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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

SIMULATED ALTITUDE PERFORMANCE OF COMBUSTORS FOR THE 24C TURBOJET ENGINE

III - PERFORMANCE OF RECTANGULAR-SLOT BASKETS

By Adelbert O. Tischler

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Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

The performance of an annular combustion chamber from a 24C turbojet engine was investigated over a range of simulated altitudes from 20,000 to 55,000 feet and corrected engine rotor speeds from 6000 to 13,000 rpm at a simulated ram-pressure ratio of 1.04. The purpose of the investigation was to determine the effects on the altitude operational limits, combustor-outlet gas temperature distribution, combustion efficiencies, and combustor inlet-to-outlet total-pressure drops of two changes in the 24C-4B basket air-passage arrangements that were designed to improve combustor-outlet temperature distribution. These changes were: (a) replacement of the downstream secondary air holes with large rectangular slots further upstream (rectangular-slot basket), and (b) enlargement of anticoking holes in the rectangular-slot basket (modified rectangular-slot basket).

The results indicate that improved outlet-gas temperature distribution of each succeeding combustor basket investigated was attained at a sacrifice in the altitude limit of operation. The altitude limits of operation of the combustor with the original basket ranged from 34,000 feet at a corrected engine speed of 6000 rpm to a maximum of 52,000 feet at 12,500 rpm. The altitude limits of the rectangular-slot basket were about 2000 feet lower throughout the engine speed range than those of the original basket. The altitude limits of the combustor with the modified rectangular-slot basket were about equivalent to those of the other baskets in the corrected-engine-speed range from 12,000 to 12,500 rpm but were about 10,000 feet lower than those of the original basket in the corrected-engine-speed range from 6000 to 9000 rpm. For the same

inlet-air conditions, the combustion efficiencies were highest for the original basket and progressively lower for each of the other two baskets. The combustor inlet-to-outlet pressure drops of all three combustor baskets at the same operating conditions were within ±10 percent of the pressure drop of the original basket.

INTRODUCTION

At the request of the Bureau of Aeronautics, Department of the Navy, an investigation to improve the performance of combustors for certain turbojet engines has been conducted at the NACA Cleveland laboratory. The altitude performances of the 24C-2 and the 24C-4 combustors are reported in references 1 and 2, respectively. An investigation on the effects of distribution of hole passage area on the simulated altitude performance of the 24C-4 combustor is reported in reference 3. Investigations of the complete engine equipped with a combustor basket having a relatively high minimum altitude operational limit (modification 2 of reference 3) resulted in failures of the turbine blades at high engine speeds (reference 4). The failures were apparently due to excessively high turbine-inlet temperatures near the root of the turbine blades. Temperature surveys across the combustor outlet disclosed high-temperature gas zones corresponding approximately to the two annuli of the double-annular combustor basket.

As the result of a systematic study by the manufacturer in an attempt to alleviate the unfavorable temperature distribution, a new type basket with large rectangular slots was developed. The rectangular slots located upstream of the combustor outlet to provide greater mixing length for the gases were intended to provide good penetration of the cold secondary air stream into the hot gases from the primary or combustion zone. In order to alleviate an uneven circumferential temperature distribution, the small anticoking holes in the upstream face of the combustor basket were enlarged.

The outlet temperature distributions and altitude operational limits of the 24C-4B combustor with the original basket, with the rectangular-slot basket, and with the rectangular-slot basket having enlarged anticoking holes, which are reported herein, were determined in a manner similar to that of reference 1. The combustor was operated at inlet-air conditions that simulated different altitudes and compressor-turbine rotor speeds in order to determine the altitude operational limits, which were indicated by the ability of the combustor to provide exhaust gases of the temperature required at the turbine inlet for engine operation. In addition, information was obtained on the combustion efficiencies, combustor-outlet velocity distribution, and combustor total-pressure losses for each combustor basket.

APPARATUS

Test Setup

A diagram of the general setup is shown in figure 1. Combustion air, low-pressure exhaust, and fuel (AN-F-28; performance grade, 100/130) were supplied by the laboratory facilities. Combustion-air flow was metered with a variable-area orifice and the air flow and combustor-inlet air pressure were controlled through butterfly regulating valves in the air-supply and exhaust line. The combustor-inlet air temperatures were regulated by electric air heaters. A plenum chamber upstream of the combustor provided uniform velocity and temperature distributions at the inlet to the combustor.

Combustor and Baskets

A longitudinal section of the 24C-4B combustor and the immediate auxiliary ducting and instrumentation planes is shown in figure 2. This installation is similar to that used in references 2 and 3; the chief difference is that the fuel-manifold housing and the combustor outer casing were taken from a flight model engine and the combustor-inlet ducting was designed to approximate closely the diffuser at the engine compressor exit. The frontal area of the compressor-turbine-shaft housing was capped with a long streamlined nose, which occupied the position of the compressor hub, and the combustor outer casing was externally reinforced to prevent collapse at experimental pressures below atmospheric.

Photographs of the three combustor baskets are shown in figure 3. Each basket consists of two concentric annular chambers having mean diameters of $14\frac{3}{8}$ and $21\frac{7}{8}$ inches. The annular chambers are approximately $14\frac{3}{8}$ inches long and each chamber wall consists of four cylindrical steps connected by corrugated spacer strips. At each successive step, the spacer increases the width of each chamber by approximately 3/16 inch, of which about one-third is open area. Cooling air thus flows along the walls of the combustion chamber.

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The width of each annular chamber is about $2\frac{1}{4}$ inches at the plane of the fuel nozzles and increases at each step to about $3\frac{1}{4}$ inches at the end of the fourth step where the two annular chambers combine to form one outlet. A fifth step about $2\frac{5}{8}$ inches long on the outer chamber walls provides additional space for mixing of the air streams. Some air for combustion is supplied through anticoking holes in the upstream face of the combustor basket (see fig. 3(c)), but most of the air is supplied through holes in the walls of the annular chambers (figs. 3(a) and 3(b)).

The baskets investigated are characterized as follows:

1. Original basket. The first basket in this investigation (fig. 3(a)) was of the same design as modification 2 of the cylindrical stepped basket reported in reference 3.

2. Rectangular-slot basket. This basket (fig. 3(b)) was similar to the original basket except that the air-passage holes in the third and fourth cylindrical steps were replaced by rectangular slots of equivalent area cut into the third step.

3. Modified rectangular-slot basket. The hole arrangement in this basket was similar to that of the rectangular-slot basket, but the anticoking holes in the upstream face of the basket were enlarged from 1/16 to 3/32 inch in diameter. The anticoking holes are shown in the face of the third basket in figure 3(c). The large holes in this figure are for the fuel nozzles and when installed are covered by the fuel-manifold fairing. The numerous small holes are the anticoking holes. The diamters of the small holes at the beginning of the first cylinder were not altered. The percentage of the total open area as a function of the distance downstream for each of the basket configurations investigated is shown in figure 4.

Each of the two annular chambers of the basket was provided with a fuel manifold. A total of 60 hollow-cone-spray fuel-injection nozzles (80° spray angle, 7 gal/hr at a pressure differential of 100 lb/sq in.) was used, 36 on the outer and 24 on the inner manifold. Gasoline fuel was supplied to the manifolds through separate inlets located at the bottom of the combustor. Fuel flow was measured with a calibrated rotameter.

Temperature and Pressure Instrumentation

Temperature- and pressure-measuring instrumentation was installed at the two sections shown in figure 2. Section A-A is designated the combustor-inlet section; section B-B is designated the combustor-outlet section and is situated in a plane that corresponds to the position of the second row of turbine stator blades in the engine. The orientation of the instrumentation in these sections and the details of construction of the thermocouple rakes and pressure probes are illustrated in figure 5. The inlet-air thermocouples were unshielded iron-constantan wire junctions and were connected to a calibrated self-balancing potentiometer through multiple switches. The exhaust thermocouples were of the unshielded exposed junction type and were made of 24-gage chromel and alumel wires connected through an automatic switching arrangement to a calibrated recording potentiometer.

Average temperatures and pressures were taken as the average of all the readings at each section. The velocity distributions were calculated from the average total-pressure and temperature readings in each of nine equal annular areas of the exhaust duct and the average exhaust-duct wall-static-pressure readings. The combustion efficiency is defined as the ratio of the average gas-temperature rise through the combustor to the temperature rise theoretically obtainable with the same fuel-air ratio.

The effective dynamic pressure q was calculated from the combustion air flow, the average inlet-air temperature and static pressure, and the maximum cross-sectional area of the combustor-housing annulus (420 sq in.). All air-pressure measurements were obtained with banks of manometers and were photographically recorded.

METHODS

The altitude performance of the 24C-4B combustor using three different baskets was investigated with the combustor-inlet conditions of air weight flow, pressure, and temperature simulating operation of the turbojet engine at various altitudes from 20,000 to 55,000 feet over a range of engine speeds from 6000 to 13,000 (corrected) rpm for a ram-pressure ratio of 1.04.

The combustor-inlet conditions of air weight flow, pressure, and temperature, and the values of the estimated combustor-outlet (turbine-inlet) temperatures required to operate the 24C engine for each altitude and engine speed were calculated from data obtained in an altitude-wind-tunnel investigation of the complete engine (reference 5). Conditions at the lowest ram-pressure ratio (1.04) at which wind-tunnel data were available were chosen because for a particular altitude and engine speed the combustor inlet-air conditions are least favorable for good combustion in the 24C-4B turbojet-engine combustor at low ram-pressure ratios, that is, low airplane speeds. In order to obtain inlet-air conditions at altitudes above 45,000 feet, it was necessary to extrapolate the wind-tunnel data and some uncertainty is therefore inherent in these estimates. Curves for the estimated combustor-inlet values of air weight flow, pressure, and temperature, and for the estimated values of combustor-outlet gas temperature required for operation of the 24C turbojet engine at a ram-pressure ratio of 1.04 are given in figure 6. The inlet-air conditions were adjusted to be within 2 percent of their estimated required values.

After ignition of the fuel-air mixture in the combustor was obtained, the combustion air flow and the inlet-air temperature were set at the desired values while the fuel flow was adjusted to maintain combustion. The inlet-air pressure was then adjusted to its proper value. The fuel flow was increased in steps while the inlet-air conditions were maintained constant in an effort to achieve an average combustor-outlet temperature equal to or greater than that required for operation of the turbojet engine at these inlet-air conditions.

RESULTS AND DISCUSSION

Altitude Operational Limits

The altitude operational limits of the 24C-4B combustor with each of the three combustor baskets at a ram-pressure ratio of 1.04 are presented in figure 7 as plots of the simulated altitude against simulated engine speed. In each plot the altitude operational limit is defined by a curve that separates the operable region where required combustor-outlet temperatures were attainable from the inoperable region where the required combustor-outlet temperatures could not be attained. At some operating conditions, the required outlet temperatures could be attained but the combustion was accompanied by explosions. In such cases the altitude limit was taken as the point where the explosions began. Such explosions often resulted in flame blow-out and usually occurred at or very near the point where the required temperature rise could not be attained. The altitude operational limits of the three combustor baskets investigated are compared in figure 7(d).

The altitude limits of the original basket were about 2000 feet higher than those of the rectangular-slot basket throughout the range of engine speeds. This increase in altitude limit is possibly due to the fact that more gradual admission of the secondary (dilution or cooling) air in the original basket allows a somewhat greater primary- (burning) zone length. The altitude limits of the original basket were about 10,000 feet higher than those of the modified rectangular-slot basket at low-engine-speed conditions. The modified rectangular-slot basket tended to blow out abruptly at the altitude operational limit at low-engine-speed conditions.

The altitude operational limits of the three baskets investigated at corrected engine speeds of 6000 and 12,500 rpm are listed in the following table; these engine speeds correspond approximately to the points of minimum and maximum altitude limits at which the engine is operable:

Combustor-basket type	Altitude operational limit (ft)	
	Corrected engine speed (rpm)	
	6000	12,500
Original	34,000	52,000
Rectangular slot	32,000	49,000
Modified rectangular slot	22,000	51,000

Repeated tests of the combustor with different baskets of the same type indicate that the reproducibility of the altitude-operational-limit determinations was about ± 2000 feet.

Temperature Distribution

The radial and circumferential temperature distributions for each of the three baskets at conditions that simulate engine operation at an altitude of 45,000 feet and a corrected engine rotor speed of 12,500 rpm are given in figure 8. These temperature data are typical for combustor operation at high simulated engine speeds at which turbine failures have occurred.

The radial temperature data of six, nine-thermocouple rakes spaced at 60° intervals in the annular combustor outlet are plotted in figure 8(a) for the original basket. These data show a double peak in the radial temperature distribution, which in the engine resulted in high turbine-inlet temperatures at points about 1 inch and $2\frac{3}{4}$ inches from the inner wall of the exhaust duct, that is, from the turbine-blade roots. The temperature pattern shows considerable variation from rake to rake. The data at 20° intervals from four circumferential rings of thermocouples covering equal annular areas are plotted in figure 8(b). These results also showed circumferential variations in the temperature pattern, with a minimum recorded temperature of 810° F and a maximum recorded temperature of 1865° F for the same inlet-air and fuel-flow conditions.

The radial and circumferential temperature distributions for the rectangular-slot basket are shown in figures 8(c) and 8(d), respectively. The peak outlet gas temperature for this basket was near the center of the outlet area. Variation of the circumferential temperature pattern was again apparent from both plots.

The modified rectangular-slot basket showed the most uniform temperatures, both in radial and circumferential outlet gas temperature distribution of the three baskets investigated (figs. 8(e) and 8(f)).

Figure 9 shows the radial temperature profiles, averaged circumferentially, for the three combustor baskets at four different engine speeds (12,500, 11,000, 8000, and 6000 rpm). In each plot the temperature profiles are for simulated altitudes near the altitude limit of operation. The altitudes for which data are plotted are 10,000 feet lower at 8000 and 6000 rpm (figs. 9(c) and 9(d)) for the modified rectangular-slot basket than for the other baskets because of the lower altitude limit for this basket. A curve showing the desired radial temperature profile, based on high-temperature-metal creep-stress data, is plotted in figure 9(a). The desired temperature profile increases from the turbine root toward the tip until the turbine outer casing wall is approached.

It is of interest to note that for the original basket, with which turbine failures in the 24C turbojet engine were encountered, the effect of increasing engine speed near the altitude operational limit was to increase the temperature near the inner wall of the combustor-outlet annulus (corresponding to the root of the turbine blades) with respect to the average outlet-gas temperature. Thus at the highest engine speeds, that is, at the highest combustor-outlet gas temperatures, the outlet temperature distribution is also the least desirable from the standpoint of turbine life.

Combustion Efficiency

The highest combustion efficiencies at each set of conditions were generally achieved with the original combustor basket and the poorest combustion efficiencies were generally obtained with the modified rectangular-slot basket. The experimentally determined fuel-air ratio and corresponding combustion efficiency necessary to obtain the required outlet-gas temperatures at several conditions of engine speed and altitude for each of the three baskets are given in the following table:

		Original basket		Rectangular-slot basket		Modified rectangular-slot basket	
Corrected engine speed (rpm)	Altitude (ft)	Fuel-air ratio	Combustion efficiency (percent)	Fuel-air ratio	Combustion efficiency (percent)	Fuel-air ratio	Combustion efficiency (percent)
12,500	45,000	0.0211	79	0.0214	78	0.0225	74
	50,000	.0240	75	.0250	72	.0260	69
11,000	40,000	0.0165	67	0.0175	63	0.0206	54
	45,000	.0192	62	.0214	56	(1)	(1)

[1]Inoperable.

The variation in combustion efficiency with fuel-air ratio is shown in figure 10 for several simulated altitudes and corrected engine speeds of 12,500 and 11,000 rpm. For most conditions the combustion efficiencies increased with increasing fuel-air ratio. The combustion efficiencies of the rectangular-slot basket at a corrected engine speed of 12,500 rpm, however, apparently passed through maximums and then decreased (fig. 10(c)). In these cases the high-fuel-air-ratio conditions were achieved with cycling and explosive combustion during which the flame did not blow out. At low engine speeds, the flame in the combustor blew out at a fuel-air ratio only slightly above the value at which cycling commenced. Figures 10(e) and 10(f) indicate that the combustion efficiencies with the modified rectangular-slot basket decreased rapidly as the fuel-air ratio was reduced. This observation reflects the fact that at low-engine-speed conditions, in which low combustor-outlet temperatures and therefore low fuel-air ratios are required, the altitude operational limits of the modified rectangular-slot basket were considerably below those of the other two baskets.

Combustor-Outlet Velocity Distributions

Typical velocity distributions at the combustor outlet for each basket investigated are shown in figure 11. The velocity profile of the original basket has a double peak as in the case of its temperature profile. The velocity profiles of the other two baskets show no double peaks, but the outlet gas velocities with all three baskets drop from a peak of about 600 feet per second at a point 2.5 inches from the inner combustor-outlet wall to about 400 feet per second at a point 0.2 inch from the outer wall. The velocity-distribution patterns in a turbojet engine might be different from the patterns indicated by these results with the combustor alone, however, because the uniform velocity profile provided to the combustor inlet in this investigation does not occur in the turbojet engine.

Combustor Total-Pressure Loss

The combustor inlet-to-outlet total-pressure loss ΔP as a function of the calculated inlet dynamic pressure q is plotted against the inlet-to-outlet gas densities ρ_A/ρ_B in figure 12. The values of $\Delta P/q$ are about 7 percent higher for the rectangular-slot basket, indicating greater total-pressure loss, and about 8 percent lower for the modified rectangular-slot basket than for the original basket.

Values of $\Delta P/q$ for each of the baskets for an inlet-to-outlet density ratio of 3.0 are listed in the following table:

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Combustor-basket type	$\Delta P/q$
Original	14.3
Rectangular slot	15.3
Modified rectangular slot	13.1

Character of Flames

At simulated conditions of altitude and engine rotor speed below the altitude limit of the engine, combustion was generally steady. Near or above the altitude limit, however, combustion was observed to change with increasing fuel-air ratio from steady combustion to combustion characterized by a periodic flickering or cycling of the flames visible in the observation window. The intensity of the cycling increased as the fuel flow was increased and particularly at high-engine-speed conditions a high fuel flow often resulted in explosions (sometimes irregular rather than periodic) of considerable violence. At conditions of cycling or explosive combustion the flame was apt to blow out abruptly.

The color of the flames was substantially yellow at simulated conditions well below the altitude limit of operation. As the altitude limit was approached, however, the flame color became progressively more blue. With cycling combustion the blue flames usually were tinged with flecks of yellow.

SUMMARY OF RESULTS

In an investigation to determine the effects on altitude operational limit and other performance parameters of a 24C-4B combustor of: (a) replacing the downstream secondary air holes in the basket by large rectangular slots further upstream for the purpose of providing a more uniform outlet temperature pattern (designated rectangular-slot basket) and, (b) of enlarging the anticoking holes in the rectangular-slot basket (designated modified rectangular-slot basket) the following results were obtained:

1. The altitude operational limits of the combustor with the original basket ranged from 34,000 feet at a corrected engine speed of 6000 rpm to a maximum of 52,000 feet at 12,500 rpm.

The altitude limits of the rectangular-slot basket were about 2000 feet lower throughout the engine-speed range than those of the original basket. The altitude limits of the combustor with the modified rectangular-slot basket were about equivalent to those of the other baskets in the corrected-engine-speed range from 12,000 to 12,500 rpm but were about 10,000 feet lower than those of the original basket in the corrected-engine-speed range from 6000 to 9000 rpm.

2. The radial outlet temperature profile of the original basket had a double peak, with high-gas-temperature zones at positions roughly corresponding to points 1 inch and $2\frac{3}{4}$ inches from the roots of the turbine blading of an engine. The rectangular-slot basket had a high-temperature zone near the center of the exhaust-duct annulus. The modified rectangular-slot basket had the most uniform temperature distribution, both radially and circumferentially, of the three combustor baskets investigated.

3. The combustion efficiencies of the original basket were highest and the combustion efficiencies of the modified rectangular-slot basket were lowest of the three baskets for all altitude and engine-speed conditions investigated.

4. The velocity distribution of the original basket showed a slight double peak as in the case of its temperature distribution. The velocity distributions of the two rectangular-slot baskets showed no double peaks. The velocities at the combustor outlet with all three baskets were low near the outer wall.

5. The combustor inlet-to-outlet total-pressure loss was about 7 percent greater for the rectangular-slot basket and about 8 percent less for the modified rectangular-slot basket than for the original basket.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, July 13, 1948.

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REFERENCES

1. Manganiello, Eugene J., Bernardo, Everett, and Schroeter, Thomas T.: Simulated Altitude Performance of Combustors for the Westinghouse 24C Jet Engine. I - 24C-2 Combustor. NACA RM No. E6J09, Bur. Aero., 1946.

2. Bernardo, Everett, Schroeter, Thomas T., and Miller, Robert C.: Simulated Altitude Performance of Combustors for the 24C Jet Engine. II - 24C-4 Combustor. NACA RM No. SE7J06, Bur. Aero., 1947.

3. Olson, Walter T., and Schroeter, Thomas T.: Effect of Distribution of Basket-Hole Area on Simulated Altitude Performance of $25\frac{1}{2}$-Inch-Diameter Annular-Type Turbojet Combustor. NACA RM No. E8A02, 1948.

4. Saari, Martin J., and Prince, William R.: Altitude-Wind-Tunnel Investigation of a 3000-Pound-Thrust Axial-Flow Turbojet Engine. VII - Pressure and Temperature Distributions. NACA RM No. E8C17,

5. Campbell, Carl E.: Altitude-Wind-Tunnel Investigation of a 3000-Pound-Thrust Axial-Flow Turbojet Engine. III - Analysis of Combustion-Chamber Performance. NACA RM No. E8B19, 1948.

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Figure 9. - Radial temperature profiles at outlet of 24C-4B combustor.
(a) Altitude, 45,000 feet; corrected engine speed, 12,500 rpm.
(b) Altitude, 40,000 feet; corrected engine speed, 11,000 rpm.
(c) Corrected engine speed, 8000 rpm.
(d) Corrected engine speed, 6000 rpm.

Figure 10. - Variation of combustion efficiency with fuel-air ratio for 24C-4B combustor.
(a) Original basket; corrected engine speed, 12,500 rpm.
(b) Original basket; corrected engine speed, 11,000 rpm.
(c) Rectangular-slot basket; corrected engine speed, 12,500 rpm.
(d) Rectangular-slot basket; corrected engine speed, 11,000 rpm.
(e) Modified rectangular-slot basket; corrected engine speed, 12,500 rpm.
(f) Modified rectangular-slot basket; corrected engine speed, 11,000 rpm.

Figure 11. - Outlet gas velocity profiles for 24C-4B combustor. Altitude, 45,000 feet; corrected engine speed, 12,500 rpm.

Figure 12. - Comparison of total-pressure drop in 24C-4B combustor.

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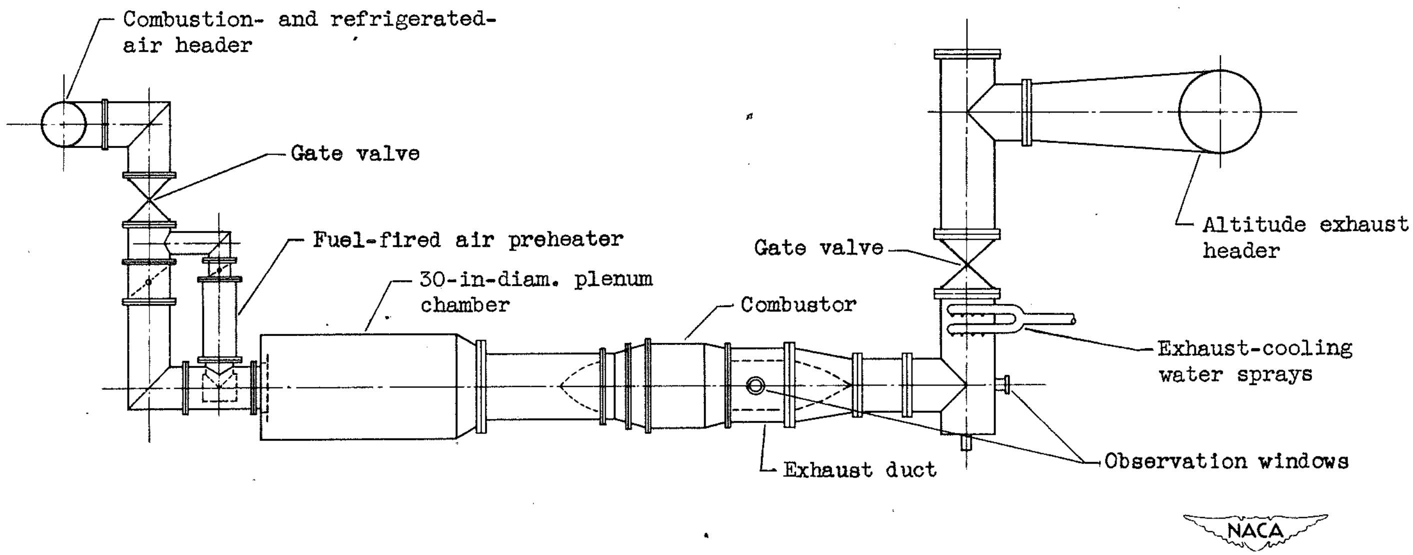

Figure 1. - Diagrammatic sketch of 24C-4B combustor setup.

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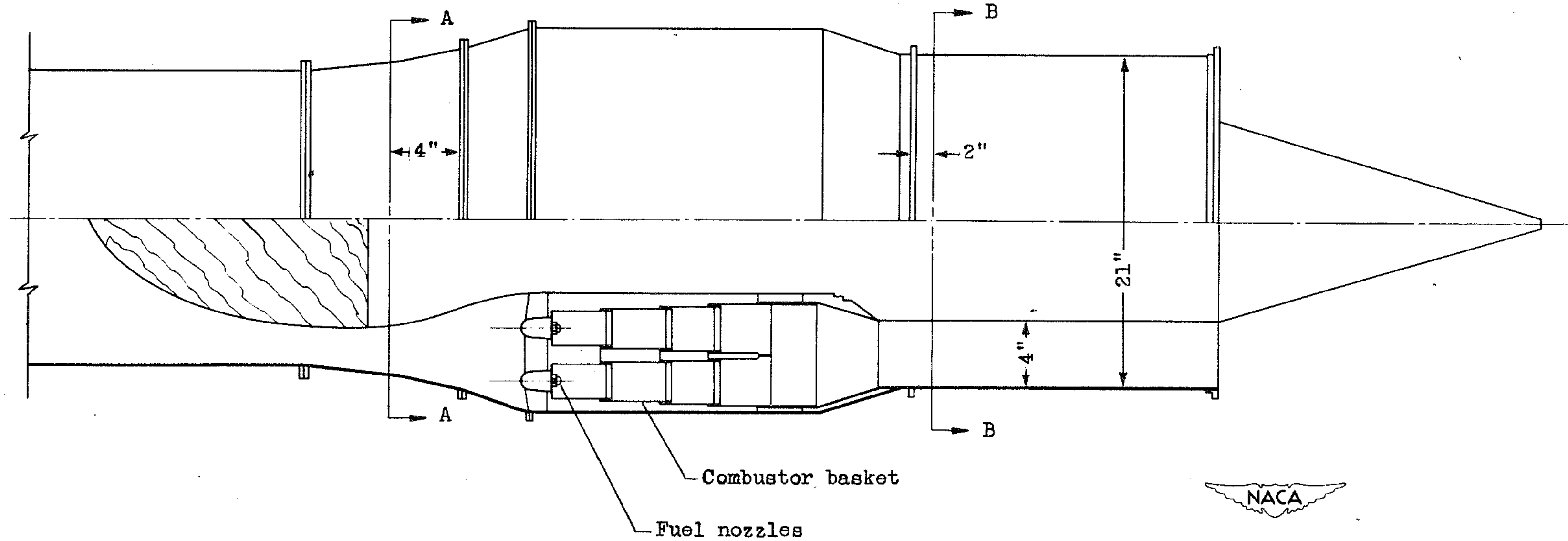
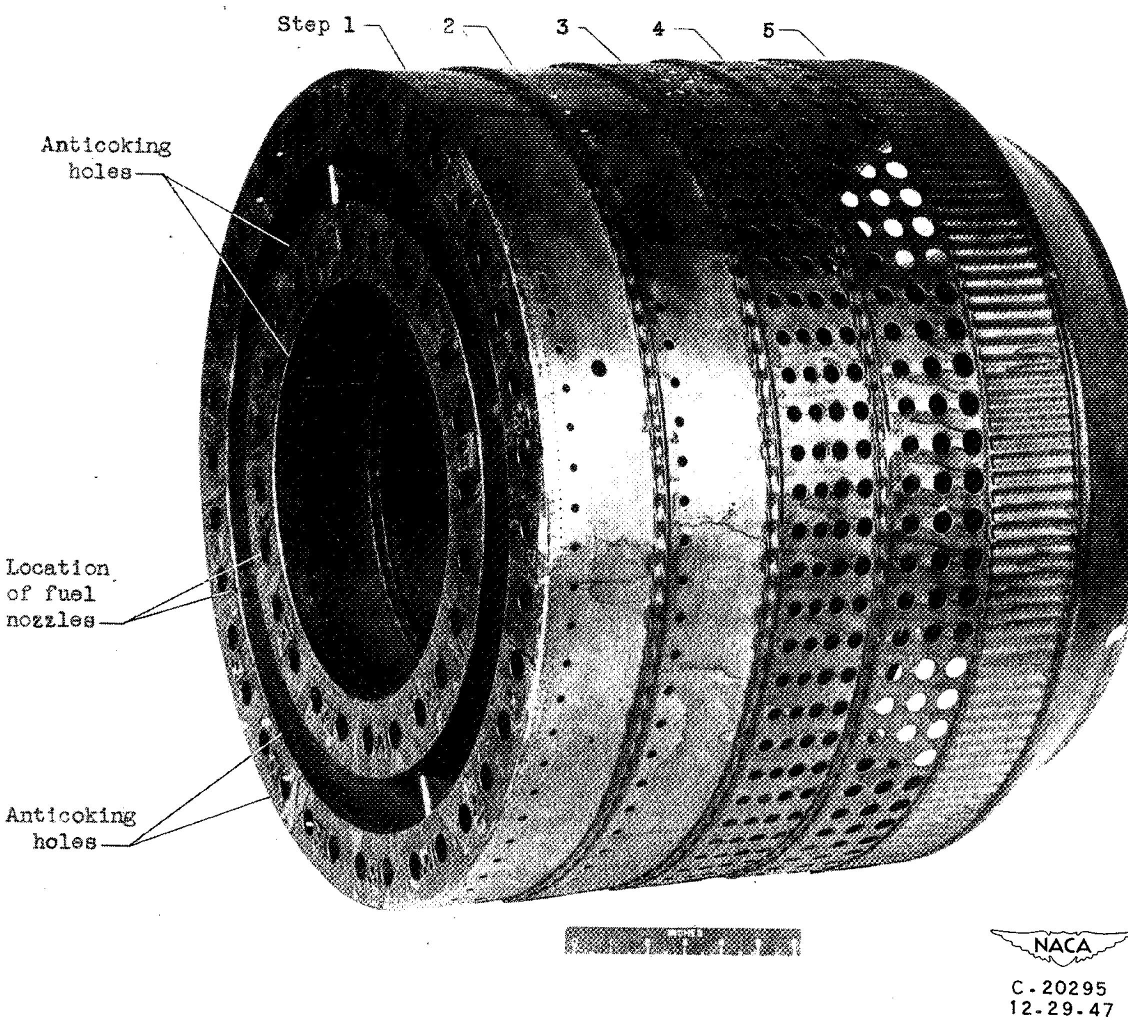
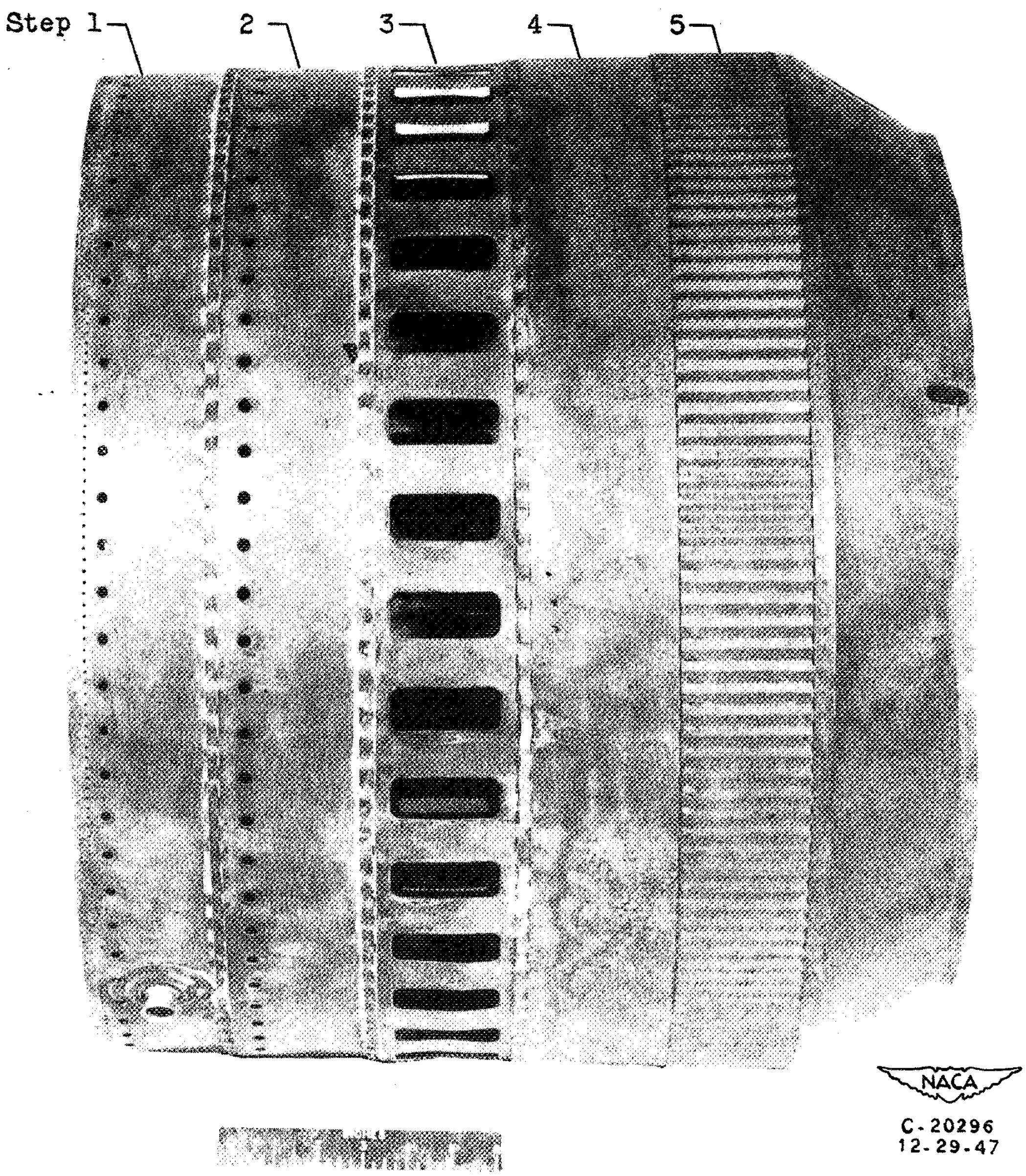


Figure 2. - Longitudinal half-section of 24C-4B combustor showing adjoining ducting and planes of instrumentation.



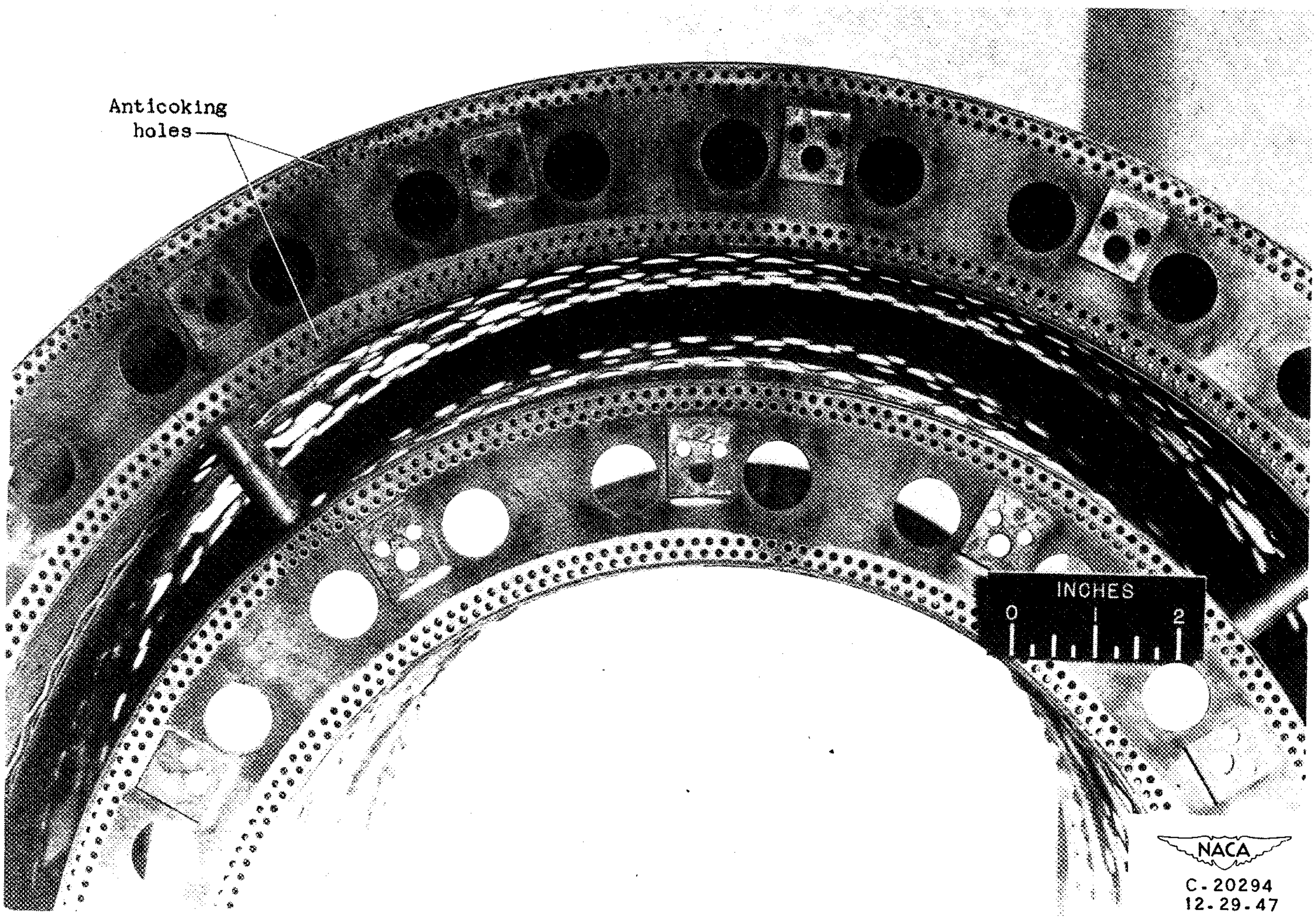
(a) Original basket.

Figure 3. - Photograph of basket for 24C-4B combustor.



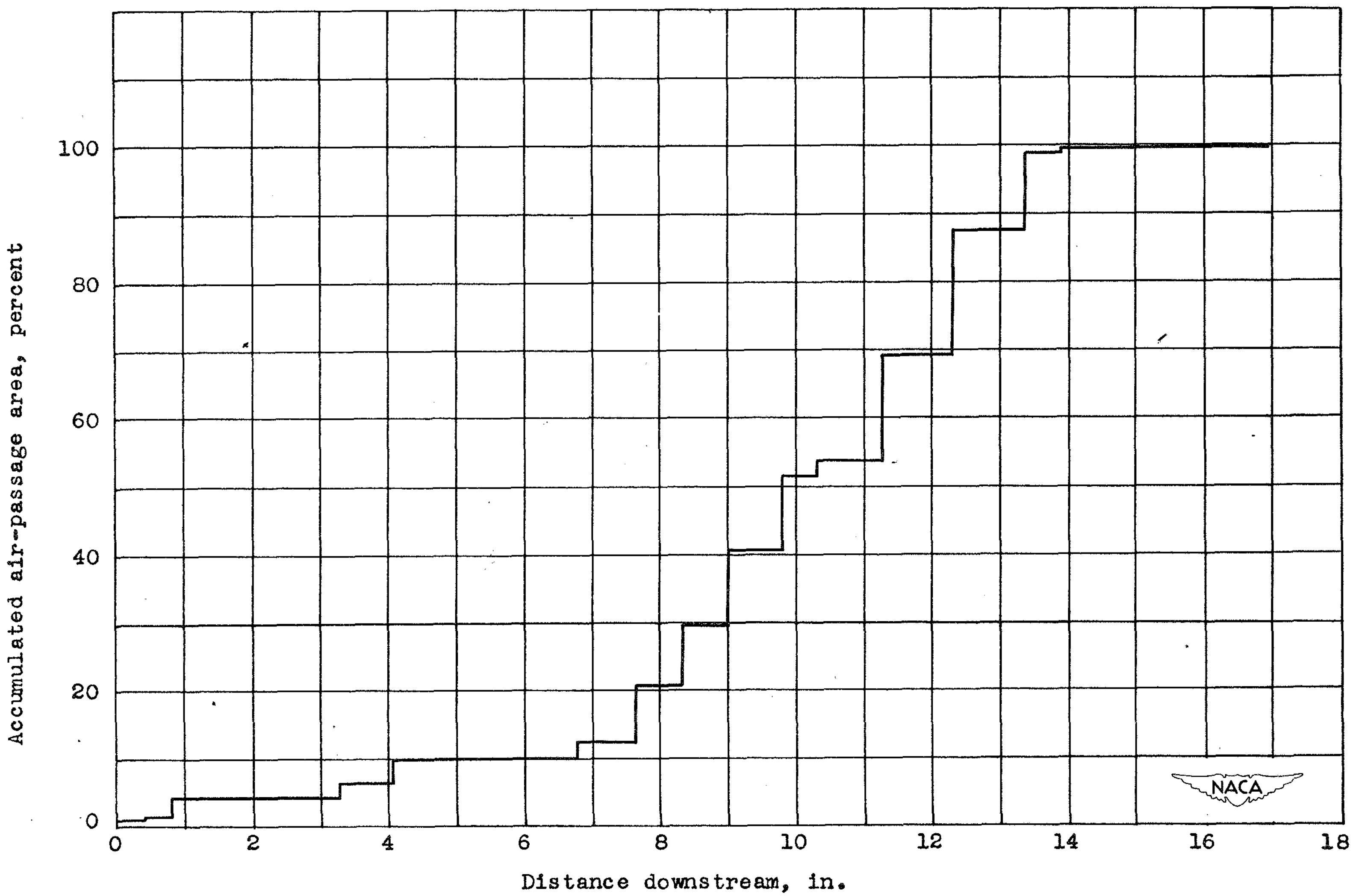
(b) Rectangular-slot basket.

Figure 3. - Continued. Photograph of basket for 24C-4B combustor.



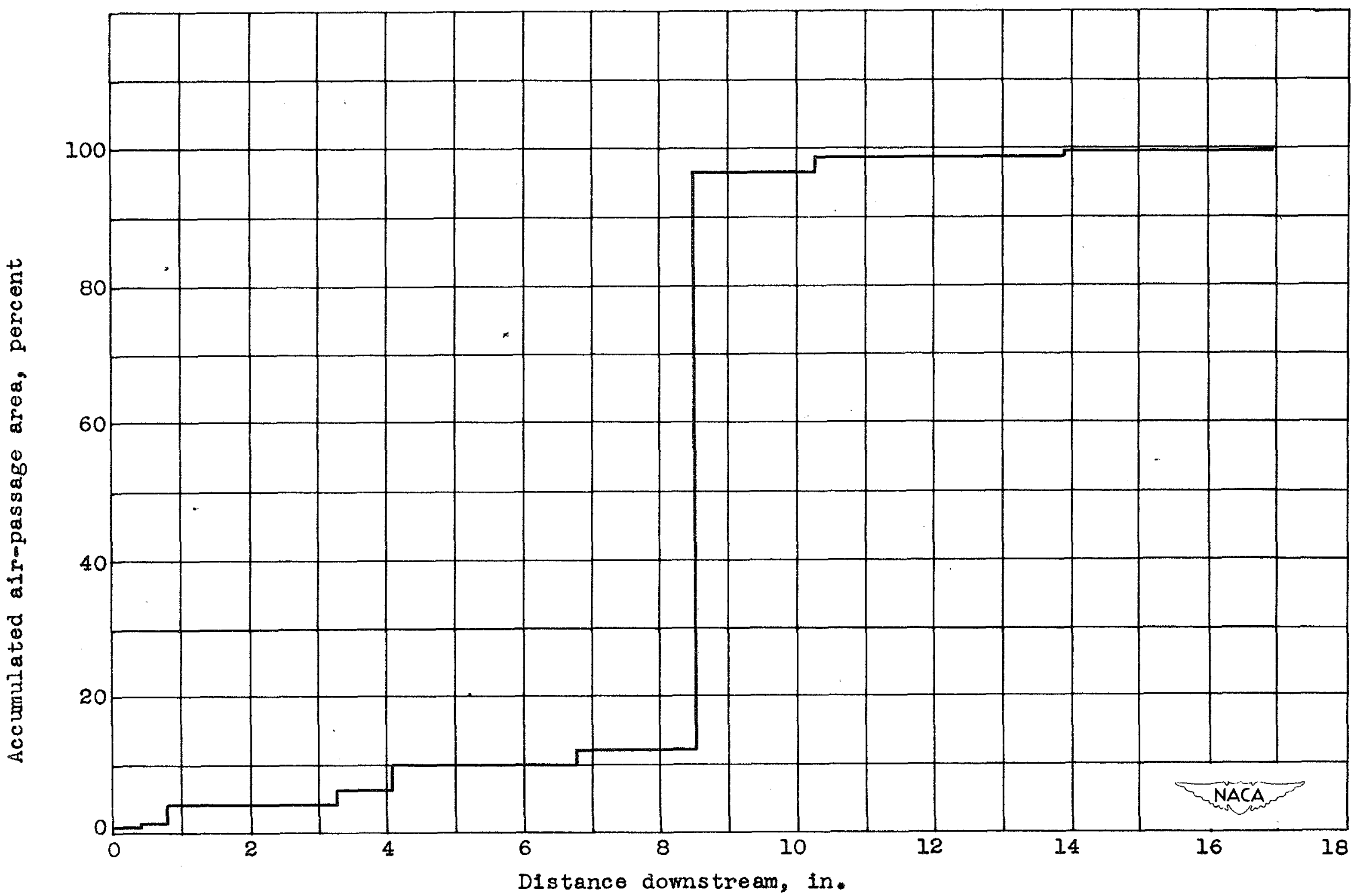
(c) Modified rectangular-slot basket showing enlarged anticoking holes.

Figure 3. - Concluded. Photograph of basket for 24C-4B combustor.



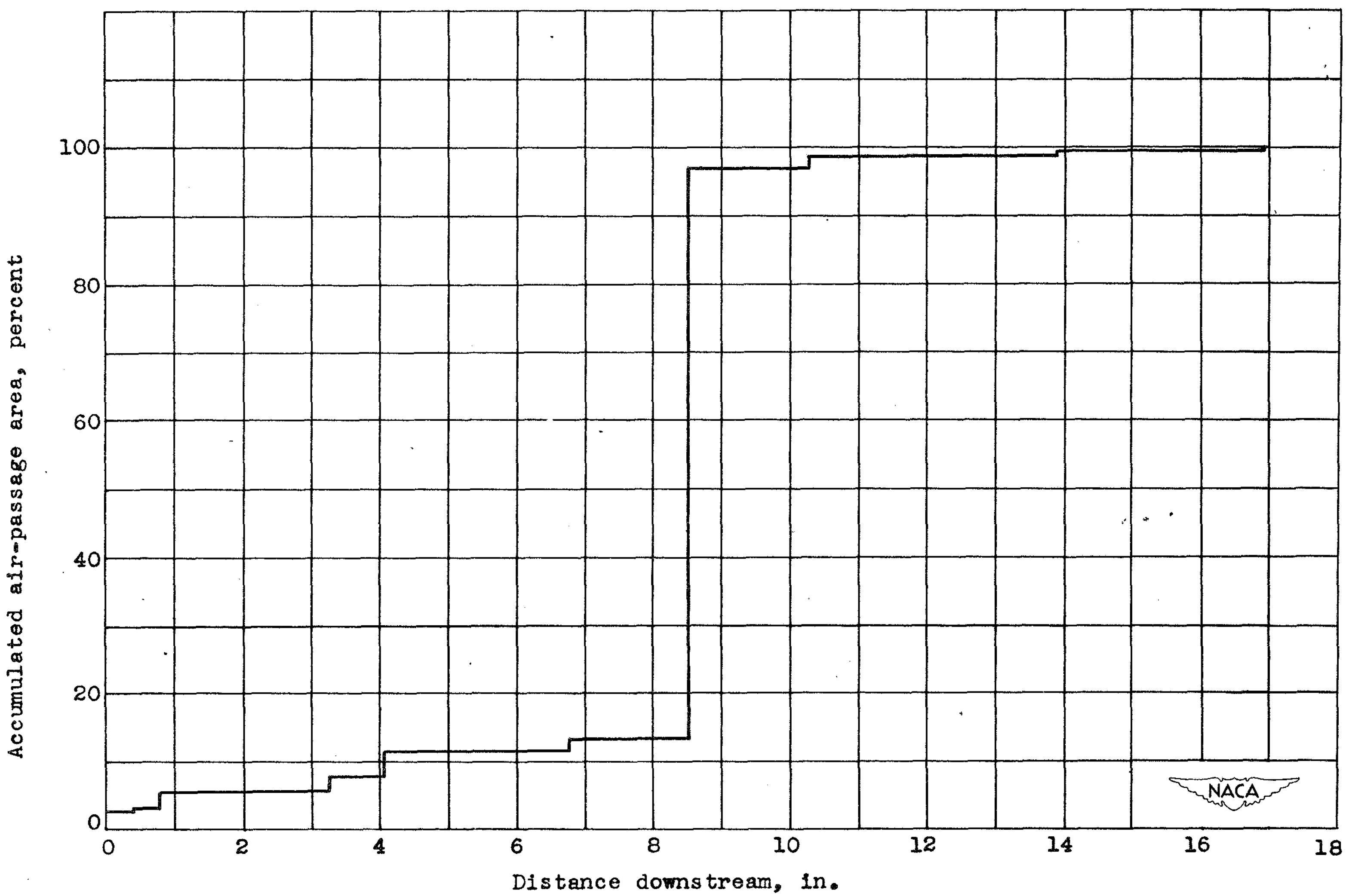
(a) Original basket; total area, 364 square inches.

Figure 4. - Accumulated air-passage area in baskets of 24C-4B combustor.



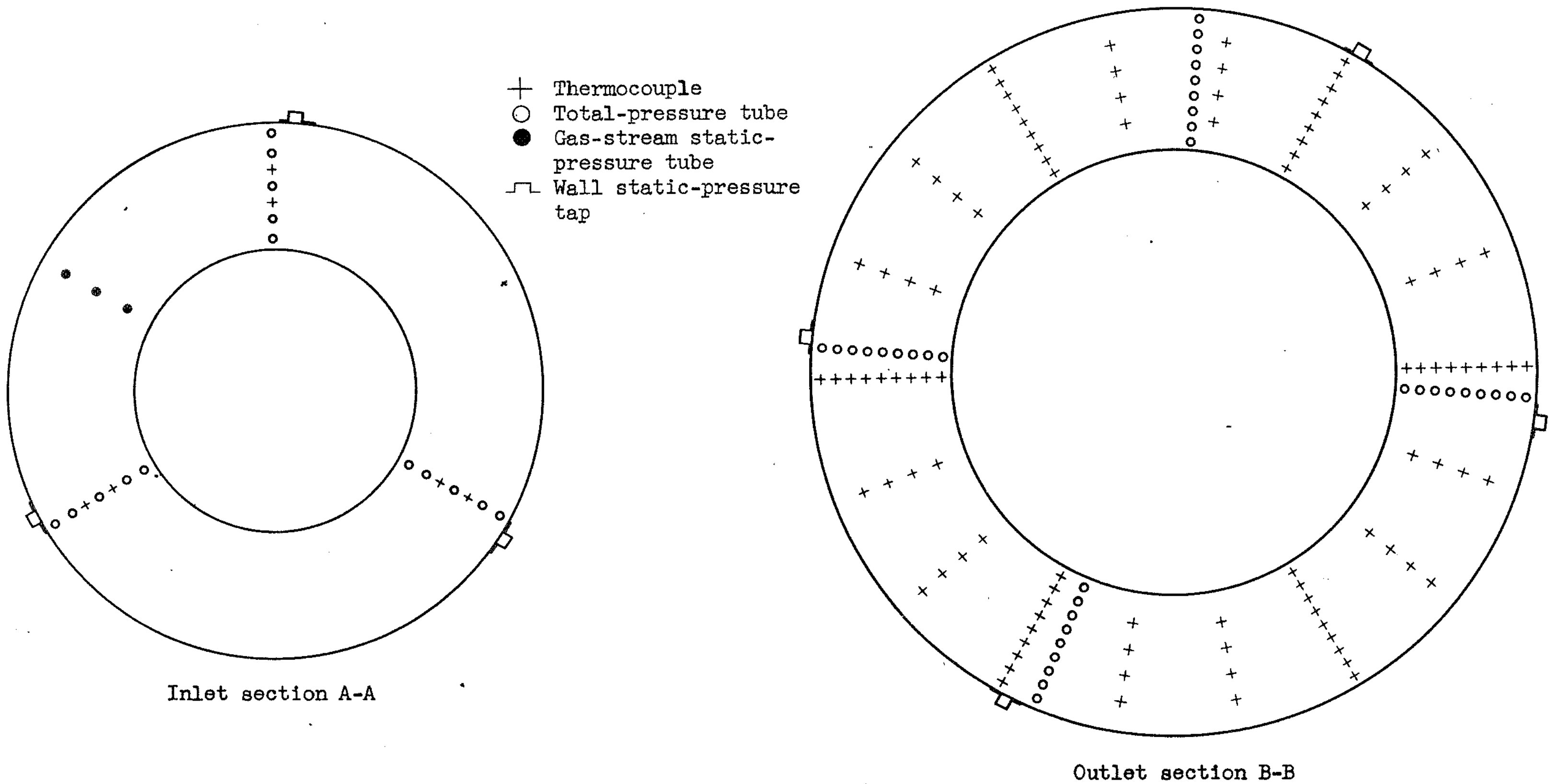
(b) Rectangular-slot basket; total area, 364 square inches.

Figure 4. - Continued. Accumulated air-passage area in baskets of 24C-4B combustor.



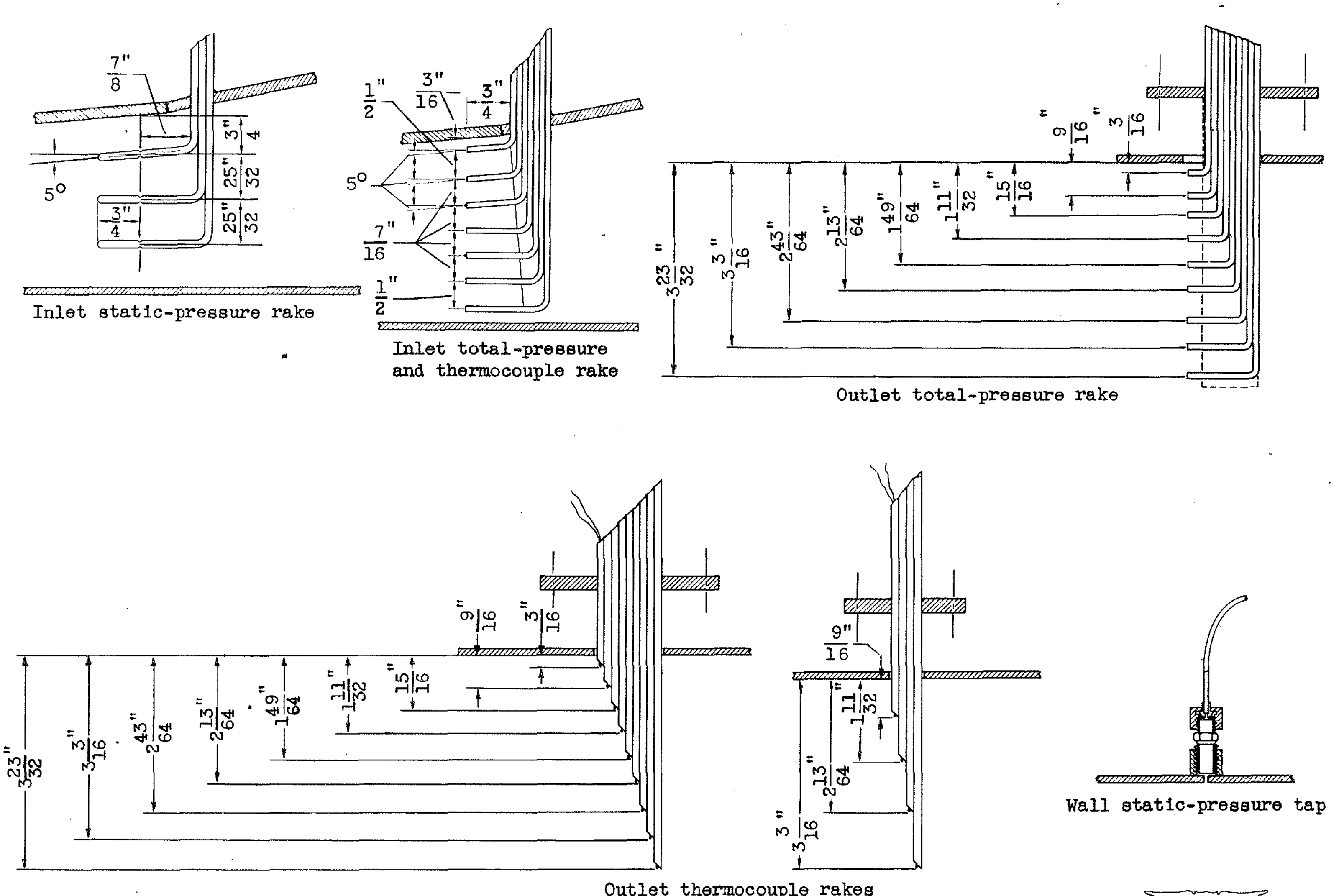
(c) Modified rectangular-slot basket; total area, 370 square inches.

Figure 4. - Concluded. Accumulated air-passage area in baskets of 24C-4B combustor.



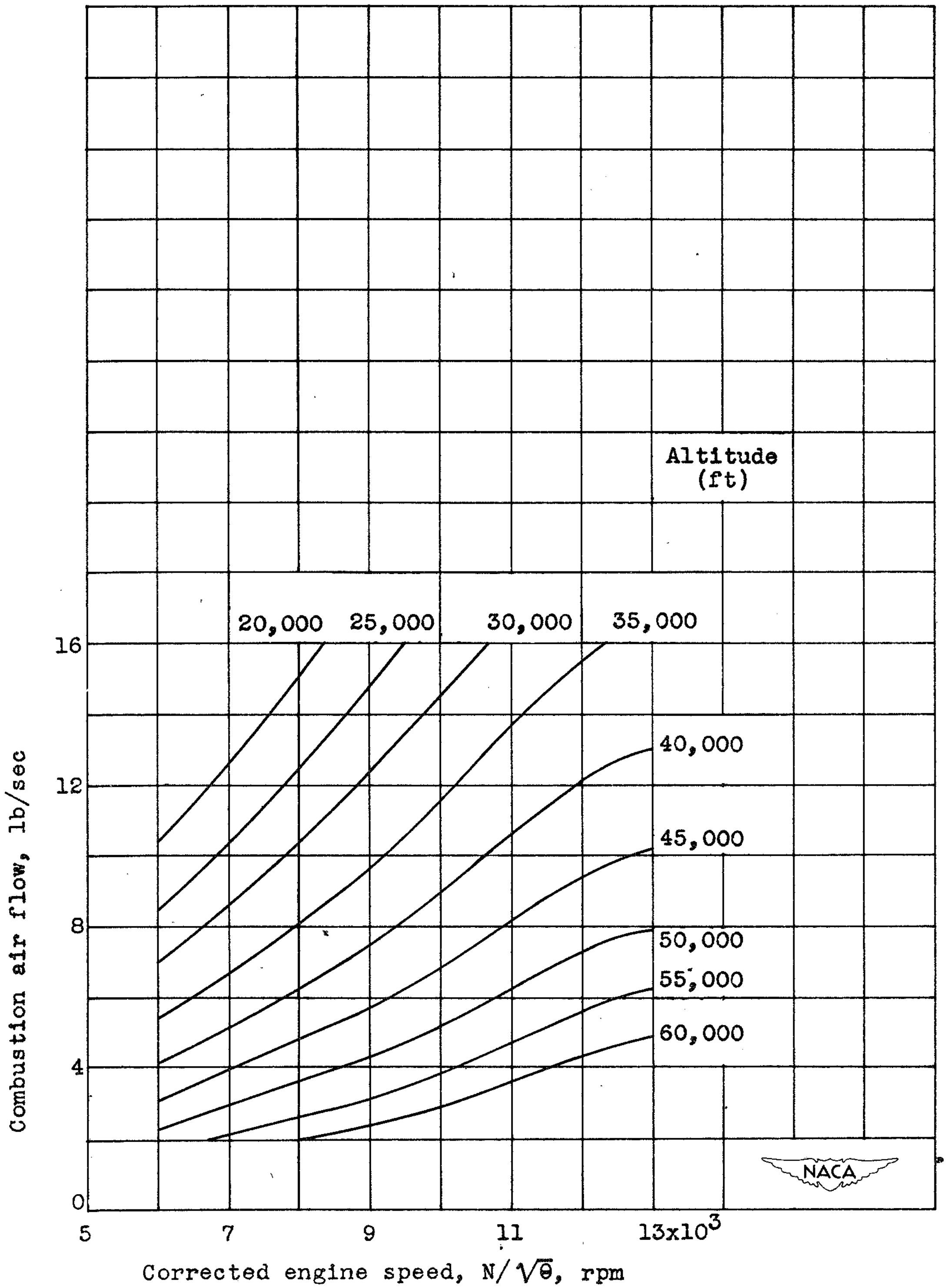
(a) Orientation.

Figure 5. - Instrumentation of 24C-4B combustor.



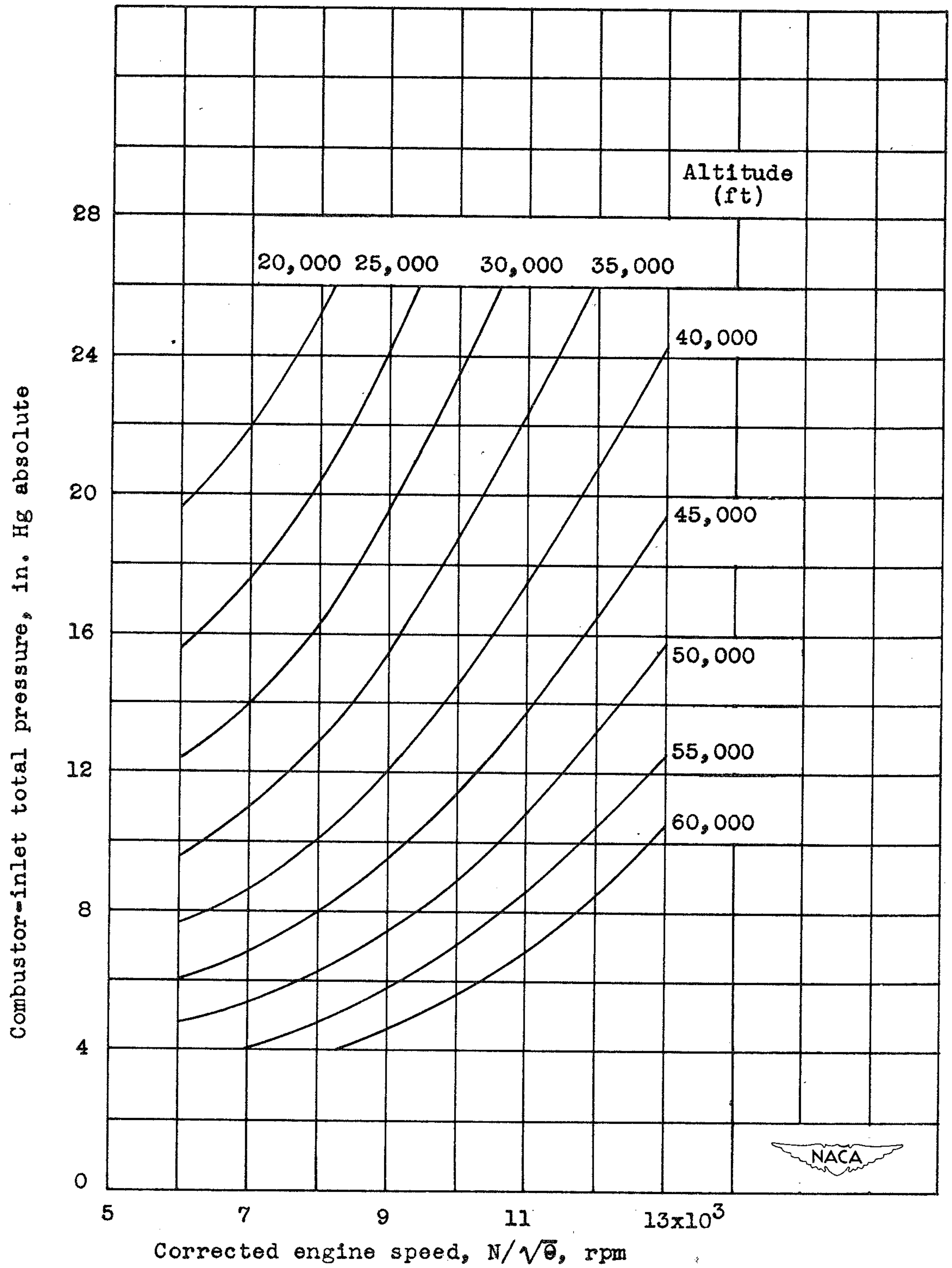
(b) Construction details.

Figure 5. - Concluded. Instrumentation of 24C-4B combustor.



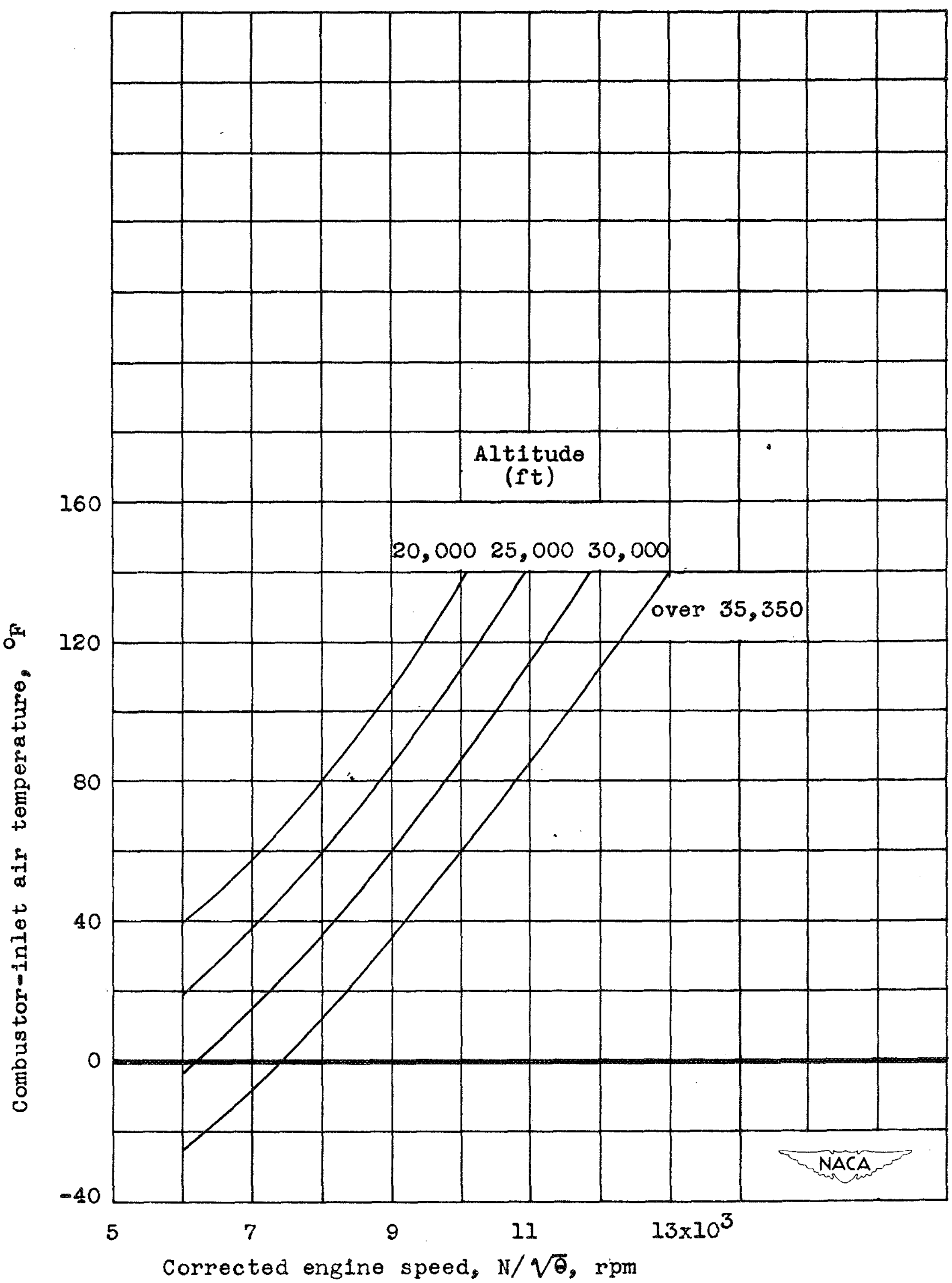
(a) Combustor air flow.

Figure 6. - Variation of combustor operating conditions with engine speed for various altitudes at ram-pressure ratio of 1.04 from performance estimates of 24C-4B turbojet engine.



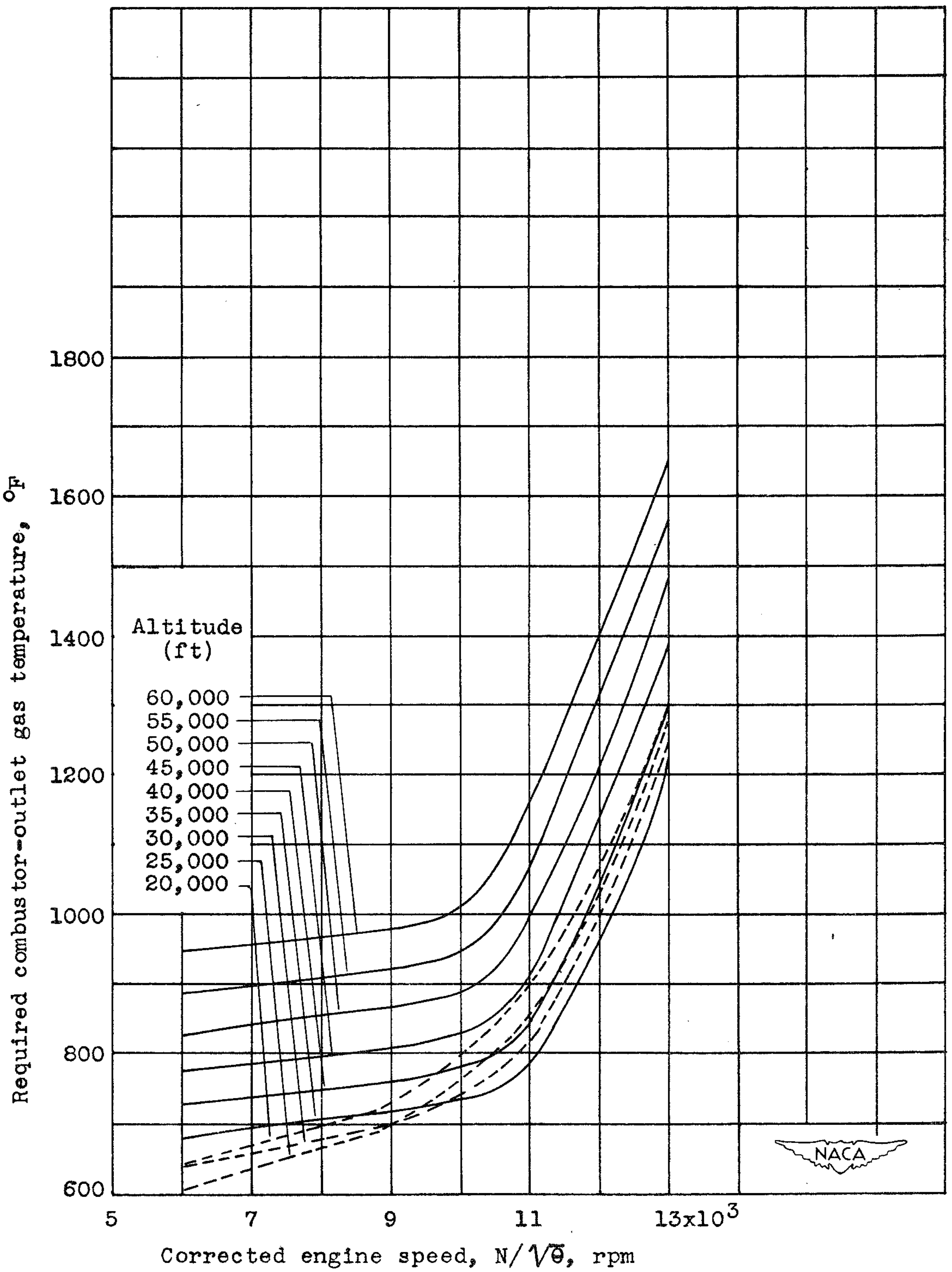
(b) Combustor-inlet total pressure.

Figure 6. - Continued. Variation of combustor operating conditions with engine speed for various altitudes at ram-pressure ratio of 1.04 from performance estimates of 24C-4B turbojet engine.



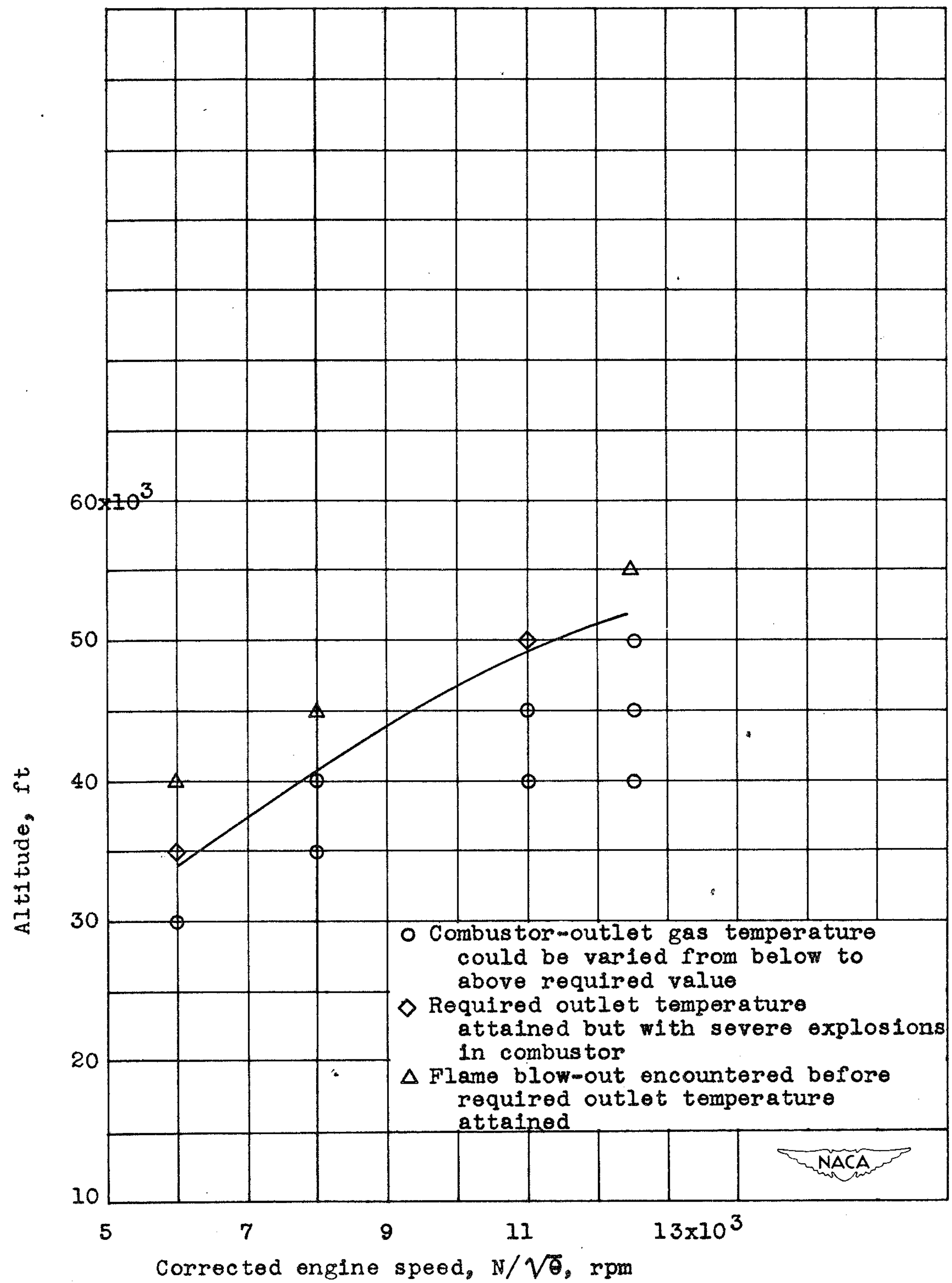
(c) Combustor-inlet air temperature.

Figure 6. - Continued. Variation of combustor operating conditions with engine speed for various altitudes at ram-pressure ratio of 1.04 from performance estimates of 24C-4B turbojet engine.



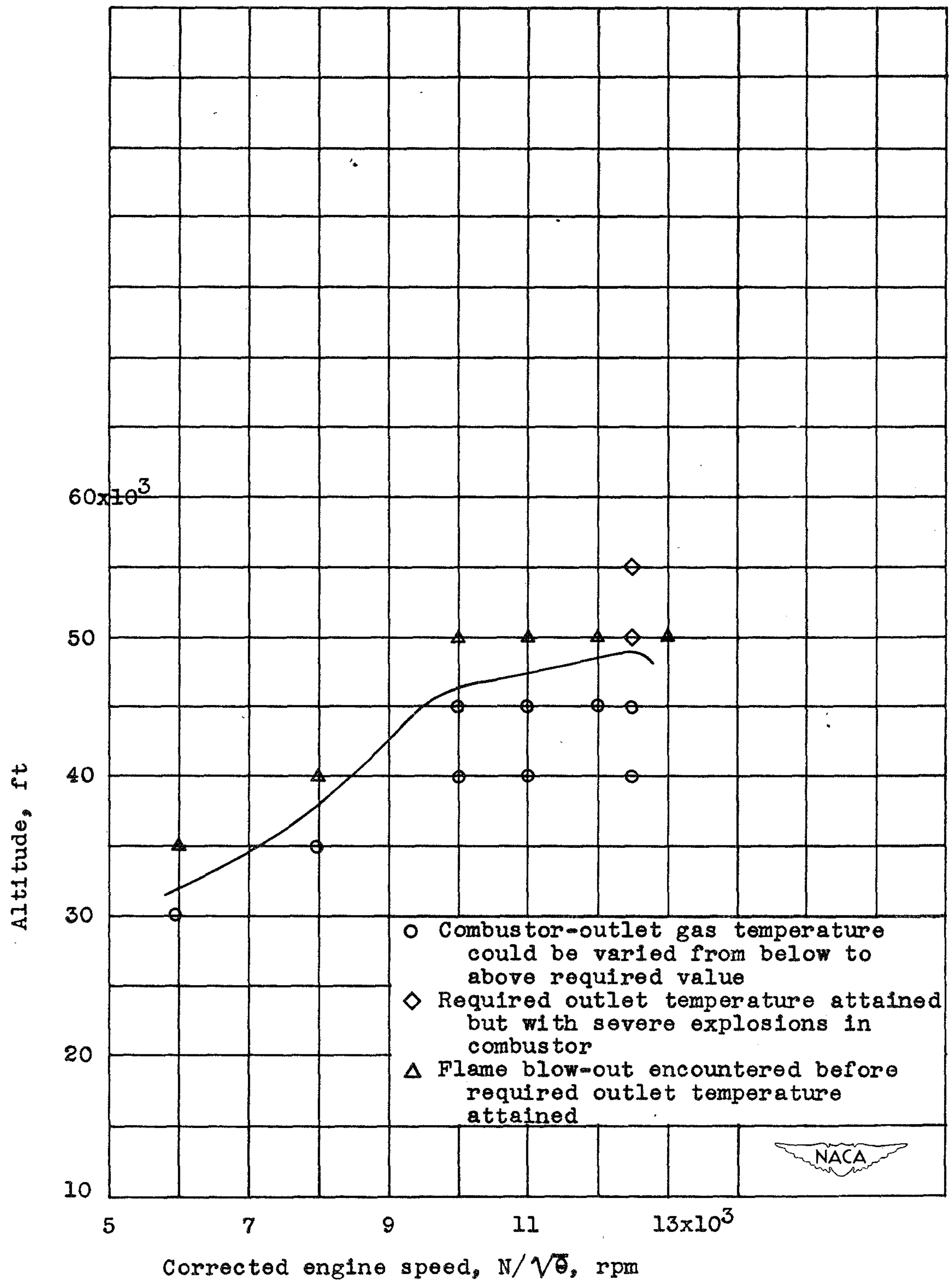
(d) Required combustor-outlet gas temperature.

Figure 6. - Concluded. Variation of combustor operating conditions with engine speed for various altitudes at ram-pressure ratio of 1.04 from performance estimates of 24C-4B turbojet engine.



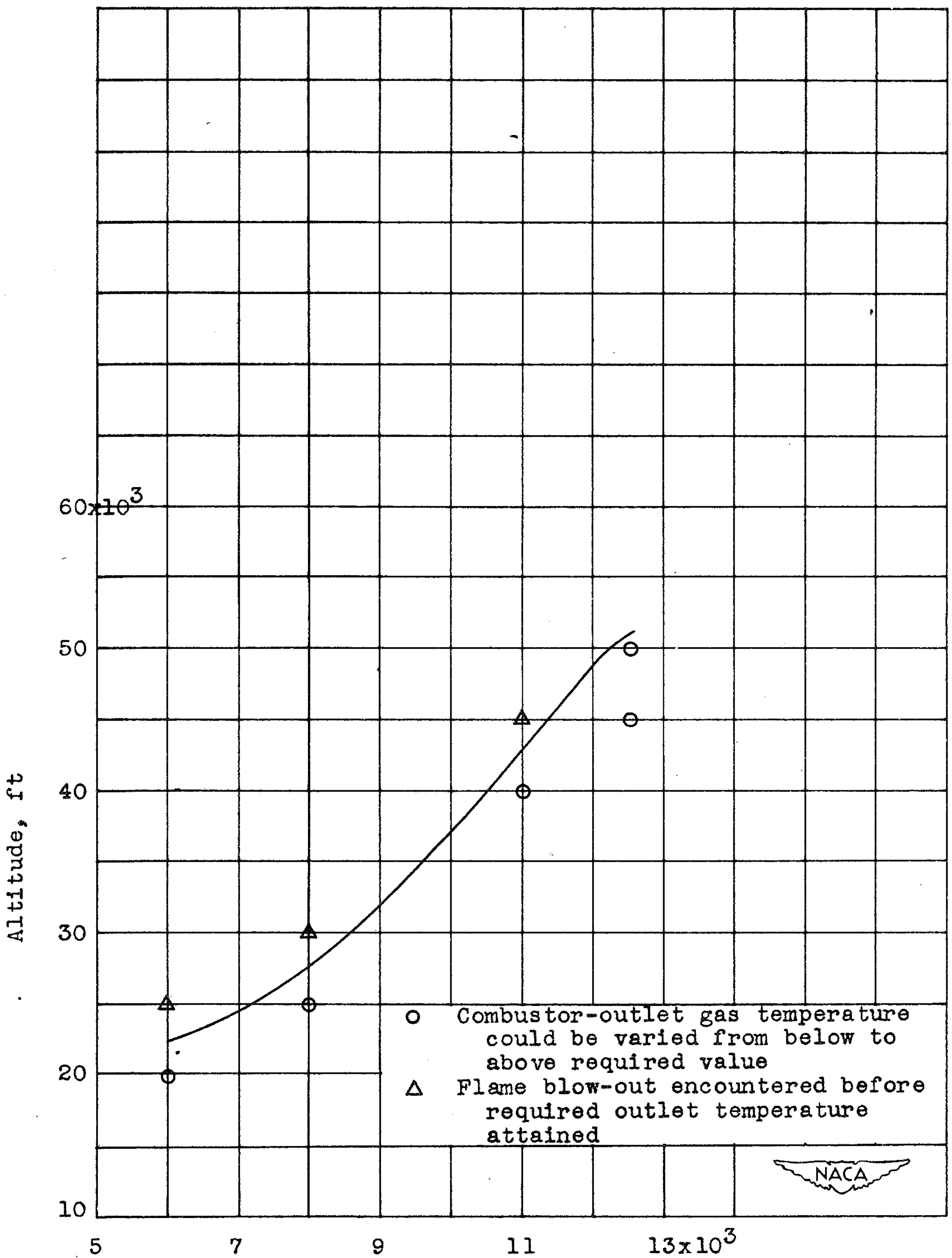
(a) Original basket.

Figure 7. - Altitude operational limits of 24C-4B turbojet engine for ram-pressure ratio of 1.04 as determined with 24C-4B combustor.



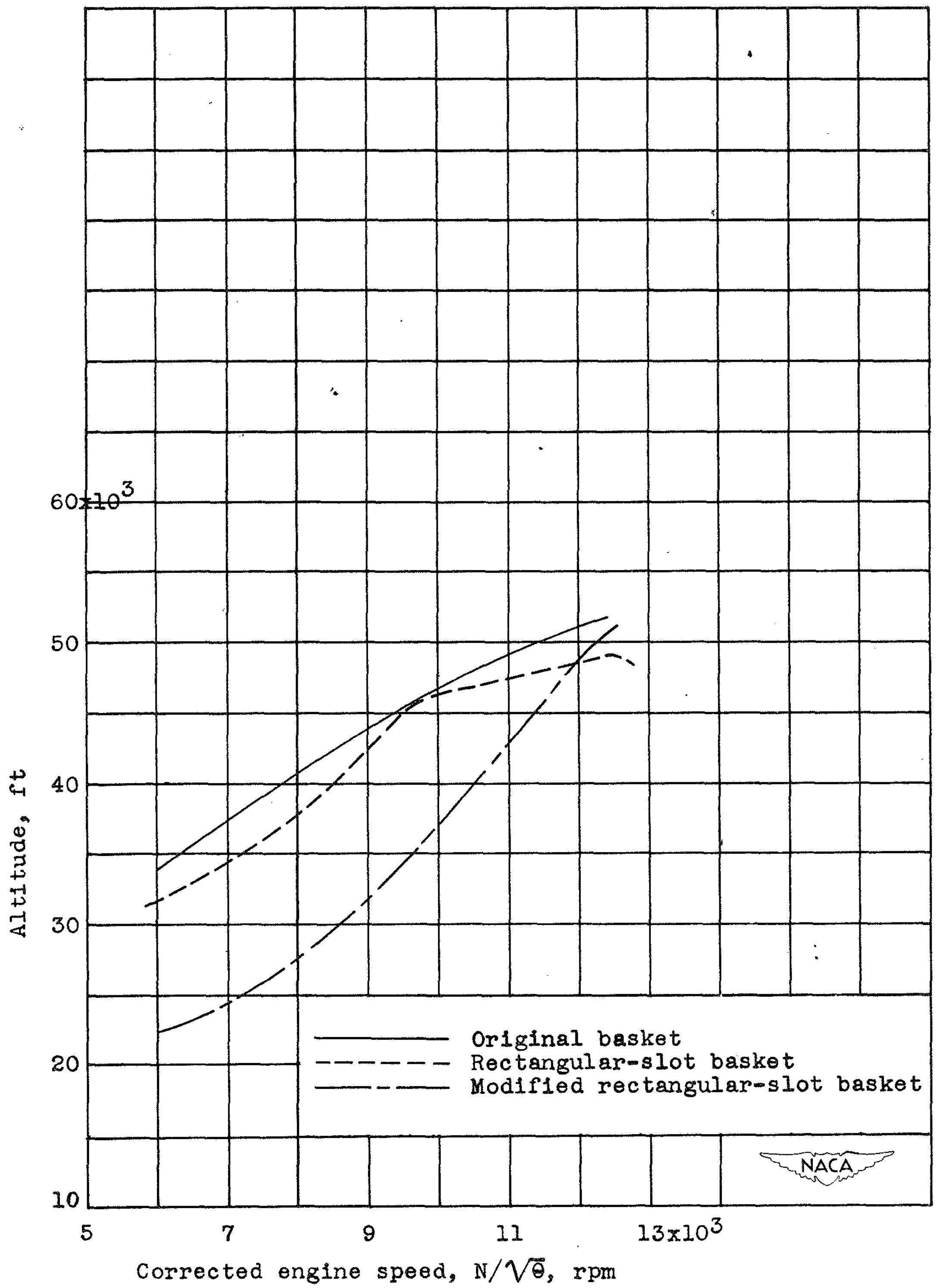
(b) Rectangular-slot basket.

Figure 7. - Continued. Altitude operational limits of 24C-4B turbojet engine for ram-pressure ratio of 1.04 as determined with 24C-4B combustor.



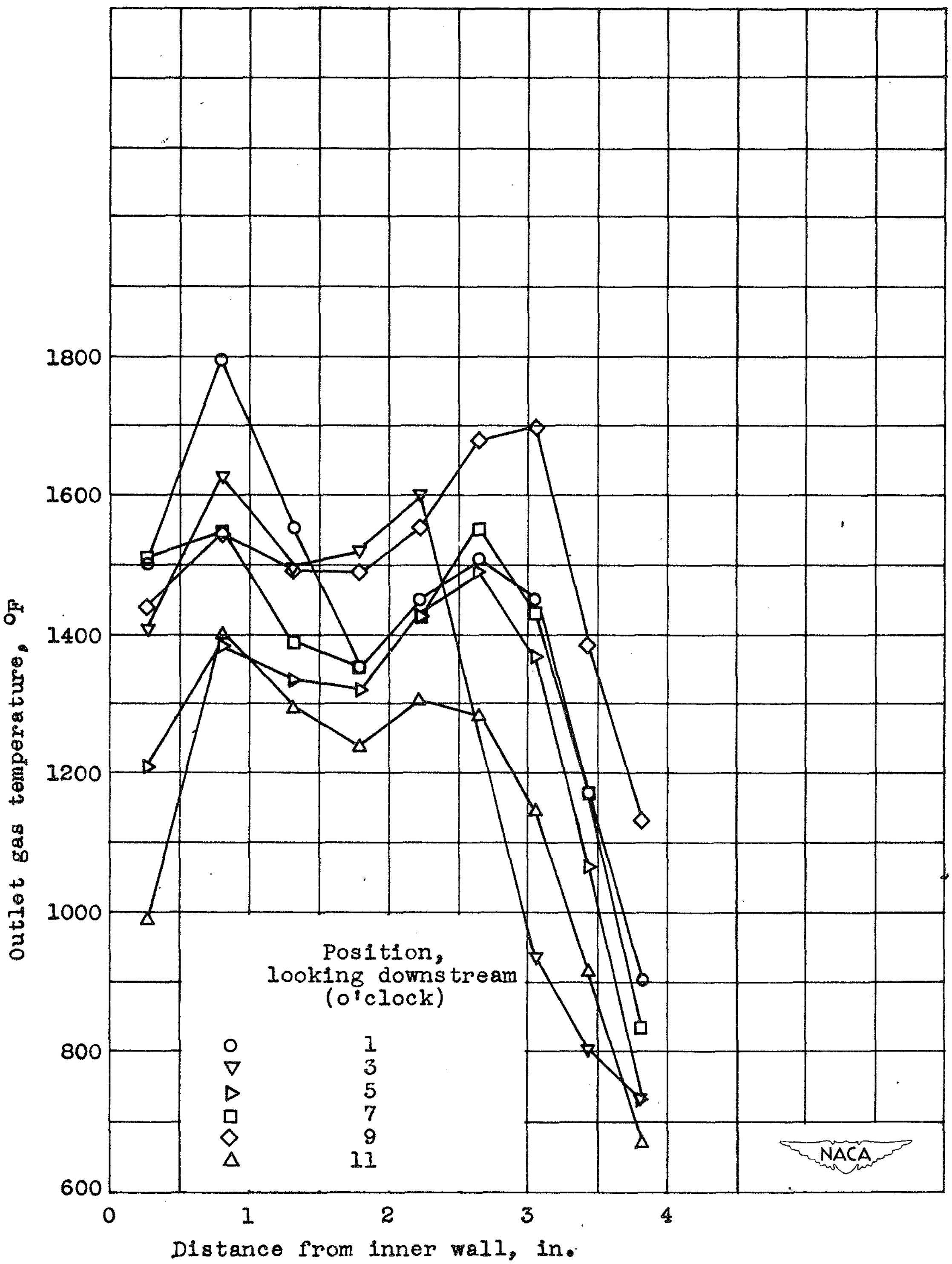
(c) Modified rectangular-slot basket.

Figure 7. - Continued. Altitude operational limits of 24C-4B turbojet engine for ram-pressure ratio of 1.04 as determined with 24C-4B combustor.



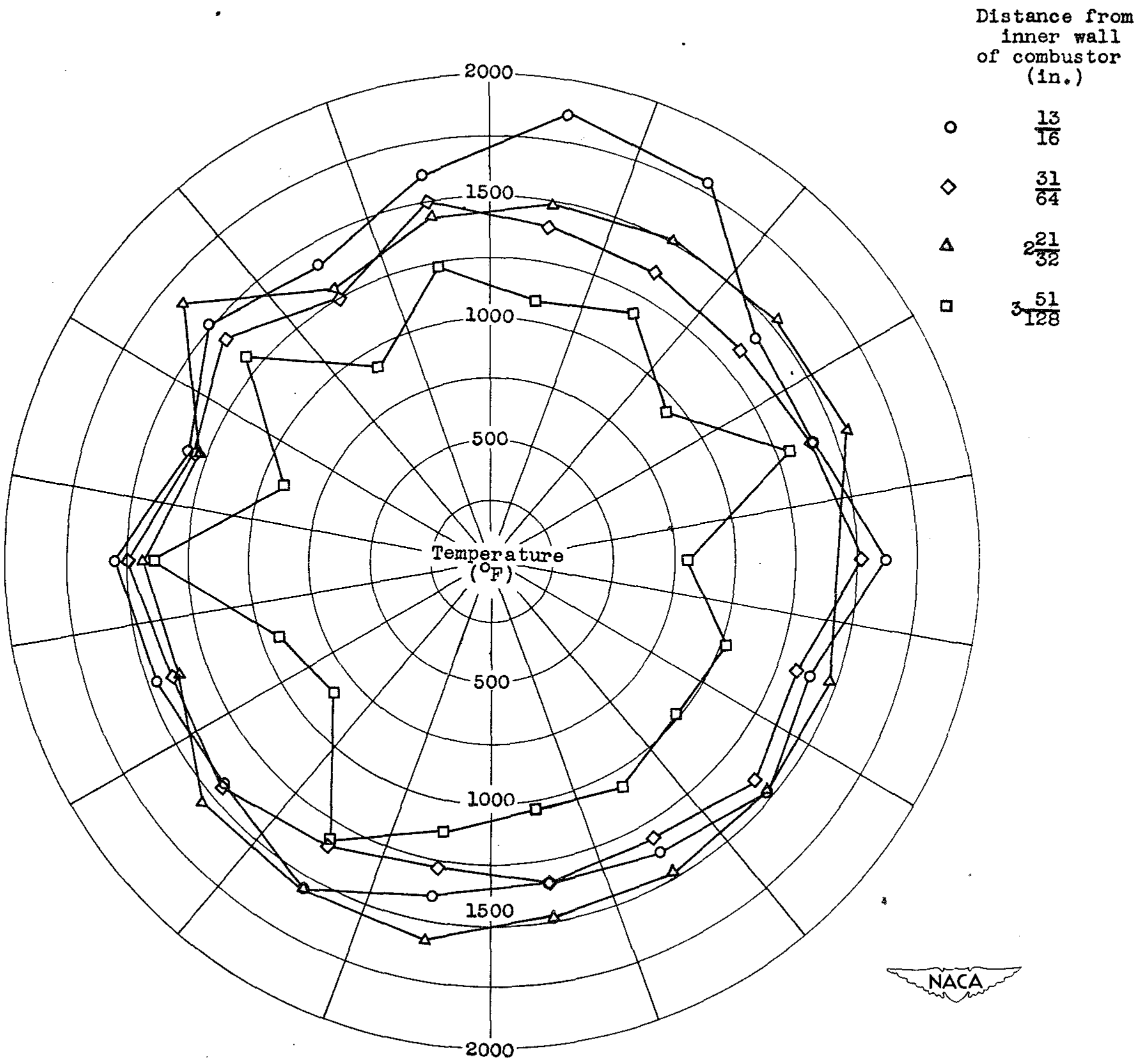
(d) Comparison of three combustor baskets.

Figure 7. - Concluded. Altitude operational limits of 24C-4B turbojet engine for ram-pressure ratio of 1.04 as determined with 24C-4B combustor.



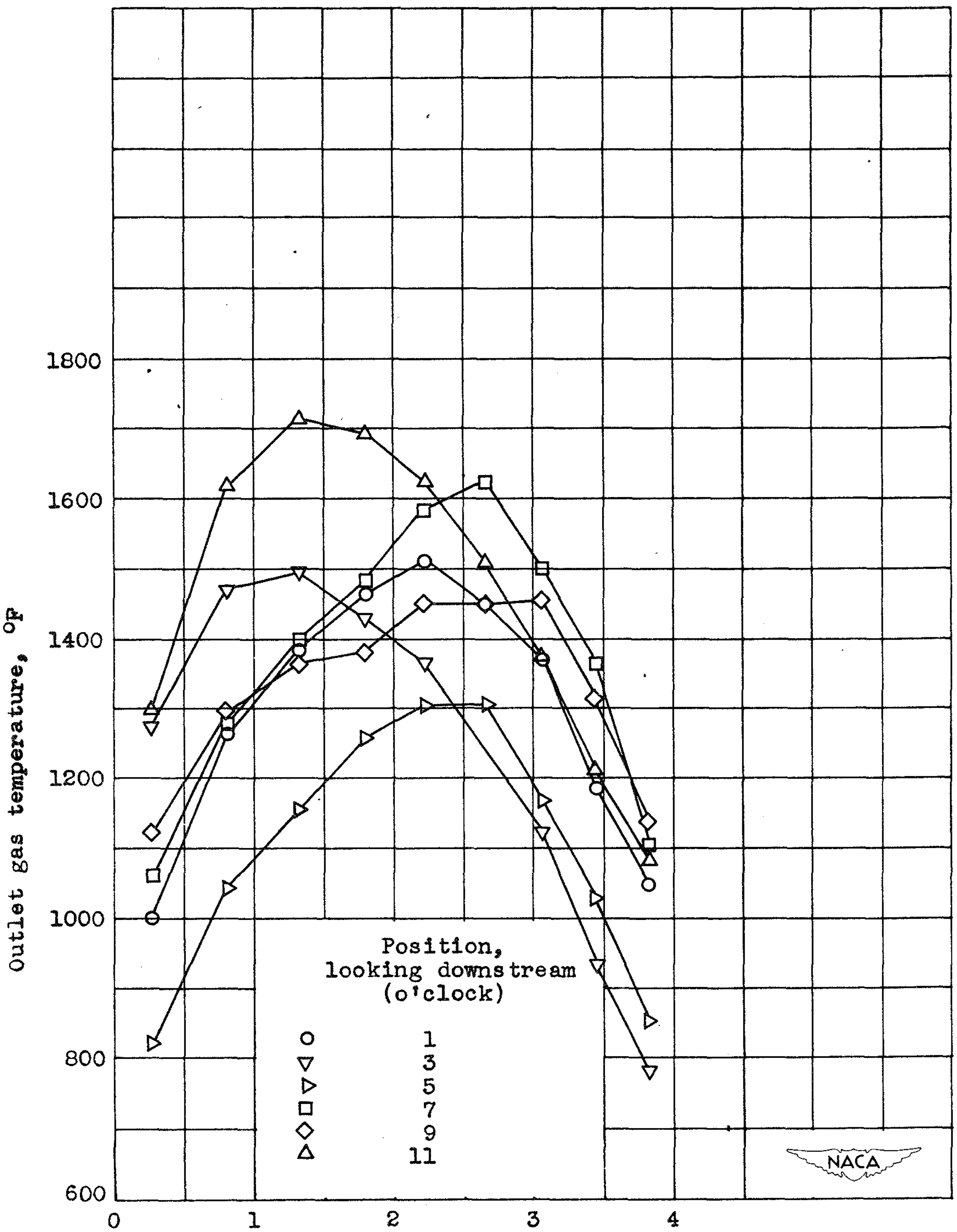
(a) Radial temperature profiles; original basket.

Figure 8. - Temperature distribution at outlet of 24C-4B combustor. Altitude, 45,000 feet; corrected engine speed, 12,500 rpm; ram-pressure ratio, 1.04.



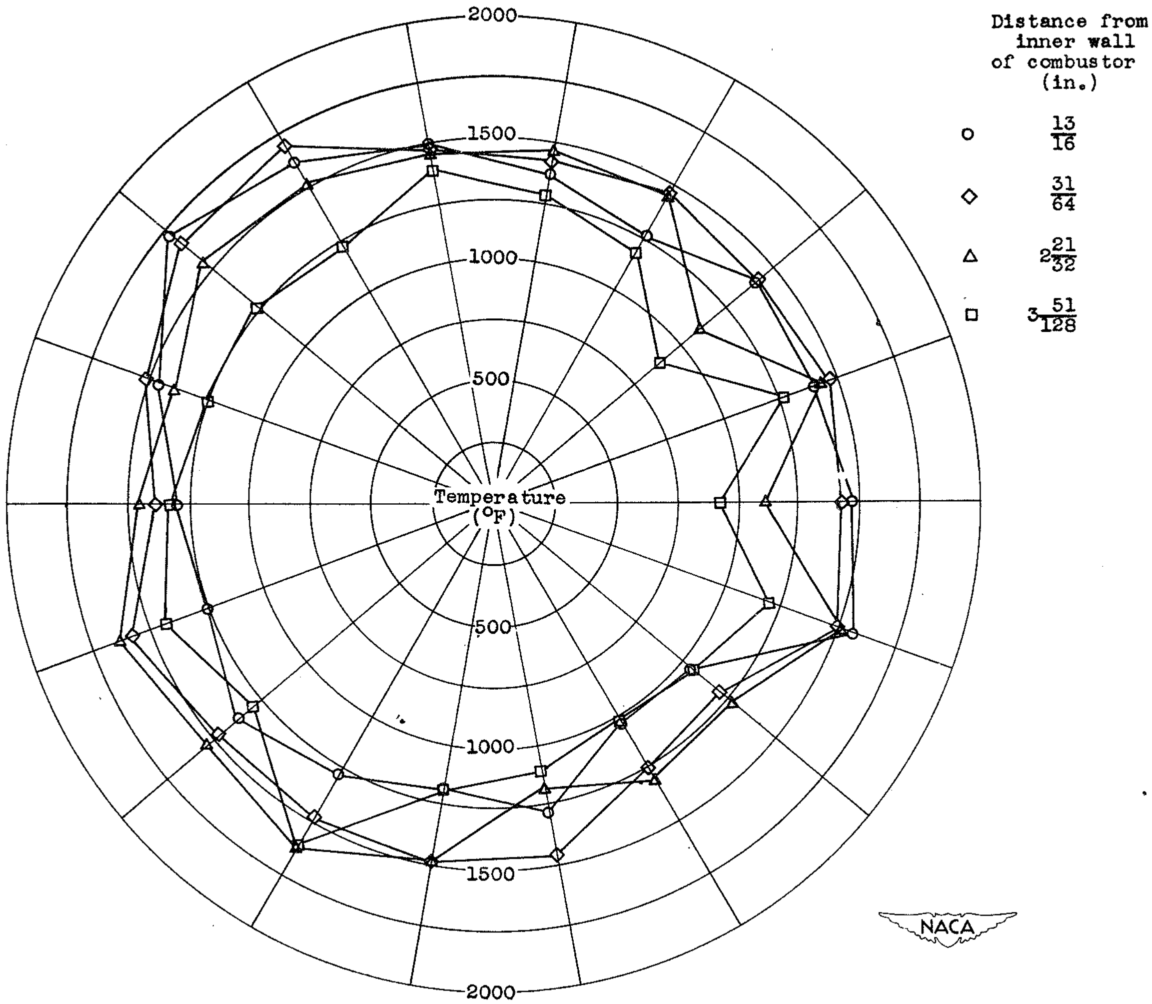
(b) Circumferential temperature distribution; original basket.

Figure 8. - Continued. Temperature distribution at outlet of 24C-4B combustor. Altitude, 45,000 feet; corrected engine speed, 12,500 rpm; ram-pressure ratio, 1.04.



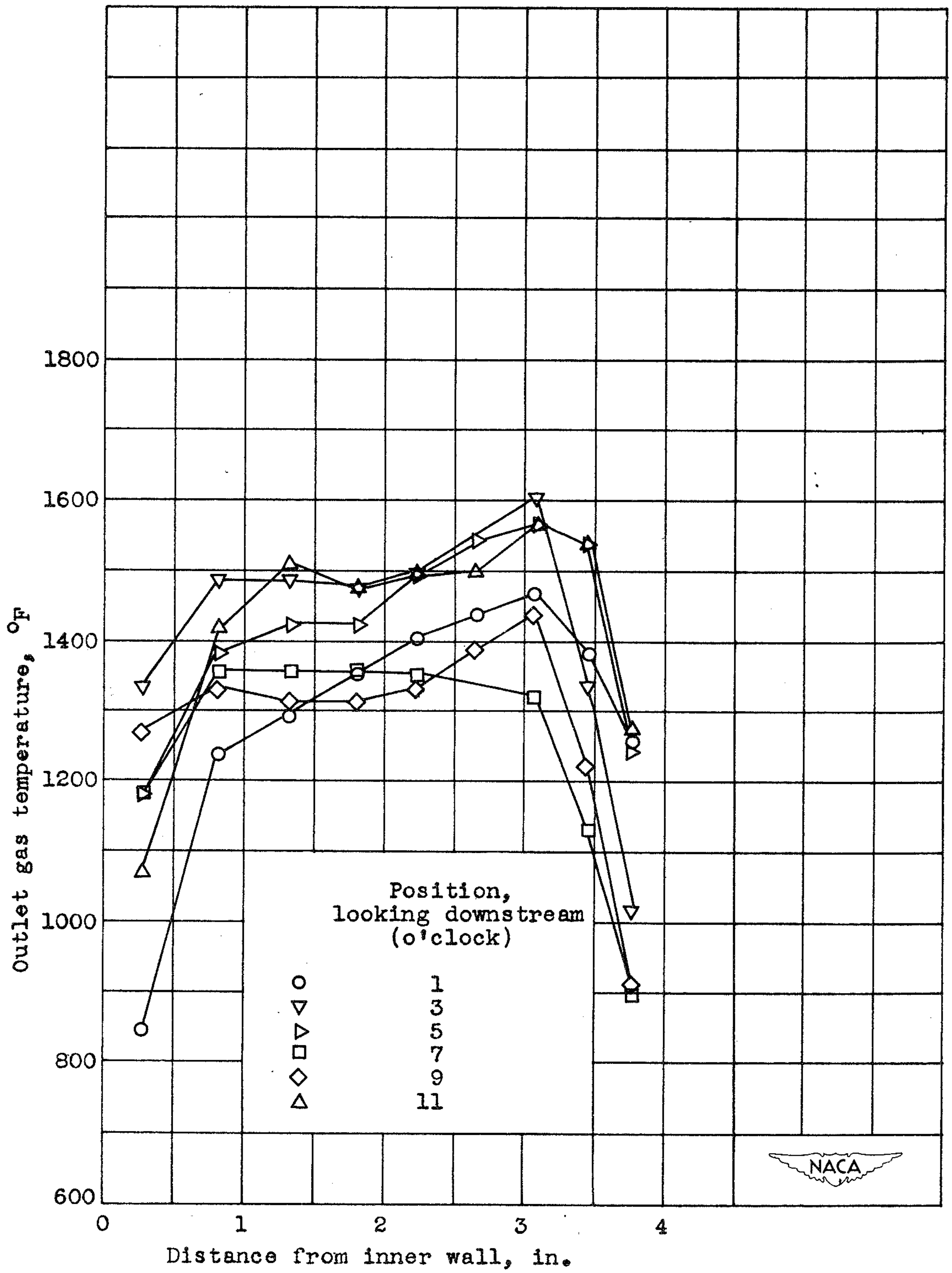
(c) Radial temperature profiles; rectangular-slot basket.

Figure 8. - Continued. Temperature distribution at outlet of 24C-4B combustor. Altitude, 45,000 feet; corrected engine speed, 12,500 rpm; ram-pressure ratio, 1.04.



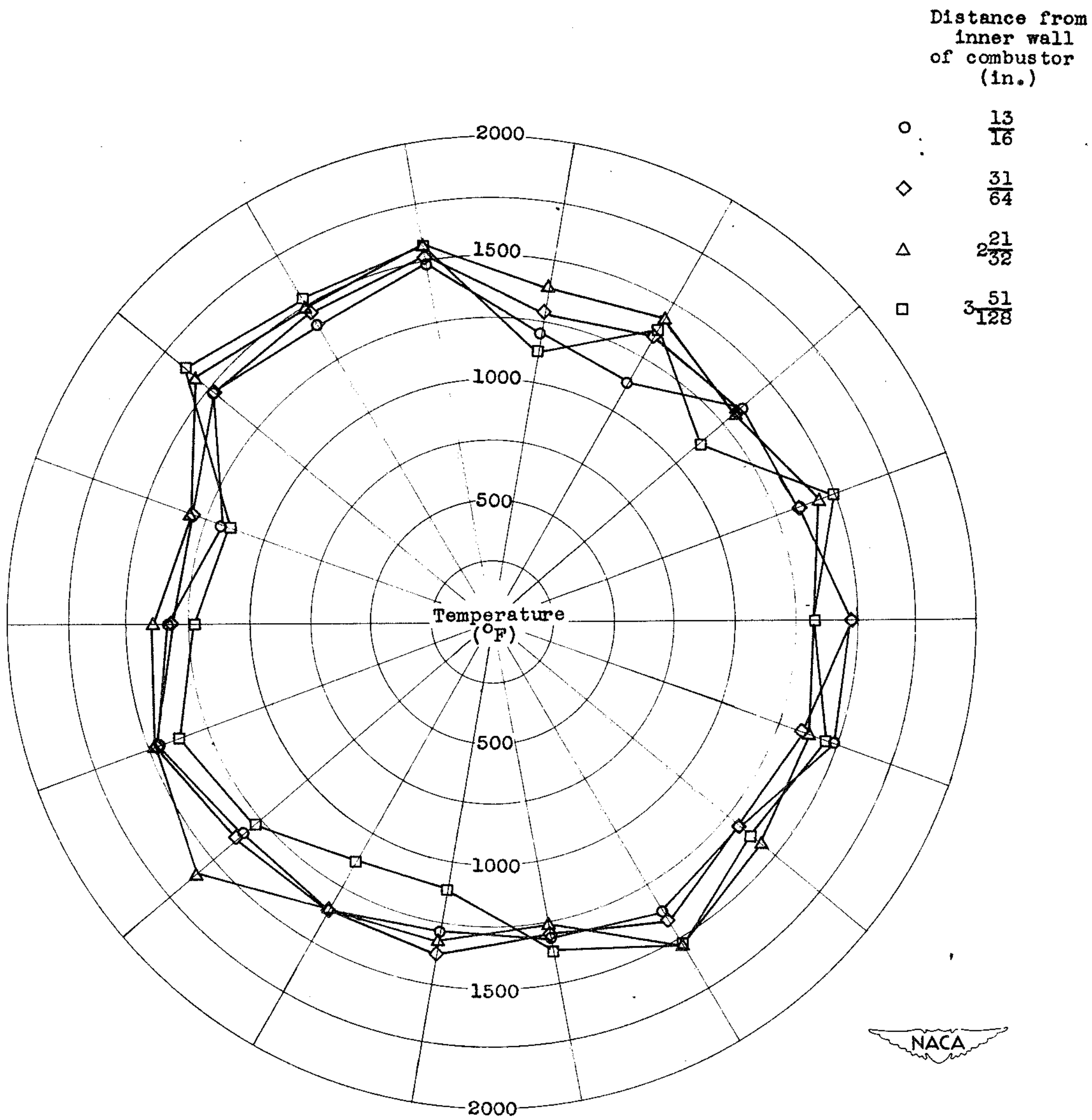
(d) Circumferential temperature distribution; rectangular-slot basket.

Figure 8. - Continued. Temperature distribution at outlet of 24C-4B combustor. Altitude, 45,000 feet; corrected engine speed, 12,500 rpm; ram-pressure ratio, 1.04.



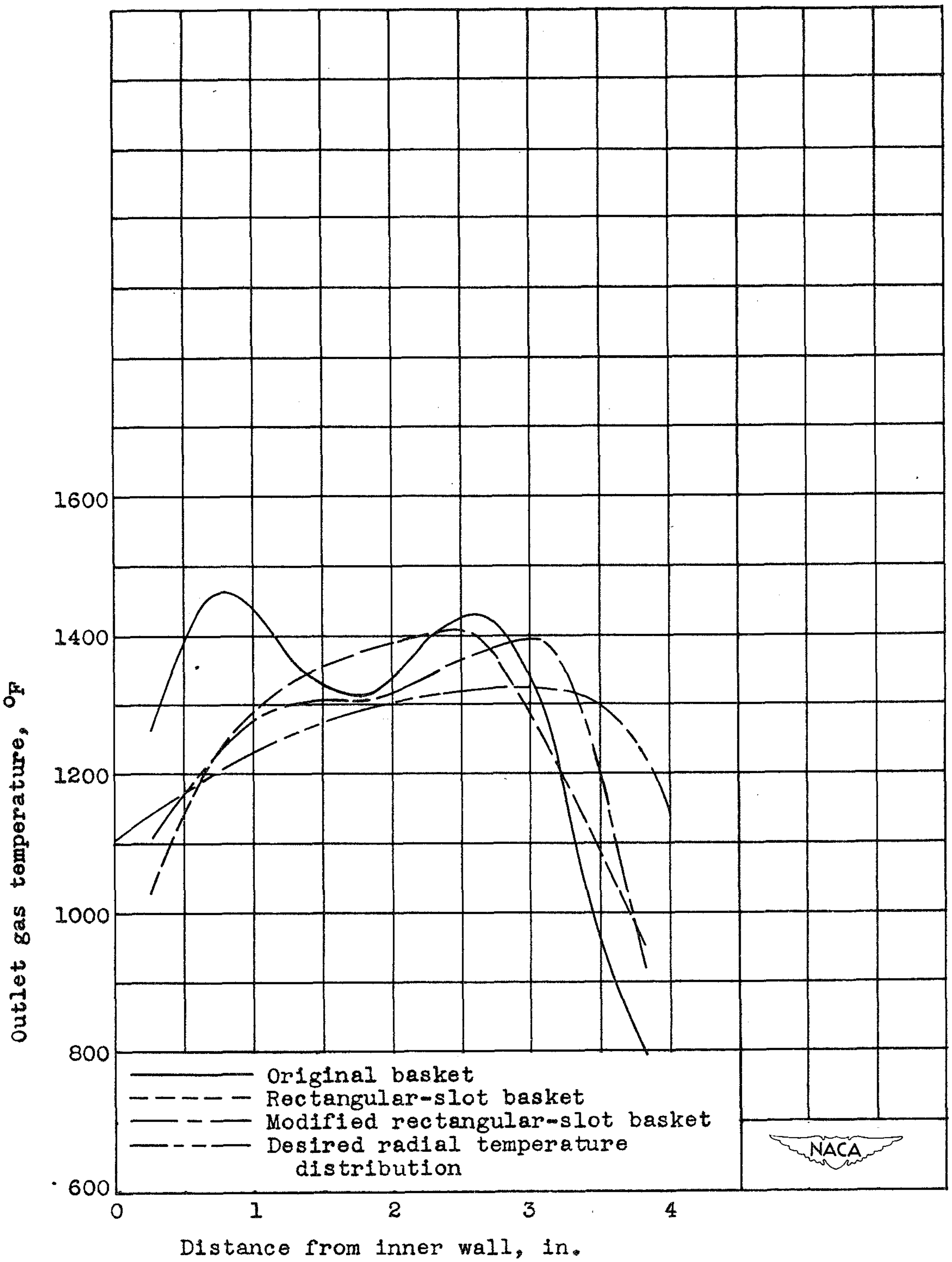
(e) Radial temperature profiles; modified rectangular-slot basket.

Figure 8. - Continued. Temperature distribution at outlet of 24C-4B combustor. Altitude, 45,000 feet; corrected engine speed, 12,500 rpm; ram-pressure ratio, 1.04.



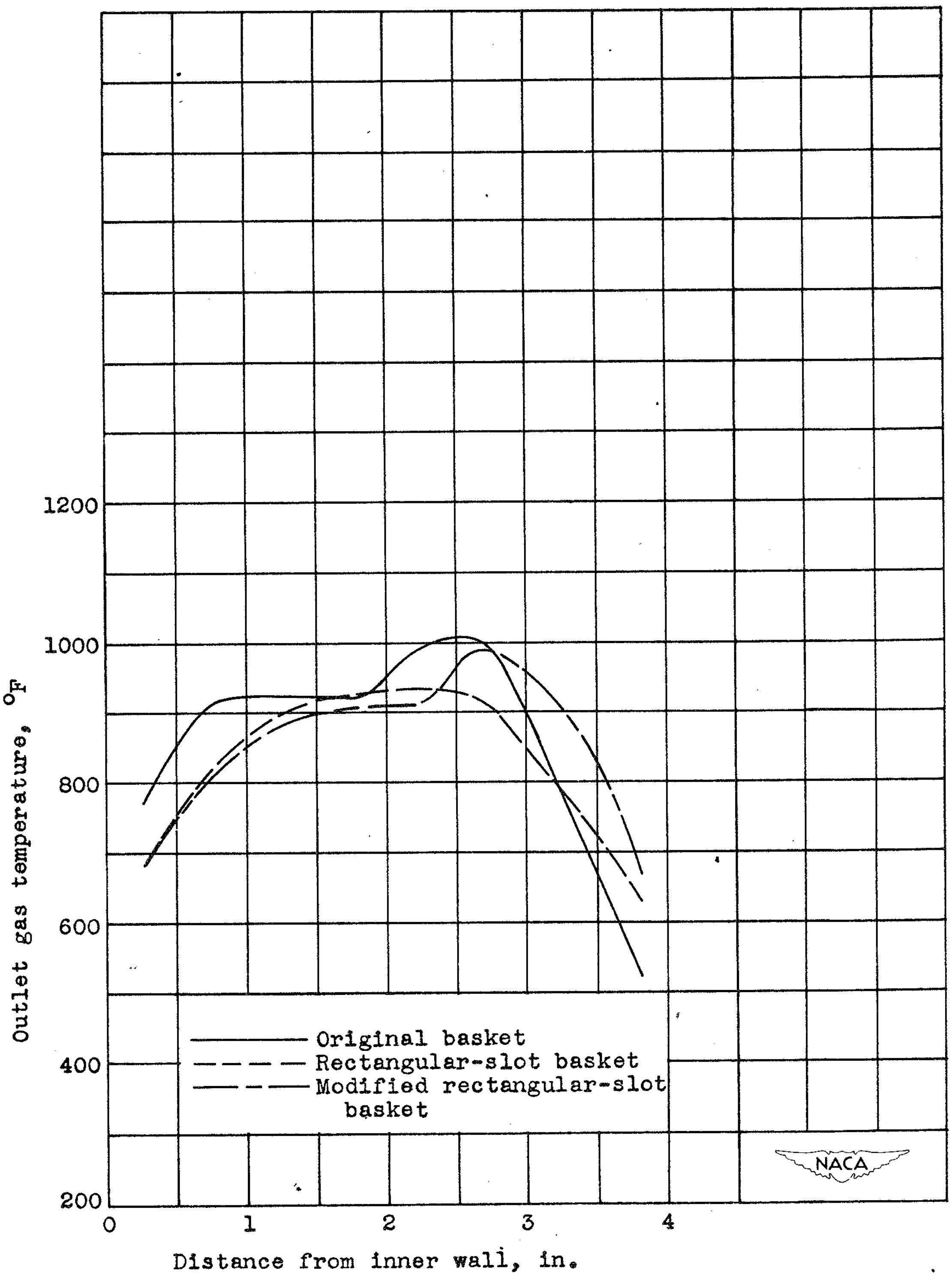
(f) Circumferential temperature distribution; modified rectangular-slot basket.

Figure 8. - Concluded. Temperature distribution at outlet of 24C-4B combustor. Altitude, 45,000 feet; corrected engine speed, 12,500 rpm; ram-pressure ratio, 1.04.



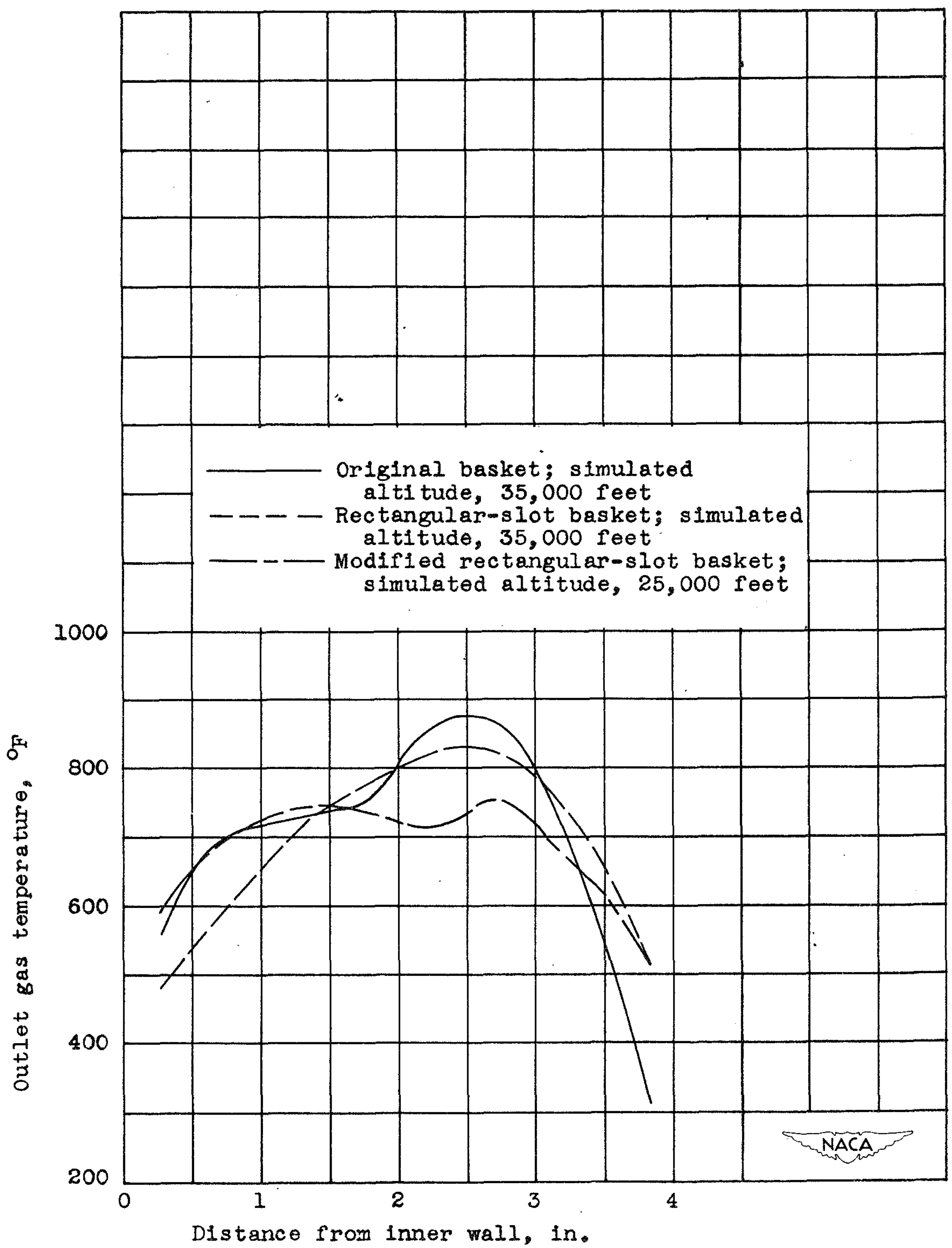
(a) Altitude, 45,000 feet; corrected engine speed, 12,500 rpm.

Figure 9. - Radial temperature profiles at outlet of 24C-4B combustor.



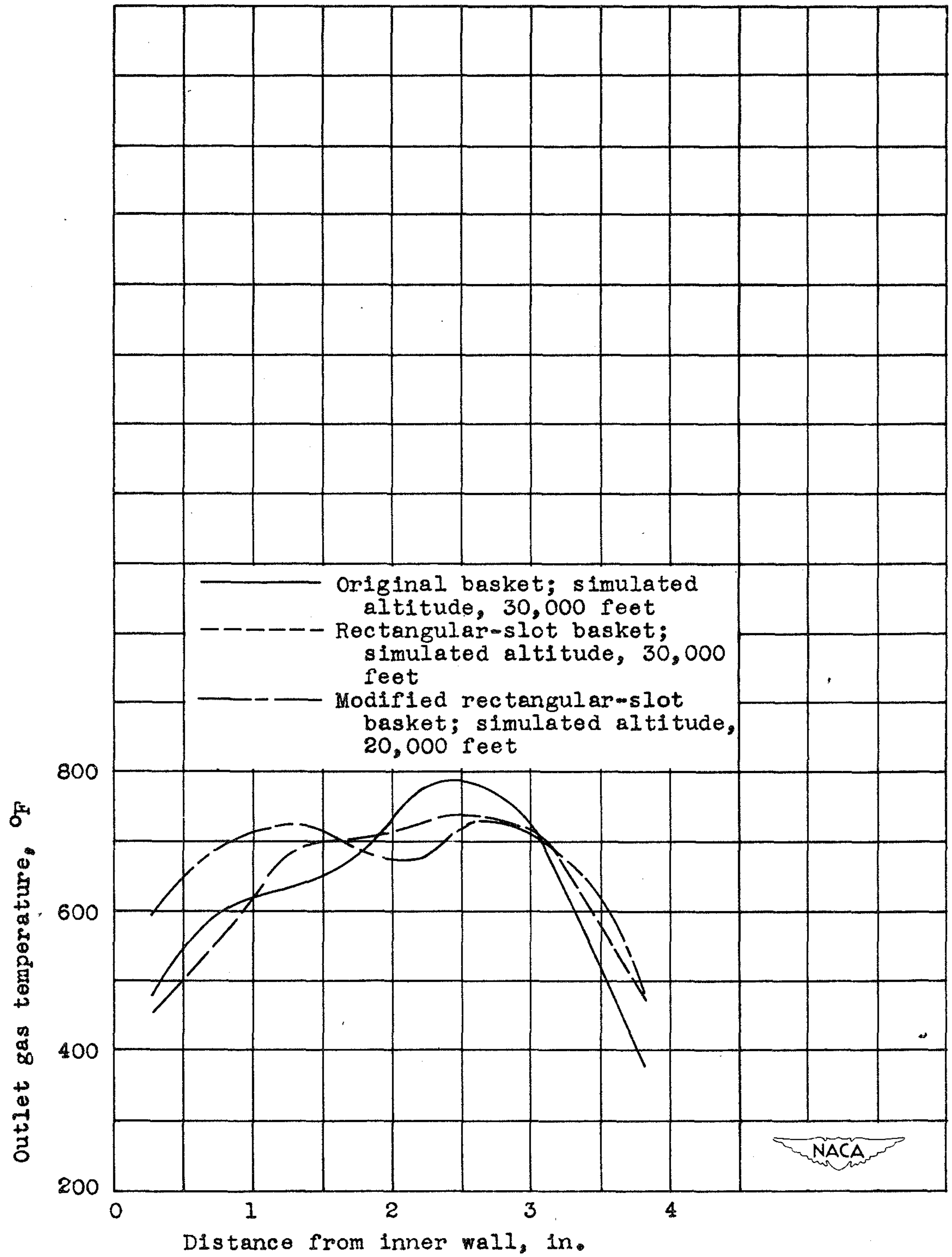
(b) Altitude, 40,000 feet; corrected engine speed, 11,000 rpm.

Figure 9. - Continued. Radial temperature profiles at outlet of 24C-4B combustor.



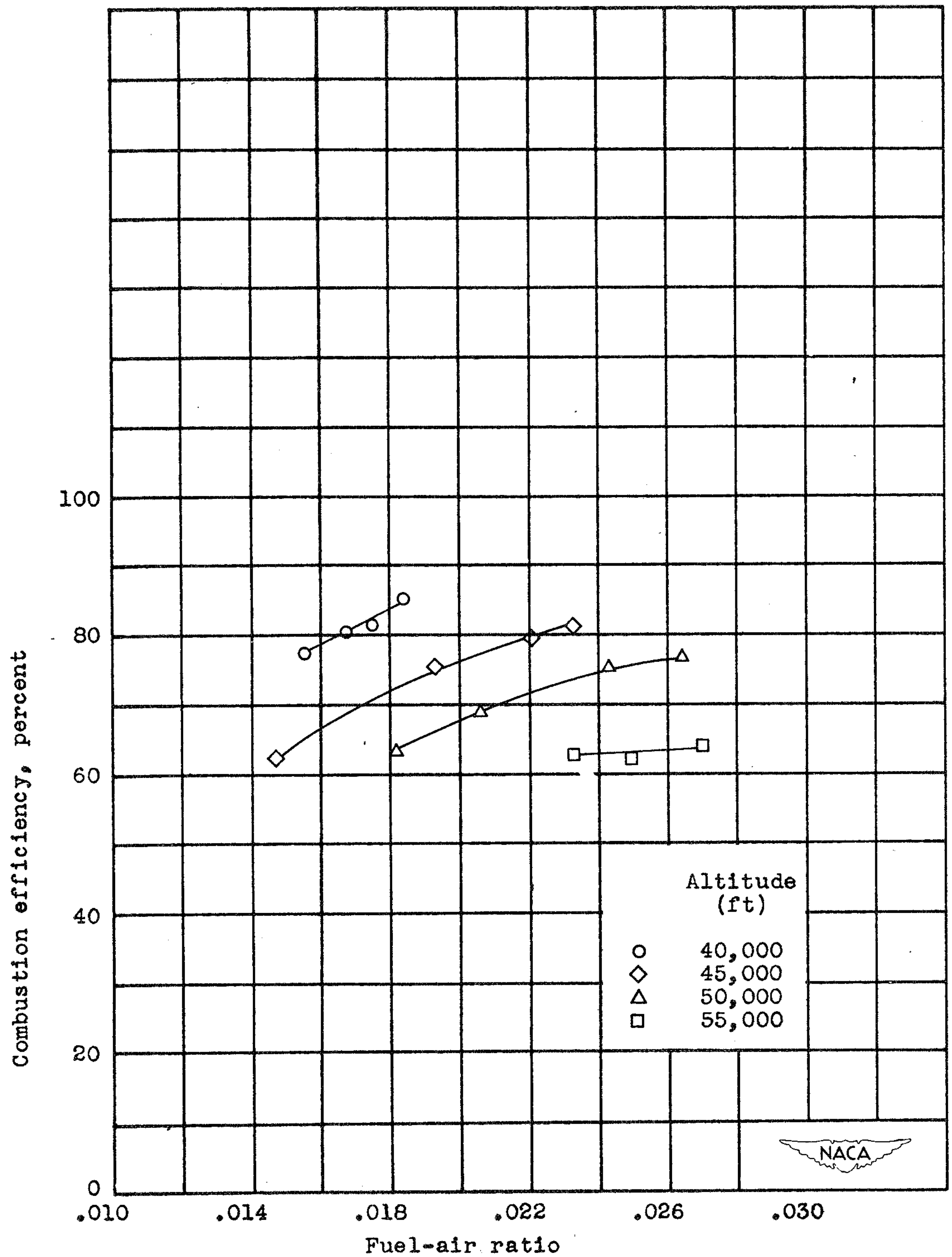
(c) Corrected engine speed, 8000 rpm.

Figure 9. - Continued. Radial temperature profiles at outlet of 24C-4B combustor.



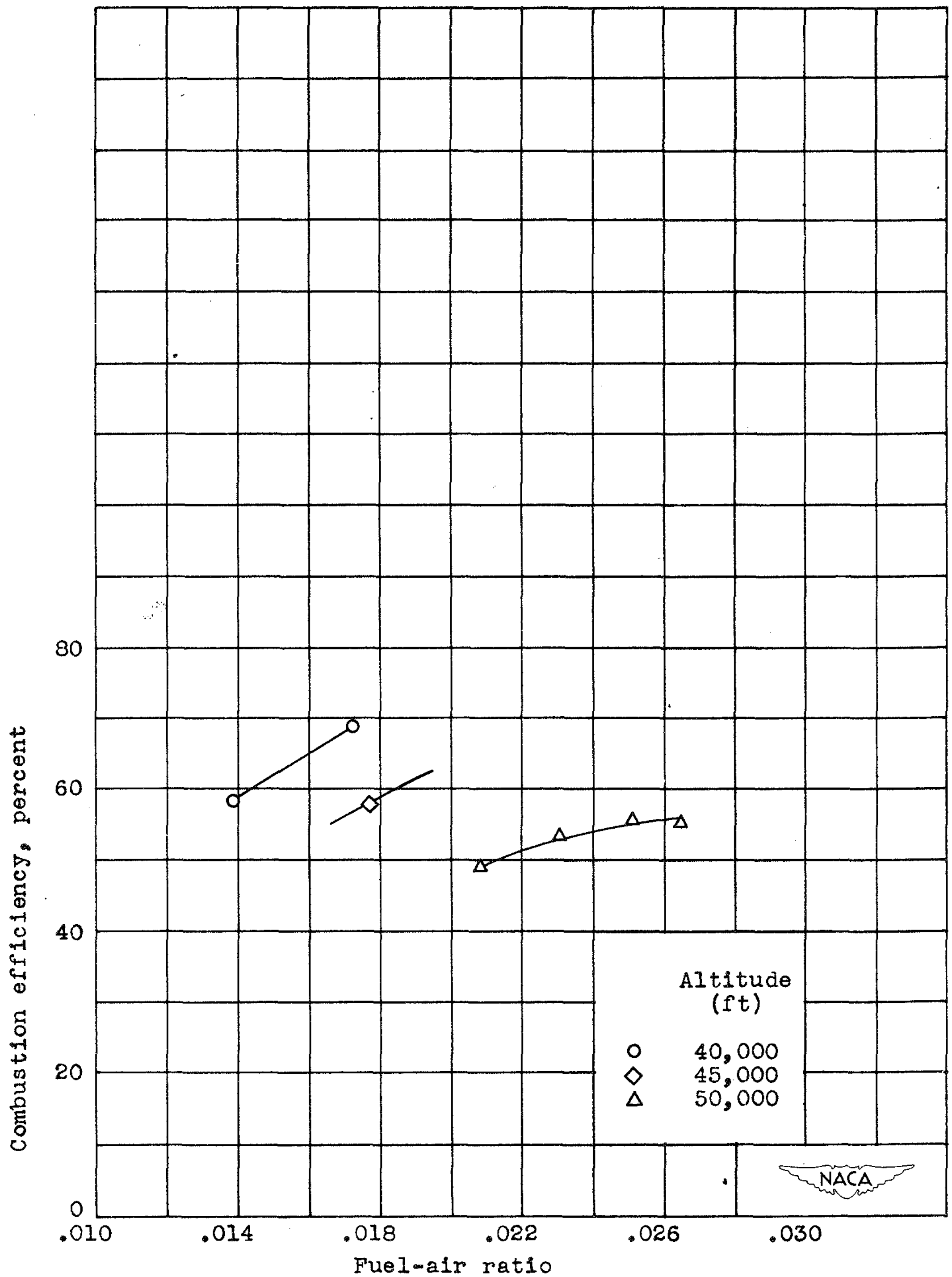
(d) Corrected engine speed, 6000 rpm.

Figure 9. - Concluded. Radial temperature profiles at outlet of 24C-4B combustor.



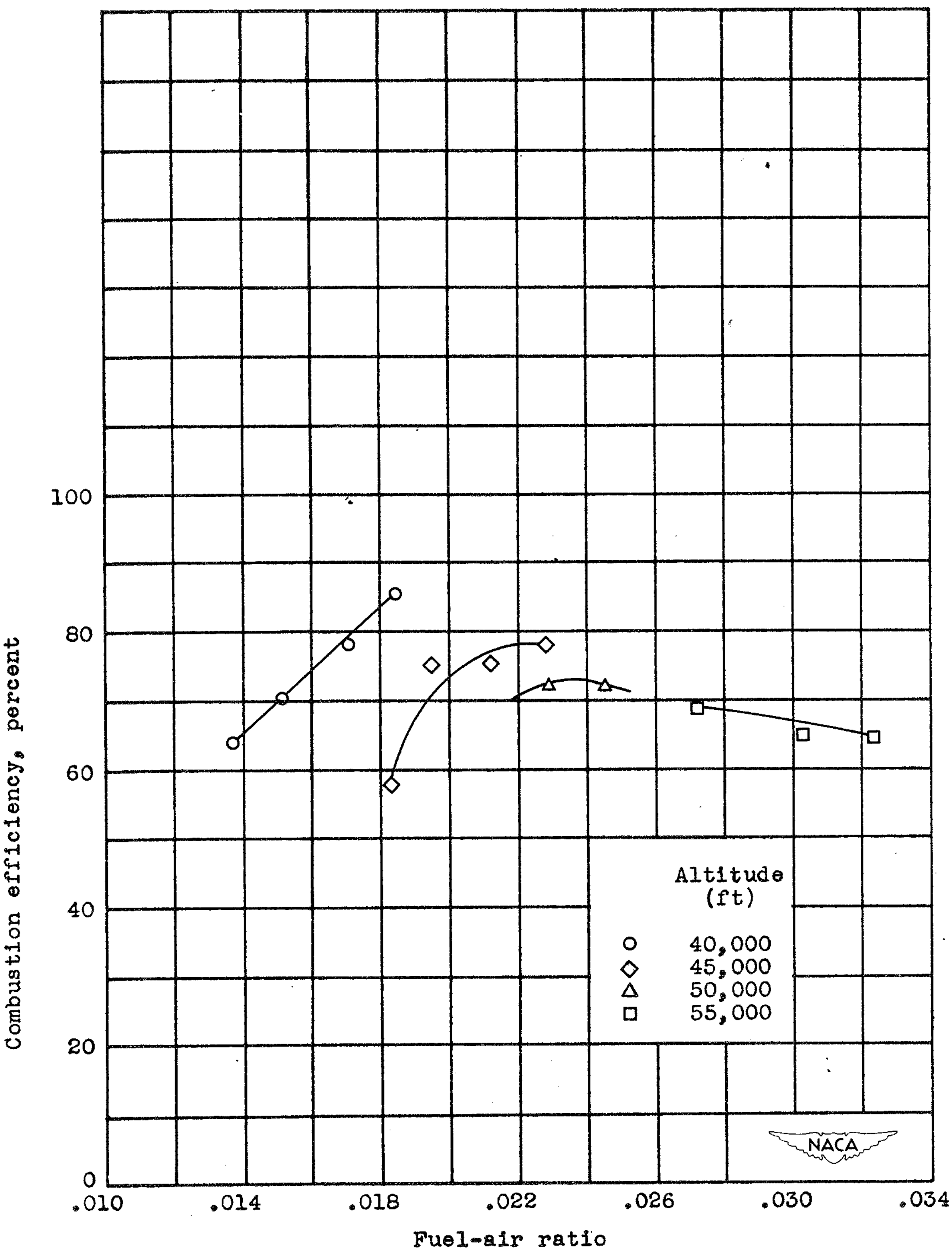
(a) Original basket; corrected engine speed, 12,500 rpm.

Figure 10. - Variation of combustion efficiency with fuel-air ratio for 24C-4B combustor.



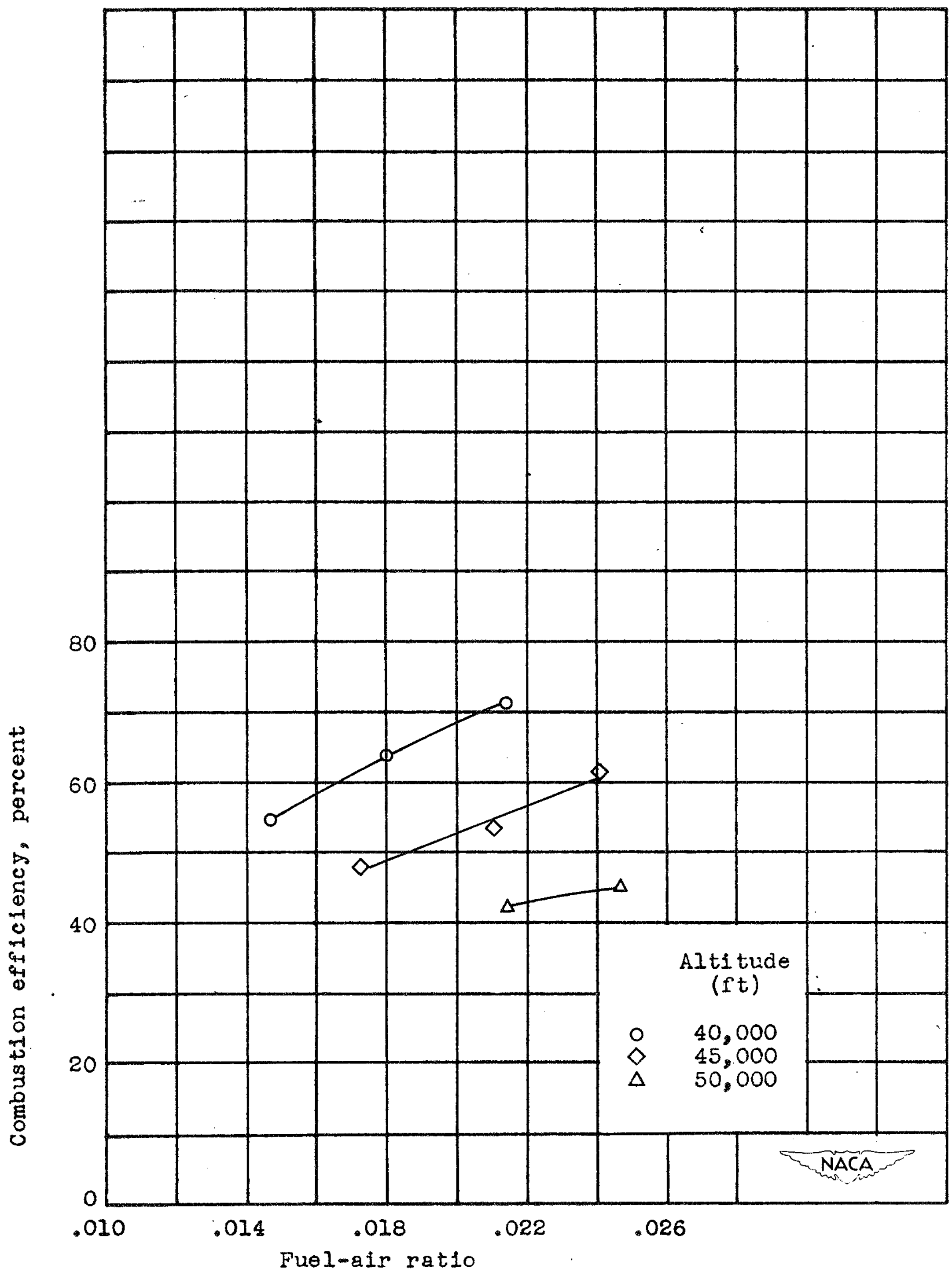
(b) Original basket; corrected engine speed, 11,000 rpm.

Figure 10. - Continued. Variation of combustion efficiency with fuel-air ratio for 24C-4B combustor.



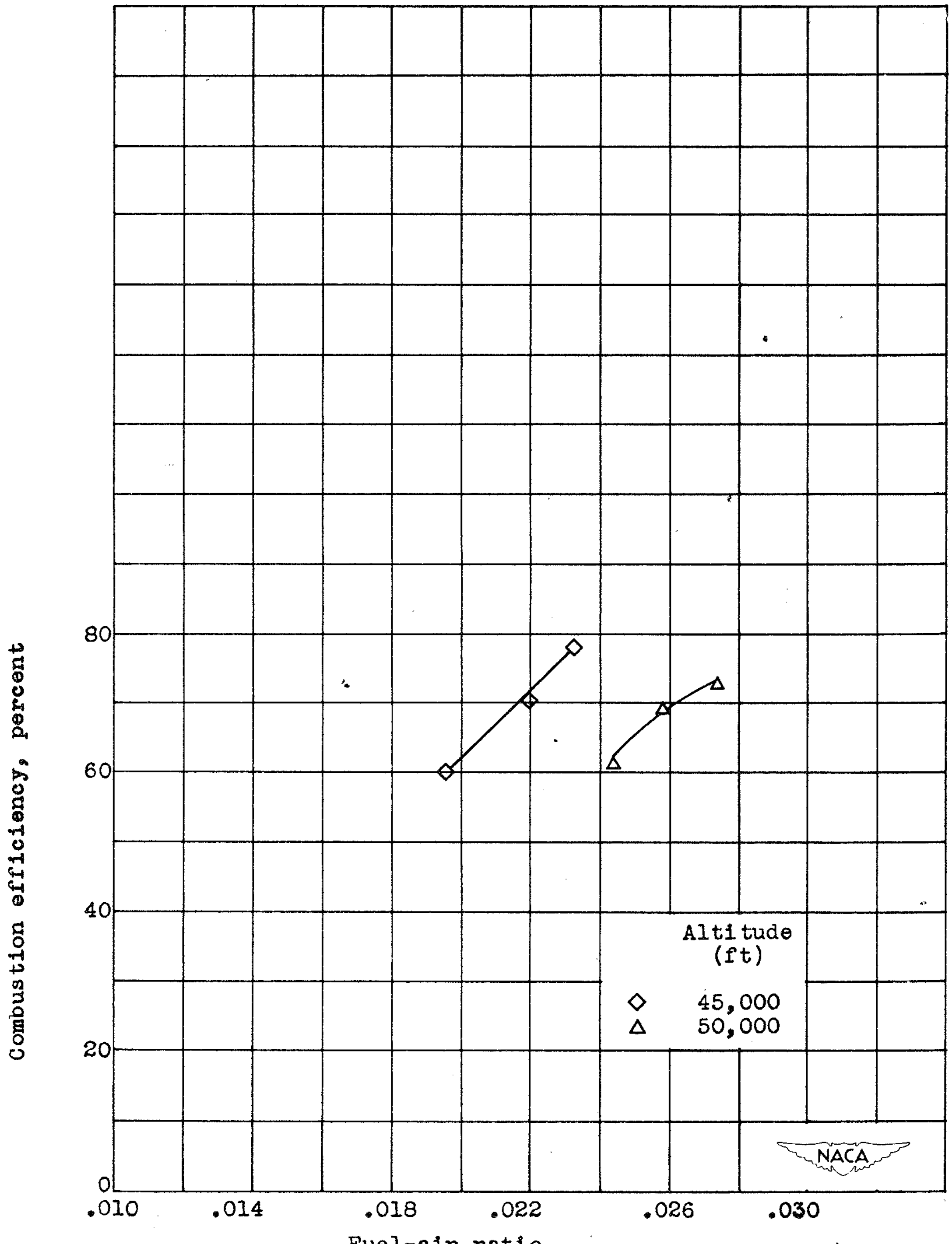
(c) Rectangular-slot basket; corrected engine speed, 12,500 rpm.

Figure 10. - Continued. Variation of combustion efficiency with fuel-air ratio for 24C-4B combustor.



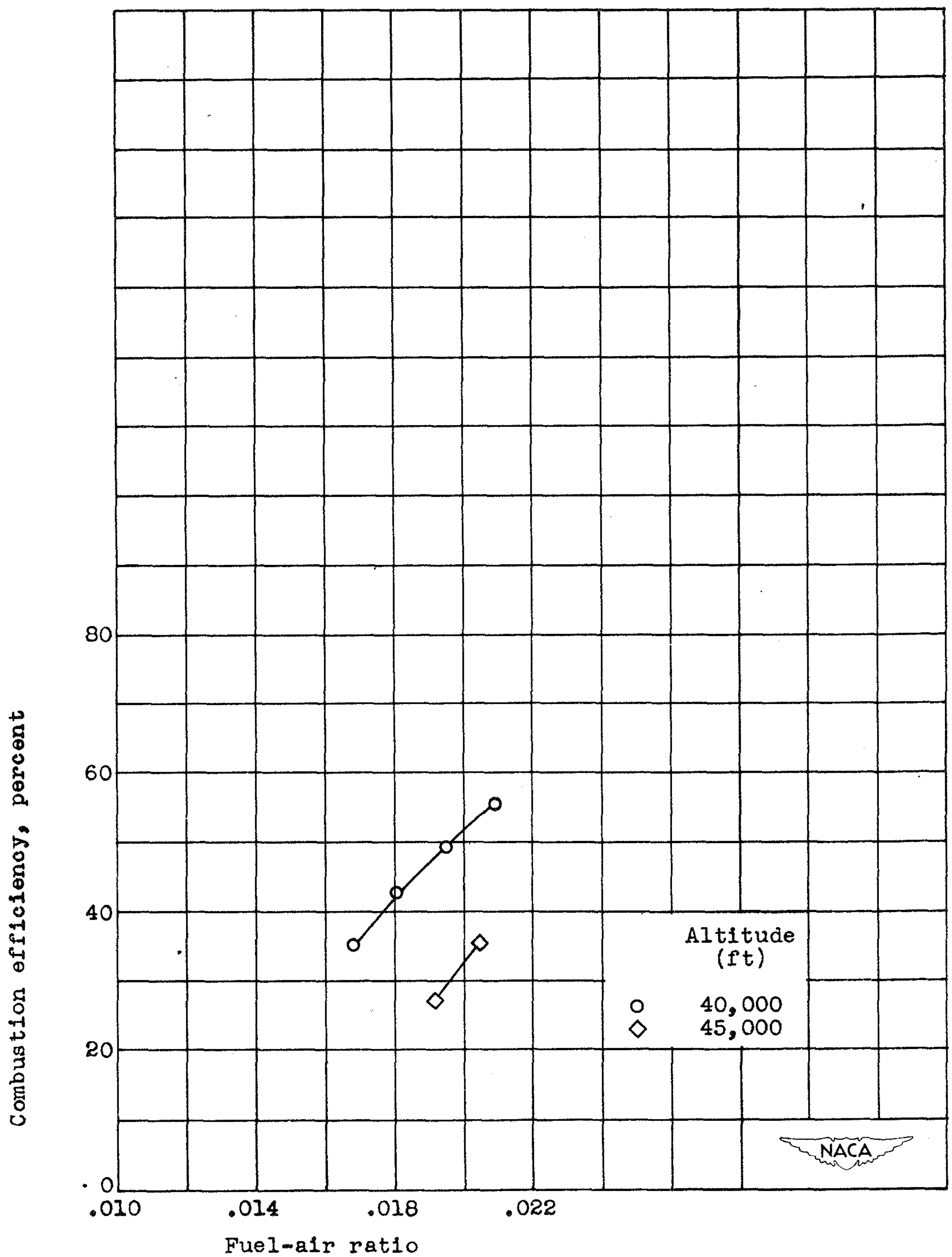
(d) Rectangular-slot basket; corrected engine speed, 11,000 rpm.

Figure 10. - Continued. Variation of combustion efficiency with fuel-air ratio for 24C-4B combustor.



(e) Modified rectangular-slot basket; corrected engine speed, 12,500 rpm.

Figure 10. - Continued. Variation of combustion efficiency with fuel-air ratio for 24C-4B combustor.



(f) Modified rectangular-slot basket; corrected engine speed, 11,000 rpm.

Figure 10. - Concluded. Variation of combustion efficiency with fuel-air ratio for 24C-4B combustor.

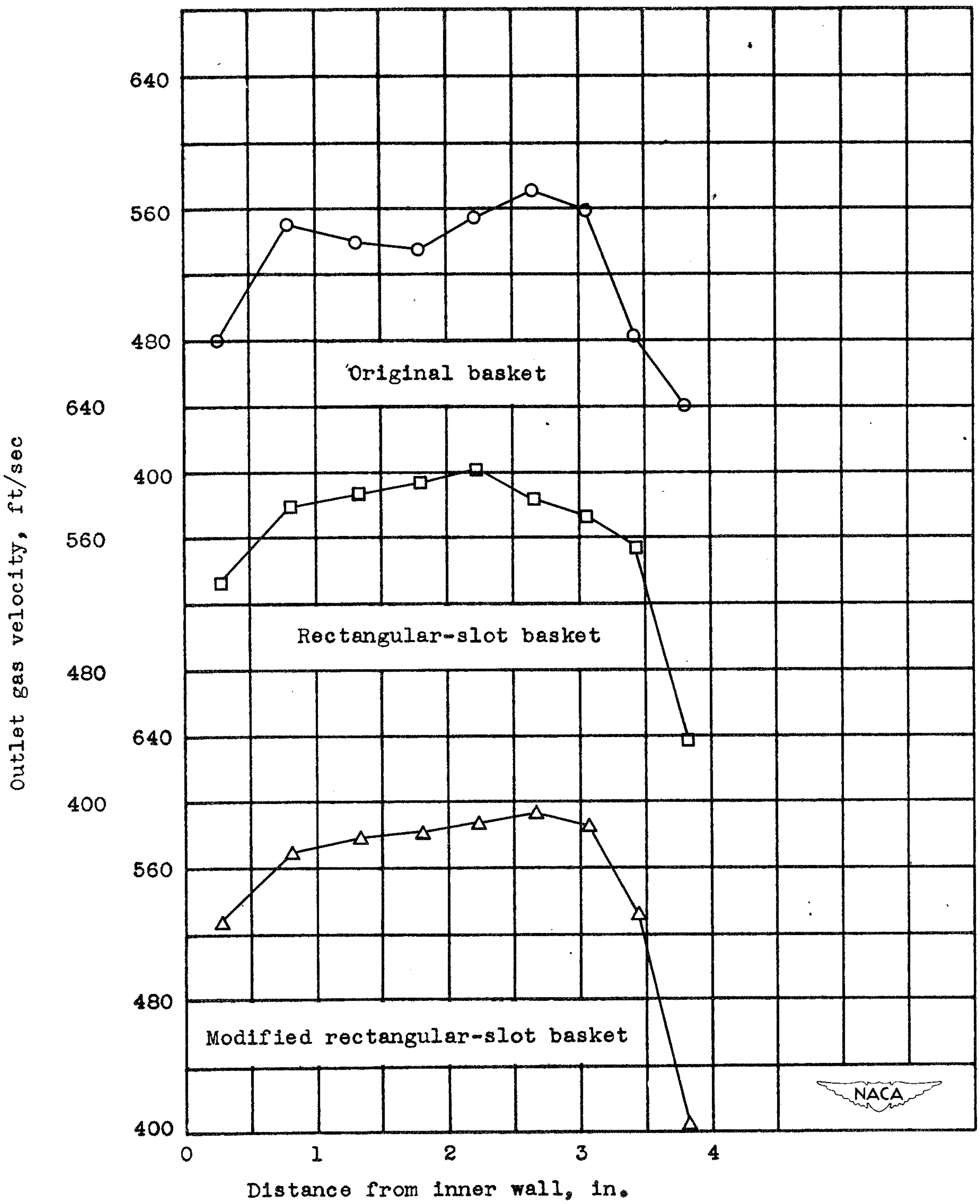


Figure 11. - Outlet gas velocity profiles for 24C-4B combustor. Altitude, 45,000 feet; corrected engine speed, 12,500 rpm.

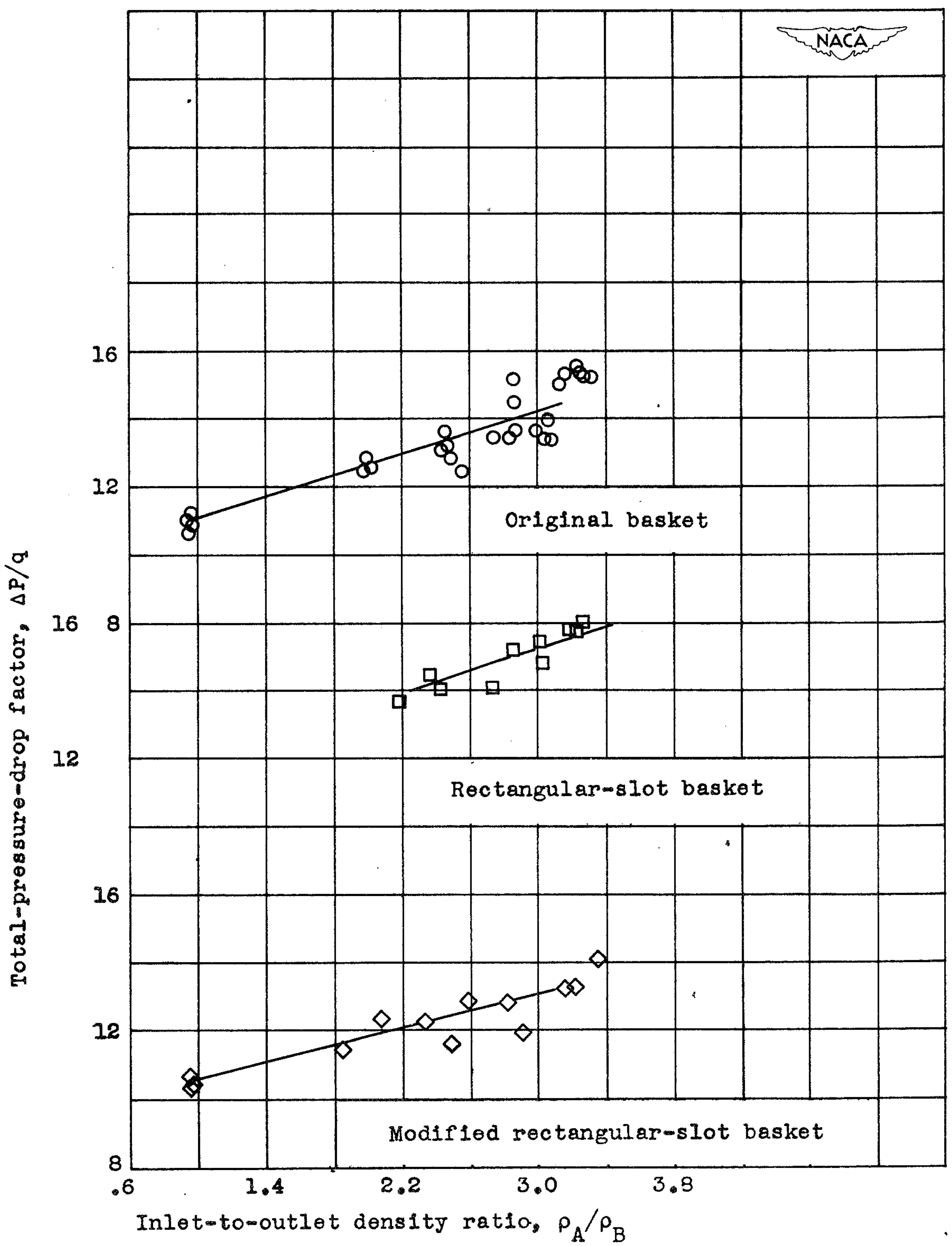


Figure 12. - Comparison of total-pressure drop in 24C-4B combustor.