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COLD-AIR INVESTIGATION OF A TURBINE WITH STATOR-BLADE TRAILING-EDGE COOLANT EJECTION

I - OVERALL STATOR PERFORMANCE

by Warren J. Whitney, Edward M. Szanca, and Frank P. Behning

Lewis Research Center
Cleveland, Ohio

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16. Abstract

Overall stator performance was obtained with ratios of coolant to primary mass flow of 0, 0.02, 0.035, 0.05, and 0.07. The effects of coolant on the performance parameters, mass flow characteristic and outlet flow angle, were determined experimentally. These effects were also determined theoretically for the condition of design primary mass flow.

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SUMMARY

An investigation was made to determine the effect on overall stator performance of stator coolant ejection from the trailing edge. A hollow-cored stator blade design, which had been previously investigated, was modified to provide a coolant ejection slot along the trailing edge. Performance characteristics of the modified stator were obtained for nominal ratios of coolant flow to primary flow of 0, 0.02, 0.035, 0.05, and 0.07. The flow characteristics of the coolant system were determined in a separate test.

The mass flow characteristic of the modified stator at zero coolant flow agreed with that of the design stator within experimental accuracy. The radial variation of outlet flow angle obtained with the modified stator at zero coolant flow was somewhat distorted from that obtained with the design stator. The distortion made it difficult to assess the overall turning function of the modified stator. It was deduced, however, from a consideration of the mass flow rate obtained at design pressure ratio that the average outlet flow angle was within 1° of design value.

The addition of coolant was found experimentally to have a small effect on stator outlet flow angle. The maximum coolant fraction (0.07) caused a decrease of 2° in outlet flow angle at design overall pressure ratio. The effect of coolant addition was also determined theoretically to reduce the outlet flow angle. A coolant fraction of 0.07 caused a decrease of $1\frac{1}{2}^{\circ}$ at design primary mass flow. The experimental results showed that coolant addition also caused the overall pressure ratio to increase for a given primary mass flow rate. At design primary mass flow the addition of a coolant fraction of 0.07 caused the overall pressure ratio to increase by about 2 percent. This effect was also predicted theoretically, however, to a much lesser degree, with a coolant fraction of 0.07 causing an increase in pressure ratio of 0.7 percent.

The flow characteristics of the stator coolant system were used with two analytical performance estimation procedures to predict the effect of the coolant on overall stage performance. Both methods indicated the work output increased in a parabolic manner with coolant addition. At a coolant fraction of 0.07, the two methods indicated the work output to be 1.074 and 1.084 that at zero coolant flow.

INTRODUCTION

Gas turbine engines used in advanced types of aircraft must use high turbine inlet temperatures to meet their mission objectives. In general, these temperatures are sufficiently high as to necessitate cooling of the turbine blading. The cooling method most commonly considered utilizes air that is bled from the compressor, ducted through the cooling passages of the blades, and then discharged into the turbine gas stream. The turbine blading for this type of application is characterized by thick profiles and blunt leading and trailing edges. These physical features result from the necessity of incorporating the blade cooling passages within the profile. It is also desirable for this type of turbine to employ a low solidity to minimize the blade surface area.

A part of the current turbine research program at NASA Lewis is concerned with the problems associated with turbines for high-temperature engine application. A 30-inch cold-air research turbine was designed for the investigation of these problems. The turbine design procedure and the overall performance of the stator component are described in reference 1. One of the problems of primary interest is that of determining the effect on turbine performance of discharging the coolant into the turbine gas stream. This effect was evaluated by analytical procedures in references 2 and 3, and it was indicated to be quite dependent on the total pressure and total temperature of the coolant relative to that of the turbine gas stream. It is desirable, therefore, to determine the effect of coolant addition from experimental measurements and to compare it with that obtained by the analytical procedures.

This report describes the initial part of the investigation, in which the trailing edge of the stator of reference 1 was modified to provide a coolant ejection slot, and includes the overall stator performance. The stator was investigated with nominal coolant fractions (ratios of coolant mass flow to primary mass flow) of 0, 0.02, 0.035, 0.05, and 0.07 over a range of pressure ratio. The stator outlet flow angle was measured for a range of outlet Mach number at zero coolant fraction and for a range of coolant fraction at design outlet Mach number. The results consist principally of the effect of coolant fraction on stator mass flow and flow angle characteristics. The results obtained at zero coolant flow are also compared with those of the design stator to determine if the modification to the blade trailing edge affected overall performance.

SYMBOLS

k_p coolant pressure coefficient, ratio of dynamic pressure of coolant to dynamic pressure of primary flow at blade outlet

N rotative speed, rpm

p absolute pressure, lb/ft^2 (N/m^2)

Re Reynolds number of coolant

V gas velocity, ft/sec (m/sec)

V_{cr} critical velocity, velocity of sound at Mach 1, ft/sec (m/sec)

w mass flow rate, lb/sec (kg/sec)

α flow angle at blade outlet, measured from axial direction, deg

δ ratio of stator inlet pressure to U. S. standard sea-level pressure

θ_{cr} squared ratio of critical velocity at stator inlet to critical velocity of U. S. standard sea-level air

τ turbine output torque, ft-lb (N-m)

Subscripts:

ann coolant supply annulus

ave average of hub and tip conditions

b barometer

c refers to coolant

h refers to hub radius

id ideal

p refers to primary air

0 station at turbine inlet (see fig. 3)

1 station at stator throat

2 station at stator trailing edge

3 station downstream of stator

Superscript:

' total state

STATOR BLADE MODIFICATION

The stator blades were hollow-cored castings of stainless steel as described in reference 1. The blade trailing edges were modified for this investigation as shown in figure 1(a). The rounded trailing edge of the original design configuration (ref. 1) was squared off and a coolant ejection slot was cut through to the core by an electric arc destruction method. The slot extended 3.95 inches (10.03 cm) along the radius, being terminated 0.025 inch (0.0635 cm) from either shroud (fig. 1(b)). The slot had a width of 0.040 inch (0.102 cm) and an orientation angle of 63.2° (from the axial direction); both of these were constant along the radius. The coolant was admitted to the blade core at the outer diameter and ejected out the slot at the trailing edge. A closeup photograph of the modified stator blade assembly installed in the facility is shown in figure 2.

APPARATUS, INSTRUMENTATION, AND PROCEDURE

The test facility described in reference 1 was modified to include the stator coolant system. The system included the supply pipe from the combustion air header, a control valve, an airflow metering venturi, coolant inlet torus, coolant supply annulus, and appropriate instrumentation for determining the coolant mass flow. A diagramatic sketch of the turbine test section is shown in figure 3, and figure 4 shows the modified stator assembly installed in the facility with the turbine outlet ducting removed. The coolant passed from the inlet torus through 12 $1\frac{1}{2}$-inch feeder pipes to the supply annulus (fig. 4), which was located directly over the blade tips (fig. 3). An overall view of the facility is shown in figure 5. In the figure the supply pipe to the coolant inlet torus is not in place and the inlet flange is capped. Since both the coolant and the primary air emanate from the laboratory combustion air system, they are at virtually the same temperature, nominally 545° R (303 K).

The instrumentation was located at stations 0, 1, 2, and 3 as shown in figure 3. This instrumentation is the same as that described in reference 1. Additional instrumentation was required to measure the coolant mass flow rate. This consisted of the venturi upstream pressure and differential pressure and the coolant air temperature at the venturi. Instrumentation was also included to measure the temperature and pressure of the coolant at the coolant supply annulus.

The stator inlet total state conditions were 30 inches of mercury absolute (1.0159×10^{5} N/m^{2}) and about 545° R (303 K). Overall pressure ratios ($p_0/p_{3,h}$) were set by adjusting the outlet pressure. At each pressure ratio the coolant mass flow rate was varied by regulating the pressure of the coolant with the coolant control valve. This regulation required a broad range of coolant inlet pressure with this pressure at some conditions being greater than turbine inlet pressure. The stator outlet flow angle was measured by traversing radially across the blade span with the probe situated midway in the flow path between trailing edge wakes. The flow angle measurements were made with the probe sensing element located 0.5 inch (1.27 cm) axially downstream of the stator blade trailing edge. The procedure was the same as that used in reference 1.

In addition to the overall stator performance tests, a flow test was made on the coolant slots. For this test the turbine outlet ducting was removed as shown in figure 4 and there was no primary mass flow. The discharge coefficient, velocity coefficient, and equivalent mass flow of the coolant slots were determined over a range of Reynolds numbers. These quantities were evaluated from inlet total state conditions measured in the coolant supply annulus. The discharge pressure for the slot flow test was barometric.

RESULTS AND DISCUSSION

The experimental results consist primarily of the flow angle and mass flow characteristics of the modified stator. The overall performance obtained with the modified stator with zero coolant flow is first compared with that of the design stator (ref. 1). The effect of coolant flow on overall performance of the modified stator is then discussed. Also included are the flow characteristics of the coolant slots that were obtained from the slot flow test. The coolant system flow coefficients are then used with analytical performance estimation procedures of references 2 and 3 to predict the effect of the coolant on turbine stage performance.

Comparison of Modified Stator with Design Stator

The comparison of the performance of the modified stator under zero coolant flow conditions with that of the design stator (ref. 1) is made on the basis of mass flow characteristics and outlet flow angle.

The mass flow characteristics of the design and modified stator configurations are shown in figure 6. In figure 6(a) the equivalent mass flow is shown as a function of the inlet total to outlet static pressure ratio at the inner and outer walls. The solid lines in the figure are the trends of the design stator and were obtained by fairing through the data points of figure 9 of reference 1. The data points shown were obtained with the modified stator. In general, the agreement between the mass flow characteristics obtained for the two stators is close. In the region corresponding to equivalent mass flows of 39.5 to 41.5 pounds per second (17.9 to 18.8 kg/sec) the greatest variance occurred with the modified stator indicating about 1 percent greater mass flow. The agreement is within 1/2 percent for the other conditions. The agreement between the two stators (1/2 to 1 percent) is within experimental error and is, in fact, within the scatter of the data obtained for the design stator. In figure 6(b) the same comparison is made using throat pressure ratios. The agreement in mass flow trend of the two stators is somewhat closer when compared on this basis. The greatest variance in figure 6(b) is between 1/2 and 3/4 percent.

The outlet flow angles obtained with the modified stator with zero coolant flow are compared in figure 7 with those obtained with the design stator (ref. 1) for a range of hub critical velocity ratios. The experimental angle traces showed reasonably good agreement with the design angle variation between the mean and tip radii (fig. 7(a)). Near the hub, however, underturning occurred with the flow angle being nearly constant for the innermost $1\frac{1}{2}$ to 2 inches. The radial variation obtained with the design stator (fig. 7(b)) was in closer agreement with the design variation. Thus, the trailing edge geometry modification has caused some distortion to the radial flow angle variation.

The effect of Mach number on the outlet flow angle of the modified stator was small, as evidenced by figure 7(a). A similar effect was noted for the design stator (ref. 1) and can be seen in figure 7(b). The effect of Mach number level on the outlet angle of the modified stator is barely perceptible for hub critical velocity ratios of 0.896 (design) and lower (see figs. 7(a-1) to 7(a-3)). As the hub critical velocity ratio increased from 0.896 to 1.1 the outlet angle decreased by 1° to 2°. The effect of outlet Mach number level on flow angle was also evaluated from theoretical considerations by using the relations between the gas states at the stator throat and outlet stations that were used in the design procedure. This determination indicated that a decrease of 0.2° to 0.3° would be anticipated at all radii as the hub critical velocity ratio varied from 0.5 to 1.1.

Because of the distorted trend of flow angle with radius obtained with the modified stator, it is difficult to evaluate the overall turning function from figure 7(a). However, since it was known that design mass flow was passed at design pressure ratio, an average outlet angle can be determined in terms of the overall total pressure loss. This was done in figure 8 by reducing the stator outlet flow to single state condition, and the flow angle was determined from continuity, the design total to static pressure ratio, and the assumed total pressure loss. The strong influence of flow angle on loss pressure ratio can be noted. One degree of overturning would require almost zero loss, whereas 1° of underturning would correspond to decreasing the loss pressure ratio from 0.97 to 0.946, or nearly doubling the stator loss. It would not be expected that the change in trailing edge configuration (fig. 1) could effect a loss change of this magnitude.

Summarizing, it can be said that the modified stator caused some distortion to the radial variation of flow angle. From a consideration of the effect of loss on flow angle and the fact that design mass flow was passed at design pressure ratio (within experimental accuracy), it is felt that average outlet angle was within 1° of design value.

Effect of Coolant on Stator Performance Characteristics

The mass flow characteristics of the stator with coolant flow are shown in figure 9. In figure 9(a) the equivalent primary mass flow is shown as a function of overall pressure ratio $p_0'/p_{3,ave}$ and coolant flow. The curve in the figure was faired through the zero coolant flow data points. Thus, the data points at various coolant fractions can be compared with the curve to show the effect of coolant on primary mass flow. The agreement in equivalent mass flow obtained at a given pressure ratio for the various coolant flows is close, with the greatest variance being 1 percent. This occurs in the range of equivalent mass flow from 37 to 41 pounds per second (16.9 to 18.6 kg/sec) for the highest coolant fraction (0.07). It is also in this range of equivalent mass flow that a slight trend of pressure ratio with coolant fraction is noticeable. This trend is that of a slight increase in pressure ratio with an increase in coolant fraction at a given equivalent mass flow. The reason for this trend is discussed in a following paragraph.

In figure 9(b) these same data are shown as a function of average throat pressure ratio $p_0'/p_{1,ave}$. The trend discernable in figure 9(a) is not seen in figure 9(b). The data for all coolant flows are seen to correlate by a single line when based on throat pressure ratio. This result is not, however, unexpected. Since the coolant enters the flow path downstream of the stator throat (fig. 1(a)) it should not affect the throat pressure ratio.

The trend mentioned in figure 9(a) probably results from continuity. At a given equivalent mass flow, the addition of coolant would cause an additional expansion or increased axial Mach number to accommodate the increased total mass flow in the annulus. This effect (i.e., the pressure difference between throat and downstream stations) increases as the equivalent flow increases because pressure ratio is affected more by a change in mass flow as the Mach number is increased. However, at equivalent mass flows of 41 pounds per second (18.6 kg/sec) and above, the trend appears to dampen out because of the low slope of the mass flow curve. This trend, however, is not too significant. For coolant fractions up to 0.05, the data in figure 9(a) are in agreement to within 0.5 percent.

The flow angles obtained at design outlet Mach number with various coolant fractions are shown in figure 10 (fig. 10(a) is a repeat of fig. 7(a-3)). The trend of flow angle with radius obtained at zero coolant flow (fig. 10(a)) is closely duplicated at all coolant flows. The effect of coolant addition on outlet angle is indicated to be small. When the angle at zero coolant is compared (fig. 10(a)) with that obtained at a coolant fraction of 0.07 (fig. 10(e)), the coolant is seen to cause about a 1° decrease in outlet angle at the inner radii and about a 2° to 3° decrease at the outer portion of the annulus. This effect averaged over the radial span is about 2°.

Summarizing, the addition of coolant air had only a very minor effect on the trend of equivalent flow as a function of overall pressure ratio. The effect of coolant on outlet flow angle was also small with 0.07 coolant flow causing a decrease in average outlet angle of about 2°.

Flow Characteristics of Stator Coolant System

The coolant system performance data are difficult to obtain under stator operating conditions because of the unknown radial variation of static pressure at the blade outlet. The performance characteristics of the coolant system were therefore determined in a separate test for which the turbine outlet ducting was removed and there was no primary flow. The results of the coolant system flow test are shown in figure 11. The discharge coefficient and the velocity coefficient are both shown as functions of Reynolds number in figures 11(a) and (b), respectively. The Reynolds number used was based on the flow at the slot and used as a characteristic length the hydraulic diameter of the slot. Above Reynolds numbers of 1×10^{4} the discharge coefficient is nearly constant at about 0.79 and the velocity coefficient increases slightly with Reynolds number.

The mass flow characteristic is shown in figure 11(c). The slots were sized to provide about 0.05 coolant fraction when coolant inlet pressure was the same as turbine inlet pressure p_0'. At a pressure ratio of 1.51, which is average design stator throat pressure ratio, the coolant flow would be about 2.05 pounds per second (0.93 kg/sec) from figure 11(c). This corresponds to a coolant fraction of 0.051.

Calculated Effects of Coolant at Design Primary Mass Flow

The theoretical effect of coolant addition on stator outlet angle and the overall pressure ratio were determined using the flow characteristics of the coolant system. This was done for the design value of primary mass flow and thus the conditions of the primary flow at the stator throat were fixed and could be obtained from the design procedure. The primary flow was equated to a single flow condition having a critical velocity ratio and flow angle that yielded design values of mass flow and angular momentum. The coolant flow angle is constant and theoretical flow conditions could be determined for a given coolant mass flow using the performance curves of figure 11. The after-mixing state of the flow was determined from the continuity relation and the assumption that total angular momentum is preserved. The change in total pressure experienced by the primary flow across the mixing process was determined as discussed in reference 2 for a unidirectional mixing process. The results of these calculations are shown in figure 12.

In figure 12(a) the theoretical effect of coolant addition on overall stator pressure ratio is compared with that obtained experimentally. In both cases an increase in pressure ratio is required as the amount of coolant is increased. The reason for this was mentioned in the discussion of figure 9(a). The experimental results indicate that an increase of about 2 percent in overall pressure ratio is effected by the addition of the maximum coolant fraction of 0.07. This effect was predicted by the theoretical calculations to be 0.7 percent.

The predicted variation of stator outlet angle as a result of coolant addition is shown in figure 12(b). The effect of coolant is to decrease the flow angle with the maximum coolant fraction of 0.07 causing a reduction of $1\frac{1}{2}^{\circ}$. This is in agreement with the experimental results (fig. 10), which also show that the coolant addition caused a reduction in outlet angle. The angle change obtained experimentally was about 2° for the maximum coolant fraction of 0.07.

The results of the coolant system performance characteristics were used to project the change in overall turbine performance. Both the isolated flow procedure (ref. 2) and the mixed flow procedure (ref. 3) were used. The coolant total pressure recovery coefficient k_p was determined from the coolant system flow characteristics. The projected effect on stage performance is shown in figure 12(c). The trends from the two methods are similar with both showing the work output increasing in parabolic fashion with increasing coolant flow. At the highest coolant fraction investigated (0.07) the two methods indicated the work output to be 1.074 and 1.084 that at zero coolant flow. The two methods agree to within 1 percent. The isolated flow procedure indicates the coolant produces a work output equal to that of the primary flow at a coolant fraction of 0.066; the corresponding coolant fraction for the mixed flow procedure is 0.054.

SUMMARY OF RESULTS

An investigation was made to determine the effect on overall stator performance of stator coolant flow ejection from the trailing edge. The performance characteristics, outlet flow angle and mass flow, were obtained for coolant rates of 0, 0.02, 0.035, and 0.07 primary mass flow. The pertinent results are as follows:

1. At zero coolant rate, the mass flow curve for the modified stator agreed with that of the original stator within experimental error. The greatest variance noted was 1 percent with the majority of the data points agreeing to within 1/2 percent.

2. At zero coolant flow, the radial variation of flow angle was somewhat distorted from that of the design stator. This distortion made it difficult to estimate the overall turning function of the modified stator. It was deduced, however, from a consideration of mass flow rate at design pressure ratio that the average stator outlet angle was within 1° of design value.

3. The effect of coolant addition on outlet flow angle at design pressure ratio was found experimentally to be small, with the maximum coolant fraction (0.07) causing a decrease in the outlet flow angle of 2°. The effect of coolant was also determined theoretically to cause the outlet angle to decrease with 0.07 coolant fraction effecting a $1\frac{1}{2}^{\circ}$ reduction in outlet angle.

4. The experimental results showed that a coolant fraction of 0.07 caused the stator overall pressure ratio to increase by 2 percent at design primary mass flow rate. The theoretical calculations also indicated this pressure ratio would increase with coolant addition, but to a lesser degree, with a coolant fraction of 0.07 causing an increase of 0.7 percent in pressure ratio.

5. The flow characteristics of the coolant system were used along with two analytical performance estimation procedures to project the effect of stator coolant ejection on overall stage performance. Both analytical procedures indicated the work output to increase in parabolic fashion with coolant addition. At a coolant fraction of 0.07 the methods indicated the work output to be 1.074 to 1.084 that at zero coolant flow.

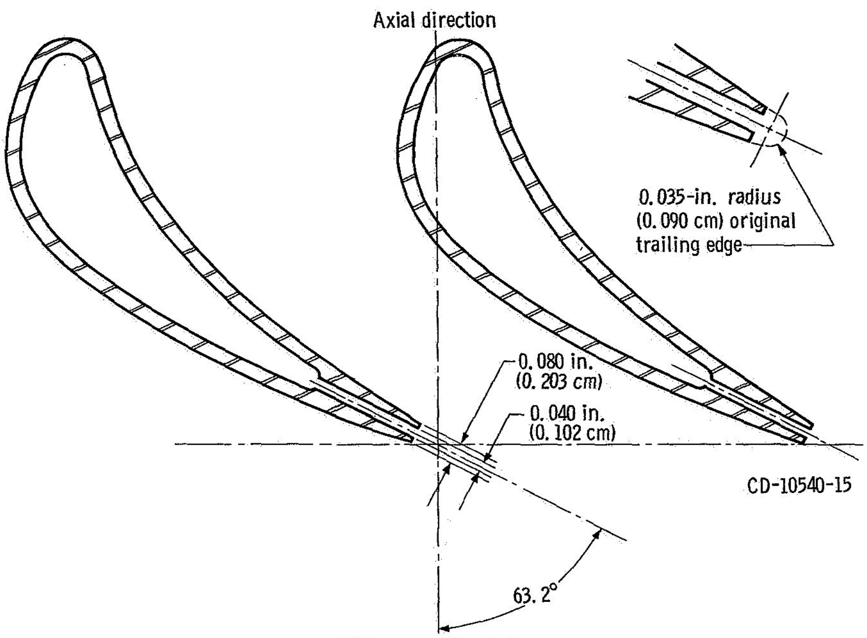
Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 7, 1969,
720-03.

REFERENCES

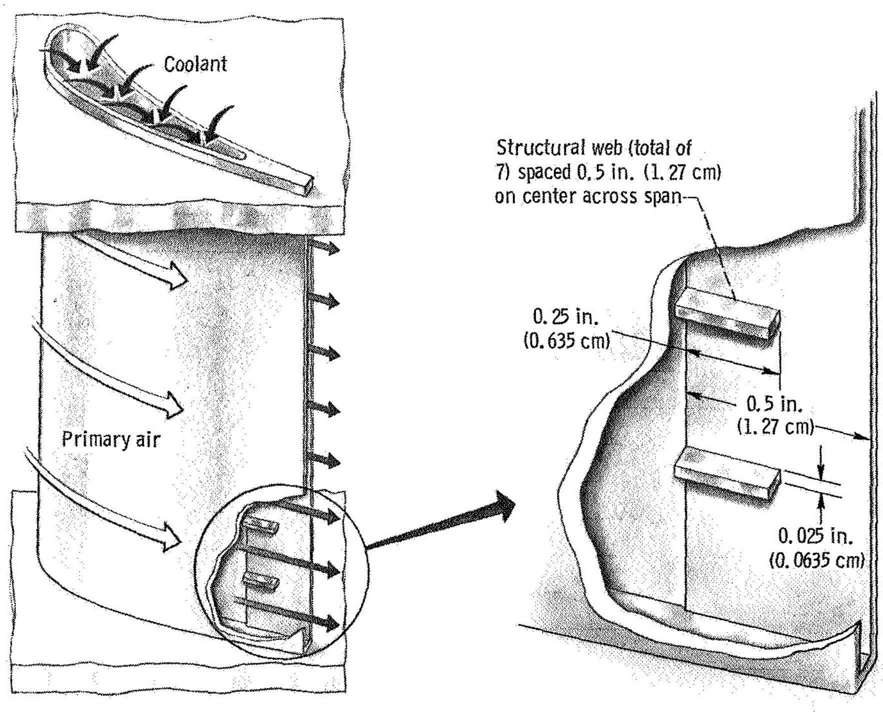
1. Whitney, Warren J.; Szanca, Edward M.; Moffitt, Thomas P.; and Monroe, Daniel E.: Cold-Air Investigation of a Turbine for High-Temperature-Engine Application. I. Turbine Design and Overall Stator Performance. NASA TN D-3751, 1967.

2. Whitney, Warren J.: Analytical Investigation of the Effect of Cooling Air on Two-Stage Turbine Performance. NASA TM X-1728, 1969.

3. Whitney, Warren J.: Comparative Study of Mixed- and Isolated-Flow Methods for Cooled-Turbine Performance Analyses. NASA TM X-1572, 1968.



(a) Cross sectional view.



(b) Cutaway view.

Figure 1. - Stator blade.

Figure 2. - Modified stator blades.

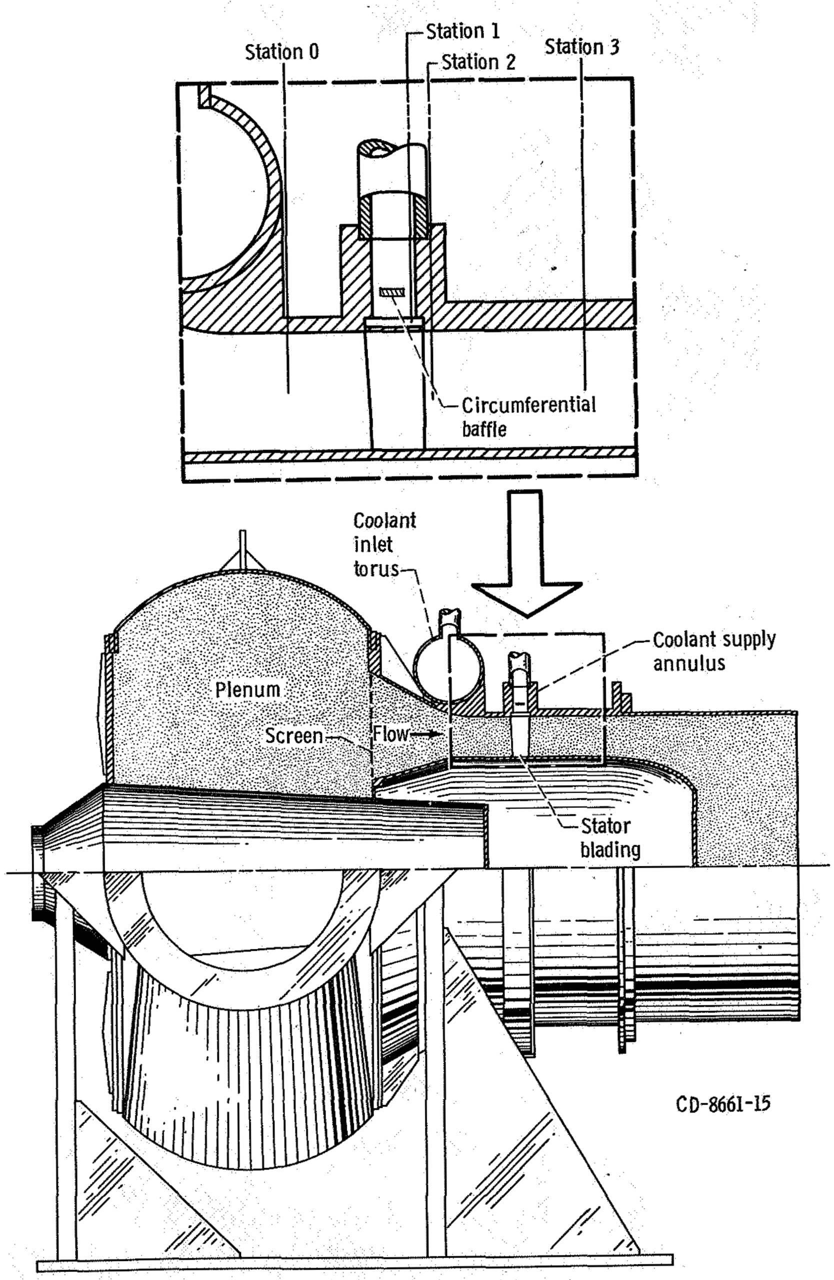


Figure 3. - Schematic diagram of turbine-stator test section.

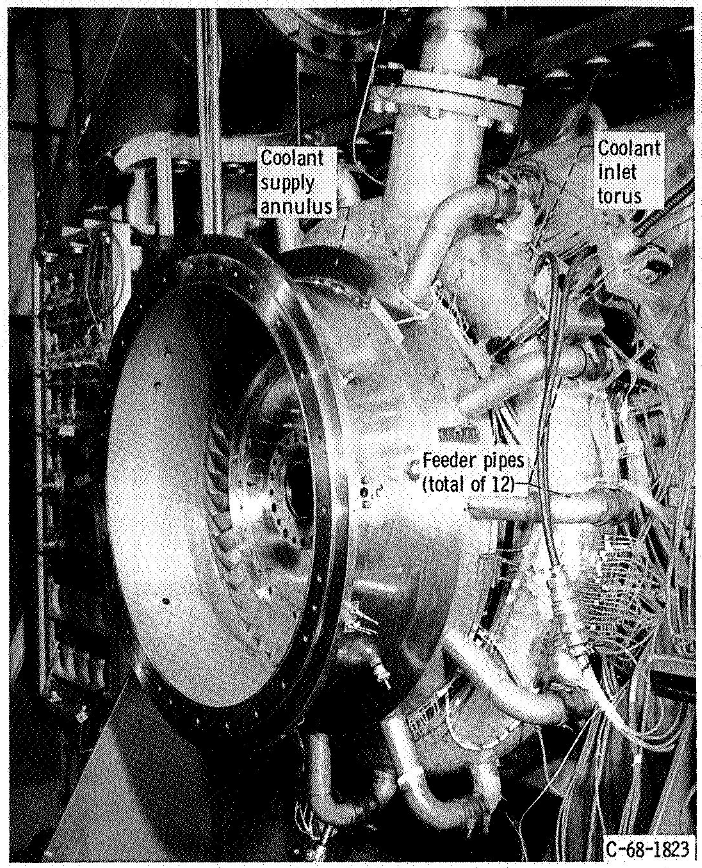


Figure 4. - Modified stator assembly installed in test facility.

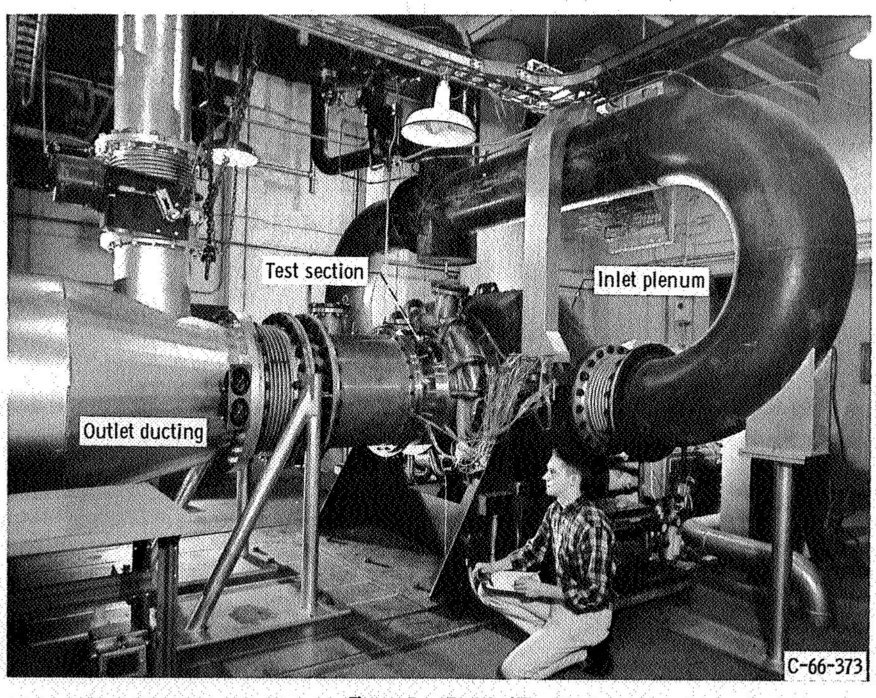
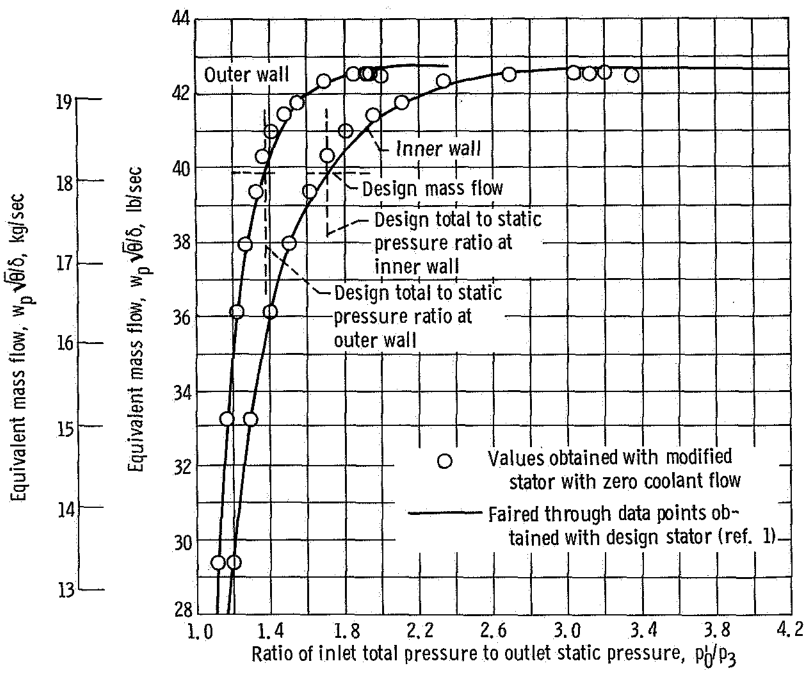
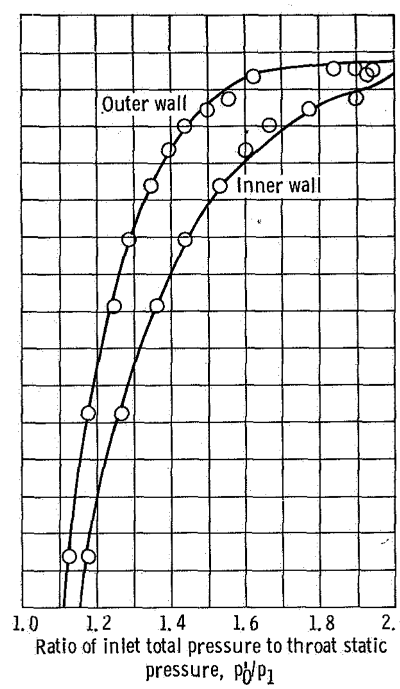


Figure 5. - Test facility.



(a) Based on overall pressure ratio.



(b) Based on throat pressure ratio.

Figure 6. - Comparison of mass flow characteristics of modified stator with those of design stator.

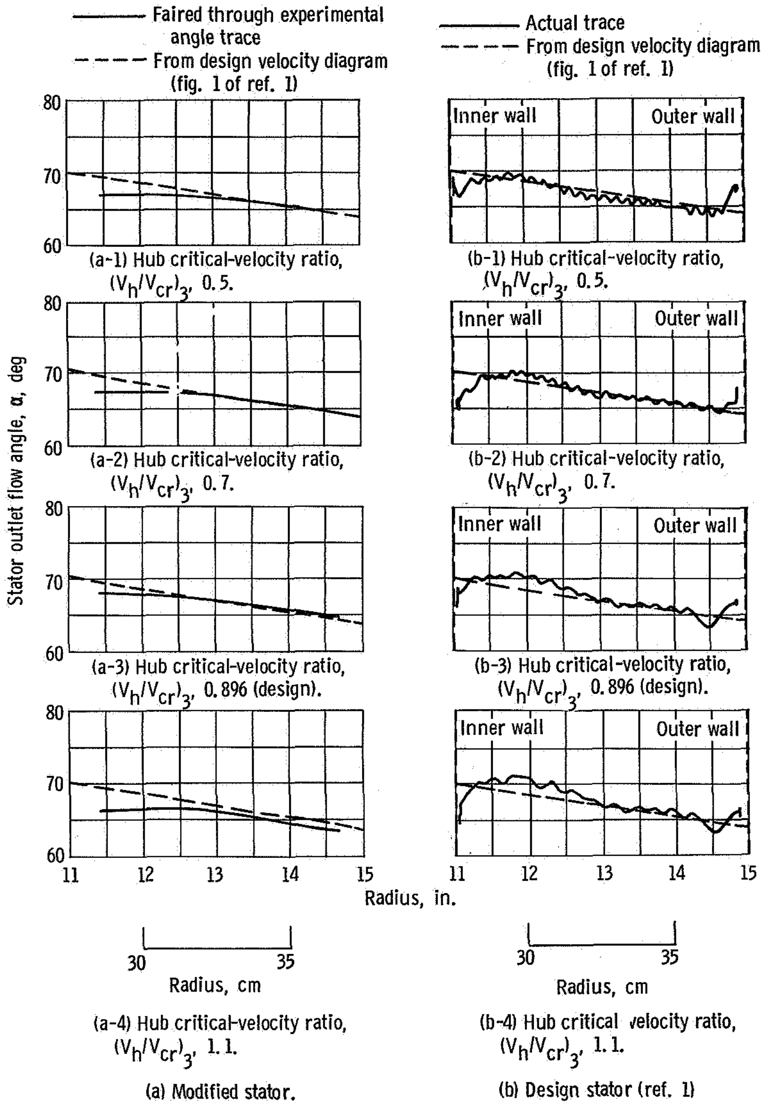


Figure 7. - Effect of stator outlet critical velocity ratio on outlet flow angle for modified stator at zero coolant flow and for design in stator (from ref. 1).

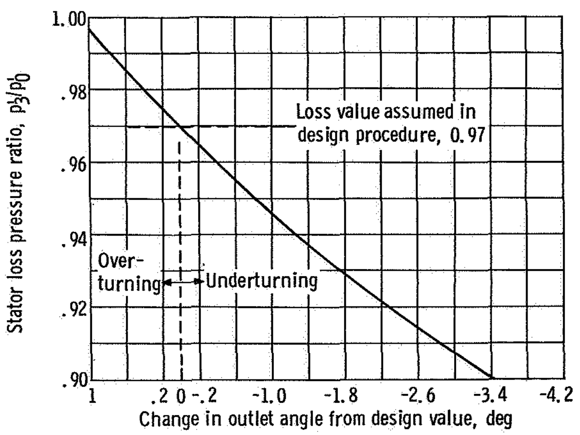
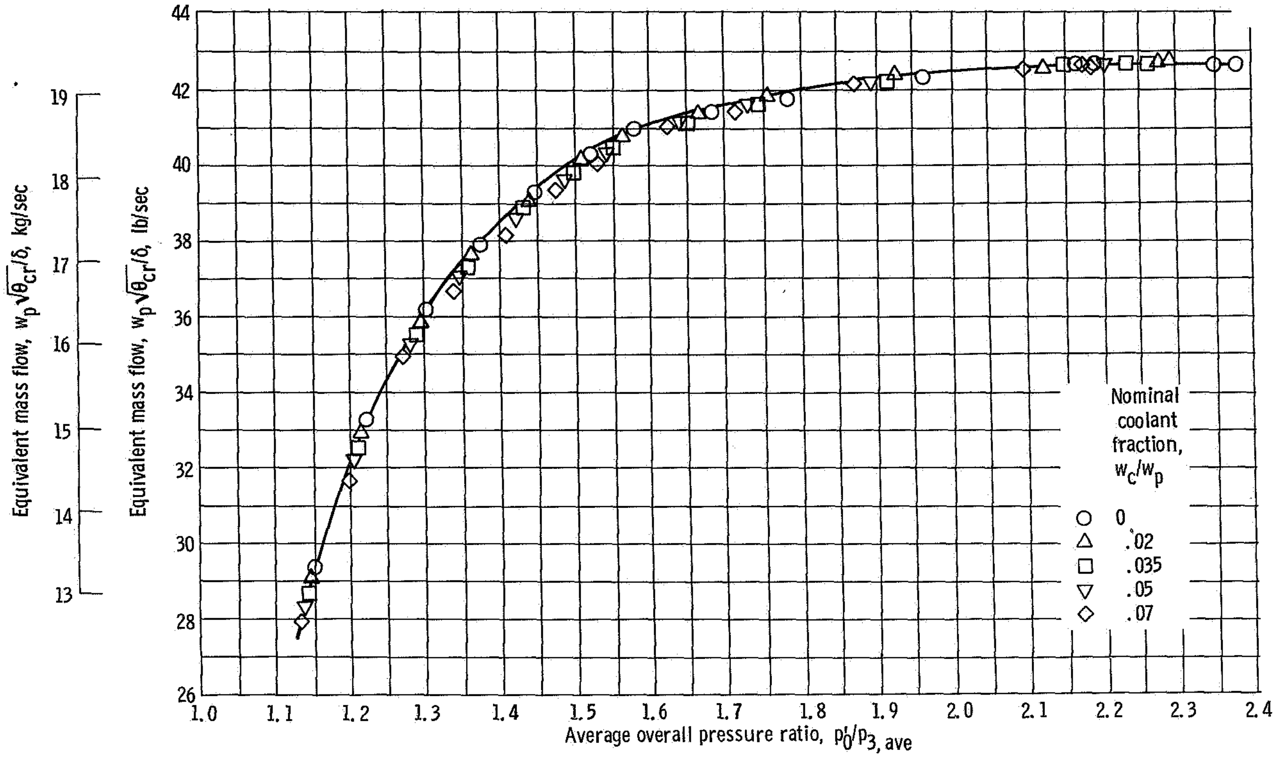
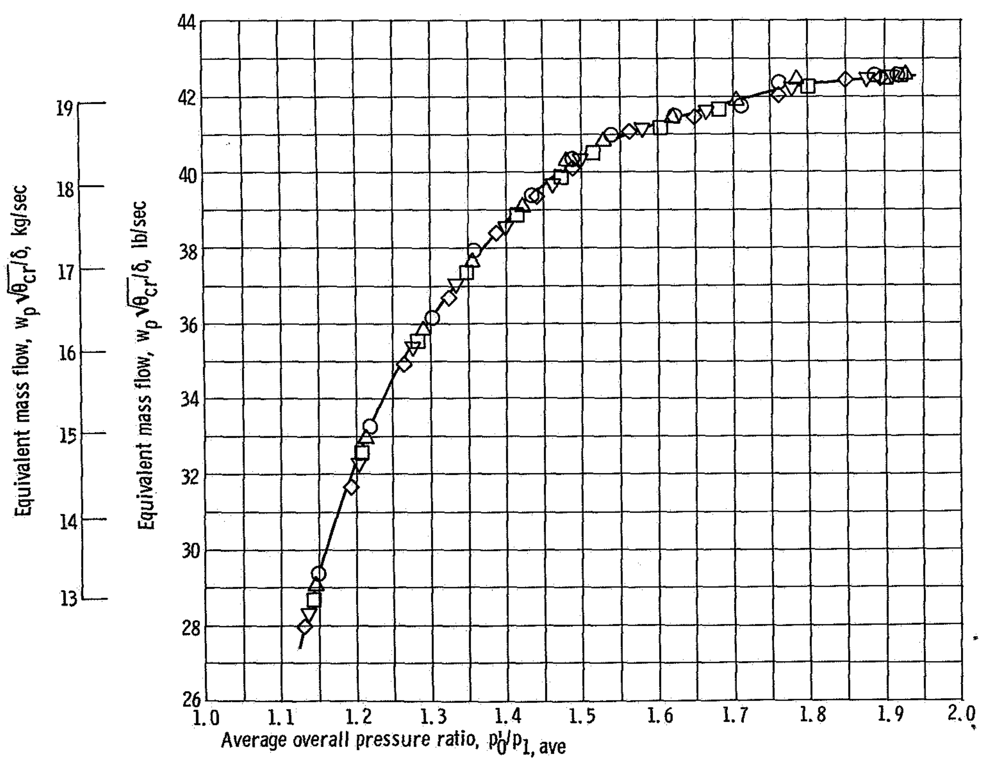


Figure 8. - Effect of average stator outlet angle on overall stator pressure loss at design mass flow.

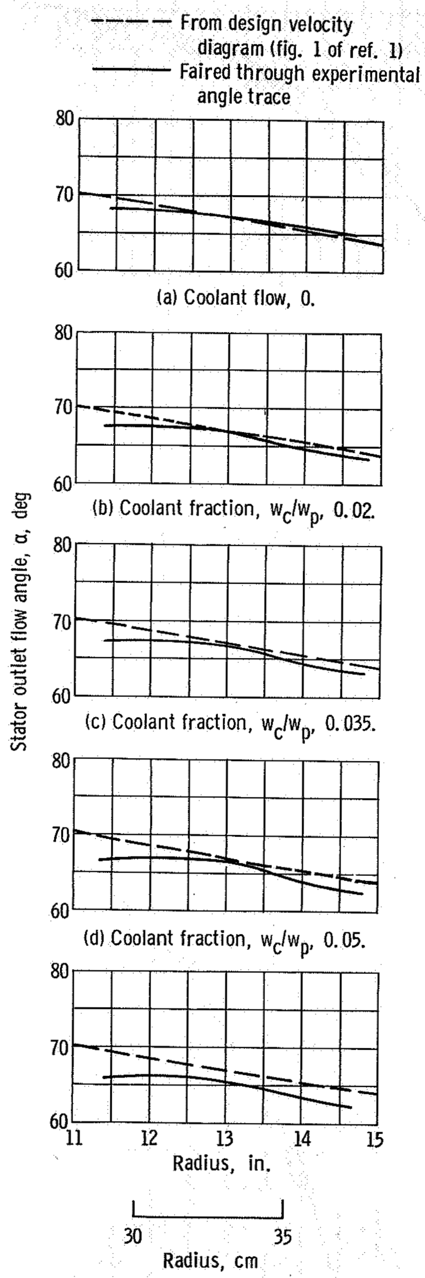


(a) Based on average overall pressure ratio.



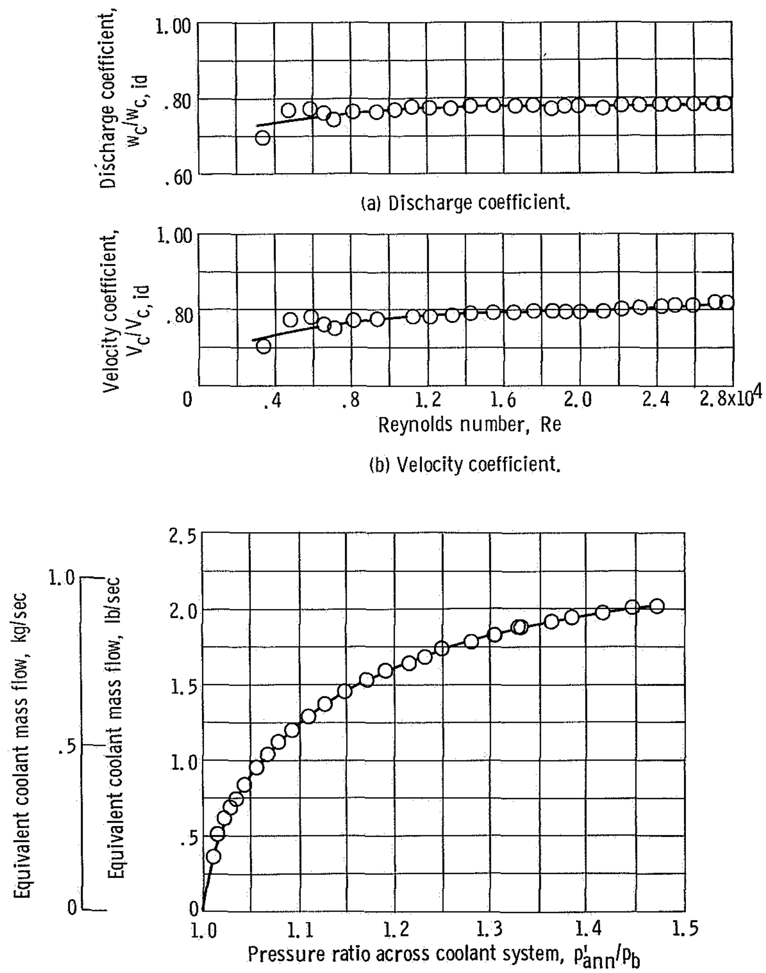
(b) Based on average throat pressure ratio.

Figure 9. - Mass flow characteristics of stator with coolant.



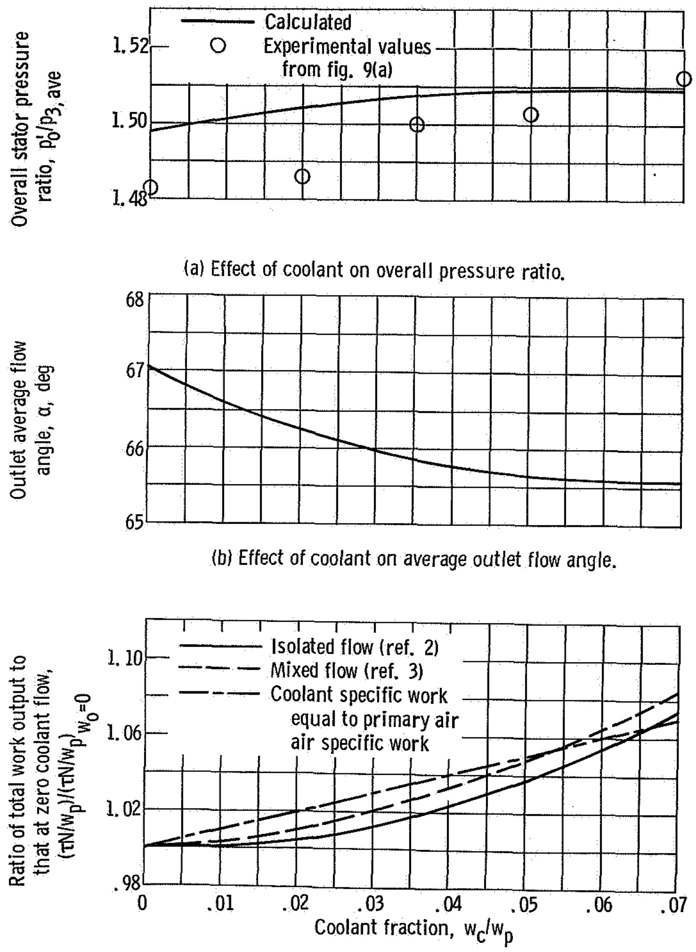
(e) Coolant fraction, w_c/w_p, 0.07.

Figure 10. - Effect of coolant on stator outlet flow angle at design outlet hub critical velocity ratio $(V_h/V_{cr})_3$ of 0.896.



(c) Mass flow characteristic.

Figure 11. - Performance characteristics of coolant flow system.



(a) Effect of coolant on overall pressure ratio.

(b) Effect of coolant on average outlet flow angle.

(c) Predicted effect of coolant on work output at total to static pressure ratio $P_0'/P_{3,ave}$ of 1.944.

Figure 12. - Calculated effect of stator coolant on overall stator performance and overall stage performance at design value of equivalent primary mass flow.

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