Effect of Moist Droplet-laden Flow on Transonic Compressor Cascade Performance

Silvio Geist, Laboratory of Turbomachinery, Helmut-Schmidt-University / University of the Federal Armed Forces, Hamburg, Germany

Niklas Neupert, Laboratory of Turbomachinery, Helmut-Schmidt-University / University of the Federal Armed Forces, Hamburg, Germany

Franz Joos, Laboratory of Turbomachinery, Helmut-Schmidt-University / University of the Federal Armed Forces, Hamburg, Germany

ISROMAC
Symposia on Rotating Machinery
Since 1985
Long Abstract

Introduction

Today, power demands are met by an increasing amount of renewable resources. However, peak loads are still covered by conventional approaches such as gas turbines which have to respond quickly on possible supply fluctuations of the renewables. In that regard, high-fogging is a common procedure to enhance both gas turbine power output. Small-sized water droplets, sprayed into the engine's inlet, are intended to evaporate thus absorbing heat from the surrounding flow. As a result the specific work needed for compression is minimised. Apparently, high-fogging is particularly useful in hot regions were cooling potential is high. Regarding, e.g. equatorial areas, operating conditions may not only be hot but also at a high level of humidity.

If so, transonic flow, as it occurs in the tip region of compressor blading and in turbine passages, is altered strongly. Schnerr and Dohrmann [1],[2] calculated transonic flow around an airfoil and found that increasing humidity decreases shock strength and shifts the shock position upwards. This is due to local condensation of water vapour. If moist air is accelerated along the airfoil's suction side, static pressure and temperature will decrease. That reduces the air's dew-point and encourages condensation. During condensation, heat is released to the surrounding gas which decreases the local Mach number and eventually reduces shock intensity.

Although moisture effects on transonic flow is studied thoroughly, the interaction of both moist and droplet-laden flow in the vicinity of shocks is not well understood.

This study presents measurements of transonic cascade flow velocity utilising a 2D-LDA/PDA system. Performance quantities deflection, velocity ratio and profile loss are used to evaluate the different flow conditions. Regarding the droplet-free flow, effects and relations observed by Schneer and Dohrmann could be confirmed for the presented cascade flow. However, the results further indicate that for droplet-laden flows humidity effects are decreased.

Methods

To clarify the impact of droplets on moist flows and vice-versa nine blades with profiles similar to modern compressor's outer cross-sections have been mounted within a cascade. The encompanied wind tunnel is situated at the Laboratory of Turbomachinery at the Helmut-Schmidt-University in Hamburg, Germany. A detailed description of the test rig can be found in [3]. Notable cross-section parameters and flow definitions are displayed in Fig. 2 for convenience. Since, the inlet Mach number of $Ma = 0.95$ is close to unity a shock system is always existent on the suction side as made visible via shadowgraphy in Fig. 1.

Overall, three data sets at different specific humidities, namely $X_L = 3\frac{g}{kg}$, $X_L = 6.5\frac{g}{kg}$ and $X_L = 11\frac{g}{kg}$ were measured at different blade loadings while the inlet Mach number was kept constant. In addition each parameter set was measured with a water mass fraction of $\xi_m = 0.01$. To ensure a well defined specific humidity two moisture sensors have been utilised. The first measures the water content of the air drawn from the environment. Based on that measurement deionized water is sprayed in the air supply's outlet to adjust moisture at the second sensor position in front of the cascade. Due to high duct temperature and residence time within the duct connecting the supply with the settling chamber the spray is evaporated entirely therein. If intended, additional water can be injected in the settling chamber via a manifold of 10-15 impingement nozzles (BETE PJ10) generating a spray with a mean diameter $D_{10} = 7.0\mu m$ and a Sauter Mean Diameter $D_{32} = 38.7\mu m$ at the cascade's entrance [4]. To maintain a quasi-2D flow in the test section the sidewall boundary is re-energized using compressed air which is injected via a slit nozzle system in front of the cascade. A non-invasive 2D-LDA/PDA technique is used to collect the flow field's velocity components . Sidewalls made of acrylic glass allow visual access. As it can be seen in Fig. 2 the system is traversed half a chord length ($c = 50mm$) in front of the flow to gather inlet information. After traversing through the passage at half pitch ($\frac{t}{2}$) the profiles wake is eventually measured. Based on that data performance parameters, profile loss and isentropic Mach number distribution through the passage are extracted and evaluated.

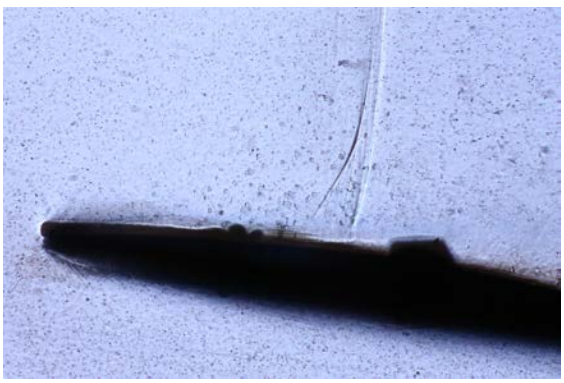

Figure 1. Shadografic image of the passage shock at high blade loading with dry but droplet-laden air.
$X_L = 3\frac{g}{kg}, \xi_m = 0.01, \beta_1 = 155\,\mathrm{deg}$

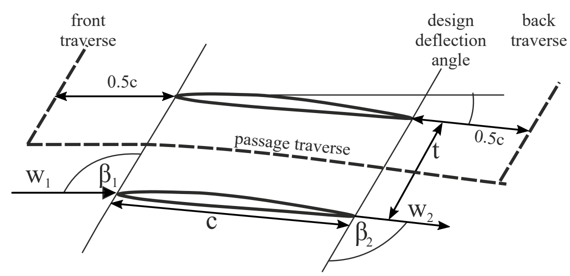

Figure 2. Definition of cascade and flow parameters

References

[1] G. H. Schnerr and U. Dohrmann. Drag and lift in nonadiabatic transonic flow. *AIAA Journal*, 32(1):101–107, 1994.

[2] G. H. Schnerr and U. Dohrmann. Transonic flow around airfoils with relaxation and energy supply by homogeneous condensation. *20th Fluid Dynamics, Plasma Dynamics and Lasers Conference*, 28(7):1187–1193, 1989.

[3] B. Ober. *Experimental Investigation on the Aerodynamic Performance of a Compressor Cascade in Droplet Laden Flow*. PhD thesis, Universitätsbibliothek der Helmut-Schmidt-Universität, Hamburg, 10 2013.

[4] N. Neupert, B. Ober, and F. Joos. Experimental Investigation on Droplet Behavior in a Transonic Compressor Cascade. *Journal of Turbomachinery*, 137(3):031009, 2014.