NOVEL PNEUMATIC PROBE FOR MORE ACCURATE MEASUREMENTS IN UNSTEADY FLOW

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ABSTRACT

Multi-hole pneumatic probes are widely used in turbomachinery experiments to measure the time-averaged three-dimensional flow angles, velocity, and total and static pressure. These measurements are ultimately relied upon to measure the efficiency of turbomachines across a wide range of research and development applications. However, when flow angles fluctuate in unsteady flows, conventional probes experience bias errors due to pneumatic averaging. Coull et al. [1] demonstrated that fluctuations induced by rotor-passing unsteadiness can cause turbine efficiency to be underestimated by up to 1.5%, an effect more pronounced when traverses are performed close to the blade trailing edges.

To help address this problem, it is required to develop new probe concepts that minimise these error sources. This work presents an initial study of a novel Kiel pneumatic probe compared to a standard five-hole-probe (5HP). The incorporation of a Kiel total pressure measurement significantly reduces the bias error in unsteady flow, while preserving the ability to measure angles, velocity and static pressure. The design, calibration and operation of this probe will be discussed in the full paper. Wake measurements are compared from a cylinder-in-crossflow experiment ($Re = \sim 8 \times 10^4$) using the Oxford 5HP of Povey et al. [2] and the novel Kiel probe. Preliminary results show that the 5HP over-estimates the loss in the wake, in line with previous results. Furthermore, when active flow control is applied to the cylinder, the conventional five-hole probe measures minimal changes in the wake, whereas the novel probe clearly captures the expected decrease in loss coefficient.

INTRODUCTION

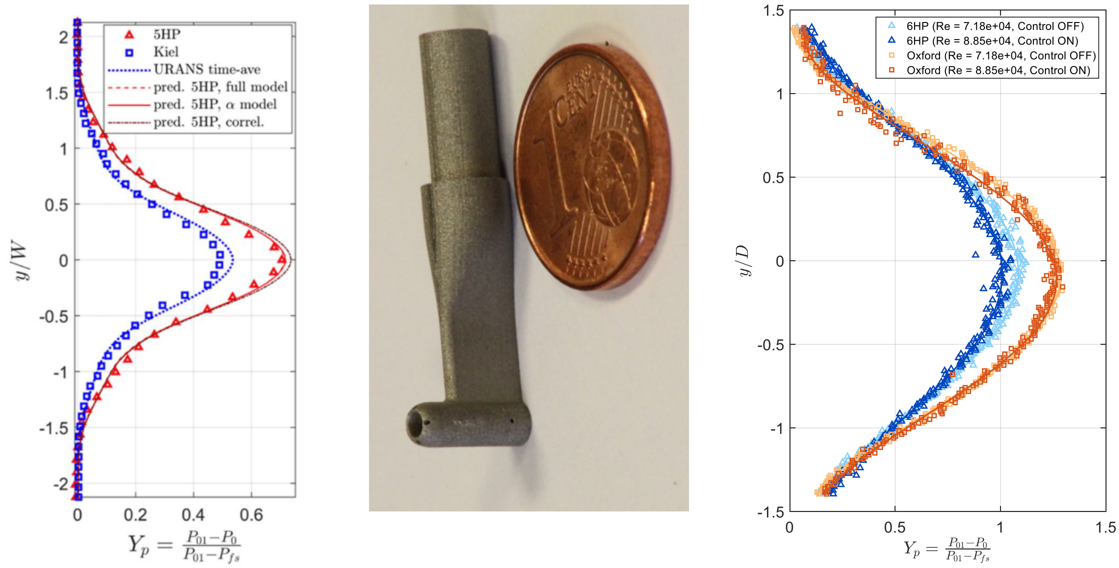
Pneumatic probes are typically used to obtain "steady" flow measurements. However, such "steady" probes are often used in unsteady flows, where a "pneumatically-averaged" pressure will be obtained for each hole. Running these measured pressures through the steady-flow calibration map can result in a flow field that differs significantly from the true time-mean. Coull et al. [1] studied these effects in detail and demonstrated that angle fluctuations are the largest cause of error. Figure 1a) [1] shows experimental measurements in the shedding wake of a D-shaped bluff body and demonstrates that the 5HP measures much higher total pressure loss than a Kiel Pitot (blue squares), which is insensitive to flow angles up to ~40°. Such errors are likely to be present in a large body of industrial and research data, in particular turbomachinery performance measurements. [1], [3]

Although it is generally accepted that the flow measured by steady pneumatic probes represents a pneumatic average that may differ from the true time-averaged flow field, little research has focused on probe designs that mitigate these errors. An exception is work by Jonsson et al. [4], who proposed a modified multi-hole probe geometry to improve measurement accuracy.

This paper introduces an alternative Kiel multi-hole probe concept that was developed concurrently with the Jonsson's design but differs in some key respects (e.g. it uses a flow-through Kiel). Further details of the probe calibration and its application will be given in the paper.

RESULTS AND DISCUSSION

A preliminary comparison of the new probe and a 5HP is shown in Figure 1c). Data are shown for wake measurements behind a cylinder, which has been designed to study active flow control via slot injection. [5] Total pressure is presented as a loss coefficient. Considering the data without active control, the 5HP measures loss, which is around 20% at the wake centreline, in a similar manner to the previous data in Figure 1a). When the control is active, the maximum loss from the 5HP decreases by only 1.6%. In contrast, the Kiel 6HP records a 7.3% reduction in peak Y_p, consistent with the expected decrease in total pressure loss. These results support the design approach of the novel 6HP, which maintains the total-pressure insensitivity of a Kiel pitot, while retaining flow-angle sensitivity through four sensing holes on the shroud. Further analysis of the data will be presented in the full paper.



a) Kiel probe vs. 5HP in a D-shape body rake, Coull et al. [1]

b) Design of the new Kiel 6HP.

c) Preliminary comparison of Kiel 6HP vs. 5HP in a cylinder wake, with and without active flow control.

Figure 1. Preliminary results

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