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# RESEARCH MEMORANDUM

COMPONENT PERFORMANCE INVESTIGATION OF J71 TYPE II TURBINES

III – OVER –ALL PERFORMANCE OF J71 TYPE IIA TURBINE

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

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COMPONENT PERFORMANCE INVESTIGATION OF J71 TYPE II TURBINES

III - OVER-ALL PERFORMANCE OF J71 TYPE IIA TURBINE

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SUMMARY

The over-all component performance characteristics of the J71 Type
IIA three-stage turbine were experimentally determined over a range of
speed and over-all turbine total-pressure ratio at inlet-air conditions
of 35 inches of mercury absolute and 700° R. The results are compared
with those obtained for the J71 Type IIF turbine, which was previously
investigated, the two turbines being designed for the same engine appli-
cation. Geometrically the two turbines were much alike, having the same
variation of annular flow area and the same number of blades for corre-
sponding stator and rotor rows. However, the blade throat areas down-
stream of the first stator of the IIA turbine were smaller than those of
the IIF; and the IIA blade profiles were curve-backed, whereas those of
the IIF were straight-backed.

The IIA turbine passed the equivalent design weight flow and had a
brake internal efficiency of 0.880 at design equivalent speed and work
output. A maximum efficiency of 0.896 occurred at 130 percent of design
equivalent speed and a pressure ratio of 4.0. The turbine had a wide
range of efficient operation. The IIA turbine had slightly higher effi-
ciencies than the IIF turbine at comparable operating conditions. The
fact that the IIA turbine obtained the design equivalent weight flow at
the design equivalent operating point was probably a result of the de-
crease in the blading throat areas downstream of the first stator from
those of the IIF turbine, which passed 105 percent of design weight flow
at the corresponding operating point. The third stator row of blades of
the IIA turbine choked at the design equivalent speed and at an over-all
pressure ratio of 4.2; the third rotor choked at a pressure ratio of
approximately 4.9.

INTRODUCTION

The NACA Lewis laboratory is currently investigating three-stage
Type II experimental turbines for the J71 turbojet engine. This research

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is part of a general study of high-work-output low-speed multistage turbines. Two different turbines were evolved for the same engine application, the Type IIF and the Type IIA. Both turbines are of conservative aerodynamic design with respect to Mach number, turning in a blade row, and work output per stage. Both incorporate fully shrouded first- and second-stage rotors and unshrouded third-stage rotors. The two turbines have the same number of blades in each corresponding blade row, and the annular-area variation through both turbines is the same. The two designs differ in blade profile shapes and blade throat areas. The blade profiles in the IIF turbine are straight-backed, whereas the IIA turbine employs curve-backed blades. The design throat area for each row of blades in the IIF turbine was greater than the corresponding area of the IIA turbine as a result of different design assumptions.

Subsequent to the design of the IIF turbine, a further analysis by the engine manufacturer indicated that the throat areas through the stators were too large. Accordingly, the turbine was fabricated with stators having 97-percent of their design throat areas. This turbine was then investigated at inlet conditions of 35 inches of mercury absolute and 700° R, and the over-all performance characteristics are reported in reference 1. At equivalent design speed and work, the turbine had a brake internal efficiency of 0.877. However, the turbine equivalent weight flow at this operating condition was 5 percent greater than the design value, even though the stator flow areas had been decreased to 97 percent of their original design value. The IIF turbine had a maximum efficiency of 0.886 at a pressure ratio of 4.0 and 120 percent of equivalent design speed. In general, the IIF turbine had a wide range of efficient operation.

In addition to the over-all performance, a detailed study of the internal flow conditions of this IIF turbine was conducted at the equivalent design operating point (ref. 2). Design stage work was obtained with local indicated stage efficiencies of 0.894, 0.858, and 0.792 for the first, second, and third stages, respectively. Contributing factors to the low efficiency of the third stage may have been the relatively large blade tip clearance (0.100 in.) and the fact that this rotor was unshrouded.

The subject report presents the over-all performance of the Type IIA turbine and compares the results with those for the Type IIF turbine (ref. 1) in order to determine the effect of decreased blade throat areas downstream of the first stator and curve-backed blades on over-all turbine performance. Reference 3 indicates that, within the range of Mach numbers encountered in the Type II turbine designs, the blade curvatures downstream of the throat sections of the IIA turbine blading would result in no increase in blade profile losses over the straight-backed blading of the IIF turbine. The effect of the blading throat-area variations of the two turbines on turbine performance, however, is difficult to predict. Consequently, in order to ascertain the effect of these two geometric variables on turbine performance, the IIA turbine was experimentally investigated at inlet conditions of 35 inches of mercury absolute and 700° R,

over a range from 20 to 130 percent of equivalent design speed and of
rating total-pressure ratio from 1.4 to 4.8.  Turbine over-all perform-
ance is presented in terms of brake internal efficiency and equivalent
work (both based on torque measurements), equivalent rating total-
pressure ratio, equivalent rotational speed, and equivalent weight flow.
Measurements of interstage static pressure are also presented.  Addition-
al data are included in table I.

## SYMBOLS

The following symbols are used in this report:

$E$          enthalpy drop based on torque measurements, Btu/lb

$g$          acceleration due to gravity, 32.174 ft/sec$^2$

$N$          rotational speed, rpm

$p$          pressure, in. Hg abs

$p_x'$       rating total pressure, static pressure plus velocity pressure
             corresponding to axial component of velocity, in. Hg abs

$R$          universal gas constant, 53.4 ft-lb/(lb)($^O$R)

$T$          temperature, $^O$R

$w$          weight flow, lb/sec

$\dfrac{wN}{608}\,\varepsilon$   weight-flow parameter based on product of equivalent weight
             flow and equivalent speed

$\gamma$     ratio of specific heats

$\delta$     ratio of inlet-air pressure to NACA standard sea-level pres-
             sure, $p_0'/29.92$

$\varepsilon$     function of   $\gamma,\ \dfrac{\gamma_{sl}}{\gamma_e}\left[\dfrac{\left(\dfrac{\gamma_e+1}{2}\right)^{\dfrac{\gamma_e}{\gamma_e-1}}}{\left(\dfrac{\gamma_{sl}+1}{2}\right)^{\dfrac{\gamma_{sl}}{\gamma_{sl}-1}}}\right]$

$\eta_i$        brake internal efficiency, ratio of actual turbine work based
              on torque measurements to ideal turbine work based on inlet
              total pressure $p_0'$ and outlet rating total pressure $p_{x,7}'$

$\theta_{cr}$   squared ratio of critical velocity to critical velocity at
              NACA standard sea-level temperature of 518.7° R,

$$\frac{\dfrac{2\gamma}{\gamma + 1} gRT_0'}{\dfrac{2\gamma_{sl}}{\gamma_{sl} + 1} gRT_{sl}}$$

$\tau$        torque, ft-lb

Subscripts:

e            engine operating conditions

$sl$          NACA standard sea-level conditions

x            axial

0,1,2,3,
4,5,6,7,    measuring stations (see fig. 2)
8

Superscripts:

'            total or stagnation state


                    APPARATUS, INSTRUMENTATION, AND PROCEDURE

        The three-stage J71 Type IIA turbine test installation used in this
investigation is the same as described in reference 1 for testing the
Type IIF turbine.  As mentioned previously, the Type IIA turbine employed
curve-backed blades and had smaller blade throat areas downstream of the
first stator than did the Type IIF turbine (ref. 1).  The design throat
areas for the IIA turbine were 94.7, 92.5, and 92.3 percent of those of
the IIF turbine for the first, second, and third stators, respectively,
and 94.9, 95.0, and 92.6 percent for the first, second, and third rotors,
respectively.  The actual measured stator throat areas for the IIA tur-
bine are 100.5, 95.4, and 92.3 percent of those for the IIF turbine for
the first, second, and third stators, respectively.  The measured varia-
tions between the corresponding stator throat areas for the IIA turbine
and the IIF turbine of reference 1 are different from the design varia-
tions, because (1) the stator areas of the IIF turbine as investigated
were intended to be 97 percent of the design area, whereas the stator
areas of the IIA turbine are 100 percent of design, and (2) these intend-
ed differences were further altered because of manufacturing tolerance

limits.  The result was the measured variations listed.  It should be noted, however, that the IIA turbine had smaller measured blade throat areas downstream of the first stator than the IIF turbine.

The sea-level design conditions, as supplied by the engine manufacturer, and the turbine design equivalent conditions are as follows:

|  | Engine sea-level design conditions, zero ram | Turbine equivalent design conditions |
| --- | --- | --- |
| Work, Btu/lb | 131.5 | 32.4 |
| Weight flow, lb/sec | 169.0 | 40.3 |
| Rotational speed, rpm | 6100 | 3028 |
| Inlet temperature, $^O$R | 2160 | 518.7 |
| Inlet pressure, in. Hg abs | 261.5 | 29.92 |

The method of deriving these equivalent design conditions is presented in reference 4.  The IIA turbine was designed so that the first stage would produce 42 percent of the total work, the second stage 34 percent, and the third stage 24 percent.  A photograph of the over-all turbine experimental setup, showing the various components, is shown in figure 1.

The instrumentation used in this investigation was the same as described in reference 1; a schematic diagram of the turbine, showing the instrumentation, is presented in figure 2.  Measurements of total pressure, static pressure, and total temperature were taken at the turbine inlet (station 0) and at the turbine outlet (station 7).  In addition, static-pressure taps were installed on the inner and outer shrouds ahead of each row of blades.

The IIA turbine was operated at constant nominal inlet pressure $p_0'$ and temperature $T_0'$ corresponding to 35 inches of mercury absolute and $700^O$ R.  Nominal pressure ratios were imposed across the turbine, and the speed was varied from 20 to 130 percent of the design equivalent speed $N/\sqrt{\theta_{cr}}$ for each pressure ratio.  A range of rating pressure ratios from 1.4 to 4.8 was investigated.

Values of equivalent torque $(\tau/\delta)\epsilon$ and equivalent weight flow $(w\sqrt{\theta_{cr}}/\delta)\epsilon$ were plotted against the rating over-all total-pressure ratio $p_0'/p_{x,7}'$, and curves were faired for each speed investigated in order to minimize random experimental inaccuracies.  The equivalent weight flows presented are corrected for the fuel addition required to maintain the $700^O$ R inlet temperature.  The turbine-outlet pressure $p_{x,7}'$, upon which the turbine efficiency is based, is calculated from the measured

total pressure, static pressure, total temperature, turbine weight flow (air flow plus fuel flow), and the known annular area at this measuring station. Efficiency based on this calculated outlet pressure charges the turbine for the energy of the rotor-discharge tangential velocity. Therefore, the values of brake internal efficiency $\eta_i$ presented are conservative.

## RESULTS AND DISCUSSION

The over-all performance of the J71 Type II turbine is presented in figure 3. The variation of equivalent shaft work $E/\theta_{cr}$ with the equivalent weight-flow parameter $(wN/60\delta)\varepsilon$ for lir. of constant equivalent rotational speed $N/\sqrt{\theta_{cr}}$ and rating total-pressure ratio $p'_0/p'_{x,7}$ is shown. Contours of constant values of brake internal efficiency $\eta_i$ are also included. All parameters are corrected to NACA standard sea-level conditions (29.92 in. Hg abs and 518.7° R). The design operating point is shown at the design equivalent speed and shaft work output (32.4 Btu/lb). This design operating point occurred at an over-all total-pressure ratio of 3.42 and an efficiency of 0.880. Values of efficiency greater than 0.89 were obtained at equivalent speeds and work outputs greater than design. The maximum efficiency of 0.896 occurred at 130 percent of design equivalent speed and a pressure ratio of 4.0. It is apparent from the performance map that a broad range of efficient turbine operation exists. Comparison of this map (fig. 3) with that for the Type IIF turbine (fig. 3, ref. 1) reveals that the two turbines had comparable efficiency characteristics, the IIA turbine exhibiting slightly higher values. It will be noted, however, that the IIA turbine handled less equivalent weight flow than the IIF turbine at any given turbine speed.

The efficiencies of the IIA and IIF turbines can be compared more readily by referring to figure 4, where these efficiencies are presented as a function of the over-all total-pressure ratio for speeds of 70, 100, and 130 percent of design equivalent speed. The Type IIA turbine presented a slightly higher efficiency (approximately 1 percent) for the two higher speeds (figs. 4(b) and (c)). At the design equivalent speed (fig. 4(b)) and near the pressure ratio at which design equivalent work was obtained for the two turbines (approximately 3.4), the IIA turbine efficiency was on the order of 0.3 percent greater than that for the IIF turbine. The change in the blade throat areas and profile shapes therefore resulted in only a slight increase in turbine efficiency.

The variation of equivalent weight flow $(w\sqrt{\theta_{cr}}/\delta)\varepsilon$ with over-all rating total-pressure ratio for the IIA turbine is presented in figure 5 for all equivalent rotational speeds investigated. The figure indicates that the turbine is choked above a pressure ratio of 4.0 for speeds

above 70 percent.  In this speed range, the choking value of weight flow
(maximum weight flow for a given speed) decreases with an increase in
rotational speed.  This indicates that, for the rotational speeds above
70 percent, the turbine chokes somewhere downstream of the first stator.

At the design operating point of 100-percent equivalent design
speed and a work output of 32.4 Btu per pound, which corresponds to an
over-all total-pressure ratio of 3.42, an equivalent weight flow of 40.4
pounds per second is indicated in figure 5.  This compares very closely
with the design value of 40.3 pounds per second.  At the corresponding
design operating point for the IIF turbine (ref. 1), 105 percent of de-
sign equivalent weight flow was observed.  The reduction in blade throat
areas downstream of the first stator of the IIA turbine from those of
the IIF turbine was probably the reason the IIA turbine obtained the de-
sign weight flow at the equivalent design operating point.

The variation of equivalent torque $(\tau/\delta)\varepsilon$  with rating over-all
total-pressure ratio for the various rotational speeds is shown in fig-
ure 6.  Over the range of conditions investigated, equivalent torque
continually increased with pressure ratio at all speeds.  This indicates
that turbine blade limiting loading was not encountered in this investi-
gation.  However, at the higher speeds and higher pressure ratios, the
slope of these torque curves continually decreases, indicating that a
blade limiting-loading condition is closely approached.

The variation of the static pressure  $p$  at the different hub meas-
uring stations with rating over-all total-pressure ratio  $p_0'/p_{x,7}'$   at
the design equivalent rotor speed is presented in figure 7.  All static
pressures were divided by the inlet total pressure  $p_0'$  in order to elim-
inate experimental variations in the inlet total pressure.  This curve
is presented in order to determine which blade rows, if any, are choked.
Blade-row choking is indicated from a plot such as figure 7 if the static
pressure at the entrance to the blade row (i.e., ratio of the static
pressure to turbine-inlet total pressure) remains constant while the
static pressure at the exit of the same blade row decreases as the over-
all total-pressure ratio across the turbine is increased.  When a blade
row does choke, the static pressures at all stations upstream of this
blade row remain constant as the over-all total-pressure ratio across the
turbine is increased.

From the foregoing discussion it may appear from figure 7 that the
first stator is choked over most of the range of over-all total-pressure
ratio investigated.  However, in the range of over-all pressure ratios
from 1.4 to 4.2, small differences in the static pressure at measuring
station 1 persist, but are somewhat difficult to note readily because of
the small scale of the ordinate.  Actually, the first stator is unchoked

over the entire range of pressure ratio, because the static- to total-pressure ratio at the exit of the first stator (measuring station 2), which in this instance is representative of the Mach number at that measuring station, is far from the choking value of 0.528.

A blade-row choking phenomenon is indicated in figure 7 across the third row of stator blades, because the static-pressure curve at measuring station 5 obtains a zero slope at and above an over-all rating total-pressure ratio of approximately 4.2, while the static-pressure curve at measuring station 6 did not. Thus, the third stator row of blades is operating in a choked condition above an over-all total-pressure ratio of about 4.2. It should be noted that this pressure ratio is well above the pressure ratio at which the equivalent design turbine work was obtained (3.42). It would also appear from the static-pressure distributions at measuring stations 6 and 7 (fig. 7) that the third rotor row of blades begins to choke at an over-all total-pressure ratio of about 4.8 or 4.9. In the IIF turbine investigation (ref. 1), the third rotor choked at a pressure ratio of 4.2. Changes in the turbine geometry, then, resulted in a shift in the initial choke point from the third rotor for the IIF turbine to the third stator for the IIA turbine.

Because the third stator of the IIA turbine choked at an over-all total-pressure ratio of approximately 4.2, all curves for the preceding measuring stations have a zero slope at and above this choking pressure ratio (see fig. 7). It would also be possible for the static-pressure curves preceding measuring station 5 to obtain a zero slope simultaneously with the curve at measuring station 5 if one or more of the blade rows preceding the third stator choked simultaneously with the third stator. While this is possible, it is not considered likely that any preceding blade row chokes with the turbine design features such as they are. It is concluded that, at the design equivalent speed, the third stator of the IIA turbine choked at an over-all total-pressure ratio of 4.2; the third rotor choked at a pressure ratio of about 4.9; the first stator was unchoked over the entire pressure-ratio range investigated; and it is possible, but unlikely, that other blade rows were choked.

SUMMARY OF RESULTS

From an experimental investigation of the J71 Type IIA three-stage turbine equipped with design stator areas and operated over a range of equivalent speed and total-pressure ratio at inlet conditions of 35 inches of mercury absolute and 700° R, the following results were obtained:

1. At equivalent design speed and work, the turbine passed the equivalent design weight flow and had a brake internal efficiency of 0.880.

2. The turbine had a wide range of efficient operation, a maximum value of 0.896 occurring at 130 percent of design equivalent speed and a total-pressure ratio of 4.0.

3. At design equivalent speed the third stator choked at an over-all pressure ratio of 4.2. Subsequently, the third rotor choked at an over-all pressure ratio of about 4.9.

4. A comparison of the over-all performance of the IIA and IIF turbines at design equivalent speed and work indicated that the use of curve-backed blades and the reduction of the blade throat areas downstream of the first stator in the IIA turbine resulted in a slight increase in efficiency and a 5-percent decrease in weight flow.

Lewis Flight Propulsion Laboratory
    National Advisory Committee for Aeronautics
        Cleveland, Ohio, January 20, 1955

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TABLE I. - DATA SUMMARY FROM EXPERIMENTAL INVESTIGATION

OF J71 TYPE IIA TURBINE

| Rating over-all total-pressure ratio, $p_0'/p_{x,7}'$ | Over-all total-pressure ratio, $p_0'/p_7'$ | Inlet total pressure, $p_0'$, in. Hg abs | Inlet total temperature, $T_0'$, °R | Outlet total temperature, $T_7'$, °R | Turbine speed, N, rpm | Turbine weight flow, w, lb/sec | Torque, $\tau$, ft-lb |
|---|---|---|---|---|---|---|---|
| 1.366 | 1.3569 | 34.98 | 701.0 | 670.7 | 740 | 34.10 | 2504 |
| 1.373 | 1.3707 | 35.24 | 701.0 | 656.5 | 1412 | 33.41 | 1914 |
| 1.380 | 1.3686 | 34.94 | 700.9 | 651.2 | 2106 | 31.99 | 1367 |
| 1.369 | 1.3546 | 35.11 | 700.8 | 652.2 | 2460 | 31.38 | 1114 |
| 1.368 | 1.3444 | 34.86 | 700.7 | 653.8 | 2812 | 30.95 | 926 |
| 1.376 | 1.3485 | 35.17 | 700.8 | 658.4 | 3168 | 30.88 | 744 |
| 1.372 | 1.3309 | 34.87 | 699.8 | 663.3 | 3515 | 30.49 | 568 |
| 1.527 | 1.5045 | 35.13 | 701.1 | 666.1 | 707 | 37.19 | 3347 |
| 1.537 | 1.5299 | 35.02 | 701.1 | 645.2 | 1403 | 36.65 | 2687 |
| 1.537 | 1.5344 | 35.03 | 701.0 | 635.1 | 2112 | 35.51 | 2025 |
| 1.546 | 1.5367 | 34.93 | 701.0 | 633.2 | 2459 | 34.95 | 1765 |
| 1.539 | 1.5194 | 34.93 | 701.0 | 633.9 | 2806 | 34.32 | 1473 |
| 1.547 | 1.5155 | 35.10 | 701.0 | 635.1 | 3165 | 34.09 | 1252 |
| 1.564 | 1.5250 | 35.06 | 701.0 | 637.7 | 3513 | 34.10 | 1092 |
| 1.568 | 1.5195 | 35.04 | 701.0 | 642.4 | 3873 | 34.10 | 921 |
| 1.577 | 1.5174 | 35.13 | 701.0 | 646.1 | 4218 | 34.13 | 750 |
| 1.587 | 1.5167 | 35.02 | 701.0 | 653.3 | 4576 | 34.10 | 596 |
| 1.744 | 1.697 | 35.11 | 701.3 | 658.1 | 701 | 39.34 | 4144 |
| 1.767 | 1.753 | 34.96 | 701.3 | 631.5 | 1417 | 38.85 | 3449 |
| 1.797 | 1.806 | 34.95 | 702.3 | 617.2 | 2108 | 38.39 | 2808 |
| 1.807 | 1.806 | 34.96 | 702.5 | 611.2 | 2471 | 38.02 | 2549 |
| 1.823 | 1.812 | 34.96 | 702.2 | 608.4 | 2812 | 37.56 | 2240 |
| 1.771 | 1.762 | 35.04 | 702.1 | 610.9 | 3167 | 36.91 | 1865 |
| 1.788 | 1.746 | 34.98 | 702.1 | 613.3 | 3514 | 36.35 | 1627 |
| 1.781 | 1.727 | 35.09 | 702.1 | 616.5 | 3869 | 36.32 | 1396 |
| 1.815 | 1.746 | 34.98 | 702.1 | 618.7 | 4219 | 36.22 | 1258 |
| 1.798 | 1.714 | 35.08 | 702.1 | 626.5 | 4578 | 36.18 | 1032 |
| 1.938 | 1.870 | 35.10 | 701.3 | 654.1 | 710 | 40.28 | 4757 |
| 1.975 | 1.948 | 35.02 | 701.3 | 622.9 | 1410 | 40.08 | 4024 |
| 2.006 | 1.994 | 34.89 | 701.3 | 603.1 | 2104 | 39.59 | 3361 |
| 2.034 | 2.027 | 34.98 | 701.3 | 596.5 | 2462 | 39.34 | 3047 |
| 2.039 | 2.027 | 34.92 | 701.3 | 592.1 | 2812 | 38.92 | 2743 |
| 2.093 | 2.068 | 35.05 | 701.3 | 587.3 | 3159 | 38.69 | 2511 |
| 2.114 | 2.082 | 35.20 | 701.2 | 586.4 | 3516 | 38.59 | 2268 |
| 2.119 | 2.070 | 35.04 | 701.3 | 587.6 | 3868 | 38.16 | 2003 |
| 2.108 | 2.038 | 35.00 | 701.2 | 590.8 | 4219 | 37.88 | 1749 |
| 2.106 | 2.019 | 35.15 | 701.1 | 597.0 | 4578 | 37.90 | 1507 |
| 2.174 | 2.128 | 35.02 | 701.3 | 615.8 | 1402 | 40.84 | 4488 |
| 2.208 | 2.188 | 34.99 | 701.3 | 593.0 | 2108 | 40.54 | 3798 |
| 2.232 | 2.223 | 34.95 | 701.3 | 585.3 | 2458 | 40.06 | 3444 |
| 2.255 | 2.237 | 34.99 | 701.3 | 580.3 | 2815 | 39.88 | 3124 |
| 2.274 | 2.265 | 35.06 | 701.3 | 576.3 | 3174 | 39.46 | 2815 |
| 2.273 | 2.237 | 35.05 | 701.3 | 575.0 | 3527 | 39.04 | 2517 |
| 2.261 | 2.209 | 35.03 | 701.1 | 575.2 | 3872 | 38.76 | 2247 |
| 2.263 | 2.190 | 35.07 | 701.2 | 578.3 | 4216 | 38.58 | 1981 |
| 2.329 | 2.220 | 35.10 | 701.3 | 577.2 | 4567 | 38.58 | 1833 |
| 2.561 | 2.432 | 35.09 | 701.4 | 603.4 | 1404 | 41.39 | 5117 |
| 2.602 | 2.606 | 35.00 | 701.4 | 577.1 | 2117 | 41.19 | 4389 |
| 2.630 | 2.599 | 34.98 | 701.3 | 566.9 | 2464 | 41.18 | 4046 |
| 2.643 | 2.630 | 34.92 | 701.3 | 559.7 | 2810 | 40.53 | 3699 |
| 2.660 | 2.630 | 35.11 | 701.3 | 555.3 | 3164 | 40.43 | 3384 |
| 2.658 | 2.658 | 34.93 | 701.3 | 554.0 | 3515 | 39.87 | 3042 |
| 2.689 | 2.653 | 35.04 | 701.3 | 552.3 | 3876 | 39.69 | 2765 |
| 2.663 | 2.600 | 34.94 | 701.3 | 553.0 | 4221 | 39.27 | 2462 |
| 2.644 | 2.564 | 34.90 | 701.3 | 556.2 | 4568 | 39.09 | 2203 |

TABLE I. - Concluded.  DATA SUMMARY FROM EXPERIMENTAL INVESTIGATION

OF J71 TYPE IIA TURBINE

| Rating over-all total-pressure ratio, $p_0'/p_{x,7}'$ | Over-all total pressure ratio, $p_0'/p_7'$ | Inlet total pressure, $p_0'$, in. Hg abs | Inlet total temperature, $T_0'$, °R | Outlet total temperature, $T_7'$, °R | Turbine speed, N, rpm | Turbine weight flow, w, lb/sec | Torque, $\tau$, ft-lb |
|---|---|---|---|---|---|---|---|
| 2.859 | 2.692 | 34.91 | 701.5 | 597.5 | 1398 | 41.86 | 5514 |
| 2.965 | 2.875 | 34.96 | 701.5 | 565.3 | 2108 | 41.54 | 4821 |
| 2.997 | 2.942 | 35.01 | 701.4 | 554.5 | 2463 | 41.61 | 4480 |
| 3.049 | 2.991 | 35.15 | 701.4 | 545.4 | 2810 | 41.53 | 4183 |
| 3.040 | 3.045 | 35.23 | 701.5 | 539.9 | 3168 | 41.27 | 3803 |
| 3.039 | 3.023 | 35.01 | 701.3 | 537.1 | 3513 | 40.88 | 3463 |
| 3.009 | 3.007 | 35.09 | 701.3 | 535.9 | 3871 | 40.43 | 3100 |
| 3.034 | 2.992 | 35.16 | 701.4 | 534.6 | 4226 | 40.27 | 2841 |
| 2.994 | 2.926 | 35.03 | 701.3 | 536.8 | 4575 | 40.19 | 2539 |
| 3.275 | 3.157 | 35.30 | 701.5 | 557.3 | 2113 | 42.08 | 5124 |
| 3.264 | 3.166 | 35.05 | 701.4 | 545.5 | 2461 | 41.84 | 4755 |
| 3.281 | 3.281 | 34.91 | 701.3 | 537.4 | 2816 | 41.70 | 4387 |
| 3.303 | 3.230 | 35.01 | 701.3 | 529.8 | 3168 | 41.49 | 4021 |
| 3.313 | 3.354 | 35.02 | 701.4 | 526.5 | 3514 | 41.13 | 3727 |
| 3.363 | 3.353 | 35.04 | 701.3 | 520.8 | 3869 | 40.66 | 3389 |
| 3.350 | 3.344 | 35.04 | 701.3 | 521.3 | 4225 | 40.62 | 3083 |
| 3.358 | 3.316 | 35.12 | 701.3 | 520.5 | 4570 | 40.50 | 2852 |
| 3.432 | 3.386 | 35.04 | 702.4 | 522.6 | 3512 | 40.57 | 3781 |
| 3.429 | 3.392 | 35.04 | 703.3 | 525.4 | 3512 | 40.52 | 3753 |
| 3.400 | 3.352 | 34.99 | 702.3 | 525.1 | 3514 | 40.50 | 3753 |
| 3.404 | 3.352 | 35.03 | 702.3 | 522.4 | 3515 | 40.61 | 3743 |
| 3.559 | 3.320 | 35.13 | 701.3 | 549.7 | 2113 | 42.16 | 5327 |
| 3.608 | 3.442 | 35.11 | 701.5 | 537.7 | 2456 | 41.49 | 4969 |
| 3.604 | 3.525 | 35.07 | 701.5 | 528.3 | 2811 | 41.63 | 4656 |
| 3.562 | 3.453 | 35.05 | 701.5 | 523.2 | 3164 | 40.96 | 4177 |
| 3.756 | 3.658 | 35.08 | 700.3 | 510.3 | 3505 | 40.86 | 3992 |
| 3.595 | 3.540 | 35.05 | 701.0 | 517.4 | 3514 | 41.05 | 3886 |
| 3.687 | 3.645 | 35.14 | 701.3 | 512.4 | 3869 | 40.92 | 3622 |
| 3.651 | 3.632 | 35.12 | 701.3 | 512.7 | 4220 | 40.56 | 3314 |
| 3.672 | 3.630 | 35.14 | 701.3 | 509.3 | 4568 | 40.30 | 3017 |
| 4.010 | 3.651 | 35.01 | 701.4 | 528.4 | 2465 | 41.92 | 5217 |
| 3.947 | 3.613 | 35.01 | 701.4 | 522.7 | 2817 | 41.58 | 4772 |
| 3.977 | 3.797 | 35.16 | 701.4 | 513.0 | 3166 | 41.46 | 4474 |
| 4.142 | 3.813 | 35.04 | 700.3 | 502.5 | 3519 | 40.88 | 4190 |
| 4.007 | 3.883 | 35.14 | 701.4 | 507.7 | 3517 | 41.21 | 4139 |
| 3.930 | 3.844 | 35.13 | 700.4 | 509.0 | 3523 | 40.90 | 4069 |
| 4.061 | 4.118 | 35.13 | 701.3 | 502.0 | 3865 | 40.90 | 3842 |
| 3.956 | 3.956 | 35.05 | 701.3 | 503.5 | 4224 | 40.34 | 3452 |
| 3.963 | 3.880 | 35.11 | 701.3 | 500.8 | 4574 | 40.38 | 3210 |
| 4.485 | 3.913 | 34.98 | 701.5 | 521.9 | 2465 | 41.97 | 5420 |
| 4.238 | 3.867 | 34.92 | 701.4 | 514.5 | 2818 | 41.40 | 4975 |
| 4.514 | 4.236 | 35.03 | 701.5 | 504.9 | 3163 | 41.33 | 4705 |
| 4.599 | 4.268 | 35.00 | 700.3 | 495.0 | 3520 | 40.82 | 4416 |
| 4.332 | 4.098 | 35.00 | 700.3 | 498.5 | 3520 | 40.90 | 4312 |
| 4.458 | 4.234 | 35.31 | 701.5 | 499.0 | 3516 | 41.05 | 4304 |
| 4.473 | 4.548 | 35.25 | 701.3 | 495.2 | 3870 | 40.87 | 3990 |
| 4.536 | 5.040 | 34.93 | 701.4 | 490.6 | 4205 | 40.13 | 3721 |
| 4.608 | 5.258 | 35.02 | 701.3 | 488.1 | 4575 | 40.08 | 3446 |
| 4.628 | 4.050 | 34.99 | 701.4 | 509.8 | 2810 | 41.70 | 5099 |
| 4.815 | 4.364 | 34.91 | 701.5 | 499.6 | 3174 | 41.06 | 4751 |
| 4.942 | 4.564 | 35.19 | 701.4 | 494.1 | 3515 | 40.91 | 4476 |
| 4.822 | 4.454 | 34.96 | 700.4 | 493.4 | 3518 | 40.74 | 4472 |
| 5.001 | 4.633 | 35.21 | 701.4 | 489.5 | 3970 | 40.84 | 4146 |
| 5.118 | 4.852 | 35.52 | 701.3 | 486.9 | 4228 | 40.85 | 3888 |
| 5.217 | 4.997 | 35.53 | 701.4 | 485.0 | 4578 | 40.80 | 3613 |
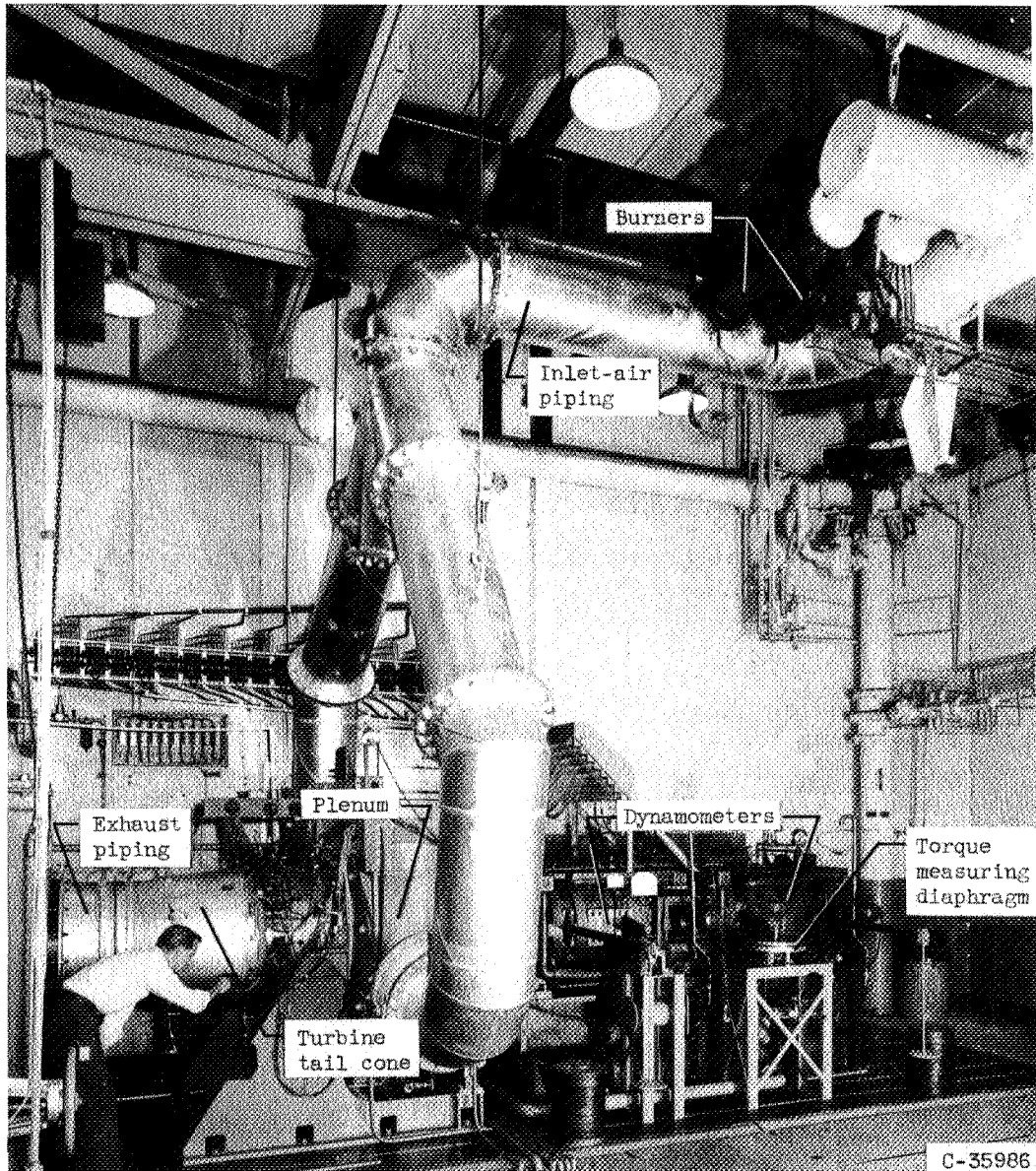
Figure 1. - Installation of J71 Type IIA three-stage turbine on full-scale turbine component test facility.

Station    0         1   2      3   4     5   6        7              8

Exhaust

——— Stagnation pressure

----- Stagnation temperature

• Static pressure

Station 0          1              2              3              4
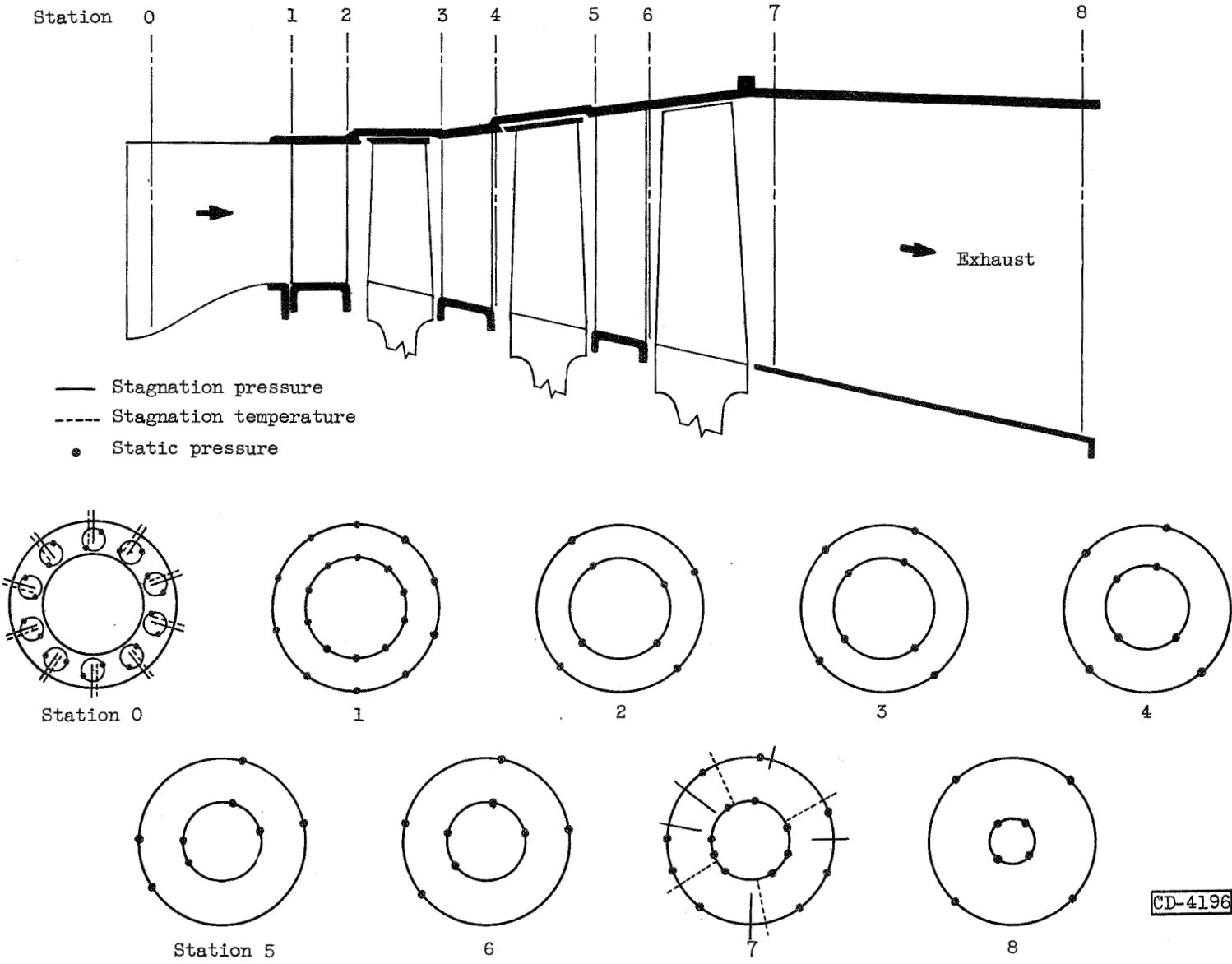
Station 5          6              7              8

CD-4196

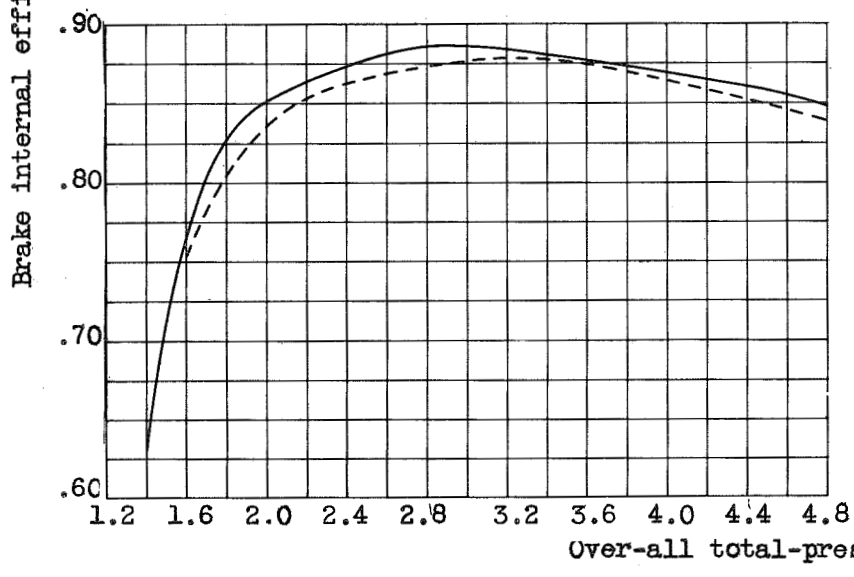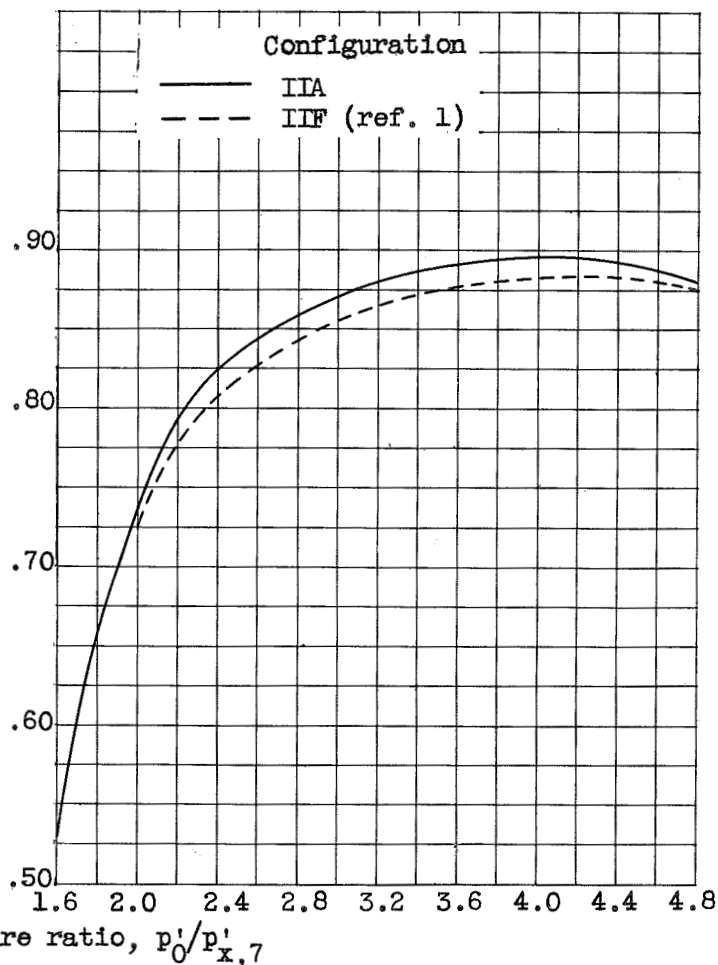Figure 2. - Schematic diagram of J71 Type IIA turbine showing instrumentation.
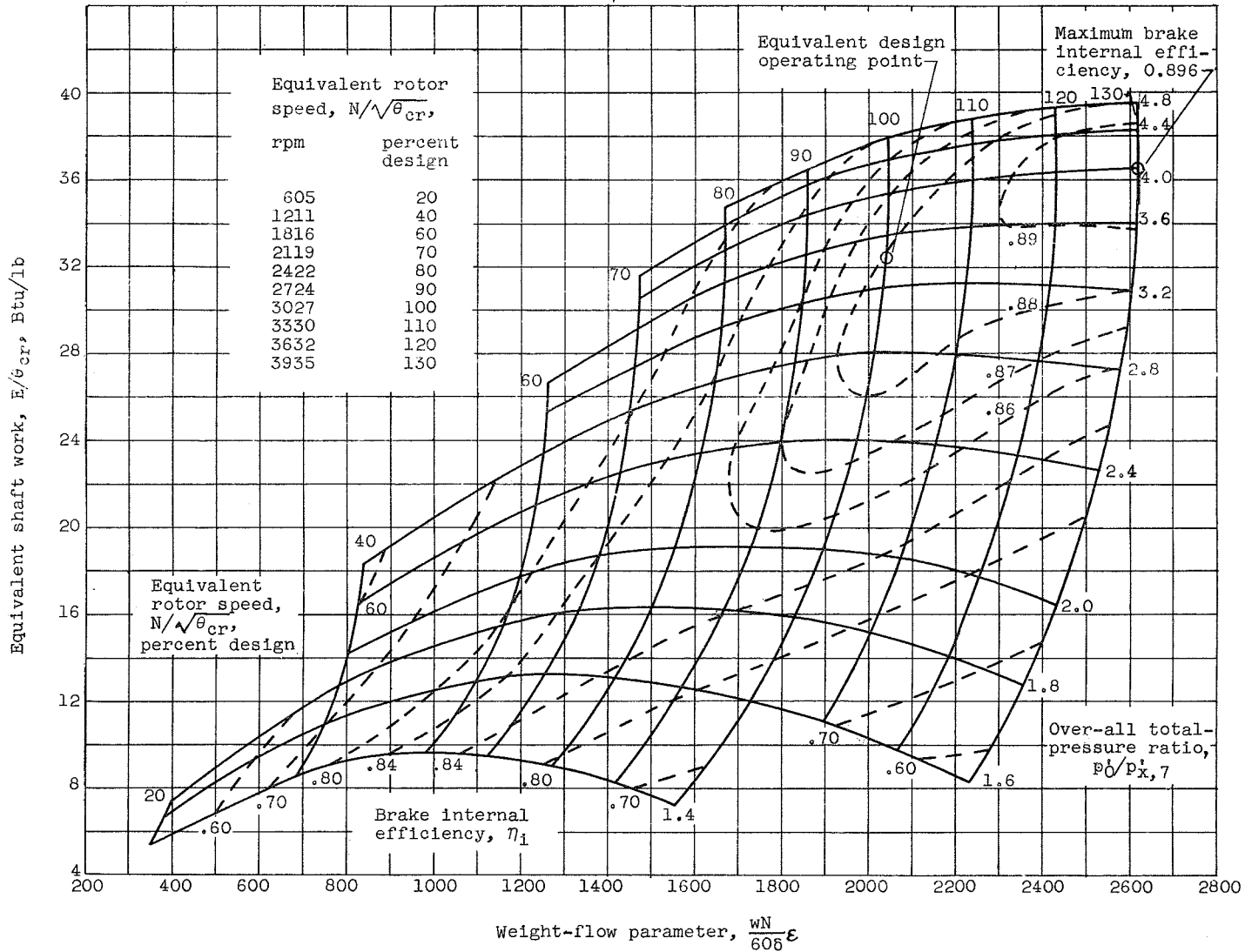
Figure 3. - Over-all performance of J71 Type IIA three-stage turbine. Turbine-inlet pressure, 35 inches of mercury absolute; turbine-inlet temperature, 700° R.
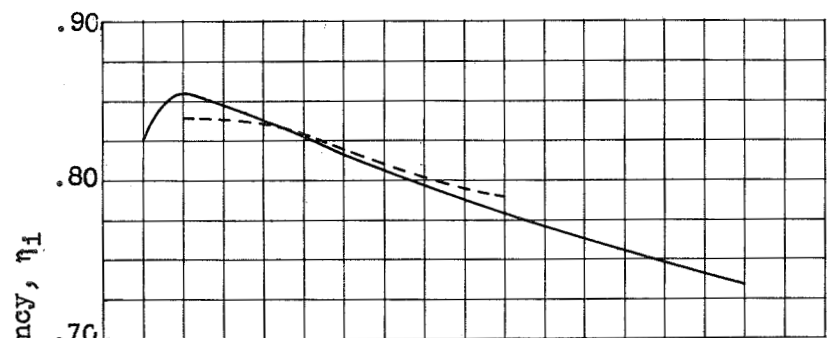
(a) Equivalent speed, 70-percent design.

(b) Equivalent speed, 100-percent design.

(c) Equivalent speed, 130-percent design.

Figure 4. - Variation of over-all turbine brake internal efficiency with over-all total-pressure ratio at three different rotational speeds for two J71 turbine configurations.
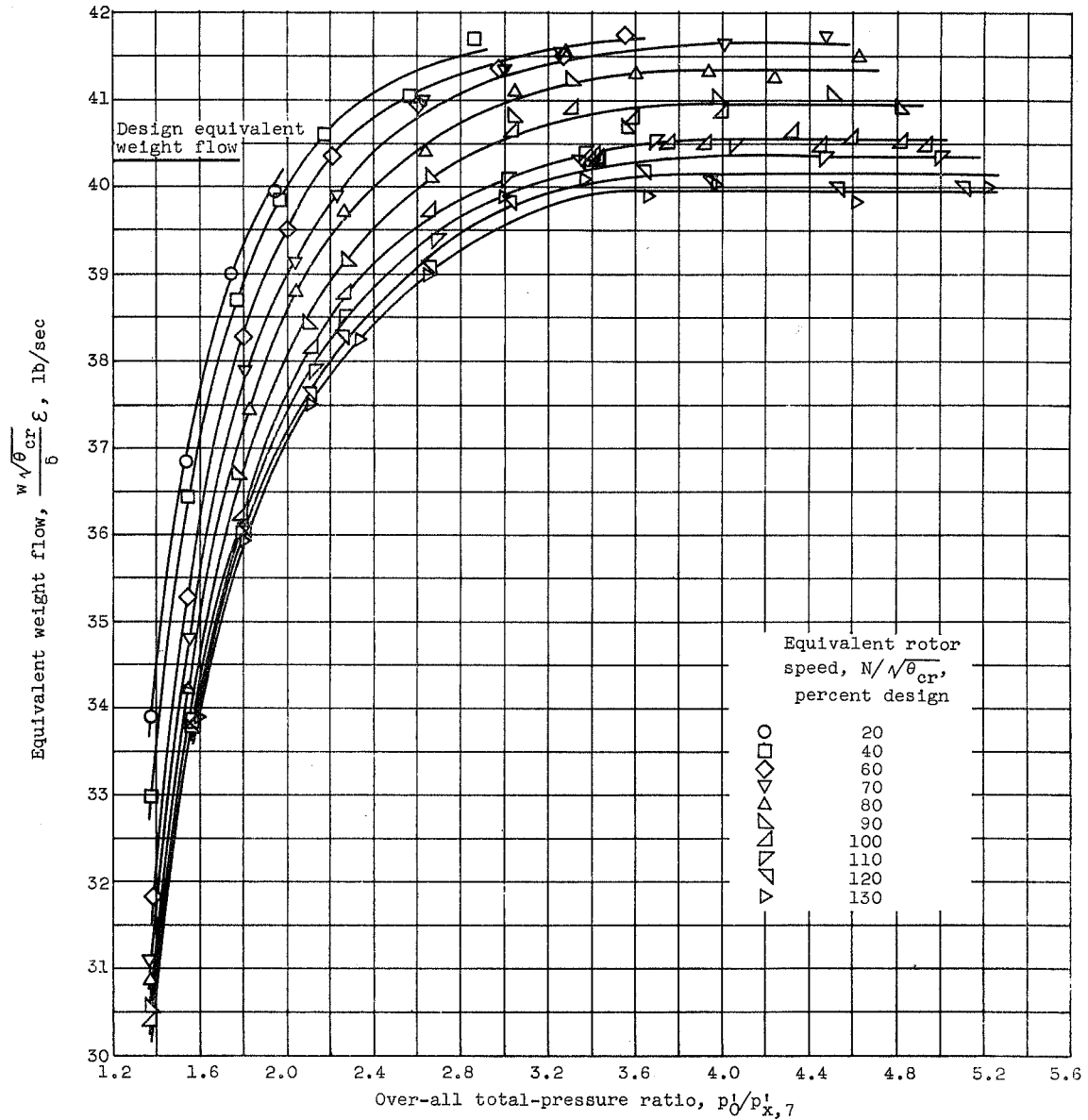
Figure 5. - Variation of equivalent weight flow with over-all total-pressure ratio for values of constant equivalent rotor speed.
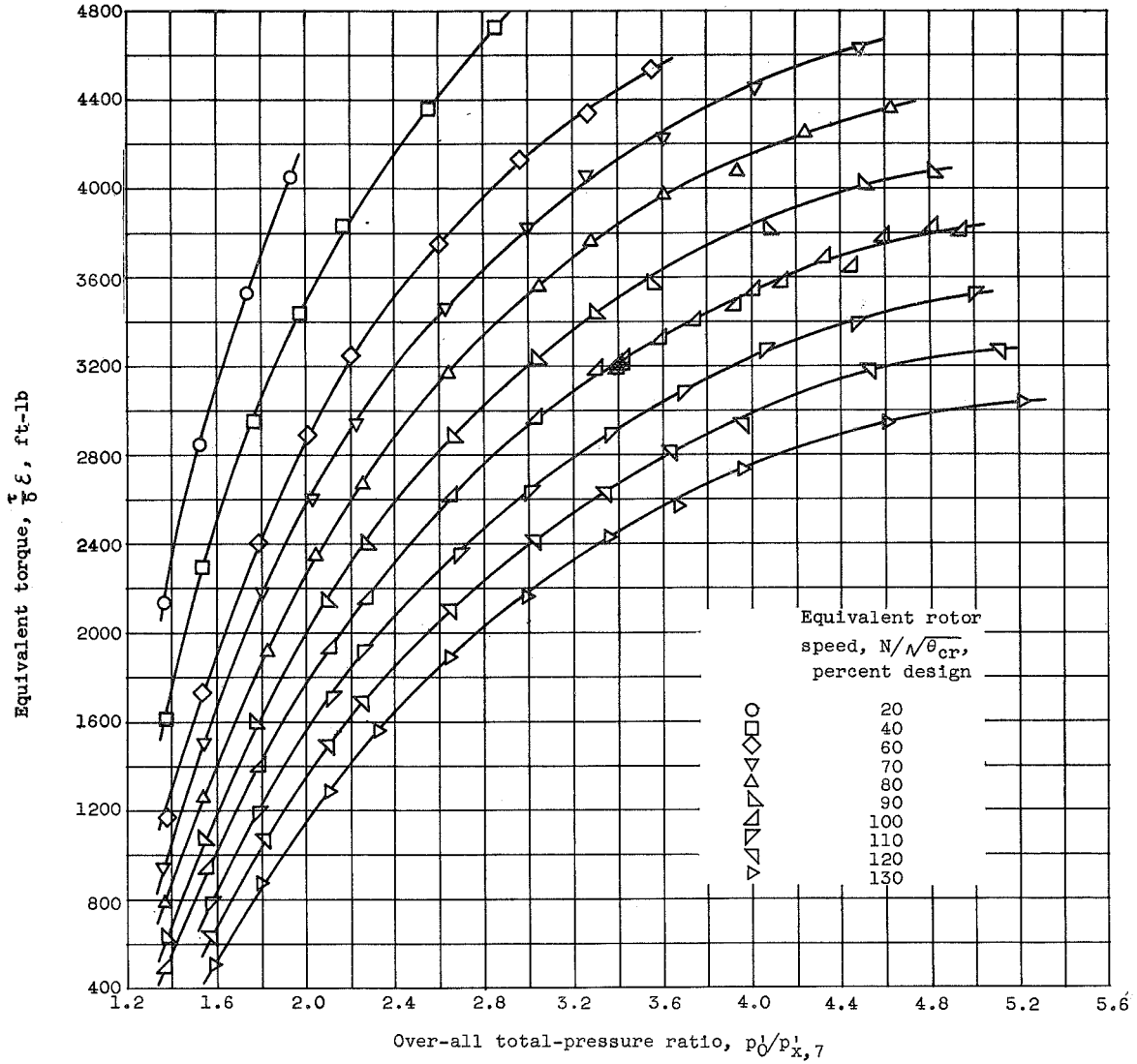
Figure 6. – Variation of equivalent torque with over-all total-pressure ratio for values of constant equivalent rotor speed.
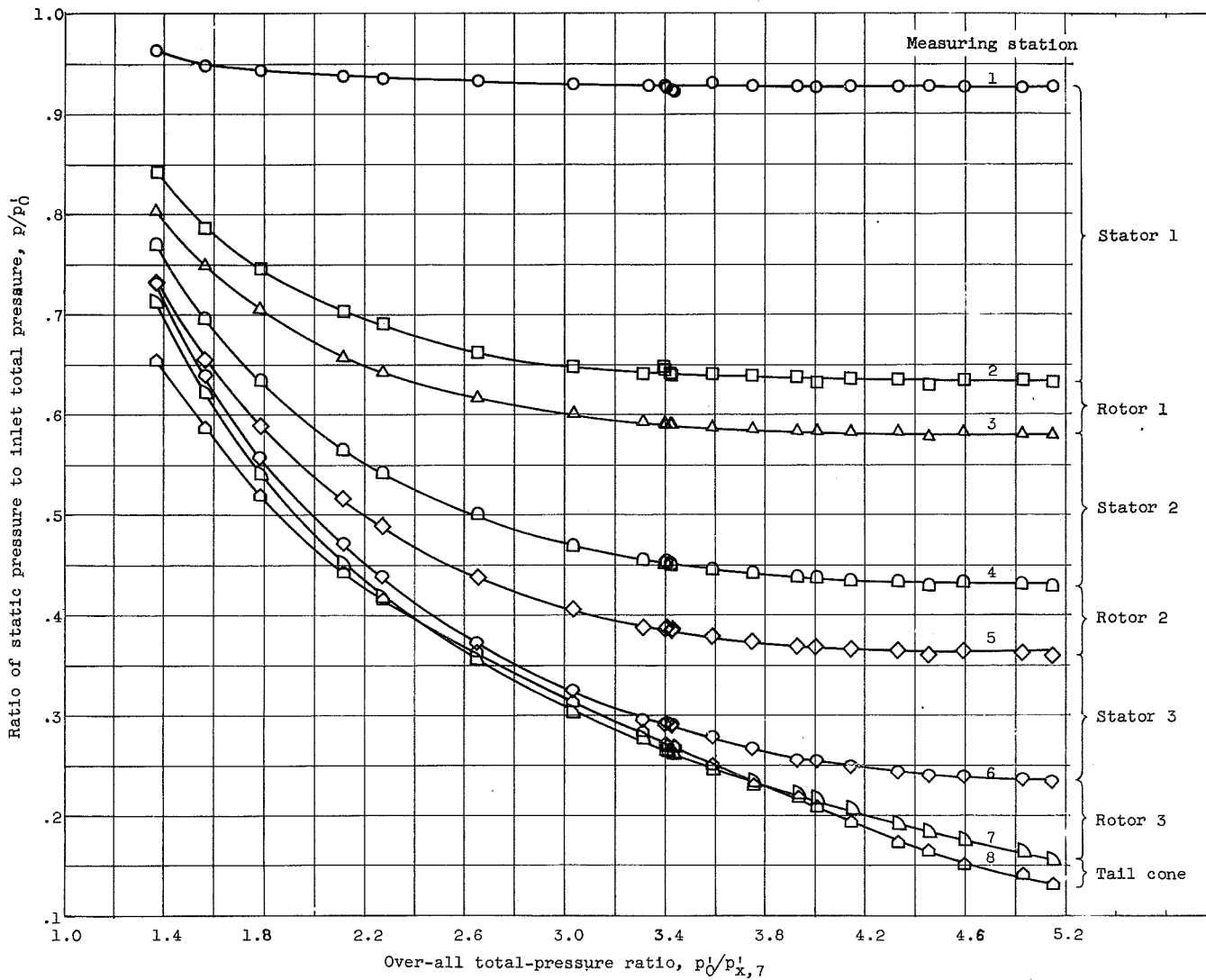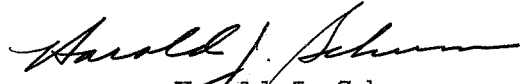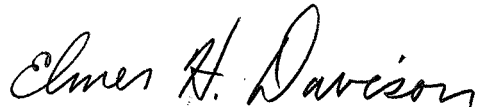
Figure 7. - Variation of ratio of static pressure at hub to inlet total pressure with over-all total-pressure ratio at different measuring stations for design equivalent speed.

COMPONENT PERFORMANCE INVESTIGATION OF J71 TYPE II TURBINES

III - OVER-ALL PERFORMANCE OF J71 TYPE IIA TURBINE

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Engines, Turbojet                                                    3.1.3

Turbine Flow Theory and Experiment                                   3.7.1

Turbines - Axial Flow                                                3.7.1.1

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COMPONENT PERFORMANCE INVESTIGATION OF J71 TYPE II TURBINES
III - OVER-ALL PERFORMANCE OF J71 TYPE IIA TURBINE

## Abstract

The J71 Type IIA turbine had a brake internal efficiency of 0.880
and passed the equivalent design weight flow at equivalent design speed
and work. A comparison of the over-all performance of this turbine with
that of the Type IIF turbine at this equivalent design operating point
indicated that the use of curve-backed blades and the reduction of the
blade throat areas downstream of the first stator in the IIA turbine
resulted in a slight increase in efficiency and a 5-percent decrease in
weight flow.