NASA TECHNICAL MEMORANDUM

NASA TM X-2459

NASA TM X-2459

EFFECT OF GROOVED CASING TREATMENT ON THE FLOW RANGE CAPABILITY OF A SINGLE-STAGE AXIAL-FLOW COMPRESSOR

by Everett E. Bailey

Lewis Research Center

Cleveland, Ohio 44135

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JANUARY 1972

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM X-2459		

4. Title and Subtitle	5. Report Date
EFFECT OF GROOVED CASING TREATMENT ON THE FLOW RANGE CAPABILITY OF A SINGLE-STAGE AXIAL-FLOW COMPRESSOR	January 1972
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Everett E. Bailey	E-6560
	10. Work Unit No. 764-74
9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135	11. Contract or Grant No.
	13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Comparisons of the results of testing a single-stage axial-flow compressor with a solid-wall casing and with grooved casings are presented. The depth, location, and number of circumferential grooves in the casing over the rotor tip were varied. The near-stall weight flow was lower than that with the solid-wall casing for all but one grooved configuration indicating an improvement in the stall margin. The greatest reduction in the near-stall weight flow was noted for the configuration with five grooves located over the blade midchord region.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Compressors Easing treatments	Unclassified - unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	15	$3.00

* For sale by the National Technical Information Service, Springfield, Virginia 22151

EFFECT OF GROOVED CASING TREATMENT ON THE FLOW RANGE CAPABILITY OF A SINGLE-STAGE AXIAL-FLOW COMPRESSOR

by Everett E. Bailey

Lewis Research Center

SUMMARY

A single-stage axial-flow compressor was tested with a solid-wall casing and with different circumferentially grooved casings over the rotor tip region. Removable aluminum casing inserts were used to facilitate modification of the grooved configurations. The depth, location, and number of the grooves were varied. This report presents comparisons of the experimental results that indicate the effectiveness of the various grooved configurations to reduce the near-stall weight flow below that obtained with the solid-wall casing. Increasing the depth of the grooves resulted in lower near-stall flows (indicative of increased stall margin) up to the maximum depth tested. The maximum flow change was obtained with five grooves located over the midchord region of the rotor blade tip.

INTRODUCTION

Present and future applications of jet engines for aircraft propulsion have indicated a need for increased stable operating flow range of the axial-flow compressors and fans This is particularly significant for those engines that incorporate advanced compressor and fan design concepts such as transonic rotors with high-stage-loading and/or high-aspect-ratio blading. In order to realize the maximum benefit, the increased flow range should be in the operating region between maximum compressor or fan efficiency and the low-flow stability limit. For many fans and compressors, this low-flow-stability limit is the onset of rotating stall. Thus, some means of delaying rotating stall and allowing the fan or compressor to operate to lower flows would be desirable.

During the testing of a rotor only configuration, a significant improvement in rotor stall limit (i. e., stall margin) was noted when a porous casing was present over the rotor blade-tip region. These results are presented in reference 1. As noted in reference 1, the improvement was most pronounced when the rotor was tested with inlet flow distortion.

Further evaluations of the concept of using rotor tip casing treatment have indicated an improvement in operating flow range, with and without inlet-flow distortion. The results of these investigations are reported in references 2 to 6. Several types of casing treatment configurations were tried on different fan or compressor stages. Varying amounts of stall margin improvement were obtained, but in many cases there was an accompanying loss in rotor and stage efficiency. However, one configuration, circumferential grooves in the casing over the rotor blade tip, indicated an improved stall margin with no significant change in efficiency (see refs. 3 and 5).

Pratt & Whitney Aircraft, Florida Research and Development Center, under NASA contract, evaluated the effects of a porous casing (honeycomb) over the rotor tip of a moderately loaded transonic stage. The results, presented in reference 2, indicated a significant improvement in stall margin with the porous casing over that for a conventional solid casing. The improvement was noted with both uniform and distorted inlet flow. However, losses of 2 to 5 points in rotor efficiency were noted with the porous casing. Using NASA hardware, Pratt & Whitney, in a company sponsored program, undertook a simple screening test program to evaluate the use of circumferential grooves in the casing. This screening was with respect to groove depth, groove location, and number of grooves.

This report presents the data obtained from this program. Results are presented primarily as comparisons of overall rotor pressure ratio and efficiency as functions of weight flow.

APPARATUS AND PROCEDURE

Test Rotor and Stator

The test rotor contained 34 blades designed with double-circular-arc airfoil sections. Design rotor pressure ratio was 1.37 at a design weight flow of 119.2 kilograms per second (265 lbm/sec) for a rotor tip velocity of 352 meters per second (1155 ft/sec). Resulting design inlet tip relative Mach number and diffusion factor were 1.15 and 0.40, respectively.

The stator contained 40 blades designed with 65 series airfoil sections. Stator hub Mach number and diffusion factor were on the order of 0.6 and 0.36, respectively.

A summary of the rotor and stator vector diagram and geometry details is given in reference 2 with additional detail in reference 7.

The outer and inner contour of the flow path in the vicinity of the stage are shown in figure 1. A description of the test facility and compressor rig is given in reference 2.

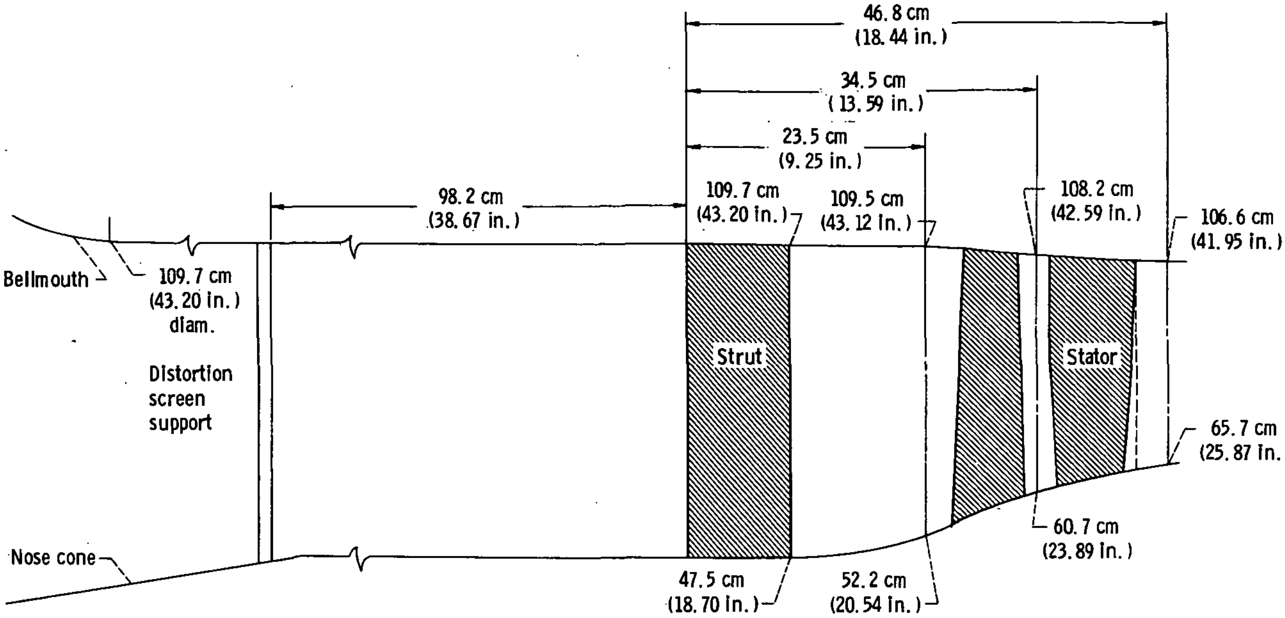


Figure 1. - Flowpath dimensions.

Grooved Casing Inserts

Removable aluminum inserts in the casing over the rotor tip were used to facilitate modification of the location, depth, and number of grooves. One solid insert (no grooves) was used to obtain baseline performance for comparison to that obtained with the various grooved configurations.

Grooves were 0.381 centimeter (0.150 in.) wide separated by a 0.127-centimeter (0.050 in.) land. Depths of 0.381, 1.143, and 2.896 centimeters (0.150, 0.450, and 1.140 in.) were evaluated. The number of grooves was varied up to a total of nine. The location of the grooved area with respect to the rotor tip was varied by selectively filling and opening certain of the nine grooves. Details of the geometry of the grooved inserts are shown in figures 2 to 4. A segment of the rotor blade tip is shown on each sketch to indicate the relation of the grooves to the blade chord.

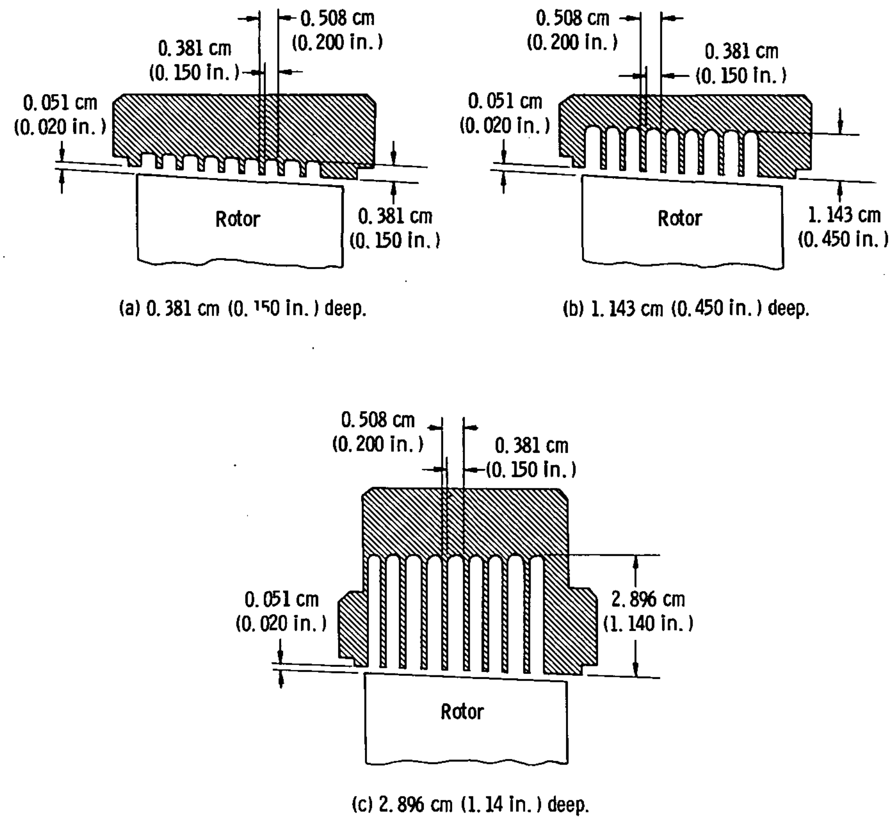
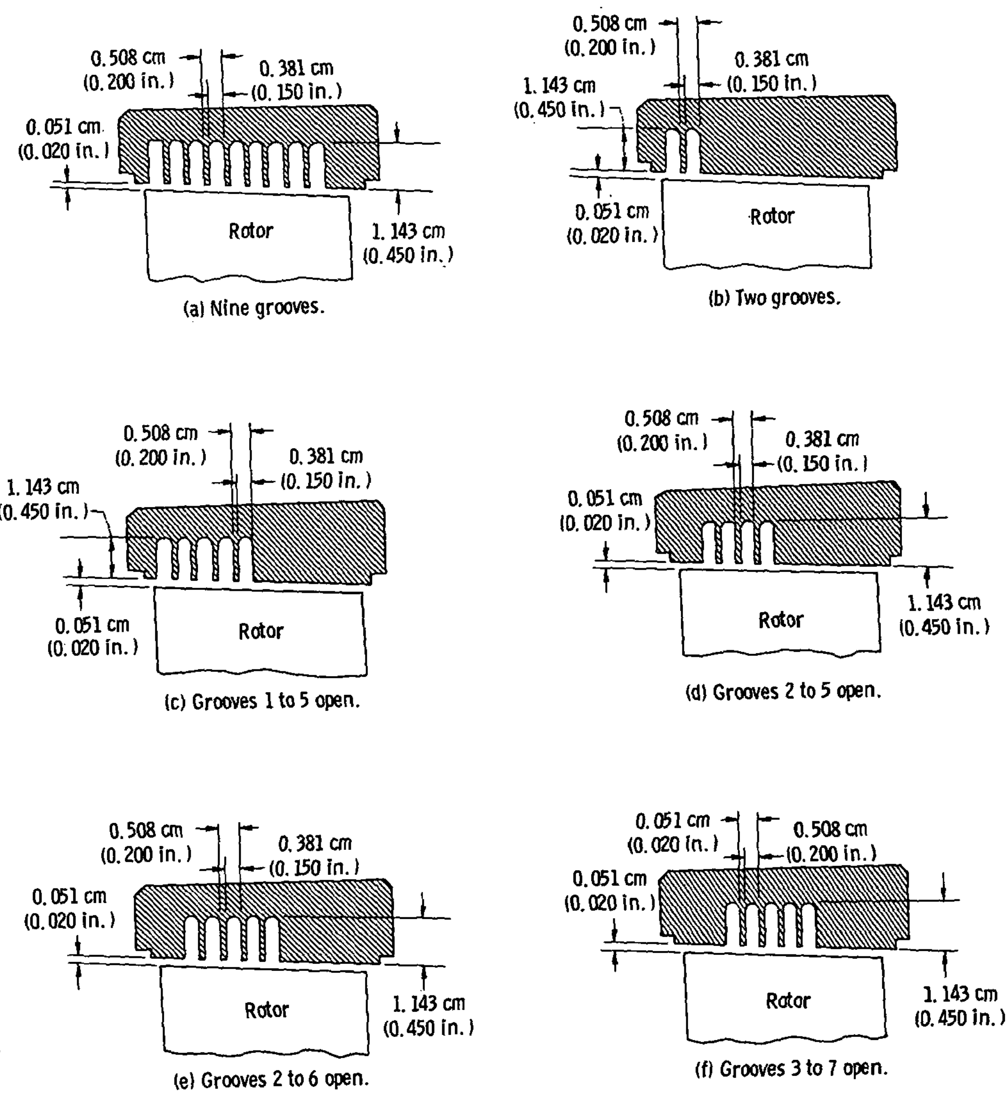


Figure 2. - Circumferential-grooved inserts showing variations in groove depth. Nine grooves open.



(a) Nine grooves.

(b) Two grooves.

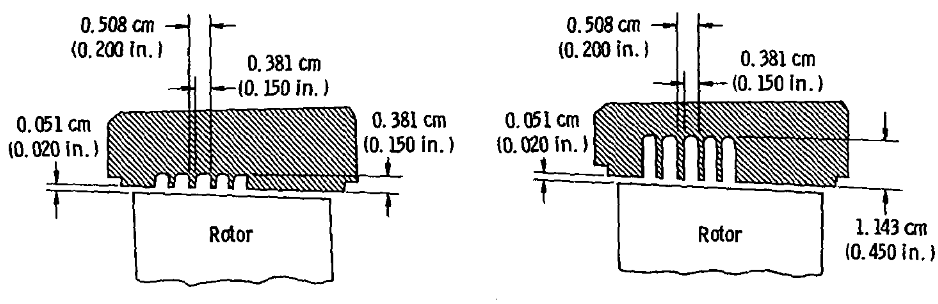
(c) Grooves 1 to 5 open.

(d) Grooves 2 to 5 open.

(e) Grooves 2 to 6 open.

(f) Grooves 3 to 7 open.

Figure 3. - Circumferential - grooved inserts showing variations in axial location and number of grooves open.



(a) 0.381 cm (0.150 in.) deep.

(b) 1.143 cm (0.450 in.) deep.

Figure 4. - Circumferential - grooved inserts showing variation in groove depth with grooves 2 to 6 open.

INSTRUMENTATION

A relatively small amount of instrumentation was used for this screening program. Measurements of pressure and temperature were made in the large plenum upstream of the stage where the velocities were low. A single, five-element total-pressure rake was located between the rotor and stator. Sensing elements were positioned radially at 10, 30, 50, 70, and 90 percent of span. Four five-element temperature rakes were located downstream of the stator. The radial positions of the five sensing elements on each rake correspond to the same spanwise positions. Photographs of representative pressure and temperature rakes are shown in figure 5. A thin-plate orifice located in

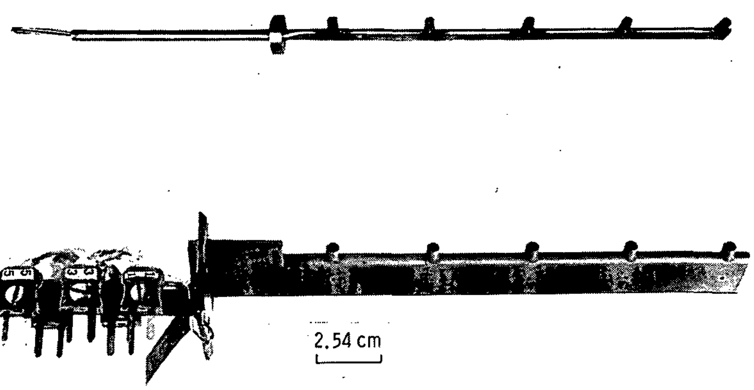


Figure 5. - Representative pressure and temperature rakes.

the inlet duct ahead of the plenum was instrumented for weight flow. Rotating speed was obtained with an electronic counter. The onset of rotating stall was detected by three high-frequency pressure transducers located behind the rotor at 10, 50, and 90 percent of span.

Test and Data Reduction Procedures

The test procedure followed was the same for all configurations. The compressor speed was set with the throttle at the full open position; after stabilization, a maximum-flow data point was recorded. The throttle was then closed, stepwise, until rotating stall was detected. The throttle was immediately opened to unstall the compressor and then was reset to a point as near as practical to stall. No stall transient instrumentation and recording equipment were used, so the weight flow at the point of the initiation of rotating stall could not be obtained. After stabilization, a steady-state data point was recorded at this near stall point. Following this, other data points were recorded between the near stall and maximum flow. The procedure was the same for both speeds, 70 and 100 percent of design.

The steady-state data were digitized and recorded for computerized data reduction. Rotor inlet total pressure was obtained from the plenum and adjusted for the loss associated with a coarse support screen located between the plenum and the rotor inlet (see fig. 1) in anticipation of testing with inlet flow distortion. The inlet pressures were adjusted using a correlation of loss values as a function of weight flow obtained from previous testing of this same hardware. Rotor discharge total pressures and temperatures were obtained from a simple numerical average of the values obtained from the rakes described in the section INSTRUMENTATION.

RESULTS AND DISCUSSION

The overall rotor baseline performance with a solid wall casing is shown in figure 6. For comparison, the overall rotor performance from reference 2 is shown as dashed lines. The data from reference 2 were obtained with mass weighted computations of

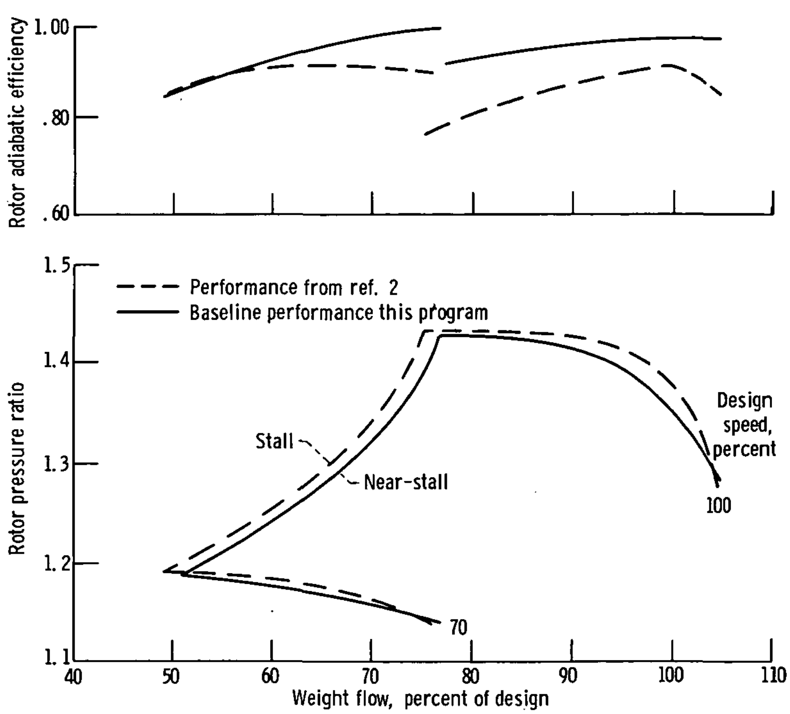


Figure 6. - Comparison of baseline performance to that from reference 2.

values from more complete survey instrumentation. Thus it is considered more precise than that for the present screening program. The differences in pressure ratio and efficiency between the two builds are a consequence of the differences in instrumentation and data handling. The differences in the minimum weight flow at each speed are a result of test procedures, with the values from reference 2 being the weight flow at the point of the initiation of rotating stall and the values for this test, the weight flow for a steady-state data point near stall. The repeatability for the near-stall point was demonstrated to be 0.6 percent or less, whereas the estimated accuracy for flow measurement is 1 percent of design flow.

The overall rotor performance obtained with the various groove configurations is compared with that for the baseline solid wall case in figures 7 to 9. The results should be used only to indicate trends. A particular configuration will be considered indicative of an improvement in stall margin if the near-stall weight flow for that configuration is less than that for another configuration with which it is being compared. The high values of efficiency indicated are not considered realistic and are included for comparative purposes only.

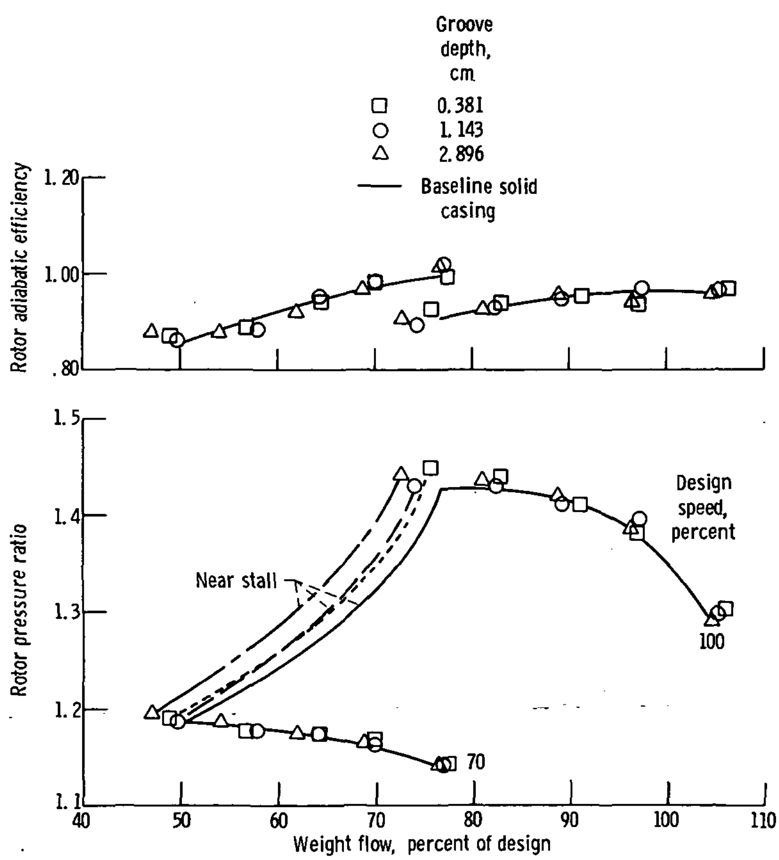
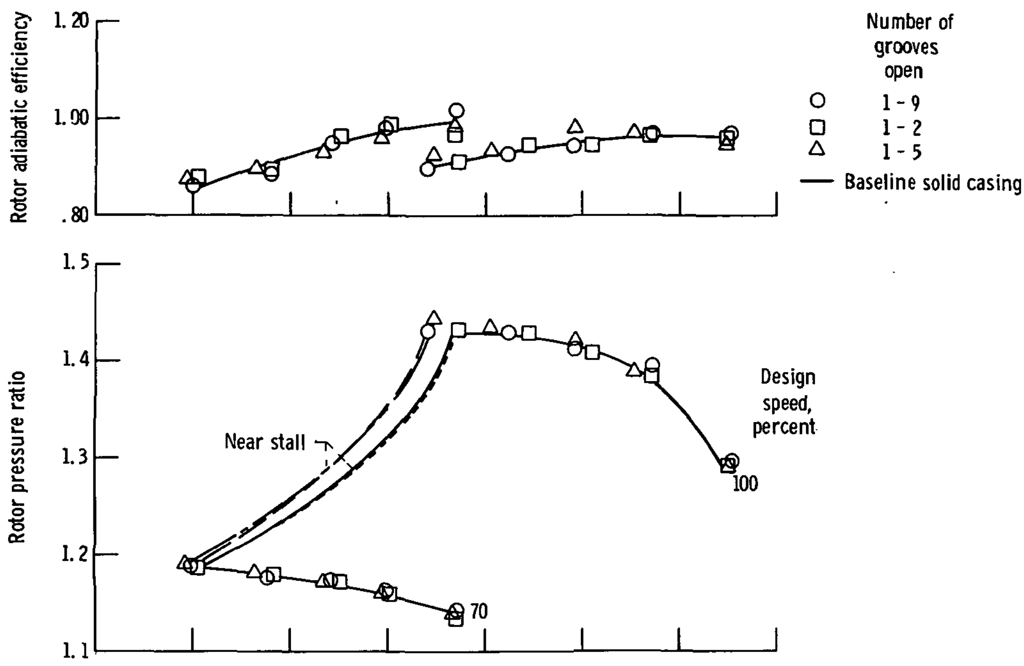
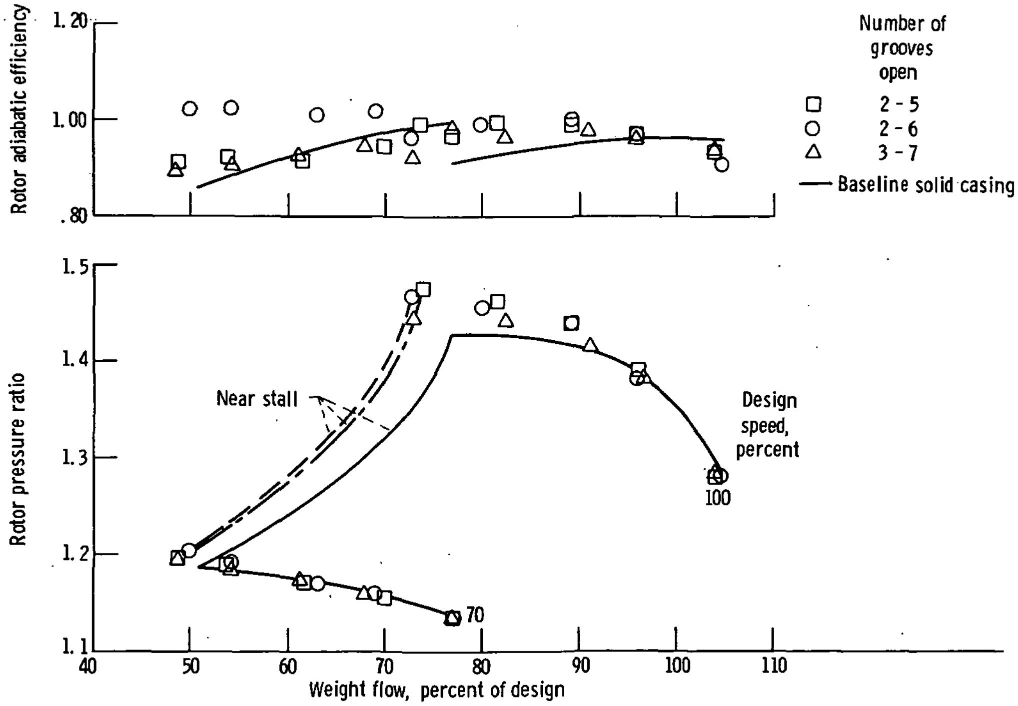


Figure 7. - Comparison of the effects of groove depth. Nine groves open.



(a) Grooves open, 1 to 9, 1 to 2, and 1 to 5.



(b) Grooves open, 2 to 5, 2 to 6, and 3 to 7.

Figure 8. - Comparison of effects of location and number of grooves open. Groove depth, 1.143 centimeters.

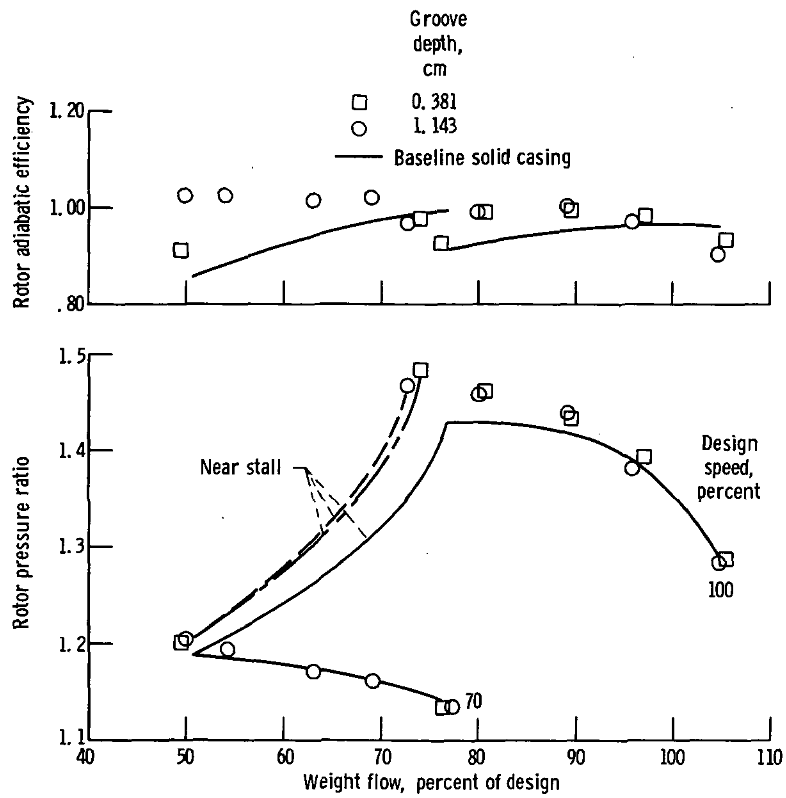


Figure 9. - Comparison of effects of groove depth. Grooves 2 to 6 open.

The discussion of specific results that follow will be limited to those for design (100 percent) speed. This is not intended to imply that these results are the most significant but that they are an indication of the general trends observed. A summary table to be presented later will include results observed at 70 percent speed.

With all nine grooves open, three values of groove depth were evaluated. These results are presented in figure 7. The 0.38-centimeter-deep grooves produced a new stall weight flow approximately 1.5 percent lower than the solid wall baseline configuration. The 1.143-centimeter-deep grooves resulted in a near-stall flow reduction of 3.6 percent at design speed; the 2.896-centimeter-deep grooves gave a 5.7-percent reduction. Within the anticipated data accuracy, the efficiencies are not significantly different from the baseline. Even though the deepest grooves indicates a marked improvement in stall margin, it is significant to note that, at disassembly, cracks in the 0.381-centimeter lands were observed. The cracks were not subjected to a thorough evaluation, but they appeared to be the results of vibratory stresses.

Various combinations of number and location of grooves were investigated using a groove depth of 1.143 centimeters. These results are shown in figures 8(a) and (b).

The configuration with grooves 2 to 6 open gave the maximum stall margin improvement. The reduction in near-stall flow amounted to 5.8 percent for design speed. As indicated, the first, possibly the second, and the two rear grooves did not appear to be contributing to the observed improvement in stall margin. In fact, the indicated improvement in stall margin is greatest when the forward and rear grooves were not used. Compared with the baseline, there tends to be an indication of some increased pressure ratio and efficiency associated with the configurations where the grooves were over the midchord region. However, because of the minimum instrumentation and the method of data computation of these parameters, these increases are not considered to be significant. They are only considered substantiating evidence of no loss in performance associated with the presence of the circumferential grooves over the rotor tip.

Considering these observations, the effect of groove depth was evaluated a second time with only grooves 2 to 6 open. The 0.381- and 1.143-centimeter depths were used. Results are shown in figure 9. As had been noted from figure 7, increased depth resulted in a greater reduction in near-stall weight flow. However, it is significant to note that the amount of the reduction in near-stall weight flow, compared with that for the solid wall casing, is greater for both groove depths with the grooves 2 to 6 open than that for comparable depths with all nine grooves open. The 0.381-centimeter-deep grooves showed a near-stall flow reduction of 3.9 percent, and the 1.143-centimeter-deep grooves 5.8 percent when compared with the solid case baseline configuration at design speed.

The following table summarizes the reductions in near-stall weight flow below that obtained with the baseline for all the grooved configurations:

Grooves open	Groove depth		Reduction in near-stall flow, percent	
	cm	in.	For 100 percent speed	For 70 percent speed
1 - 9	0.381	0.150	1.5	3.5
	1.143	.450	3.6	1.6
	2.896	1.140	5.7	7.2
1 - 2	1.143	.450	[a]-.6	0
1 - 5			2.8	2.4
2 - 5			4.2	3.9
2 - 6			5.8	1.4
3 - 7			5.5	4.1
2 - 6	.381	.150	3.9	2.2

[a]Increase.

Close examination of the table will indicate two areas where the 70-percent speed results are inconsistent with those for 100 percent speed. With all nine grooves and at 70 percent speed, the 1.143-centimeter-depth groove indicated a reduction in near-stall flow less than that for the 0.381-centimeter depth. Also, for the 1.143-centimeter-depth grooves, the 2 to 6 grooves open configuration indicated a smaller improvement in stall margin that either the 2 to 5 or the 3 to 7 grooves open configurations. The reasons for these inconsistencies are not clear; however, it should be noted that the accuracy of flow measurement is not as good at the lower speed as that at the higher speed.

Figure 10 shows a plot of the percent decrease in near-stall weight flow at design speed as a function of groove depth for grooves 1 to 9 open and for grooves 2 to 6 open. Since a zero depth groove is a solid wall casing, the curves are shown going through zero. However, there may be some finite depth below which the effects will be indicated as zero.

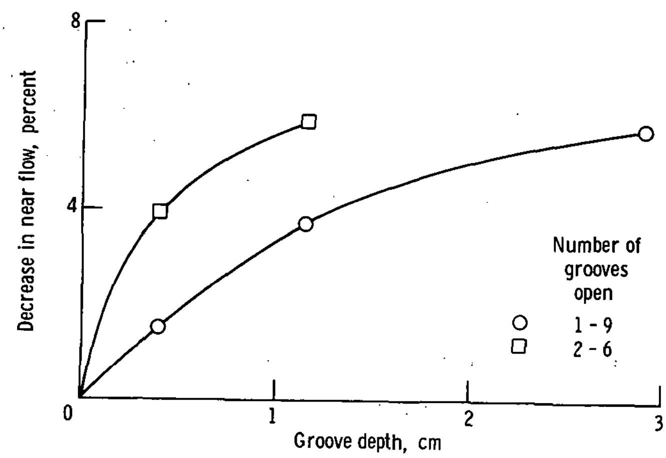


Figure 10. - Effects of groove depth on near-stall flow.

CONCLUDING REMARKS

Casing treatments such as honeycomb, slots, or grooves in the casing over the rotor blade tip have indicated improvements in stall margin over that obtained with a conventional solid wall. In order to obtain an optimum configuration and realize the maximum benefit from casing treatment, it is necessary to ascertain the effects of changes in certain geometric parameters. In this investigation, the number, depth, and location of circumferential grooves in the casing over the rotor blade tip was varied to study the effect on stage stall margin and efficiency. Some specific results are given herein along with some general relations and analogies that were observed for various casing treatments during similar investigations.

All but one of the circumferential groove configurations improved stall margin. Within experimental accuracy, the level of efficiency obtained with the grooves present was unchanged from that obtained with the solid wall. Other types of casing treatments have indicated larger improvements in stall margin. But a loss in efficiency was usually noted. The greatest improvement in stall margin was obtained with the circumferential grooves over the rotor blade tip midchord region only. Reducing the length of the blade angle slots (ref. 3) and the skewed slots (ref. 5) so that they covered a similar portion of the blade chords resulted in an increased stall margin and, also, less degradation of efficiency. This suggests that midchord may be the critical flow region with respect to the initiation of rotating stall.

Increasing the depth of the circumferential grooves resulted in increased stall margin and no significant effect on efficiency. Similar results were noted in reference 5 for circumferential grooves with increased depth. Also noted in reference 5, increasing the depth of the skewed slots resulted in an increase in stall margin, but an accompanying further decrease in efficiency was observed.

In general, circumferential grooves provide a moderate improvement in stall margin with no significant decrease in efficiency. Other casing treatments such as honeycomb, skewed, and blade angle slots, provided greater improvements in stall margin but were accompanied by decreases in efficiency. Thus, the types of casing treatment selected for a particular application depends on the relative importance of stall margin and efficiency.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 6, 1971,
764-74.

REFERENCES

1. Bailey, Everett E.; and Voit, Charles H.: Some Observations of Effects of Porous Casings on Operating Range of a Single Axial-Flow Compressor Rotor. NASA TM X-2120, 1970.

2. Oscarson, R. P.; and Wright, D. L.: Experimental Evaluation of a Honeycomb Rotor Shroud Configuration to Improve the Stall Margin of a 0. 5 Hub-Tip Ratio Single-Stage Compressor. Volume 1: Data and Performance Report. PWA-FR-4008, Pratt & Whitney Aircraft (NASA CR-72808), Dec. 1970.

3. Osborn, Walter M.; Lewis, George W., Jr.; and Heidelberg, Laurence J.: Effect of Several Porous Casing Treatments on Stall Limit and on Overall Performance of an Axial-Flow Compressor Rotor. NASA TN D-6537, 1971.

4. Moore, Royce D.; Kovich, George; and Blade, Robert J.: Effect of Casing Treatment on Overall Blade-Element Performance of a Compressor Rotor. NASA TN D-6538, 1971.

5. Tesch, W. A.: Evaluation of Range and Distortion Tolerance for High Mach Number Transonic Fan Stages. Volume 1 - Task IV Stage Data and Performance Report for Casing Treatment Investigations. Rep. R71 AEG 149, General Electric Co. (NASA CR-72862), May 1971.

6. Harley, K. G.; Harris, J.; and Burdsall, E. A.: High-Loading Low-Speed Fan Study. III - Data and Performance - Slotted Blades and Vanes and Rotor Tip Treatment. PWA-3899, Pratt & Whitney Aircraft (NASA CR-72895), July 1971.

7. Jones, B. A.; and Wright, D. L.: Single Stage Experimental Evaluation of Variable Geometry Guide Vanes and Stators. Part 1. Analysis and Design. PWA-FR-2112, Pratt & Whitney Aircraft (NASA CR-54554), Aug. 2, 1968.

NASA-Langley, 1972 —— 1 E-6560

NATIONAL AERONAUTICS AND SPACE ADMISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

U.S.MAIL

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Return

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546