RESEARCH MEMORANDUM

EFFECT OF REDUCED STATOR-BLADE TRAILING-EDGE THICKNESS ON OVER-ALL PERFORMANCE OF A TRANSONIC TURBINE

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SUMMARY

A transonic turbine with a stator trailing-edge thickness reduced from 0.030 to 0.010 inch has been investigated experimentally. An efficiency of 0.872 was obtained at design operating conditions; this efficiency represents an increase of 0.6 of a point as compared with the design-point efficiency obtained with the original stator, which had a trailing-edge thickness of 0.030 inch. An increase in efficiency was noted over the entire performance map, amounting in some cases to 2.4 points. Although the increase in design-point efficiency was small, it was felt to be significant that the efficiency could be increased by reducing the stator-blade trailing-edge thickness within this range. The experimentally indicated increase in efficiency could be only partially accounted for by the theoretical change in mixing loss for the two stator-blade rows. It was therefore felt the improvement in performance obtained with the thin trailing-edge stator was largely due to a decreased amount of low-velocity fluids which entered the rotor and the interference effect of these fluids with the mainstream flow.

INTRODUCTION

The investigation of the various losses that affect turbine performance is part of the general turbine research program being conducted at the NACA Lewis laboratory. One source of turbine loss is that associated with the wake region that occurs immediately downstream of the stator-blade trailing edge. This wake region can be identified as a region of high total-pressure loss downstream of the trailing edge (ref. 1, fig. 6, e.g.). Theoretically, the stream static pressure is assumed to extend throughout the wake region and the wake region is assumed to consist of (1) a mass-flow void region, the width of which (measured normal to the blade-outlet direction just at the trailing edge) is equal to the trailing-edge thickness, and (2) two regions of low total pressure that are caused by losses arising from the blade suction- and pressure-surface boundary layers (refs. 2 and 3). According to this concept the mass-flow void part of the wake region would be directly dependent on the trailing-edge thickness; whereas the part of the wake caused by the boundary layers would be affected only slightly or not at all by a change in trailing-edge thickness, since the basic blade form would not be changed significantly.

The manner in which the over-all turbine performance is affected by the presence of these wake regions depends on the nature of the mixing process that occurs as the flow proceeds downstream of the stator trailing edge. If complete mixing is accomplished before the flow enters the rotor, the velocity and flow angle relative to the rotor would be circumferentially uniform. This mixing, however, would cause a total-pressure loss which would be small in the case of most turbine stators. If only partial mixing has occurred by the time the flow enters the rotor, the interference effect of the low-velocity elements of the flow with the mainstream fluid may induce an appreciable rotor loss, as discussed in reference 4.

The actual influence of these wake regions on over-all performance is difficult to ascertain analytically, because the nature of the mixing process in a turbine is unknown. It has been shown (ref. 5) that the over-all turbine performance would be impaired if the stator trailing edge were made excessively thick. It is not known, however, if there would be any appreciable gain in over-all performance by a reduction in trailing-edge thickness that was originally reasonably thin. The stator blade of the transonic turbine of reference 6 was modified by reducing the trailing-edge thickness from 0.030 to 0.010 inch, effecting a reduction in the thickness-to-pitch ratio from 0.0257 to 0.0085. According to reference 2, the change in over-all performance effected by changing the stator trailing-edge thickness within this range would hardly be noticeable. This conclusion was based on the small theoretical difference in mixing loss across the two blade rows. It is indicated in reference 4, however, where the stator thickness-to-pitch ratio is 0.0261, that the effects of the stator wakes were in evidence downstream of the rotor and that they caused an appreciable variation in the local adiabatic efficiency. It was therefore of interest to determine experimentally the effect of reducing the trailing-edge thickness in the low range of thickness-to-pitch ratio.

The over-all performance was obtained for the thin-trailing-edge stator over a range of speeds and pressure ratios. In addition to the over-all performance, total-temperature and total-pressure surveys were made downstream of the stator at design operating conditions in order to determine the behavior of the stator wakes. This report will present the over-all performance and the survey data obtained with the thin-trailing-edge stator. The experimental results obtained with the original stator (ref. 6) will be included. From a comparison of the over-all performance obtained with the two stator configurations, the effect of reduced stator trailing-edge thickness will be evaluated.

SYMBOLS

The following symbols are used in this report:

$\frac{\Delta h'}{\theta_{cr}}$	equivalent specific work output based on total state, Btu/lb
p	absolute pressure, lb/sq ft
N	rotational speed, rpm
w	weight flow, lb/sec
γ	ratio of specific heats
δ	ratio of inlet total pressure to NACA standard sea-level pressure, p_0'/p^*
ε	function of γ, $\frac{\gamma^*}{\gamma}\left[\frac{\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}}}{\left(\frac{\gamma^*+1}{2}\right)^{\frac{\gamma^*}{\gamma^*-1}}}\right]$
η_l	local adiabatic efficiency based on total-state measurements from surveys downstream of rotor
η_t	total-pressure-ratio adiabatic efficiency, ratio of turbine work based on torque, weight flow, and speed measurements to ideal work based on inlet total temperature, inlet total pressure, and outlet total pressure

Subscripts:

0	station upstream of turbine stator
3	station at stator outlet
6	station downstream of turbine rotor

Superscripts:

*	NACA standard conditions
'	total state

3798

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APPARATUS, INSTRUMENTATION, AND METHODS

The apparatus, instrumentation, and methods of calculating the performance parameters used in this report are the same as described in references 6 and 7. The turbine is the same as that of reference 6 except for the modification to the stator trailing edge shown in figure 1. Performance runs were made over a range of speeds from 60 to 130 percent of design speed. At each speed the total-pressure ratio was varied from 1.5 to a value approaching turbine limiting loading. The turbine-inlet conditions were maintained constant at nominal values of temperature and pressure of 600° R and 32 inches of mercury absolute, respectively.

The surveys of total temperature and total pressure that were made downstream of the rotor consisted of circumferential traverses at the various radii with self-alining total-temperature and total-pressure probes. The circumferential arc of the traverses included approximately $1\frac{1}{4}$ stator passages. The total-temperature and total-pressure data were simultaneously plotted against circumferential position on an automatic curve tracer.

RESULTS AND DISCUSSION

Over-All Performance

The over-all performance of the turbine operated with the thin-trailing-edge stator is presented in figure 2, with equivalent specific work output $\Delta h'/\theta_{cr}$ shown as a function of the weight-flow - speed parameter $\varepsilon wN/\delta$ for the various total-pressure ratios. Efficiency contours and constant-speed lines are superimposed on the figure. The maximum efficiency obtained for this configuration was 0.878 at 110 percent design speed, and the efficiency at the design point was 0.872. The performance obtained with the original stator (ref. 6) is presented in figure 3. The efficiency at the design point was 0.866, and the maximum efficiency was 0.87. Thus the indicated effect of reducing the stator trailing-edge thickness was to increase the design-point efficiency by 0.6 of a point. At off-design conditions an increase in efficiency can be noted over the entire performance range investigated, amounting in some cases to 2.4 points (at 90 percent speed and an equivalent specific work output $\Delta h'/\theta_{cr}$ of 13 Btu/lb).

As mentioned in the INTRODUCTION, the improvement in over-all performance, as indicated by reference 2, would hardly be noticeable. The effect of the reduction in trailing-edge thickness on over-all performance was also computed using equation (C22) of reference 3 with the results of stator-outlet survey data obtained at the mean radius. This computation indicated an increase of 0.2 of an efficiency point for the thin-trailing-edge stator as compared with that obtained with the original stator at design-point operation; at off-design conditions the increase in efficiency varied from 0.2 of a point to slightly less than 0.1 of a point. Thus the experimentally indicated improvement in performance obtained by reducing the stator-blade trailing-edge thickness can be only partially accounted for by the theoretical difference in mixing loss (refs. 2 and 3) for the two stator-blade rows. It is felt, therefore, that the improvement in performance was largely due to the reduced amount of low-velocity fluid entering the rotor and the interference effect of this fluid with the mainstream flow.

Stator Surveys

The results of detailed total-pressure surveys that were made about 3/16 of an inch downstream of the stator-blade trailing edge are shown in figure 4 for the two stator configurations as contours of total-pressure ratio across the stator. The stator wakes can be compared near the mean radius where the effects of secondary-flow losses and end-wall boundary layer are the least pronounced. From a comparison of figures 4(a) and (b) it can be seen that the thin-trailing-edge stator has a noticeably smaller wake region. It can also be seen from the figures that complete mixing has not been obtained at this location, which was about halfway between the stator and the rotor.

Rotor Surveys

The results of the detailed total-temperature and total-pressure surveys that were made downstream of the rotor at approximately design operating conditions are shown as contours of local efficiency η_l in figure 5 for the two stator configurations. From a comparison of figures 5(a) and (b) it can be seen that the thin-trailing-edge stator effected an increase in the local efficiency over most of the annular segment. The drop off in efficiency in the outer one-third portion of the blade height is much more marked for the original stator than for the thin-trailing-edge stator. This effect is felt to result from the larger amount of low-velocity fluids (resulting from stator losses) which are centrifuged toward the tip region in the rotor passage and cause a lower over-all efficiency in this region.

Evaluation of Results

With regard to the reliability of the data, it should be mentioned that the improvement in efficiency noted, as a result. of reduced trailing-edge thickness, is within experimental error on the basis of a point-by-point comparison over a large portion of the performance range. It is believed, however, that the indicated improvement in performance is reliable because the improvement is consistent, occurring in varying degrees throughout the performance range. In addition, the results of the surveys made downstream of the rotor show that the design-point efficiency obtained with the thin-trailing-edge stator is increased over that obtained with the original stator. The survey data were obtained and computed independently of the over-all performance results. Thus the survey data substantiate qualitatively the improvement in design-point performance noted from the over-all performance results.

The weight flow obtained with the thin-trailing-edge stator was design weight flow, whereas the weight flow obtained with the original stator (ref. 6) was about 1 percent below design value. From unpublished data obtained with the thin-trailing-edge stator and a transonic turbine rotor, the design of which was similar to that of the subject rotor, it was indicated that the effect of increasing the weight flow by 1 percent would be to lower the design-point efficiency by about 0.5 of a point. It is felt, therefore, that the difference noted herein in over-all performance as a result of reducing the stator trailing-edge thickness is conservative and had the two stator configurations been compared at equal weight flows, the improvement would probably have amounted to 1 efficiency point rather than 0.6 of a point. Although the increase in efficiency of 0.6 of a point could be regarded as a small effect, it might be pointed out that the trailing-edge thickness of the original stator would be considered to be close to a minimum value by current design criteria, the thickness-to-pitch ratio being 0.0257. It is felt to be significant that the efficiency could be increased by reducing the trailing-edge thickness within this range.

SUMMARY OF RESULTS

A transonic turbine with a stator-blade trailing-edge thickness of 0.010 inch has been experimentally investigated; the results were compared with those obtained with the original stator, which had a trailing-edge thickness of 0.030 inch.

The efficiency of the turbine at design operating conditions was 0.872, and the maximum efficiency was 0.878. At design point the efficiency represents an increase of 0.6 of a point as a result of reducing the trailing-edge thickness, and at off-design conditions the increase varied from 0.6 to 2.4 points. Although this may be regarded as a small improvement in design-point performance, it is felt to be significant that the efficiency could be increased by reducing the stator-blade trailing-edge thickness within this range. The increase in efficiency noted herein is felt to be reliable because it was consistent, occurring throughout the performance range, and because the performance results at design operation are qualitatively substantiated by the rotor surveys.

The indicated improvement in performance that was obtained as a result of reducing the trailing-edge thickness could be only partially accounted for theoretically on the basis of reduced mixing loss for the two stator-blade rows. It was therefore felt that the improvement was largely due to the decreased amount of low-velocity fluids entering the rotor and the interference effect of these fluids with the mainstream flow.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, August 19, 1955

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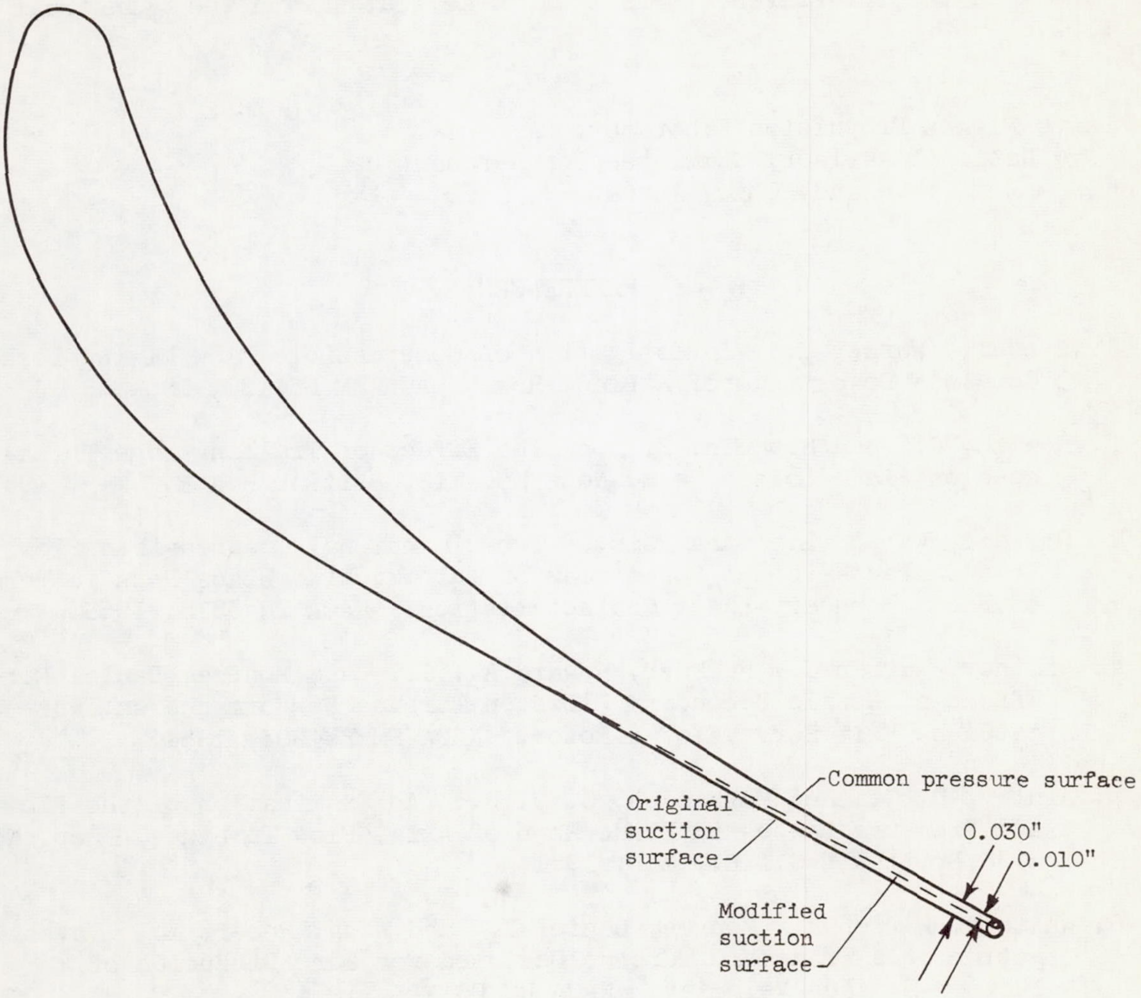


Figure 1. - Sketch of stator-blade section at mean radius showing original and modified blade configurations.

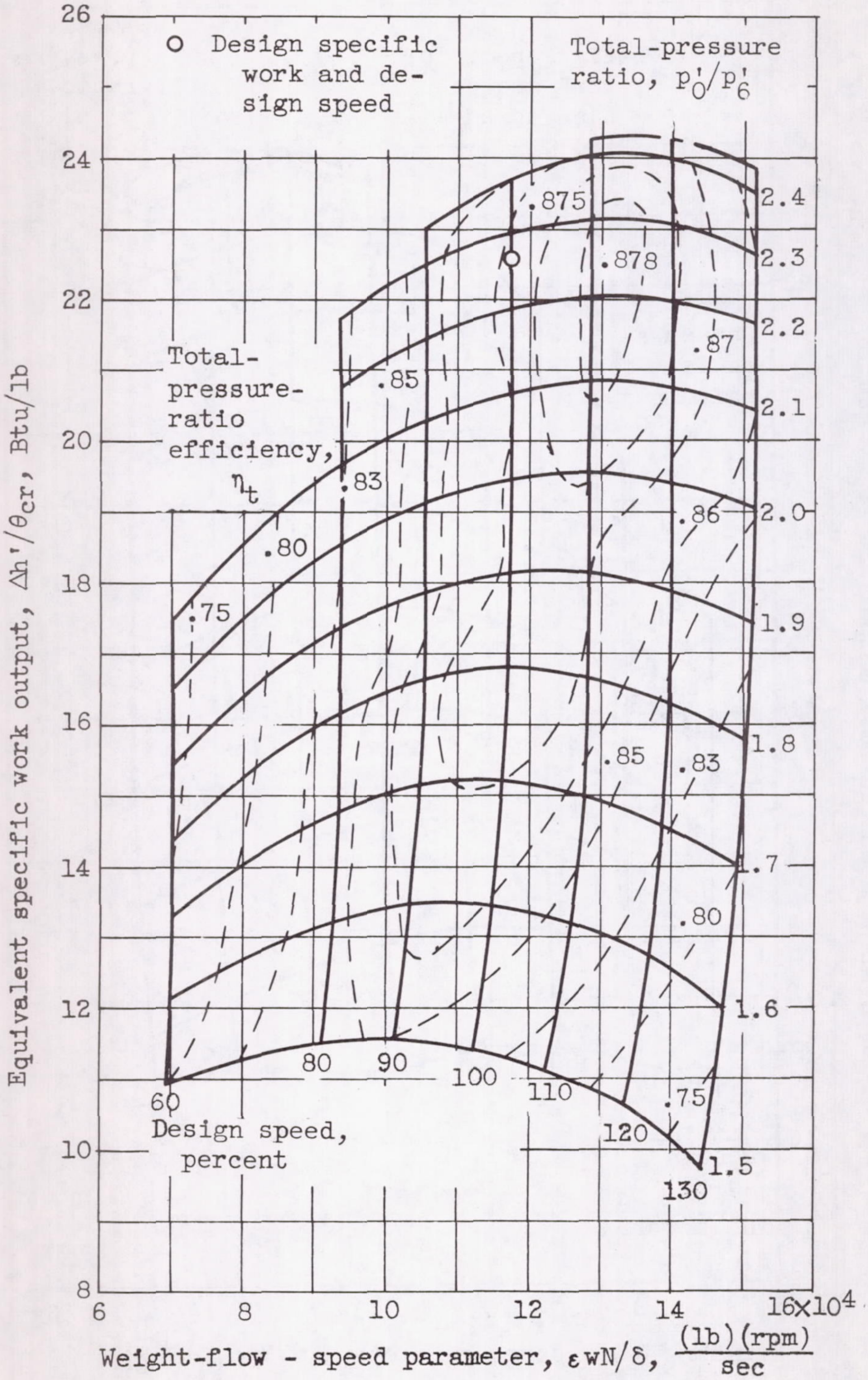


Figure 2. - Over-all turbine performance obtained with thin-trailing-edge stator.

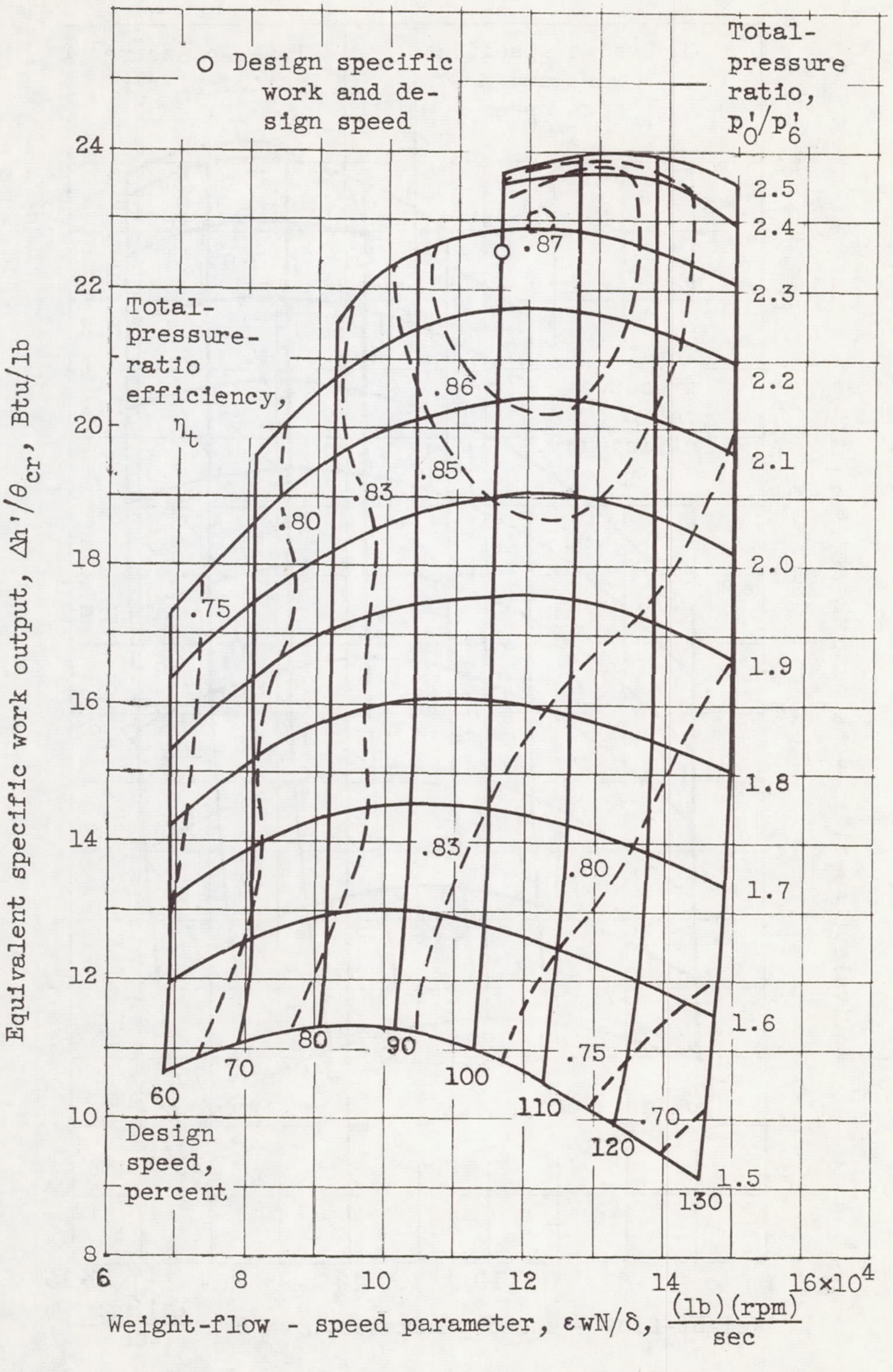
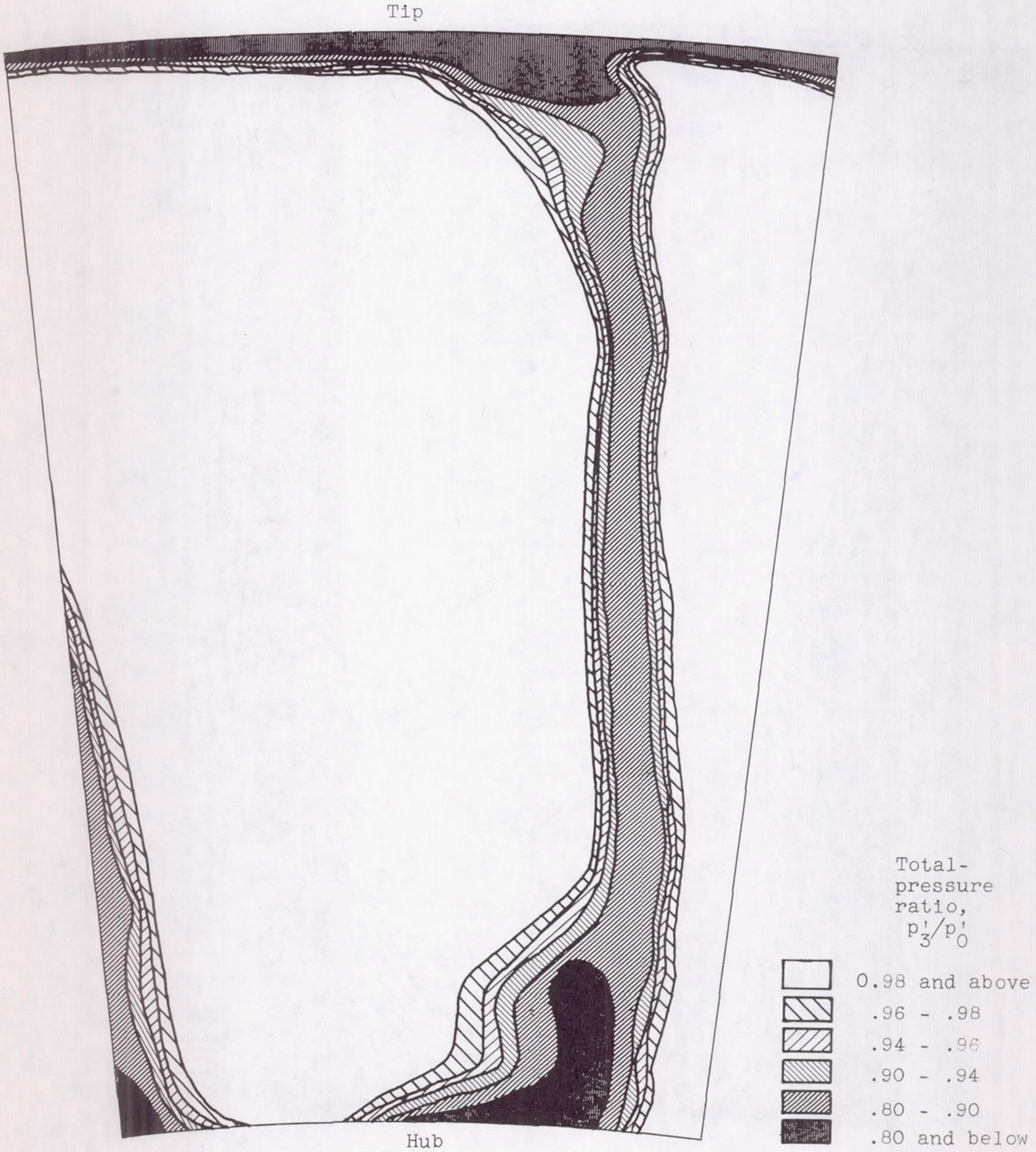
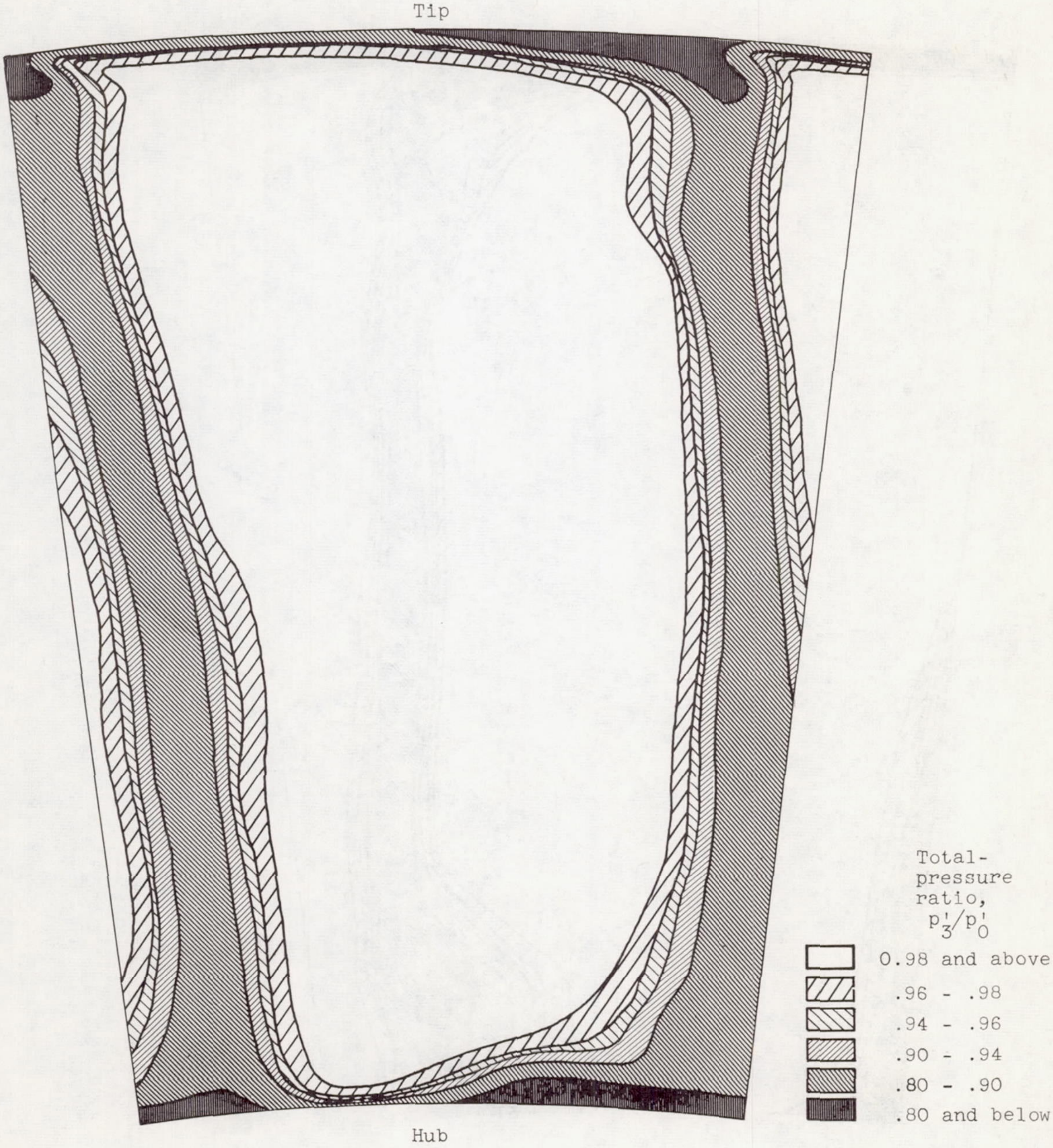


Figure 3. - Over-all turbine performance obtained with original stator.



(a) Thin-trailing-edge stator.

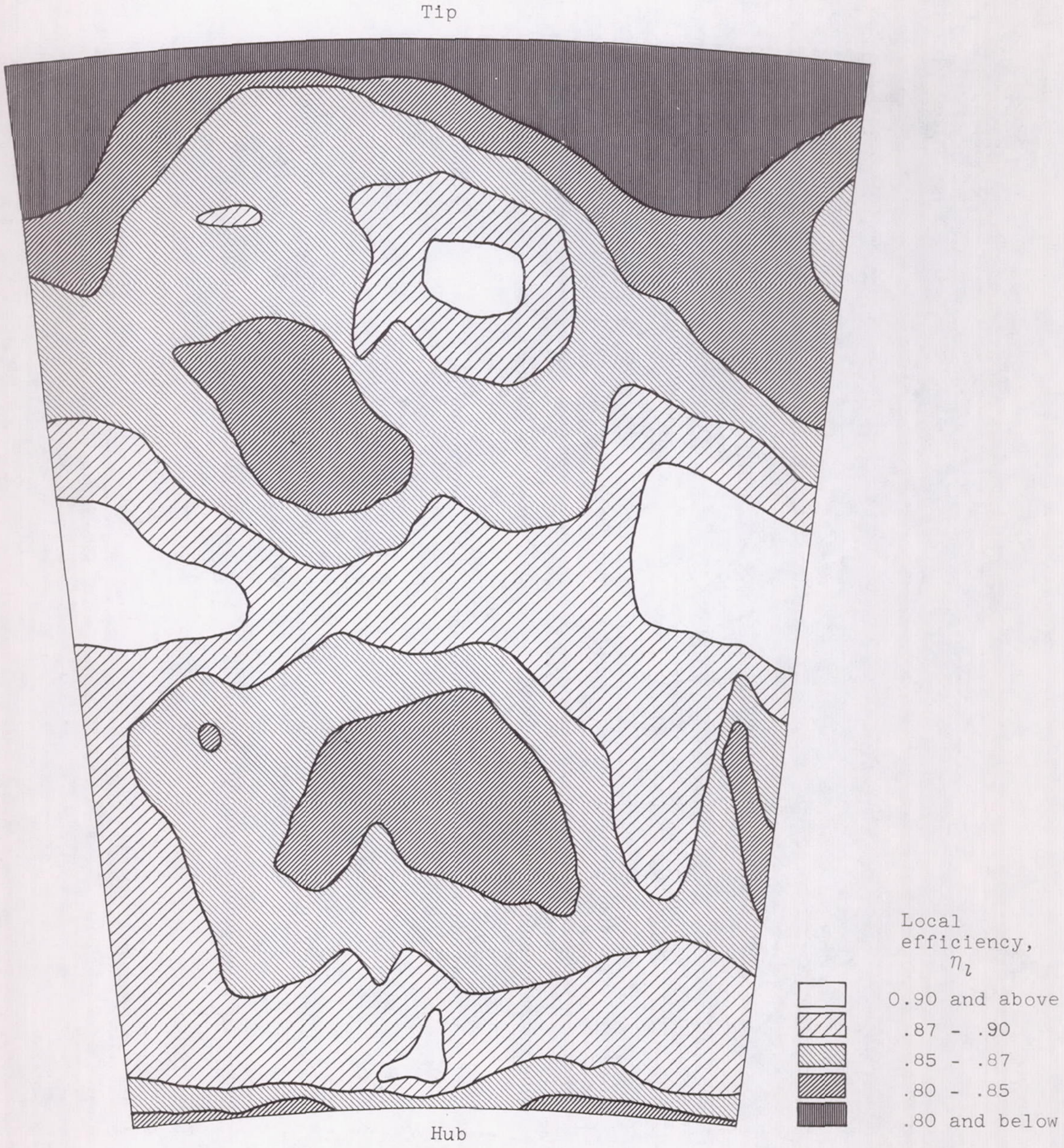
Figure 4. - Contours of total pressure from detailed surveys made approximately 3/16 inch downstream of stator-blade trailing edge.



(b) Original stator (ref. 1).

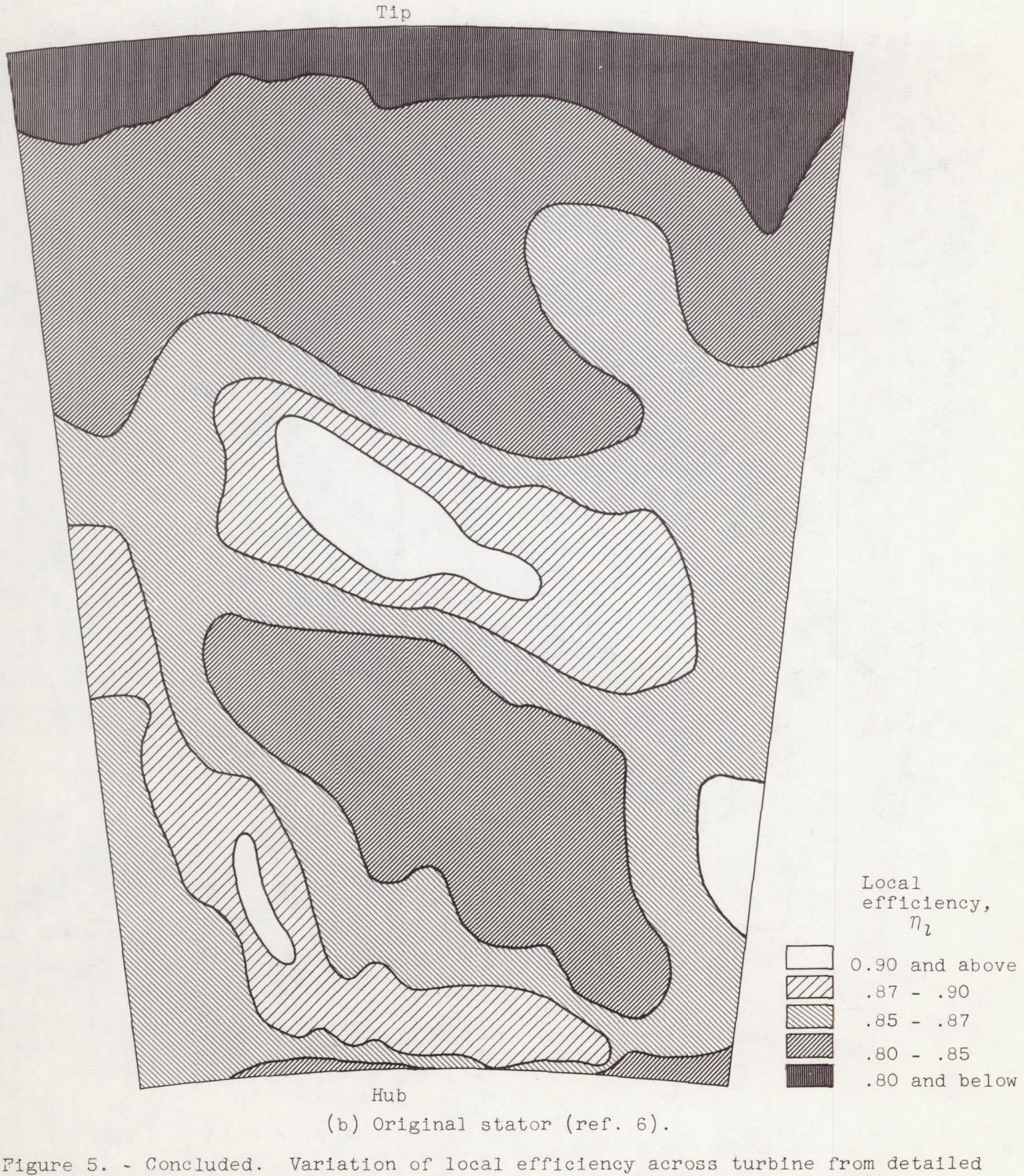
Figure 4. - Concluded. Contours of total pressure from detailed surveys made approximately 3/16 inch downstream of stator-blade trailing edge.

3798



(a) Thin-trailing-edge stator.

Figure 5. - Variation of local efficiency across turbine from detailed surveys made downstream of rotor with turbine operated at design conditions.



(b) Original stator (ref. 6).

Figure 5. - Concluded. Variation of local efficiency across turbine from detailed surveys made downstream of rotor with turbine operated at design conditions.

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