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RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Force

PERFORMANCE OF AXIAL-FLOW SUPERSONIC COMPRESSOR OF XJ-55-FF-1 TURBOJET ENGINE

I - PRELIMINARY PERFORMANCE OF COMPRESSOR

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SUMMARY

An investigation was conducted to determine the performance characteristics of the axial-flow supersonic compressor of the XJ-55-FF-1 turbojet engine. The test unit consisted of a row of inlet guide vanes and a supersonic rotor; the stator vanes after the rotor were omitted.

The maximum pressure ratio produced in the single stage was 2.28 at an equivalent tip speed of 1614 feet per second with an adiabatic efficiency of approximately 0.61 and an equivalent weight flow of 13.4 pounds per second. The maximum efficiency of 0.79 was obtained at an equivalent tip speed of 801 feet per second.

INTRODUCTION

At the request of the Air Materiel Command, U. S. Air Force, the NACA Lewis laboratory is conducting an investigation of the performance characteristics of the axial-flow supersonic compressor of the XJ-55-FF-1 turbojet engine. Because the supersonic-type compressor has potentialities for producing high pressure ratio per stage with good weight-flow characteristics, it is particularly suited to the turbojet engine, which requires high weight flow and stage pressure ratio in a light compact unit.

Preliminary investigations of supersonic compressors designed by the NACA have shown encouraging results (references 1, 2, and 3). The rotor blades of the XJ-55-FF-1 supersonic compressor are based on design methods developed by the Langley laboratory. Aerodynamic

and thermodynamic design data for this compressor are given in reference 4. The complete compressor consists of a row of inlet guide vanes, a supersonic rotor, and two rows of stator vanes after the rotor. The test unit consisted of the inlet guide vanes and rotor blades, without the stator blades. Preliminary performance data were obtained for a range of equivalent tip speeds from 409 to 1614 feet per second and equivalent weight flows as high as 13.4 pounds per second.

APPARATUS AND PROCEDURE

Compressor. - The compressor assembly consists of a row of inlet guide vanes (fig. 1) and the supersonic rotor (fig. 2). The 27 blades of the inlet guide vanes have constant hub and tip diameters of 10.20 and 13.25 inches, respectively. The rotor has 38 blades with a tip diameter of approximately 13.00 inches and a hub diameter varying from 10.20 inches at the inlet to 10.65 inches at the outlet.

Two compressor assemblies were used for this performance investigation. A test rig failure, which occurred before any data were obtained, resulted in the destruction of the first compressor assembly; the compressor rotor after the rig failure is shown in figure 3.

Damage to the leading edges of the rotor blades on the second compressor rotor was incurred after the over-all performance investigation was nearly complete. This damage, which was in the form of a rolling-over of the thin leading edges of the blades, is shown in figure 4. After hand-finishing the leading edges, tests were resumed and a similar damage again occurred. The blades were again refinished, the investigation was resumed, and the blade leading edges were again rolled over. The experimental investigation was then terminated; condition of the second rotor after completion of this investigation is shown in figure 5.

Compressor installation. - Air was inducted from the laboratory refrigerated-air system through a measuring orifice in the inlet pipe. A depression tank was placed ahead of the compressor to insure smooth entry of flow in accordance with the standard procedures for testing axial-flow compressors (reference 5). The rotor was straddle-mounted, with the shaft supported on two self-alining journal bearings. The front bearing and the stationary hub section ahead of the rotor were supported by four airfoil struts.

Air discharged from the rotor through an annular passage into a collector, and then through two radial outlet pipes to the laboratory altitude-exhaust facilities. In this installation, the outlet stator blades were replaced by six airfoil struts set at an angle corresponding to the design angle of flow into the stator at the pitch section. These struts support the stationary hub behind the rotor.

Compressor pressures were regulated by butterfly throttle valves in the inlet and outlet pipes. The compressor was driven by a 2500-horsepower motor through speed-increaser gears.

Instrumentation. - The air weight flow through the compressor was measured by an adjustable orifice in a straight section of the inlet pipe. Measurements at the compressor inlet were made by four thermocouples in the depression tank, as recommended in reference 5. Because the velocity of the air in the tank was negligible, four static-pressure taps, installed as recommended in reference 5, were used to measure total pressure.

Two thermocouple rakes and two total-pressure rakes 180° apart were located approximately 6 inches downstream of the rotor and 3 inches downstream of the trailing edge of the support struts. Each rake consisted of three instruments located at the area centers of equal annular areas. The tubes were insensitive to yaw over a range of ±30°; at each speed, therefore, the rakes could be set for accurate readings over the range of air flows and air-discharge angles encountered. Four static-pressure taps 90° apart were provided on both the inner and the outer walls at the rake station.

All pressures were measured with mercury manometers and all temperatures were taken with iron-constantan thermocouples calibrated for recovery coefficient over the Mach number range of the investigation. The difference in potential between the hot junction and the ice bath was measured with a calibrated potentiometer in conjunction with a spotlight galvanometer. The compressor rotor speed was measured with an electric chronometric tachometer.

Procedure. - Performance data were obtained over a range of equivalent weight flows $W\sqrt{\theta}/\delta$ from wide-open throttle to stall at constant values of equivalent tip speeds $U/\sqrt{\theta}$ in the range from 409 to 1614 feet per second;

where

W weight flow, lb/sec

θ ratio of actual inlet stagnation temperature to standard sea-level temperature, $T_1/518.4$

δ ratio of actual inlet total pressure to standard sea-level pressure, $P_1/2116$

U velocity of rotor, ft/sec

Inlet pressure was maintained at 30 inches of mercury absolute for speeds from 409 to 801 feet per second and 20 inches of mercury absolute for speeds from 1000 to 1614 feet per second. Inlet temperatures varied from 0° F to -60° F. The low temperatures reduced the actual tip speed for a given equivalent tip speed, which helped to keep the bearing temperatures within reasonable limits.

Total-pressure ratio is defined as P_6/P_1, where P_6 is the arithmetic average of total pressures measured at the area centers of three equal annular areas at the rake station.

Adiabatic efficiency η_{ad} is defined

$$\eta_{ad} = \frac{T_1\left[\left(\frac{P_6}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1.0\right]}{T_6 - T_1}$$

where

T total (stagnation) temperature, °R

P total (stagnation) pressure of absolute air, lb/sq ft

γ ratio of specific heats for normal air, 1.40

Subscripts:

1 compressor inlet

6 rake measuring station

T_6 is the arithmetic average of total temperatures measured at the area centers of three equal annular areas at the rake station.

RESULTS AND DISCUSSION

The curves of pressure ratio as a function of equivalent weight flow with superimposed contours of adiabatic efficiency are shown in figure 6 for equivalent tip speeds from 409 to 1614 feet per second. Performance data are limited at equivalent tip speeds of 1498 and 1614 feet per second because of the mechanical difficulties; the estimated performance for these two speeds is shown as dashed lines.

Maximum total-pressure ratios varied from 1.08 at 409 feet per second to 2.28 at 1614 feet per second. The equivalent weight flow was 13.4 pounds per second at maximum pressure ratio for an equivalent tip speed of 1614 feet per second.

A maximum efficiency of 0.79 was obtained at an equivalent tip speed of 801 feet per second. At tip speeds greater than 801 feet per second, the adiabatic efficiency decreased with increasing tip speed; a maximum efficiency of approximately 0.61 was obtained at the maximum-pressure-ratio condition for a tip speed of 1614 feet per second.

SUMMARY OF RESULTS

The following preliminary results were obtained in an investigation of the axial-flow supersonic compressor of the XJ-55-FF-1 turbojet engine:

1. The maximum pressure ratio varied from 1.08 at 409 feet per second to 2.28 at 1614 feet per second. The equivalent weight flow at the maximum-pressure-ratio condition at 1614 feet per second was 13.4 pounds per second.

2. A maximum efficiency of 0.79 was obtained at an equivalent tip speed of 801 feet per second. Maximum efficiency decreased with higher tip speeds; an adiabatic efficiency of approximately 0.61 was obtained at the maximum-pressure-ratio condition at an equivalent tip speed of 1614 feet per second.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, January 31, 1949.

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jgm

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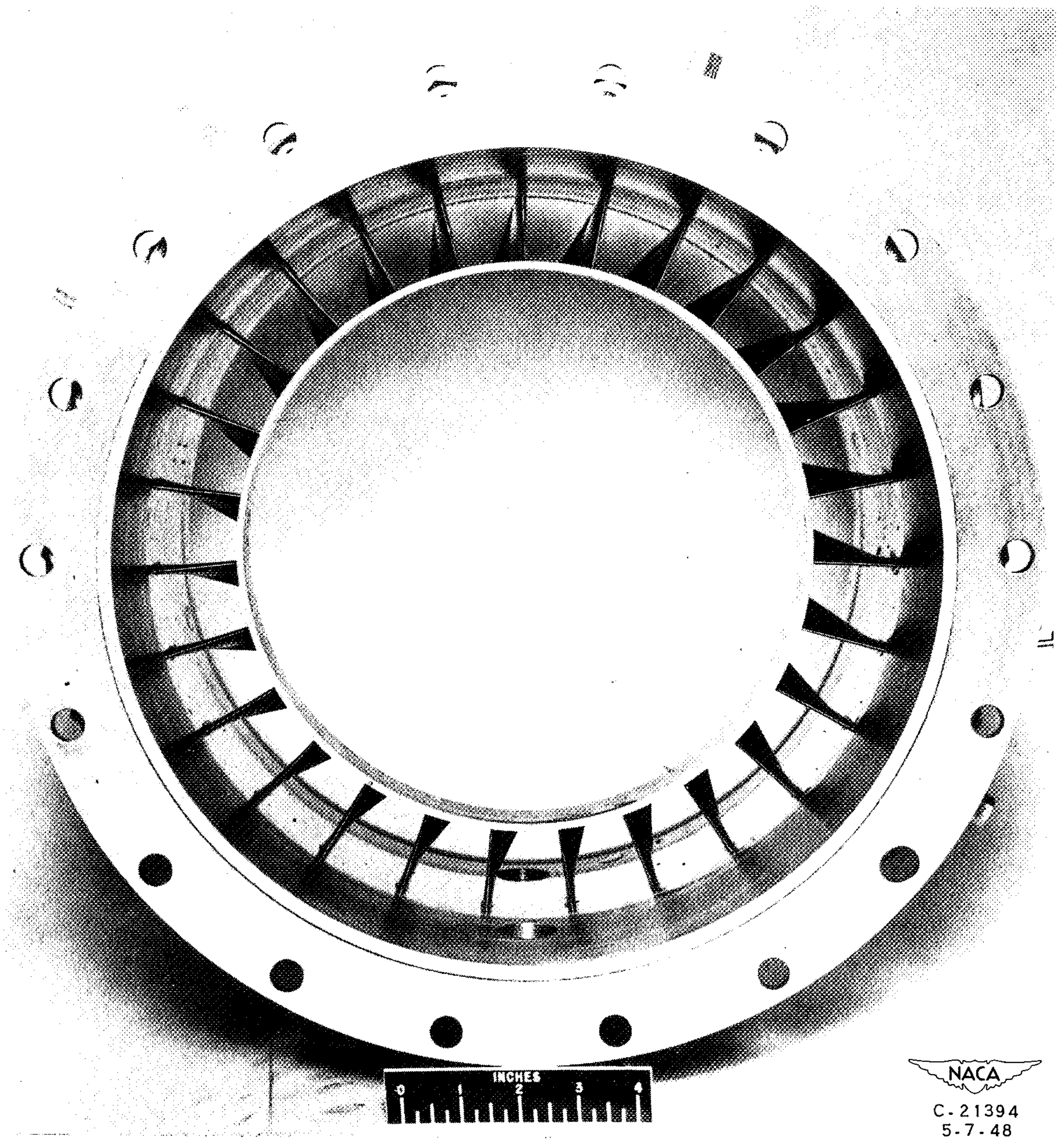

Figure 1. - Inlet guide vanes for supersonic compressor of XJ-55-FF-1 turbojet engine.

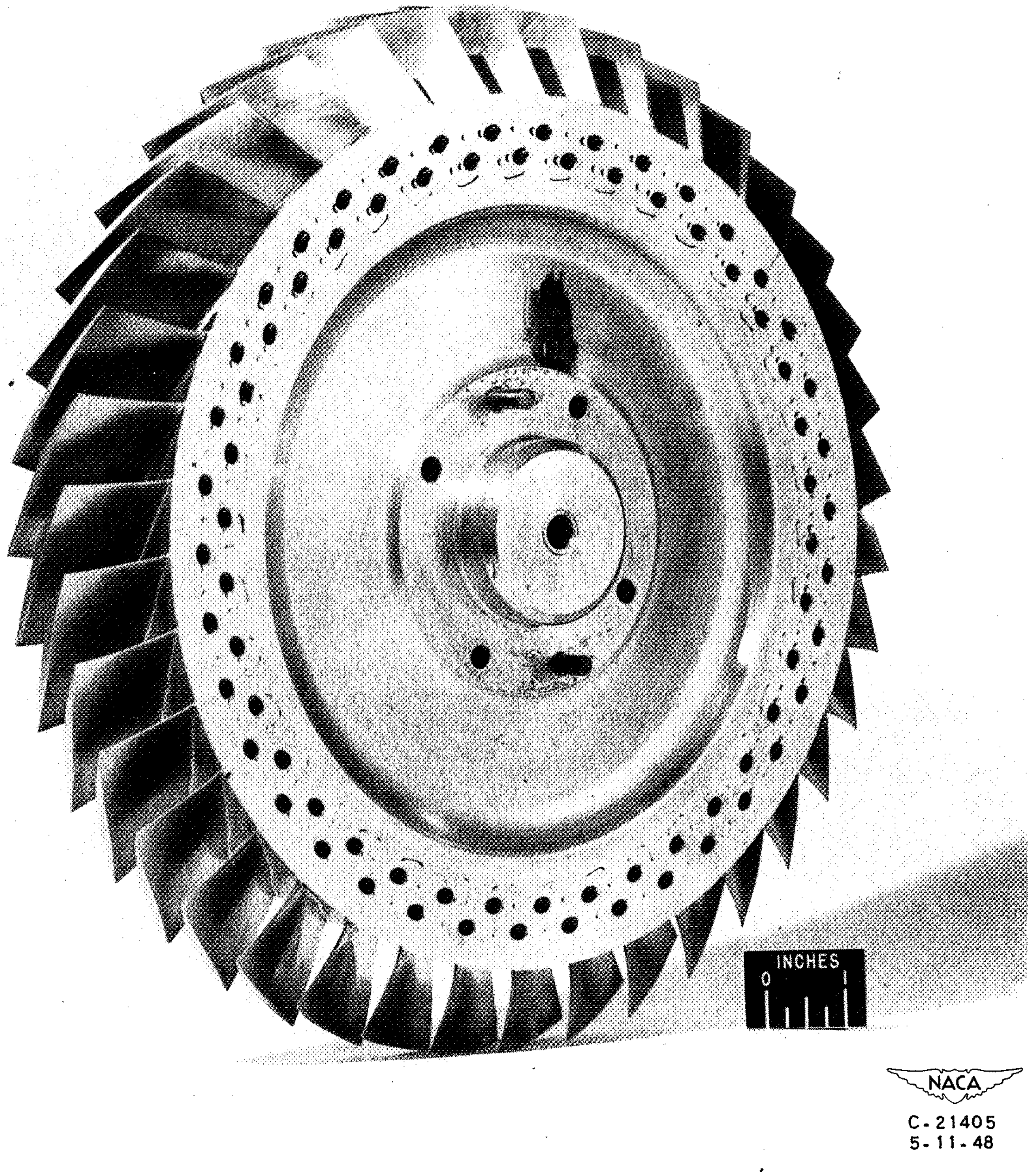

Figure 2. - Rotor for supersonic compressor of XJ-55-FF-1 turbojet engine.

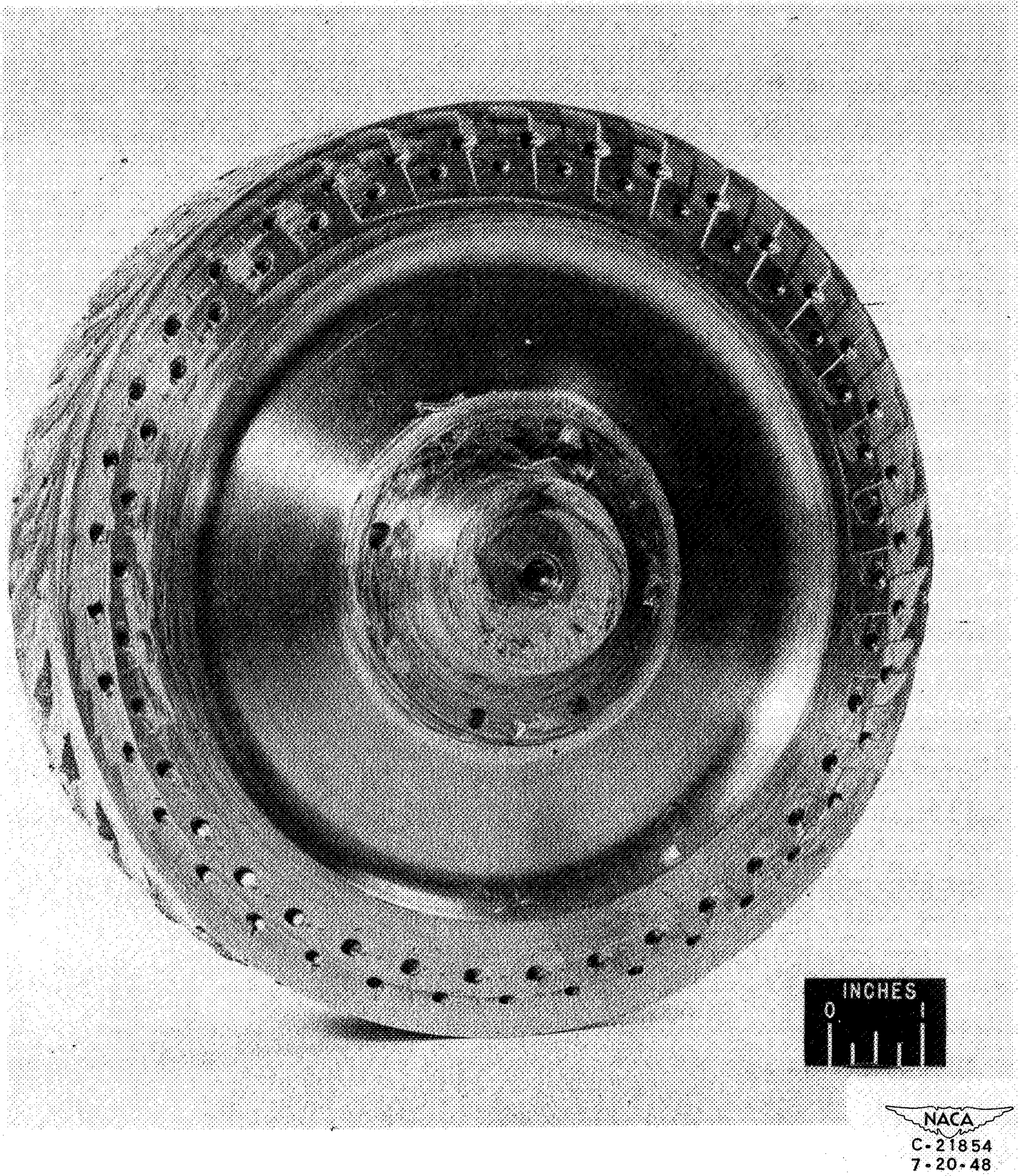

Figure 3. - First compressor rotor after rig failure.

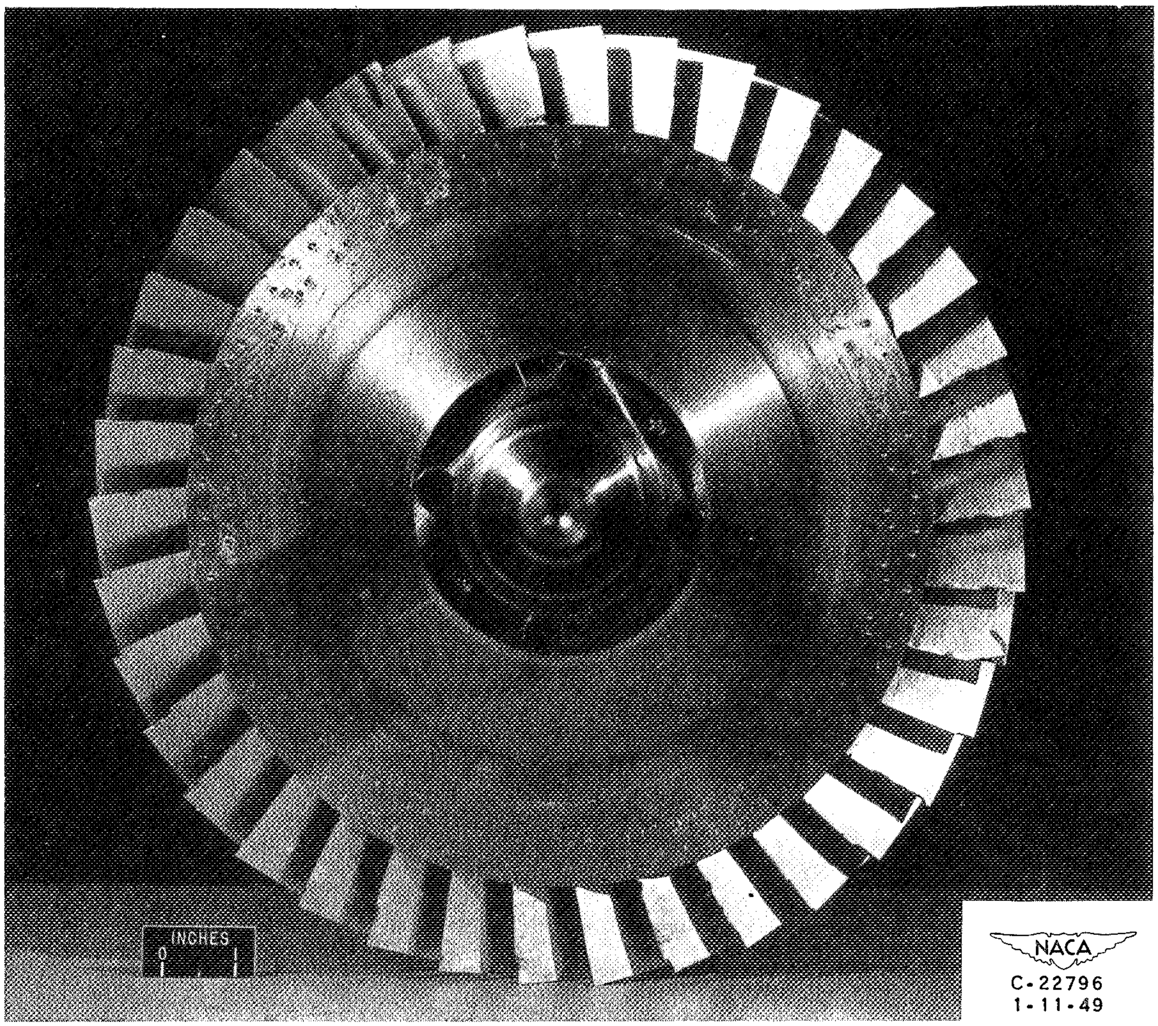

Figure 4. - Initial damage to second compressor rotor.

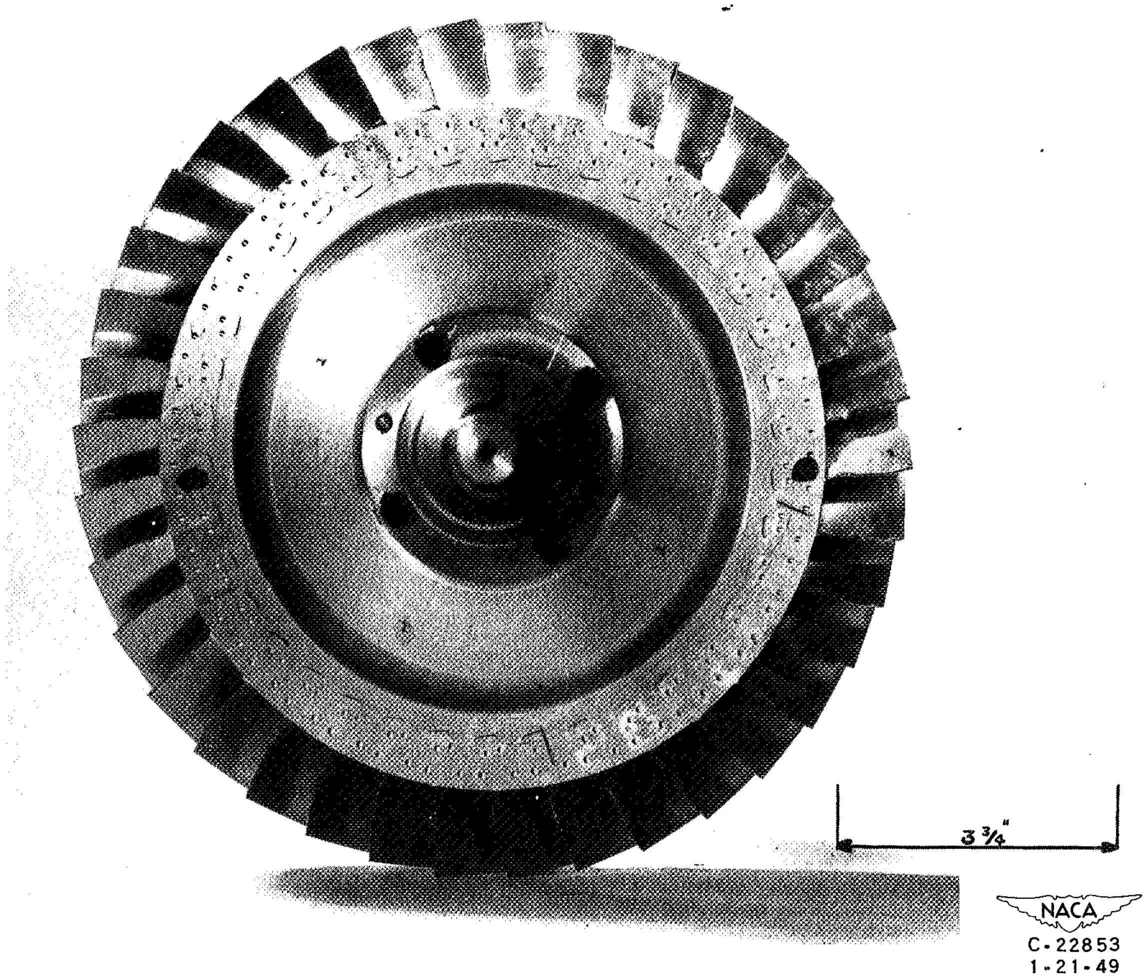

Figure 5. - Final condition of second compressor rotor.

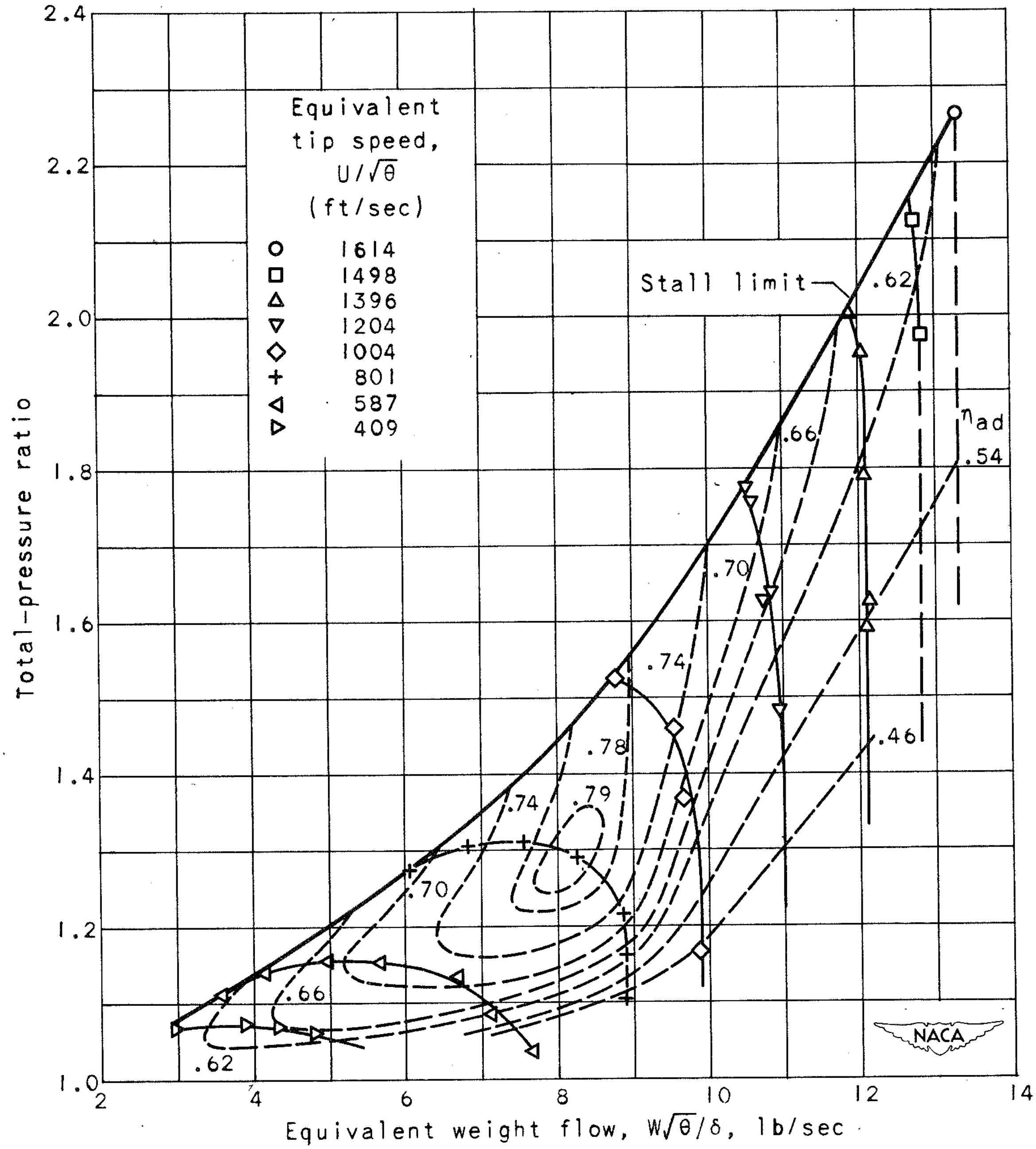

Figure 6. - Performance characteristics of axial-flow supersonic compressor for XJ-55-FF-1 turbojet engine.