NACA RM E56I13

NACA

RESEARCH MEMORANDUM

COMPONENT PERFORMANCE INVESTIGATION OF J71 EXPERIMENTAL TURBINE

VIII - EFFECT OF FIRST-STATOR ADJUSTMENT; INTERNAL FLOW CONDITIONS OF J71-97 TURBINE WITH 70-PERCENT-DESIGN STATOR AREA

By Donald A. Petrash, Harold J. Schum, and Elmer H. Davison

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
WASHINGTON
January 18, 1957

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

COMPONENT PERFORMANCE INVESTIGATION OF J71 EXPERIMENTAL TURBINE

VIII - EFFECT OF FIRST-STATOR ADJUSTMENT; INTERNAL FLOW CONDITIONS OF J71-97 TURBINE WITH 70-PERCENT-DESIGN STATOR AREA

By Donald A. Petrash, Harold J. Schum, and Elmer H. Davison

SUMMARY

The throat area of the first-stage stator of the J71-97 experimental turbine was reduced to 70 percent of the design value, and an experimental radial survey investigation was conducted at one turbine operating point. The first-, second-, and third-stage efficiencies were 0.900, 0.759, and 0.828, respectively. The over-all turbine efficiency was 0.865.

A comparison of the 70-percent-turbine survey with a 97-percent-turbine survey made previously indicated that (1) the Mach numbers at the outlet of the first stator increased by approximately 40 percent, (2) large angles of incidence were present on all blade rows downstream of the first-stage stator except the third-stage rotor, and (3) the over-all efficiency was not adversely affected to any great extent.

INTRODUCTION

The NACA Lewis laboratory is currently conducting a study of the effect of adjusting the first-stage-stator throat area on the performance of the experimental three-stage J71 turbine. The over-all performance of this turbine with first-stator areas that were nominally 70, 87, 97, and 132 percent of design has been obtained and is presented in references 1, 2, 3, and 4, respectively. Reference 2 shows that a considerable variation in equivalent weight flows can be obtained without any large adverse effect on turbine efficiency. For example, the maximum efficiencies for all four turbine configurations were high, varying only between 0.87 and 0.89. The effect of these area changes on the internal flow conditions is also being studied. Results of a survey of the 97-percent turbine are presented in reference 5. The purpose of the subject report is to present the results of the survey investigation of the 70-percent turbine at one turbine operating point and, in addition, to compare these results with those obtained with the 97-percent turbine.

The operating point selected for the survey of the 97-percent turbine was the turbine match point chosen to satisfy an arbitrary mode of engine operation during which the compressor remains at constant equivalent design conditions. Turbine match points for such a mode of engine operation were obtainable for all configurations but the 70-percent turbine, as shown in reference 2. The 70-percent turbine did not develop the work required to maintain the compressor at its equivalent design point at the turbine equivalent match speed. In selecting a survey point for the 70-percent turbine, therefore, it was arbitrarily decided to survey at the turbine equivalent match speed and maximum obtainable work output at that speed.

4235

SYMBOLS

The following symbols are used in this report:

c blade chord, ft

p pressure, lb/sq ft

s blade spacing, ft

T temperature, °R

β relative flow angle (measured from axial direction), deg

η efficiency based on measured total temperatures and pressures

σ solidity, ratio of actual blade chord to blade spacing, c/s

$\bar{\omega}$ loss coefficient, $\dfrac{p_i'' - p_o''}{p_i'' - p_o}$

Subscripts:

i inlet

o outlet

0,1, 2,3, 4,5, 6,7 measuring stations (see fig. 1)

Superscripts:

' stagnation or total state

" relative stagnation or total state

APPARATUS AND INSTRUMENTATION

For the subject turbine investigation, the first-stage stator of the 97-percent turbine was replaced with one having a throat area 70 percent of the design value. In order to accomplish this area reduction, the stagger angle of the design blade profiles was increased about 7° from axial. The test installation used for the survey investigation of the 70-percent turbine was the same as that used in the 97-percent survey investigation and is described in reference 6.

A schematic diagram of the turbine showing the axial and circumferential locations of the instruments is presented in figure 1. Radial measurements of total pressure, total temperature, and flow angle were made using combination probes mounted in remotely controlled movable actuators. Data were obtained at the turbine inlet (station 1, fig. 1) and at the outlet of each succeeding blade row. At the outlet of each rotor row of blades data were obtained from two actuators located at different circumferential positions. Subsequent radial measurements of static pressure were made by replacing the combination probes with static-pressure wedges. Wall static taps were located at the hub and tip at each measuring station. Figure 2 is a photograph of the type of probes used in this investigation.

METHODS AND PROCEDURE

The survey investigation of the 70-percent turbine was conducted at the equivalent match speed of 3781 rpm and the maximum obtainable equivalent work output at that speed (44.38 Btu/lb). The inlet total pressure and temperature were nominally 35 inches of mercury absolute and 750° R, respectively.

As was pointed out in reference 1, the Mach number at the outlet of the first-stage stator was 1.34 or slightly lower. In this range of Mach number the static-pressure wedge is not reliable. Therefore, at station 2, the static pressure at any radius was obtained by assuming a linear variation between the average of the values measured by the wall static taps on the inner and outer shrouds. The radial variation of static pressure at all other measuring stations was obtained from the static-pressure wedges. Where duplicate sets of measurements were obtained, the measurements were numerically averaged at their corresponding radial positions.

The parameters used herein to describe the internal flow conditions were calculated by the procedure described in reference 5.

RESULTS AND DISCUSSION

The results of the radial survey investigation of the subject turbine are presented in terms of stage efficiency, work parameter, Mach numbers, and flow angles. These results are presented in figures 3 and 4. The individual stage performance and over-all turbine characteristics 4235
are discussed in order in terms of these parameters.

First-Stage Performance

Figure 3 presents the radial variation of stage efficiency η and the stage work parameter $\Delta T'/T'$ with percent of rotor-outlet annular area. Included in figure 3 are the over-all and the mass-averaged values of the parameters. The results from the survey investigation of the 97-percent turbine (ref. 5) are also shown. The mass-averaged value of the first-stage efficiency of the 70-percent turbine is 0.900. In general, the efficiency variation was similar to that of the 97-percent turbine over most of the blade span, the subject turbine having slightly higher efficiencies in the tip region and a small decrease at the blade hub.

The radial variations of the absolute and relative Mach numbers and flow angles entering and leaving each rotor blade row are presented in figure 4 for both the subject turbine and the 97-percent turbine (ref. 5). Also included in the figure are the radial variations of the design values obtained from the design velocity diagrams presented in reference 7. The chord angle with respect to axial of the first-stage stator was increased by about 7° from that of the 97-percent turbine in order to obtain the desired throat area of 70 percent of the design value. Approximately the same change in flow angle was measured at the exit of the first stator, being on the order of 8° to 10° over most of the blade span (see fig. 4(a)). The relative flow angle at the inlet of the first rotor is considerably greater than the design value, on the order of 14° at the hub to 24° at the blade tip. This indicates that the incidence angle, defined as the deviation from the design inlet flow angle, on the first-stage rotor is quite high. As a result of the reduced first-stator throat area, the absolute and relative Mach numbers were increased on the order of 40 percent at the inlet to the first rotor. The flow conditions at the exit of the first rotor were similar to those found in the 97-percent-turbine investigation, except that the absolute flow angle has become more axial, thereby causing the second-stage stator to operate with large negative angles of incidence. This angle is on the order of 26° more toward axial than design over most of the blade span.

Second-Stage Performance

The mass-averaged value of efficiency for the second stage is 0.759 (see fig. 3). This is considerably lower than that obtained with the 97-percent turbine. Figure 3 indicates that the second-stage efficiency of the 70-percent turbine has decreased over most of the blade span with large decreases in efficiency in the hub and tip regions. Figure 4(b) indicates that the absolute and relative Mach numbers at the inlet and outlet of the second-stage rotor are of the same order of magnitude as
4235 were found in the survey investigation of the 97-percent turbine. The relative flow angle at the inlet of the second rotor is considerably smaller than the design value, on the order of 25° at the blade hub to 10° near the tip. This causes the second-stage rotor to operate with large negative angles of incidence. The absolute flow angle at the outlet of the second rotor is more nearly axial than in the case of the 97-percent turbine. The absolute flow angle is also less than the design angle by about 18° over most of the blade span, indicating a large negative angle of incidence on the third-stage stator.

Third-Stage Performance

The mass-averaged value of the third-stage efficiency is 0.828 (fig. 3). The spanwise variation of the third-stage efficiency for the 70-percent turbine is changed considerably from that obtained in the 97-percent turbine. A marked region of low efficiency exists at the hub, as seen from figure 3. Figure 4(c) indicates that the flow conditions at the inlet to the third-stage rotor approach the design flow more closely than did those of the 97-percent turbine. At the exit, however, the absolute and relative Mach numbers are significantly increased, because the 70-percent turbine operates nearer limiting loading at the survey point than does the 97-percent turbine. In addition, the turbine-outlet absolute flow angle (fig. 4(c)) indicates that the third-stage rotor overturns the air some 10° to 14° over the major portion of the blade span, and this whirl, if charged to the turbine, would result in lower turbine efficiency.

Over-All Performance

Figure 3 indicates that the variation of the over-all turbine efficiency for the 70-percent turbine is similar to that found in the survey investigation of the 97-percent turbine. Regions of low efficiency still persist near the hub and tip. The mass-averaged value is 0.865, which compares with 0.858 for the 97-percent turbine (ref. 5). The mass-averaged values of the equivalent stage work parameter for the first, second, and third stages represent 49.8, 20.8, and 29.4 percent, respectively, of the over-all turbine work output. This compares with 42.9, 32.3, and 24.8 percent for the first, second, and third stages of the 97-percent turbine.

Loss Function

The variation of stage loss function $(\bar{\omega} \cos \beta)/\sigma$ with percent of rotor-outlet annular area is presented in figure 5. Included are similar results from the survey of the 97-percent turbine. The stage loss coefficient $\bar{\omega}$ is the relative total-pressure drop across the rotor divided by the difference between the total and static pressures at the exit of the rotor.

Figure 5 indicates that the level of the loss function has increased 4235
in the first and second stages and decreased in the third stage. The regions of highest loss still occur near the hub and tip of the blades, with the exception of the third stage, where some improvement can be noted in the loss function over the upper 60 percent of the blade span.

SUMMARY OF RESULTS

A survey investigation of the J71-97 experimental turbine equipped with a first stator with a throat area 70 percent of design revealed:

1. The mass-averaged values of efficiency for the first, second, and third stages were 0.900, 0.759, and 0.828, respectively.

2. Large angles of incidence were present on all blade rows downstream of the first stator except the third-stage rotor.

3. The Mach numbers at the inlet to the first- and third-stage rotors and at the third-rotor outlet were considerably higher than design.

4. Although the stage efficiencies and loss distributions were changed from those when the first-stator area was 97 percent of design, the over-all efficiency was not adversely affected to any great extent. More whirl was present at the exit of the subject turbine, however, which would lower the efficiency if this whirl were charged to the turbine.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, September 14, 1956

REFERENCES

1. Schum, Harold J., Petrash, Donald A., and Davison, Elmer H.: Component Performance Investigation of J71 Experimental Turbine. VI - Effect of First-Stator Adjustment; Over-All Performance of J71-97 Turbine with 70-Percent-Design Stator Area. NACA RM E56B24, 1956.

2. Schum, Harold J., Petrash, Donald A., and Davison, Elmer H.: Component Performance Investigation of J71 Experimental Turbine. VII - Effect of First-Stator Adjustment; Over-All Performance of J71-97 Turbine with 87-Percent-Design Stator Area. NACA RM E56F20, 1956.

3. Petrash, Donald A., Schum, Harold J., and Davison, Elmer H.: Component Performance Investigation of J71 Experimental Turbine. III - Effect of Third-Stage Shrouding on Over-All Performance. NACA RM E55C29, 1956.

4. Davison, Elmer H., Petrash, Donald A., and Schum, Harold J.: Component Performance Investigation of J71 Experimental Turbine. IV - Effect of First-Stator Adjustment; Over-All Performance of J71-97 Turbine with 132-Percent-Design Stator Area. NACA RM E55H09, 1956.

5. Petrash, Donald A., Schum, Harold J., and Davison, Elmer H.: Component Performance Investigation of J71 Experimental Turbine. V - Effect of Third-Stage Shrouding on Internal-Flow Conditions of J71-97 Turbine. NACA RM E55K02a, 1956.

6. Schum, Harold J., and Davison, Elmer H.: Component Performance Investigation of J71 Experimental Turbine. I - Over-All Performance with 97-Percent-Design Stator Areas. NACA RM E54J15, 1956.

7. Rebeske, John J., Jr., and Petrash, Donald A.: Component Performance Investigation of J71 Experimental Turbine. II - Internal-Flow Conditions with 97-Percent-Design Stator Areas. NACA RM E54L16, 1956.

4235

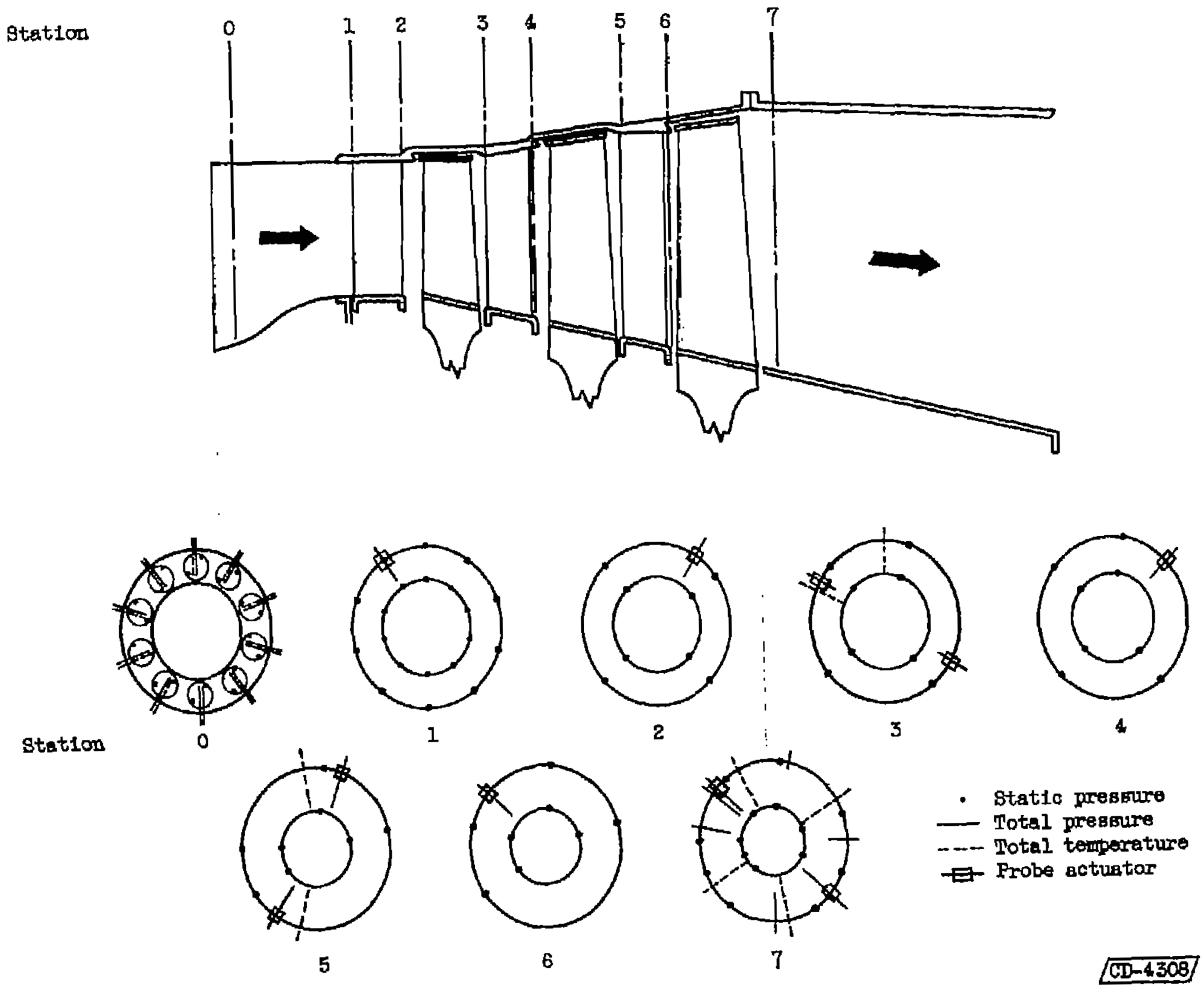
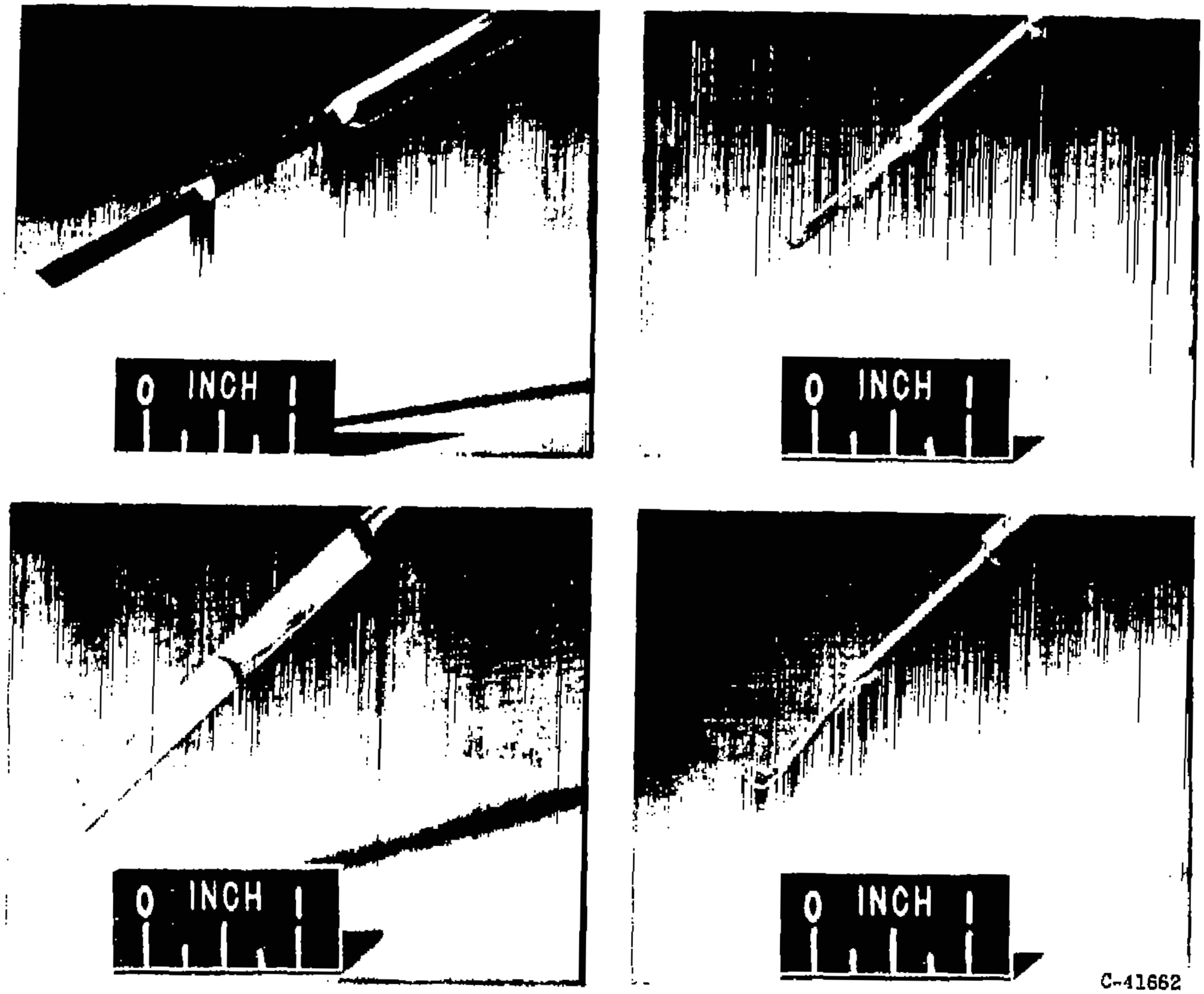


Figure 1. - Schematic diagram of J71-70 turbine showing instrumentation.



(a) Static-pressure wedge.

(b) Total-pressure, total-temperature, and angle probe.

Figure 2. - Typical static-pressure wedge and probe for measuring total pressure, total temperature, and angle.

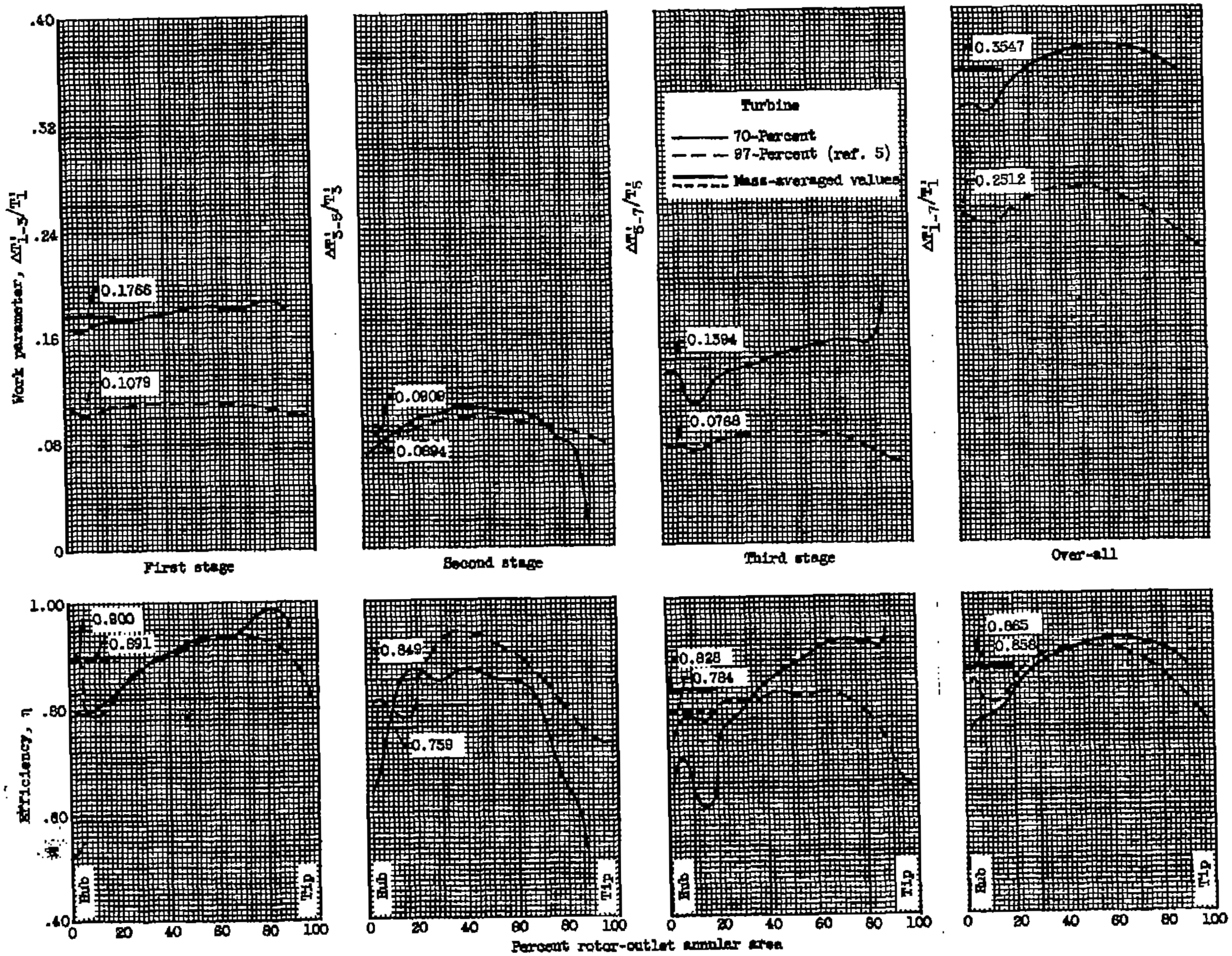
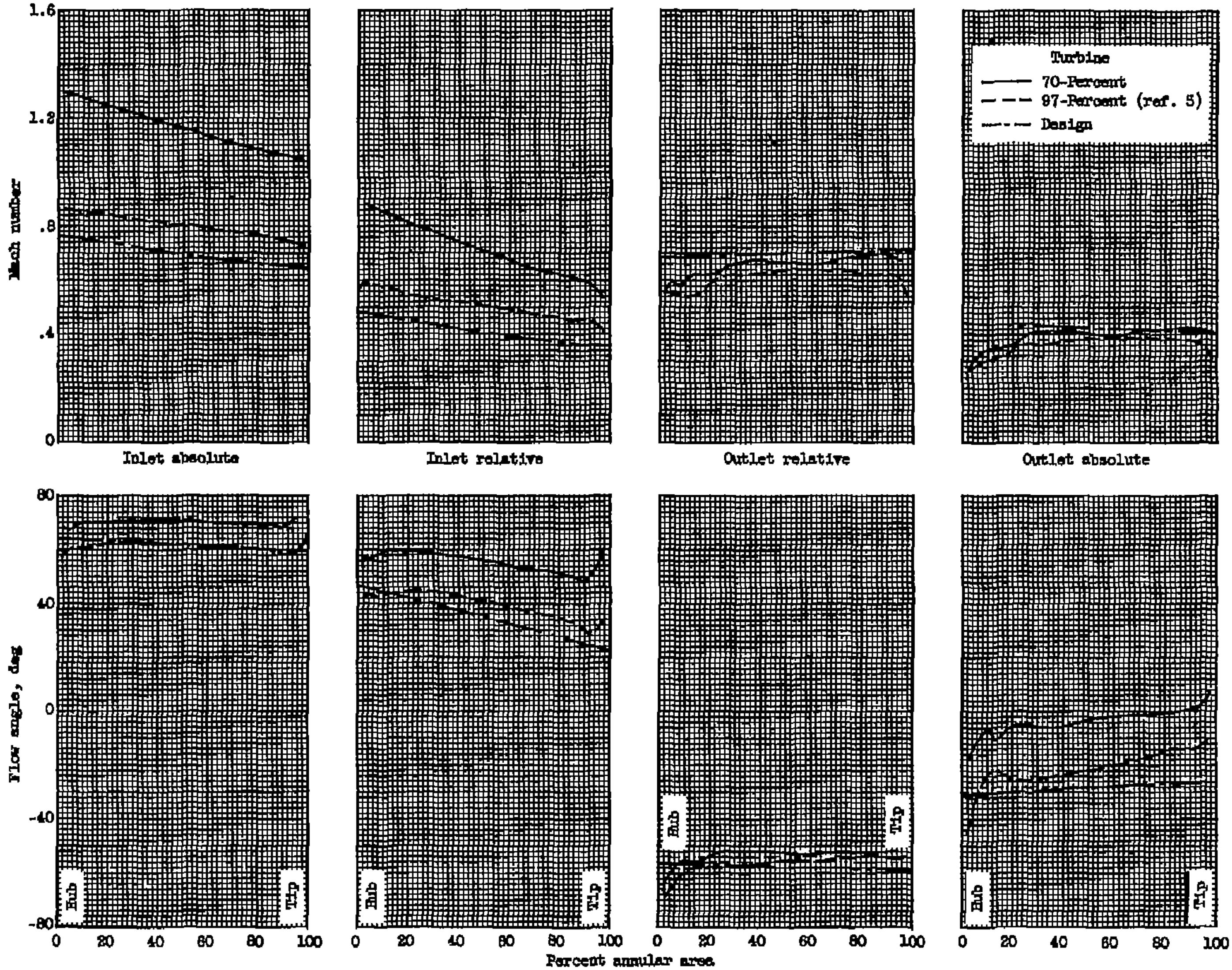


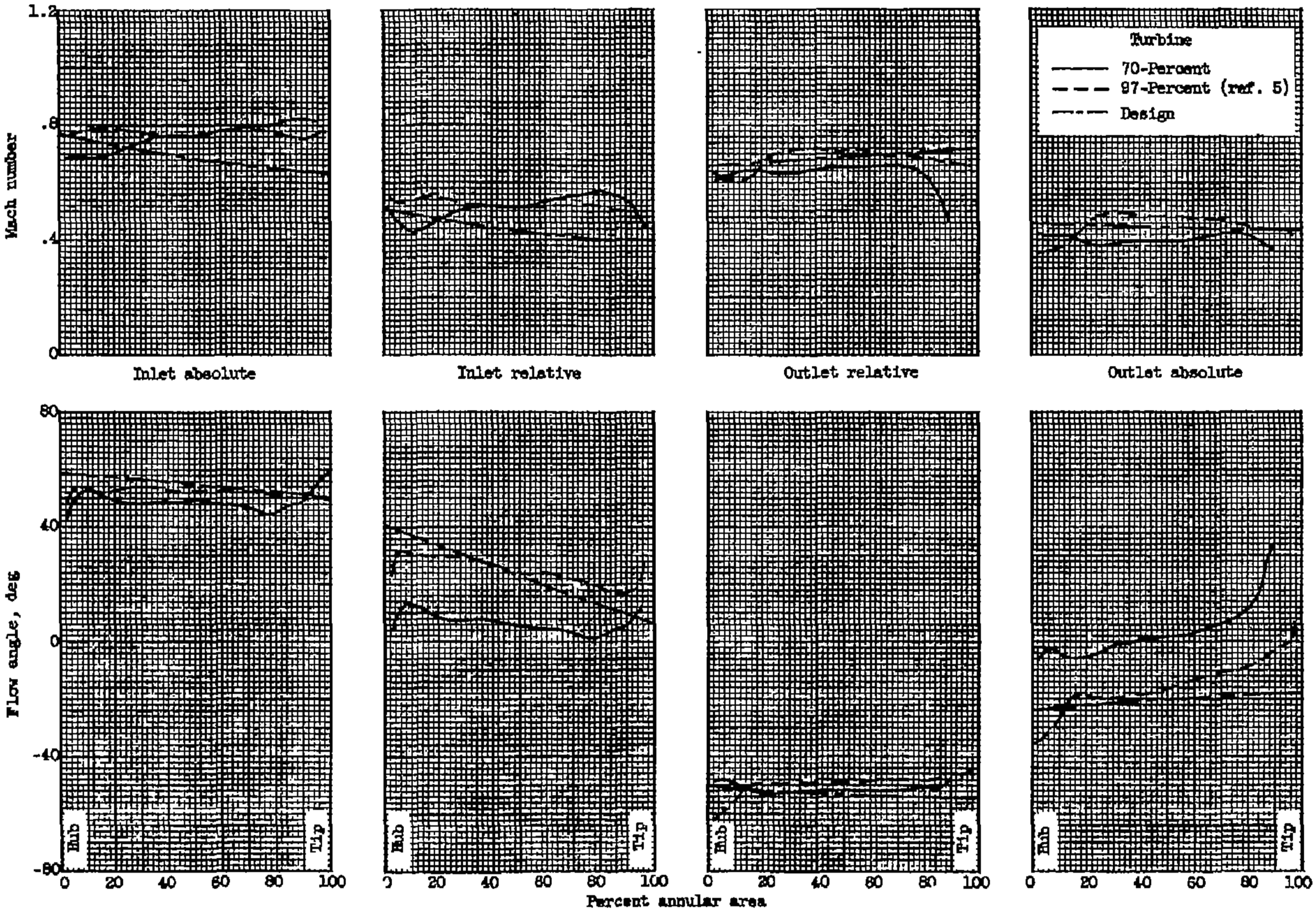
Figure 3. - Variation of stage and over-all work and efficiency with annular area at rotor outlets.

[redacted]



(a) First rotor.

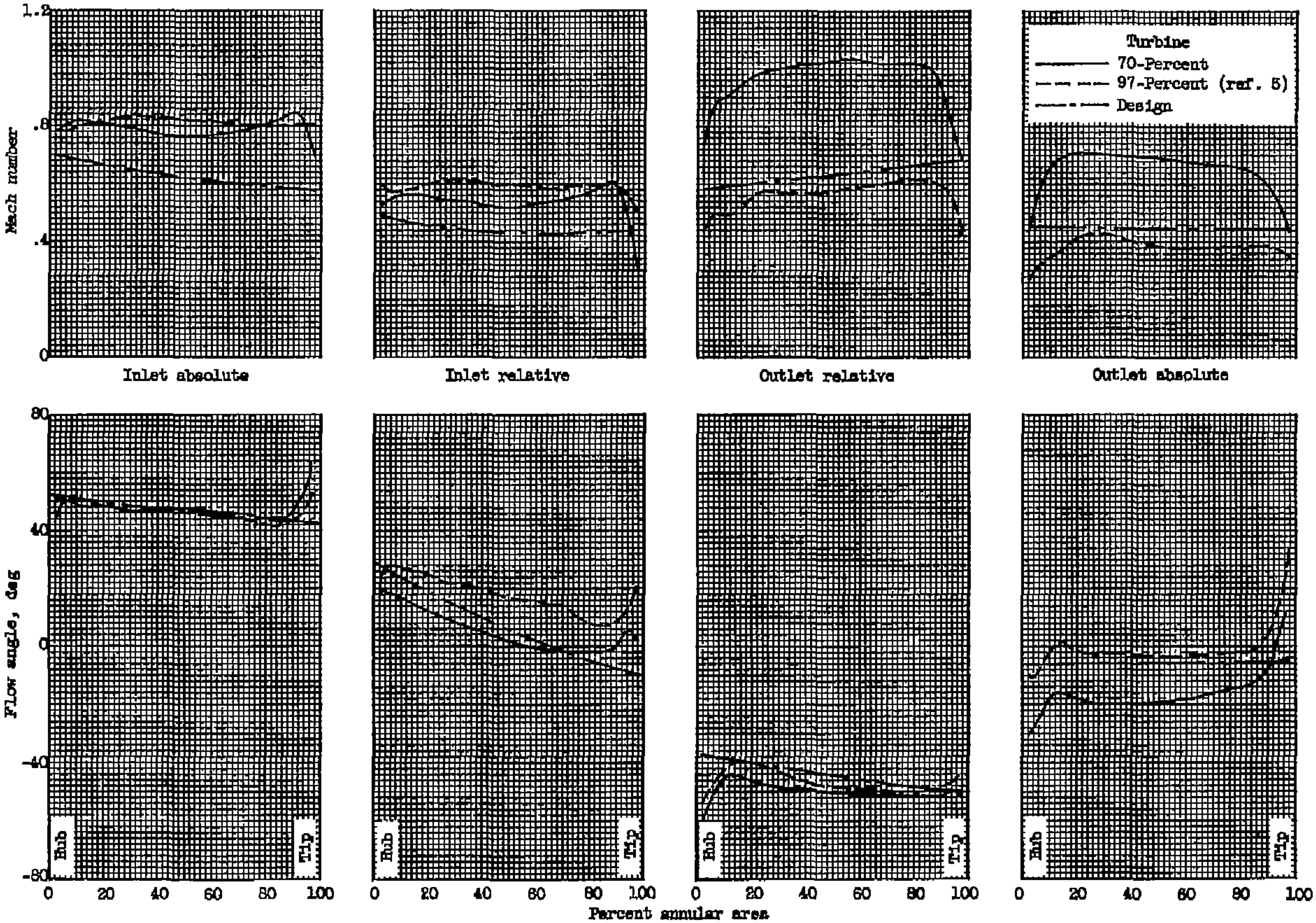
Figure 4. - Variation of absolute and relative Mach number and flow angle at rotor inlet and outlet with annular area.



(b) Second rotor.

Figure 4. - Continued. Variation of absolute and relative Mach number and flow angle at rotor inlet and outlet with annular area.

[redacted]



(c) Third rotor.

Figure 4. - Concluded. Variation of absolute and relative Mach number and flow angle at rotor inlet and outlet with annular area.

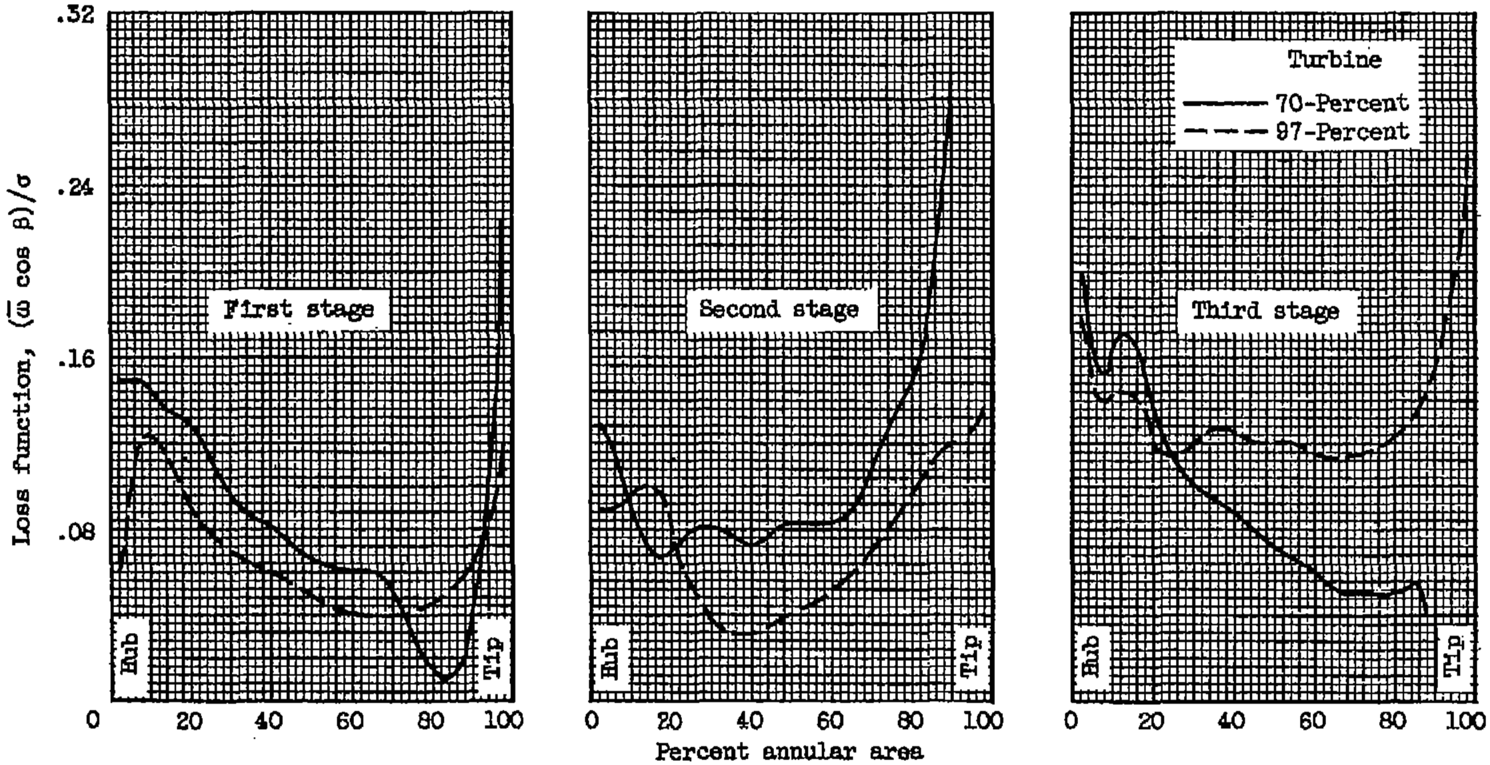


Figure 5. - Variation of loss function with annular flow area.