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RESEARCH MEMORANDUM

EFFECT OF UNEVEN AIR-FLOW DISTRIBUTION TO THE TWIN INLETS OF AN AXIAL-FLOW TURBOJET ENGINE

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...ssification cancelled (or changed to Unclassified)

By Authority of NASA Tech Pub Announcement #3

By ..... 4 Feb. 59

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January 26, 1953

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECT OF UNEVEN AIR-FLOW DISTRIBUTION TO THE TWIN INLETS OF AN AXIAL-FLOW TURBOJET ENGINE

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SUMMARY

A brief investigation was conducted in the NACA Lewis altitude wind tunnel to determine the effects of a 60-40 air-flow distribution to the twin inlet ducts of an axial-flow turbojet engine. Data were obtained at rated engine speeds over a range of exhaust-gas temperatures for altitudes of 15,000, 30,000, and 45,000 feet at a flight Mach number of 0.64.

It was found that the uneven air-flow distribution produced by layers of screen in one of the twin inlets did not appreciably affect the total-pressure distribution at the compressor outlet or beyond; however, sizable temperature gradients were introduced throughout the engine. The large pressure differences at the inlet and the relatively uniform pressure profile at the outlet indicated that half the compressor operated above the normal pressure-ratio range and the other half below. At high altitude, the compressor-half downstream of the inlet blockage screens may have been operating in stall although the engine operation as a whole was stable. Engine air flow was reduced by the distortion, and this reduction, combined with reduced component efficiencies, resulted in thrust reductions of as much as 25 percent. No reduction occurred in combustion efficiency; however, specific fuel consumption was increased substantially. Also, at high altitudes and corrected engine speeds, operation at military power was prevented by the occurrence of compressor surge.

INTRODUCTION

During operation of a turbojet engine with nonsymmetrical inlet ducting, or of an airplane with a high degree of yaw or angle of attack, a nonuniform pressure distribution may exist at the compressor inlet. For example, in one proposed design for the installation of a turbojet engine, 60 percent of the total air flow is supplied to one of the split engine-inlet ducts and 40 percent to the other during some flight conditions. Although the effects of smaller inlet-air distortions on engine performance are negligible, as reported in reference 1, no data are available for inlet air distortions of this order of magnitude. A brief study was therefore made in the NACA Lewis laboratory altitude wind tunnel to evaluate the effects on performance of a nonuniform pressure profile at the inlet of an axial-flow turbojet engine.

Sufficient fine-mesh screens were installed in one of the twin inlet ducts of an engine to cause a 60-40 air-flow division between the two ducts. The changes produced in the engine pressure and temperature distributions, the component efficiencies, and the over-all engine performance by the uneven air-flow distributions are shown herein. The data 2716 cover a range of exhaust-nozzle areas at rated engine speed and altitudes from 15,000 to 45,000 feet at a flight Mach number of 0.64.

APPARATUS

Engine

The manufacturer's guaranteed sea-level static performance of the turbojet engine which was used in the investigation is 7500 pounds thrust at a speed of 7260 rpm and a turbine-inlet gas temperature of 1425° F. Main components of the engine (fig. 1) are an 11-stage axial-flow compressor, a single-annular combustor, a two-stage turbine, and a continuously variable clam-shell-type exhaust nozzle. Primary control of the engine was accomplished electronically, with a hydraulic control providing emergency protection. The over-all length of the engine is 186 inches, the maximum diameter of engine and accessories is 45.5 inches, the width is 42.25 inches, and the total dry weight is 2980 pounds. Two elliptical air inlets are used (total area, 4.26 sq ft), one on either side of the accessory gear case (see figs. 2 and 3). The air passages join to form an annulus (area, 3.65 sq. ft.) approximately 2 inches upstream of the inlet guide vanes.

INSTALLATION

As shown in figure 1, the engine was mounted on a wing spanning the test section of the altitude wind tunnel. Dry refrigerated air was supplied to the engine from the tunnel make-up air system through a duct connected to the engine inlet. Manually controlled butterfly valves in this duct were used to adjust the total air pressures at the engine inlet. A slip joint with a frictionless seal was used in the duct, to make possible the measurement of thrust and drag with the tunnel scales.

Instrumentation for measuring pressures and temperatures was installed at various stations in the engine (fig. 3) to determine the steady-state performance. A traverse mechanism comprising 10 sonic-type thermocouples (reference 2) was supplied by the engine manufacturer to determine the gas-temperature pattern at the turbine inlet. Fine-mesh screens that were installed in the right inlet duct approximately 50 inches upstream of the engine inlet flange caused a 60-40 air-flow division between the two ducts.

PROCEDURE

In order to isolate the effects occurring within the engine from the duct losses which would accompany such a severe distortion, the inlet pressure (which was used in the calculation of net thrust and flight Mach number) was considered as the arithmetic average of the pressures in the blocked and unblocked ducts at station 3 (see fig. 3). The effects of inlet-duct pressure losses on performance can however be evaluated by the methods presented in reference 3. Performance of the engine with uniform and nonuniform pressure distributions is compared on the basis of a common arithmetically averaged total pressure at the compressor-inlet face.

The air flow through the make-up air duct was throttled from approximately sea-level pressure to a total pressure at the compressor inlet (station 3) corresponding to the desired flight Mach number at a given altitude. The static pressure in the tunnel test section was maintained to correspond to the desired altitude. Engine inlet air temperatures were held at approximately NACA standard values corresponding to the simulated flight conditions, except for high altitudes and low flight Mach numbers. Inlet-air temperatures below about -20° F were not obtained.

Complete engine-performance data were obtained at the following operating conditions with and without the blockage screens installed and at several exhaust-nozzle-area settings:

Altitude (ft)	Flight Mach number	Corrected engine speed (rpm)	Actual engine speed (rpm)
15,000	0.64	7400	7260
30,000	.64	7700	7260
45,000	.64	7790	7260

Compressor surge prevented operation at military rated temperature at high altitudes; accordingly, the maximum corrected engine speed at which military temperature could be obtained without surge was determined at altitudes from 37,500 to 45,000 feet.

All symbols used in this report are defined in appendix A and the calculations are given in appendix B.

RESULTS AND DISCUSSION

The air-flow distributions with and without the screens installed are shown in figure 4. It will be noted that for operation at all altitudes investigated, about 62 percent of the air flow passed through the unobstructed duct over the complete range of turbine-outlet temperatures (and therefore compressor pressure ratios) covered. For operation without blockage screens installed, the air flow was equally divided between the two ducts. 2716

Effect on pressure and temperature patterns. - The tendency of the distortion to persist or dissipate in passing through the engine is shown by the data of figures 5 through 11. Total-pressure profiles obtained with three rakes at the compressor outlet are compared (fig. 5) for operation at approximately the same exhaust-gas temperature with and without the blockage screens. Although the general pressure level obtained with the screens installed was low, there appeared to be no large change in the pressure distributions. This typical plot, indicates that the compressor pumps the air up to a common exit pressure despite the difference in inlet pressure required to obtain the 60-40 air-flow distribution.

Compressor-outlet temperatures obtained with two rakes 180° apart are shown for the same altitude and flight Mach number in figure 6. The temperatures measured by the two rakes were only 20° F different when no inlet blockage screens were used; but when the screens were installed in one of the inlets, the temperature differed by as much as 164° F, the rake in line with the blocked duct giving the higher values. Such a temperature distribution would be expected even if no change in compressor efficiency occurred, inasmuch as the compressor pressure ratio across the compressor downstream of the screens is much higher than that downstream of the standard inlet duct.

For a few conditions, a complete survey of the temperature pattern at the turbine inlet was obtained by the use of 10 thermocouples mounted on a traverse mechanism. A comparison of figures 7 and 8 shows the effect of blockage screens on the radial profile. Symbols are used to denote the 10 circumferential positions at which temperature traverses were obtained. The manufacturer's maximum and minimum allowable temperature and the stationary-blade critical temperatures are superimposed on both figures. The change in the average temperature distribution (indicated by solid symbols) is not large and would probably not be detrimental to turbine life. The spread between the individual thermocouple readings increased appreciably, particularly near the root section. For the point shown, figure 8, the local maximum hub temperature exceeded the manufacturer's limit by about 200° F. Thus, conforming to this limit would require that the mean temperature be reduced by about the same amount with a corresponding reduction in thrust.

Circumferential temperature patterns at two blade heights are compared in figure 9 for the same conditions shown in figures 7 and 8. At a distance of 3.5 inches from the blade root, addition of the blockage screens had little effect on the temperature distribution. However, at a distance of only 0.4 inch from the root, an extremely hot region existed over at least 50° of the circumference when blockage screens were installed. Although these local temperatures are appreciably outside the maximum- and minimum-limit curves shown in figure 8, the intermittent exposure of the rotor blades might allow safe rotor operation because of the thermal lag of the blades. The maximum-temperature curve as dictated by limitations of the stator assembly is as shown on figure 8, and it will be noted that for the condition shown in figure 9 the local temperatures were for the most part within the allowable curve. Despite these considerations, prolonged operation would be hazardous because the extreme temperature gradients would probably cause warping and eventual failure of the turbine stator assembly.

Total-pressure distributions at the turbine outlet are compared in figure 10 for the same data points as figures 5 and 6. No appreciable shift in the radial pattern was apparent; however, the circumferential spread was somewhat larger with the distortion, probably as a result of the temperature gradients at the turbine inlet (fig. 9). The largest effect, of course, is the much lower pressure level that exists at a given turbine-outlet temperature when inlet blockage screens are used. Both this large reduction in pressure and the small losses in component efficiency (discussed in subsequent sections) result in lower thrust and higher specific fuel consumption.

The temperature pattern at the turbine outlet (fig. 11) showed no large effect on the radial pattern; however, the circumferential spread was greater with the uneven air-flow distribution.

Compressor performance. - Characteristic curves for the compressor operating with the inlet blockage screens installed in one of the twin inlet ducts are presented in figure 12, for altitudes of 15,000, 30,000 and 45,000 feet. The inlet pressure used to calculate the pressure ratio and to correct the air flow through each duct is the mass-flow averaged pressure measured 4 inches upstream of the compressor face in each of the twin inlet ducts. At 15,000 feet, increasing the turbine-inlet temperature (by decreasing the exhaust-nozzle area) raised the compressor pressure ratio at constant corrected air flow as would be expected for an axial-flow compressor operating at rated engine speed. However, at 45,000 feet, an increase in exhaust-gas temperature produced practically no change in pressure ratio, but instead decreased the corrected air flow.

At 30,000 feet, a transition occurs wherein the pressure ratio first increases at constant air flow as the turbine-inlet temperature is raised, and thereafter remains constant with decreasing air-flow. At all altitudes, the corrected air-flow and the pressure ratio with the blockage installed were less than the value obtained for normal compressor operation. To help explain this phenomena, compressor characteristic lines were calculated for each half of the compressor using the pressure and the air supplied by the open duct for the one half and the pressure and air supplied by the screen-blocked duct for the other half. The air-flow values for each half were multiplied by 2 to put them on a comparable basis with the standard compressor. As shown in figure 13, 2716
the resulting corrected flows were not equal. Although a reduction in flow might be expected for the blocked half, no increase should occur in the unblocked half. The flow through the unblocked half is higher than for normal compressor operation, because these values are the flows through the two halves of the duct rather than the two halves of the compressor. It is believed that a cross flow occurs just upstream of the inlet guide vanes in the space where the two ducts join to form an annulus. The pressure differential available to induce such cross flow would produce an initial cross velocity of the order of 600 feet per second where the ducts join. Thus, the actual flow through both halves of the compressor is probably closer to the value obtained during normal operation than that shown in figure 13. At 15,000 feet, the compressor curves are nearly vertical for both compressor halves; that is, a small change in corrected air flow occurred with increasing compressor pressure ratio (see fig. 13). Although the pressure ratios are considerably higher for the compressor half with the blocked inlet duct, most of the values are below the surge pressure ratio (5.6) for the standard compressor at these conditions. At 45,000 feet, the characteristic curve for the compressor-half with the "unblocked" inlet has a very small slope; that is, the air flow decreases with increasing compressor pressure ratio. However, the characteristic curve for air from the blocked inlet is horizontal; that is, increasing the turbine inlet temperature decreased the corrected air flow but had no effect on the compressor pressure ratio. This pressure ratio is only slightly higher than the surge value for the standard compressor at this operating condition (6.1). The inability of the compressor to further increase pressure ratio and the progressive reduction in air flow at 45,000 feet is attributed to stall in the latter stage or stages of the compressor. Whereas the term surge is used to denote the violent low-frequency instability commonly experienced; stall is used herein to denote a local flow disturbance within the compressor such that the engine operation appears entirely normal when steady-state or even transient instrumentation with a linear response up to 30 or 40 cycles per second is used. Although insufficient instrumentation was installed to permit a definite explanation of flow conditions within the compressor, the following two concepts (of the several possible) are advanced, either one of which appears to fit the results obtained:

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(1) Because all the pressure ratios for the blocked compressor-half are at or above the surge pressure ratio for the standard compressor configuration, it can be assumed that the last or latter stages are operating in a stall condition. The choked flow at the turbine nozzles requires that the relation $\frac{W_{g,5}\sqrt{T_5}}{P_5} = \text{constant}$ be maintained. An increase in turbine-inlet temperature T_5 would normally result in higher pressure ratios across the compressor, but the stalled latter stages prevent any rise in pressure; therefore, the air flow is forced lower. This reasoning cannot be used on the compressor-half with the unblocked inlet duct because the pressure ratio is considerably lower than the surge value; however, it is conceivable that some of the low-energy air from the stalled compressor-half remains in the flow passages for part of the time the blade row is moving through the unstalled compressor-half. The low energy air in part of the unstalled compressor-half would not only impair the total flow of air through it but would also reduce the efficiency; this will subsequently be shown to be the case.

(2) Whereas, in the first concept, it is assumed that the blades of one or more stages are stalled in a large single region of the circumference downstream of the blocked inlet; the second concept deals with local stall regions occupying perhaps the width of only a few blade passages, the stall region rotating around the compressor at one-third to one-half the rotor speed as shown in reference 4. As discussed in this reference, a recirculation is believed to exist such that the reverse flow in one passage increases the angle of incidence on an adjacent blade, causing it to stall and thereby propagating the segment stall around the annulus.

As the pressure ratio of the blocked half approaches the value which produced surge in the standard compressor, segment stall appears in the latter stage or stages and increase in size or number as the turbine-inlet temperature is raised. Because of this increase, the effective flow area and hence the air flow is reduced. Surge does not occur because of a momentum interchange along the boundaries, and also because of the fact that the segment-stall regions rotate. Such a stall region would probably originate downstream of the blockage screens where the pressure ratio is high and disappear as it rotated into the lightly loaded region of the unblocked compressor-half. The passage of these rotating segment stall areas into or through the unblocked half accounts for the decreased mass flow and efficiency observed for the corresponding half of the compressor.

It should be noted that, even with the unusual compressor characteristics shown, in which stall regions apparently exist for an extensive portion of the compressor annulus, the engine operation was to all appearances stable, and over the range of conditions shown in figures 12 and 13 no surge was encountered. As shown in figure 12, the over-all slope of the compressor characteristic lines, although greatly different from those of the unblocked half, was negative (that is, air flow decreases as pressure ratio increases) or nearly zero. These results seem to substantiate the conclusion of reference 5: that a positive slope of the compressor characteristic lines may be necessary before engine surge can occur. 2716

Compressor efficiencies for the two compressor halves are compared with the standard compressor-efficiency values for the three altitudes in figure 14. At 15,000 feet, the compressor efficiencies for both halves were about the same and were about 2 percent lower than for the standard compressor. However, at 45,000 feet, the efficiency for the stalled compressor-half was as much as 12 percent lower than the standard compressor efficiency. The efficiency for the unblocked compressor-half was about midway between the curves for the blocked compressor-half and the standard compressor. The accuracy of these compressor efficiencies (computed by use of the pressures and temperatures in each compressor, half) was checked by two methods of calculation and was found to be within 2 percent. (The alternate method of calculation used is outlined in appendix B.) The efficiency results then generally substantiate the concepts of the existance of the previously discussed stall regions in the compressor.

Effect on combustor performance. - Combustion efficiency of the engine with and without blockage screens installed is shown in figure 15 for operation at altitudes of 15,000, 30,000, and 45,000 feet. The maximum difference in combustion efficiency occurred at 30,000 feet at high turbine-outlet temperatures. At this altitude, the combustor efficiency was 3.5 percent higher for the engine having blockage screens, however, the difference is probably of the same order of magnitude as the accuracy of the data. It therefore appears that the screens had no significant effect on the performance of the combustor.

Effect on turbine performance. - In figure 16 turbine efficiencies for operation with and without blockage screens are plotted against exhaust-gas temperature for operation at altitudes of 15,000, 30,000, and 45,000 feet. At 15,000 feet, the turbine efficiency was reduced only slightly by the inlet screens; whereas the reduction was about 5 percent at 45,000 feet. At all three altitudes, the decrease was slightly larger at high exhaust-gas temperatures. The reductions in turbine efficiency are attributable to the large variations in the turbine-inlet-temperature pattern existing when the blockage screens were installed.

Engine pumping characteristics. - The engine pumping characteristics, with and without blockage screens, are presented in figure 17 where engine temperature ratio is shown as a function of engine pressure ratio. The data shown are for an altitude of 45,000 feet; however, the results are similar at altitudes of 15,000 and 30,000 feet. In all cases, operation at a given engine temperature ratio resulted in much lower engine pressure ratios when screens were installed. This reduction in pressure ratio, which was first evident in figure 10, results from the reduced aerodynamic efficiency of the engine components, and is reflected, of course, in reduced engine thrust.

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Over-all engine performance. - In figure 18, the net thrust for the engine with and without blockage screens are compared for operation at altitudes of 15,000, 30,000, and 45,000 feet for the same average pressure at the compressor inlet. At all the altitudes, the loss in thrust resulting from the uneven air flow due to the blockage screens in one inlet duct varied between 20 and 25 percent for all the exhaust-gas temperatures investigated. These losses in thrust reflect both the losses in aerodynamic efficiency of the components and the reduction in air flow, but as noted earlier, do not include pressure losses in the inlet ducts. Although no data were obtained at the rated turbine-outlet temperature (1600° R), it is obvious that thrust losses at this condition would be substantial.

Specific fuel consumption data both with and without inlet blockage screens are presented in figure 19. The increase in specific fuel consumption resulting from the inlet blockage screens varied between 17 and 23 percent at all engine operating conditions. Inasmuch as the engine combustion efficiency was not significantly affected by the screens, the increases in specific fuel consumption are due to changes in aerodynamic efficiency of the components.

Operational characteristics. - During the normal operation of the engine, no significant change was noted in either the altitude starting characteristics or in acceleration characteristics. It was, however, impossible to obtain military turbine-outlet temperature at an altitude of 55,000 feet and a flight Mach number of 0.21 without encountering compressor surge when the blockage screens were installed. The occurrence of surge at this operating condition was attributed to the low ambient-air temperature. For a given turbine-outlet temperature, reducing the engine inlet temperature resulted in an increase in compressor pressure ratio because of the increase in engine temperature ratio. Also, as the engine inlet air temperature was reduced, the corrected engine speed increased.

The relation of compressor surge to corrected engine speed for operation at military rated turbine-outlet temperature is illustrated in figure 20. The data points show the corrected engine speed at which surge occurred when military temperature and engine speed were maintained while the inlet-air temperature was reduced. Military turbine-outlet temperature could thus be obtained in the region to the left of the curve, however, in the region to the right, it was possible to avoid compressor surge only by reducing the turbine-outlet temperature. Data were not obtained at altitudes above 43,500 feet because of a temporary limitation in tunnel exhauster capacity. The variation of the engine-speed limit with altitude results from the Reynolds number effect on the compressor pressure ratio and a possible change in the surge limit of the compressor.

CONCLUDING REMARKS 2716

A severe distortion of the inlet-air distribution to a turbojet engine, produced by screens in one of the twin inlets, did not affect the total-pressure distribution at the compressor outlet, and accordingly the compressor pressure ratio was greatly different for the two halves (blocked and unblocked) of the compressor. Because of the large difference in pressure ratio and also in efficiency, large temperature gradients existed around the annulus at the compressor outlet. This large circumferential gradient was reflected as variations in temperature at both the turbine inlet and the turbine outlet. Although the combustion efficiency was not affected, turbine efficiency was reduced, particularly at high-temperature levels. Compressor efficiency was reduced also, apparently as a result of the existence of local regions within the compressor which were operating in stall. At an altitude of 45,000 feet and a flight Mach number of 0.64, it appeared that the compressor-half downstream of the screen may have been operating in stall for all turbine-outlet temperatures although the engine operation as a whole was stable.

As a result of the reduced component efficiencies and air flow, the thrust was reduced by as much as 25 percent and specific fuel consumption was increased appreciably at a given exhaust-gas temperature. Operation of the engine at military temperature was impossible at high corrected engine speeds above an altitude of about 37,000 feet because of compressor surge.

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APPENDIX A

SYMBOLS

The following symbols are used in this report:

F	thrust, lb
K	constant
N	engine speed, rpm
P	total pressure, lb/sq ft abs.
p	static pressure, lb/sq ft abs.
T	total temperature, $^{\circ}R$
W	weight flow, lb/sec
W_f/F_n	specific fuel consumption based on engine fuel flow and net thrust, (lb)/(hr)(lb thrust)
γ	ratio of specific heat at constant pressure to specific heat at constant volume
δ	ratio of absolute total pressure at engine inlet to absolute static pressure at NACA standard atmosphere sea-level conditions
η	efficiency, percent
θ	ratio of absolute total temperature at engine inlet to absolute static temperature at NACA standard atmosphere sea-level conditions

Subscripts:

a	air
b	burner
c	compressor
e	engine
f	fuel

g	gas
L	left
n	net
R	right
1	cowl inlet
2	engine inlet 2716
3	compressor inlet (4 in. upstream of compressor face)
4	compressor outlet
5	turbine inlet
6	turbine outlet

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APPENDIX B

ALTERNATE METHOD OF CALCULATING COMPRESSOR EFFICIENCY

As noted in the body of the report, a method was desired to check the values of compressor efficiency computed directly in a conventional manner because of the meager instrumentation (not designed for the subject study) used at the compressor outlet.

When critical flow exists in the turbine, the corrected mass flow through the turbine remains constant and proportional to the effective area of the turbine. The corrected flow is constant for operation at maximum engine speed, hence

$$\frac{W_g\sqrt{T_5}}{P_5} = K_1 \qquad \text{(B1)}$$

If these quantities are generalized to engine-inlet conditions by the use of the factors δ and θ, and the value of 2116 is included in the constant, the following equation is obtained:

$$\frac{\dfrac{W_a\sqrt{\theta_2}}{\delta_2}\sqrt{\dfrac{T_5}{\theta_2}}}{\dfrac{P_5}{P_2}} = K_2 \qquad \text{(B2)}$$

If it is assumed that the ratio of air flow to gas flow is constant, and that the pressure drop across the combustor is a constant percentage of the compressor-outlet pressure, equation (B2) may be rewritten as follows:

$$\frac{\dfrac{W_a\sqrt{\theta_2}}{\delta_2}\sqrt{\dfrac{T_5}{\theta_2}}}{\dfrac{P_4}{P_2}} = K_3 \qquad \text{(B3)}$$

Equation (B3) then provides a relation between the compressor pressure ratio, the turbine-inlet temperature, and air flow. The value of K_3 was determined from a large quantity of data obtained previously with the undistorted inlet-air pattern. Engine air-flow values were measured. The turbine-inlet temperature T_5 was determined empirically as a function of the measured turbine-outlet temperature. The relation between these two temperatures was examined for several different engines to determine whether changes in compressor efficiency would effect the relation, however, no effect was apparent for compressor efficiency change as large as 0.10. By use of the values of T_5 thus determined from previous performance data, equation (B3) was used to find the compressor pressure ratio. 2716

Inasmuch as the enthalpy rise across the compressor equals the enthalpy drop across the turbine corrected for the ratio of air flow to gas flow, the enthalpy and therefore the temperature at the compressor outlet was determined by subtracting the enthalpy rise across the entire engine from the turbine-inlet enthalpy. The mass-flow weighted value of compressor inlet pressure used may be defined as

$$P_2 = \frac{P_{2,2}\, W_{a,L} + P_{2R}\, W_{a,R}}{W_{aL}} \tag{B4}$$

Compressor adiabatic efficiency was then calculated by use of the conventional equation

$$\eta_c = \frac{\left(\frac{P_4}{P_2}\right)^{\left(\frac{\gamma-1}{\gamma}\right)} - 1}{\frac{T_4}{T_2} - 1} \tag{B5}$$

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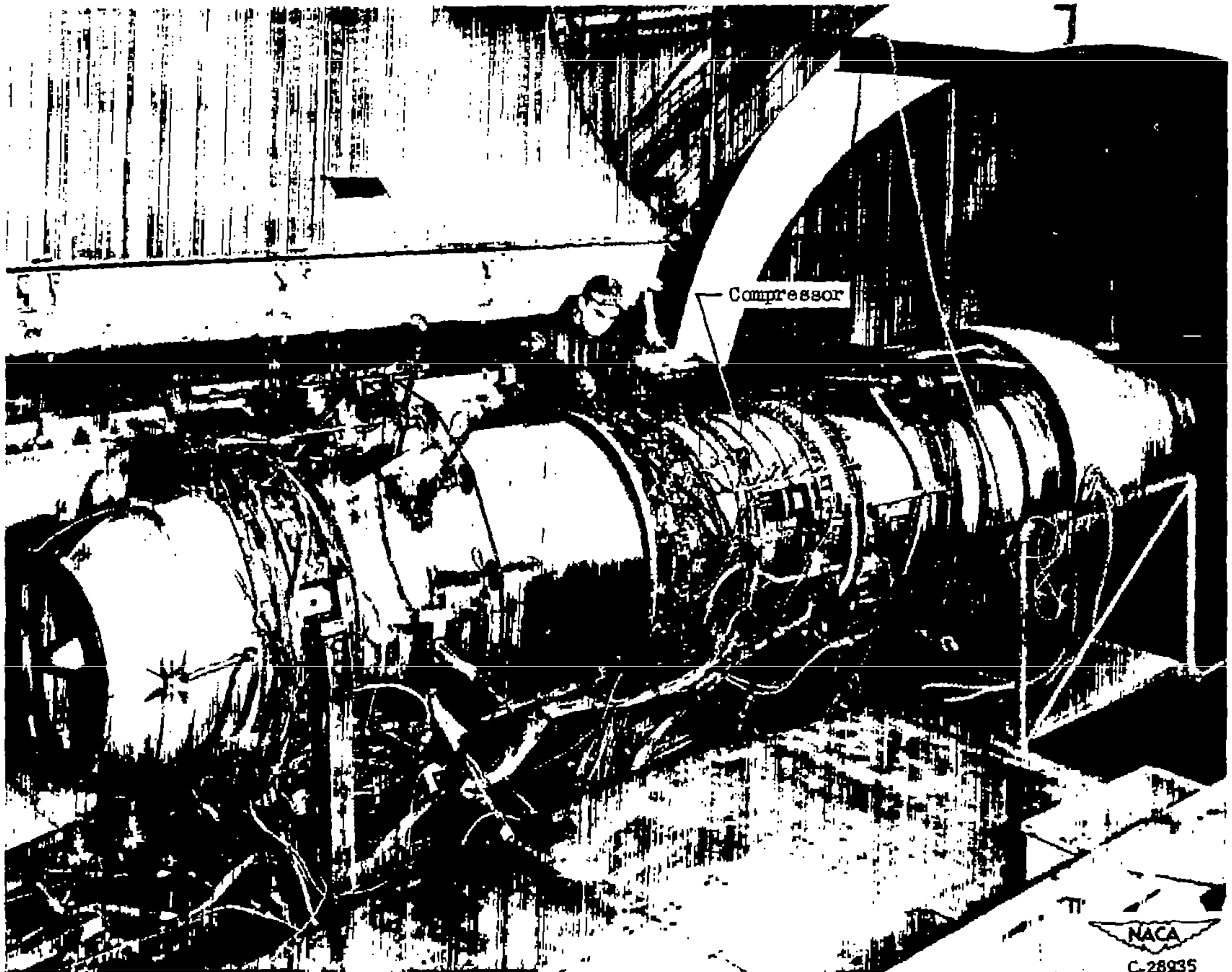

Figure 1. - Turbojet engine used for uneven air-flow-distribution study.

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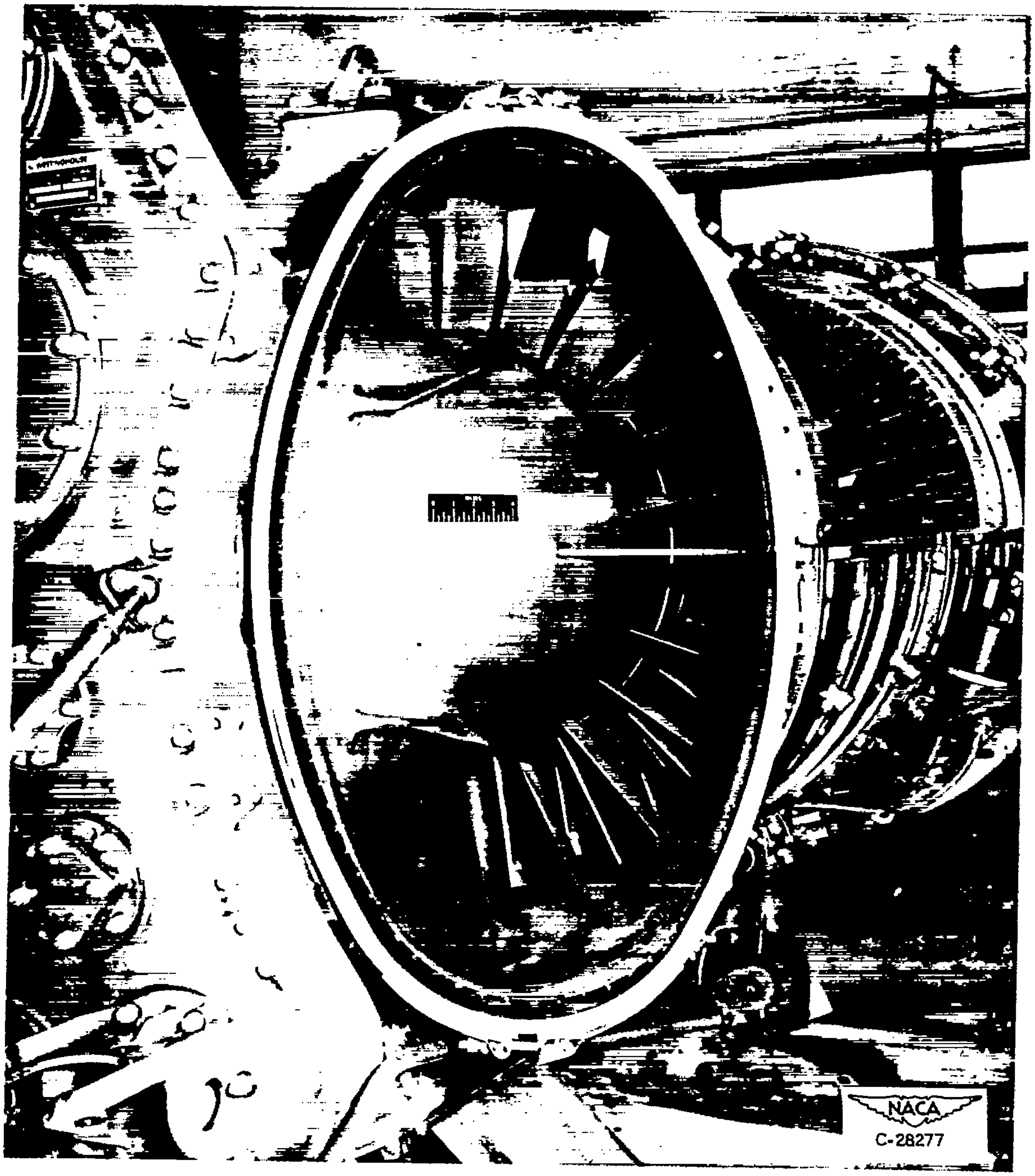
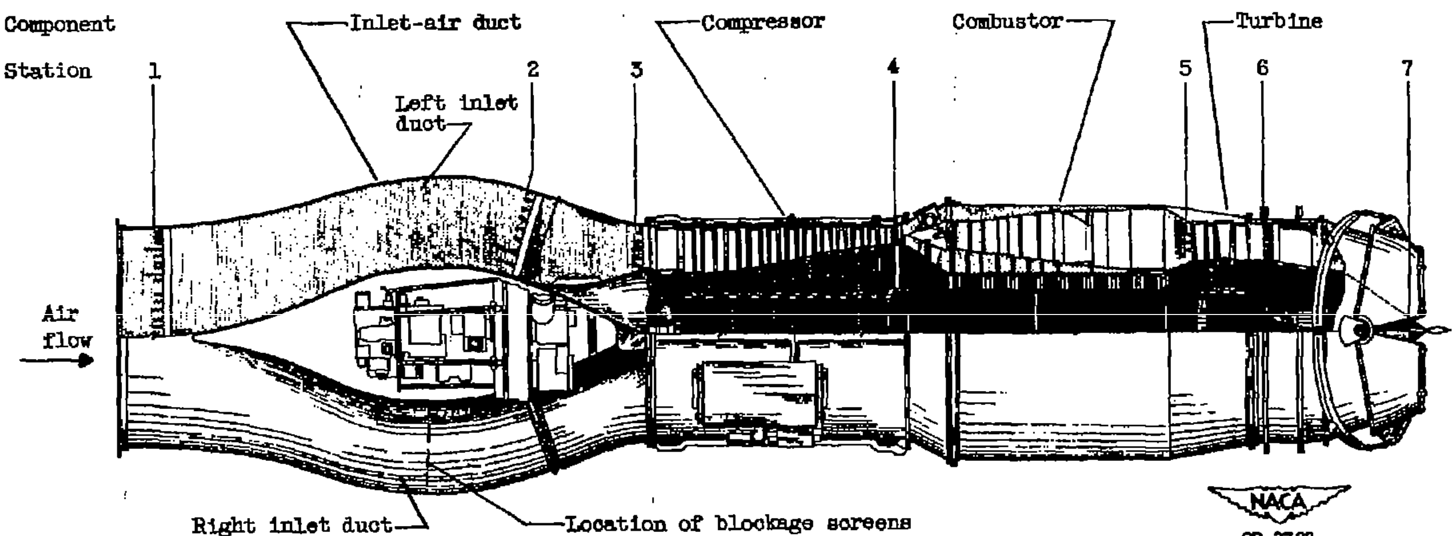


Figure 2. - Compressor-inlet-duct section.



Station	Location	Total-pressure tubes	Static-pressure tubes	Wall static-pressure orifices	Thermo-couples
1	Inlet-air duct	29	12	6	10
2	Engine inlet	18	0	4	0
3	Compressor inlet	23	3	7	0
4	Compressor outlet	18	0	3	6
5	Turbine inlet	5	0	0	10*
6	Turbine outlet	20	0	8	24
7	Exhaust-nozzle inlet	16	2	8	0

*Sonic flow probes

Figure 3. - Top view of turbojet-engine installation showing stations at which instrumentation was installed.

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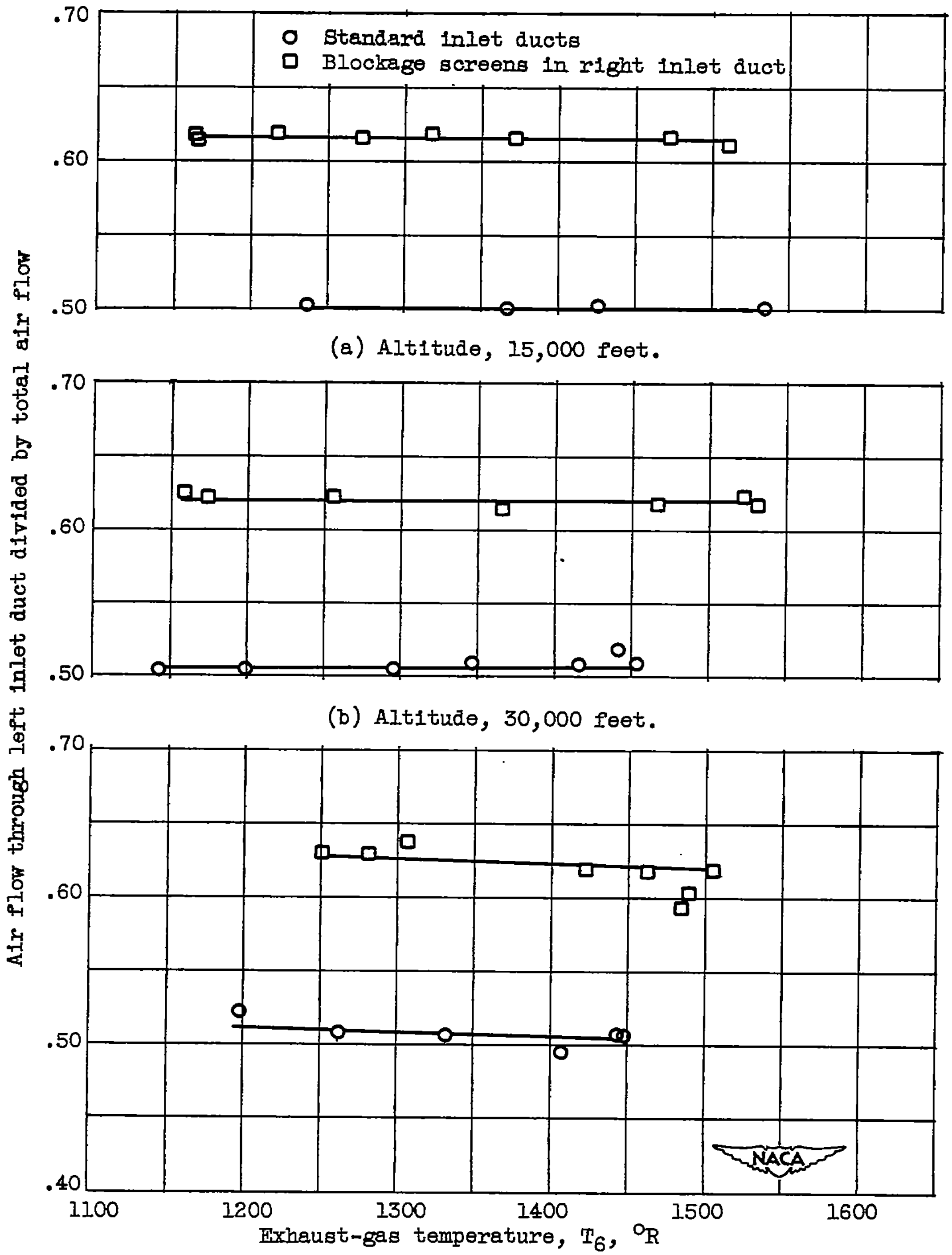

(c) Altitude, 45,000 feet.

Figure 4. - Division of air flow between inlet ducts with and without blockage screens in right inlet duct.

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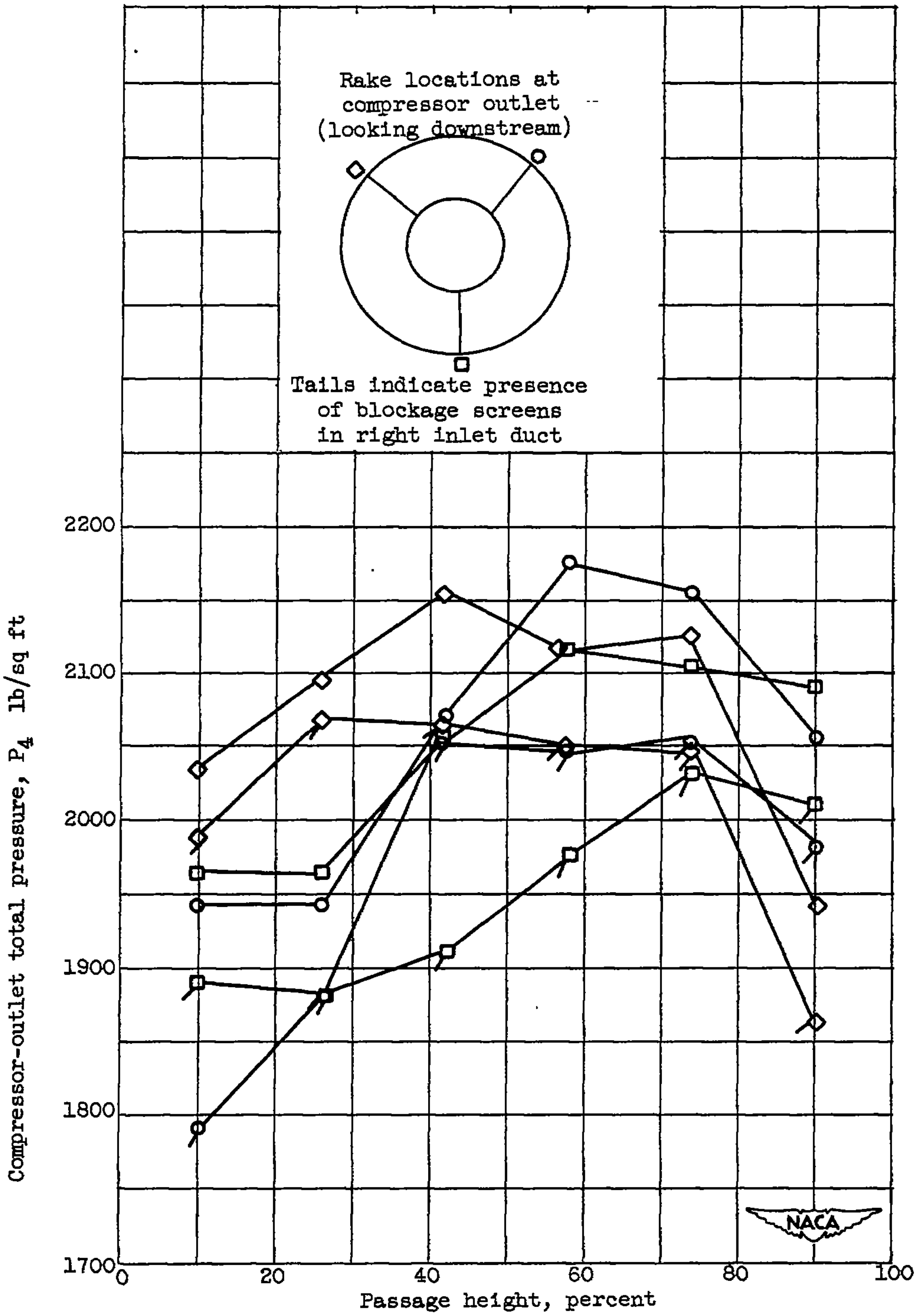

Figure 5. - Effect of blockage screens in right inlet duct on compressor-outlet pressure profiles at constant exhaust-gas temperature. Altitude, 45,000 feet; flight Mach number, 0.64.

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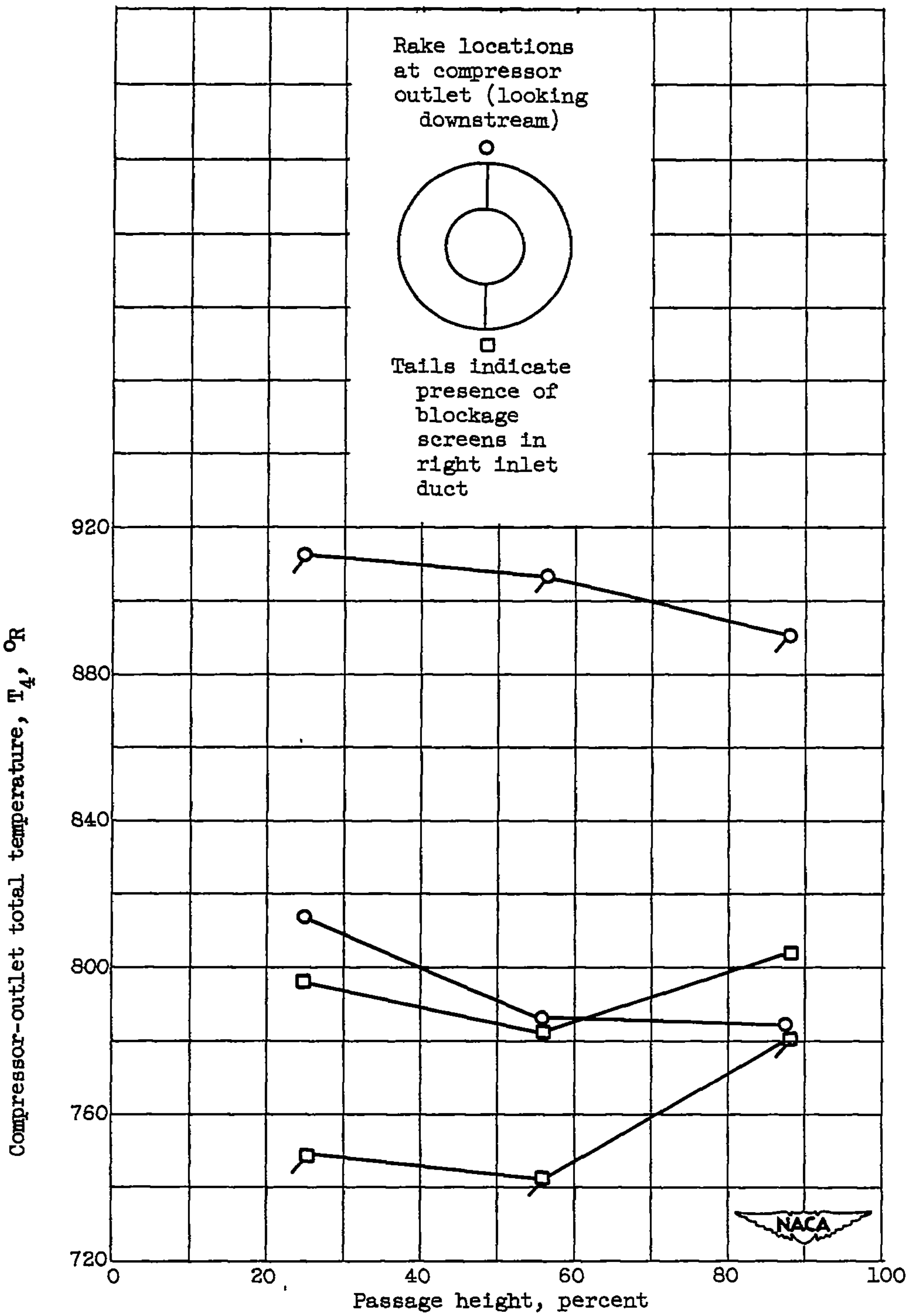

Figure 6. - Effect of blockage screens in right inlet duct on compressor-outlet temperature profiles at constant exhaust-gas temperature.

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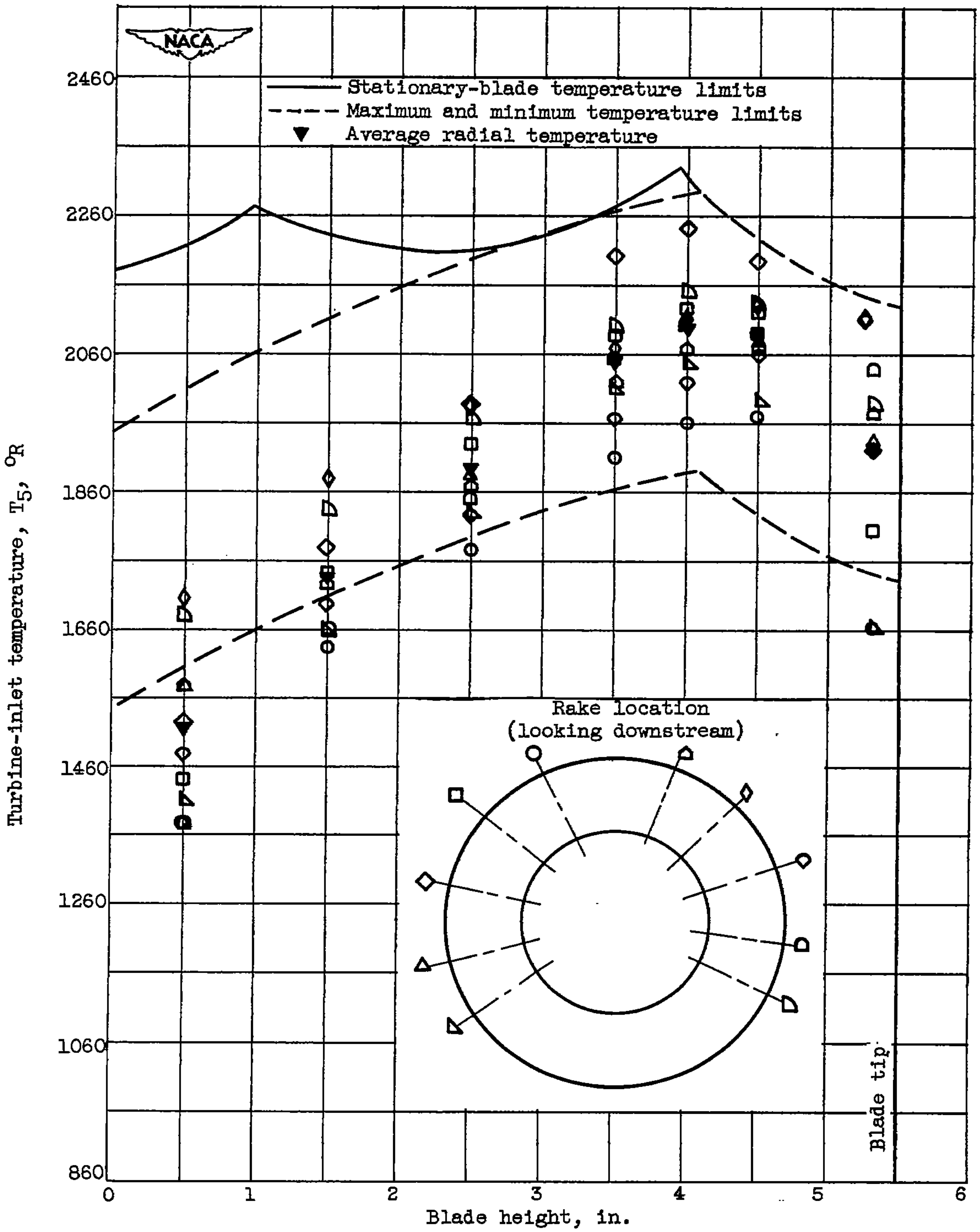

Figure 7. - Turbine-inlet temperature distribution without blockage screens in right inlet duct. Altitude, 30,000 feet; ram-pressure ratio, 1.32; exhaust-gas temperature, 1486 °R.

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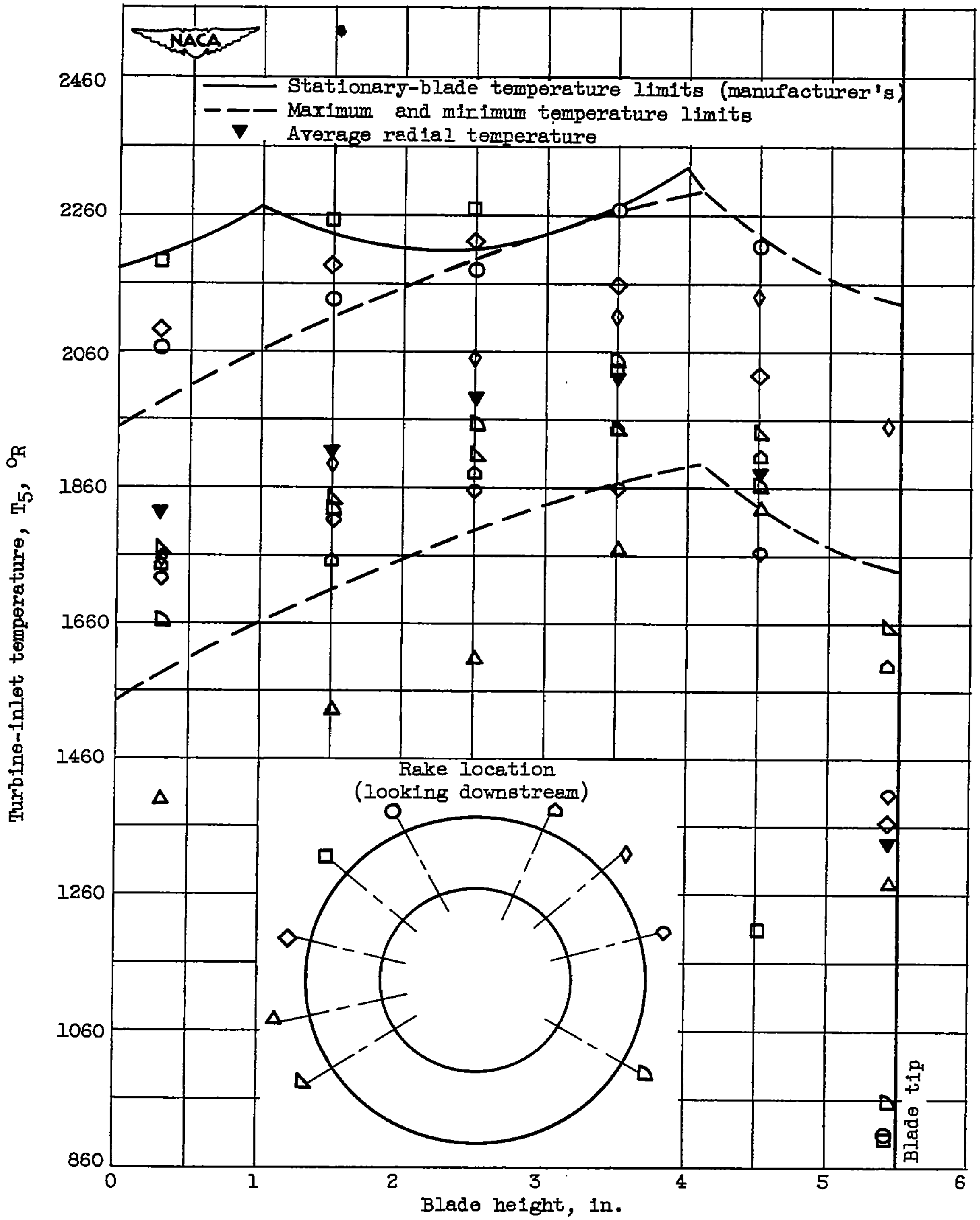

Figure 8. - Turbine-inlet temperature distribution with blockage screens in right inlet duct. Altitude, 30,000 feet; ram-pressure ratio, 1.32; exhaust-gas temperature, 1510 °R.

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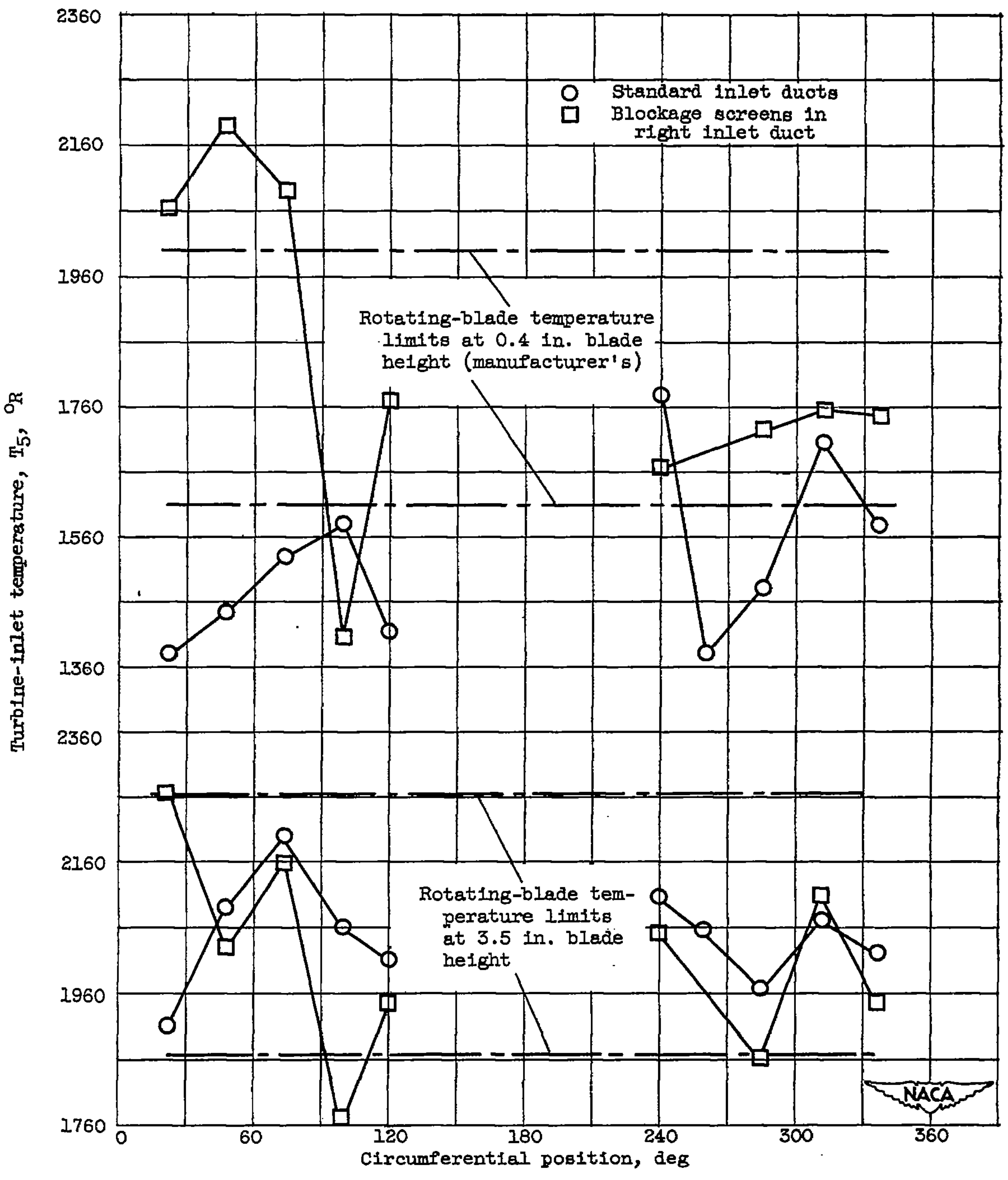

Figure 9. - Turbine-inlet circumferential temperature pattern with and without blockage screens in right inlet duct. Altitude, 30,000 feet; ram-pressure ratio, 1.32; exhaust-gas temperature, 1486° R.

2716

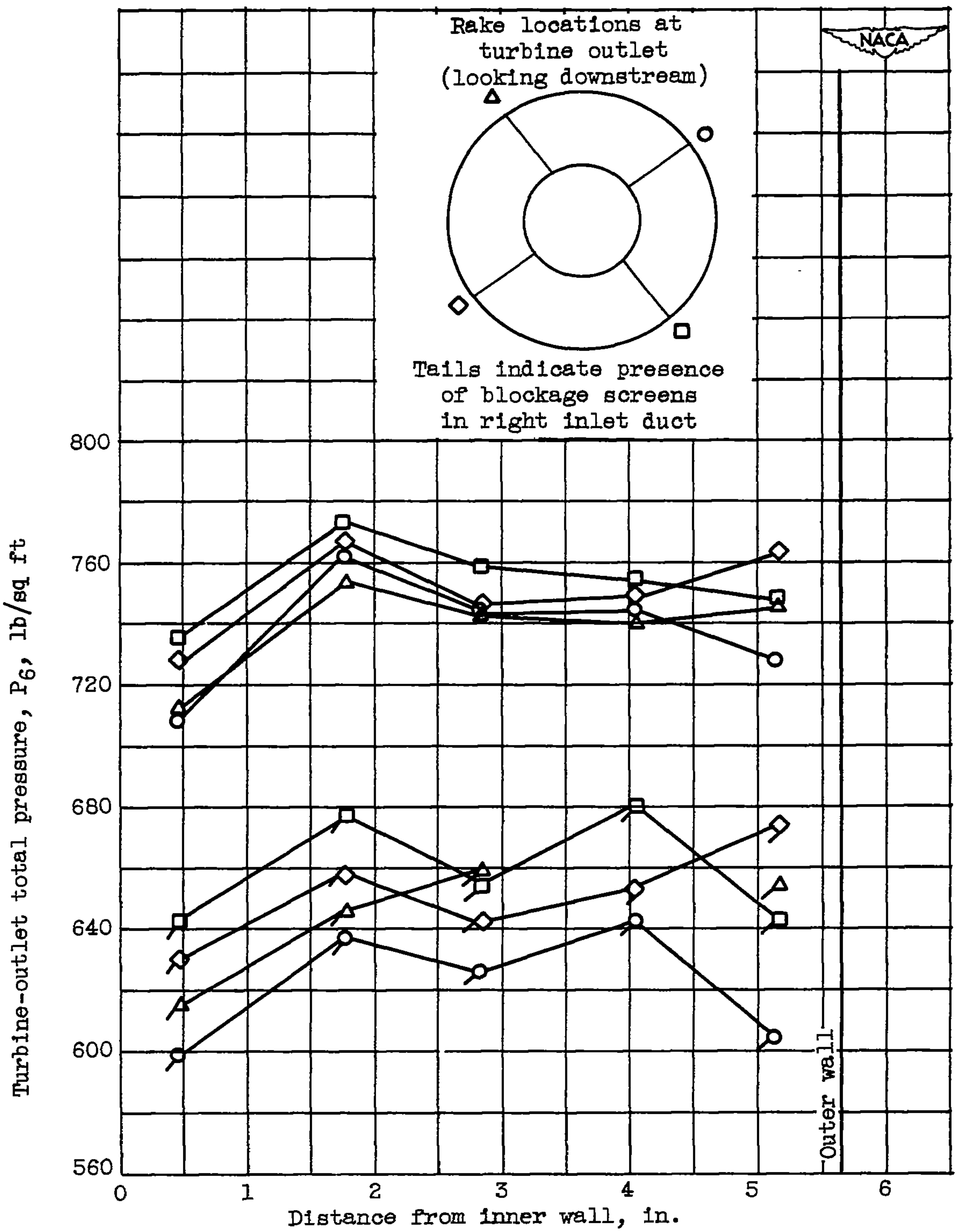

Figure 10. - Effect of blockage screens in right inlet duct on turbine-outlet pressure profiles at constant exhaust-gas temperature.

2716

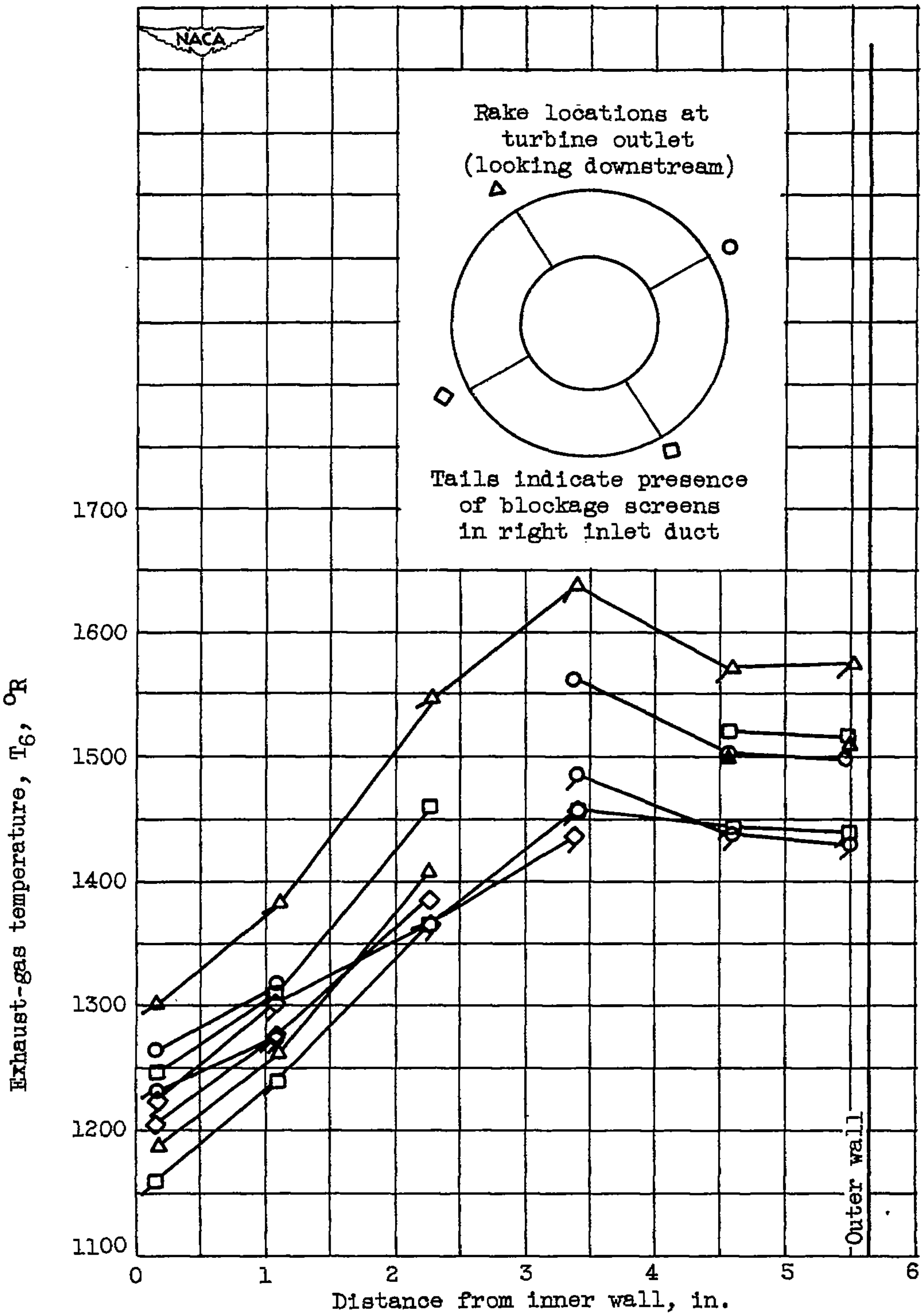

Figure 11. - Effect of blockage screens on exhaust-gas temperature distribution at constant exhaust-gas temperature.

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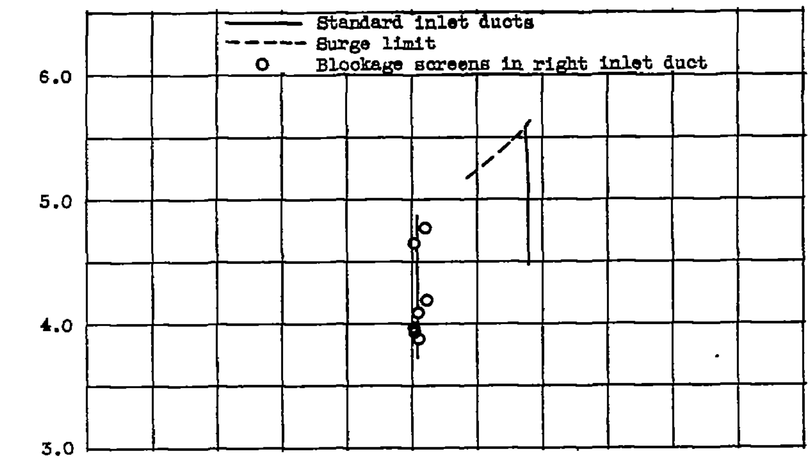
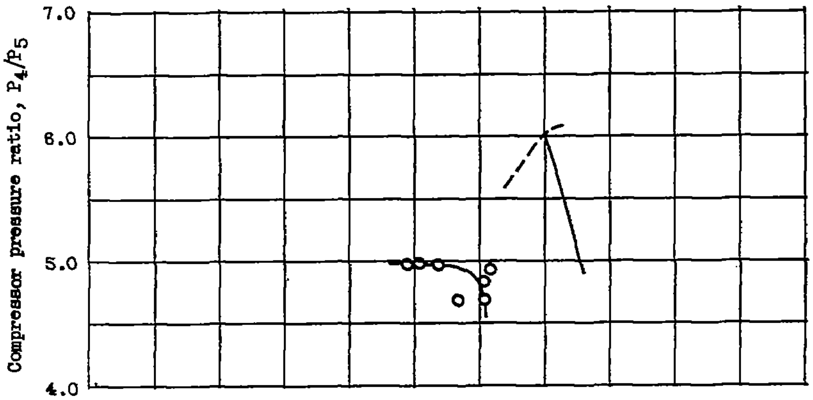
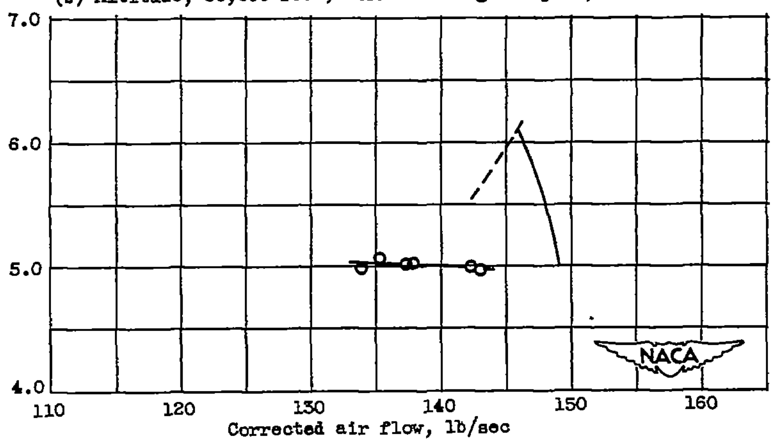


(a) Altitude, 15,000 feet; corrected engine speed, 7400 rpm.

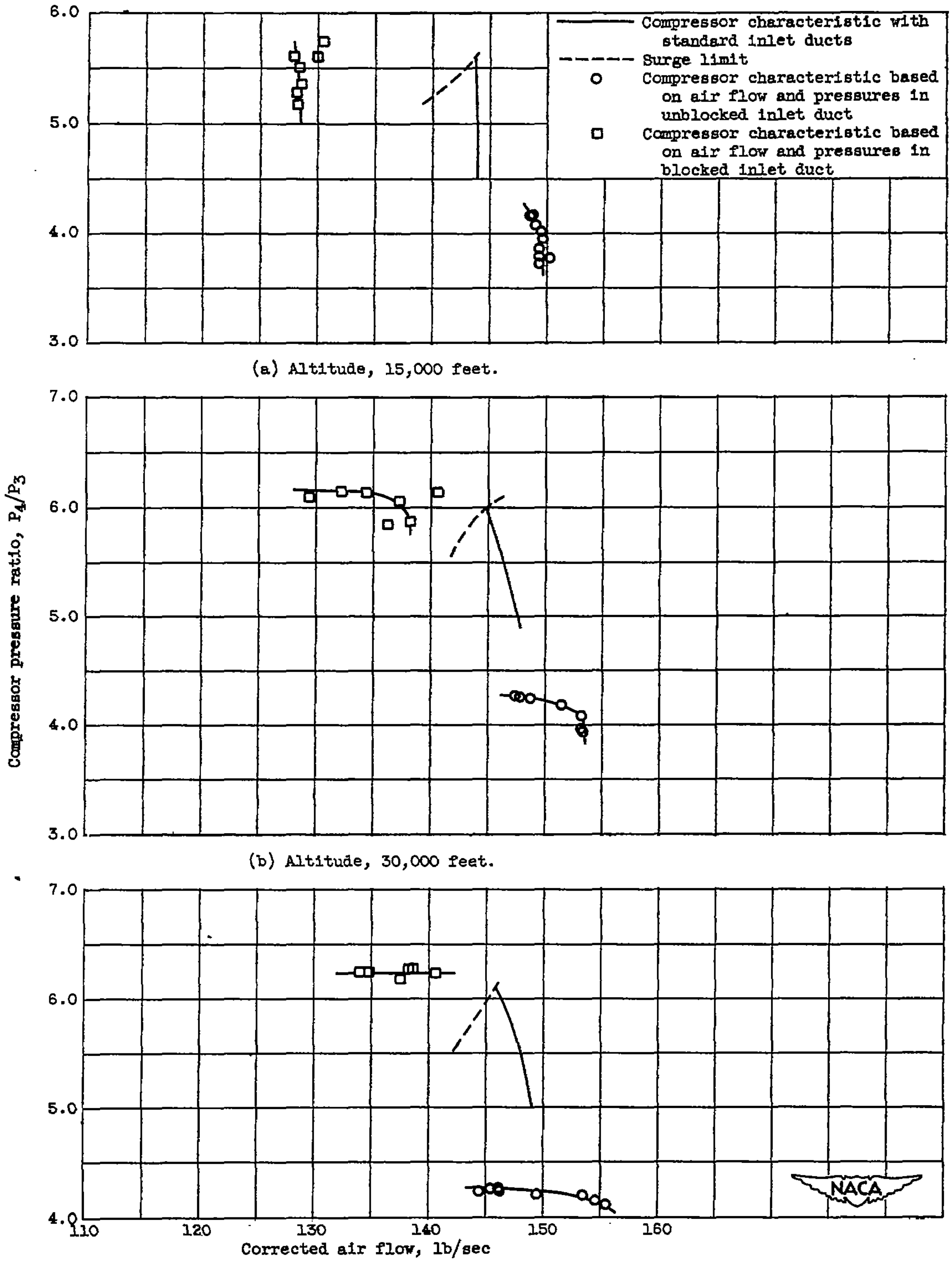


(b) Altitude, 30,000 feet; corrected engine speed, 7700 rpm.



(c) Altitude, 45,000 feet; corrected engine speed, 7790 rpm.

Figure 12. - Compressor characteristic lines for compressor with and without blockage screens in right inlet duct. (Inlet pressures averaged by mass-flow weighting.)



(c) Altitude, 45,000 feet.

Figure 13. - Compressor characteristic lines for: (1) air flow and pressures in open inlet duct and (2) air flow and pressures in blocked inlet duct. Air flow in each duct was multiplied by 2 in order to simulate complete compressor.

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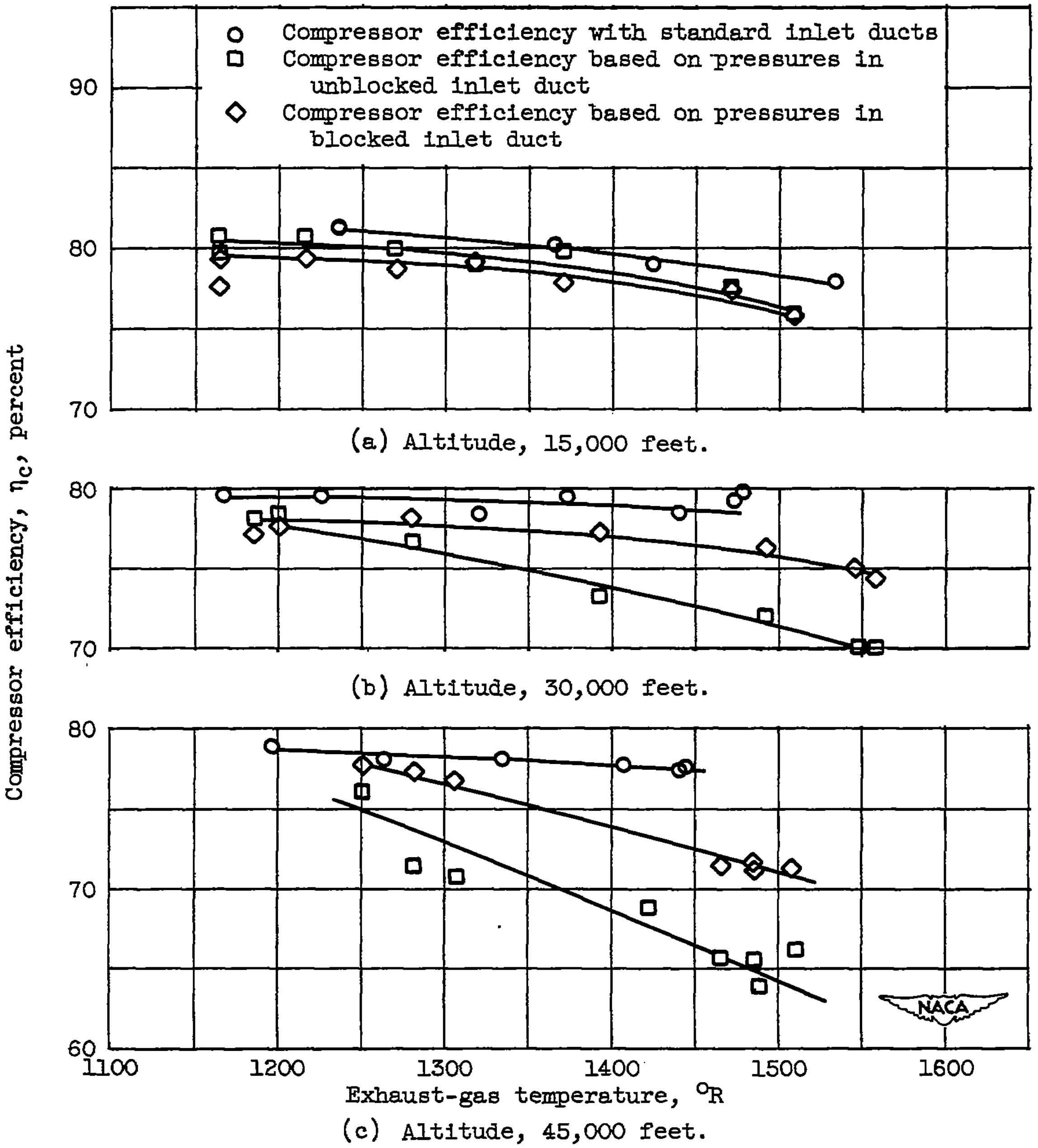

Figure 14. - Effect of blockage screens in right inlet duct on compressor efficiency for range of altitude at flight Mach number of 0.64.

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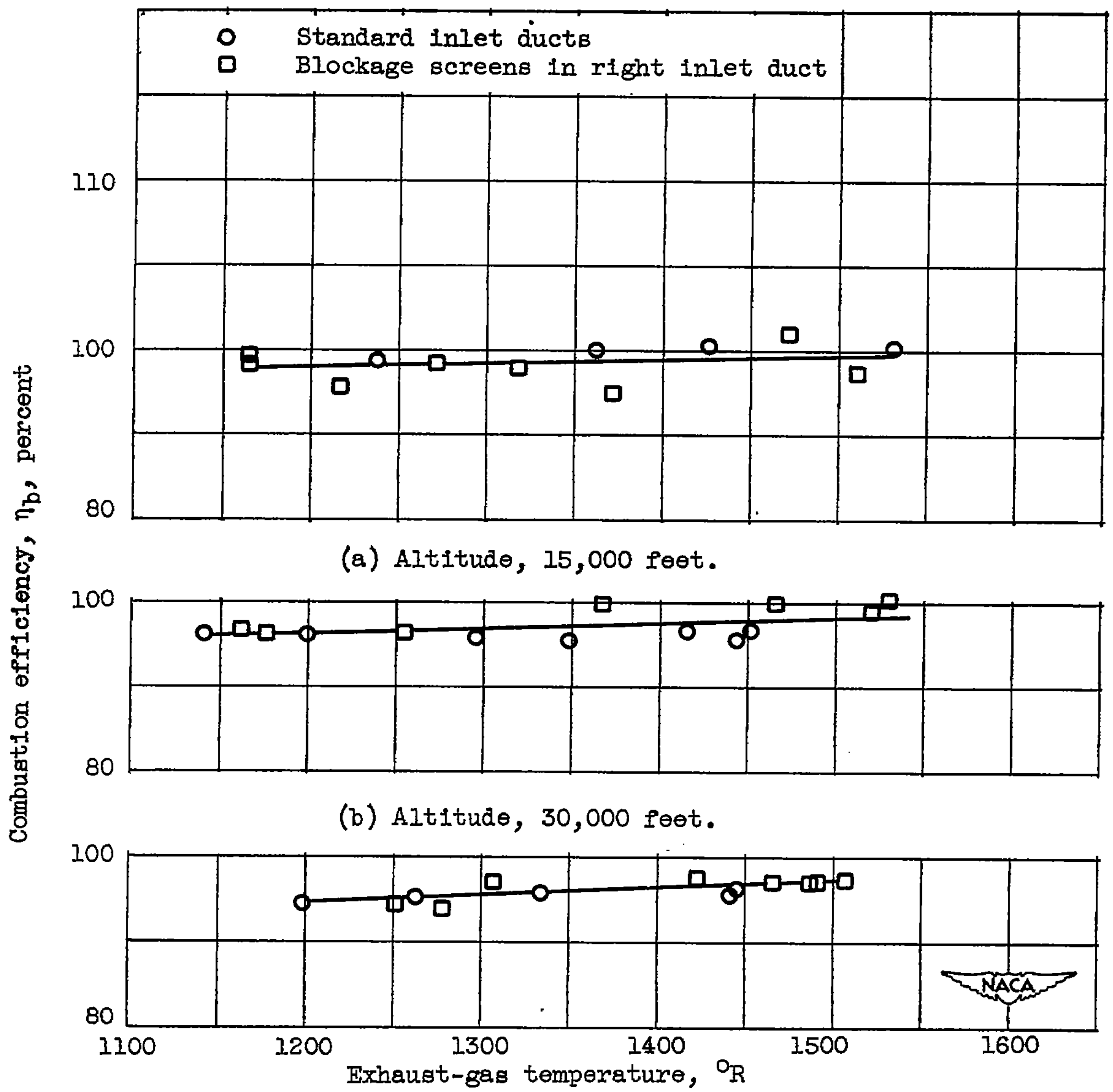

(c) Altitude, 45,000 feet.

Figure 15. - Variation of engine combustion efficiency with exhaust-gas temperature with and without blockage screens in right inlet duct. Flight Mach number, 0.64.

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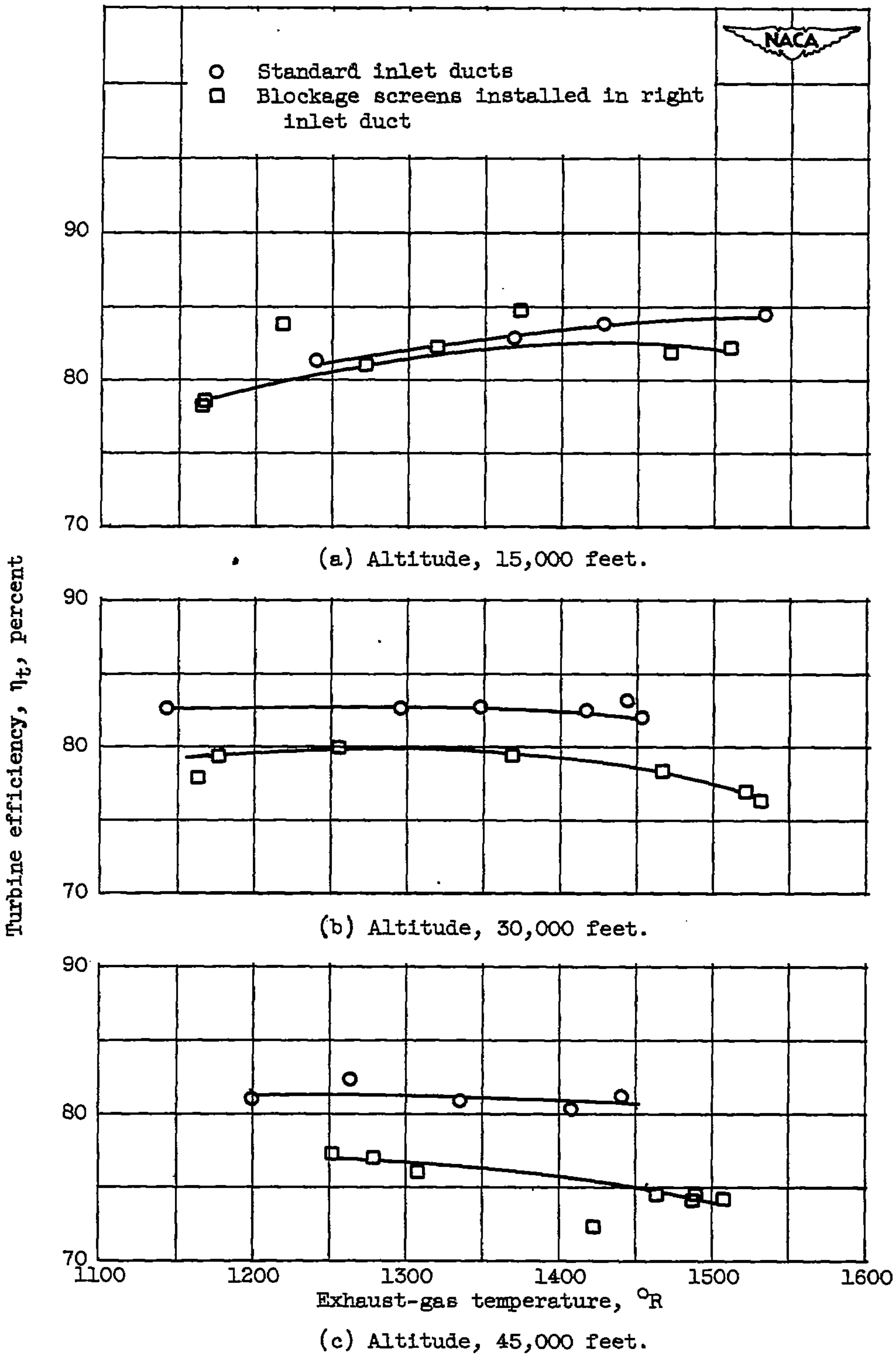

Figure 16. - Effect of blockage screens in right inlet duct on turbine efficiency at altitudes of 15,000, 30,000, and 45,000 feet. Flight Mach number, 0.64.

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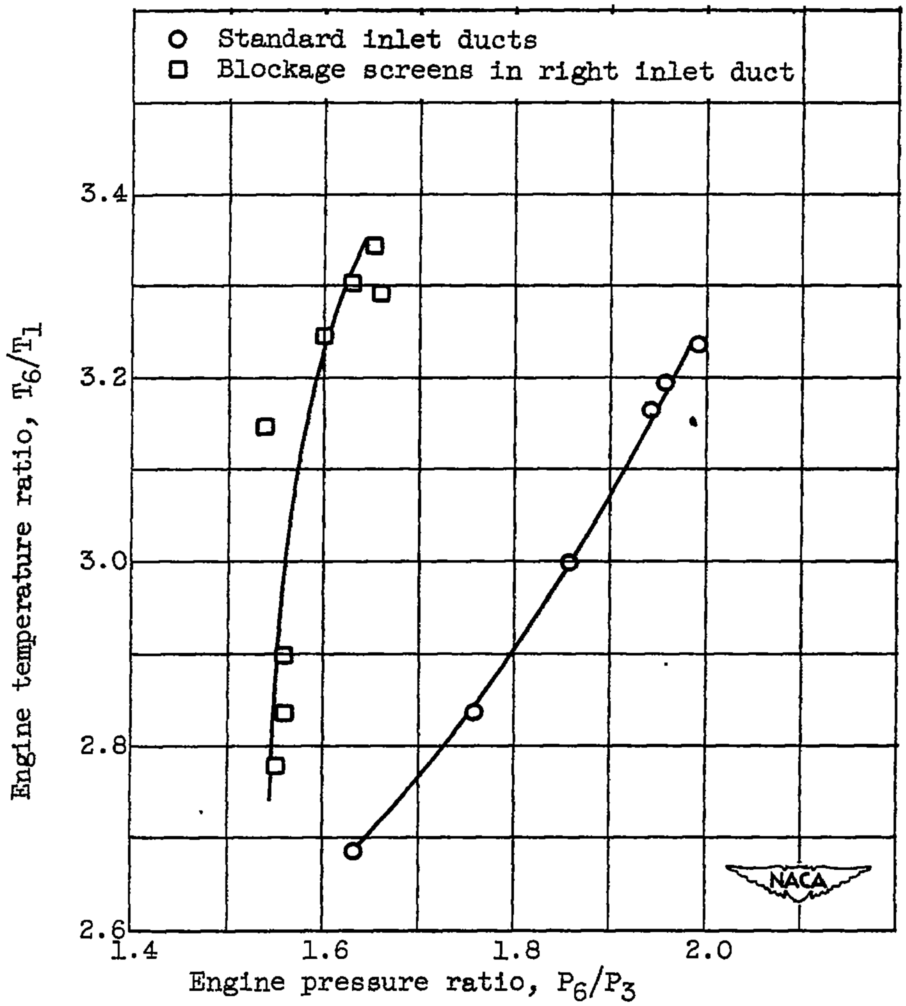
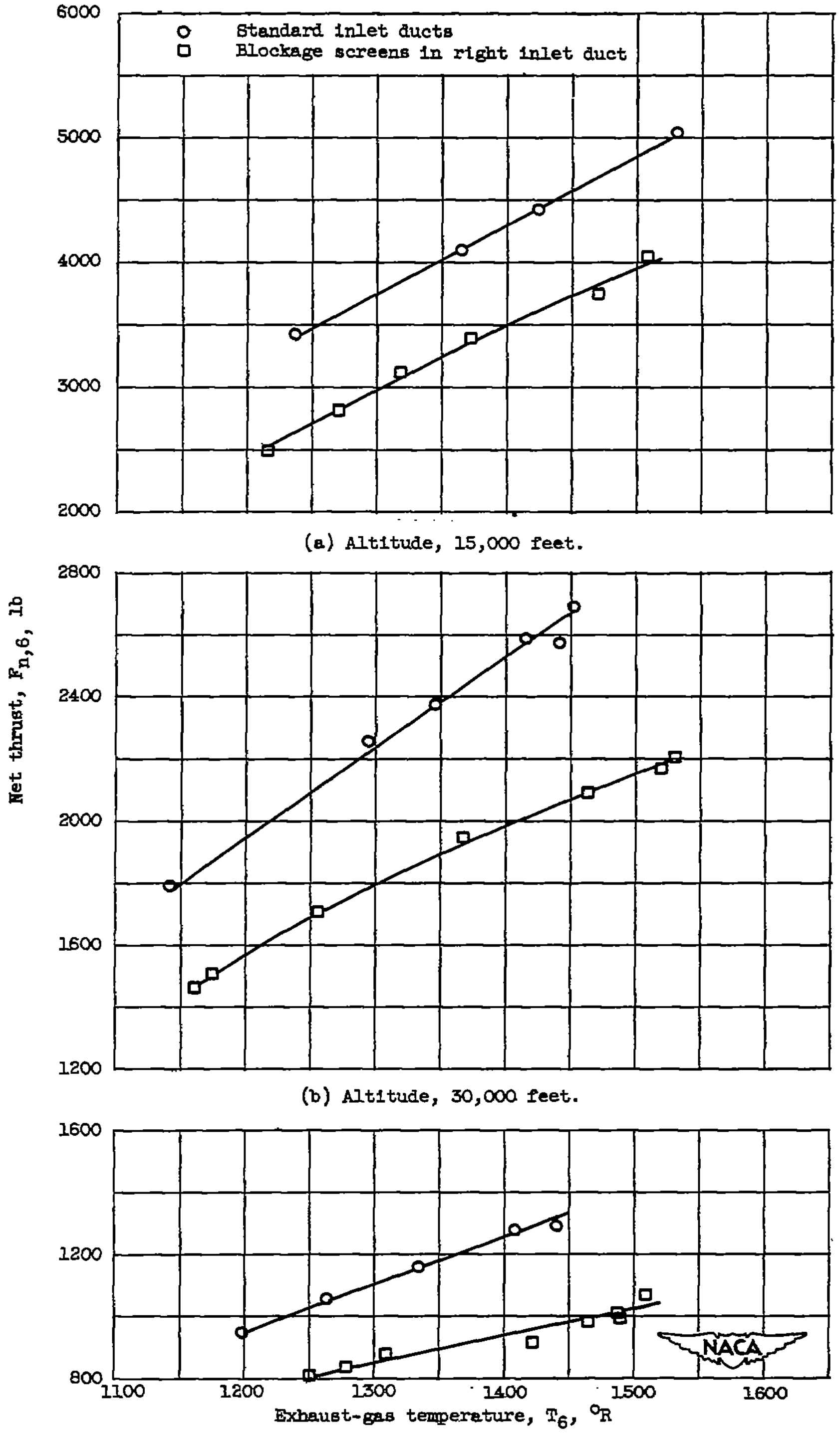


Figure 17. - Comparison of engine pumping characteristics with and without blockage screens in right inlet duct. Altitude, 45,000 feet; flight Mach number, 0.64; corrected engine speed, 7790 rpm.



(c) Altitude, 45,000 feet.

Figure 18. - Variation of net thrust with exhaust-gas temperature with and without blockage screens in right inlet duct for altitudes of 15,000, 30,000, and 45,000 feet.

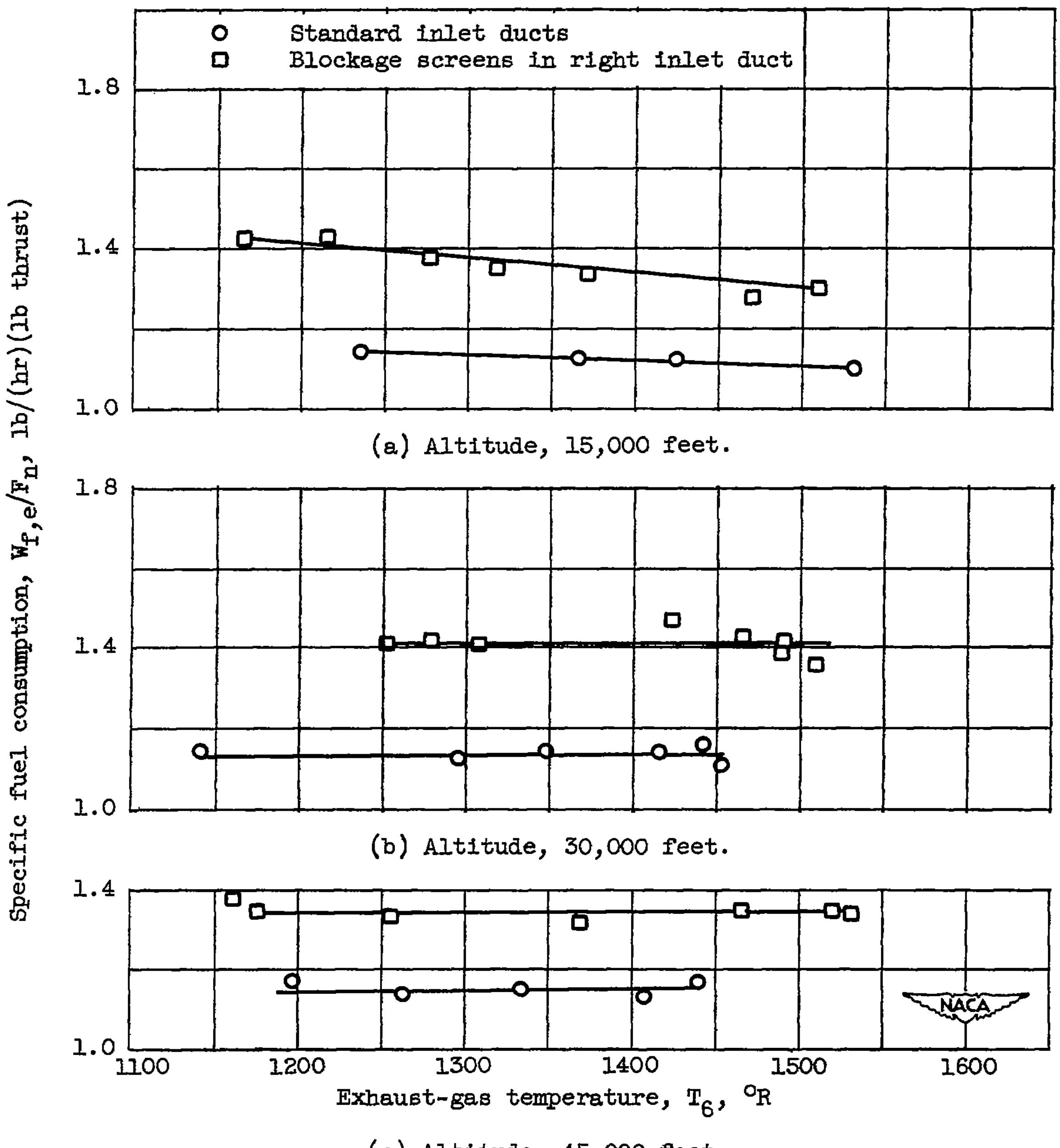


Figure 19. - Variation of specific fuel consumption with exhaust-gas temperature with and without blockage screens in right inlet duct at altitudes of 15,000, 30,000, and 45,000 feet.

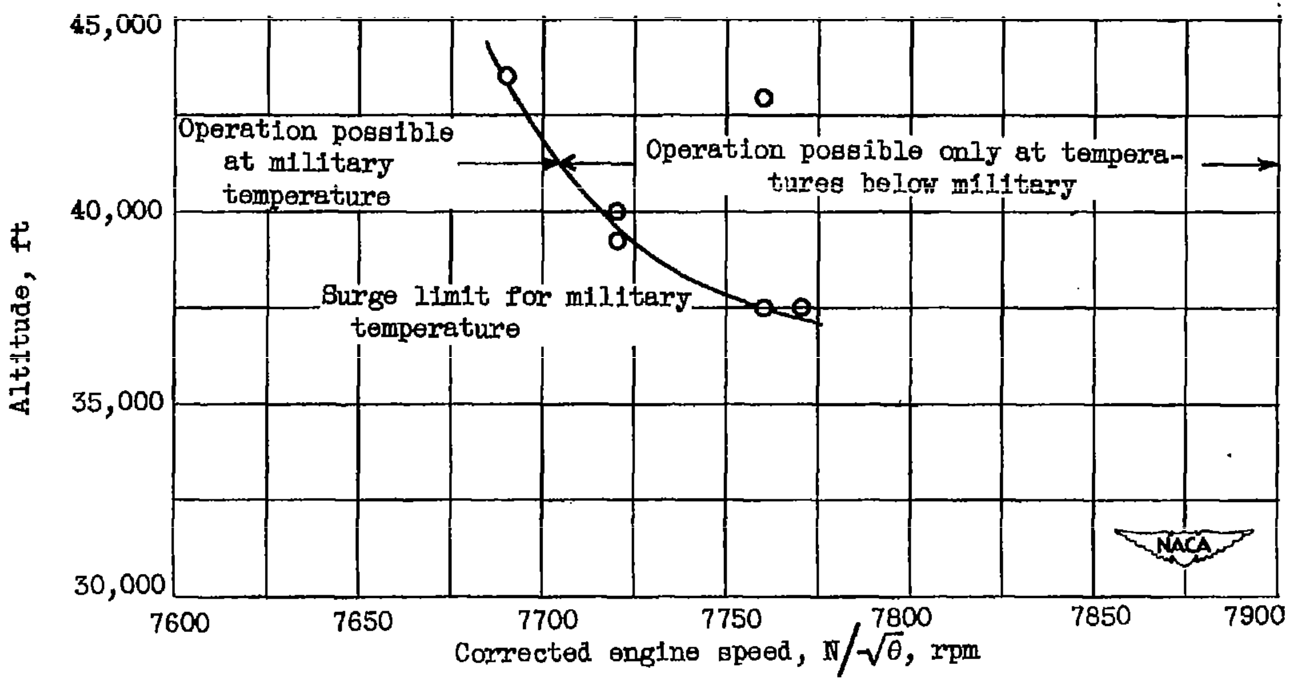


Figure 20. - Effect of altitude on maximum corrected engine speed at which operation at military rated temperature is possible.

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