AN IMPROVED TRANSIENT METHOD FOR THE SIMULTANEOUS DETERMINATION OF FREE-STREAM REFERENCE TEMPERATURE AND CONVECTIVE HEAT TRANSFER COEFFICIENT :

"***The Invariant h Method***"

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Abstract

Heat transfer coefficient h in forced convection experiments is considered to be an indicator of the fluid dynamic status of the viscous flow domain contained between a wall and a fluid capable of transferring thermal energy via convection. The heat transfer coefficient h is obtained by normalizing the local heat flux rate by a proper thermal driving potential. This thermal potential is usually the difference between the free stream temperature and the wall temperature . h is a quantitiy which is independent of the thermal boundary conditions. Any variation in the free stream temperature or the wall temperature does not alter the magnitude of h provided that the local Reynolds number is kept constant at the specific location. By definition, q_w is linearly dependent on $(To_\infty\text{-}Tw)$ by the relation $q_w=h(To_\infty\text{-}Tw)$. In transient heat transfer experiments, either the free stream is impulsively started over a stationary test object or the heat transfer model is suddenly injected into a free stream flow which is already at a steady state. The model and free stream temperatures are selected at sufficiently different levels so that a measurable transient in wall temperature can be recorded accurately. Typically, an inverse solution of the transient heat conduction equation at the fluid-solid interface converts the recorded wall temperature transient into a wall heat flux trace in time. In addition to the re-construction of $q_w(t)$, an accurate measurement of the gas temperature To_∞ is required to obtain the heat transfer coefficient h. Once the initial disturbances of a transient experiment are settled down, the measured heat transfer coefficient h should remain unchanged in time, provided that the flow facility generates constant local Reynolds numbers over the model. This paper deals with the development of a new method that can obtain heat transfer coefficient h and free stream temperature (adiabatic wall temp.) simultaneously by using the useful property that "***h does not vary in time provided that the mean flow conditions are stationary***". The concept is explained and experimentally validated by using carefully selected transient heat transfer simulations. The new "***invariant h method***" can analytically determine local free stream temperatures in internal flow cases in which heat pick-up (or heat loss) is at a non-negligible magnitude. The method eliminates the need for cumbersome and error prone free stream gas temperature measurements using conventional sensors. The general method described in this paper is applicable to many different surface temperature mapping schemes that has a capability of mapping the surface at each time step during the experiment. The mapping techniques in this category are discrete temperature sensors, infrared imaging and temperature sensitive paints (thermographic phosphors).

An extension of the "***invariant h method***" can also be made for the direct determination of adiabatic wall effectiveness values in gas turbine cooling research using liquid crystal coatings. Modifications to the general method is required because the liquid crystal techniques can not produce temperature mapping at each time step of a transient experiment. A successful modification of the general method using liquid crystals without and with film cooling conditions are described in part-2 of this paper.