Check for updates

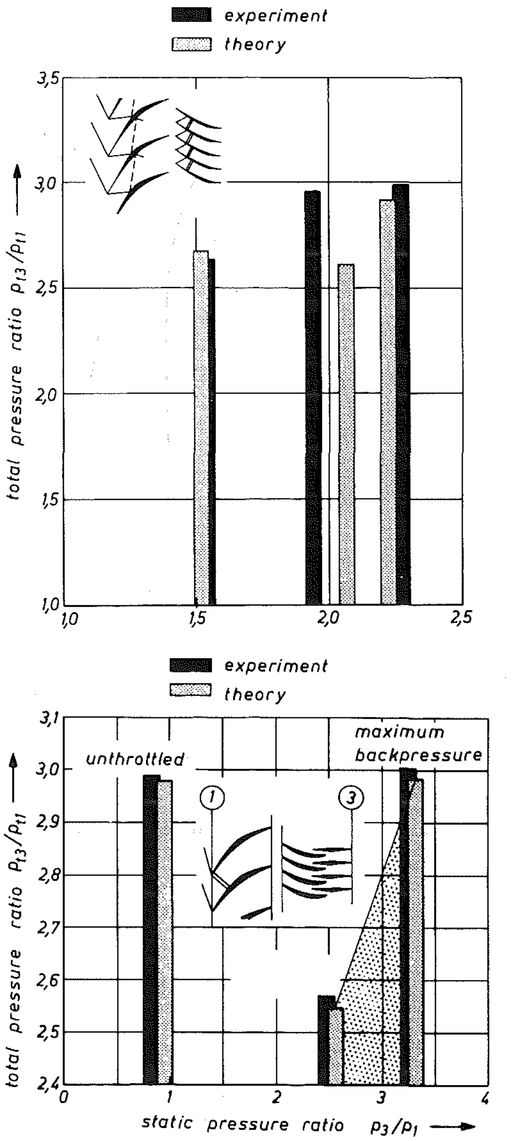

**Fig. 14 Total pressure at the outlet of the impulse-type and shock-rotor stage**

within the stator passage in the whole operation range. This can be realized by stators with variable geometry.

## Acknowledgments

The presented investigations were supported by the "Deutsche Forschungsgemeinschaft," and the researching "Institut für Strahlantriebe und Turboarbeitsmaschinen, RWTH Aachen," and the authors would like to express their sincerest thanks for this promotion.

## References

1 Weise, A., "Überschallaxialverdichter," Bericht 171 der Lilienthal-Gesellschaft, 1943.

2 Ritter, W. K., and Johnsen, I. A., "Performance of 24-Inch Supersonic Axial-Flow Compressor at Design Tip Speed of 1600 Feet per Second," NACA RM E7 L10, 1948.

3 Hartmann, M. J., and Tysl, E. R., "Investigation of a Supersonic-Compressor Rotor With Turning to Axial Direction. II—Rotor Component Off-Design and Stage Performance," NACA RM E53 L24, 1953.

4 Wennerstrom, A. J., Buzzel, W. A., and De Rose, R. D., "Test of a Supersonic Axial Compressor Stage Incorporating Splitter Vanes in the Rotor," ARL TR 75-0165, 1975.

5 Breugelmanns, F., "On the Use of a Pseudo-Shock System in Supersonic Compressors," *WGLR-Jahrbuch*, 1965.

6 Paulon, J., Reboux, J., and Sovrano, R., "Comparison of Test Results Obtained on Plane and Annular, Fixed or Rotating Supersonic Blade Cascades," ASME Paper No. 74-GT-49, 1974.

7 Simon, H., "Anwendung verschiedener Berechnungsverfahren zur Auslegung eines Überschallverdichter-Laufrades und dessen experimentelle Untersuchung," Diss. RWTH, Aachen, 1973.

8 Bohn, D., "Untersuchung zweier verschiedener axialer Überschallverdichter-Stufen unter besonderer Berücksichtigung der Wechselwirkungen zwischen Lauf- und Leitrad," Diss. RWTH, Aachen, 1977.

9 Broichhausen, K.-D., and Gallus, H. E., "Theoretical and Experimental Analysis of the Flow Through Supersonic Compressor Rotors," *AIAA Journal*, Vol. 20, No. 8, 1982.

10 Fuchs, R., and Starken, H., "Experimental Investigations of Supersonic Cascades Designed for High Static Pressure Ratios," ASME Paper No. 77-GT-37, 1977.

11 Broichhausen, K.-D., and Gallus, H. E., "Influence of Shock and Boundary-Layer Losses on the Performance of Highly Loaded Supersonic Axial Flow Compressors," AGARD-CPP 400/401, 1986.

12 Monsarrat, N. T., Keenan, M. J., and Tramm, P. C., "Design Report: Single-Stage Evaluation of Highly Loaded High-Mach-Number Compressor Stages," NACA CR-72562, 1969.

13 Moeckel, W. E., "Approximate Method for Predicting Form and Location of Detached Shock Waves on Cones and Spheres," NACA TN 2000, 1950.

14 Miller, G. R., Lewis, G. W., and Hartmann, M. J., "Shock Losses in Transonic Compressor Blade Rows," ASME *Journal of Engineering for Power*, Vol. 83, 1961.

15 Donaldson, C., and Lange, R. H., "Study of the Pressure Rise Across Shock Waves Required to Separate Laminar and Turbulent Boundary Layers," NACA TN 2770, 1952.

16 Boxer, E., "A Method for Predicting the Performance of High Reaction Supersonic Compressor Blade Sections," AIAA Paper No. 69-522, 1969.

17 Volkmann, H., Fottner, L., and Scholz, N., "Aerodynamische Entwicklung eines dreistufigen Transsonik Frontgebläses," *ZFW*, Vol. 22, 1974.

18 Novak, R. A., "Streamline Curvature Computing Procedures for Fluid-Flow Problems," ASME *Journal of Engineering for Power*, Vol. 89, 1967.

19 Spindler, G., and Pätzold, H., "The Classical Streamline Curvature Method in the Supersonic Range: A Numerically Ill-Posed Boundary Value Problem," *ZFW*, Vol. 2, 1986.

20 Lichtfuss, H.-J., and Starken, H., "Supersonic Cascade Flow," *Progress in Aerospace Science*, Vol. 15, 1974.

21 Kauke, G., "Untersuchungen zur Nachlaufwechselwirkung im Tandem-Leitrad einer axialen Überschallverdichterstufe," Diss. RWTH, Aachen, 1986.

## DISCUSSION

**R. Fuchs[1] and H. Starken[1]**

The authors present a very interesting paper on an important field of compressor research activity. Three different supersonic stages have been examined (Fig. 2) using fixed and variable geometry stators. It would be very interesting to compare these different types of stage, especially to see the payoff by the variable stator stage configuration.

The authors give some hints in Section 4.1 on a considerable improvement of stage performance by combining the impulse-type rotor with the variable single-row stator. In order to verify this, a presentation and comparison of the different performance maps would be very valuable. Of course, the performance map of the variable geometry stage is more complex due to the additional stagger angle parameter. But it is not easy to evaluate the different stage results from the diagrams in the paper. Using performance maps not only off-design comparisons would be possible, but also design performance comparisons, which are of great interest too.

If no performance map can be presented, it would be very useful to get additional information on the following matters:

In the introduction the authors present only the experimental results at design point for one rotor/stator combination (shock-rotor/tandem stator) under consideration. What about the design performance of the other configurations, especially the variable geometry one?

---

[1] DFVLR, Institut für Antriebstechnik, Köln, Federal Republic of Germany.

Copyright © 1988 by ASME

Downloaded from http://mechanismsrobotics.asmedigitalcollection.asme.org/turbomachinery/article-pdf/110/3/322/5839429/321_1.pdf by guest on 10 November 2024

We would like to point out that in the bottom diagram of Fig. 3 the stagger angle $\alpha_{st}$ of the turnable stator is measured toward the blade pressure side, whereas in Fig. 11 $\alpha_{st}$ is measured toward the suction side. That results in a difference of 7 deg [22]. In the definition of Fig. 11 the design value of $\alpha_{st}$ is 47 deg.

The results presented in Fig. 11 extend from $\alpha_{st} = 61$ to 53 deg. Therefore the lowest value of $\alpha_{st}$ is still 6 deg above design. Are there any results close to the design value of $\alpha_{st} = 47$ deg? Also results for the rotor/stator combination of Fig. 11 taken at higher than the starting rotor speed would be of great interest.

From Fig. 13, where the fixed and the turnable stator stages are compared at design speed, the question arises as to whether the results of the turnable stator are taken at the design stagger angle. From the shock system on the stator cascade sketch given in this diagram, this seems not to be the case. The flow case shown in Fig. 13 with no suction surface leading edge oblique shock wave [22] belongs to a stator blade stagger position of 7 deg or more above design.

Similar questions arise for Fig. 14 (upper part): Have the compared results been obtained at design speed, design stator blade stagger angle position of $\alpha_{st} = 47$ deg and, as in the lower part of this diagram for the fixed tandem stator blade stage, at maximum back pressure? The maximum back pressure presented for the turnable stator blade stage seems to be quite low.

### References

22 Fuchs, R., *Design and Investigation of Static Pressure Compressor Cascades Behind Impulse Rotors*, ESA-TT-629, Nov. 1980.

## Authors' Closure

The authors thank Dr. Fuchs and Dr. Starken for their detailed discussion.

The following closure is arranged systematically with respect to the main topics of the discussion.

**1 Influence of the Stator Setting on the Starting Process (Impulse-Type Rotor/Variable Geometry Stator).** The definition of the stagger angle in Fig. 3 representing blade geometry data is correct. In Fig. 11, explaining mainly the velocity triangle at stator inlet, the stagger angle should also be measured with respect to the pressure side. This inaccuracy in the preprint is already corrected in the printed version. Thus $\alpha_{St} = 53$ deg corresponds to the closest stator setting (Design 54 deg).

**2 Lack of Results Regarding the Impulse-Type Rotor/Variable Geometry Stator at Speeds Higher Than the Starting Speed (Fig. 11).** As can be seen from the axial Mach number distribution versus speed ratio in Fig. 11, the axial flow is clearly supersonic if the starting speed is exceeded. For this case the rotor exit average data coincide with the data for rotor-alone operation and are omitted for clearness reasons.

**3 Design Performance Comparison of the Different Supersonic Compressor Stages.** The main features of the flow at design speed and increased back pressure are described in Section 4.2.

"Regarding the *impulse-type rotor and tandem stator*, the close vicinity of starting and design speed . . . did not allow a throttling" (Section 4.2). Consequently no data for design back pressure can be presented.

The design-speed line of the *shock-rotor/tandem stator* combination is given in Figs. 13 and 14. Stable operation and the design data (see introduction) have been achieved with satisfying efficiency.

Regarding the *impulse-type rotor and variable geometry stator* the corresponding data are also shown in Figs. 13 and 14. The results at maximum back pressure refer to the closest throttle position with stable operation corresponding to the surge margin of the compressor stage. Contrary to design condition the interaction of shocks with wall boundary layers at hub and casing prevents a deceleration of the flow to subsonic exit conditions. In the real compressor a pseudoshock system is achieved, generating nearly sonic speed at the stator exit (see section 4.2).

For these reasons further investigation of supersonic compressors at the Technical University Aachen is mainly focused on the development of shock rotors in combination with tandem stators [23].

### References

23 Mönig, R., Broichhausen, K.-D., and Gallus, H. E., "Applications of Highly Loaded Single-Stage Mixed-Flow Compressors in Small Jet-Engines," AGARD Conference Proceedings No. 421, 1987.

Downloaded from http://mechanismsrobotics.asmedigitalcollection.asme.org/turbomachinery/article-pdf/110/3/322/5839429/321_1.pdf by guest on 10 November 2024