COOLED FAST-RESPONSE PRESSURE PROBES DESIGN METHODOLOGY FOR HARSH ENVIRONMENT APPLICATIONS

Julien Clinckemaillie
von Karman Institute for Fluid Dynamics
clinckemaillie@vki.ac.be

Fabrizio Fontaneto
von Karman Institute for Fluid Dynamics
fontaneto@vki.ac.be

ABSTRACT

The present paper discusses in detail the concept and design of a water-cooled fast-response wall-static pressure probe intended for gas turbine combustors measurements. The proposed design approach is structured upon four main steps. In the first step, the measurement performance of the probe in terms of usable frequency bandwidth is optimized by means of theoretical line-cavity correlations, further validated by a series of shock tube experiments. In the second step, different reduced order correlations for convective and radiative heat transfer are used to derive the heat load at which the measurement device is submitted. In the third part, a quasi-2D conjugate heat transfer (CHT) model is developed and operated through the application of the boundary conditions computed in the previous step. In the final step, the obtained design candidate is further validated by means of state-of-the-art fully 3D CHT numerical simulations performed on a probe geometry characterized by an increased degree of complexity.

INTRODUCTION

In an effort to extend the knowledge around combustion instabilities while supporting the development of more performant combustion control systems, the availability of fast-response pressure measurement devices able to operate in the harsh environment of gas turbine combustors is fundamental. The severe heat load at which they are submitted forces the adoption of a cooling layout in order to keep the probe material well below its maximum operating temperature. This constraint becomes even more critical when the fragile sensing element of conventional off-the-shelf piezo-resistive fast-response pressure transducers is considered. Their large bandwidth over a wide pressure range, as well as their ability to measure both the steady and unsteady component of pressure makes them the most widely used type of sensors for fast-response static or total pressure measurements. The datasheets of conventional off-the-shelf miniature piezo-resistive pressure transducers quote a maximum operating temperature range up to 546K, while state-of-the-art SOI (silicon-on-insulator) and SiC (silicon-carbide) sensors allowed the use of fast-response pressure sensors at temperatures up to 780K and 880K respectively. However, in order to reach even higher temperatures in a continuously immersed configuration, efficient sensor cooling becomes obligatory for their protection.

RESULTS

A methodology for the assessment of the measurement performance and of the cooling layout design of a water-cooled fast response static pressure probe using a conventional off-the-shelf miniaturized Kulite pressure sensor is described and presented in this paper.

In a first step, the measurement performance of the probe is assessed in terms of usable frequency bandwidth by means of reduced order models. The obtained results are then compared with a series of representative shock tube tests. A very good agreement is obtained between the experimental results, which indicated a flat ±1 dB dynamic behavior present up to 6 kHz and a resonance peak frequency f_n = 45.1 kHz (Figure 1), and the theoretical predictions, which predicted a resonance peak frequency in the [42.4 – 45.3] kHz range.

In a second step, reduced-order correlations for convective and radiative heat transfer are used to characterize the aero-thermally demanding combustion chamber environment in which the probe will be immersed. From this characterization, the heat load on the immersed probe and its fragile sensing element is derived and quantified.

A quasi-2D heat transfer model is then developed, allowing fast and reliable evaluations of global parameters of the cooling layout such as external wall temperatures or coolant (i.e. water) temperature. The aero-thermal boundary conditions determined in the previous step are applied to the quasi-2D model, and the performance of the cooling layout is assessed by means of the quasi-2D model.

Finally, state-of-the-art 3D conjugate heat transfer simulations are carried out in an effort to further assess the performance of the cooling layout in more details. The survivability of the sensing element in the harsh combustion chamber environment is demonstrated (Figure 2), with sensor temperatures remaining below 410K for all investigated coolant flow rates ([0.5 – 2.0] l/min).

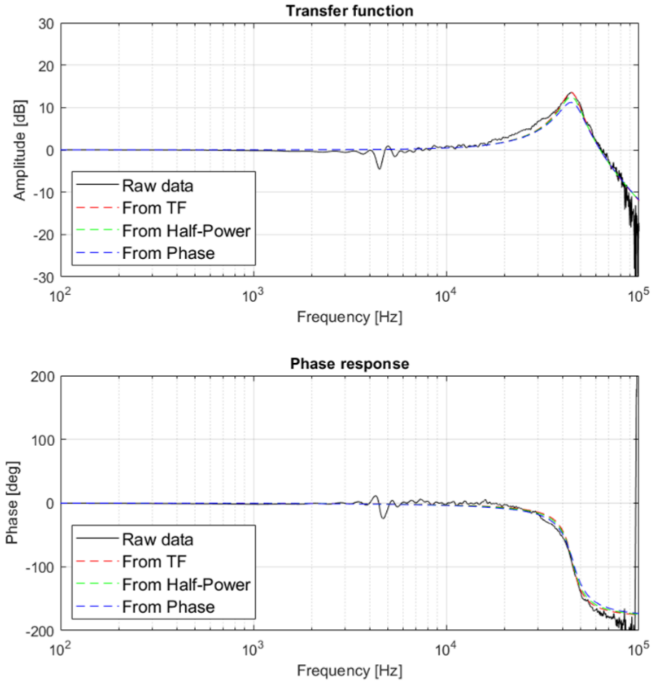

Figure 1: *Experimental transfer function of the probe design*

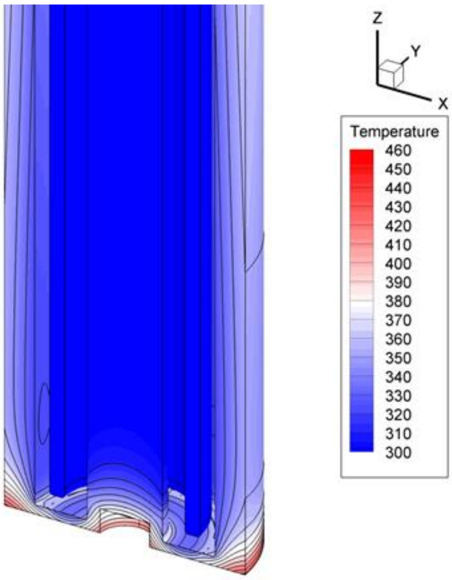

Figure 2: *Probe temperature contours for a coolant flow rate of 1.0 l/min – CHT simulations*