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RESEARCH MEMORANDUM

INVESTIGATION OF ALTITUDE PERFORMANCE OF AN-F-58 FUELS IN ANNULAR COMBUSTOR OF J34-WE-22 ENGINE

By Adelbert O. Tischler and Wilfred E. Scull

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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INVESTIGATION OF ALTITUDE PERFORMANCE OF AN-F-58 FUELS IN ANNULAR COMBUSTOR OF J34-WE-22 ENGINE

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SUMMARY

An investigation was conducted in the combustor of a 3000-pound-thrust turbojet engine to determine the altitude performance characteristics of AN-F-58 fuels. Three fuels conforming to AN-F-58 specification were prepared in order to determine the influence of boiling-temperature range and aromatic content on altitude performance. The performance of the three AN-F-58 fuels was compared with the performance of AN-F-48 (grade 100/130) fuel in the range of simulated altitudes from 20,000 to 55,000 feet, corrected engine speeds from 6000 to 12,500 rpm, and flight Mach numbers of 0.2 and 0.6.

At a flight Mach number of 0.2, the altitude limits of two AN-F-58 fuels were the same and about 1000 to 3000 feet higher than the limits of AN-F-48 fuel over the range of engine speeds examined. The altitude operational limit of the AN-F-58 fuel having a higher boiling-temperature range and a higher aromatic content than the other two AN-F-58 fuels was 1000 to 7000 feet lower than the limits of the other two AN-F-58 fuels over the range of engine speeds investigated. At a Mach number of 0.6, the altitude limits of the three AN-F-58 fuels and the AN-F-48 fuel were approximately the same.

At any fixed operating condition, the combustion efficiency decreased as the volumetric average boiling temperature of the fuel increased. The arithmetical differences in combustion efficiency between the most volatile fuel (AN-F-48) and the least volatile AN-F-58 fuel were as great as 12 to 14 percent at some conditions near the altitude operational limit.

Light deposits of carbon were found with two AN-F-58 fuels and no deposits were found with the AN-F-48 fuel. The third AN-F-58 fuel having a high boiling-temperature range and high aromatic content produced formations of carbon on the first step of the combustor basket. These deposits, although not considered sufficiently large to be objectionable, were considerably greater than the deposits obtained with the other fuels.

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INTRODUCTION

The potential availability of AN-F-32 fuels for jet-propulsion engines is limited because of restrictions in boiling range and composition. In order to increase the potential supply of fuel for jet-propulsion engines a new specification, AN-F-58, which has wider limits, has been proposed. A comprehensive program was undertaken at the NACA Lewis laboratory to determine the performance characteristics of fuels conforming to the AN-F-58 specification in current turbojet engines and combustors from these engines.

In the combustor investigations, special attention was given to the influence of physical properties of AN-F-58 fuels on combustor performance in order to determine whether the limitations on physical properties in the proposed specification are too liberal or too restrictive. The effects of boiling-temperature range and aromatic concentration within the AN-F-58 specification on altitude performance in the combustor of a 3000-pound-thrust (J34-WE-22) turbojet engine are presented. Combustion efficiencies and altitude operational limits were determined in the range of simulated altitudes from 20,000 to 55,000 feet, corrected engine speeds from 6000 to 12,500 rpm, and flight Mach numbers of 0.2 and 0.6.

Comparisons of AN-F-58 fuels with an AN-F-48 fuel (grade 100/130) were also made at these conditions.

FUELS

Specifications for and analyses of the AN-F-58 fuels and the AN-F-48, Amendment-3, fuel (NACA fuel 48-359) used in this investigation are presented in table I.

Three fuels conforming to AN-F-58 specification were used. The first of these (NACA fuel 48-249) was a uniform mixture of several tank-car lots of AN-F-58 fuel as received from the supplier. For purposes of this investigation, this fuel, which boiled between 110° and 560° F and contained 19 percent aromatics, was considered a base stock. A second AN-F-58 fuel (NACA fuel 48-258) was prepared by blending 92 percent of the base stock with 8 percent of a number 3 fuel oil. The resulting blend boiled between 110° and 590° and contained 19 percent aromatics. This blend is hereinafter identified as the high-end-point fuel. Comparisons of these two fuels (NACA fuels 48-249 and 48-258) were intended to indicate the effect of fuel boiling temperatures on turbojet-engine performance.

A third AN-F-58 fuel (NACA fuel 48-279) was prepared by blending 79 percent of the base stock with 13 percent redistilled hydroformate bottoms and 8 percent number 3 fuel oil. The resulting blend boiled between 110° and 590° F and contained 29 percent aromatics. This blend is hereinafter identified as the high-aromatic fuel. Comparisons of this fuel (NACA fuel 48-279) with NACA fuel 48-258 were intended to indicate the influence of aromatic content. Because of the manner in which the blend (NACA fuel 48-279) was made, however, the boiling temperatures (table I) were changed as well as the aromatic content. As shown in table I, NACA fuel 48-279 approaches the maximum limit of the specification with respect to aromatic content and final boiling temperature.

Inasmuch as the silica-gel determination for aromatic content (table I) is considered more reliable than A.S.T.M. determinations for AN-F-58 fuels, all aromatic concentrations referred to were determined by the silica-gel method.

APPARATUS

Setup

A diagram of the general setup is shown in figure 1. Combustion air, low-pressure exhaust, and fuel were supplied by the laboratory facilities. Combustion-air flow was metered with a variable-area orifice and the air flow and the combustor-inlet-air pressure were controlled by means of butterfly regulating valves in the air-supply and exhaust lines. 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

A longitudinal section of the J34-WE-22 combustor and the immediate auxiliary ducting and instrumentation planes are shown in figure 2(a). The fuel-manifold housing, the fuel spray nozzles, 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 outlet. 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. The combustor basket was a rectangular slot basket having enlarged anticoking holes in the upstream face of the basket. 1079

Instrumentation

Temperature and pressure-measuring instrumentation was installed at the two sections shown in figure 2(a). 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 is illustrated in figure 2(b). 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-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.

Fuel flows were measured with a rotameter separately calibrated for each fuel. The combustion efficiency is defined as the average gas-temperature rise through the combustor to the temperature rise theoretically obtainable at the same fuel-air ratio.

PROCEDURE

The altitude performance of the combustor using four different fuels was investigated with the combustor-inlet conditions of air flow, pressure, and temperature simulating operation of the turbojet engine at various altitudes from 20,000 to 55,000 feet over a range of corrected engine speeds from 6000 to 12,500 rpm and for flight Mach numbers of 0.2 and 0.6, corresponding to ram pressure ratios of 1.04 and 1.28, respectively, with 100-percent diffuser efficiency.

The combustor-inlet conditions of air flow, pressure, and temperature and the values of the estimated combustor-outlet (turbine-inlet) temperature required to operate the engine for each altitude and engine speed for a flight Mach number of 0.2 were based on data obtained in an altitude-wind-tunnel investigation of the complete engine. At a flight Mach number of 0.6, inlet-air conditions were calculated on the basis of 100-percent ram recovery. The combustor-inlet and combustor-outlet conditions

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for flight Mach numbers of 0.2 and 0.6 are plotted in figure 3 against corrected engine speed $N/\sqrt{\theta}$, where θ is the ratio of ambient-air temperature at altitude to ambient sea-level temperature.

After ignition in the combustor, the air flow and the inlet-air temperature and pressure were set at the required values of simulated flight conditions at altitude intervals of 10,000 feet at four engine speeds. At each point the fuel flow was increased by increments in an effort to achieve an average combustor-outlet temperature equal to or in excess of that required for operation of the turbojet engine at the simulated flight condition. Simulated flight conditions at which the required combustor-outlet temperature could be obtained were considered to be in the operable range of the engine. Conditions at which the required combustor-outlet temperature could not be obtained were considered to be in the inoperable range.

In order to evaluate the relative carbon-deposition rates of the AN-F-58 fuels in the combustor, the unit was operated at simulated conditions of 35,000-foot altitude and corrected engine speed of 12,500 rpm (87 percent of rated engine speed) at a flight Mach number of 0.2 for 6-hour uninterrupted periods with each fuel. The combustor basket was brushed clean before each run and the combustor disassembled and inspected for carbon deposits at the conclusion of each run.

DISCUSSION OF RESULTS

Altitude Operational Limits

The data obtained in the investigation of the four fuels are shown in figure 4 as plots of altitude against corrected engine speed for flight Mach numbers of 0.2 and 0.6. The curves shown in this figure represent the altitude limits of the fuels. The position of the altitude limit was estimated from the excess of available temperature rise at each operable point.

In order to simplify the comparison of altitude operational limits for the four fuels, the curves from figure 4 have been replotted in figure 5. Differences in altitude operational limit less than 2000 feet are difficult to determine experimentally because of the unstable and often erratic performance of the combustor at points near the altitude limit. Each of the curves in figures 4 and 5 should therefore be considered a mean curve drawn through a band of altitude in which the operation of the engine is uncertain. As shown in figure 5, the altitude operational limits for NACA fuels 48-249 and 48-258 are the same.

At a flight Mach number of 0.2 (fig. 5(a)), the altitude limits of the base-stock AN-F-58 fuel (NACA fuel 48-249) and the high-end-point AN-F-58 fuel (NACA fuel 48-258) were the same and about 1000 to 3000 feet higher than the limits of AN-F-48 fuel over 1079
the range of engine speeds investigated in spite of lower combustion efficiencies obtained with the AN-F-58 fuel. Higher altitude limits with lower combustion efficiencies have been previously observed with different fuels in an annular-type combustor (reference 1). The altitude operational limit of the high-aromatic AN-F-58 fuel (NACA fuel 48-279) was 1000 to 7000 feet lower than the limits for the other AN-F-58 fuels.

At a flight Mach number of 0.6 (fig. 5(b)), the altitude operational limits for all four fuels were about the same over the range of engine speeds examined.

Combustion Efficiencies

The combustion efficiencies for all points in the operable range of figure 4 are presented in table II.

Previous investigations (references 2 and 3) have indicated that combustion efficiencies of various fuels may be correlated with volumetric average boiling temperatures of the fuels. This correlation appears to apply to data obtained in the present investigation, as may be seen in figure 6. In this figure, the combustion efficiencies for the three AN-F-58 fuels and the AN-F-48 fuel have been plotted against volumetric average boiling temperatures at flight Mach numbers of 0.2 and 0.6, an altitude of 45,000 feet, and a corrected engine speed of 12,500 rpm. These data indicate that the combustion efficiency decreases as the boiling temperature of the fuel is increased. The arithmetical differences in combustion efficiency (fig. 6) between the most volatile fuel (AN-F-48) and the least volatile fuel (high-aromatic AN-F-58 fuel, NACA fuel 48-279) at the specified altitude and engine speed were 9 and 12 at Mach numbers of 0.2 and 0.6, respectively. This difference in efficiency changes with change in operating conditions. In general, the combustion efficiencies of the AN-F-58 fuels were about 8 percent lower than those of the AN-F-48 fuel in the vicinity of the altitude operational limit. As the operational altitude is reduced, the combustor efficiencies of the several fuels increase and tend to approach each other.

Similar data at other conditions (table II) substantiate the relation shown in figure 6 and the arithmetical differences in combustion efficiency between the least volatile fuel and the AN-F-48 fuel were for the conditions investigated never greater than 14 percent.

It is emphasized that the manner of preparing the AN-F-58 fuels for this investigation was such that both boiling temperature and composition (particularly aromatic content) were varied. The correlations shown in figure 6 therefore essentially represent the influence of both boiling temperatures and composition on combustion efficiency.

Carbon Deposition

Only small amounts of carbon were deposited at the conditions used in this investigation with the base-stock AN-F-58 fuel (NACA fuel 48-249) and the high-end-point AN-F-58 fuel (NACA fuel 48-258) and these deposits were merely thin scales deposited on the first step of the combustor basket. With the high-aromatic AN-F-58 fuel (NACA fuel 48-279), however, formations of carbon (fig. 7) were deposited on the first step of the basket. These deposits although not considered sufficiently large to be objectionable were considerably greater than the deposits obtained with the other AN-F-58 fuels (NACA fuels 48-249 and 48-258).

No deposits were obtained with AN-F-48 fuel.

SUMMARY OF RESULTS

From an investigation of the effects of fuel properties on altitude performance in the combustor of a 3000-pound-thrust turbojet engine, the following results were obtained at simulated engine conditions of 20,000- to 55,000-foot altitudes, corrected engine speeds from 6000 to 12,500 rpm, and flight Mach numbers of 0.2 and 0.6.

1. At any fixed operating condition, the combustion efficiency decreased as the volumetric average boiling temperature of the fuel increased. The arithmetical differences in combustion efficiency between the most volatile fuel, AN-F-48, and the least volatile AN-F-58 fuel was as great as 12 to 14 percent at some conditions near the altitude operational limit.

2. At a flight Mach number of 0.2, the altitude limits of two AN-F-58 fuels were the same and about 1000 to 3000 feet higher than the limits of AN-F-48 fuel over the range of engine speeds examined. The altitude operational limit of the AN-F-58 fuel having a higher boiling-temperature range and a higher aromatic content than the other two AN-F-58 fuels was 1000 to 7000 feet lower than the limits of the other AN-F-58 fuels over the range of engine speeds investigated.

3. At a flight Mach number of 0.6, the altitude limits of the three AN-F-58 fuels and the AN-F-48 fuel were approximately the same.

4. Light deposits of carbon were found with two AN-F-58 fuels and no deposits were found with the AN-F-48 fuel. The AN-F-58 fuel having a high boiling-temperature range and high aromatic content produced formations of carbon on the first step of the combustor basket. These deposits, although not considered sufficiently large to be objectionable, were considerably greater than the deposits obtained with the other fuels.

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National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. McCafferty, Richard J.: Effect of Fuels and Fuel-Nozzle Characteristics on Performance of an Annular Combustor at Simulated Altitude Conditions. NACA RM No. E8C02a, 1948.

2. Tischler, Adelbert O., and Dittrich, Ralph T.: Fuel Investigation in a Tubular-Type Combustor of a Turbojet Engine at Simulated Altitude Conditions. NACA RM No. E7F12, 1947.

3. Dittrich, Ralph T.: Combustion-Efficiency Investigation of Special Fuels in Single Tubular-Type Combustor at Simulated Altitude Conditions. NACA RM No. E7F11, 1947.

TABLE I - SPECIFICATIONS AND ANALYSES OF FUELS USED

NACA fuel	Specifications AN-F-58	Analyses			
		AN-F-58			AN-F-48
		48-249	48-258	48-279	48-359
A.S.T.M. distillation D 86-40, °F					
Initial boiling point	-----------	110	110	110	105
Percentage evaporated					
5	-----------	135	137	133	130
10	-----------	157	157	164	144
20	-----------	192	198	215	162
30	-----------	230	248	273	178
40	-----------	272	291	327	191
50	-----------	314	332	370	202
60	-----------	351	373	407	210
70	-----------	388	410	437	219
80	-----------	427	450	464	225
90	425 (min.)	473	500	501	236
Final boiling point	600 (max.)	560	590	590	299
Residue, (percent)	1.5 (max.)	1.0	1.0	1.0	0.5
Loss, (percent)	1.5 (max.)	1.0	1.0	1.0	1.5
Freezing point, °F	-76 (max.)	<-76	<-76	<-76	<-76
Accelerated gum, (mg/100 ml)	20 (max.)	2.9	12.4	17.3	4.4
Air-jet residue, (mg/100 ml)	10 (max.)	2.6	4.8	8.0	--------
Sulfur, (percent by weight)	0.50 (max.)	0.03	0.04	0.04	<0.005
Aromatics, (percent by volume) A.S.T.M. D-875-46T	30 (max.)	17	17	26	7.5
Silica gel	-----------	19	19	29	6
Specific gravity	-----------	0.769	0.775	0.806	0.704
Viscosity, (centistokes at -40° F	10.0 (max.)	2.67	2.94	4.26	--------
Bromine number	14.0 (max.)	13.8	13.3	12.4	5.6
Reid vapor pressure, (lb/sq in.)	5-7	5.4	5.1	4.8	6.6
Hydrogen-carbon ratio	-----------	0.163	0.161	0.150	0.184
Net heat of combustion (Btu/lb)	18,200 (min.)	18,640	18,690	18,480	18,980
Hydrocarbon analyses (percent by volume)					
Single ring aromatics		15.0	13.2	14.8	--------
Fused ring aromatics		3.0	4.1	12.8	--------
Unfused two-ring aromatics		0.5	1.5	1.4	--------
Olefin		7.1	6.2	5.3	--------
Nonaromatic cyclo-paraffin ring		15.7	16.7	14.3	--------
Nonaromatic paraffin and paraffin side chain		58.7	58.3	51.4	--------

[redacted]

TABLE II - COMBUSTION EFFICIENCIES IN VICINITY OF ALTITUDE OPERATIONAL LIMIT

Altitude (ft)	Corrected engine speed $N/\sqrt{\theta}$ (rpm)	Flight Mach number	Combustion efficiency (percent)			
			AN-F-58			AN-F-48
			NACA fuel 48-249	NACA fuel 48-258	NACA fuel 48-279	NACA fuel 48-359
20,000	6000	0.2	44.0	42.1	40.3	50.3
25,000	6000	0.2	38.7	38.1	37.9	44.6
	8000	.2	47.8	46.1	44.0	55.8
	8000	.6	50.4	--------	--------	56.3
35,000	11,000	0.2	55.3	--------	50.9	61.4
	12,500	.2	67.7	66.9	65.3	79.5
	11,000	.6	58.0	52.6	54.5	66.4
45,000	11,000	0.2	46.5	47.5	--------	55.5
	12,500	.2	68.2	67.8	63.9	73.3
	11,000	.6	--------	49.5	49.3	57.9
	12,500	.6	68.0	65.0	65.2	77.2

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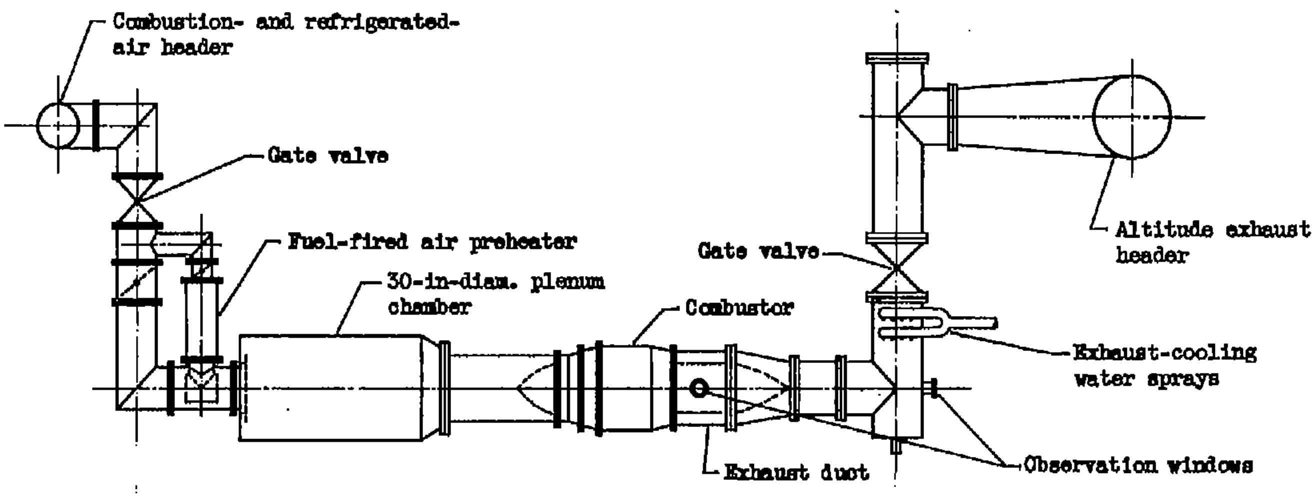
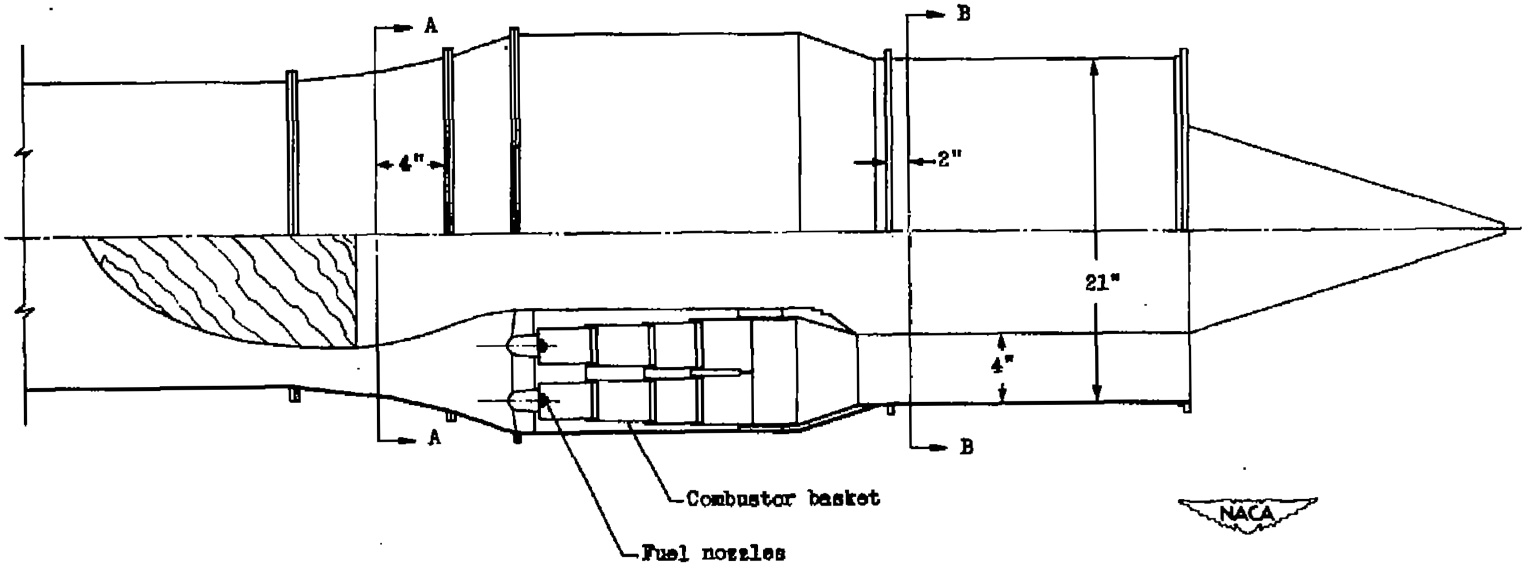
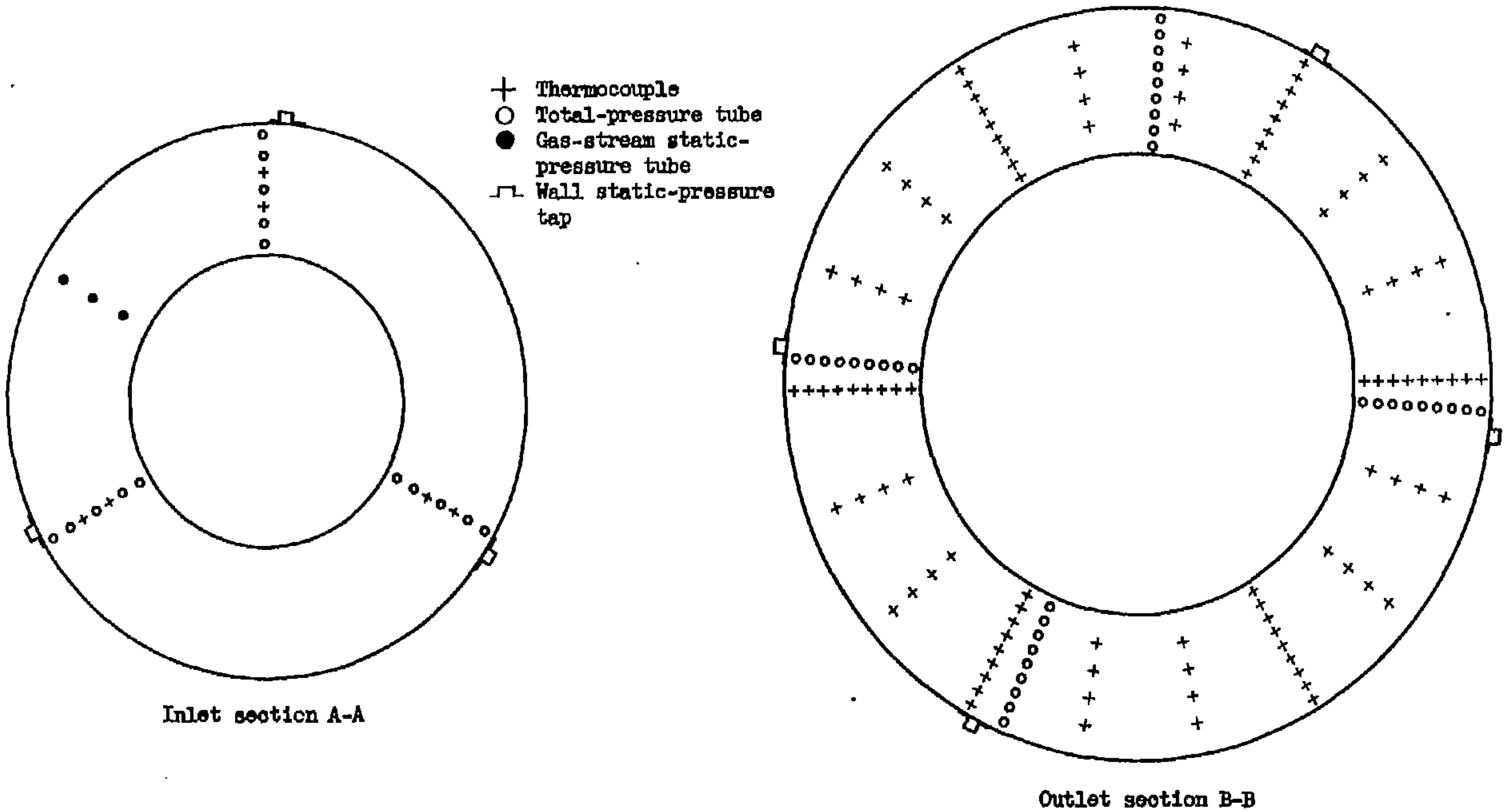


Figure 1. - Diagrammatic sketch of combustor setup.



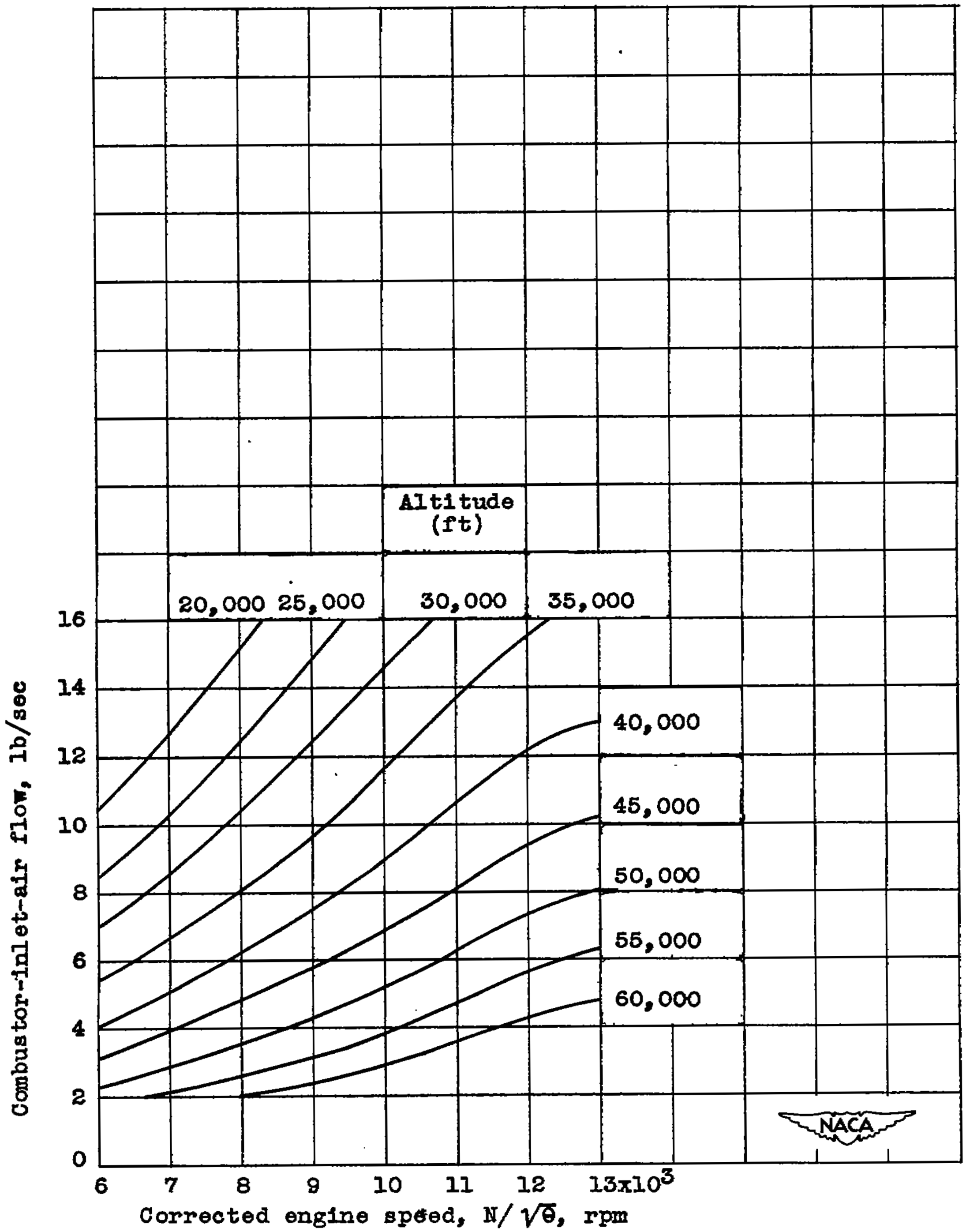
(a) Longitudinal half section of combustor.

Figure 2. - Longitudinal half section of combustor showing adjoining ducting and planes of instrumentation.



(b) Instrumentation of combustor.

Figure 2. - Concluded. Longitudinal half section of combustor showing adjoining ducting and planes of instrumentation.



(a) Combustor-inlet-air flow. Flight Mach number, 0.2.

Figure 3. - Variation of combustor operating conditions with corrected engine speed at various altitudes.

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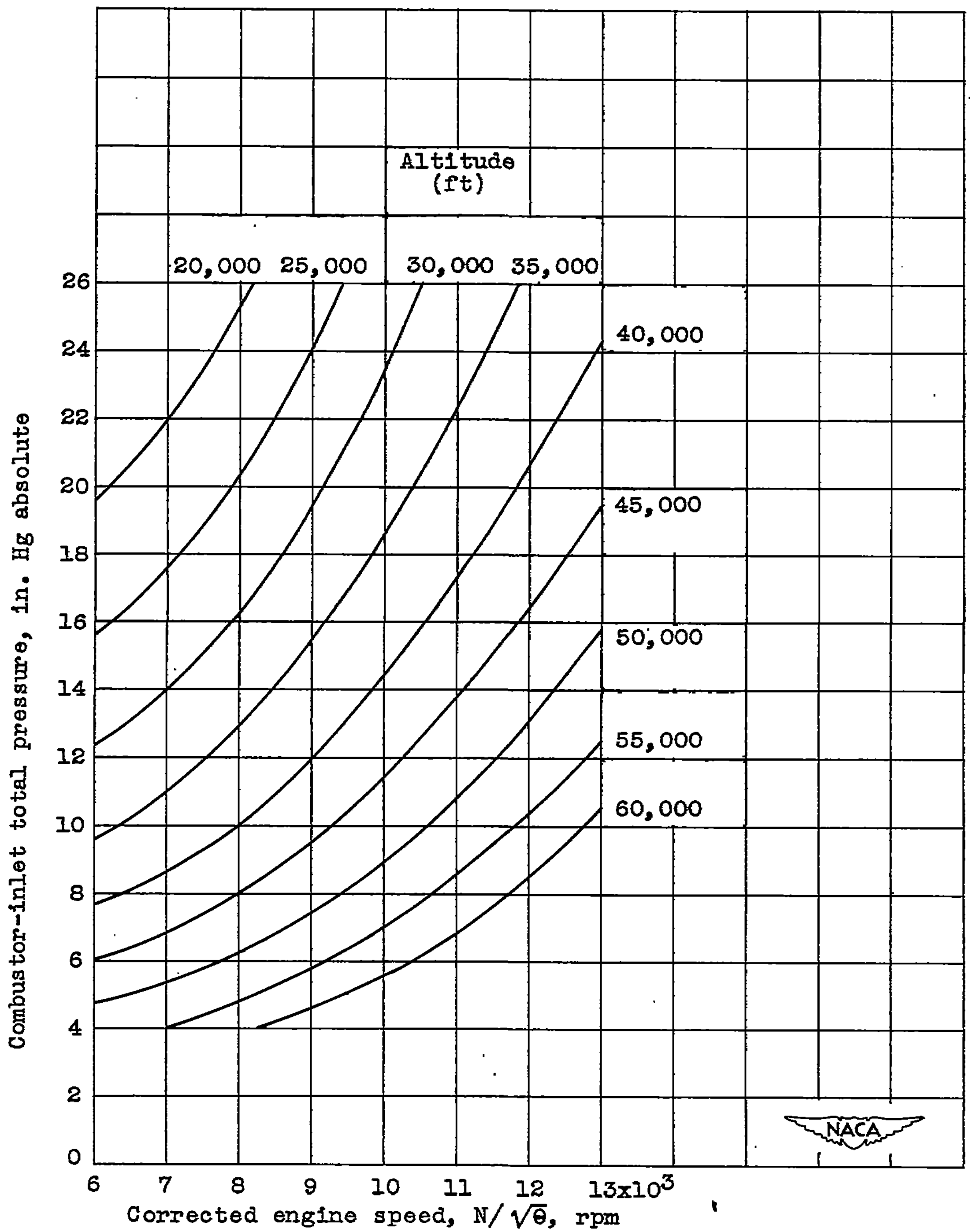
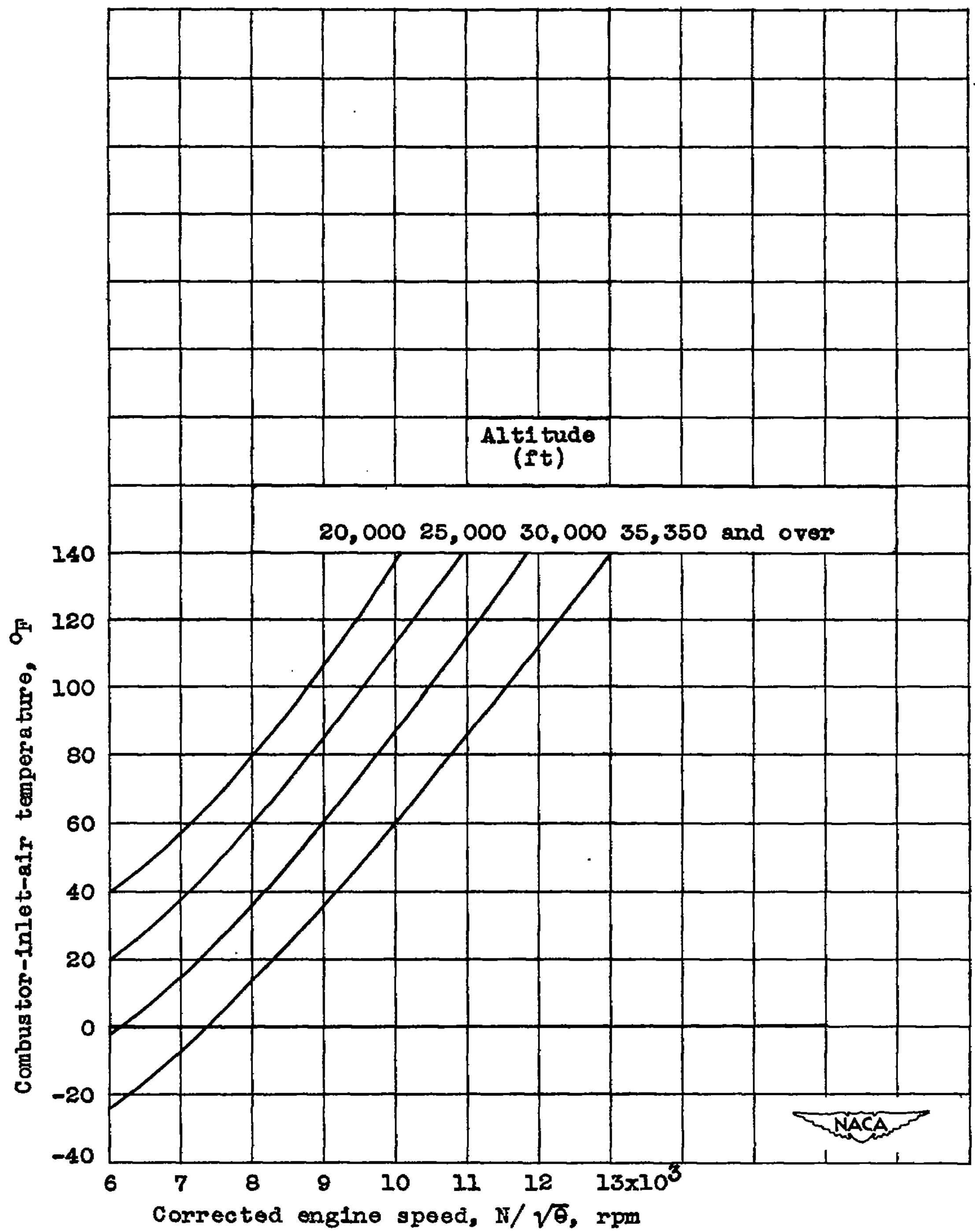


(b) Combustor-inlet total pressure. Flight Mach number, 0.2.

Figure 3. - Continued. Variation of combustor operating conditions with corrected engine speed at various altitudes.



(c) Combustor-inlet-air temperature.
Flight Mach number, 0.2.

Figure 3. - Continued. Variation of combustor operating conditions with corrected engine speed at various altitudes.

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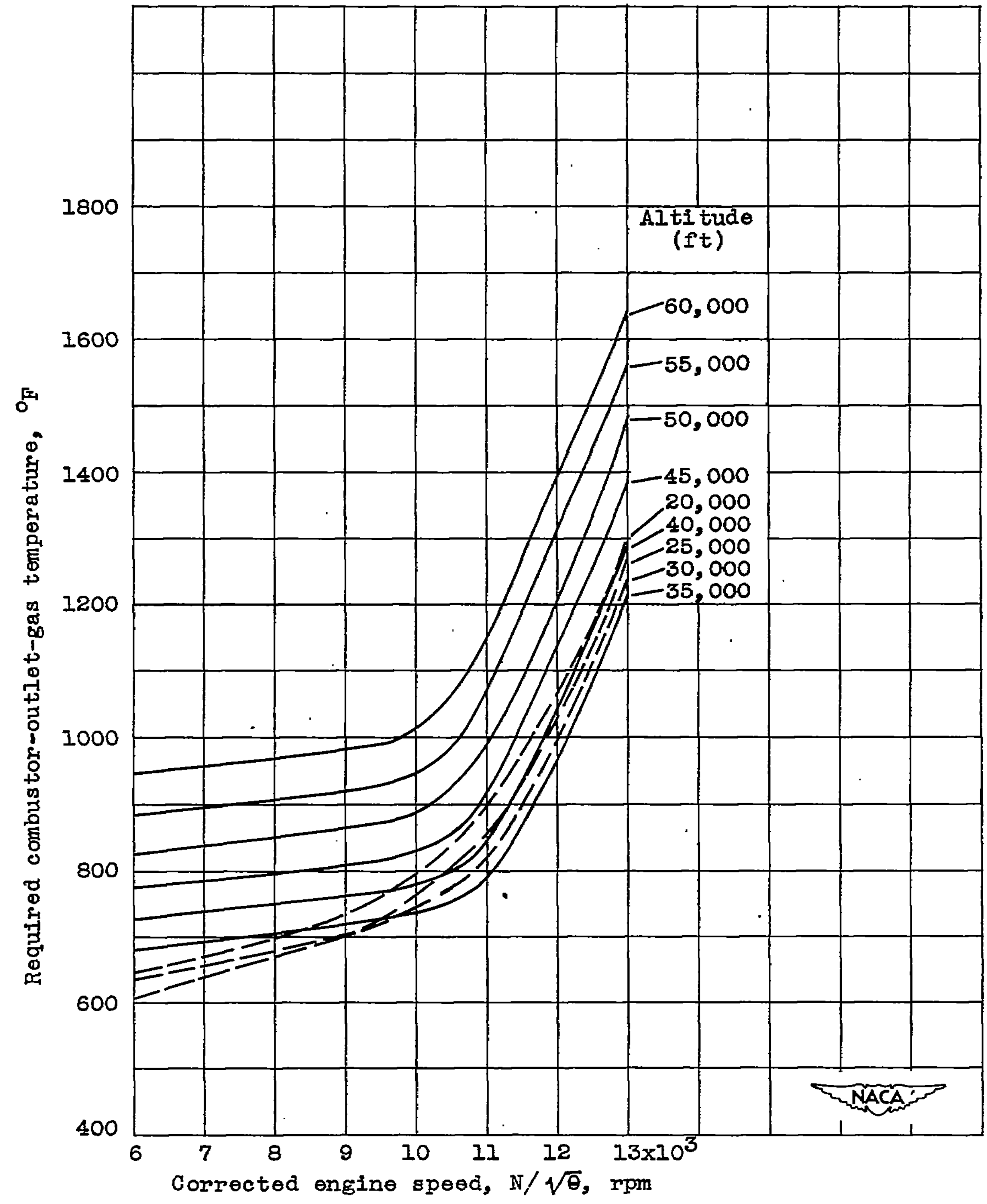

(d) Combustor-outlet-gas temperature. Flight Mach number, 0.2.

Figure 3. - Continued. Variation of combustor operating conditions with corrected engine speed at various altitudes.

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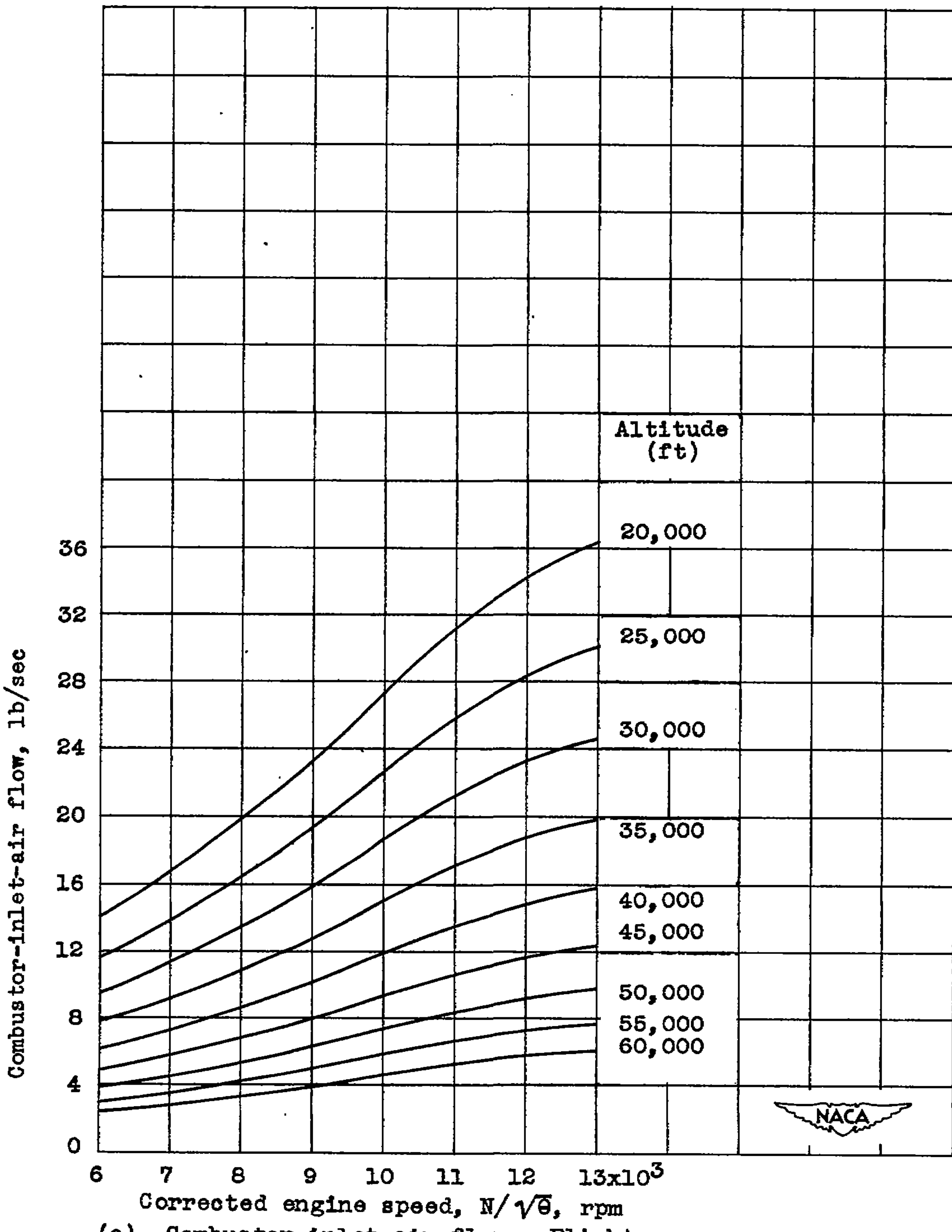

(e) Combustor-inlet-air flow. Flight Mach number, 0.6.

Figure 3. - Continued. Variation of combustor operating conditions with corrected engine speed at various altitudes.

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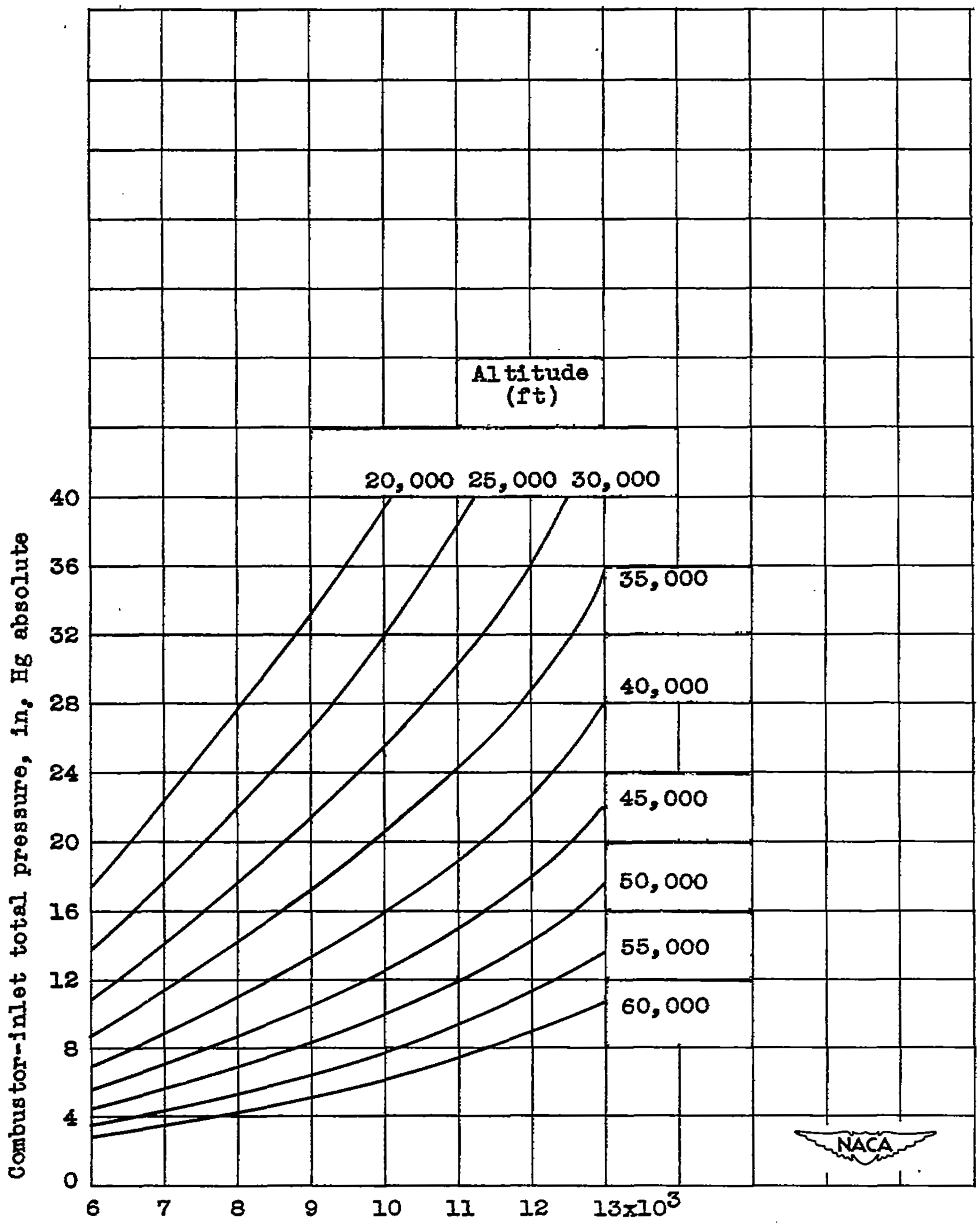

(f) Combustor-inlet total pressure.
Flight Mach number, 0.6.

Figure 3. - Continued. Variation of combustor operating conditions with corrected engine speed at various altitudes.

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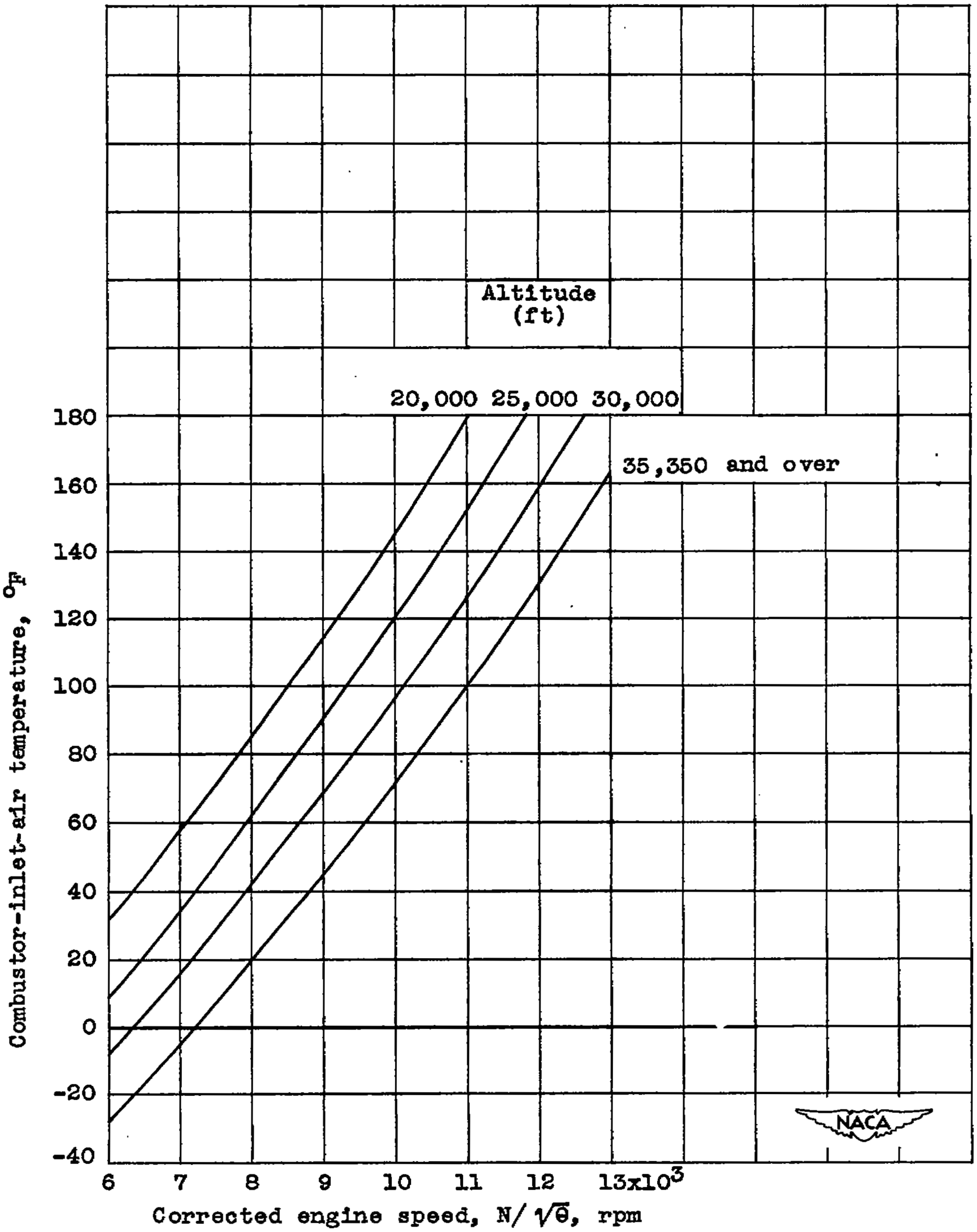

(g) Combustor-inlet-air temperature.
Flight Mach number, 0.6.

Figure 3. - Continued. Variation of combustor operating conditions with corrected engine speed at various altitudes.

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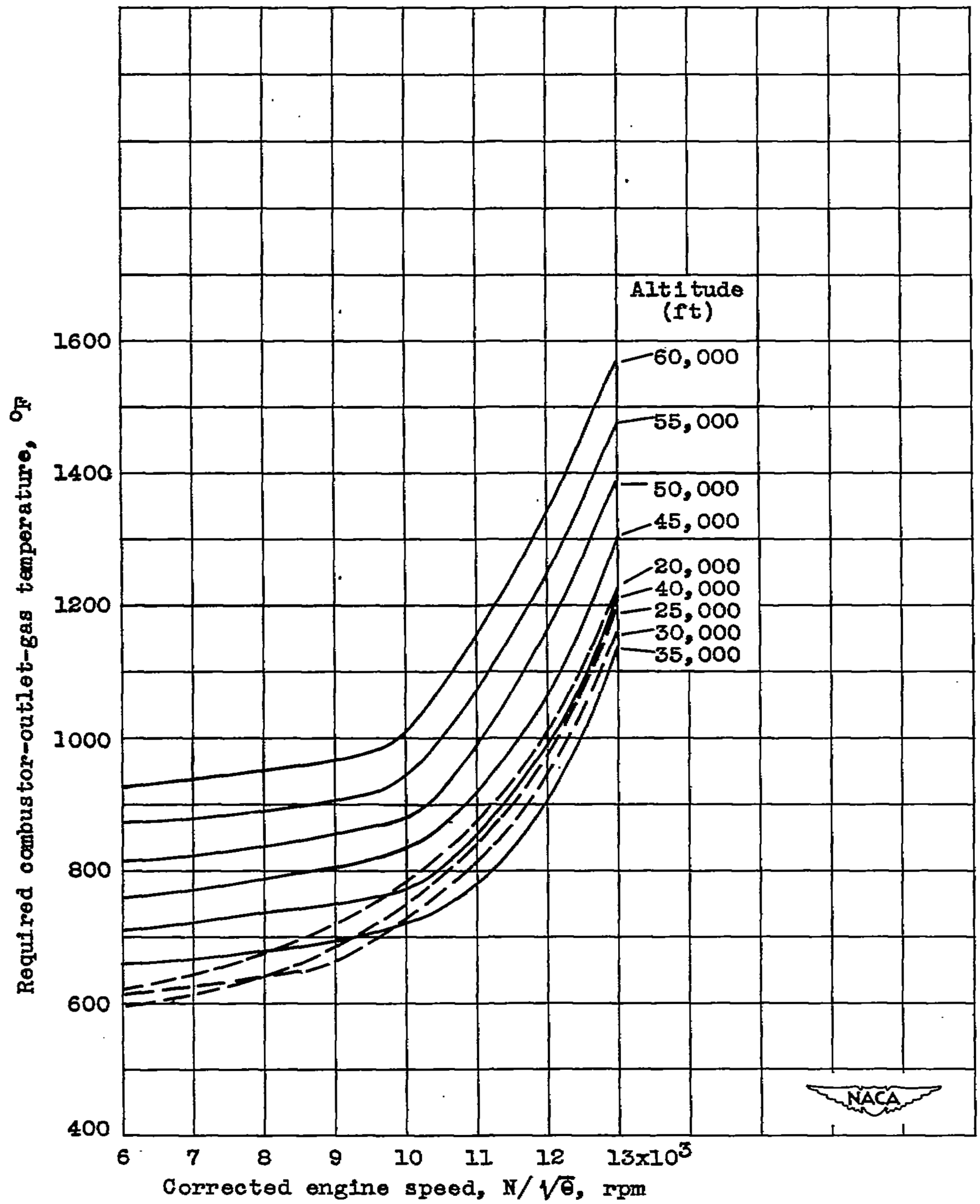

(h) Combustor-outlet-gas temperature. Flight Mach number, 0.6.

Figure 3. - Concluded. Variation of combustor operating conditions with corrected engine speed at various altitudes.

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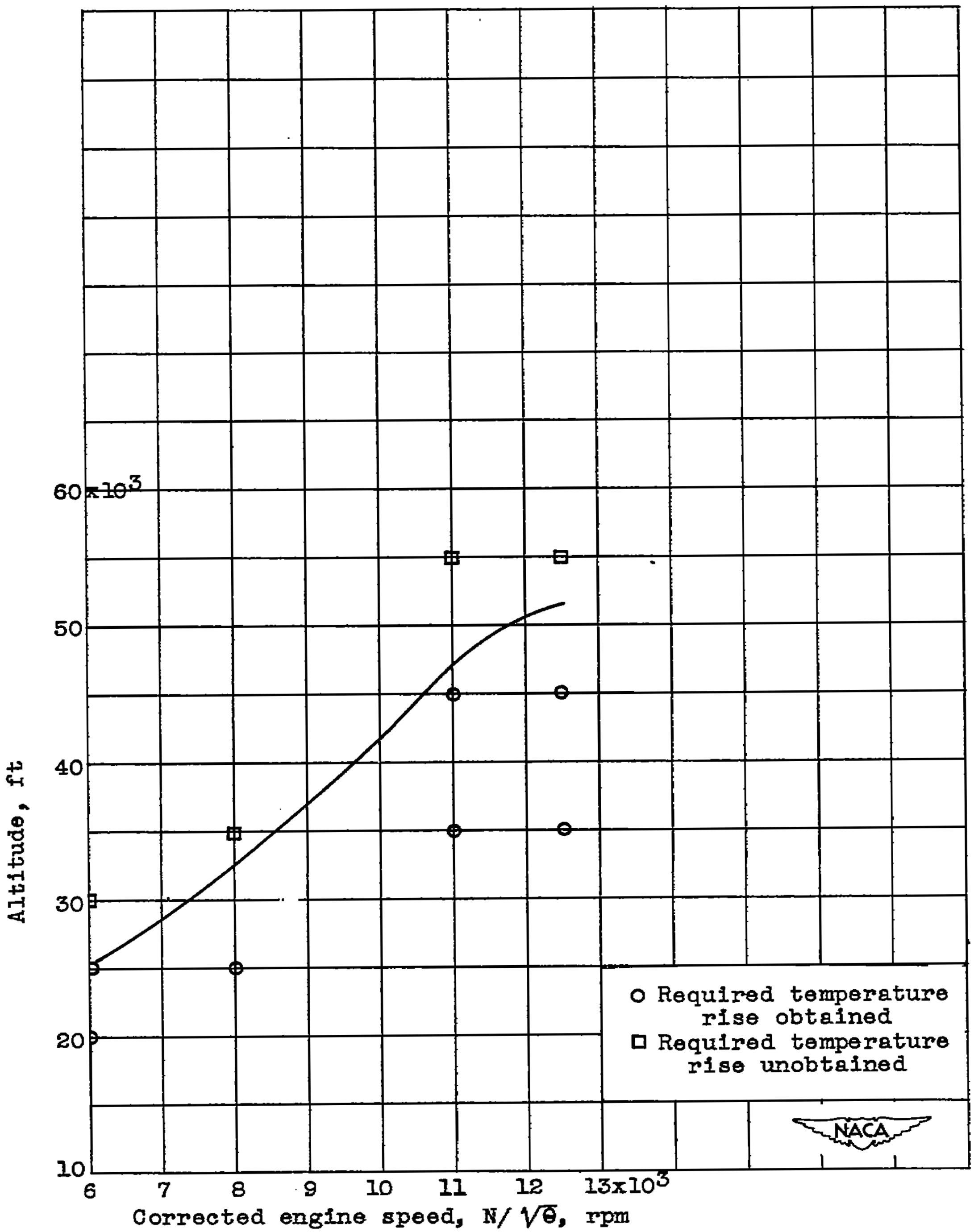

(a) Fuel, AN-F-48 (NACA fuel number 48-359); flight Mach number, 0.2.

Figure 4. - Altitude operational limits for combustor.

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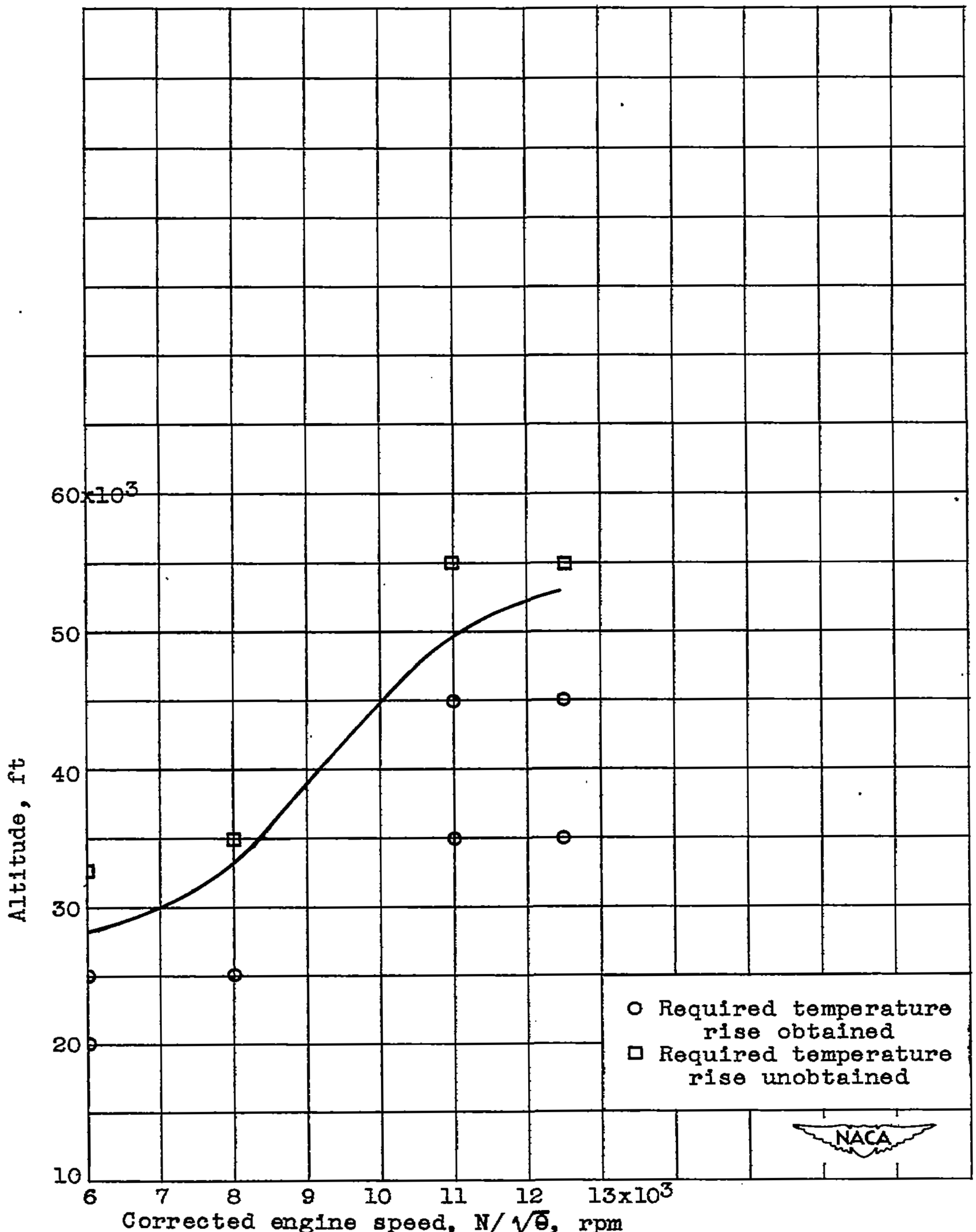

(b) Fuel, AN-F-58 (NACA fuel number 48-249); flight Mach number, 0.2.

Figure 4. - Continued. Altitude operational limits for combustor.

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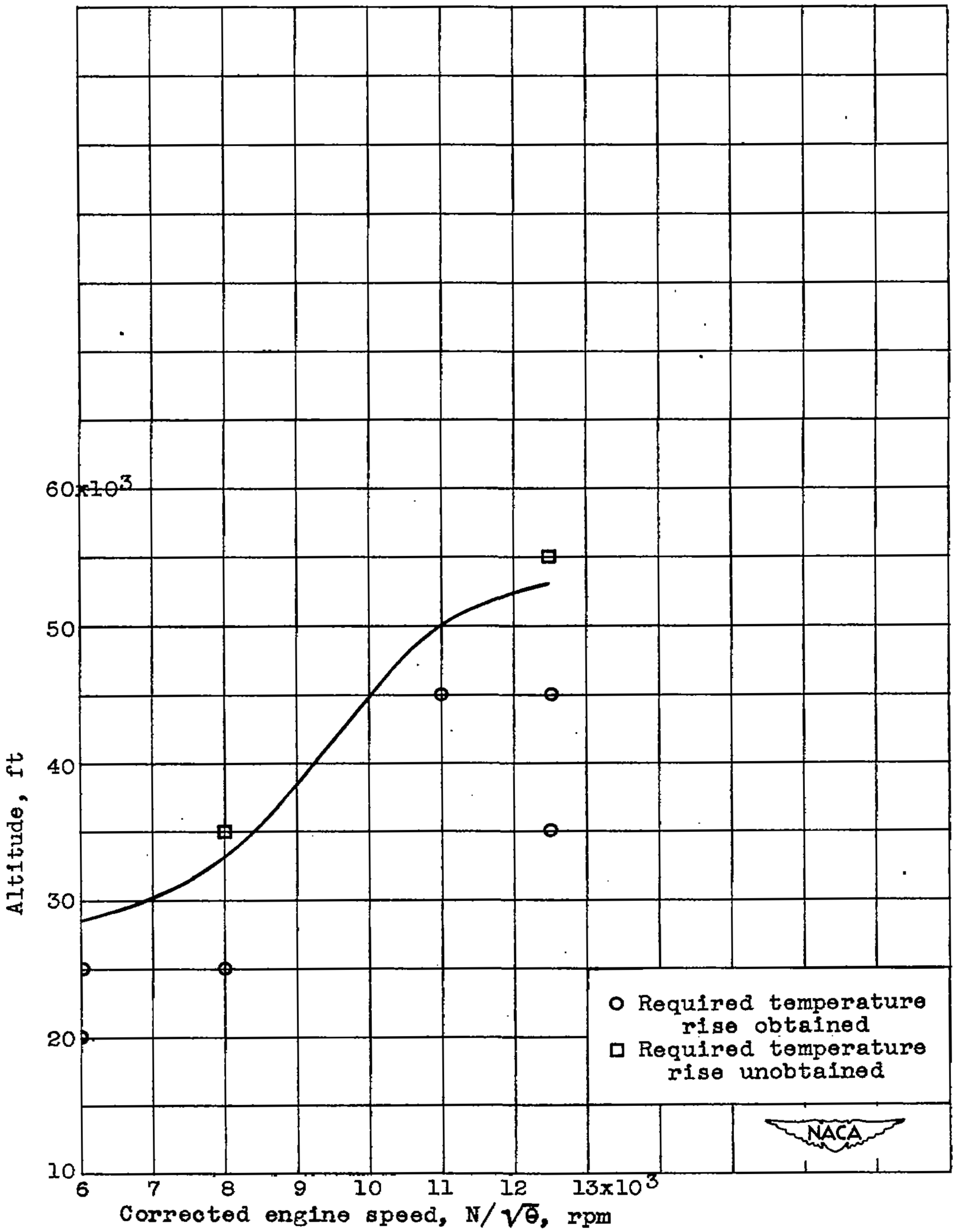

(c) Fuel, AN-F-58 (NACA fuel number 48-258); flight Mach number, 0.2.

Figure 4. - Continued. Altitude operational limits for combustor.

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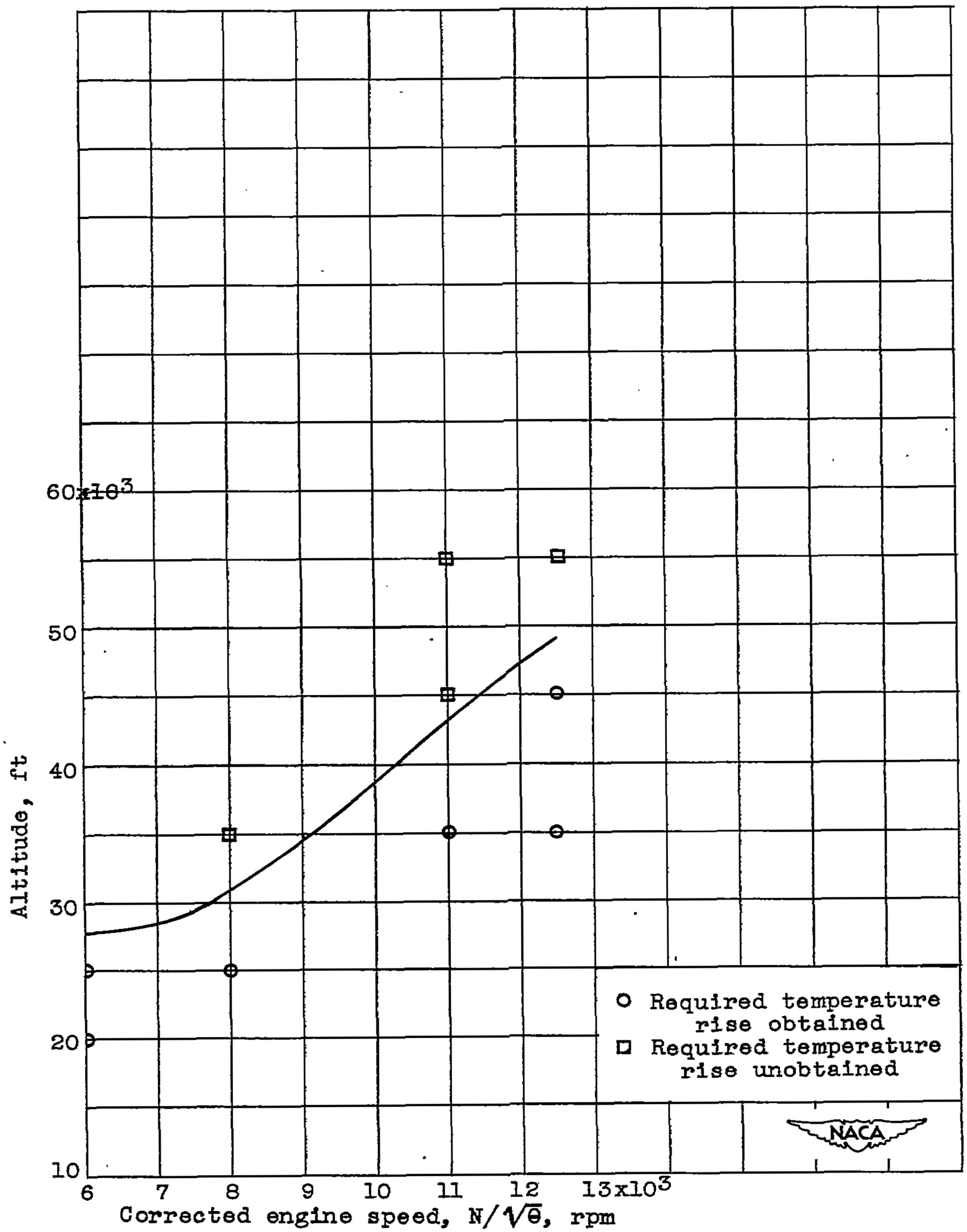

(d) Fuel, AN-F-58 (NACA fuel number 48-279); flight Mach number, 0.2.

Figure 4. - Continued. Altitude operational limits for combustor.

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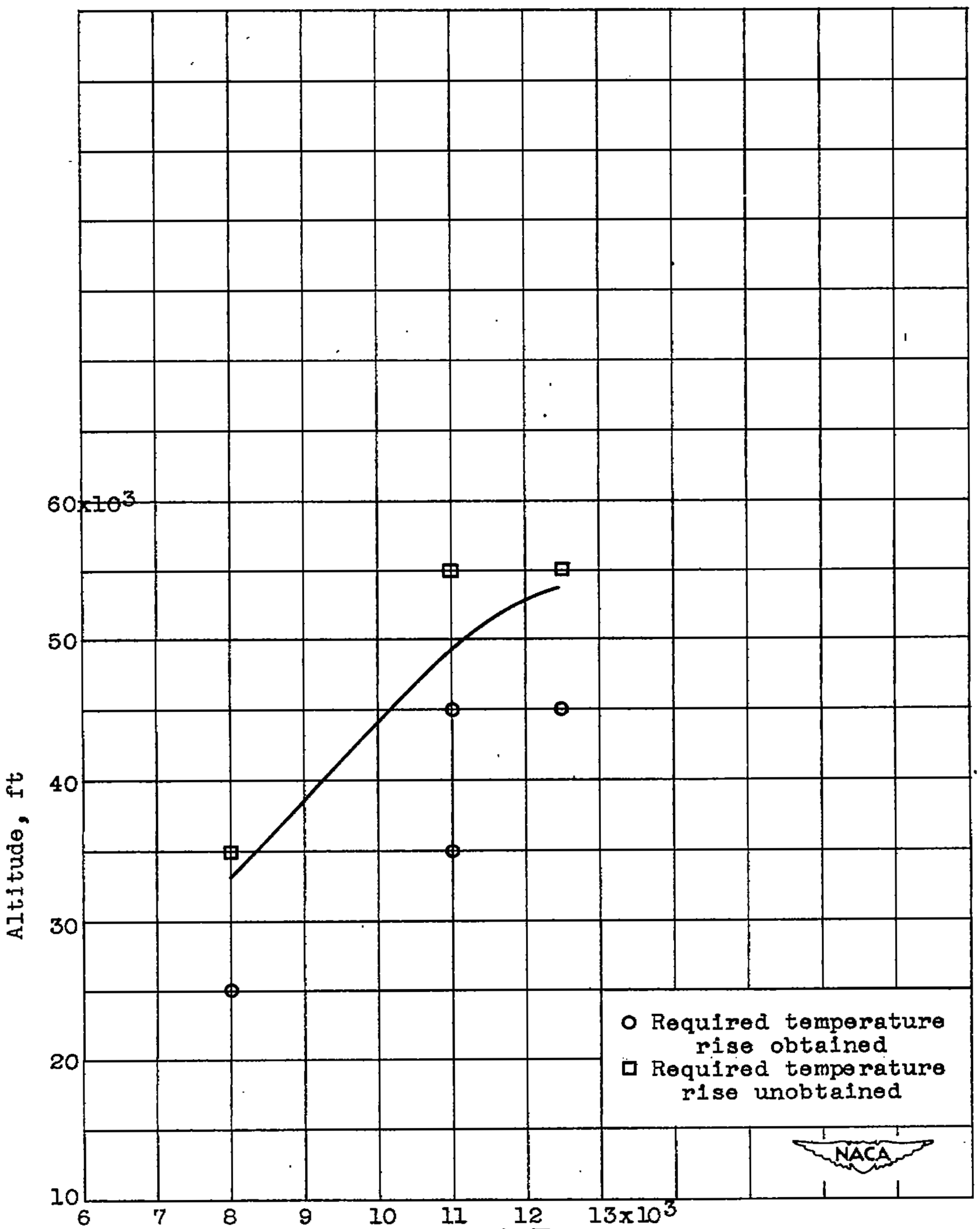

(e) Fuel, AN-F-48 (NACA fuel number 48-359); flight Mach number, 0.6.

Figure 4. - Continued. Altitude operational limits for combustor.

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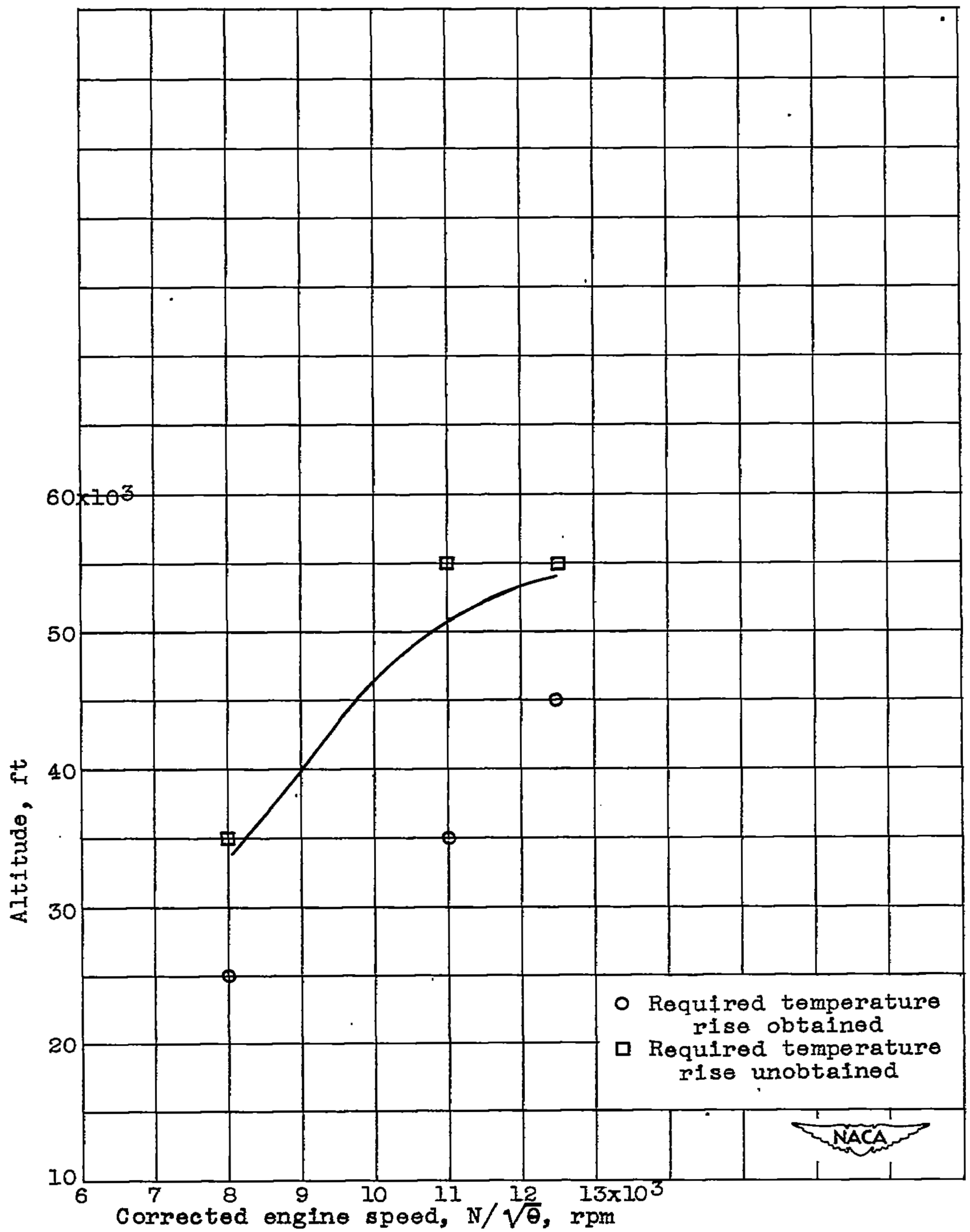
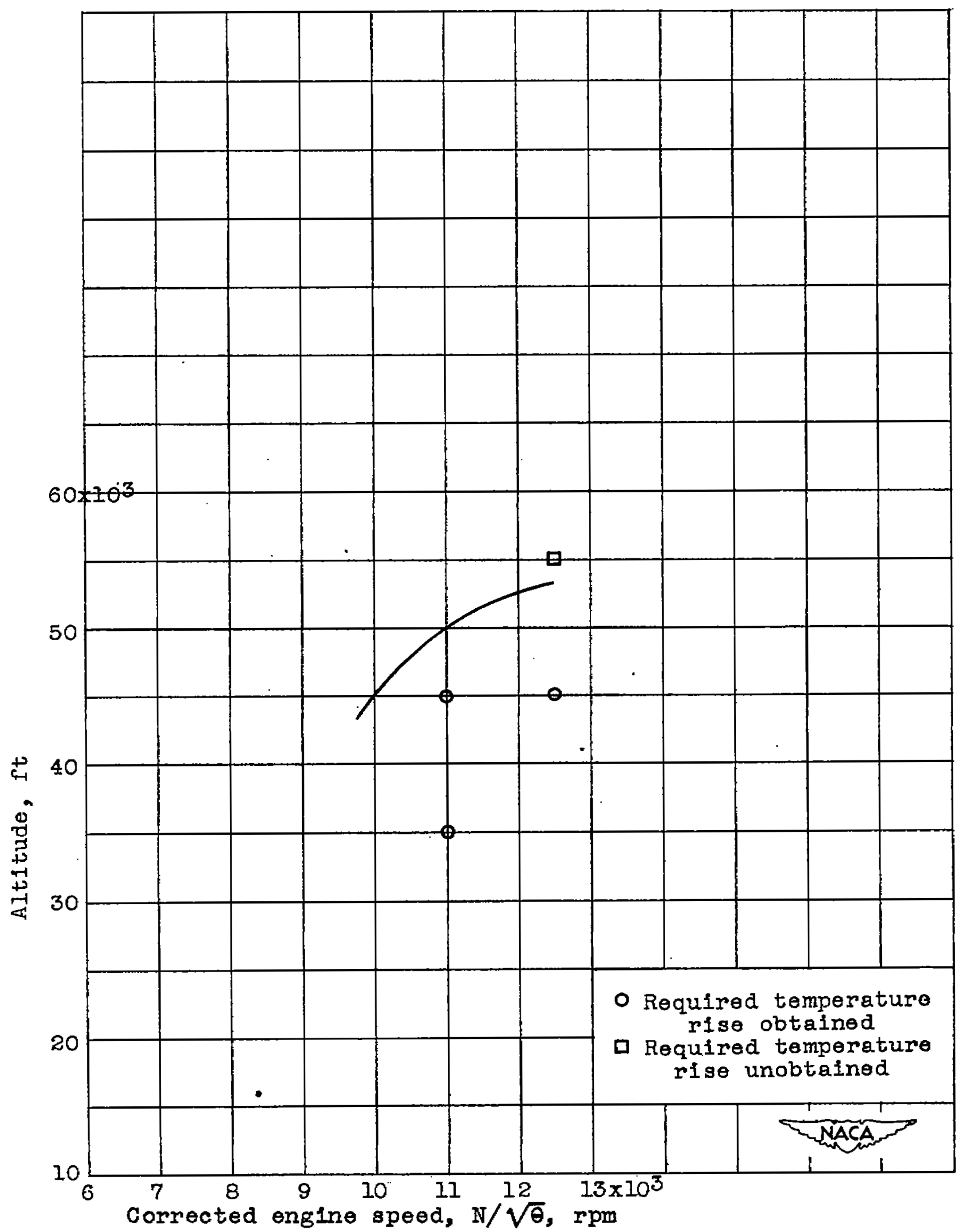


(f) Fuel, AN-F-58 (NACA fuel number 48-249); flight Mach number, 0.6.

Figure 4. - Continued. Altitude operational limits for combustor.



(g) Fuel, AN-F-58 (NACA fuel number 48-258); flight Mach number, 0.6.

Figure 4. - Continued. Altitude operational limits for combustor.

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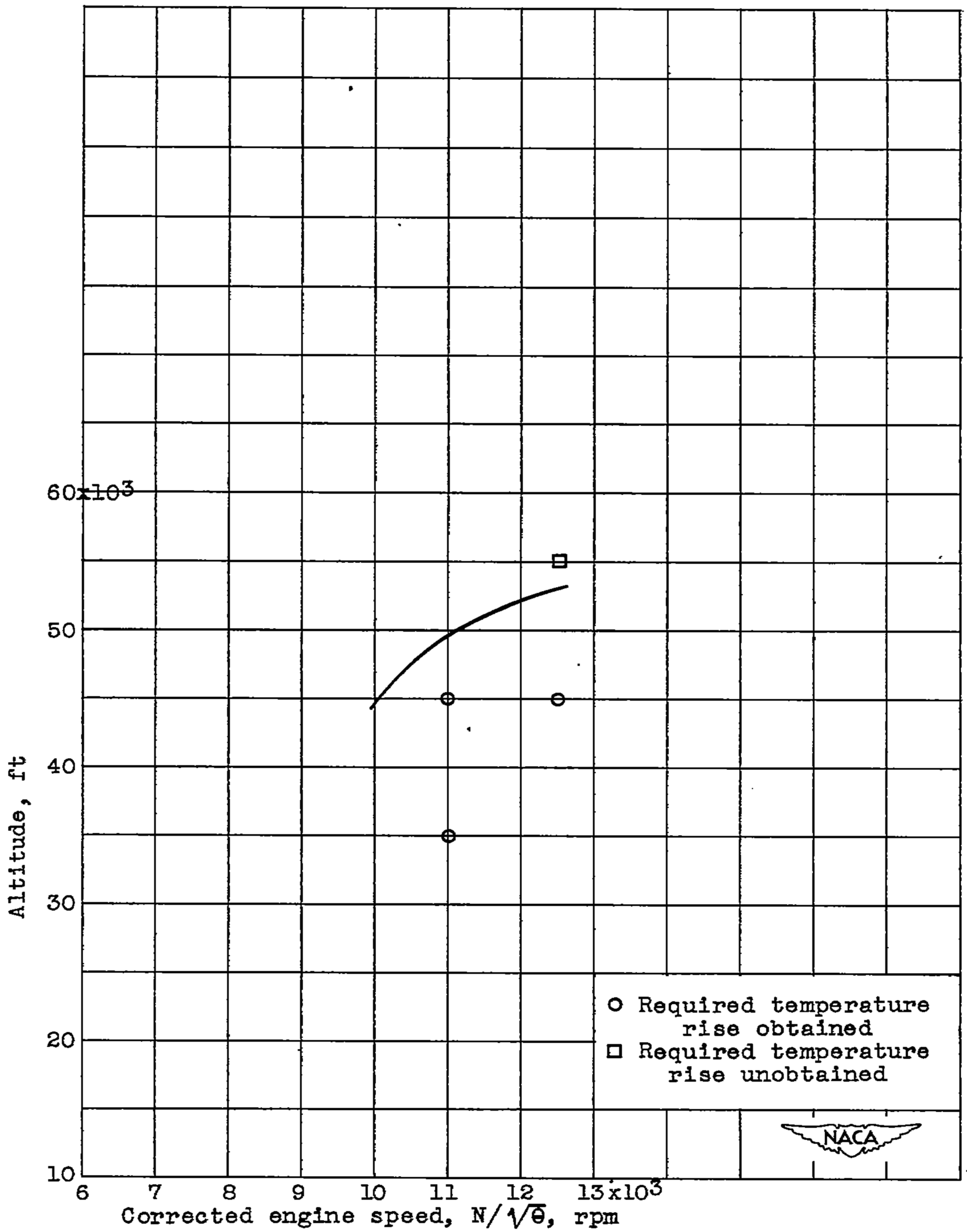
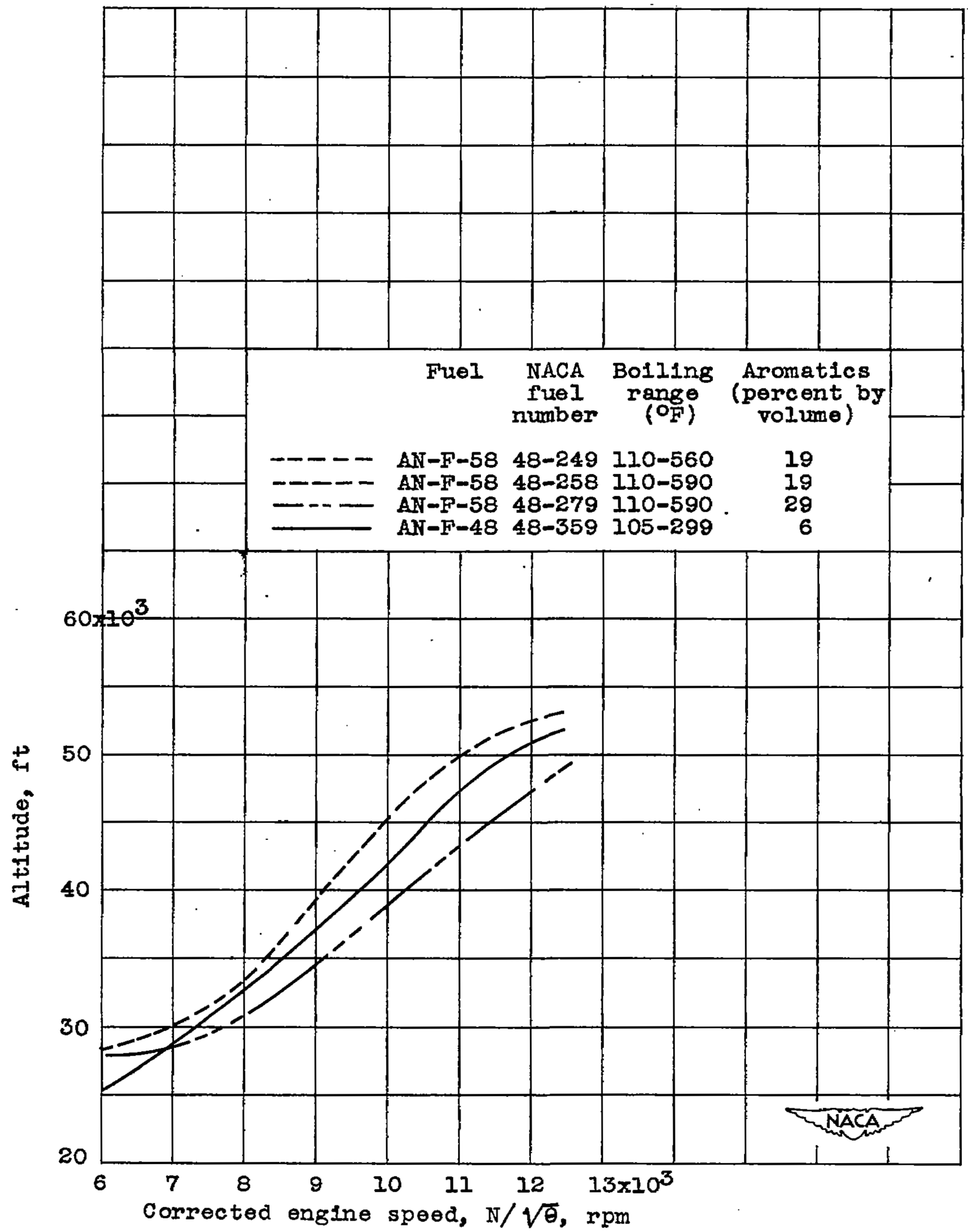


(h) Fuel, AN-F-58 (NACA fuel number 48-279); flight Mach number, 0.6.

Figure 4. - Concluded. Altitude operational limits for combustor.

[redacted]



(a) Flight Mach number, 0.2.

Figure 5. - Estimated altitude operational limits for combustor with AN-F-58 fuels and AN-F-48 fuel.

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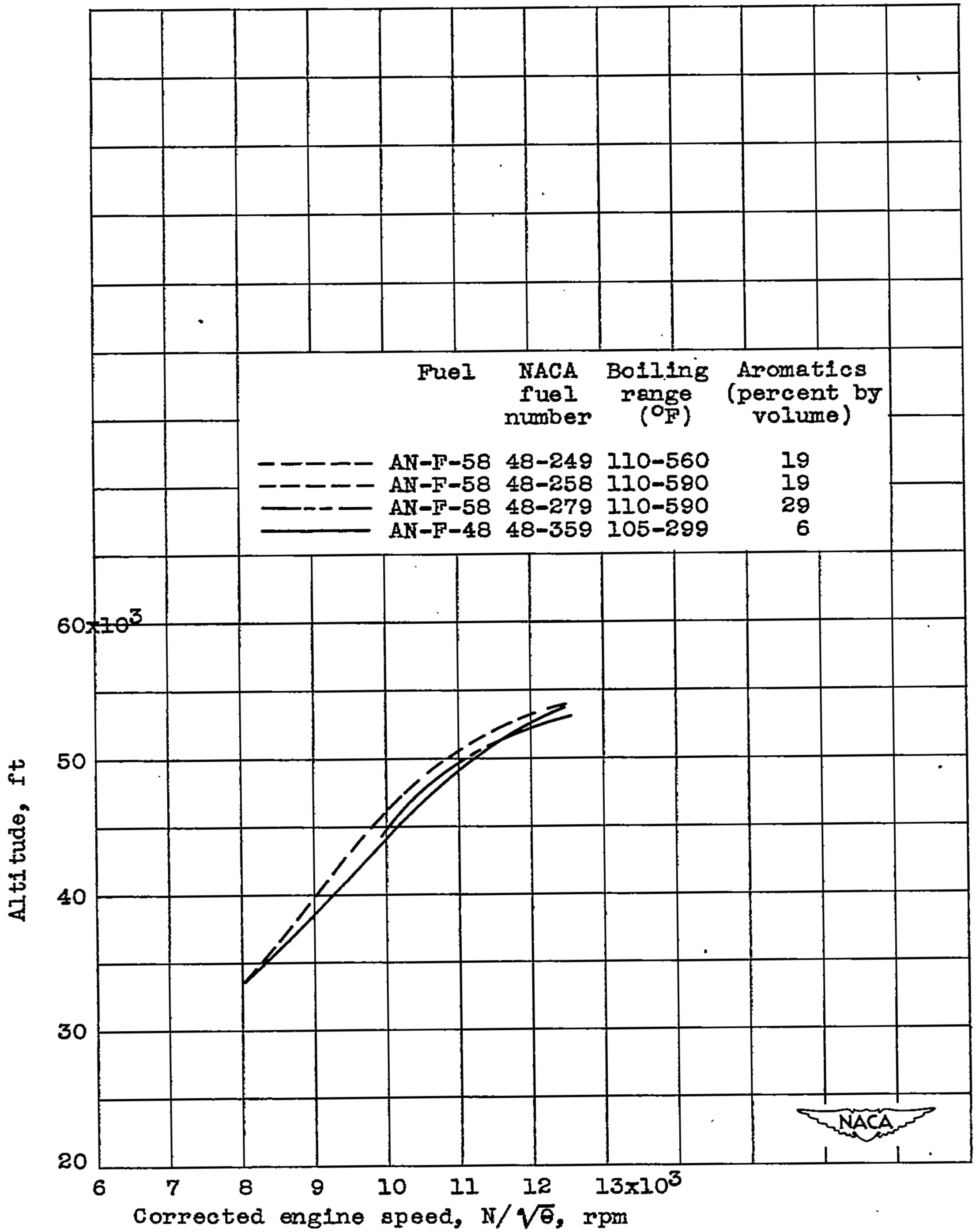
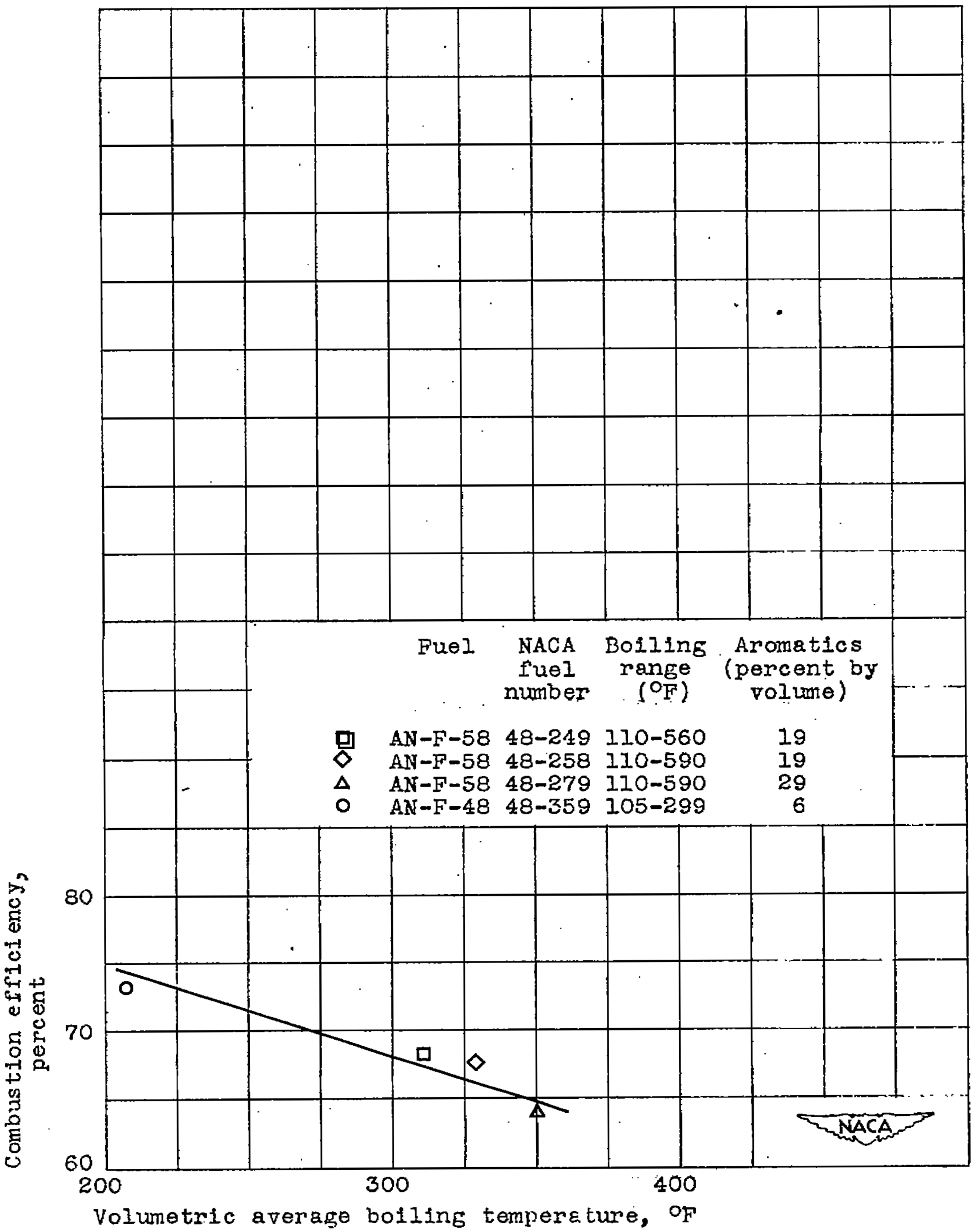


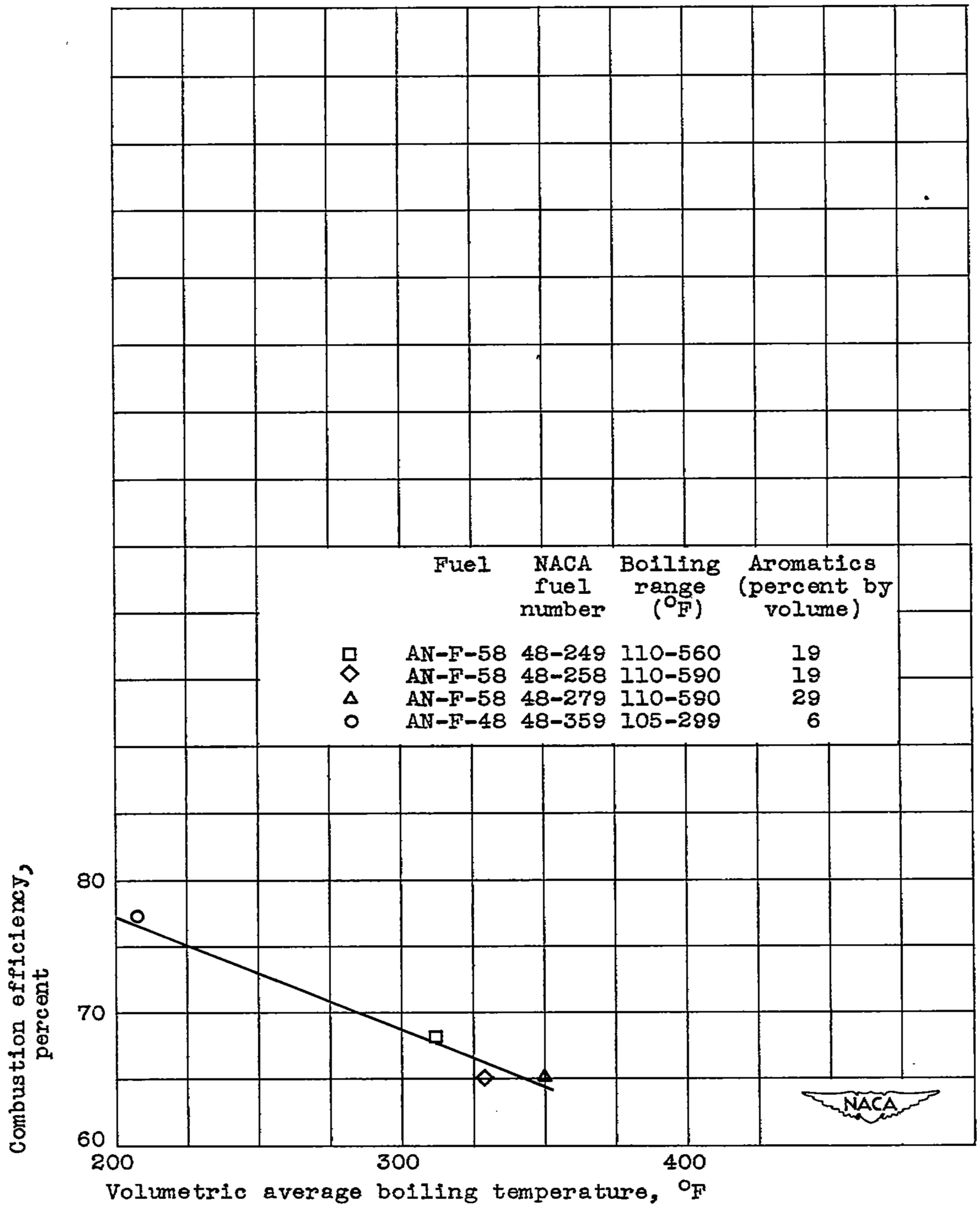
(b) Flight Mach number, 0.6.

Figure 5. - Concluded. Estimated altitude operational limits for combustor with AN-F-58 fuels and AN-F-48 fuel.



(a) Flight Mach number, 0.2.

Figure 6. - Correlation of combustion efficiencies of AN-F-58 fuels and AN-F-48 fuel with volumetric average boiling temperature. Altitude, 45,000 feet; corrected engine speed, 12,500 rpm.



(b) Flight Mach number, 0.6.

Figure 6. - Concluded. Correlation of combustion efficiencies of AN-F-58 fuels and AN-F-48 fuel with volumetric average boiling temperature. Altitude, 45,000 feet; corrected engine speed, 12,500 rpm.

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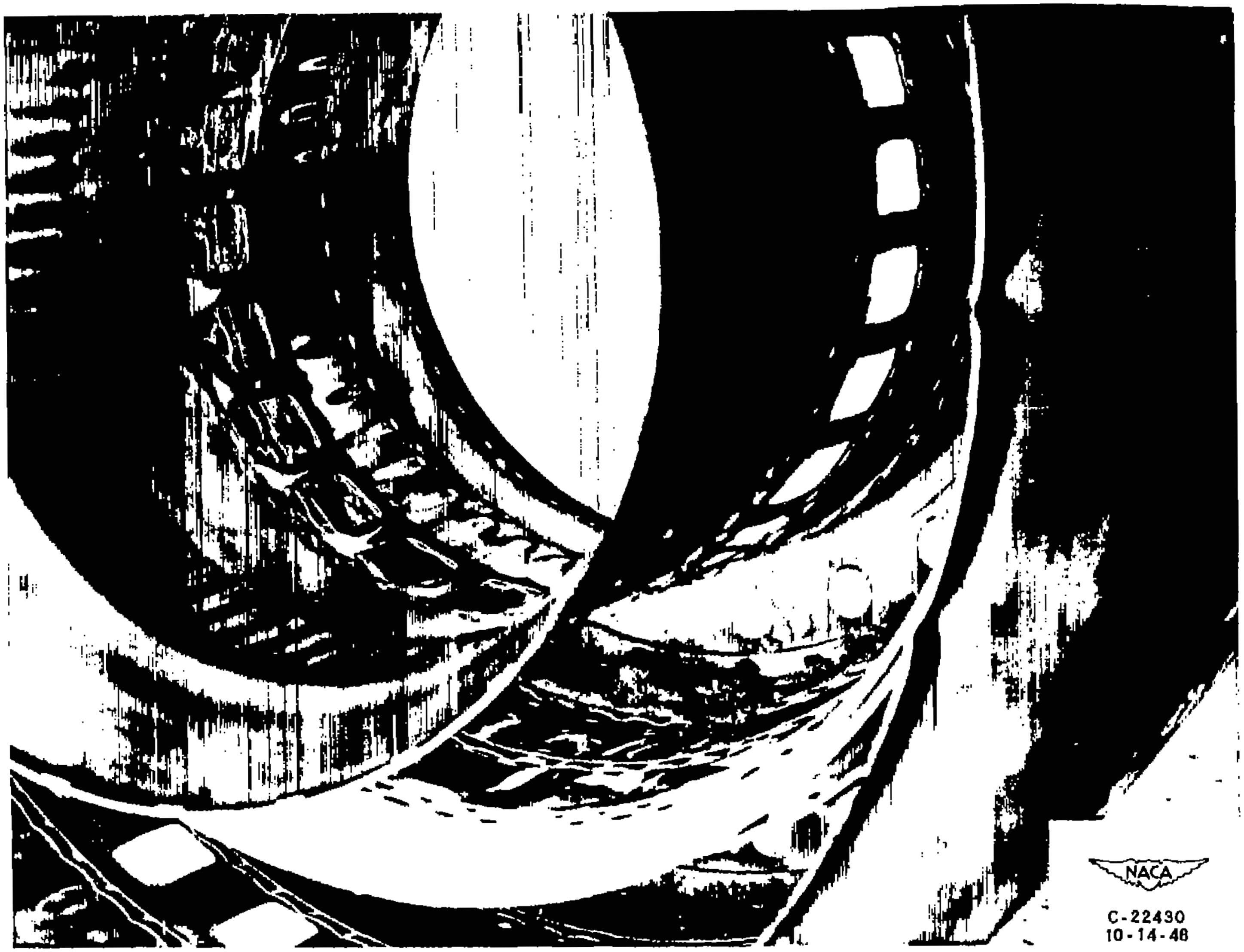

Figure 7. - Combustor basket after 6-hour run with AN-F-58 fuel (NACA fuel 48-279). Altitude, 35,000 feet; corrected engine speed, 12,500 rpm; flight Mach number, 0.2.

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