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RAPID TECHNIQUE OF RETRIEVING THE HEAT TRANSFER COEFFICIENT

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ABSTRACT

There are several reasons for retrieving the heat transfer coefficient (HTC). The experimentally determined HTC are used in structural thermomechanics in cases when direct CFD simulations are too expensive preventing from solving a coupled convection conduction problem. Moreover, in some cases, e.g. boiling, jet impingement, the precision of the available models is low so that reliable heat exchange data can be obtained only experimentally. Direct determination of the HTC by a solution of appropriate inverse problem is an alternative of retrieving this coefficient indirectly by solving inverse problems for the boundary temperature and heat flux. The disadvantage of this approach is that the resulting distribution of the HTC is irregular, as both the temperature and heat flux may vary independently. The proposed method produces the spatial distribution of the HTC explicitly from transient temperature measurements. The paper is follow up of our earlier work [1] where an implicit technique has been employed.

It should be noticed that for linear boundary value problems, the temperature field depends linearly on the boundary temperature and heat flux. The dependence of the temperature field on HTC is, however, nonlinear even in the case the corresponding direct problem is linear. This feature strongly deteriorates the numerical efficiency of the inverse analysis, which relays on the least square fit of the model and measurements In the case HTC is retrieved directly, the resulting nonlinear optimization problem needs to be solved iteratively, invoking at each iteration step the direct solver. The aim of this solver is to produce for a current distribution of the HTC the temperature field. If the sensitivity matrix is also evaluated, the direct solver needs to be invoked several times at a given iteration step. The proposed technique reduces significantly the computational burden as in this case the direct solver is invoked outside of the iterative loop.

The developed method resorts to the superposition principle. In the first step of the approach, two sets of elementary fields Θ_j and Ξ_j $j = 0, 1, 2, \ldots, J$ are evaluated. The members of the first are obtained by solving a linear direct problem. The problems have homogeneous boundary conditions at all boundaries except the surface where the HTC is sought for. At this boundary the temperature is described by a sequence of linear compact support functions depending on space $N_j(\mathbf{r})$ and time $M(t)$.

The second set of elementary functions is obtained analogously. The only difference is that this time it is the boundary heat flux which is defined by sequence of linear compact support functions. It can be shown that the members of both sets can be interpreted as distributions of the sensitivity coefficients of the temperature with respect to parameters describing the distribution of the boundary temperature and heat flux. In the second step the temperature field is expressed as a linear combination of the already obtained fields.

$$T_T(\mathbf{r},t) = \Theta_0(\mathbf{r},t) + \sum_{j=1}^{J} T_j \Theta_j(\mathbf{r},t), \qquad T_q(\mathbf{r},t) = \Xi_0(\mathbf{r},t) + \sum_{j=1}^{J} q_j \Xi_j(\mathbf{r},t) \tag{1}$$

where Θ_0 and Ξ_0 are temperature fields corresponding to homogeneous boundary conditions on the surface where the HTC is to be retrieved with the remaining boundary conditions left intact. The coefficients T_j and q_j of the combinations are evaluated from the least square fit of the model and the measurements

$$\min \Phi = \sum_{i=1}^{I} (\hat{T}_i - T_T(\mathbf{r}_i, t_i, T_1, T_2, \ldots, T_J))^2 + \sum_{i=1}^{I} (\hat{T}_i - T_q(\mathbf{r}_i, t_i, q_1, q_2, \ldots, q_J))^2 \tag{2}$$

where $\hat{T}_i$ stand for measured temperature at point $\mathbf{r}$ and time instant t_i. The condition of a constant HTC is ensured by including an additional constraint ie. linking the values of T_j and q_j. The optimization least square problem is solved using Levenberg Marquardt technique, while the elementary temperature fields are evaluated using a commercial FEM code. Thus, the developed technique is capable of dealing with the arbitrary geometry. The main advantage of the developed technique is that the only a finite number of linear direct problems needs to be solved, as the evaluation of the elementary fields is carried out only once, and takes place outside the iterative loop. The sensitivity matrix (Jacobian) used in the Levenberg-Marquardt solver is evaluated by adding two constant matrices (sampled elementary fields Θ_j and Ξ_j multiplied by some unknown parameters). Thus, although the Jacobian depends on the current solution, the cost of generating this matrix is marginal. The developed method not only reduces the computational time but also, through the application of the locally based approximation functions, filters out the high frequency noise.

The paper presents the results of several numerical tests. The test were performed to validate the method as well as its implementation in the code. The approach used here was the *pseudo measurement* technique where the results of the measurements were substituted by solutions of a direct problem. The presence of measurement errors has been accounted for by adding random numbers of prescribed amplitude. The paper presents the comparison between two methods of the HTC retrieval: *implicit* and developed *explicit* one. The results show, that in the presence of measurement errors, the *explicit* technique gives significantly better results.

The developed method will be employed in the context of impingement cooling. The experimental rig is currently under development. Impingement is a frequently employed technique of cooling car or aircraft engines, electronics and many other devices [2]. The momentum of the jet of the cooling fluid (air, oil), which impinges the cooled surface, destroys the boundary layer at the surface. Because of this, very high values of the local HTC can be obtained.

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