LHD 国际学术报告会(2011 年 11 月 3 日周四 9:00-10:30)

报告题目：

Surface Heat Flux Prediction: Transducer Characterization,Calibration and Experimental Design

演讲人：

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地点：力学所小礼堂内会议室

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报告摘要：

In aerospace heat transfer, the prediction of the surface heat flux and temperature are of great importance for material development, design and safe usage. Prediction of the surface thermal condition requires in-depth sensors due to the highly hostile nature of the surface heating. Thus, much attention has been afforded to the investigation of the so-called inverse heat conduction problem. That is, the goal of the study is to reconstruct of the surface thermal effects based on an ill-posed mathematical statement involving experimental data containing noise.

This talk illustrates the need to a) quantify thermocouple characteristics for transient inverse diffusion studies involving surface boundary-condition reconstruction and the estimation of thermophysical properties; b) carefully interrogate collected data and implement the proper removal of undesirable high frequency signal content when warranted; c) carefully design experiments in an optimal setting with the aid of sensitivity analysis; and, d) develop novel calibration methods based on fundamental physical and mathematical principles. Both computational and fundamental experimental results are presented. In fact, our recent experimental studies strongly suggest that several transducer properties should be identified and characterized as part of any heat transfer study. For the inverse heat conduction problem of estimating the surface heat flux from in–depth measurements, the actual process leads to a sequential series of inverse problems.

The first involves the inverse transducer problem (ITP) while the second involves the

classical inverse heat conduction problem (IHCP). In particular, if thermocouples are installed then the thermocouple time constants and conductive lead loss parameters (if the thermocouples are not parallel to isotherms) should be estimated through a calibration study having a well-quantified heating source. Identical thermocouples could have dissimilar time constants since this parameter is a function of geometry, bead thermophysical properties and contact conductance introduced by the installation process. Omission of characterizing the transducer properly can lead to timedelayed and attenuated results in both temperature and heat flux.

Data collection for inverse studies requires careful interrogation prior to usage. Diffusion physics requires signal damping as the thermal signal penetrates a body from a surface source. With this basic assumption, proper digital or analog filtering is appropriate especially in the context of inverse heat conduction. A basic tool for studying the spectral content of the signal lies in the classical discrete Fourier transform (DFT). This tool provides the power spectra and gives insight into the dominant frequencies (leading to a cut-off frequency for a filter) and also gives insight into the experimental platform (proper grounding and environmental issues). Data quality (voltage) is a fundamental component to all inverse studies even prior to conversion to temperature. Care must be taken in the complete experimental processes. It is the high frequency oscillations in the data that play havoc on the projection process for the so-called inverse heat conduction problem (IHCP). The classic inverse heat conduction problem can be recast into a Volterra integral equation of the first kind involving an infinitely smoothing operator (i.e., highly ill posed). The sequential inverse problem worsens the process further.

In response, a newly devised calibration approach for the IHCP is presented that inherently contains the: i) complete sensor characterization; ii) probe position; and, iii) precise knowledge of the host's thermophysical properties. These equations require regularization based on either mathematical principles or preferably physical principles involving signal-to-noise reasoning. The physics-based calibration method has been experimentally verified indicating the merit and accuracy of the approach. Sensor characterization, sensor positioning and thermophysical properties are inherently contained without being explicitly expressed in the final mathematical expression relating the surface heat flux to in-depth temperature measurements. A unified theoretical basis is presently under development that encompasses one-, two-, and threedimensional, multi-region geometries possessing orthotropic thermophysical properties. Additionally, the mathematical formalism will recover either the local surface heat flux or total surface heat transfer.

In summary, a strong interaction among theory, computations, experimental design and data collection is required for developing optimal results. A great experimentalist must have a good understanding of physics and mathematics while a great analyst must have a good understanding of experimental design and experimental process.