ON TURBULENCE MEASUREMENTS WITH MULTI-SENSOR FAST RESPONSE AERODYNAMIC PROBES IN A HIGH-PRESSURE TURBINE

A.C. Chasoglou[1], P. Tsirikoglou[2], A.I. Kalfas[3], R.S. Abhari[1]

[1] Laboratory for Energy Conversion, ETH Zurich, Sonneggstrasse 3, Zurich, CH-8092, Switzerland
[2] Limmat Scientific AG, Weinbergstrasse 31, Zürich, CH-8006, Switzerland
[3] Department of Mechanical Engineering, Aristotle University of Thessaloniki, Thessaloniki, 54124, Greece

ABSTRACT

The current work describes the methodology and first results from a turbulence study where miniature fast response aerodynamic probes (FRAP) with 4 sensors (4S) are used, able to perform measurements in unsteady three-dimensional flow field. The effect of probe size on the turbulence statistics is investigated in a one-and-a-half stage, high-pressure axial turbine facility LISA at ETH Zurich. Different probe sizes with same external geometry are investigated. The results indicate that increasing the probe sensing area results in higher detected turbulence levels.

INTRODUCTION

In modern computational fluid dynamics studies in turbomachinery, time-, length-scales and turbulence intensity and isotropy are important for accurate modelling. To meet this end, experimental data are required to validate the numerical algorithms. Unsteady aerodynamic probes are a favored measurement technique in turbomachines, due to their robustness, simplicity of installation and operation, high frequency response (over 40 kHz) and direct measurement of pressure and thus quantification of losses. Nevertheless, probe measurements are intrusive, thus miniaturization is a priority when designing such an instrument. To tackle this issue, the turbomachinery community has been mainly utilizing 1- or 2-sensor probes that operate under virtual multi-sensor mode operation. This operation mode requires substantial time during experiments, which directly translates to cost. For this reason, a number of research groups has currently renewed their interest towards multi-sensor probes that can simultaneously measure the unsteady three-dimensional flow velocity vector. Currently proposed designs use commercially available pressure sensors which yield probe tip sizes of 6mm or more. Inevitably, the spatial resolution is decreased in respect to virtual-mode probes, and the probes are susceptible to large errors when strong gradients and non-uniformities are present in the flow.

This work is focused on the size effects of multi-sensor fast response aerodynamic probes (FRAP) on the derived flow quantities. FRAP are being developed in the Laboratory for Energy Conversion for over two decades, that allow time-resolved flow field measurements in complex turbomachinery flows. Recently [1], 4-sensor FRAP were developed and tested in one-and-a-half stage, high-pressure axial turbine facility LISA at ETH Zurich. In order to reduce the errors associated with blockage, wall-effects, flow gradients and unsteady flow effects, miniaturization was the major target. The final design demonstrates a 4-sensor FRAP with 3mm tip diameter. Along the design process another two probe designs emerged, of 4mm and 5mm probe tip diameter.

RESULTS AND DISCUSSION

In order to calculate only the stochastic (turbulent) part of the fluctuations, Fourier filtering is applied to the raw signal to remove all deterministic contributions, as described in [2] for a single-sensor unsteady pressure probe. For the FRAP-4S the Tu are calculated from the unsteady velocity components *u', v', w'* computed according to the Reynolds decomposition i.e. raw minus phase-locked averaged (PLA) signal. The Tu levels presented by FRAP-4S are calculated based on the following equation, were *c* is the PLA absolute velocity at each spatial point.

$$Tu = \sqrt{\frac{\overline{u'^2} + \overline{v'^2} + \overline{w'^2}}{3 \cdot \tilde{c}^2}}$$

The first results indicate that increasing the sensing area (reducing spatial resolution), results in elevated turbulence levels (up to 5% difference), especially in the location of the wake as depicted in **Figure 1**. In the same regions of elevated turbulence for the larger dimension probes, the integral length scales are computed to be minimum, lower than 5mm in size.

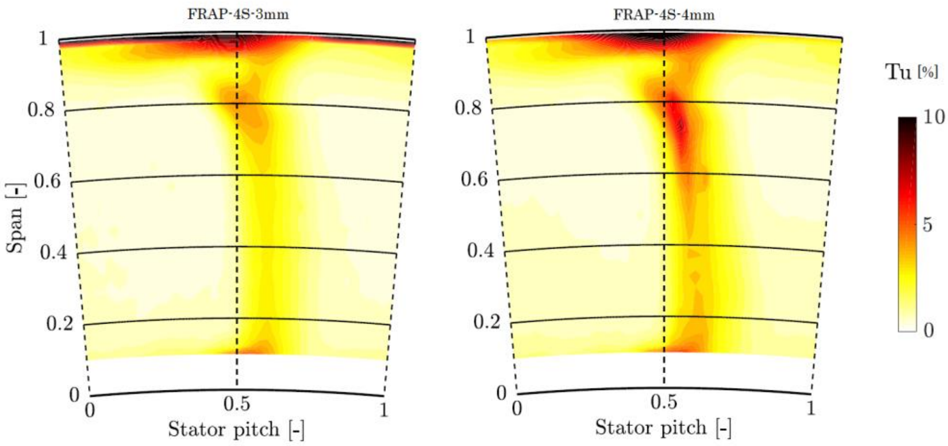

Figure 1. Turbulence at the exit of first stator with FRAP-4S 3mm (left) and 4mm tip diameter (right).

REFERENCES

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