Paper 6

DEVELOPMENT OF A SEALING CONSTRUCTION TO PREVENT LEAKAGE FLOW DURING FLUTTER TESTS IN A LINEAR CASCADE

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Development of a Sealing Construction to Prevent Leakage Flow During Flutter Tests in a Linear Cascade

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ABSTRACT

Time-dependent flow tests on a single airfoil have been conducted in a closed nozzle. The airfoil is on one side suspended to the nozzle wall and is forced to vibrate in the bending mode. The measurements require a gap in the nozzle wall around the airfoil, and this results in a leakage flow. Tests with a relative gap width of 1% of the blade chord have shown that the leakage flow influences the main flow for up to 70% of the blade height. The aspect ratio is 0.51. To suppress the leakage flow on the vibrating airfoil, different sealing elements were tested.

A double-sided labyrinth sealing solution has been found which consists of steel-plates and plexi-plates, the latter acting as moving parts adjusted to fit on the airfoil. All the plates are placed in a labyrinth-housing. Surface paint tests show a decrease in the effected flow region from 70% to 25% of the nozzle width at the trailing edge. Vortices which arose on the blade surface due to the leakage flow also disappear. The airfoil movement is not influenced by the labyrinth sealing and the construction allows flow visualization. From static pressure measurements on the blade surface in the middle of the nozzle, it is shown that the difference between the tests without a gap and the tests with the labyrinth sealing is negligible.

INTRODUCTION

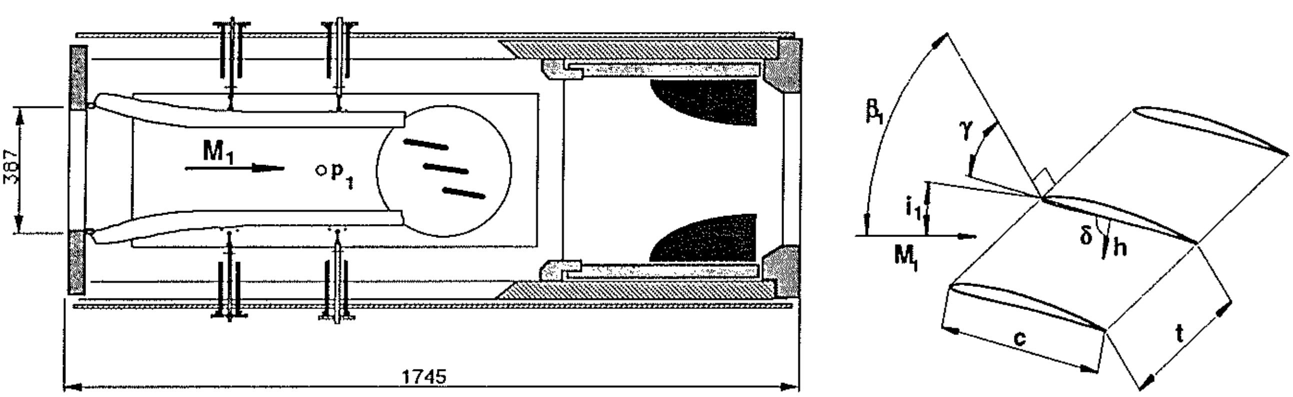
Unsteady flow phenomena in a turbomachine blade system lead to a high variation of the aerodynamic forces which are acting on the turbomachine blades. As a consequence vibration of the blades occurs. This can, under certain circumstances, lead to fissuring and eventual failure of the blades. Controlled vibration of turbomachine blades is an excellent way to study the flutter phenomena experimentally. A two-dimensional flow is required to study the complex unsteady flow phenomena, especially for a transonic flow condition.

The tests are conducted in a closed nozzle. For flutter tests in the bending mode (direction δ in Fig. 1b.) a gap in the nozzle wall is required around the vibrating airfoil. This results in a leakage flow. During flutter tests with controlled blade vibration a remarkably high influence of this leakage flow on the main flow in the test section is seen. To prevent this leakage flow a sealing has been developed.

In this paper the development of a suitable sealing is presented. The tests were conducted in a closed nozzle with an inlet Mach number of 0.6 and blade frequencies between 120 and 190 Hz, ($k_{max} = \frac{\pi f c}{U} = 0.20$).

TEST FACILITY

The tests were performed with a NACA-3506 profile. To obtain, on the instrumented airfoil, cascade-like pressure distributions a "compressor cascade" was built with three blades (Fig. 1.). The centre blade is on one side suspended to the nozzle wall and with an electro-magnetic system forced to vibrate in the bending mode (f=100-200 Hz, amplitude ±0.5 mm). The gap in the side wall around the profile is 0.8 mm. One side wall is polished to allow flow visualization with Schlieren visualization and holographic interferometry. The other side wall admits optical access with a plexi-plate. The cascade has a pitch chord ratio, t/c = 56.6 / 78 = 0.73.



a.) b.) c=78 mm; t=56.6 mm; γ=40°

Figure 1 *Configuration a.) of the nozzle, width 40 mm and b.) of the three blade compressor cascade.*

The compressed air for the test facility is produced by a continuously running four stage radial compressor which has a maximum mass flow rate of 10 kg/s and a maximum pressure ratio of 3.5.

AERODYNAMIC TESTS CONDUCTED WITH DIFFERENT CONSTRUCTIONS

To prevent the leakage flow, five sealing constructions have been developed and tested in the nozzle. The leakage flow was identified with surface paint tests (on the suction side) and static pressure measurements at mid-span of the nozzle. Reference measurements were conducted without the leakage flow, that is, with the gap in the nozzle wall closed with clay. The reference surface paint tests showed, in this case, a perfect two-dimensional flow on the blade surface. In Table 1 a brief description of the sealing constructions can be found. The tests were conducted with the incidence angle $i = 8.3^{\circ}$. The isentropic inlet Mach number for the tests was $M_{1s} = 0.6$. The flow conditions were adjusted from the calculated inlet isentropic Mach number measured at a position 120 mm before the leading edge of the centre blade.

No.	Specifications
I	small plate fixed in the nozzle wall; not touching the vibrating blade
II	one-sided labyrinth with five steps
III	one-sided labyrinth with five steps + O-ring
IV	one-sided labyrinth with five steps + airtubes
V	double-sided labyrinth with three steps

Table 1 *Configurations of different sealings.*

RESULTS AND DISCUSSION OF THE AERODYNAMIC TESTS WITH THE SEALING CONSTRUCTIONS

The goal was to seal the gap between the fixed nozzle wall and the vibrating airfoil. The sealing should deliver the same Mach number distribution at mid-span of the nozzle with and without the gap. The construction should also be easy to put together. Furthermore, it is important that flow visualization, Schlieren-films and holographic pictures, can be done. In the following, different sealing variants are described.

<u>Sealing variant No. I (Fig. 2.):</u> The concept of a small plate; it should prevent the leakage flow over the airfoil and the flow on the airfoil should be parallel to the side walls. According to the surface paint tests with this variant a relatively large leakage flow still exists, which results in visible vortices just above the blade surface, up to 70% of the blade width at the trailing edge. There is no significant difference between the paint traces for the tests with and without (Fig. 5a.) the small plate.

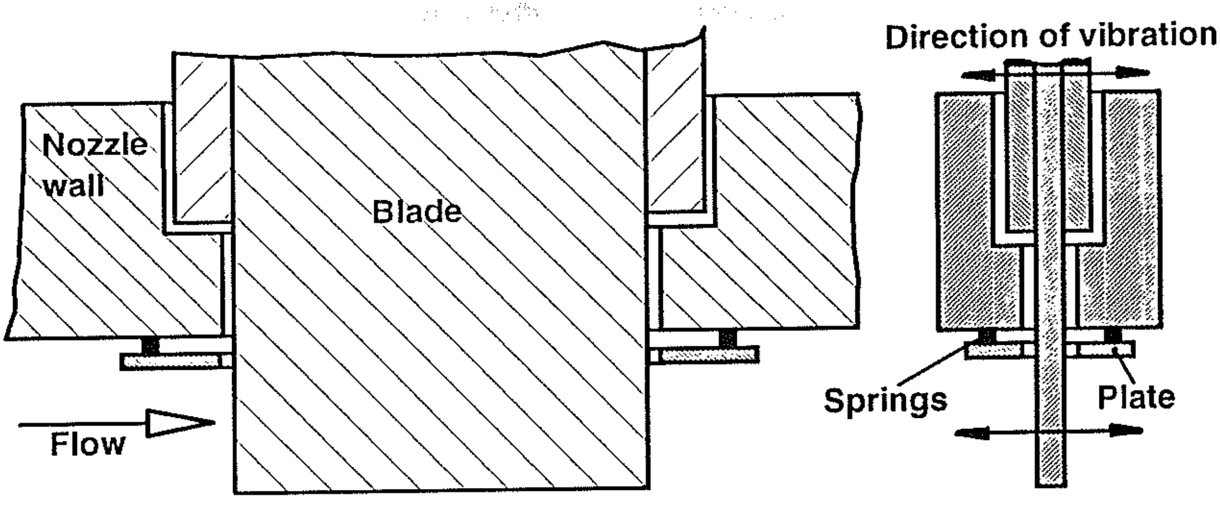


Figure 2 The small plate fixed in the wall with springs, sealing variant I.

Sealing variants No. II and No. III (Fig. 3.): The objective of the tests was to investigate if the amount of the leakage flow decreases sufficiently with a one-sided sealing labyrinth and also with an O-ring inside the sealing labyrinth. The one-sided sealing labyrinth consists of four steel-plates and five Aluminum-plates. All plates are adjusted to fit into a labyrinth-housing. The inside edges of the plates have the blade form. The space between the Fe-plates and the blade and the Al-plates and the blade are 1 mm and 4 mm , respectively. A small gap was still left between the O-ring itself and the blade.

The Mach number distributions on the blade suction side for the tests with the labyrinth and for the tests with the O-ring inside the labyrinth show still a relatively big difference in comparison to the reference measurements, (Fig. 4). The results of the surface paint tests match those of the tests with the small plate, that is, a leakage flow appears up to 70% of the blade width at the trailing edge.

Sealing variant No. IV (Fig. 3.): The behavior of the leakage flow is investigated with two airtubes in a one-sided sealing labyrinth. The air pressure in the tubes was taken from a high pressure reservoir and it was controlled with a regulator. During these tests it was found that, the blade movement is influenced by the airtubes during the unsteady tests. When the pressure in the tubes is high enough to stop the leakage flow, the blade movement stops. With decreased pressure in the airtubes the blade movement improves, but the effect of the sealing gets worse. The pressure in the airtubes is rather high during the tests discussed in this paper, the absolute value being 2.3 bar.

The Mach number distributions with the airtubes in the labyrinth show good results indeed, but as the blade could not move, it is not possible to use them. Although the blade was vibrating on the outside of the nozzle, the blade inside the nozzle, because of the sealing, was blocked. The blade surface paint tests are also very good, since the gap in the nozzle wall is almost closed with the airtubes.

Sealing variant No. V (Fig. 3.): From the previous tests on a one-sided labyrinth it was concluded that the leakage flow passes close to the surface of the blade. A two-sided sealing labyrinth prevents this flow. Two Al-plates from the one-sided sealing labyrinth were exchanged with two plexi-plates. The plexi-plates are adjusted to fit on the vibrating blade. They have an space of 1 mm to the labyrinth-housing. One Fe-plate (thickness 0.55 mm) was taken away to allow the plexi-plates to slide against the Fe-plates. The plexi-plates are treated with a spray (MOLYKOTE[1]) to decrease the sliding friction between the plates.

The results from the Mach number distributions with the plexi-plates were very similar to the reference measurements, (Fig. 4). The surface paint measurements show that the leakage flow has been limited up to 20 - 25 % of the blade width at the trailing edge, (Fig. 5). The plexi-plates do not influence the blade movement for the unsteady measurements, as the mass of the plexi-plates is negligible in comparison to the mass of the blade.

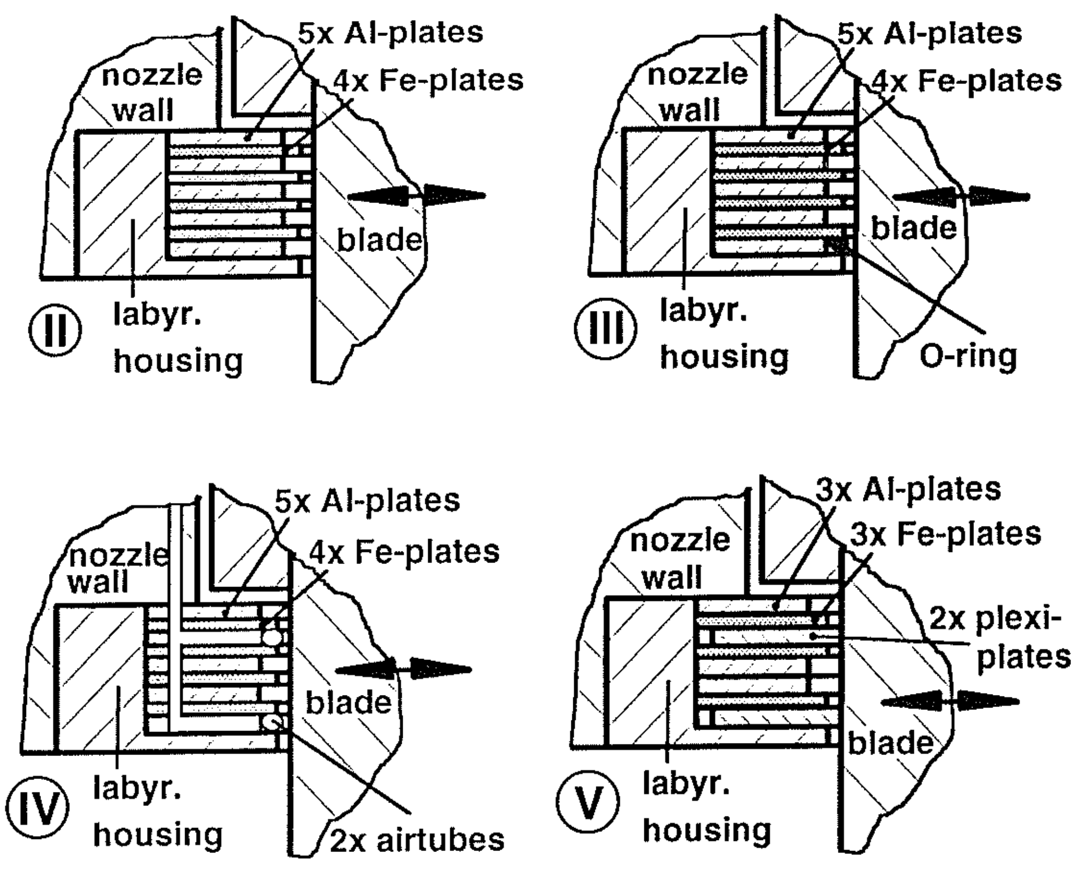


Figure 3 *The four labyrinth sealing configurations.*

1 Molykote type: 321 R with molybdenum disulphide (MoS_2), CREDIMEX AG (CH).

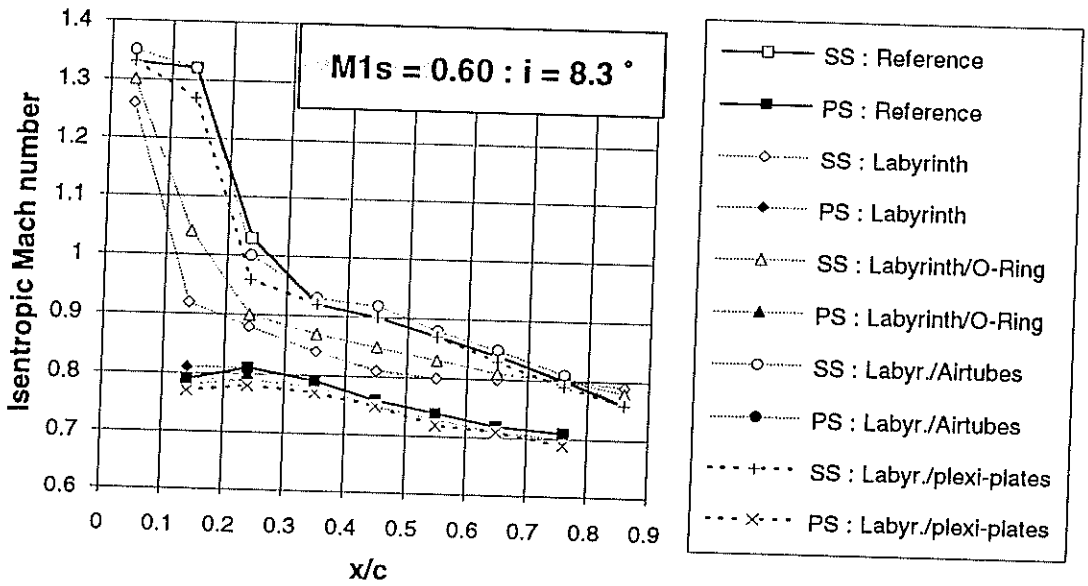


Figure 4 Comparison of blade surface Mach number distribution, three-blade compressor cascade.

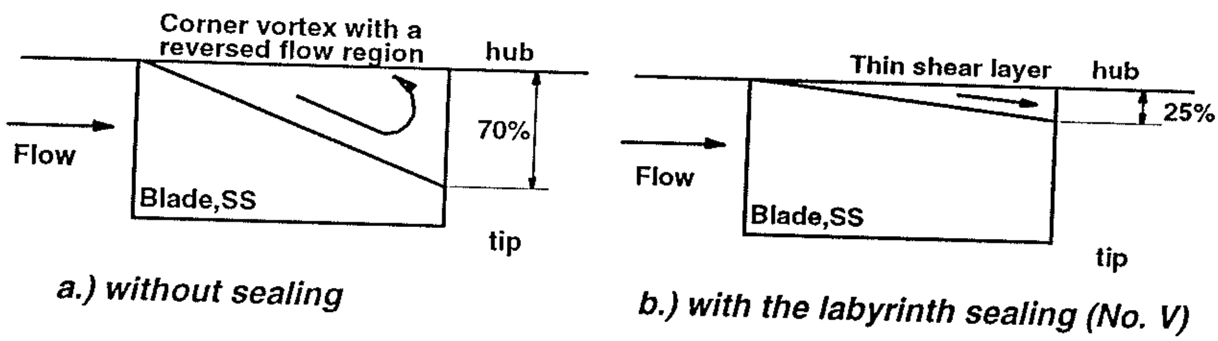


Figure 5 Leakage flow, with and without the labyrinth.

Conclusion

During flutter tests in a closed nozzle for the bending mode a leakage flow appeared which had a significant influence on the main flow in the test section. The construction which best minimizes this leakage flow is a double-sided labyrinth sealing (variant No. V) with two plexi-plates attached directly to the vibrating blade. The labyrinth-plates are placed in a labyrinth-housing, which is built into the nozzle wall. Paint traces showed that the leakage flow had been minimized up to 20 - 25 % (from 70%) of the nozzle width at the trailing edge. From static pressure measurements on the blade surface in the middle of the nozzle, it is shown that the difference between tests without a gap and tests with the double-sided labyrinth sealing is negligible.