Experimental Data for the Fourth Standard Configuration in the Workshop on Aeroelasticity in Turbomachine-Cascades

by

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Abstract

Steady and unsteady measurements on a highly cambered turbine blading with subsonic and supersonic outlet velocities are presented. The experiments have been peformed in an annular cascade with controlled bending vibration of the blades.

From the unsteady measurements the overall damping coefficient is calculated and presented in function of the outlet Mach number and the interblade phase angle. It is seen that the cascade exhibits flutter tendencies at some interblade phase angles at transonic outlet velocities.

The experimental data represent the fourth standard configuration in the "Workshop on Aeroelasticity in Turbomachine-Cascades" [1]. In the present short note only the experimental results are presented. The complete data from the investigation with the analysis of the results will be published in a near future.

Nomenclature

The nomenclature used in this paper corresponds to the one defined in the "Workshop on Aeroelasticity in Turbomachine-Cascades" [1] and a abstract of thus is given in annexe.

1. Introduction

At the conference "Aeroelasticity in Turbomachines" in Lausanne in 1980 it was decided to collect experimental data on flutter measurements for compressor and turbine bladings. This data base will serve as test cases for theoretical

calculations organized in the frame of the "Workshop on Aeroelasticity in Turbomachine-Cascades" [1].
The "Laboratory of Applied Thermodynamics and Turbomachines" (LTT) at the EPF-Lausanne participates in this workshop with measurements on a highly cambered turbine cascade in bending vibration mode. The experiments performed in an annular test facility cover a wide range of subsonic and supersonic outlet Mach numbers and the whole interblade phase angle range.
Eight typical experiments will be presented in this brief note. A complete version of all experimental results is given in Ref. [2], which can be obtained upon request.

2. Test facility and test cascade

The aeroelastic investigation was carried out in the annular test facility at the LTT which is described in detail in Ref. [3] and [4].

Assembled cascade

Single blade

Fig. 1 Cascade geometry and location of the pressure transducers

The inlet flow angle in the nonrotating test cascade can be varied between 12° and 60° and the outlet Mach number can reach M_2=1.6 for turbine cascades.
The test cascade consists of twenty vibrating blades suspended on the same central spring system as in Ref. [3] and the control of the blade vibrations is performed with an electromagnetic excitation system [4,5].
The tip diameter of the test cascade is 400 mm and the blade height is 40 mm. The geometrical data of the cascade are given in Fig. 1.

3. Steady state flow measurements

The steady state pressure data have been obtained, with the blades in a non-vibrating condition, by pressure tappings on the blade and on the side walls.
The blade pressure tappings are located at midspan; 14 on the pressure side (upper surface) and 15 on the suction side (lower surface).

Fig. 2 Measured isentropic Mach number distribution on the blade

The Fig. 2 shows an example of the measured isentropic blade surface Mach number distribution for constant inlet flow conditions with outlet Mach numbers increasing from subsonic to supersonic velocity.
The limit loading condition for the turbine cascade is M_{2max}=2.11. Up to this Mach number, at supersonic outlet condition, the shock from the trailing edge of the neighboring blade impinges upon the suction side of the reference blade.

4. Unsteady measurements

The movement of the elastically suspended blades was measured and analysed as described in [4]. The unsteady pressure on the blades was determined by miniature pressure transducers (manufacturer ENDEVCO), mounted inside of the blade as shown in Fig. 3. Five transducers are mounted on the pressure surface and six on the suction surface of two neighboring blades. The time dependent values have all been recorded on an analog tape and processed off-line as described in [4].

Fig. 3 Mounting of the high response pressure transducers

5. Tests performed

A large number of experiments have been performed, covering a wide range of inlet and outlet flow conditions from subsonic to supersonic speeds. Out of the results, eight were selected as test cases for the workshop on aeroelasticity in turbomachine-cascades (Table 1). In the following, the analysis and presented results will be limited to these eight cases.

The flutter behaviour of the cascade is described by the aerodynamic damping coefficient which represents the work of the unsteady pressure on the

Test case	1	2	3	4	5	6	7	8
M_1	0.19	0.26	0.28	0.29	0.29	0.28	0.28	0.28
	45	45	45	45	45	45	45	45
M_2	0.58	0.76	0.90	1.02	1.19	0.90	0.90	0.90
	-90	-90	-90	-90	-90	180	90	0
k	0.168	0.128	0.107	0.095	0.082	0.107	0.107	0.107

Table 1 Selected test cases of the 4-th standard configuration

oscillating blade. The definition used corresponds to the nomenclature in [1]. Positive values of the damping coefficient indicate stable (damped) and negative value unstable (amplified) behaviour of the vibrating blade.

The Fig. 4 shows the local damping coefficient determined from the pressure transducer measurements on the blade for an interblade phase angle of = -90° for three different outlet Mach numbers.

In this example the local damping coefficient ( ) on the pressure side is always stable. The behaviour on the suction surface varies however with the outlet flow conditions. For high subsonic and sonic outlet conditions the whole suction surface shows an unstable behaviour and the global aerodynamic damping coefficient ( ) is negative (cases 3 and 4 in Fig. 4). At supersonic outlet conditions the part of the blade with unstable behaviour is reduced to a zone close to the leading edge, and the global damping coefficient becomes positive (case 5).

Fig 4 Local aerodynamic damping coefficient with outlet Mach number as parameter (=-90°)

The flutter stability of the blading depends upon the integral of the local damping coefficient around the blade. This global aerodynamic damping coefficient of the blade is shown in Fig. 5 as a function of the outlet Mach number for various interblade phase angles for the eight cases given in Table 1. The test cases for 0° 180° show stable behaviour of the vibrating blade, but for interblade phase angle -90° the blade is stable at low subsonic and high supersonic outlet conditions and unstable in the transonic region.

Fig. 5 Global aerodynamic damping coefficient in dependence of outlet Mach number and interblade phase angle

Summary

An experimental aeroelastic investigation of a high cambered turbine cascade in bending vibration mode have been performed at the LTT as a contribution to the Workshop on Aeroelasticity in Turbomachine-Cascades.

The investigation demonstrates the influence of outlet Mach number and interblade phase angle upon the flutter behaviour of the turbine cascade. The global aerodynamic damping coefficient has been measured as positive for 0° 180°. However, for =-90 and near sonic outlet conditions the cascade shows flutter tendency.

Further investigations will be performed on the cascade to complete the data base for theoretical investigations.

References

[1] T.H. Fransson — Workshop on Aeroelasticity in Turbomachine-Cascades
Proceedings of the Symposium "Unsteady Aerodynamics of Turbomachines and Propellers" - Cambridge, Sept. 1984

[2] A. Bölcs, M. Degen, D. Schlaefli — Flutter Investigation of a Highly Cambered Turbine Cascade in Sub- and Supersonic Flow
Report LTT/EPFL-85

[3] A. Bölcs — A Test Facility for the Investigations of Steady and Unsteady Transonic Flows in Annular Cascades
ASME Paper 83-GT-34

[4] A. Bölcs, D. Schlaefli — Flutter Phenomena in a Transonic Turbine Cascade
Proceedings of the Symposium "Unsteady Aerodynamics of Turbomachines and Propellers" - Cambridge, Sept. 1984

[5] A. Kirschner, B. Fosco — Control of Vibration in Aeroelastic Cascade Experiments
Comm. ITA N° 10 - Proceedings of the 2nd Int. Symposium "Aeroelasticity in Turbomachines" - Lausanne - Sept. 1980