RM No. SE8C15

NACA

RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Forces

PERFORMANCE OF J-33-A-21 TURBOJET-ENGINE COMPRESSOR

I - OVER-ALL PERFORMANCE CHARACTERISTICS

AT EQUIVALENT IMPELLER SPEEDS

FROM 6000 TO 13,400 RPM

By William L. Beede, Karl Kovach, and John W. R. Creagh

Flight Propulsion Research Laboratory
Cleveland, Ohio

CLASSIFIED DOCUMENT

This document contains classified information affecting the National Defense of the United States within the meaning of the Espionage Act, USC 50:31 and 32. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law. Information so classified may be imparted only to persons in the military and naval services of the United States, appropriate civilian officers and employees of the Federal Government who have a legitimate interest therein, and to United States citizens of known loyalty and discretion who of necessity must be informed thereof.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

for the

Air Materiel Command, U.S. Air Forces

PERFORMANCE OF J-33-A-21 TURBOJET-ENGINE COMPRESSOR

I - OVER-ALL PERFORMANCE CHARACTERISTICS AT EQUIVALENT IMPELLER SPEEDS FROM 6000 TO 13,400 RPM

By William L. Beede, Karl Kovach, and John W. R. Creagh

SUMMARY

The NACA is investigating a series of J-33 turbojet-engine compressors to determine the over-all and component performances and to improve theories of flow through large centrifugal compressors. The production model J-33-A-21 was operated over a range of inlet temperatures from 80° to -40° F and inlet pressures from 14 to 5 inches mercury absolute for equivalent impeller speeds from 6000 to 13,400 rpm.

At the equivalent design speed of 11,500 rpm, the compressor had a peak pressure ratio of 3.98 at an equivalent weight flow of 73.4 pounds per second and an adiabatic temperature-rise efficiency of 0.701. When the compressor speed was reduced from the design speed to 6000 rpm, the adiabatic temperature-rise efficiency increased to 0.747. At the maximum equivalent speed investigated (13,400 rpm), a peak pressure ratio of 5.09 was obtained at an adiabatic temperature-rise efficiency of 0.617 and an equivalent weight flow of 86.0 pounds per second. An increase in inlet pressure from 5.5 to 14 inches mercury absolute, with a consequent increase in Reynolds number index, improved the pressure ratio but had no apparent effect on the ratio of temperature rise through the compressor to inlet temperature. The variation of the peak adiabatic temperature-rise efficiency with inlet pressure is in the direction that would be expected from a Reynolds number effect. Decrease in the inlet temperature from 80° to -40° F, with a consequent increase in Reynolds number index, resulted in scatter of the pressure-ratio data and increased values of temperature ratio. The

variation of the adiabatic temperature-rise efficiency with inlet temperature is probably the result of heat-transfer effects and scatter in the pressure ratio.

INTRODUCTION

At the request of the Air Materiel Command, U.S. Air Forces, an investigation is being conducted at the NACA Cleveland laboratory to determine the performance characteristics of a series of J-33 turbojet-engine compressors. The objectives of the investigation are to increase the weight flow per unit frontal area of the compressor, improve the pressure ratio and efficiency at a given speed, and increase the fundamental knowledge of flow through large centrifugal compressors. Because the maximum potentialities of the compressor are being sought, a separate investigation of the compressor rather than of a complete turbojet engine is being made. The compressor will be extensively instrumented to determine the over-all performance of the compressor, the characteristic performance of the compressor components, and the state of the air at the combustion-chamber inlet-guide vanes. A series of configurations of impellers and diffusers will be experimentally investigated to determine possible sources of losses and to analyze improvements afforded by subsequent modifications. Compressor performance augmentation, such as that offered by water injection (reference 1), will also be considered.

The first investigation was made of a production model J-33-A-21 compressor. Runs were made over a range of equivalent impeller speeds from 6000 to 11,500 rpm with an inlet pressure of 14 inches mercury absolute and inlet temperature of 80° F. Additional runs at the design equivalent speed (11,500 rpm) were made with an inlet pressure of 5.5 inches mercury absolute and inlet temperatures of 0° F and -40° F to determine the effect of inlet pressure and temperature on compressor performance. A run was also made at 5 inches mercury absolute and the highest equivalent impeller speed possible, 13,400 rpm, the actual rotor speed being limited by the emergency rating of 12,000 rpm. An increase in weight flow for an equivalent impeller speed of 13,400 rpm necessitated decreasing the inlet pressure from 5.5 to 5 inches mercury absolute. Compressor performance was determined at all inlet conditions and over a range of weight flows at each speed investigated.

APPARATUS AND INSTRUMENTATION

Apparatus

The J-33-A-21 compressor assembly consists of a double-entry centrifugal impeller, a vaned diffuser, and a compressor casing. As a component of a turbojet engine this compressor produced a maximum pressure ratio of 3.90 at a weight flow of 76 pounds per second with standard sea-level inlet conditions and an actual impeller speed of 11,500 rpm. The compressor dimensions are as follows:

Impeller-inlet diameter, inches	18.31
Impeller-outlet diameter, inches	30.00
Number of impeller vanes, per side	31
Diffuser inlet-vane diameter, inches	34.06
Number of diffuser passages	14
Mean diffuser discharge diameter, inches	42.88
Diffuser outlet passage area, square inches per passage	10.41

A photograph of the experimental setup is shown in figure 1. The compressor assembly (impeller, diffuser, and casing) was mounted inside a stagnation chamber, which was an air-tight steel tank 6 feet in diameter and approximately 13 1/2 feet in length (fig. 2). Three screens were fitted into the tank near the midsection to remove any foreign particles and to insure smooth flow. Because of the large cross-sectional area of the tank, the velocity of the air through the tank was negligible and the kinetic energy of the inlet air was assumed to be small. The turbine end of the compressor was bolted to a bulkhead plate and fastened to the rear of the stagnation chamber. A single modified aircraft strut supported the accessory end of the unit from the bottom of the tank to prevent the unit from being completely supported as a cantilever.

The impeller was driven by a 9000-horsepower variable-frequency induction motor, with a maximum speed of 1793 rpm, through an 8.974:1 speed increaser. A splined coupling connected the speed increaser to the compressor impeller shaft.

The inlet air passed through a submerged adjustable orifice in the inlet ducting, into the stagnation chamber housing the compressor, and into the compressor. Air discharged from the impeller through the 14 diffuser passages into 14 diffuser-outlet transition ducts approximately 16 5/8 inches in length. A discharge duct 3 7/8 inches in diameter and 22 5/8 inches in length extended from each of the diffusor-outlet transition ducts to provide the space for compressor-outlet instrumentation. These transition and discharge ducts have an approximate over-all length of 39 inches and are not found in the conventional turbojet-engine assembly. The air was then discharged into a central collecting chamber. Two 20-inch radial outlet pipes on diametrically opposite sides of the collecting chamber discharged the air into a common 24-inch duct connected to the laboratory exhaust facilities.

Compressor inlet and outlet pressures were regulated by butterfly throttle valves. The inlet ducting, stagnation chamber, and the 14 diffuser discharge ducts were insulated to minimize heat transfer between the working fluid and the room air.

Instrumentation

The weight flow through the compressor was measured by a submerged adjustable orifice located in a straight section of the inlet ducting. The pressure drop across the orifice was measured by a water differential manometer. The temperature and the static pressure upstream of the orifice were measured to determine the density of the air.

Two thermocouple rakes on opposite sides of the stagnation chamber together with two total-pressure rakes and two static-pressure taps were used to determine the state of the inlet air. Each of the thermocouples and total-pressure tubes was located at the root-mean-square radius of the three annular areas. The wall static-pressure taps were located in the same plane as the thermocouple rakes and total-pressure rakes. All instrumentation in the stagnation chamber was made in a plane downstream of the screens, approximately midway between the screens and the compressor installation.

Compressor outlet measurements were taken in the 14 diffuser discharge ducts approximately 34 1/2 inches from the diffuser elbow. Two wall static-pressure taps were installed on either side of each duct. Two total-pressure tubes were installed 90° from the static-pressure taps and placed at a position one third the passage diameter. In addition, a single thermocouple was located at the center of each duct. All outlet measurements were made in the same cross-sectional plane.

Pressures were measured with water and mercury manometers. All temperatures were measured on a calibrated potentiometer in conjunction with a spotlight galvanometer. The speed of the compressor was determined by an electric chronometric tachometer.

The precision of the measurements are estimated to be within the following limits:

Temperature, °F	±0.5
Pressure, inches mercury absolute	±0.04
Air weight flow, percent	-0.50 to -1.50
Speed, percent	±0.3

METHODS

The runs to determine the over-all performance characteristics of the compressor were made at 80° F and at the highest inlet pressure possible as limited by the power and gear ratio of the drive unit. Runs to determine the effect of inlet pressure and temperature were made. The lowest inlet temperature investigated was -40° F, which could be obtained only by reducing the inlet pressure to approximately 5.5 inches mercury absolute because of the limited quantity of refrigerated air available. A run was also made with an inlet temperature of 0° F. A summary of the conditions is given in the following table:

Equivalent impeller speed, $N/\sqrt{\theta}$ (rpm)	Equivalent tip speed, $U/\sqrt{\theta}$ (ft/sec)	Inlet pressure (in. Hg abs.)	Inlet temperature[1] (°F)	Determine effect of
6,000	786	14.0	80	Speed
7,000	916	14.0	80	
8,500	1113	14.0	80	
9,000	1178	14.0	80	
10,000	1309	14.0	80	
11,000	1440	14.0	80	
11,500	1505	14.0	80	Inlet pressure
11,500	1505	5.5	80	
11,500	1505	5.5	0	Inlet temperature
11,500	1505	5.5	-40	
13,400	1755	5.0	-40	Speed

[1]Room-air temperature varied from 75° to 85° F

All data were corrected to NACA standard sea-level conditions where:

N actual impeller rotative speed, rpm
U actual impeller tip speed, feet per second
δ ratio of inlet total pressure to sea-level pressure
θ ratio of inlet total temperature to sea-level temperature

RESULTS AND DISCUSSION

Effect of speed. - In figure 3, the pressure ratio P_2/P_1 is shown as a function of equivalent weight flow $W\sqrt{\theta}/\delta$ and equivalent volume flow $Q/\sqrt{\theta}$ with efficiency contours. The peak pressure ratio at the design equivalent speed of 11,500 rpm was 3.98 and the flow at this point was 73.4 pounds per second. Figure 4 presents the corresponding variation of compressor adiabatic temperature-rise efficiency η_{ad} with equivalent weight flow. Peak adiabatic temperature-rise efficiency at the design equivalent speed of 11,500 rpm was 0.701 and was obtained at an equivalent weight flow of 73.4 pounds per second. When the compressor speed was reduced from 11,500 to 8500 rpm, the peak efficiency increased slightly to 0.710; peak efficiency then increased to 0.747 as the speed was reduced to 6000 rpm.

The performance of the compressor at the maximum permissible speed in this installation is shown in figure 5. A peak pressure ratio of 5.09 was obtained at an equivalent weight flow of 86.0 pounds per second and an adiabatic temperature-rise efficiency of 0.617, which is 0.084 lower than that obtained at the design speed. This drop in efficiency indicates a critical flow condition between 11,500 and 13,400 rpm.

Effect of inlet temperature. - The effect of inlet temperature on adiabatic temperature-rise efficiency and pressure ratio is presented in figure 6. The peak adiabatic temperature-rise efficiency was affected only slightly when the inlet temperature was reduced from 80° to 0° F. The peak efficiency then dropped 0.013 when the inlet temperature was reduced to -40° F. The efficiency at an inlet temperature of 0° F was higher than at 80° F in general, but between 0° and -40° F, the trend is apparently reversed. The maximum variation in peak pressure ratio was slightly more than 0.1 (approximately 2.5 percent). The peak pressure ratio increased with a drop in temperature. The effect of inlet temperature on equivalent weight flow was small (1.0 percent) and within the accuracy of the air metering device.

Effect of inlet pressure. - The effect of inlet pressure on adiabatic temperature-rise efficiency and pressure ratio is presented in figure 7. The peak adiabatic temperature-rise efficiency decreased 0.010 when the inlet pressure was decreased from 14 to 5.5 inches mercury absolute. Over the range of air flows obtained, an approximate decrease of 0.010 was observed at a constant weight flow with a decrease in inlet pressure. The peak pressure ratio decreased approximately 0.08 (2.0 percent) when the inlet pressure was reduced to 5.5 inches mercury absolute. The equivalent weight flow was decreased with a decrease in air pressure. This decrease amounted to 2.5 pounds per second or approximately 3 percent when the inlet pressure was reduced from 14 to 5.5 inches mercury absolute. Data for inlet pressure of 29.92 inches mercury absolute would probably show a corresponding increase in weight flow.

Effect of Reynolds number. - The variation of adiabatic temperature-rise efficiency, peak pressure ratio, and temperature ratio $(T_2 - T_1)/T_1$ with Reynolds number index $P_1/(\mu\sqrt{T_1})$ is presented in figure 8. An increase in inlet pressure from 5.5 to 14 inches of mercury absolute with a consequent increase in the Reynolds number index resulted in an improved peak pressure ratio, whereas a decrease in the inlet temperature caused a scatter of pressure-ratio data. Increase in the inlet pressure and Reynolds number index caused no appreciable effect upon $(T_2 - T_1)/T_1$. An increase in the Reynolds number index with a decrease in inlet temperature from 80° F to -40° F resulted in increasing values of $(T_2 - T_1)/T_1$. This trend may be ascribed to heat transfer. The variation in peak adiabatic temperature-rise efficiency with inlet pressure is in the direction that would be expected from a Reynolds number effect; however, the variation of efficiency with inlet temperature and its resultant Reynolds number index is fortuitous. This variation is probably the result of scatter in over-all pressure ratio and of heat-transfer effects.

SUMMARY OF RESULTS

An investigation of the performance of the J-33-A-21 turbojet-engine compressor produced the following results:

1. At an equivalent design speed of 11,500 rpm the compressor had a maximum pressure ratio of 3.98 at an equivalent weight flow of 73.4 pounds per second and an adiabatic temperature-rise efficiency of 0.701.

2. When the compressor equivalent speed was reduced from 11,500 to 8500 rpm, the peak adiabatic temperature-rise efficiency increased slightly to 0.710; peak efficiency then increased to 0.747 as the speed was further reduced to 6000 equivalent rpm.

3. At the maximum equivalent speed investigated, 13,400 rpm, a peak pressure ratio of 5.09 was obtained at an adiabatic temperature-rise efficiency of 0.617 and an equivalent weight flow of 86.0 pounds per second.

4. With a decrease in inlet temperature from 80° to 0° F the peak adiabatic temperature-rise efficiency was affected only slightly; the peak efficiency dropped 0.013 when the inlet temperature was reduced to -40° F. Over the greater part of the flow range the efficiency at an inlet temperature of 0° F was higher than that at 80° F, but then decreased as the inlet temperature was reduced to -40° F.

5. With a decrease in inlet temperature from 80° to -40° F, the maximum variation in peak pressure ratio was slightly greater than 0.1 (approximately 2.5 percent). The peak pressure ratio obtained with the inlet temperature of 0° F was greater than that observed with the inlet temperature of -40° F; peak pressure ratio with inlet temperature of 80° F was less than that obtained at the two lower inlet temperatures, 0° F and -40° F.

6. The effect of inlet temperature on equivalent weight flow was small (1.0 percent) and within the accuracy of the air metering device.

7. Peak adiabatic temperature-rise efficiency decreased 0.010 when the inlet pressure was reduced from 14 to 5.5 inches mercury absolute at a constant inlet temperature of 80° F. Over the range of air flows obtained, an approximate decrease of 0.010 was observed at a constant weight flow with a decrease in inlet pressure.

8. The peak pressure ratio decreased approximately 0.08 or 2 percent when the inlet pressure was reduced from 14 to 5.5 inches mercury absolute at a constant inlet temperature of 80° F.

9. The equivalent weight flow decreased as the inlet pressure was reduced. This decrease amounted to 2.5 pounds per second, or approximately 3 percent when the inlet pressure was reduced from 14 to 5.5 inches mercury absolute at a constant inlet temperature of 80° F. Data for inlet pressure of 29.92 inches mercury absolute would probably show a corresponding increase in weight flow.

10. Variation in the inlet pressure from 5.5 to 14 inches mercury absolute with a consequent increase in Reynolds number index resulted in an improved over-all pressure ratio but caused no appreciable effect on the temperature ratio. The variation of peak adiabatic temperature-rise efficiency with inlet pressure and Reynolds number index is in the direction that would be expected from a Reynolds number effect.

11. Variation in the inlet temperature from 80° to -40° F with a consequent increase in Reynolds number index resulted in scatter of the over-all pressure ratio and in increasing values of the temperature ratio; this increase is probably due to heat transfer. The variation of the peak adiabatic temperature-rise efficiency with inlet temperature and Reynolds number index is fortuitous. This variation is probably the result of scatter in the over-all pressure ratio and of heat-transfer effects.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, March 15, 1948.

William L. Beede

William L. Beede,
Aeronautical Research
Scientist.

Karl Kovach

Karl Kovach,
Aeronautical Research
Scientist.

John W. R. Creagh

John W. R. Creagh,
Aeronautical Research
Scientist.

Approved:

Robert O. Bullock,
Aeronautical Research
Scientist.

Oscar W. Schey,
Aeronautical Research
Scientist.

mjz

REFERENCES

1. Beede, William L.: Performance of J-33-A-21 and J-33-A-23 Compressors With and Without Water Injection. NACA RM No. SE8A19, Army Air Forces, 1948.

2. Ellerbrock, Herman H., Jr., and Goldstein, Arthur W.: Principles and Methods of Rating and Testing Centrifugal Superchargers. NACA ARR, Feb. 1942.

946

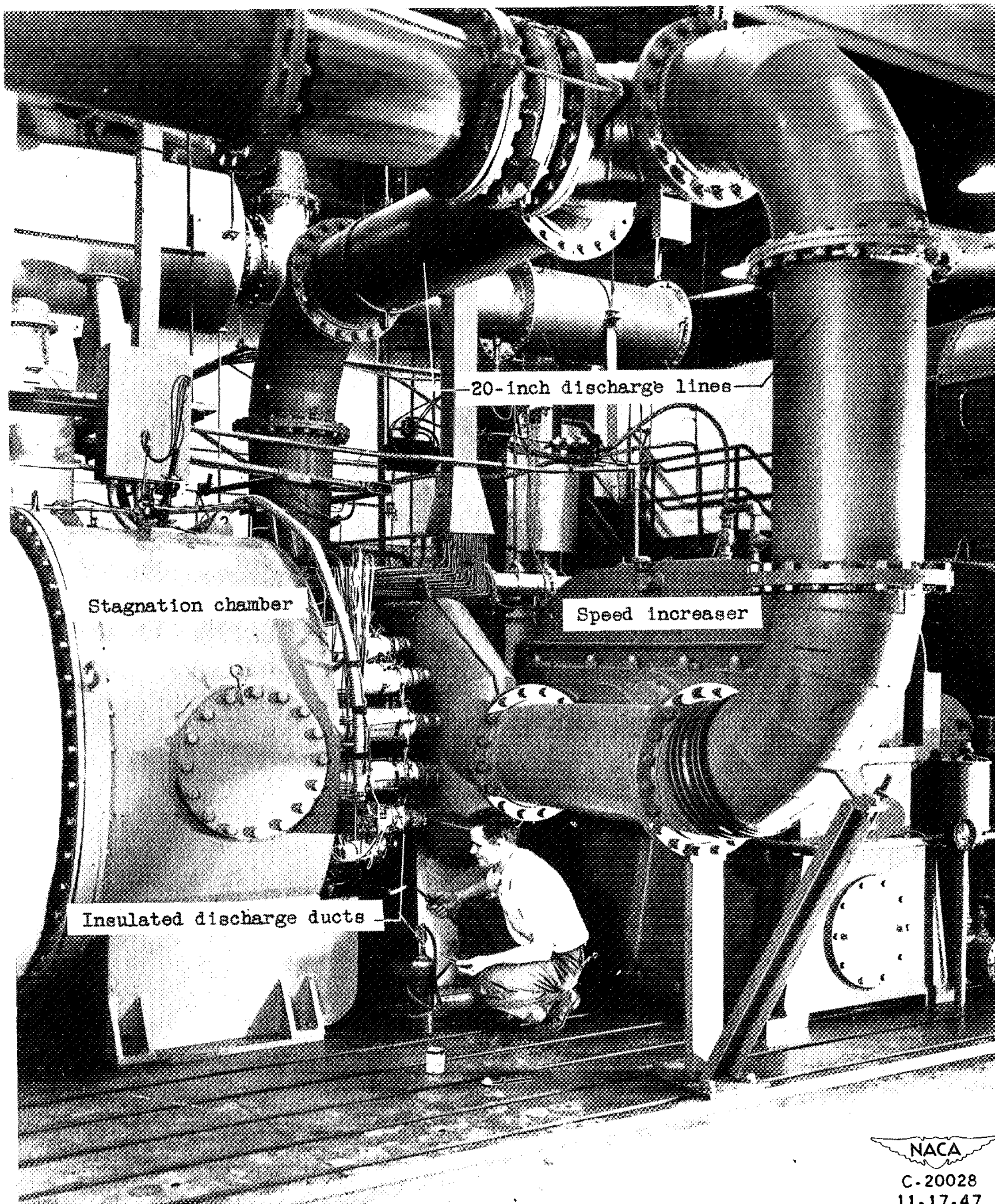

Figure 1. - Setup for investigating performance of J-33-A-21 turbojet engine compressor.

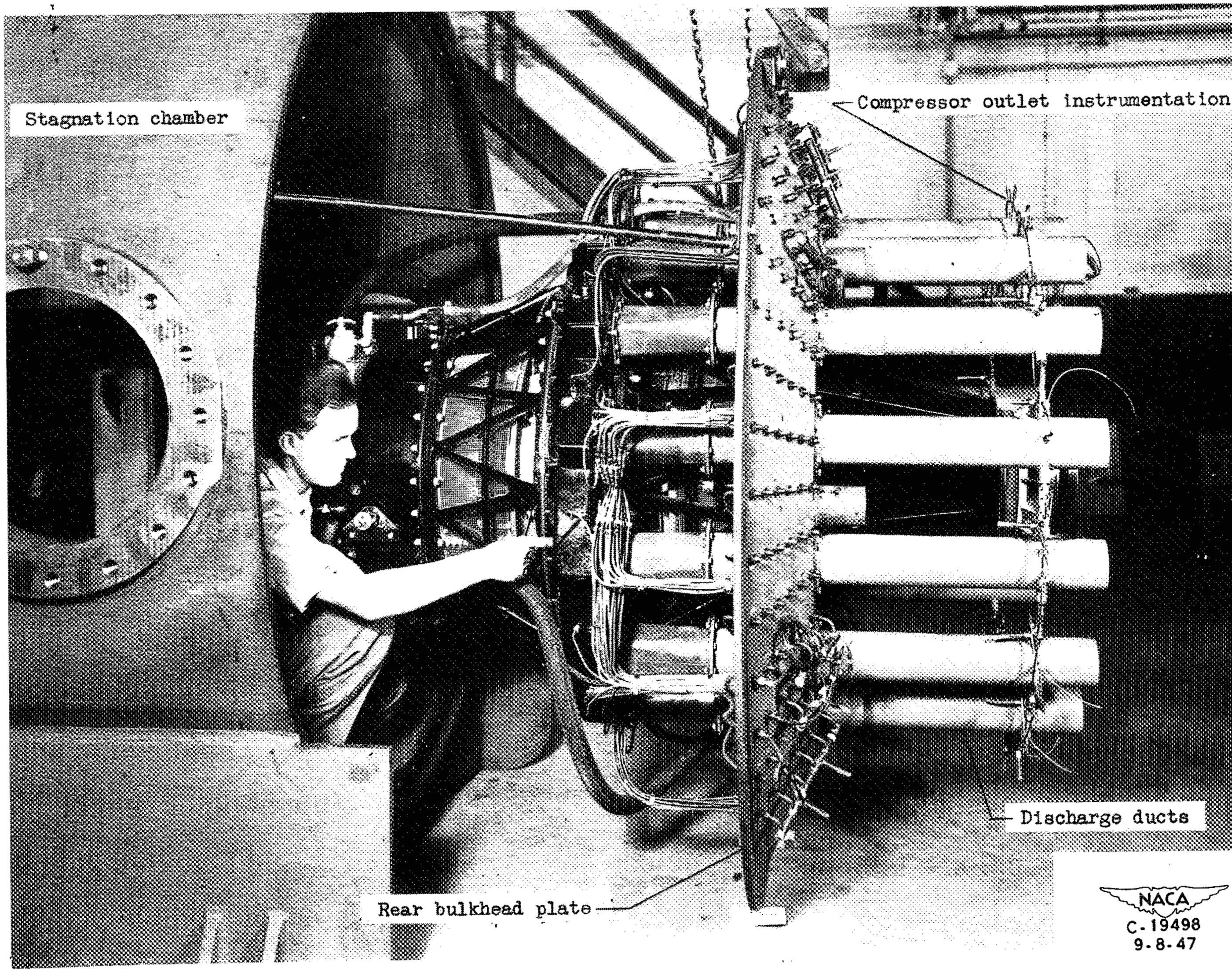

Figure 2. - Installation of J-33-A-21 turbojet engine compressor.

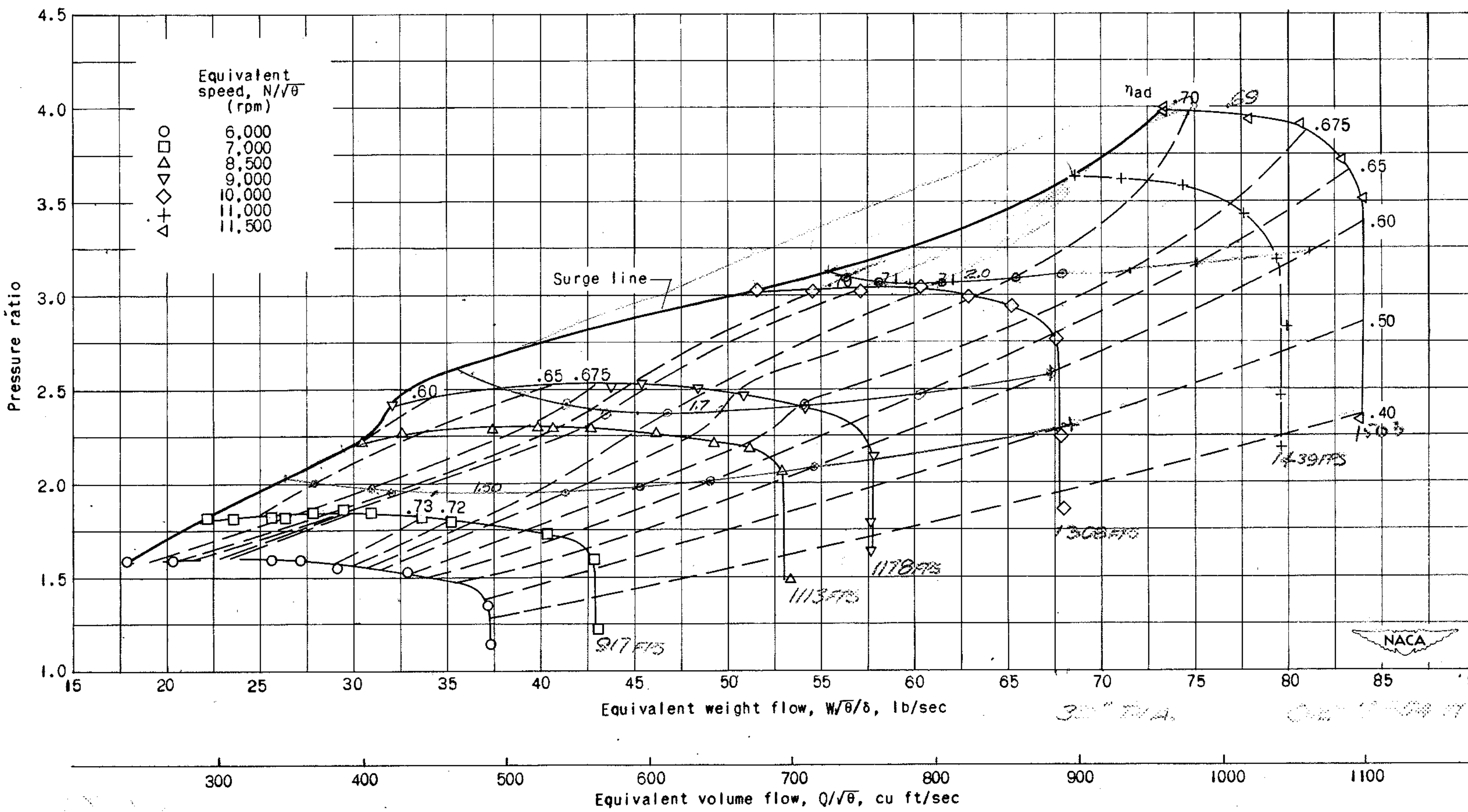

Figure 3. - Variation of pressure ratio with equivalent weight flow at inlet pressure of 14 inches mercury absolute and inlet temperature of 80° F.

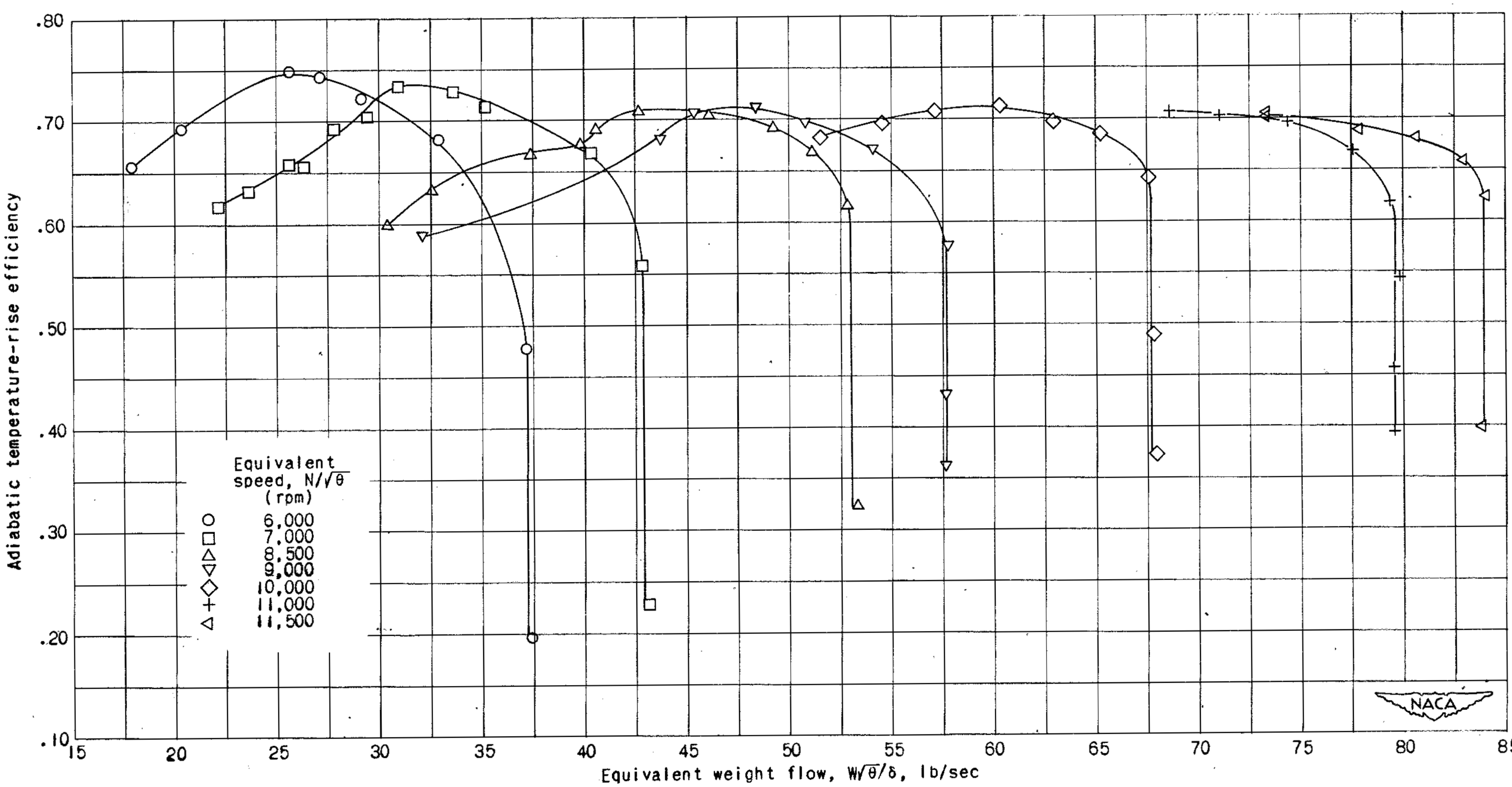

Figure 4. - Variation of adiabatic temperature-rise efficiency with equivalent weight flow at inlet pressure of 14 inches mercury absolute and inlet temperature of 80° F.

946

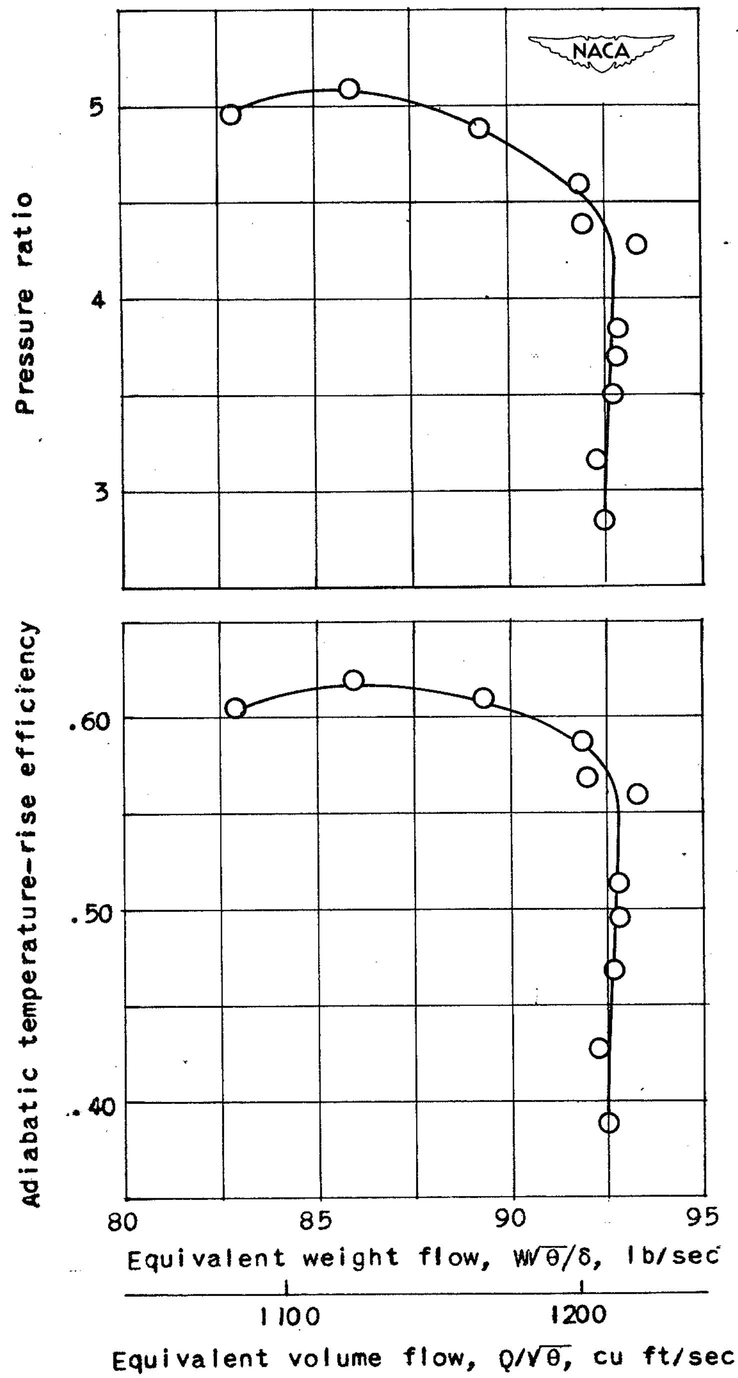

Figure 5. - Variation of pressure ratio and adiabatic temperature-rise efficiency with equivalent weight flow at inlet pressure of 5.0 inches mercury absolute, inlet temperature of -40° F, and equivalent speed of 13,400 rpm.

946

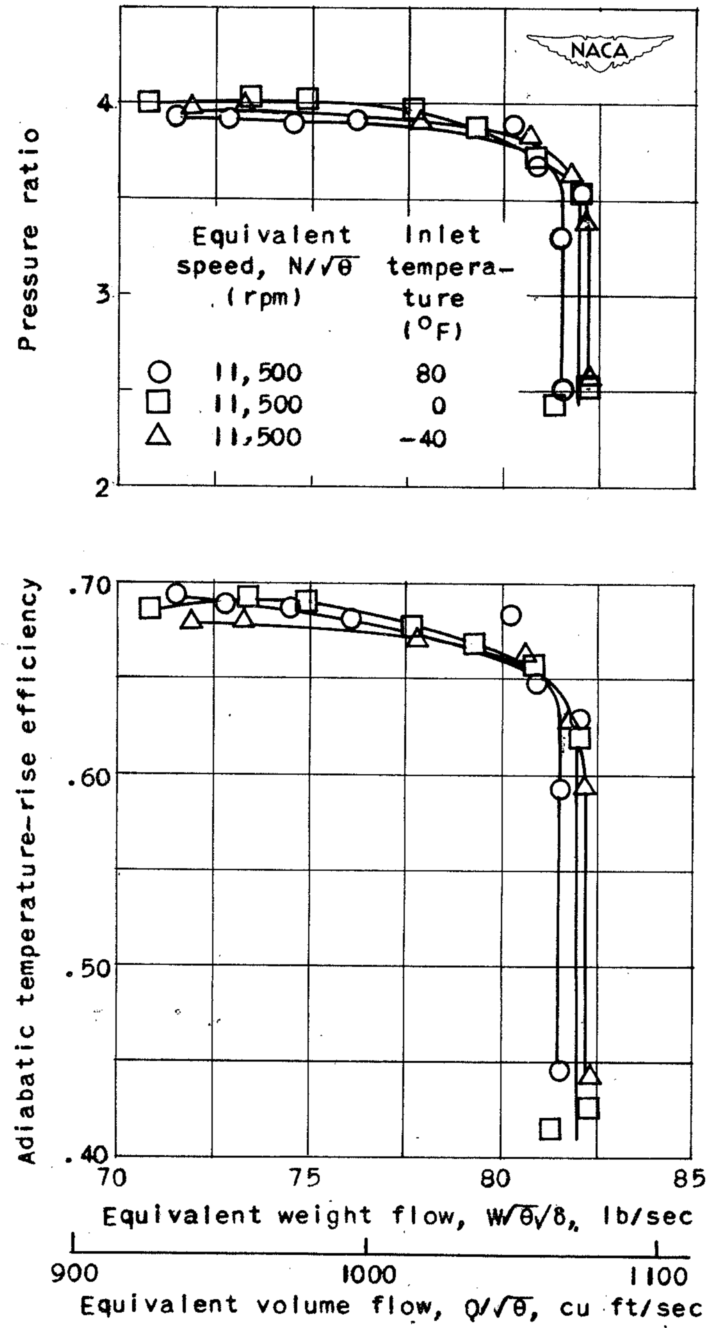

Figure 6. - Variation of compressor pressure ratio and adiabatic temperature-rise efficiency with equivalent weight flow at inlet pressure of 5.5 inches mercury absolute.

946

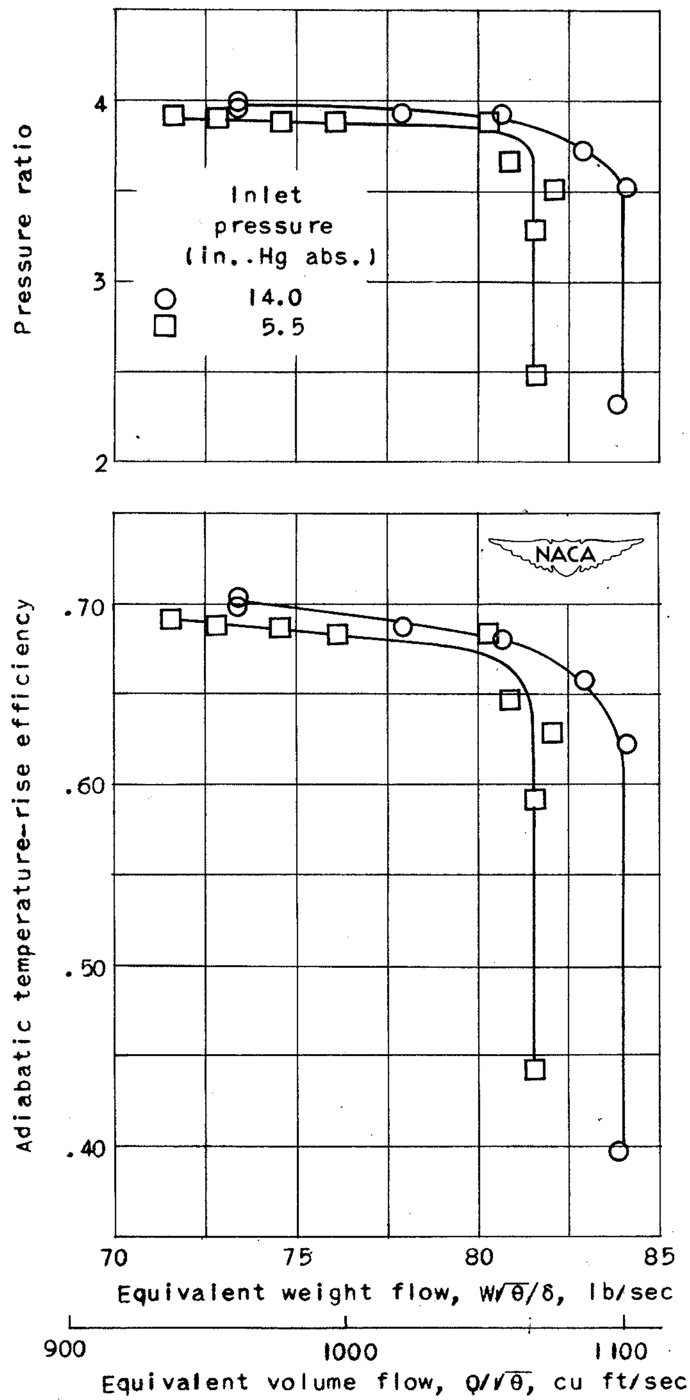

Figure 7. - Variation of pressure ratio and adiabatic temperature-rise efficiency with equivalent weight flow at inlet temperature of 80° F and equivalent design speed of 11,500 rpm.

946

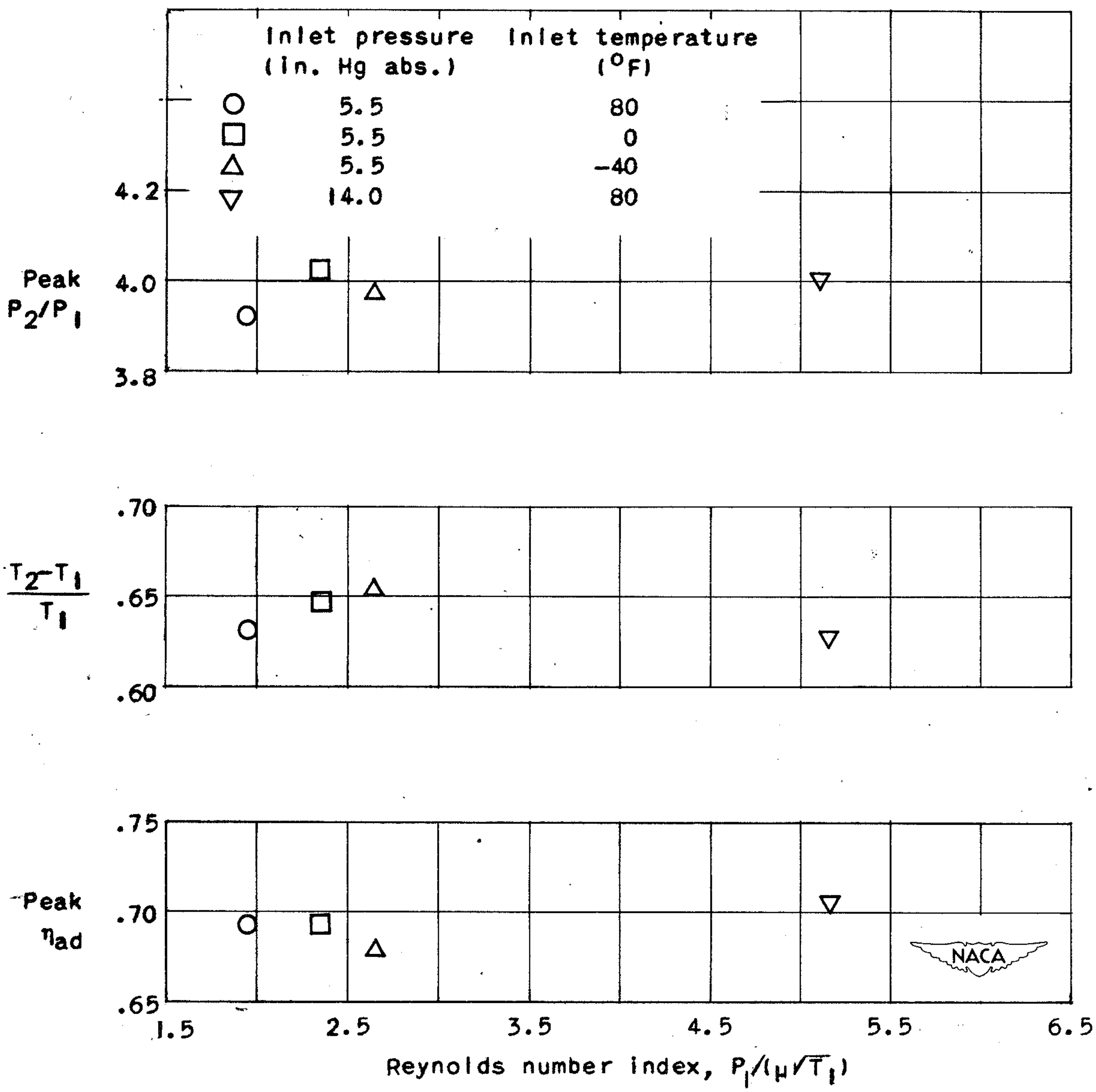

Figure 8. - Effect of inlet pressure and temperature on compressor performance at equivalent design speed of 11,500 rpm.