On influence of the approximation parameters on the reconstructed heat transfer coefficient for an array of jets

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Abstract

The spatial distribution of the heat transfer coefficient (HTC) for an array of air jets is the main objective in the following work. The spatial distribution of the HTC is estimated directly from the transient temperature measurements which are taken at the opposite to impinged surface of the object. The least-square sense by modified Levenberg-Marquardt algorithm taken from ISML Fortran library is used to minimized the objective function. Infrared camera is used to measure temperatures entering the objective function

Keywords: HTC, air jets, inverse analysis, Levenberg-Marquardt algorithm

1. Introduction

The research is aimed at retrieving the spatial distribution of the heat transfer coefficient (HTC) for an array of air jets.

The jet impingement involves a nozzle from which a high velocity jet is released towards the heated/cooled object [1]. By adjusting the number, location and velocity in the nozzles an arbitrary heat flux distribution can be produced. As a single jet has very limited range in practice the sets of jets are used.

Application of the inverse analysis allows for decoupling the complex fluid flow from the conduction inside the impinged object. The approach allows for estimating the spatial distribution of the HTC directly from the transient temperature measurements. The measurements are taken at the opposite to impinged surface of the object. The superposition principle is used to divide the reconstructed field into small number of locally defined, simple fields called trial (approximation) functions. In general they can be any functions as long as their sum for all points of the retrieval area and whole time of the analysis is equal to 1.

Each function is associated with certain location and time moment and has one prescribed estimation parameter attached to it. In the proposed approach constant and linear functions are used. For each field a simple forward heat conduction problem has to be solved. The resulting temperature field gives the distribution of the smoothed sensitivity coefficients required by the inverse solver.

Calculation of the sensitivity coefficients is the most time consuming part of the algorithm. It should be noticed that the dependence of the temperature field on HTC is nonlinear. This strongly deteriorates the numerical efficiency of the inverse analysis, which relies on the least square fit of the model and measurements.

Therefore a special formulation of the objective function was introduced. Such approach allows for avoiding the time expensive iterations as the Jacobi matrix is determined once, before entering the iterative loop. The detailed description of the inverse technique applied for the HTC determination can be found in [2, 3].

The approximation coefficients are determined by minimization of the difference of measured and computed temperatures:

$$\min \Phi = \sum_{z=1}^{Z} [T_{z,m} - T_T(\mathbf{T})]^2 + \sum_{z=1}^{Z} [T_{z,m} - T_q(\mathbf{T},\mathbf{h})]^2 \quad (1)$$

where $T_{z,m}$ stands for measured temperature while vectors T and h contain approximating coefficients of temperature and HTC. T_T temperature from inverse model for temperature retrieval and T_q temperature from inverse model for heat flux retrieval. Subscript z denotes number of measurement. The objective function (1) is minimized in the least-square sense by modified Levenberg-Marquardt algorithm taken from ISML Fortran library.

The measured temperatures entering the objective function (1) come from an infrared camera. This method of solving the inverse problem together with local definition of the partial problems, improve the stability of the algorithm by filtering high frequency errors.

2. Results

There are several important factors that influence the quality of the reconstruction. In the case of the array of jets one spatial trial function has to be associated with each nozzle. As the temperature field beyond the impinged area seems to be rather uniform, only two functions are used there: one that is located

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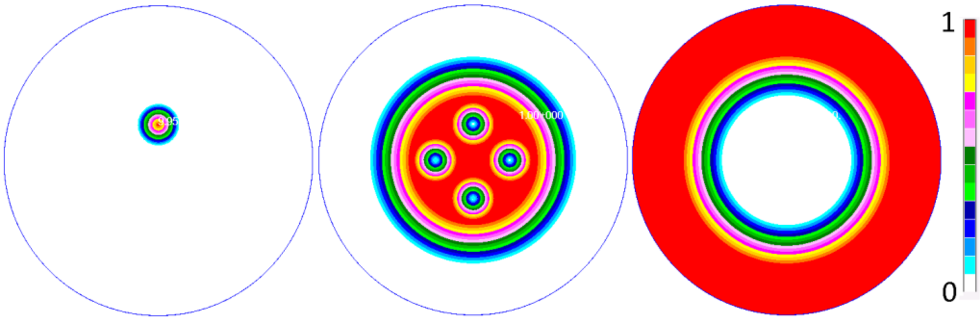

Figure 1. Spatial distribution of the radial based trial functions (example for round shape of nozzle function).

Table 1: Results for various parameters of the approximation.

Set:	A	B	C	D	E	F	G	H
Shape of nozzle function	square	round	square	round	round	round	round	round
Range of nozzle function, mm	30	10	15	15	20	30	30	20
Time interval, s	28	30	14	36	30	30	36	60
No. of temporal functions	3	2	2	4	2	2	4	2
Nozzle 1	211.9	600.6	377.3	381.1	249.5	227.9	225.0	49.4
Nozzle 2	218.0	515.3	334.3	336.1	229.3	212.2	209.2	41.1
Nozzle 3	212.4	620.0	385.8	389.7	253.5	231.9	229.1	15.8
Nozzle 4	200.0	559.1	357.6	357.9	242.8	224.3	220.2	76.9
F5	74.5	97.1	92.8	90.1	82.5	74.2	72.3	13.4
F6	25.7	9.4	10.3	10.8	12.4	14.1	14.5	2.4
ΔT_{av}	0.307	0.732	0.371	0.357	0.296	0.283	0.302	1.321

in between the nozzles (F5) and the other that covers outer area of the sample (F6). The set of spatial trial functions has been depicted in Figure 1. The only parameter which is to be set is the range of the functions connected with the nozzles. Other parameters involves: considered time interval, time step, number of temporal functions and the shape of the spatial function.

Once the parameters are set and the HTC is retrieved it is used as an input data to direct analysis. In the last step the temperatures from this direct run are compared with the measurements which allows for judging the quality of the result. Average temperature difference is denoted as ΔT_{av}. Comparison of the results is shown in Table 1.

For one measurement set the HTC has been reconstructed with various parameters (sets denoted as A to H). There are several similar results for which the nozzle HTC varies between 200 and 250 W/(m^{2}K) and the average temperature difference for those cases are around 0.3 K. For other cases the temperature difference was higher – between 0.37 and 1.32 K and there the HTC differ significantly from good quality results. The best results were obtained for time interval of 28-36 s and two to four temporal functions. The spatial range affected by each jet was 30 mm which is maximum range due to nozzles distribution. This behavior was expected as analysis of the measurements indicate that the most significant temperature changes occurs during first 30-40 s.

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