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ESTIMATION OF SURFACE HEAT FLUX FOR ABLATION AND CHARRING OF THERMAL PROTECTION MATERIAL

Abstract

In the reentry process of the hypersonic flight vehicle, the surface temperature is very high and there often exist ablation, charring and recession phenomena. So the temperature sensors only can be placed appropriately far from the heated surface in the thermal protection layer and the measured temperature histories are used to estimate the surface heat flux. This is a typical IHCP problem and is much more complex than the conventional case because the physics of pyrolysis, charring, and geometry variation have to be taken into account in the estimation algorithm. In the paper, a two-layer model is adopted to model the ablation and charring of the material and the differential equations with two regions can be got. The two regions are the char layer and the virgin material, and the pyrolysis zone is simplified to be a surface connecting the two regions. To solve the equations numerically, the FCV(Finite Control Volume) method is chosen. Since the heated boundary position is a function of time, every control volume moves accordantly, and the net enthalpy flux into the control volume resulting from control volume boundary translation should be considered in the discretization process. The correctness of FCV can be verified by solving a variable-geometry heat conduction problem with analytical solution. In the estimation process, the heat flux is unknown and the temperature and ablative surface position histories at some locations are measured. The heat flux is to be determined by solving an optimization problem of finding a heat flux profile that minimize the objective function of the discrepancy between temperature histories calculated by the heat flux profile and the measurements. To solve this optimization problem, the Lagrange multiplier method and the Variational principle are used to deduce the adjoint equation and obtain the gradient of the objective function with respect to the heat flux values at different times, and the Conjugate Gradient Method (CGM) is used to carry out the optimization. This estimation method is verified with a numerical example at first, the results show that the estimation method is feasible and not very sensitive to the measurement noise. Furthermore, the estimation method is used to analyze the experimental data of ablation of blunt Carbon-phenonic material Narmco4028 in an arc-heater. It is shown that the estimated surface heat flux is close to the heating flux value of the arc-heater, and the estimation method exhibits a good potentiality of application in flight practices.