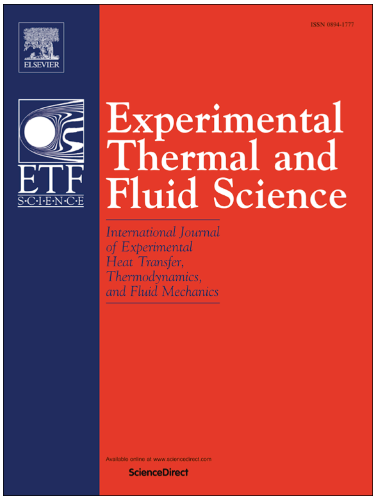

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Stefano Discetti, Marco Raiola, Andrea Ianiro

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Estimation of time resolved turbulent fields through correlation of non-time resolved field measurements and time-resolved point measurements

Stefano Discetti[a,*], Marco Raiola[a], Andrea Ianiro[a]

[a] *Aerospace Engineering Group, Universidad Carlos III de Madrid, Avenida de la Universidad 30, 28911 Leganés, Spain*

Abstract

A method for the estimation of time-resolved turbulent fields from the combination of non-time-resolved field measurements and time-resolved point measurements is proposed. The approach poses its fundaments on a stochastic estimation based on the Proper Orthogonal Decomposition (POD) of the field measurements and of the time-resolved point measurements. The correlation between the temporal modes of the field measurements and the temporal modes of the point measurements at synchronized instants is evaluated; this correlation is extended to the "out-of-sample" time instants for the field measurements, i.e. those in which field data are not available. In the "out-of-sample" instants, POD modes time coefficients are estimated and the flow fields are reconstructed. The proposed method extends the work by Hosseini *et al.* (Experiments in fluids, 56, 2015) by proposing a truncation criterion which allows removing the uncorrelated part of the signal from the reconstruction of the flow fields. The truncation is fundamental in case of turbulent flow fields, in which a great wealth of scales is involved, thus reducing the correlation between the probe signal and the field measurements. The threshold selection poses its basis on the random distribution of the uncorrelated signal. Additionally, the selection of the probe timespan to perform the POD analysis on the probe signal is discussed. The method is validated with a synthetic test case and an experimental one. A Direct Numerical Simulation database of a channel flow is selected since its spectral richness is expected to represent a significant challenge for this method. This dataset allows isolating the effects of correlation between field measurements and point measurements, removing issues connected to noise contamination or to the finite spatial resolution which would inevitably affect experimental data. The quality of the dynamic estimation is found to be affected by the noise contamination of the data and by the poor convergence of the POD modes, which add on the effect of the probe location, i.e. on the correlation between probe events and flow features. The squared correlation coefficient between reconstructed data and in-sample data is proposed as an assessment of the flow fields estimation quality. The use of the squared correlation coefficient directly on in-sample data is allowed by the truncation itself.

Keywords: Proper Orthogonal Decomposition, Linear Stochastic Estimation, Dynamic Estimation, PIV

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1. Introduction

In the last decades experimental fluid mechanics has experienced the flourishing of field measurement techniques, disclosing the access to the instantaneous distribution of field quantities such as velocities, concentrations, temperatures or pressures as in Particle Image Velocimetry [1], thermographic phosphors [2], Infrared thermography [3] or pressure sensitive paints [4]. Unfortunately due to limitations related to data rate or sensor technology, it often occurs that such measurement techniques can not be applied to provide information on the flow dynamics, such as for instance in moderate to high Reynolds number turbulent flows. For example, for the case of Particle Image Velocimetry, although the most recent technological developments have led in the last decades to powerful high speed light sources and fast high-resolution scientific cameras, which have enabled the flourishing of novel approaches exploiting time resolution (see, e.g. the reviews in [5] and [6]), time-resolved PIV remains of real practical use prevalently for low Reynolds numbers flows.

When the real-flow dynamics are not accessible due to hardware limitations, dynamic estimation of coherent structures is an extremely appealing option. Dynamic estimation often relies on low order models, and has proven to be a prominent candidate to elaborate flow control strategies (see, e.g. [7, 8]). Low order models often truncate small scales and aim to model prevalently the dynamics of large scale structures, thus losing detail of description in high Reynolds number flows. Nonetheless, large scale structures are widely recognized to be the main actors in momentum transport in turbulent flows. For example in wall-bounded flows large scale structures carry the bulk of the kinetic energy and

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*Corresponding author
Email address: `sdiscett@ing.uc3m.es` (Stefano Discetti)