DEVELOPMENT OF FAST-RESPONSE MULTI-HOLE PROBES FOR AERODYNAMIC MEASUREMENTS IN TURBOMACHINERY

B. Cernat, S. Marzullo, S. Lavagnoli
von Karman Institute for Fluid Dynamics
Rhode Saint Genèse, Brussels, Belgium

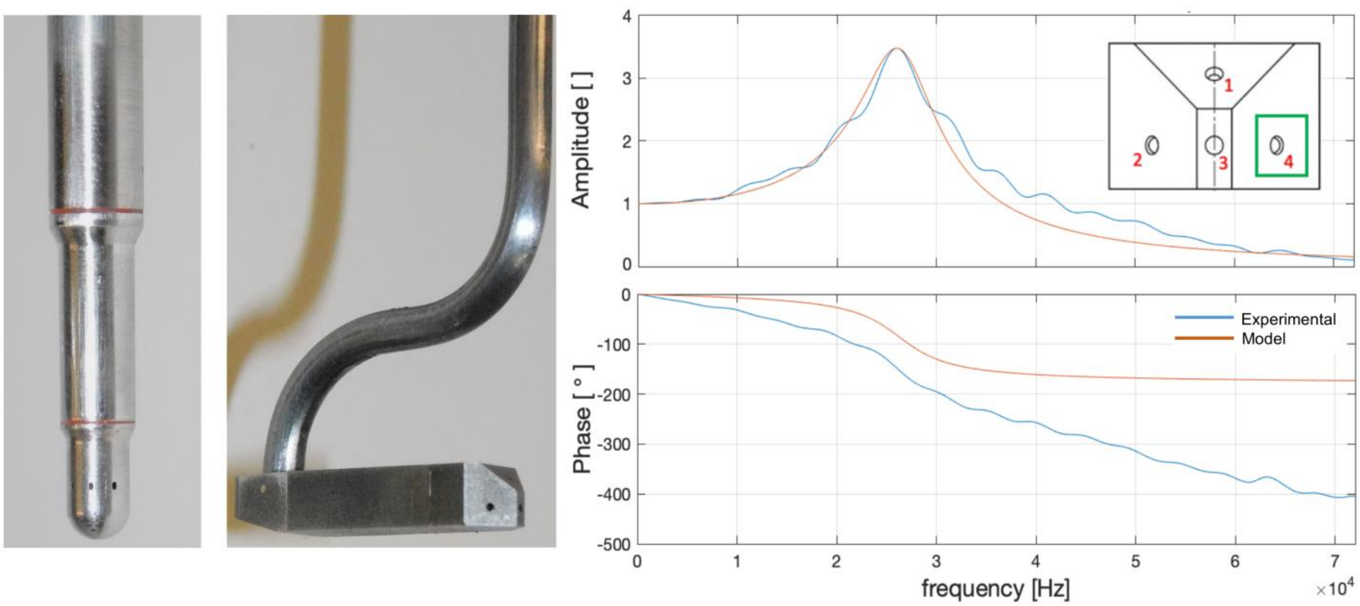
Abstract
This paper presents the conception, design and experimental validation of two novel multi-hole aerodynamic probes for high-bandwidth measurements in turbomachinery flows. The probes target time-resolved flow measurements at the outlet of a high pressure turbine (HPT) stage operated in the short-duration annular cascade of the von Karman Institute.
A cylindrical four-hole probe, featuring a hemispherical head, is purposely designed to provide an improved spatial resolution in close proximity to the outer turbine casing (Figure 1a). The hole pattern allows to reconcile an increased measurement range in the yaw flow angle plane ($\pm 30°$) with an adequate measurement sensitivity. A Cobra-type four-hole probe, featuring a truncated pyramid head as shown in Figure 1b, is conceived for the characterization of the near-hub flow region. The head design offers an improved sensitivity to the yaw flow angle variations while fulfilling the reduced measurement range predicted in the lower part of the blade span ($\pm 20°$). The probes are equipped with piezo-resistive fast response pressure sensors connected to the probe surface by line-cavity systems. The lines are purposely designed to resolve the flow unsteadiness up to several harmonics of the blade passing frequency (4.7 kHz).
The second part of the paper presents the aerodynamic characterization of the four-hole probes in a dedicated calibration jet facility that allows an accurate incremental traversing of the heads along the yaw and pitch angle planes. A dynamic calibration is conducted in a shock tube facility to assess the frequency response of the two probes and model the transfer functions employed in the turbine test data reduction procedure.

Introduction
A deep understanding of the unsteady aerodynamics established in the hot-gas path of modern aeroengines represents still an indispensable, yet challenging, element in the seek for machines with ever-increasing efficiency levels. High-fidelity numerical flow predictions, employed to evaluate the performance of advanced turbomachinery designs, need time-resolved flow measurements collected with high spatial resolution in engine-relevant test environments.
The present research entails the design and testing of two fast-response miniaturized four-hole probes aimed at the experimental assessment of the highly unsteady, three-dimensional flow at the outlet a high pressure turbine (HPT) stage. The test article is operated at high level of engine flow similarity in the short-duration rotating turbine rig of the von Karman Institute. The two four-hole probe designs are diversified in order to tackle different areas of the rotor outlet plane.
A cobra-type probe is developed for the near-hub flow assessment. The probe head presents a truncated-pyramid geometry with an included angle of 90° in the horizontal plane, allowing to maximize the measurement sensitivity to the yaw flow angle, and an upper hole surface inclined at 45° with respect to the horizontal plane. To minimize the sensitivity to the flow Reynolds number, the pressure taps, of 0.5 mm diameter, are perpendicular to the probe surface. A cylindrical probe with hemispherical head is purposely designed in order to resolve the larger flow gradients established by the unshrouded HPT rotor in the near-casing region. The probes design targets a frequency response between 20 and 30 kHz, to allow the full resolution of the stage outlet flow unsteadiness up to the 4^{th}-5^{th} harmonic of the blade passing frequency.

The head dimensions are minimized within the physical limits imposed by the presence of the miniaturized pressure sensors to limit the measurement intrusiveness.

Results

The frequency response of the two probes is validated experimentally by conducting a shock-tube dynamic calibration. Figure 1c shows the transfer function of the line-cavity system of one lateral tap of the Cobra-probe. This particular sensor, indicated by the green square in the front view of the probe head, was chosen as representative of the worst dynamic performance among the four taps. The experimental analysis, indicated by the blue line, shows the natural frequency of the line-cavity system at 27 kHz, that is above the 5th harmonic of the HPT rotor blade passing frequency at nominal test conditions. The modeled transfer function, indicated by the orange line, is generated by means of a second order system identification algorithm. The modeled functions will be employed to demodulate the unsteady signals recorded in test environment and maximize the exploitable bandwidth of the probes.



[a] [b] [c]

Figure 1 Hemispherical (a) and Cobra-type (b) multi-hole probes. Transfer function of sensor 4 of Cobra-type probe determined by shock tube test.