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MULTIPLE JET IMPINGEMENT – A REVIEW

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Jet impingement systems provide an effective means for the enhancement of convective processes due to the high heat and mass transfer rates that can be achieved. The range of industrial applications that impinging jets are being used in today is wide. In the annealing and tempering of materials, impinging jet systems are finding use in the cooling of hot metal, plastic, or glass sheets as well as in the drying of paper and fabric. Compact heat exchangers, with applications in the aeronautical or the automotive sector, often use multiple impinging jets in dense arrangements. Impingement systems in micro scale applications are commonly used for the cooling of electronic components, particularly electronic chips. In gas turbine applications (the focus of this investigation), jet impingement has been routinely used for a long time. Requirements are being imposed by demands for increased power output and efficiency as well as for reduced emissions. High thermal efficiency can be realized by increasing turbine inlet temperatures and compressor ratios. As a result of this, many gas turbine components, such as rotor disks, turbine vanes and blades, or combustion chamber walls, are operated at temperatures well above highest allowable material limits. In order to assure durability and long operating intervals, effective cooling concepts are required for these highly loaded components. Due to the complex geometry of turbine system coupled with high turbulence, the understanding of the flow and heat transfer characteristics remains a challenging subject [e.g. Han and Goldstein 2001, Son et al. 2001].

Depending mainly on geometrical conditions, flow and heat transfer characteristics of multiple impinging jets can differ substantially from those of single jets. This is, as in a multijet configuration the individual jets can be affected by essentially two types of interactions that do not occur in single jet systems. The first is the possible jet-to-jet interaction between pairs of adjacent jets prior to their impingement onto the target plate. This type of interference is of importance for arrays with closely spaced jets and large separation distances between the jets and the impingement surface. Secondly, there is the interaction between the impinging jets and the flow formed by the spent air of the neighboring jets. These disturbances predominantly occur for arrays with small interjet spacing, small separation distances, and large jet velocities. The strength of crossflow within the impingement array is determined further by the design of the outflow (see Figs. 1 and 2).

It is due to these interferences that the use of single jet heat transfer results for the design of multiple jet configurations becomes significantly complicated or even erroneous. While heat transfer rates due to single jets can be functionally expressed by relatively simple power-functions of Reynolds and Prandtl number, correlations for multijet heat transfer rates require the consideration of a number of additional characteristic numbers.

Although there exists a considerable amount of reviews on jet impingement heat transfer, e.g. Han & Goldstein [2001], Viskanta [1993], or Martin [1977], the design of a multijet configuration with respect to heat transfer still remains a complex task due to the large number of influencing factors. Numerous correlations have been developed, but the small number of comparisons is aggravating the choice. New experimental work has been contributed since appearance of the latest reviews that has not been reviewed or collated before. An overview on the fast developed numerical predictions of multijet heat transfer from the last years has not been published so far.

The present review paper summarizes relevant experimental and numerical results on multijet impingement heat transfer including the latest developments in literature. The objective is to provide profound knowledge for the design of such configurations complemented by a structured listing of the influencing factors for heat transfer. The area of application is aimed at gas turbines, therefore only round air jets are considered. The paper first describes the physics of multiple jet configurations. Characteristics of flow field and heat transfer are introduced and compared to those of single impinging jets. The dimensional groups influencing the flow and heat transfer pattern are determined by means of dimensional analysis. Experimental studies are reviewed with regards to the effects of jet pattern, jet diameter or open area, crossflow effects, separation distance, and jet-to-jet spacing. A section on multijet impingement combined with surface enlargement emphasizes the potential in heat transfer augmentation. The review of experimental studies concludes with a section dedicated to optimization studies for impingement arrays.
In the review of numerical works, the main focus is set on an estimate on the accuracy of present CFD tools in predicting local multijet heat transfer rates. Methodologies for efficient numerical treatment are discussed. Figure 3 gives an impression on the quality of state-of-the-art CFD simulations. The results have been obtained by the authors of this paper.
In a section on error analysis, an estimate on the measurement uncertainty is provided, which is aimed to provide kind of an evaluation criterion for the reader when reviewing experimental studies. Uncertainties involved with numerical predictions are also discussed.
Different analytical models correlating the results of the respective experimental study are collated. The models differ in their range of applicability and in the number of mainly geometric parameters taken into consideration. Results predicted by the different models are compared.

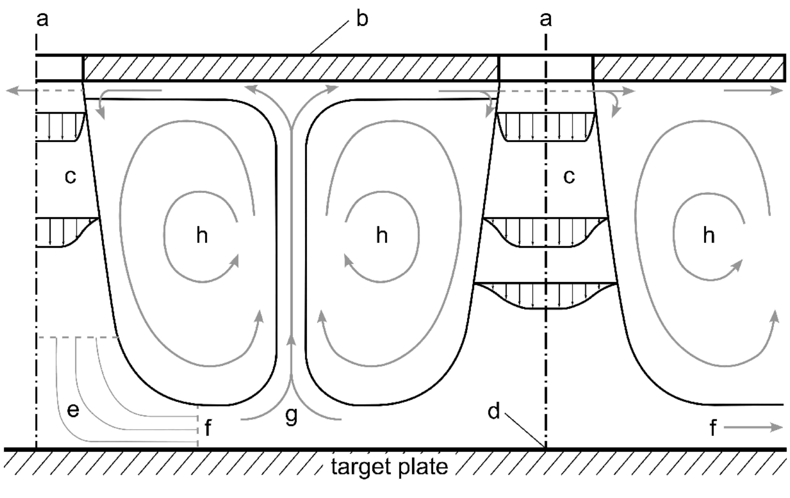

Figure 1. Complex flow pattern within an array of impinging jets due to jet-to-jet interference (after Glaser [1962])
a – orifice, b – impingement plate, c – free jet, d – stagnation point, e – stagnation zone, f – decelerated flow, g – recirculating flow, h – vortices

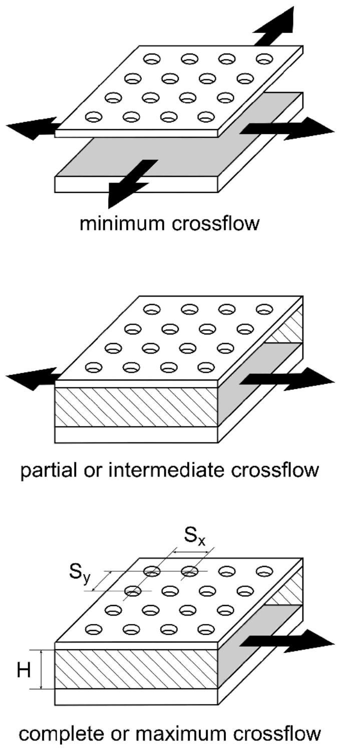

Figure 2. Definition of crossflow schemes in multijet systems (after Obot & Trabold [1987])

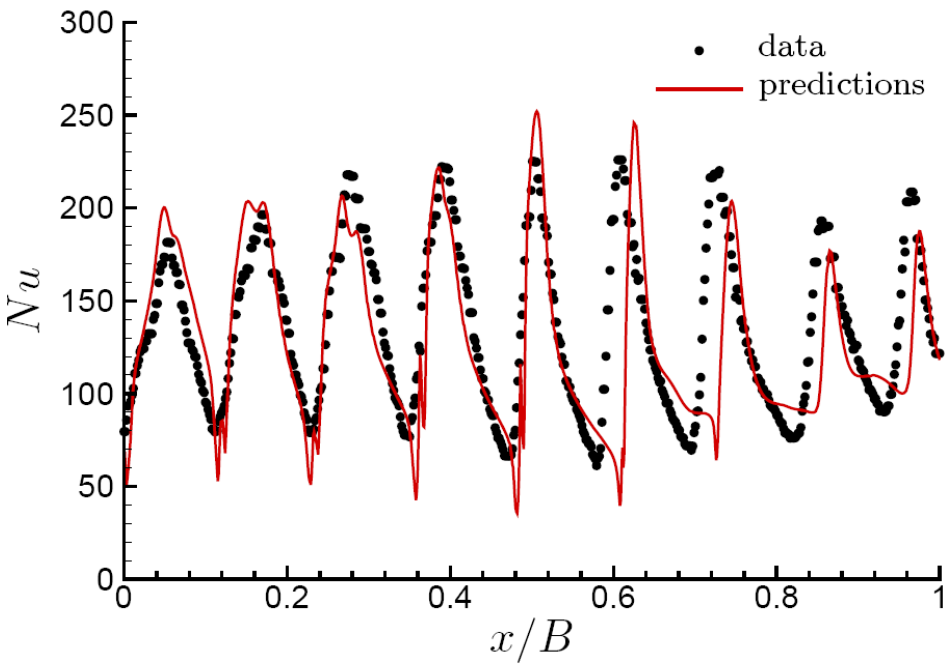

Figure 3. Comparison of local heat transfer rates from experiments and CFD for an inline impingement array with crossflow due to spent air (own calculations, ITLR, 2009)

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