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Investigation and Modeling of Two Phase Flow through a Compressor Stage

Niklas Neupert[1], Franz Joos[1], Hassan Gomaa[2], Bernhard Weigand[2]

[1]Helmut-Schmidt-University, University of the Federal Armed Forces
Laboratory of Turbomachinery (LSM),
Holstenhofweg 85, 22043 Hamburg, Germany
Neupert@hsu-hh.de, Joos@hsu-hh.de

[2]Institute of Aerospace Thermodynamics, Stuttgart University
Pfaffenwaldring 31, 70569 Stuttgart, Germany
Hassan.Gomaa@itlr.uni-stuttgart.de, Bernhard.Weigand@itlr.uni-stuttgart.de

Abstract

For stationary gas turbines, the injection of water sprays into the compressor inlet is used to increase the power output, which can be used for rapid correction of power fluctuations appearing in power supply systems with today's increased use of wind and solar energy. By water injection and the subsequent evaporative cooling before and within the compressor, the compression work is reduced and the mass flow is increased. A lot of different phenomena are present for this process which needs detailed investigation and modeling. The groups of F. Joos and B. Weigand have worked together on this for several years. The present paper will present different results from phenomena of two phase flow in a compressor cascade, detailed modeling of these phenomena and the potential consequences of these phenomena on the discharge droplet spectrum and the aerodynamic performance of a compressor. The presented data contains experimental and numerical results obtained at the Institute of Aerospace Thermodynamics, Stuttgart and the Laboratory of Turbomachinery, Hamburg.

Dependant on the operating conditions and fineness of the spray a significant portion of the water droplets pass into the cascade leading to interactions between droplets and blades. In general smaller droplets evaporate faster and show a better follow-up behavior in the accelerated flow and are therefore favorable [5,6]. Large injected mass flows lead to the appearance of larger droplets (~ D > 30 µm) which do not follow the accelerated gas flow closely. This leads to several phenomena in a compressor flow. First of all a separation of droplet classes in the cascade is visible leading to the formation of a inhomogeneous distribution of droplets in the outlet of the cascade as shown in Fig.1.

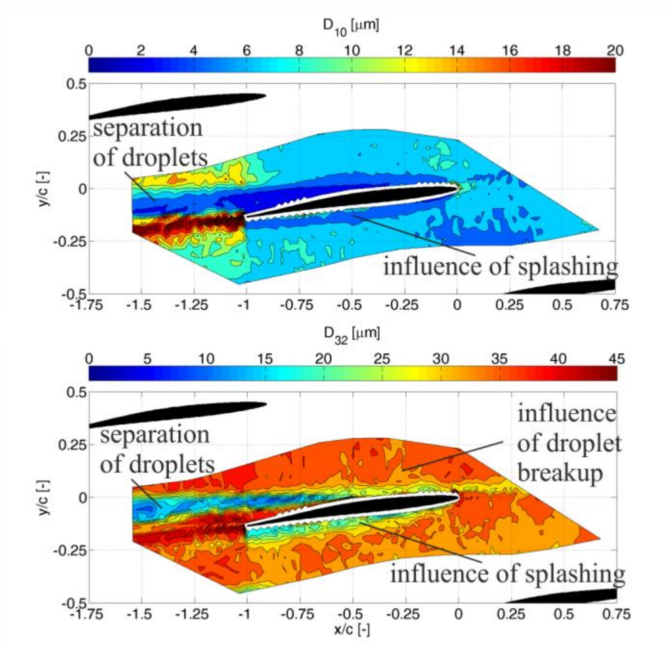

Fig. 1 Contour plot of D_{10} and D_{32} around a transonic profile at a water load ξ_w=1.3%, Ma_1=0.89 and inlet flow angle β_1=153° [4].

Further velocity differences between the gas and the droplet can lead to significant aerodynamic forces acting on the droplet resulting in a deformation or even breakup. The influence of this phenomenon on the droplet distribution is visible in a reduction of the D_{32} in the acceleration zone of the droplet [4].

Another consequence of the poorer ability of larger droplets to follow the gas flow is the splashing of these droplets on the blades causing erosion problems and the formation of a fine spray at the leading edges of the blades. At the same time some liquid remains on the blades' surfaces forming thin films or streaks that propagate along the shell to the trailing edge where they are disintegrated in the shear layer and form drops that are ejected into the flow field.

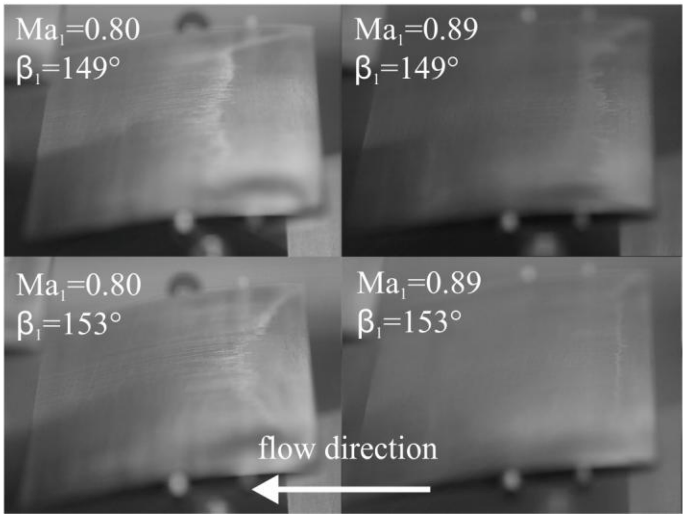

Fig. 2 Wall film pattern at ξ_w=1.3%, Ma_1=0.80 (left) and Ma_1=0.80 (right) at β_1=149° (top) and β_1=153° (bottom) [4].

At the trailing edge the disintegration process and the possible formation of larger drops reasons the significance and interest in this process, since larger droplets might enter the following cascade leading to erosion problems again. For the understanding of the disintegration process and its modeling it is of major significance to know the film thickness and its velocity. Unfortunately, it is extremely difficult to measure the wall film properties at real flow conditions and only relatively imprecise optical evaluations of the film could be conducted showing the variation of the film length with different inflow conditions. This reasons the necessity for numerical investigations on the subject. To take into account small scale processes of single droplets within the numerical study of the whole cascade flow an Euler-Lagrange approach is applied. While the flow field of the cascade is computed by solving the Navier-Stokes Equations, the behavior of the droplets is computed in terms of solving the equations of motion and the resulting trajectories. In the case that a droplet trajectory hits a blade the developed model is applied, which provides an elaborate prediction of the ejected secondary droplet diameter [3]. Applying this to a big amount of droplets yields the droplet diameter spectrum of the spray in front of the blades' leading edges, which play an important role, since it dominates the flow field close to the blades. Additionally, the model facilitates the quantification of the specified film properties.

The data basis for modeling the droplet impact process is gained from a parameter variation, consisting of over 150 direct numerical simulations (DNS) with each ~17Mio. grid cells, which was carried out with the in-house code FS3D, that was specially developed for the DNS computation of two phase interfacial flows and is well validated [2]. A new droplet wall interaction model was implemented into a commercial CFD code and is applied to the blade geometry of a transonic cascade flow field that was measured by the Laboratory of Turbomachinery [1,5]. The computed velocity field for a certain inflow condition is shown in figure 3. The application of the novel model then yields the droplet diameter spectrum close to the blade, especially at the leading edge. In combination with a wall film module the quantification of the wall film thickness depending on the inflow conditions as well as the incoming droplet diameters is possible.

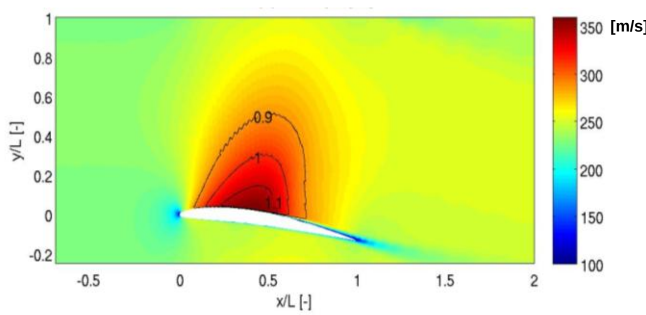

Fig.3 Velocity contours around blade.

These numerical results are compared with experimental data of the droplet spectrum in the discharge of the cascade. As will be shown the influence of splashing on the leading edge and the pressure side and the droplet class separation due to the different follow up-ability can be seen. The influence of the droplet breakup due to aerodynamic forces in the flow field is considerably small and is not detectable in the discharge spectrum.

The paper will contain detailed descriptions of several investigations which have been done in both groups. The results are focused on droplet dynamical aspects of a two-phase compressor flow.

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