INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: **Surface Heat Flux Recovery during Short Duration Experiments–Conceptual Demonstration from Probe Design to Soft computing Analysis**

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SHORT ABSTRACT

Recovery of surface heat flux in short duration experiments is a challenging task due to the dominance of unsteadiness in the temperature signal. Therefore, the heat flux estimation is carried out using the transient temperatures through suitable sensor modeling. In most of the cases (e.g., in thin-film gauges and coaxial probes), the sensor is assumed as a semi-infinite body with one-dimensional heat conduction through the sensing surface and substrate. In some cases, the surface heat flux is computed through numerical simulation. Nevertheless, all these processes involve various assumptions, simplifications and mathematical complications. In recent years, the advanced data science and soft computing methods are considered as important techniques in various applications. Therefore, the theme of the thesis is to introduce soft computing approach as a benchmark tool for recovery of surface heat flux in short duration experiments. The foremost intention of the present study is to implement a soft computing technique; Adaptive neuro-fuzzy inference system (ANFIS), to recover heat flux from the temperature signal in case of short duration experiments. The ANFIS technique needs a training process through known data sets (temperature signals and their corresponding heat flux). Therefore, the training data sets (transient temperature and surface heat flux) have been generated through various heat transfer experiments involving step and impulsive loads, convective and radiative heat loads. Side by side, numerical modelling of sensors (with similar experimental environment) is also considered as training data generation for ANFIS methods. Subsequently, inverse approach is followed to recover unknown (surface heat flux) parameters through trained data sets of ANFIS.

The short duration experiments (during millisecond flow duration) are characterized as transient for which there is no possibility of ensuring steady flow over a test model. In fact, these are the flow environments of ground-based aerodynamic experimental facilities (shock tubes and shock tunnels, expansion tubes). Capturing of the signatures of high-speed flows in these facilities need high frequency sensors. The calorimetric heat flux gauges (thin film sensors

and coaxial surface junction thermocouples) are used to measure temperature responses from the flow environment for estimation of surface heat fluxes. These heat flux parameters are required for the management of “thermal protection system” of re-entry vehicles. Nevertheless, each sensor has advantages and limitations depending on the flow condition and experimental requirements. For example, the thin film gauges provide very fast response, but prone to shear after each blow-down. Apart from this, these probes are not efficient for measuring heat flux of higher order of magnitude. On the other hand, the coaxial thermal probes are rugged, can measure high heat flux, and have appreciable fast response. Unlike thin film gauges, it has the advantage of easy junction repair if lost during experimentation. Considering various advantages, coaxial thermal probes (CTPs) are found appropriate and cost-effective sensors at laboratory scale. An E-type CTP has been fabricated in-house from chromel and constantan materials. The constantan wire (0.91mm diameter and 15 mm length) is placed inside the chromel cylinder with a thin layer of insulation thickness (~20 μm) in between them. The junction is prepared at the surface through the abrasion technique, which forms a junction between the two thermo-elements of the coaxial probe. The material property of the thermo-elements is obtained through energy dispersive *x*-ray technique and the internal as well as external surface dimensions have been checked through field emission scanning electron microscope. The sensor is calibrated experimentally using a glycerin bath to obtain the “sensitivity” value (relation between voltage and temperature). Similarly, water plunging and droplet techniques are used to obtain “thermal product value” of sensing substrate for surface heat flux estimation. Finally, the CTP is used to generate training data sets experimentally and the same sensor model is used for the numerical simulation.

Prior experimentation, the selection of an appropriate sensor for short duration experiments is the primary requirement. The ground-based experimental facilities are used for the generation of artificial shock wave over the aerodynamic models mounted in the test section. They mimic similar environment as experienced by the aero-vehicles during their realistic operation. In the present investigation, shock tube is used as an experimental tool for exposing the sensors for step heat loads with typical flow duration of 2 ms. By mounting the sensors at the driven section of the tube, the temperature response (static as well as stagnation) of shock wave can be captured. Due to the short experimental time scale, these facilities never have a scope for equilibrium (steady state) temperature measurement; thereby, the “heat flux” measurement leads the side as an essential thermal parameter.

As an experimental calibration of CTP for step/ramp heat loads, the E-type CTP is exposed to a laser source of known wattage and the corresponding temperature signals are recorded. In numerical simulations, step/ramp heat inputs (1W-5W) are applied to the CTP and temperature response are obtained using ANSYS module. All these signals are used for training and recovery purpose to test the applicability of the ANFIS system for short duration step/ramp thermal load recovery. The heat flux is recovered using ANFIS for two different modes of experimentation; convection and radiation. In the convection mode, the static temperature from the shock tube is recovered in a 2 ms time scale after training the system with known data set obtained from numerical simulation. For the radiation mode of experimentation, the heat flux signal is recovered from the trained ANFIS after training it with the combined signals from laser-based experiments and numerical simulations for 0.4s. The “time-temperature-heat flux” is used to train the ANFIS module using the Matlab platform, and the heat flux is recovered. These results are also compared with analytical and numerical heat flux signals obtained from the same temperature signal. Hence, it can be emphasized that ANFIS based soft-computing approach can be used as a potential computational tool for inverse prediction of short duration thermal loads in aerodynamic experiments.