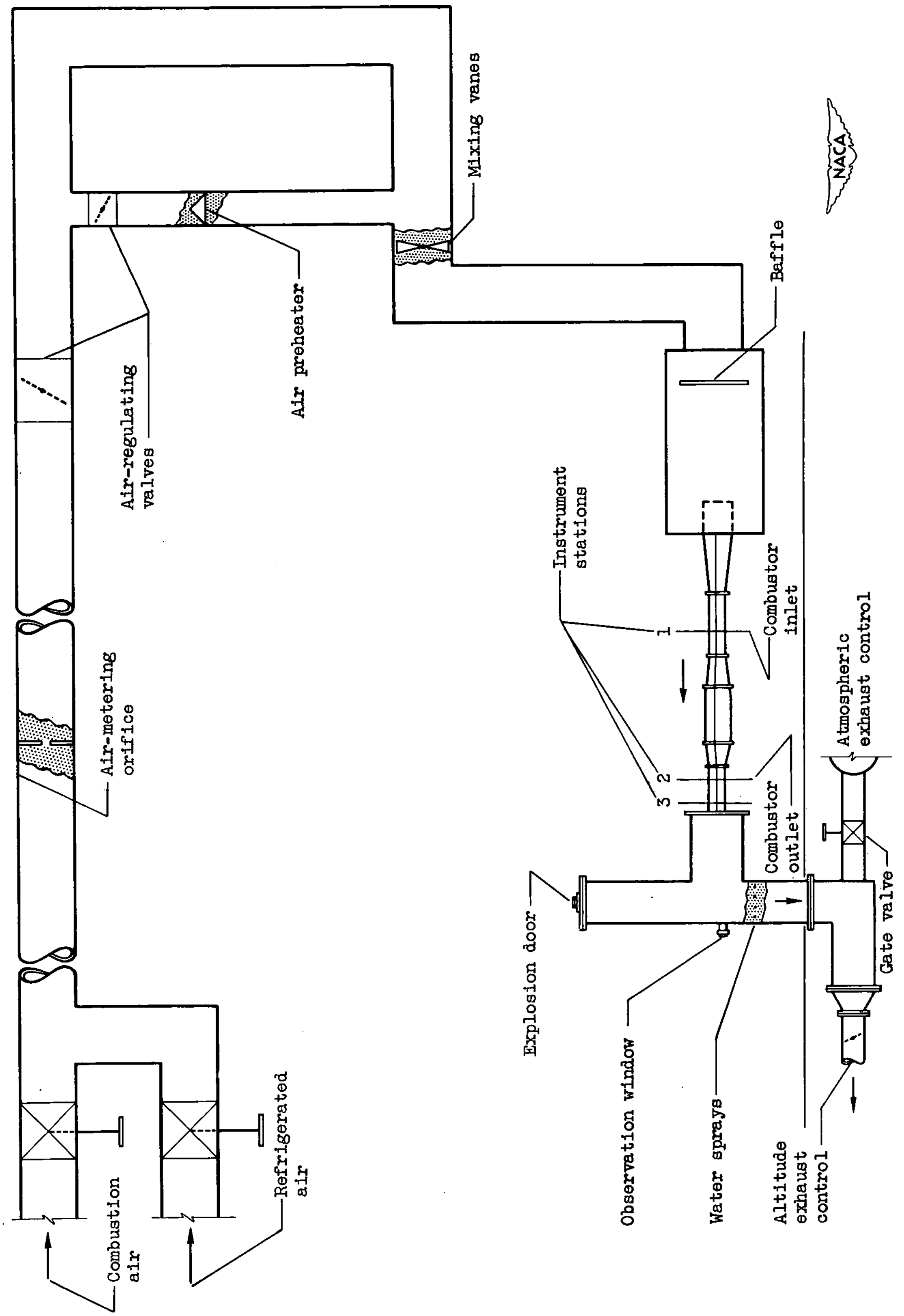
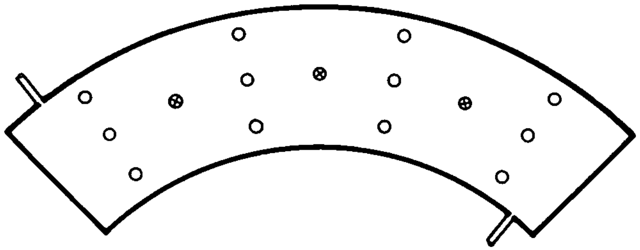
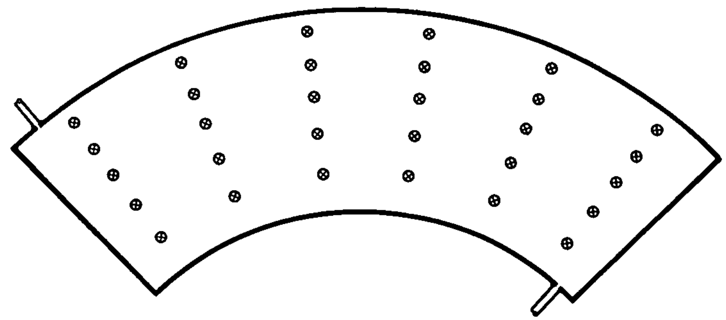


Figure 1. - Diagram of arrangement of one-quarter sector of $25\frac{1}{2}$-inch-diameter annular combustor setup.

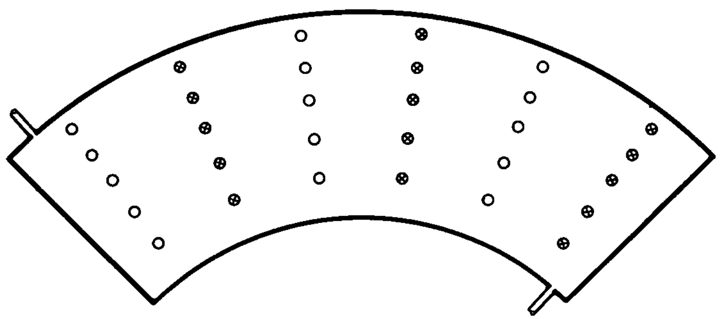


(a) Inlet thermocouples (iron-constantan)
and inlet total-pressure rakes at plane 1.



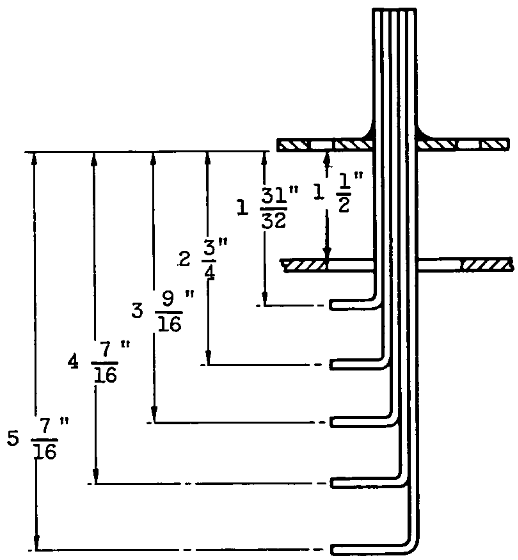
(b) Outlet thermocouples at plane 2
(chromel-alumel).

⊗ Thermocouple
○ Total-pressure rake
┘└ Static-pressure orifice

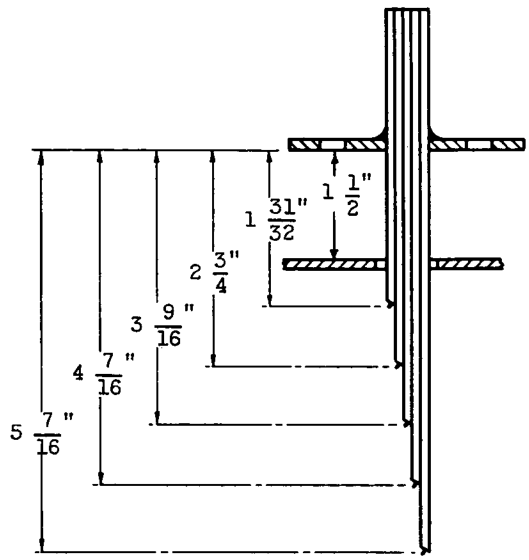


(c) Outlet thermocouples (chromel-alumel)
and outlet total-pressure rakes at plane 3.

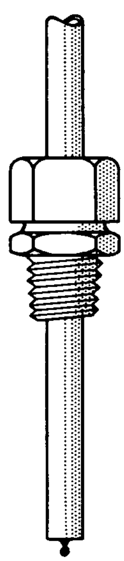
Figure 2. - Instrumentation.



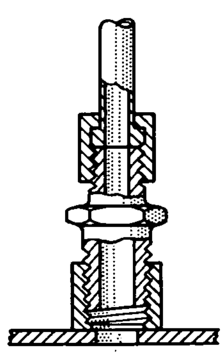
(a) Outlet total-pressure rake.



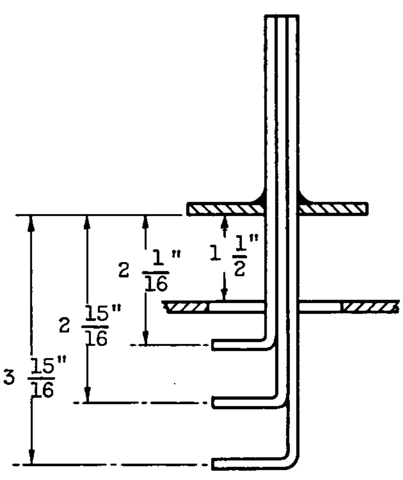
(b) Outlet thermocouple rake.



(c) Inlet thermocouple.

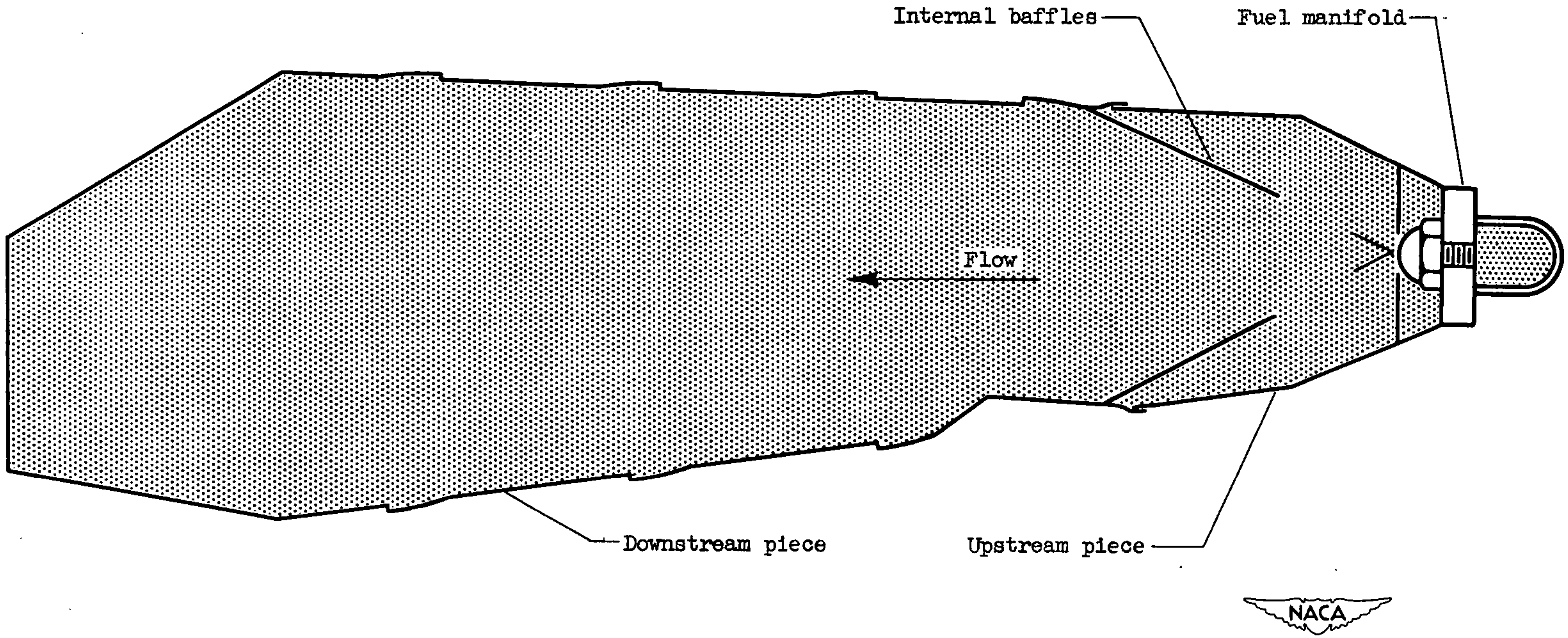


(d) Static-pressure orifice.



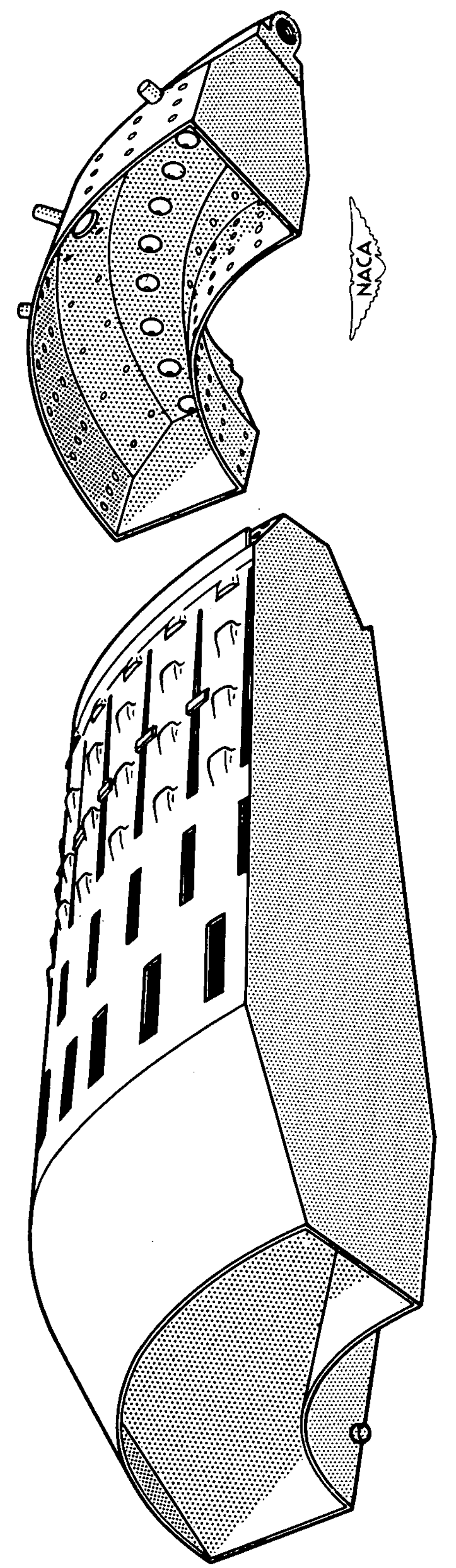
(e) Inlet total-pressure rake.

Figure 3. - Details of instrumentation.



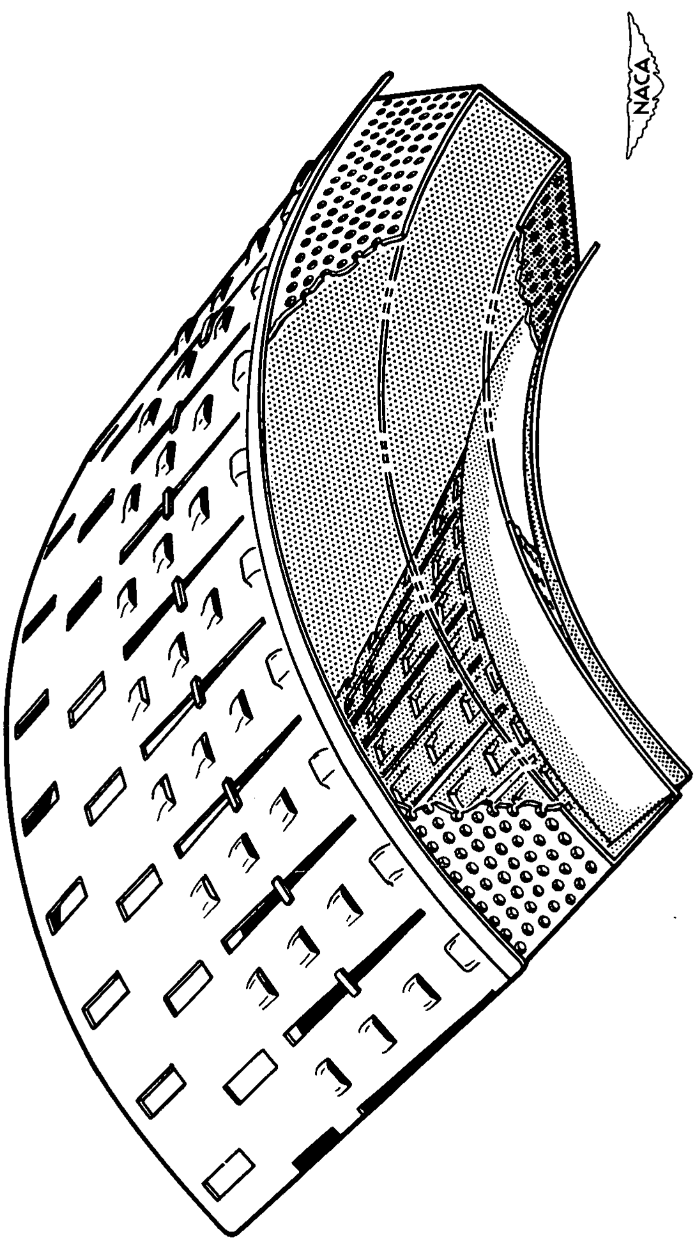
(a) Diagrammatic sketch of liner with internal baffles.

Figure 4. - Arrangement and construction of one-quarter-sector single-annulus combustor liner.



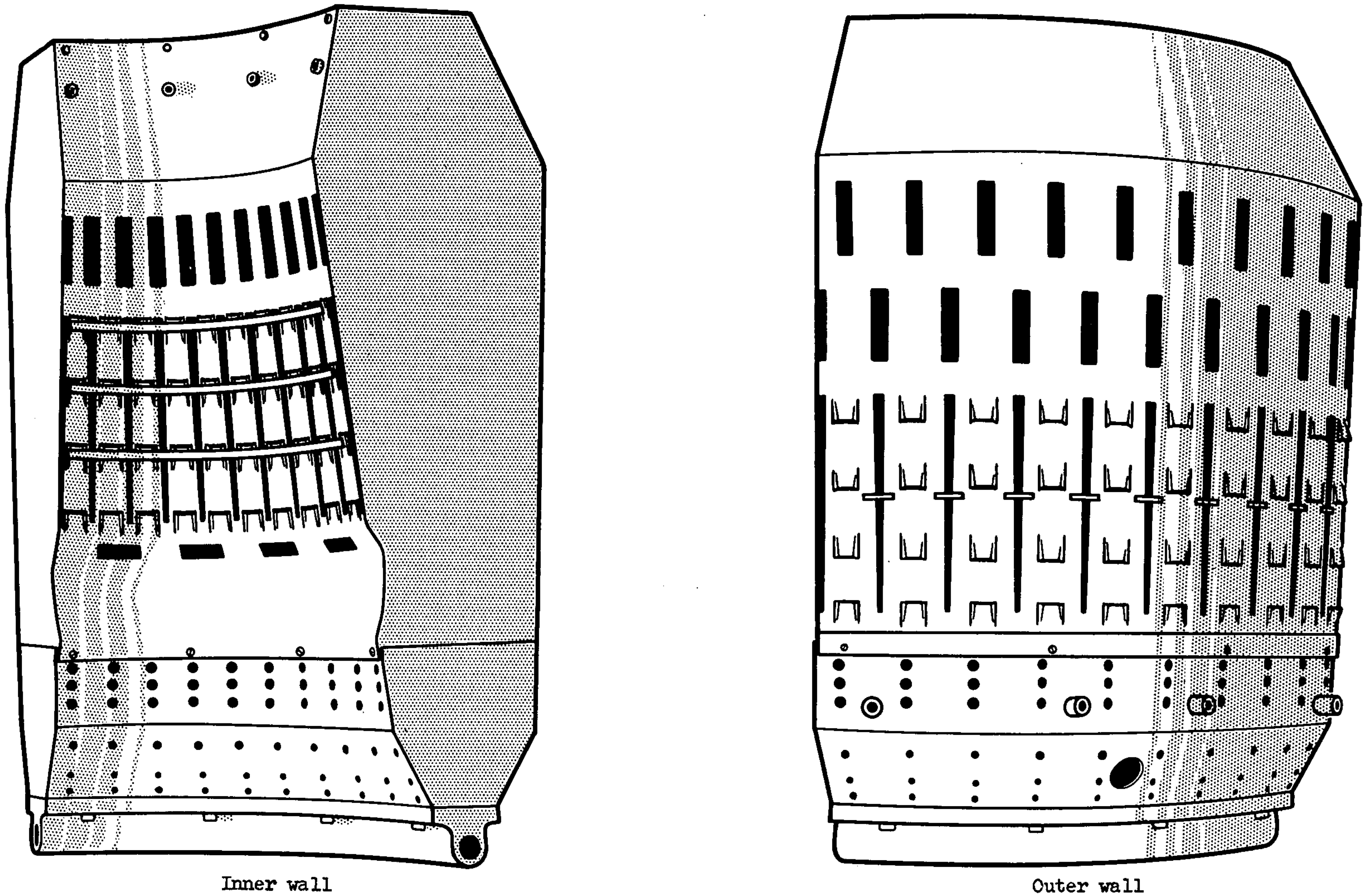
(b) Three-quarter exploded view of liner with internal baffles.

Figure 4. - Continued. Arrangement and construction of one-quarter-sector single-annulus combustor liner.



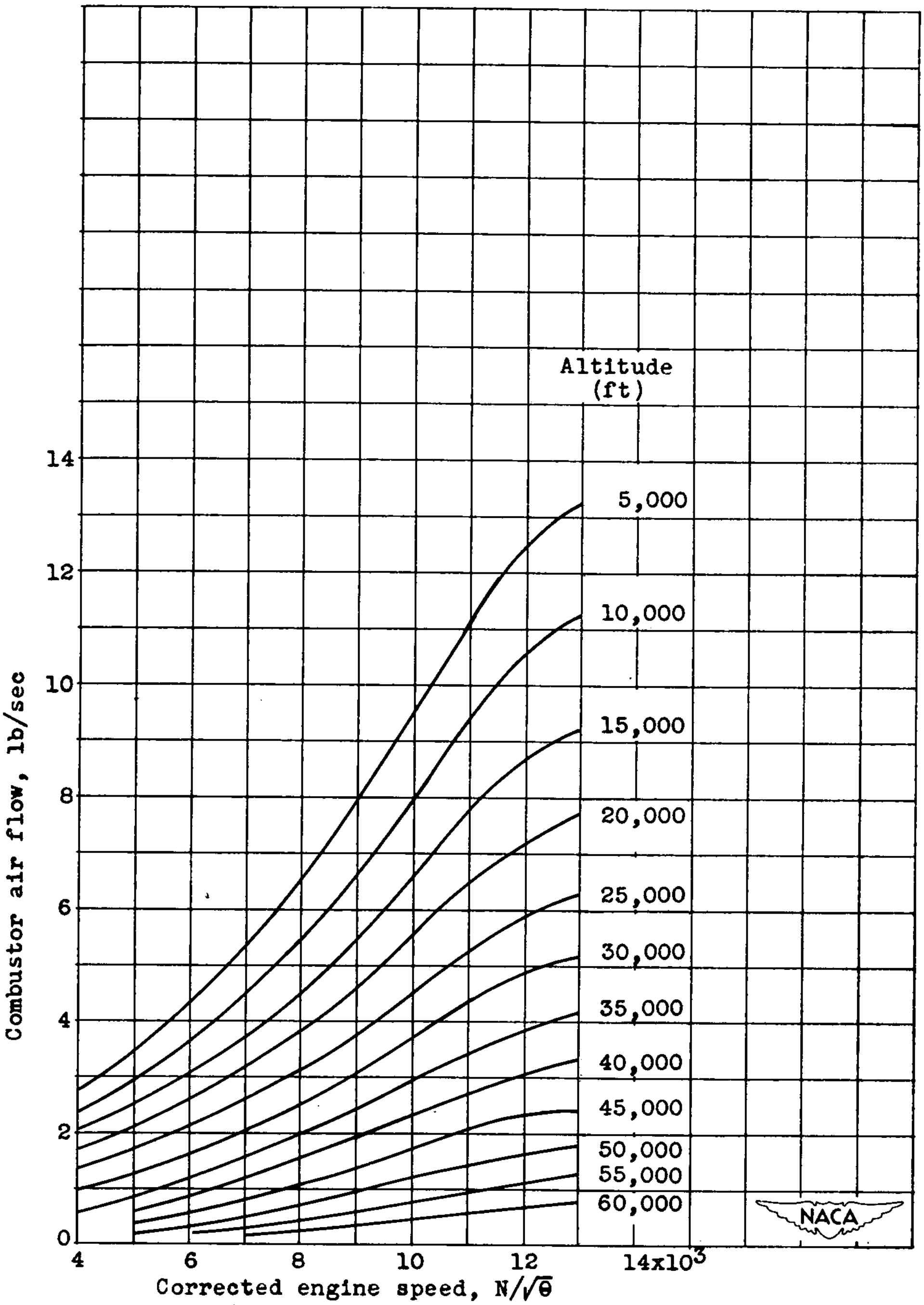
(c) Downstream piece with internal baffles exploded.

Figure 4. - Continued. Arrangement and construction of one-quarter-sector single-annulus combustor liner.



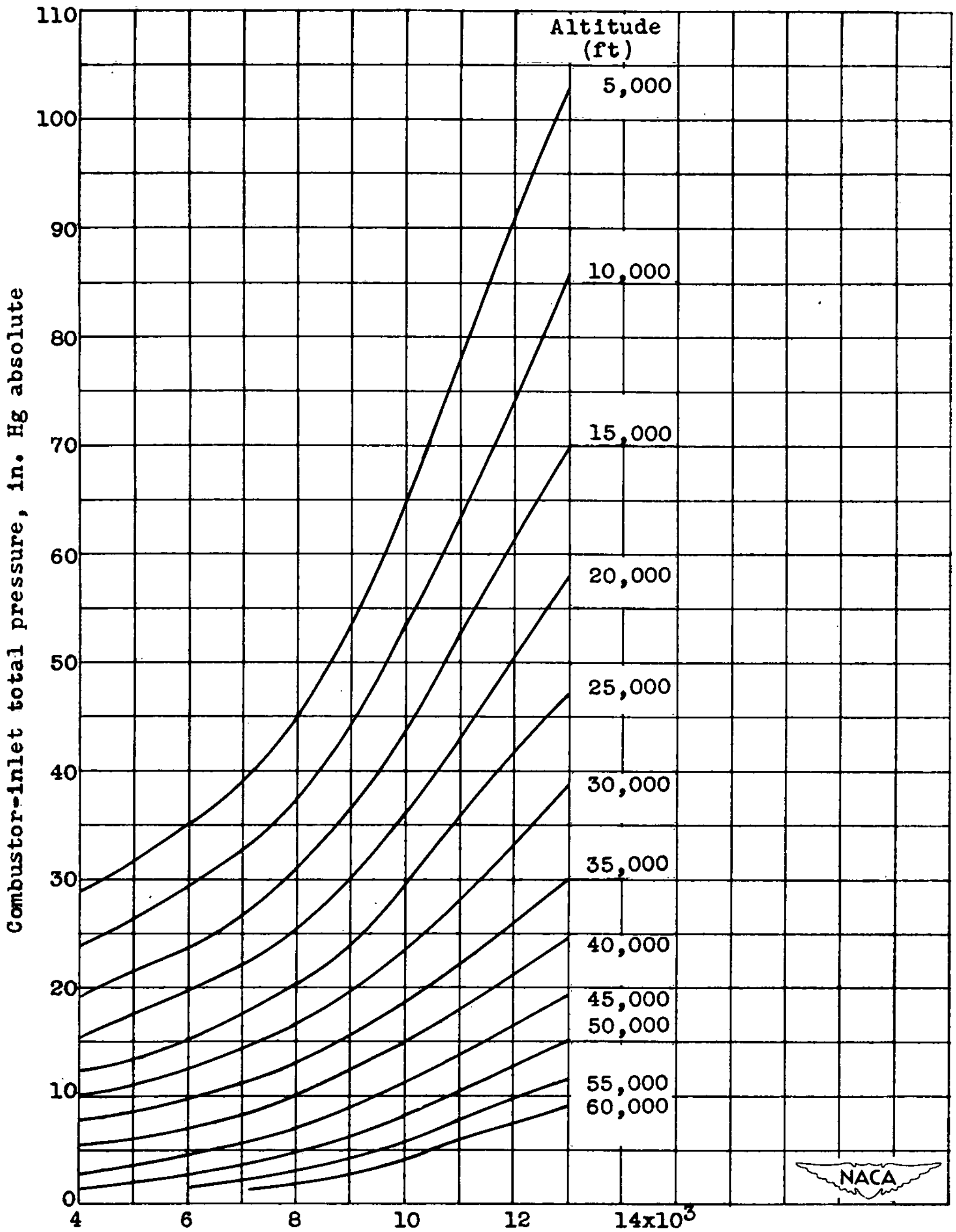
(d) Inner- and outer-wall design.

Figure 4. - Concluded. Arrangement and construction of one-quarter-sector single-annulus combustor liner.



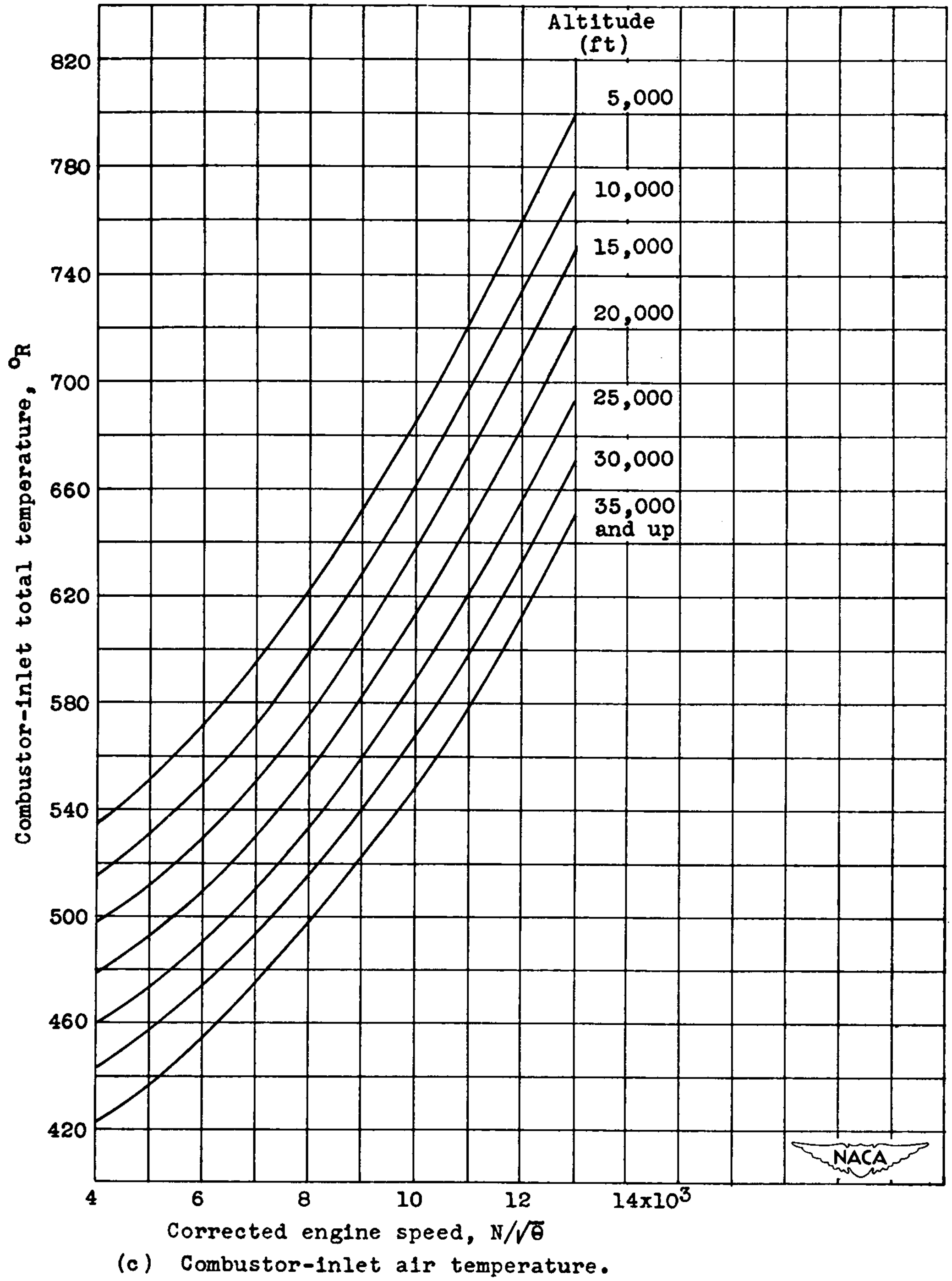
(a) Air flow for one-quarter sector.

Figure 5. - Operating characteristics for reference turbojet engine. Ram pressure ratio, 1.04.



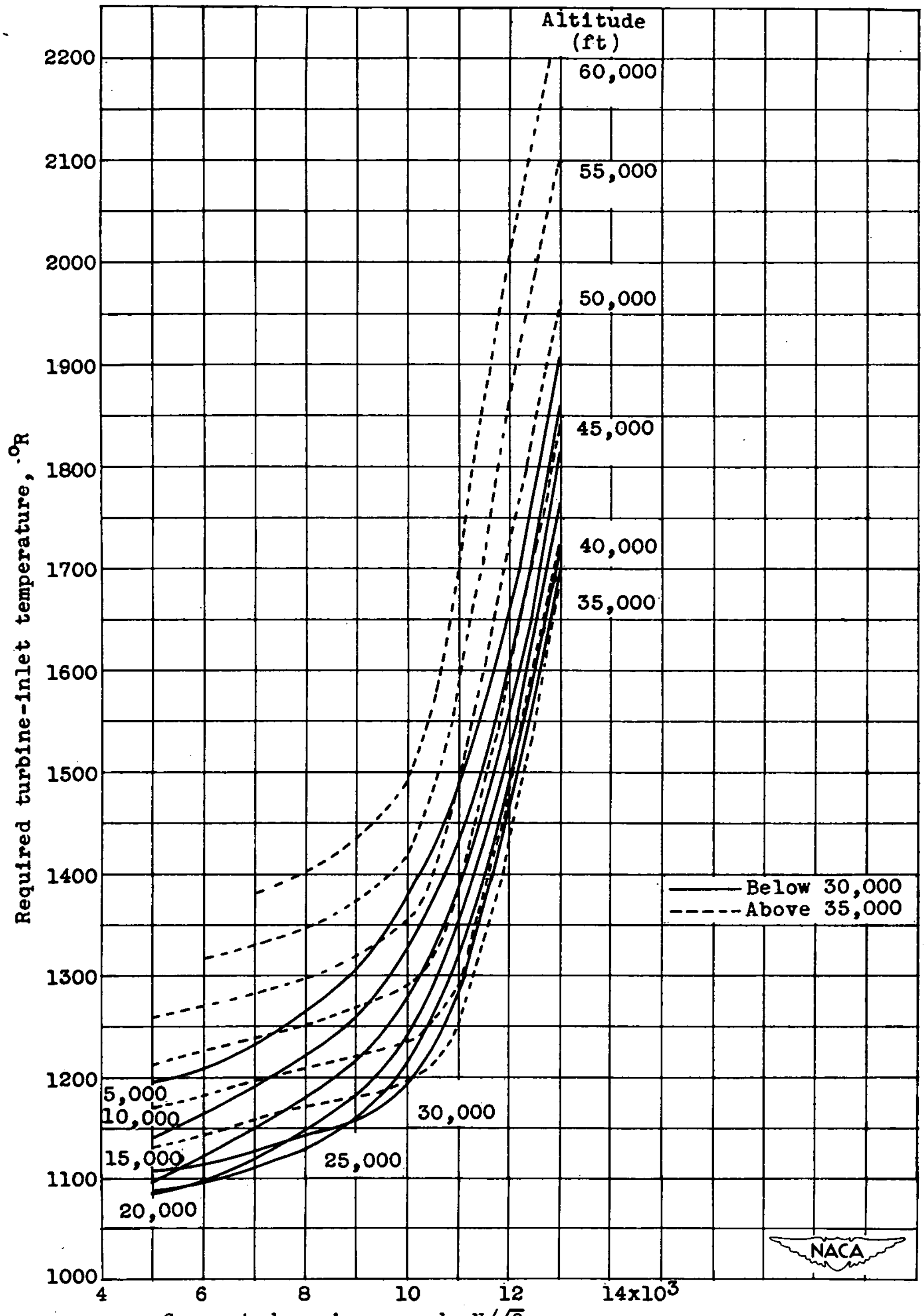
(b) Combustor-inlet air pressure.

Figure 5. - Continued. Operating characteristics for reference turbojet engine. Ram pressure ratio, 1.04.



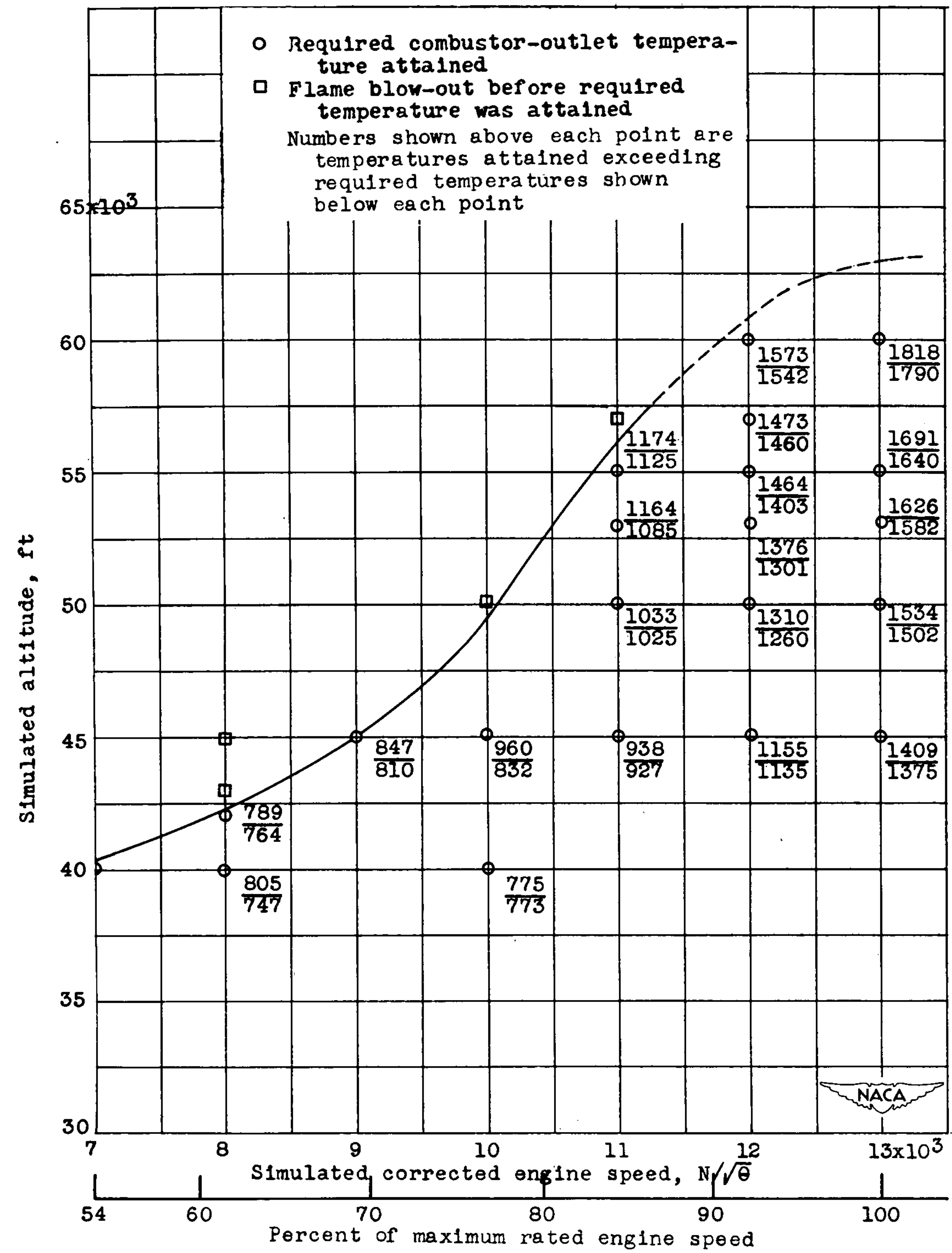
(c) Combustor-inlet air temperature.

Figure 5. - Continued. Operating characteristics for reference turbojet engine. Ram pressure ratio, 1.04.



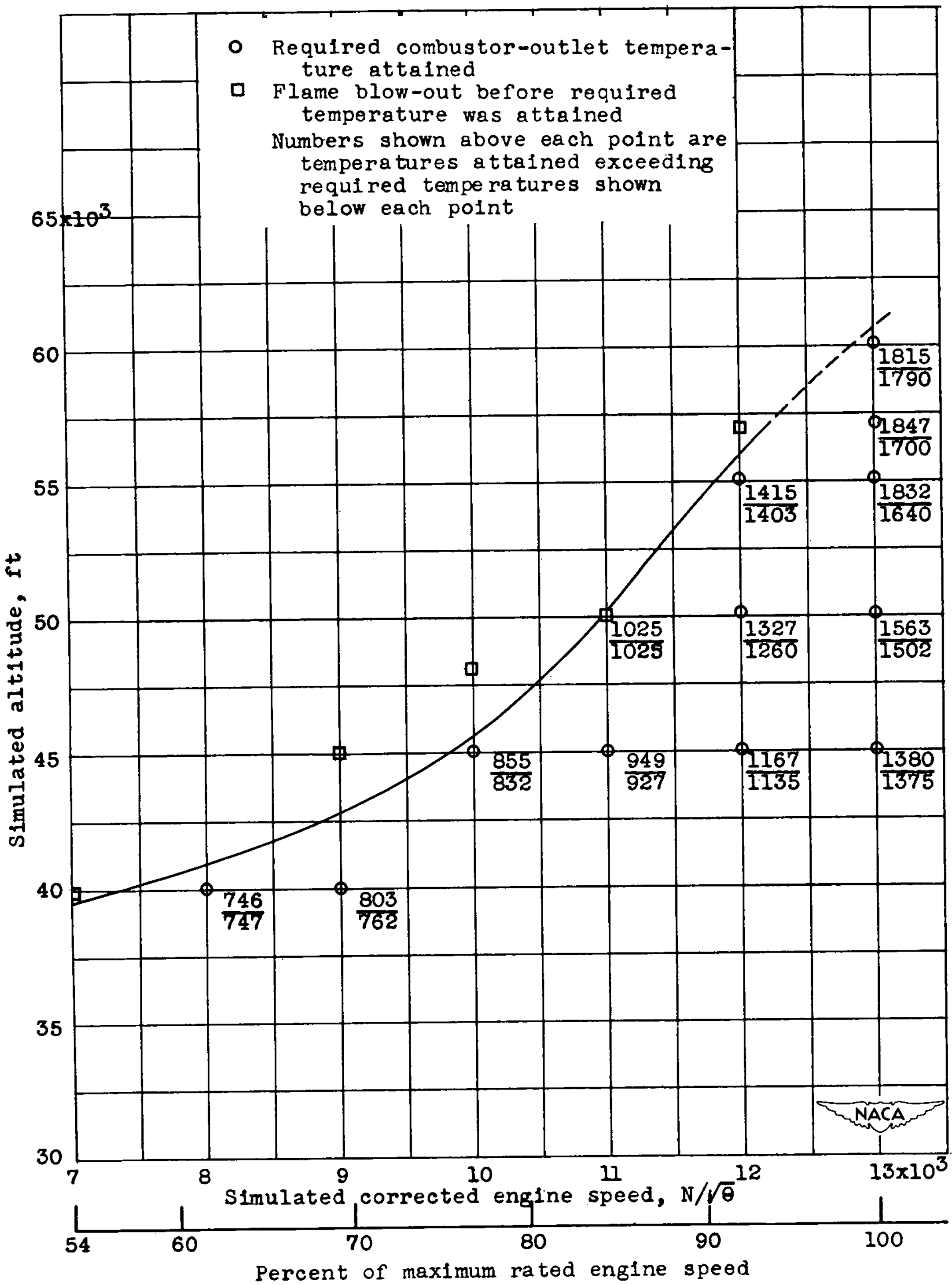
(d) Required turbine-inlet temperature.

Figure 5. - Concluded. Operating characteristics for reference turbojet engine. Ram pressure ratio, 1.04.



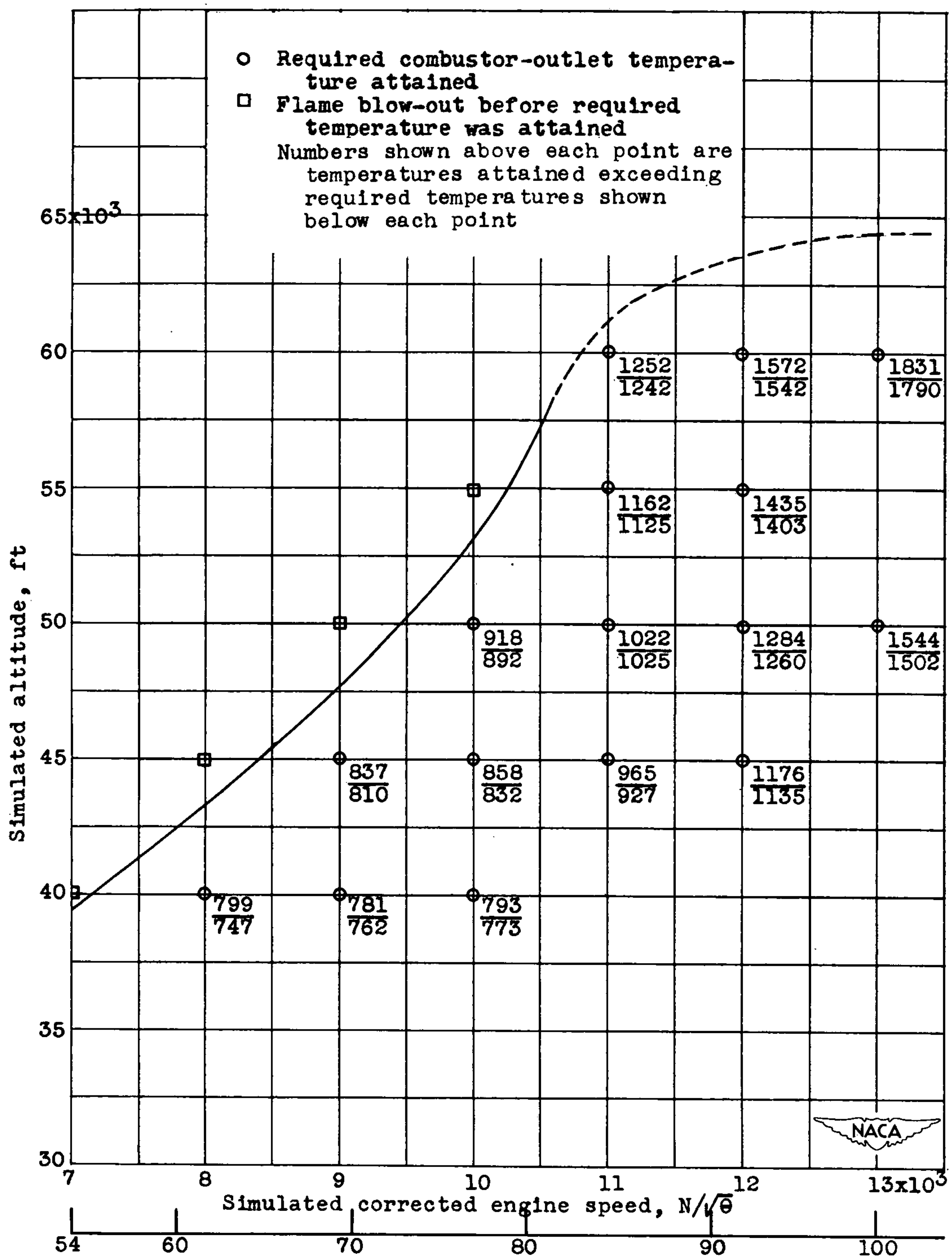
(a) Combustor with internal baffles; fuel, AN-F-32.

Figure 6. - Altitude operating limits of one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor for ram pressure ratio of 1.04.



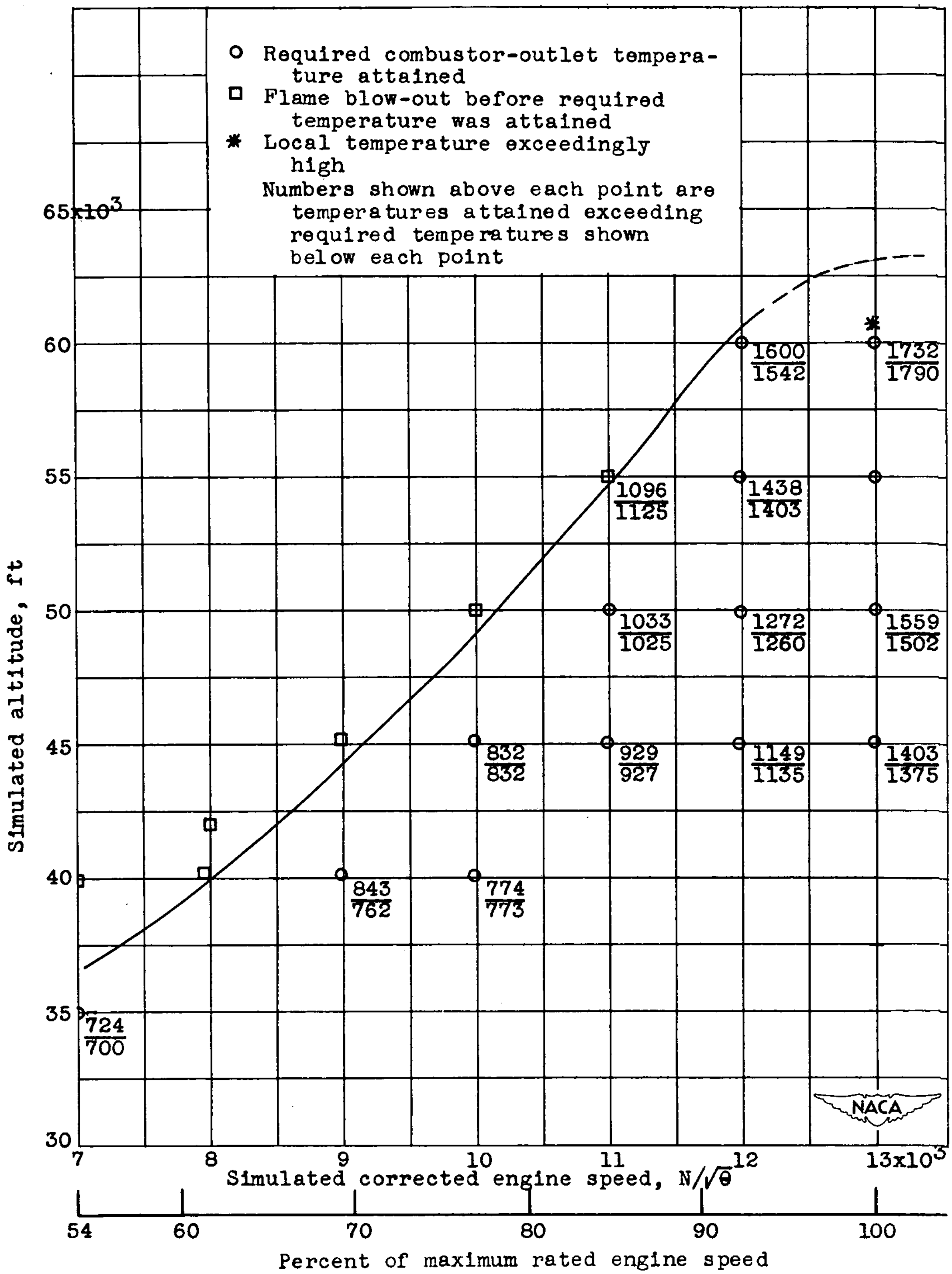
(b) Combustor with internal baffles; fuel, AN-F-58.

Figure 6. - Continued. Altitude operating limits of one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor for ram pressure ratio of 1.04.



(c) Combustor without internal baffles; fuel, AN-F-32.

Figure 6. - Continued. Altitude operating limits of one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor for ram pressure ratio of 1.04.



(d) Combustor without internal baffles; fuel, AN-F-58.

Figure 6. - Concluded. Altitude operating limits of one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor for ram pressure ratio of 1.04.

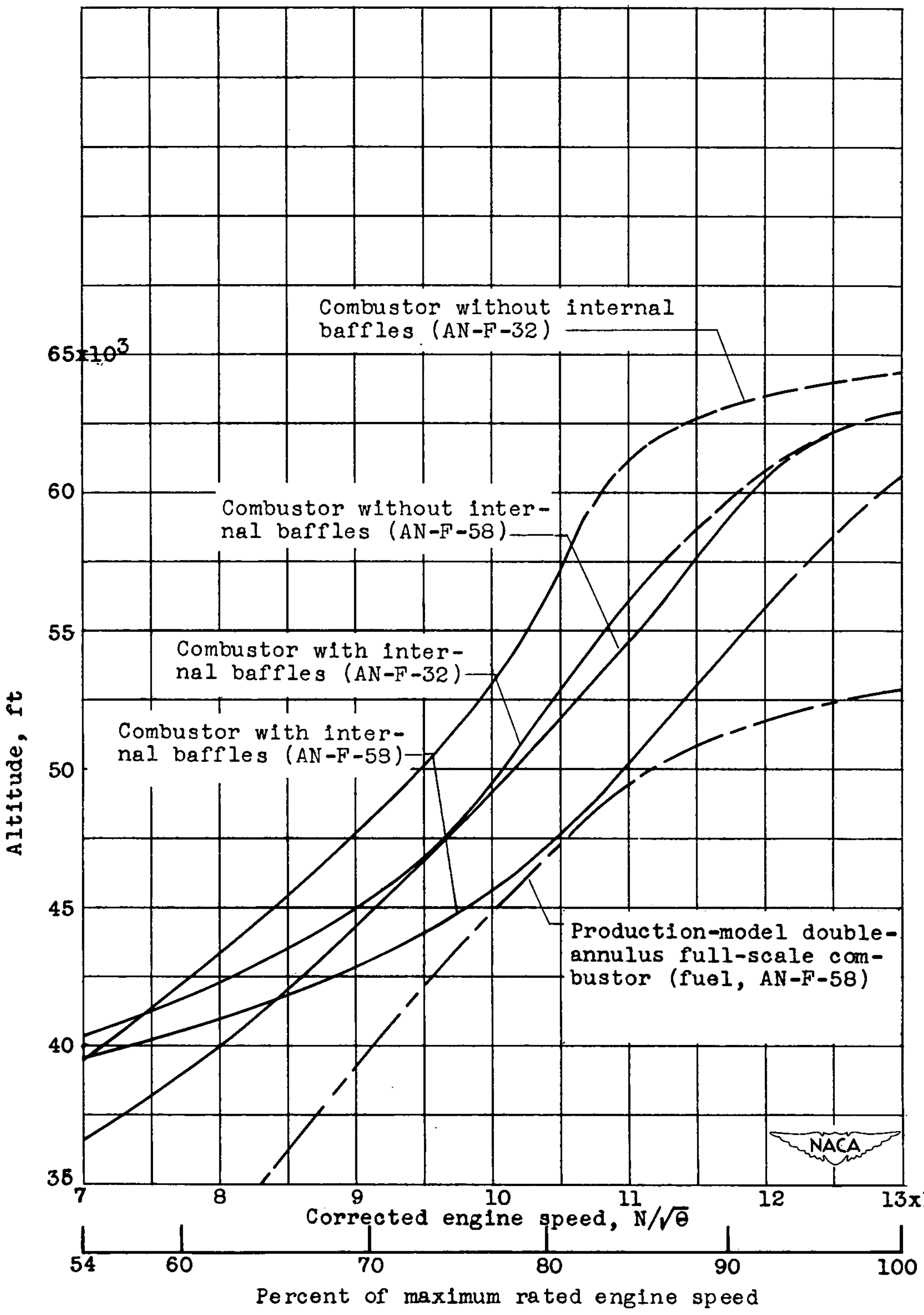
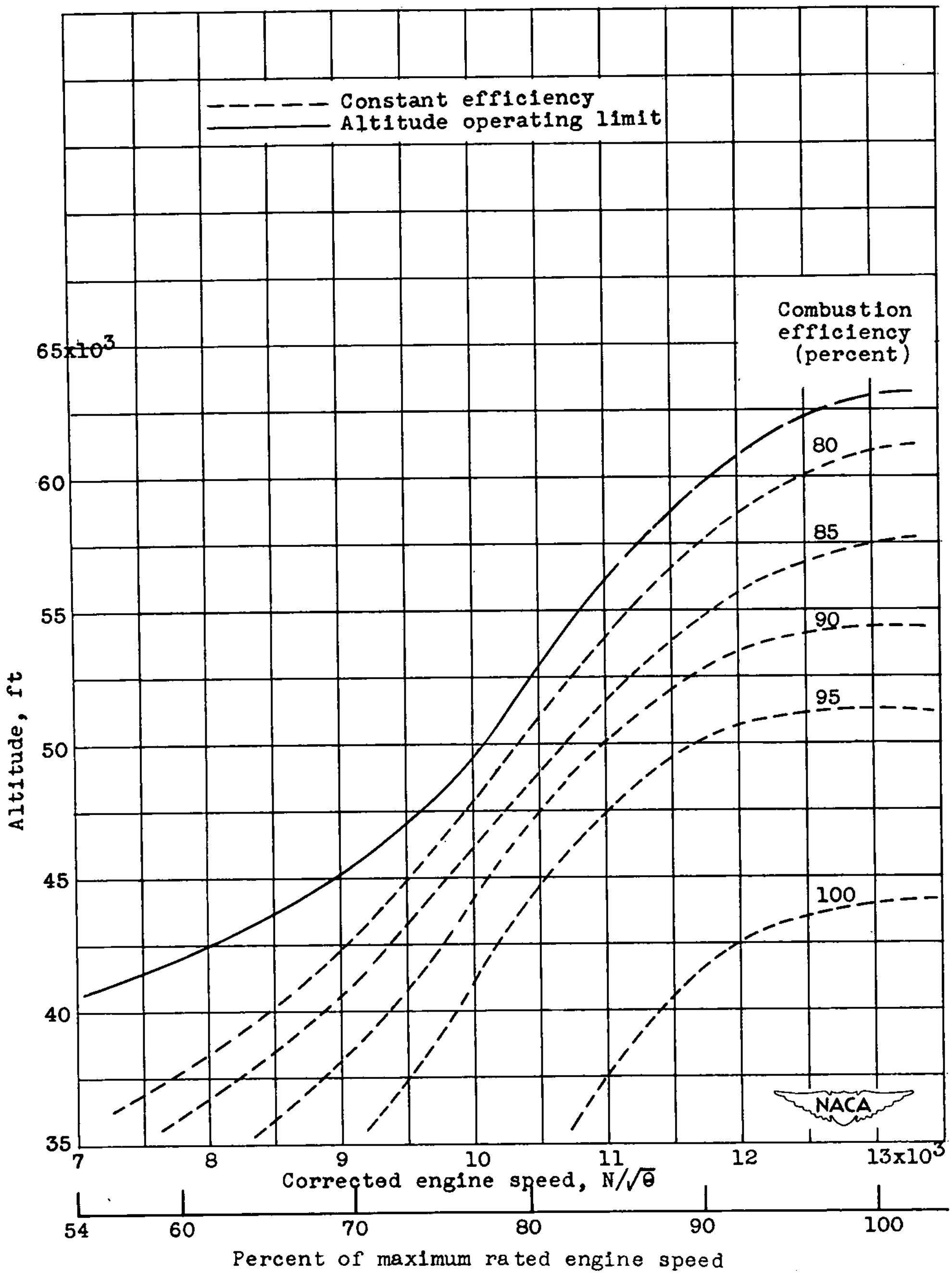
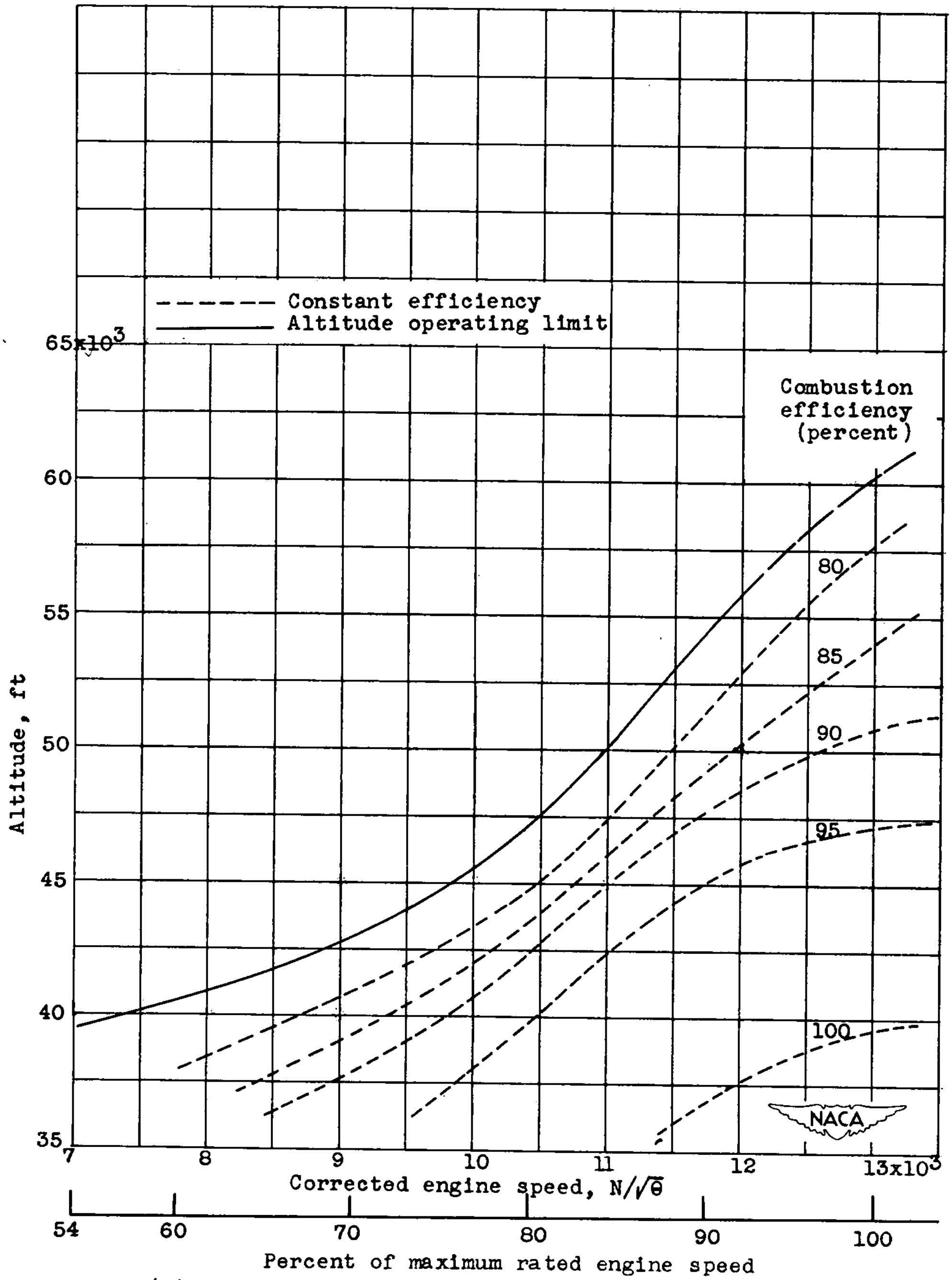


Figure 7. - Comparison of altitude operating limits of one-quarter sector of single-annulus turbojet combustor and production-model double-annulus turbojet combustor. Ram pressure ratio, 1.04.



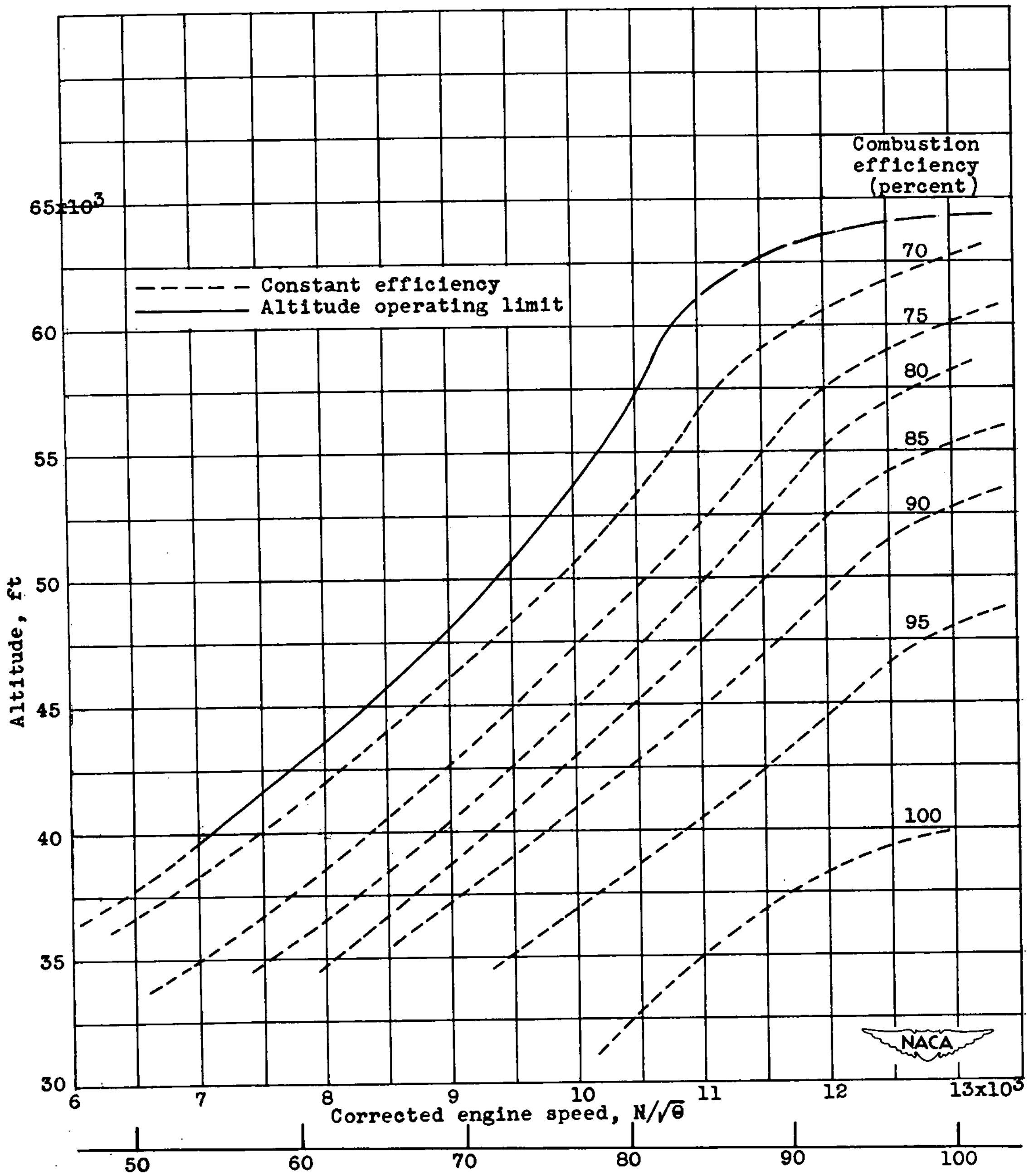
(a) Combustor with internal baffles; fuel, AN-F-32.

Figure 8. - Variation of combustion efficiency with altitude and corrected engine speed for one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor.



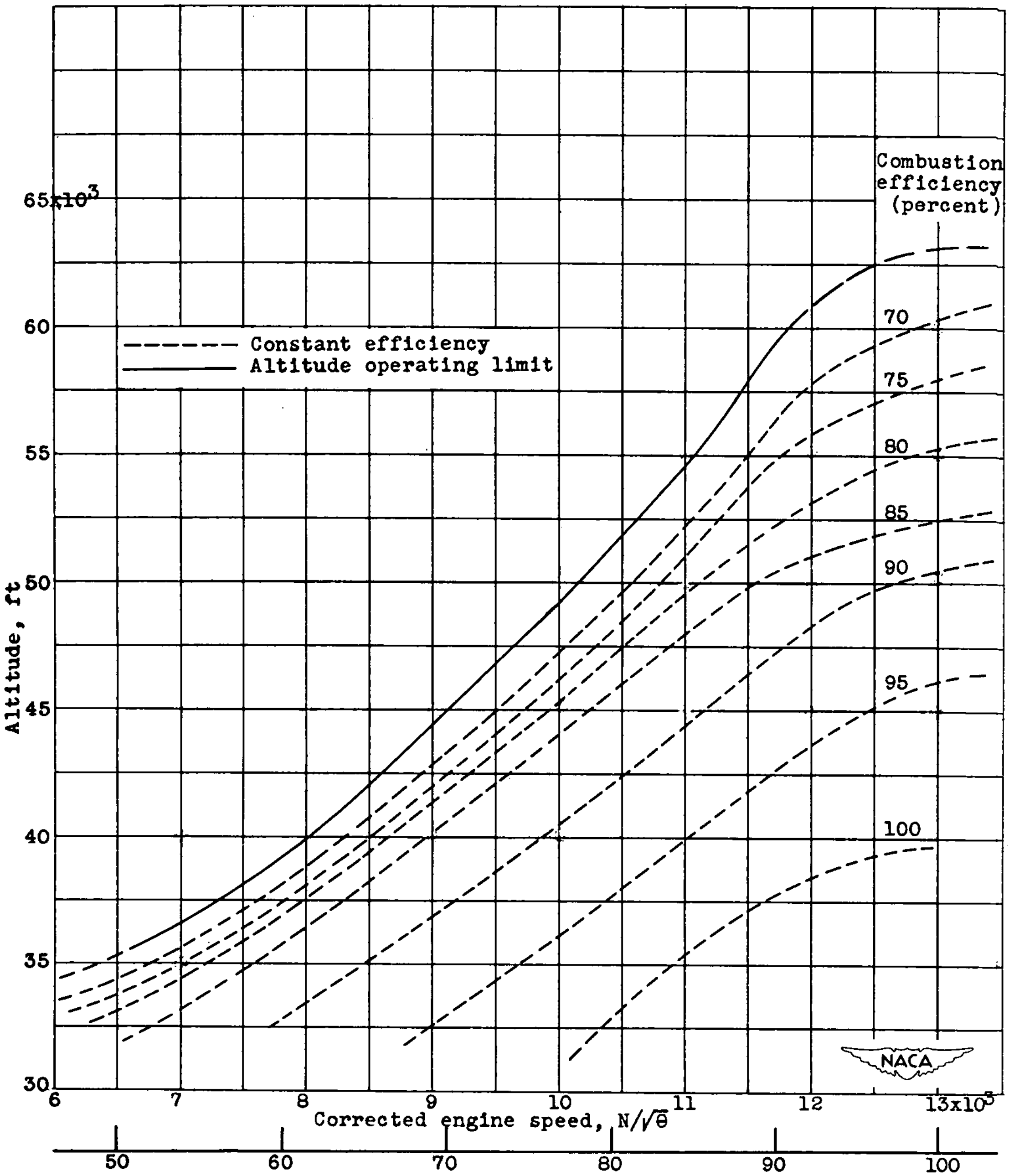
(b) Combustor with internal baffles; fuel, AN-F-58.

Figure 8. - Continued. Variation of combustion efficiency with altitude and corrected engine speed for one-quarter sector of 25½-inch-diameter single-annulus turbojet combustor.



(c) Combustor without internal baffles; fuel, AN-F-32.

Figure 8. - Continued. Variation of combustion efficiency with altitude and corrected engine speed for one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor.



(d) Combustor without internal baffles; fuel, AN-F-58.

Figure 8. - Concluded. Variation of combustion efficiency with altitude and corrected engine speed for one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor.

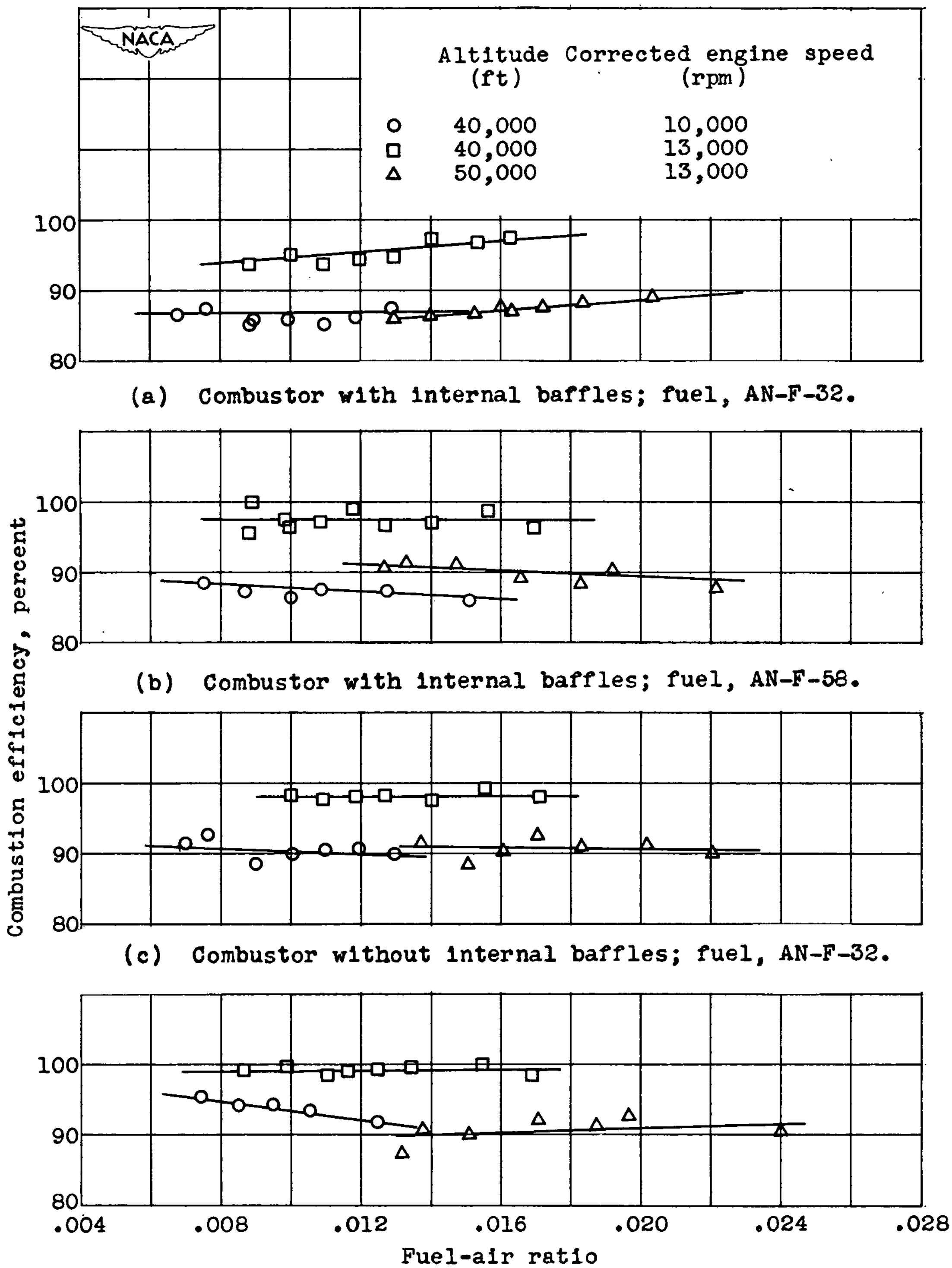


Figure 9. - Variation of combustion efficiency with fuel-air ratio for one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor. Ram pressure ratio, 1.04.

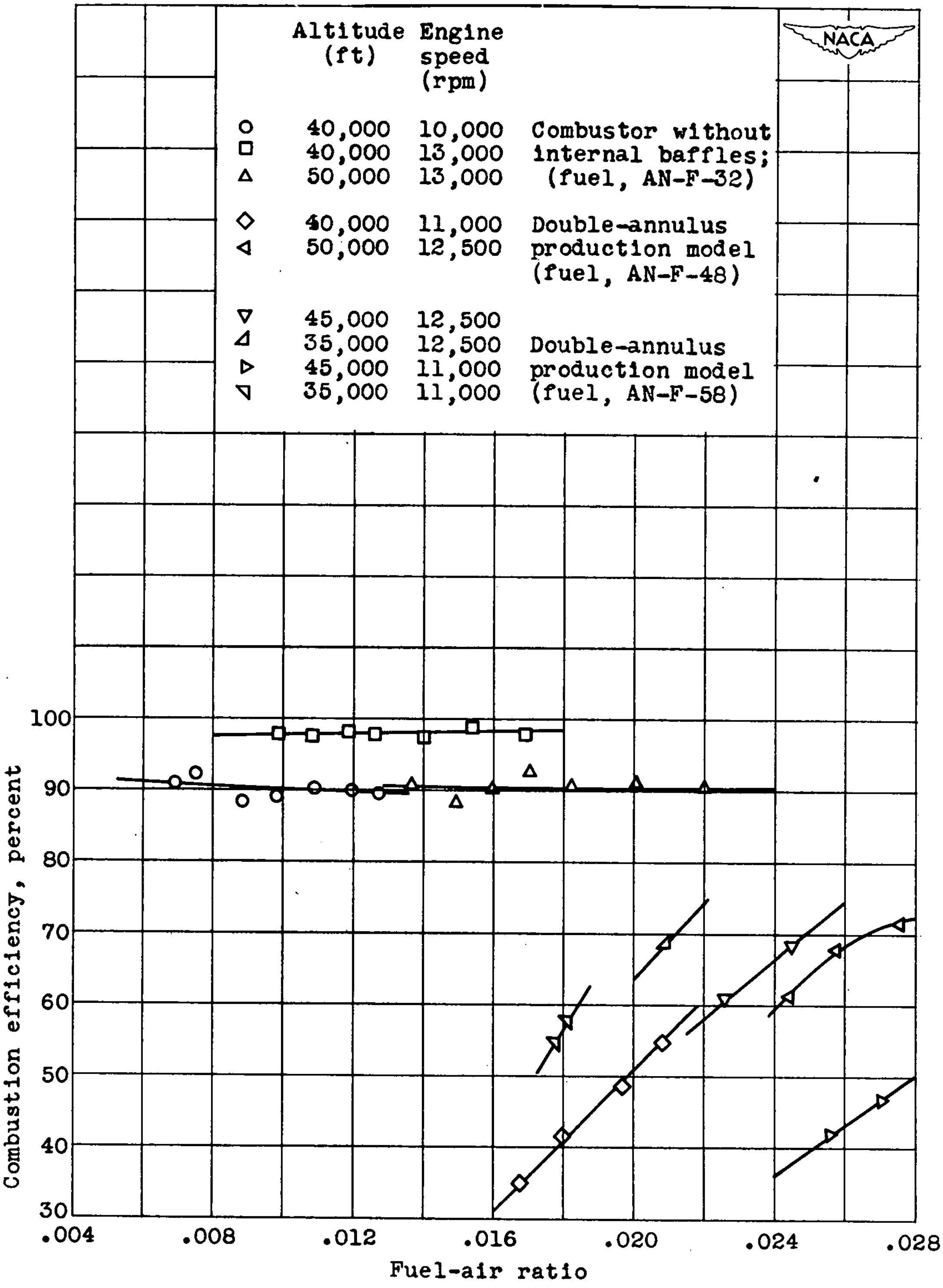
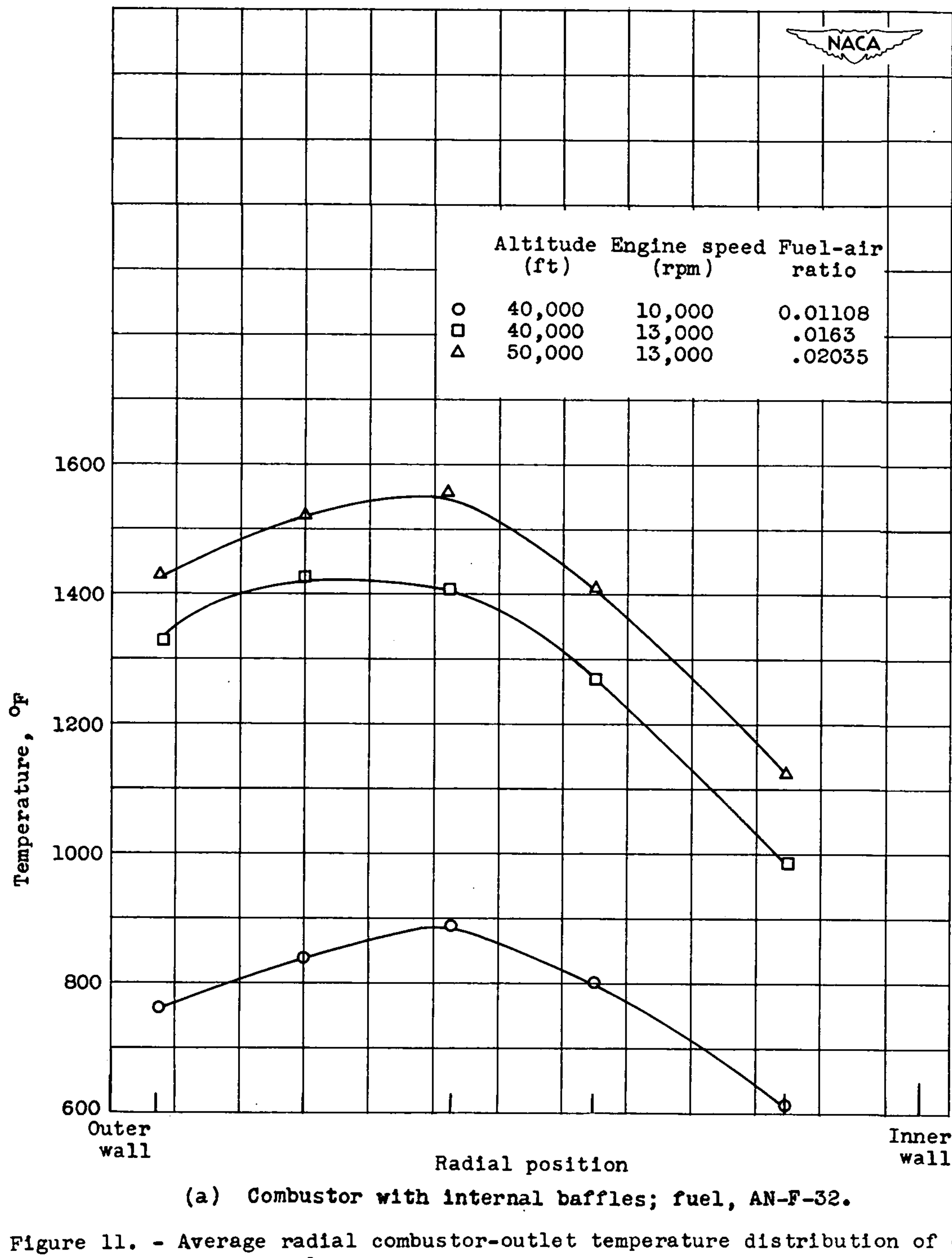
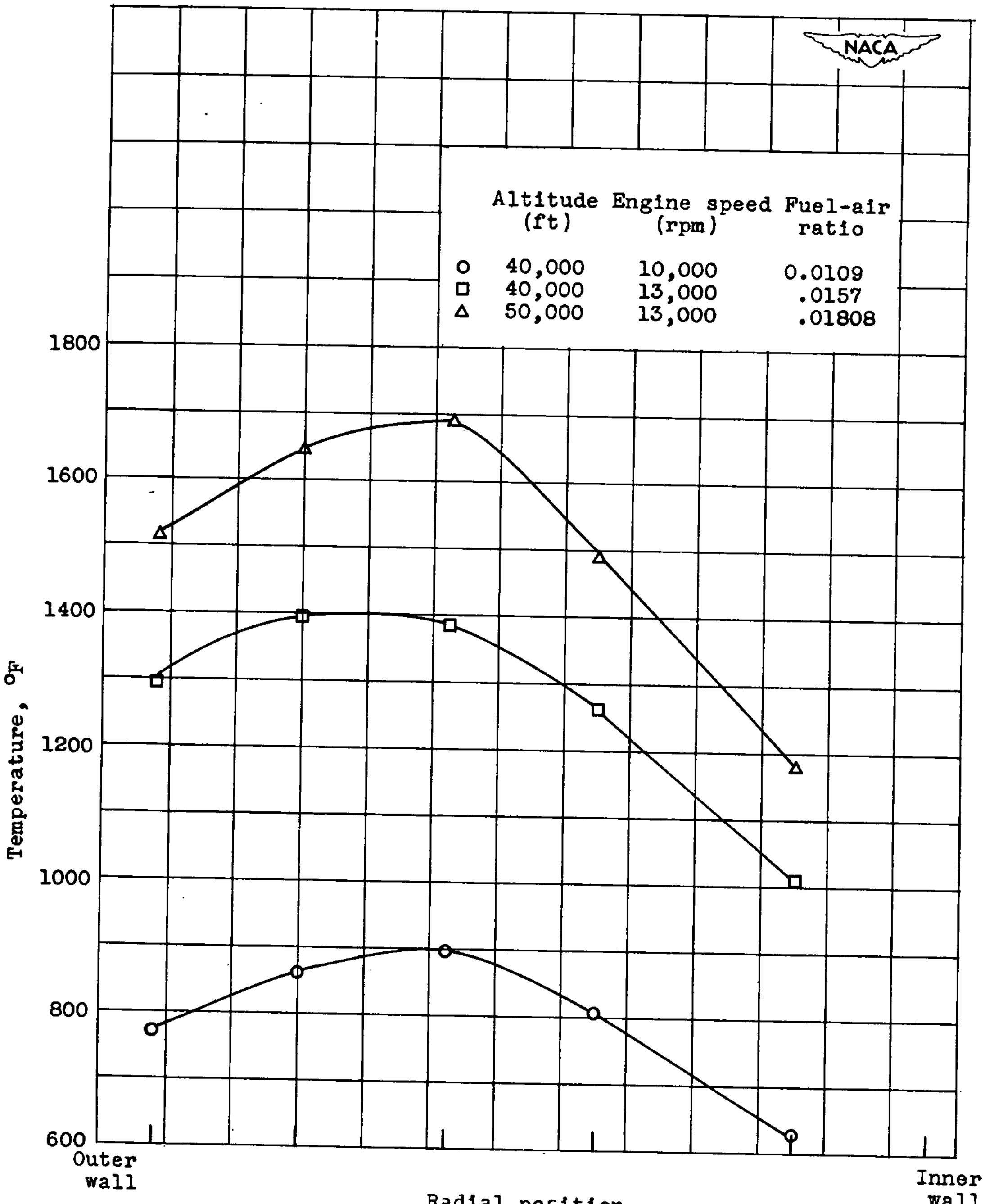


Figure 10. - Comparison of combustion efficiencies of one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor and full-annulus production-model combustor. Ram pressure ratio, 1.04.



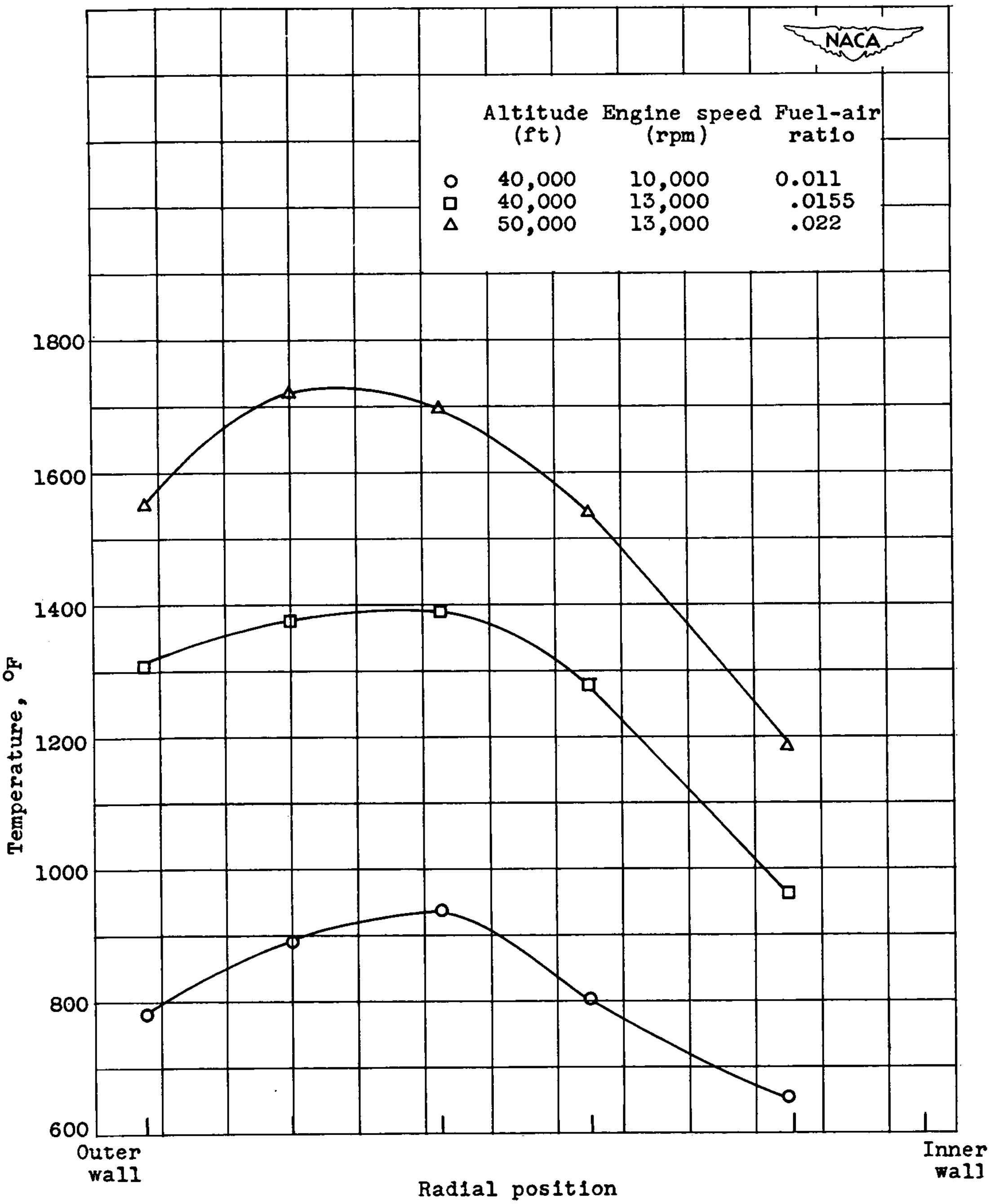
(a) Combustor with internal baffles; fuel, AN-F-32.

Figure 11. - Average radial combustor-outlet temperature distribution of one quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor.



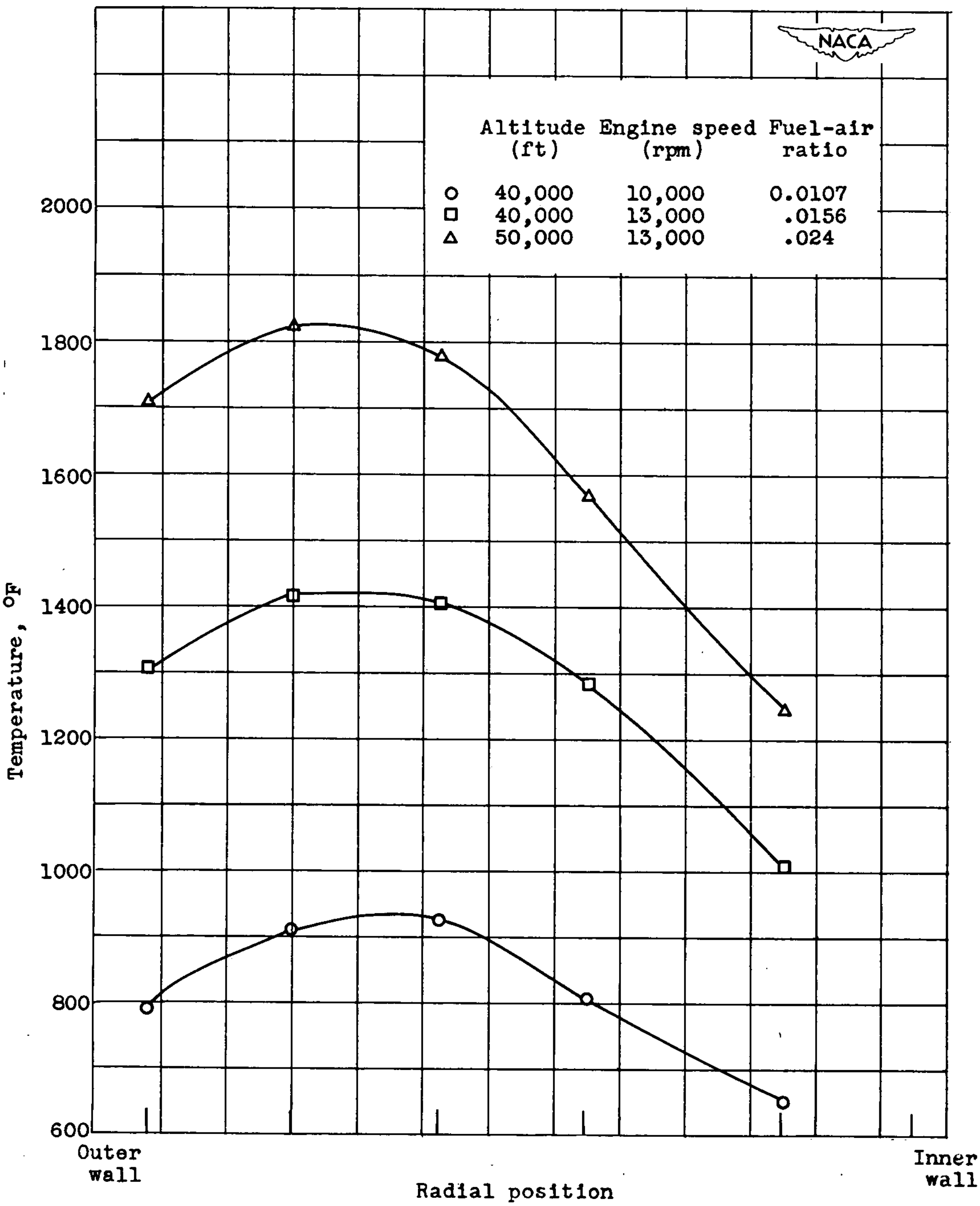
(b) Combustor with internal baffles; fuel, AN-F-58.

Figure 11. - Continued. Average radial combustor-outlet temperature distribution of one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor.



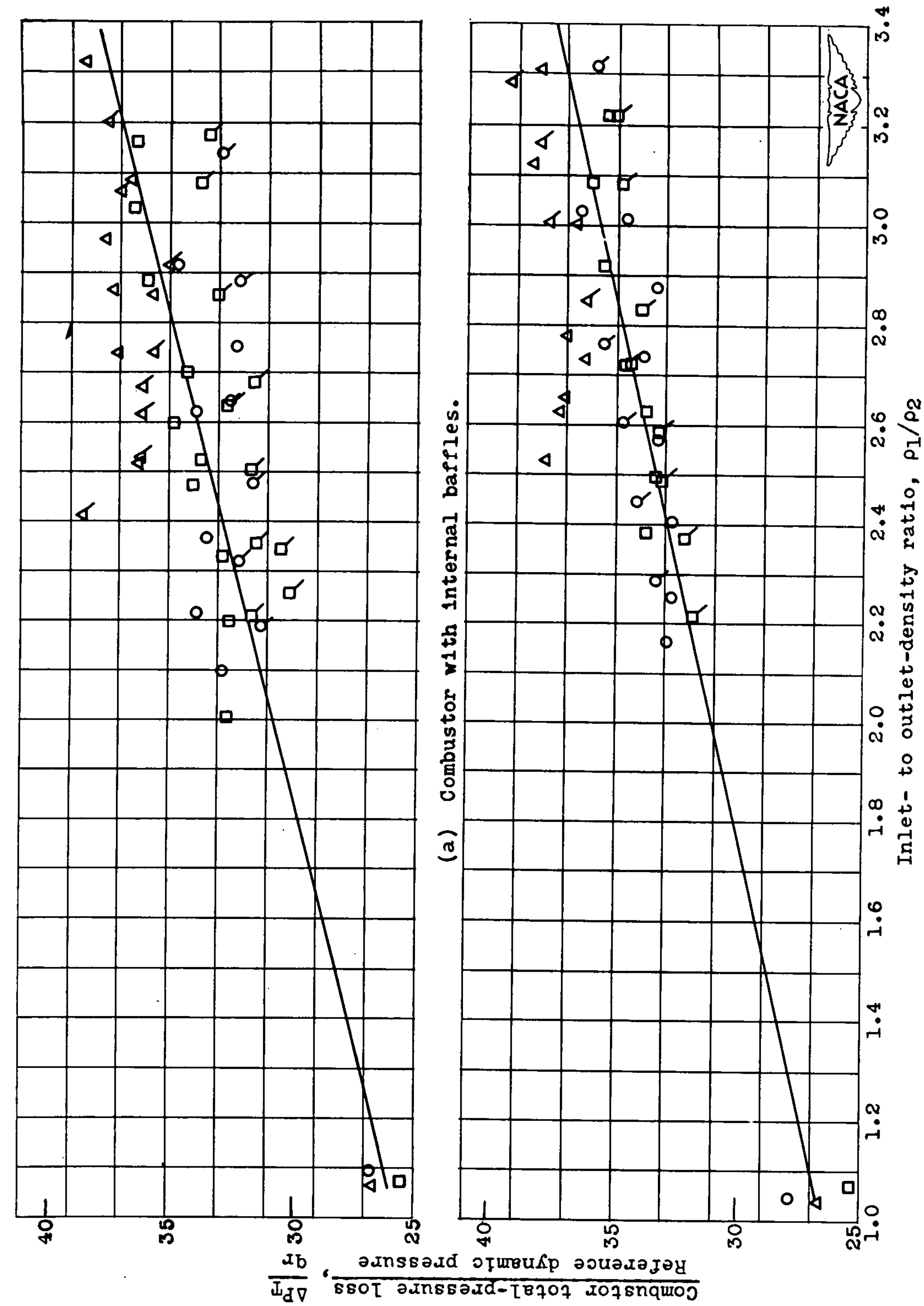
(c) Combustor without internal baffles; fuel, AN-F-32.

Figure 11. - Continued. Average radial combustor-outlet temperature distribution of one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor.



(d) Combustor without internal baffles; fuel, AN-F-58.

Figure 11. - Concluded. Average radial combustor-outlet temperature distribution of one-quarter sector of $25\frac{1}{2}$-inch-diameter single-annulus turbojet combustor.



(b) Configuration 2.

Figure 12. - Total-pressure loss through combustor segment as function of inlet- to outlet-density ratio.