IMPULSE-RESPONSE DECONVOLUTION TECHNIQUE TO IMPROVE EFFECTIVE FREQUENCY RESPONSE OF PRESSURE AND TEMPERATURE PROBES

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ABSTRACT

Probes used for aerodynamic surveying (e.g. pressure and temperature probes) have frequency response characteristics that generally limit either the temporal scale that can be resolved (for example, flow unsteadiness cannot be resolved beyond a certain frequency limit) or the physical scale that can be resolved (for example, a traversing probe moving through a spatially varying field). In this paper we use impulse-response deconvolution techniques—familiar to the heat transfer research community—to improve the effective frequency response characteristics of both pressure and temperature probes. This technique allows a probe to resolve flow unsteadiness to higher frequencies than the 'natural' limit of the probe, expanding the temporal and spatial frequency ranges over which probes can be used. The technique has wide application in aerodynamic surveying applications where spatial or temporal resolution is limited by probe frequency response.

The technique is demonstrated using experimental data from a high-speed turbine experiment. Aerodynamic survey data were collected in a series of experiments with traverse speeds both above and below the effective spatial frequency limit of the probe. Impulse-response deconvolution techniques are used to reconstruct data beyond the natural frequency limit, demonstrating the method and establishing limits on the accuracy with which the method can be used in practical environments.

INTRODUCTION

The frequency response of probe systems places a limit on spatial or temporal resolution of data that can be obtained in aerodynamic surveying applications. For aerodynamic pressure probes, the natural frequency limit is a function of probe design, the connecting tubing geometry, and the transducer fill volume. For thermocouple probes, the natural frequency limit is a function of the flow speed around the thermocouple bead (sometimes artificially reduced for structural reasons, as in the case of aspirated probes) and the thermal mass of the bead. Corrections may also be necessary for the thermal conductivity of the wire support and surrounding radiations corrections, which may be unsteady in time.

A processing technique familiar to the heat transfer community is the impulse-response deconvolution method [1], which can be used to establish the unsteady heat flux to a surface from the surface transient temperature response. The surface temperature response is heavily damped (by the thermal properties of the surface) in comparison to heat flux signal which is *recovered* by the deconvolution. Thus, the effective frequency of the measurement is increased by this method. To apply the technique, the *impulse-response* of the surface must be calculated. To do this, a pair of corresponding input-output transients for the system are required, for example, the transient response of the surface $T(t)$ when subject to a step change (in time) in heat flux. For a given system, the input-output pair could be analytically derived, experimentally determined from a single experiment (e.g. a step change in heat load is applied, by a laser for example), or experimentally determined from a sequence of experiments. Once the particular impulse-response for the system is known, a digital filter can be created to de-convolve the damped output signal to recover the higher frequency input signal.

In this paper we are concerned with the practical application of the impulse-response processing technique to pressure and temperature measurements using traversing probes. We compare three different methods for generating the required impulse-response filter for the cases of a multi-hole pneumatic pressure probe and a thermocouple probe. The methods are:

1) *Theoretical system models*. Analytical models which use as inputs the physical geometry and fluid properties of the system. We compare several models and comment on the results. The obvious advantage is that this does not require complex processing or experimental system characterisation.

2) *Experimental step-response characterisation.* The response of the system to a step change in pressure is measured directly using the balloon method (described later).

3) *Multi-experiment in-situ characterisation.* A number of experiments are conducted in which data is acquired at different traverse speeds and the impulse response of the system is determined as the function which best reduces the data to a common input signal.

In each case we demonstrate application of the technique to traverse data taken in a high speed experimental facility downstream of an annular cascade of high pressure nozzle guide vanes.

RESULTS AND DISCUSSION

For the case of traverse measurements through a spatially and temporally steady pressure field, the temporal pressure signals recorded by the probe, $p'(t)$, can be thought of as being filtered by the probe system filter. The underlying signal, $p(t)$, is recovered by de-convolving $p'(t)$ and the probe impulse response. The effect of increasing probe speed is to impose increasing spatial shifts in the data in the direction of probe travel, and to lower the peak height when the probe passes through a spatial excursion in pressure. This effect is illustrated in Figure 1, for an identical input signal measured at four different traverse speeds, a nominal speed v (features almost fully resolved), and higher speeds, $5v$, $10v$ and $20v$. An increasing disagreement is evident between the resulting output signals traversed in opposite directions.

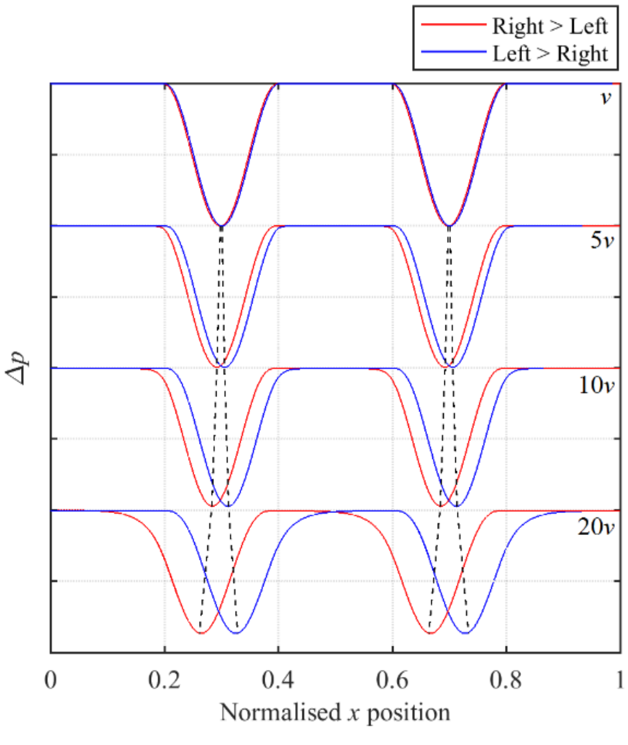

Figure 1. Example pressure signals traversed at four different speeds and in two directions

REFERENCES

[1] Oldfield, M.L.G., 2008, Impulse Response Processing of Transient Heat Transfer Gauge Signals, ASME J. Turbomachinery, Vol. 130(2), 021023 (doi: 10.1115/1.2752188)