Temporal enhancement of experimental non-time-resolved measurements

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Figure 1: Airflow separating from a wing at a high angle of attack. Source: wikipedia

ABSTRACT
A novel method is proposed for doing time-super sampling of non-time-resolved measurements and reconstructing the flow dynamics. The complexity of real-time resolved measurements and the turbulent flow equations (Navier-Stokes equations) results in the need to work with reduced-order models based on data obtained from scaled experiments conducted in the laboratory. With this method, the target is developing closed-loop control laws to optimize aircraft performance and reduce aircraft fuel consumption.

CCS CONCEPTS
• Applied computing → Aerospace.

KEYWORDS
Aerospace, Experimental Aerodynamics, Fuel consumption reduction, Flow control, Time-resolved measurements

1 INTRODUCTION
In recent years, the Aerospace sector has placed a significant emphasis on reducing its environmental impact. This objective involves the implementation of various strategies, mainly aiming at reducing the fuel consumption of aircraft. Different approaches can be considered, such as the optimization of aircraft flying performance by using optimal control laws adapted to different flying conditions. The airflow around the aircraft is highly turbulent, therefore, we need to develop efficient methods able to control these turbulent flows to minimize the corresponding drag force directly linked to fuel consumption.

Despite knowing the turbulent flow equations (Navier-Stokes equations), which are very difficult to work with, no closed solution has been found yet. It is thus needed to perform experiments to identify the flow dynamics. Additionally, due to the complexity of real-time measurements, the target is to train the models in the laboratories with scaled experiments and then extrapolate them to real-life conditions. The proposed strategy is based on closed-loop control models, which enable online adjustments to the incoming flow dynamics, requiring real-time-resolved measurements of the flow around the aircraft’s control surfaces. Acknowledging the complexities and expenses associated with time-resolved measurements, the objective is to develop numerical models based on data (the so-called data-driven methods) to reconstruct the flow dynamics. Therefore, the difficulties imposed by both the time-resolved measurements and the Navier-Stokes equations on the data processing, it is needed the use of reduced-order models that capture the main features of the flow in terms of their energy content.

In this work, an innovative approach based on the Galerkin Projection is employed to perform the time super sampling of non-time-resolved measurements.
2 METHODOLOGY
The reconstruction of the flow dynamics occurring between a set of time-independent snapshots is done with a Galerkin model. This model is based on data, typically velocity and acceleration maps obtained from experimental measurements. These are obtained with Particle Image Velocimetry, an experimental technique to measure and visualize the flow velocity fields (also called snapshots) of the fluid flow. This technique consists of seeding the fluid with small particles and then capturing the image of these particles using optical techniques involving lasers, lenses, and high-speed cameras. All this equipment combined with the data post-processing makes time-resolved PIV a costly technique unfeasible for real-time applications.

From the measured set of non-time-resolved instantaneous PIV snapshots, a modal decomposition of the data [3] into the main features (represented by energy-sorted orthogonal modes) is done to keep the main structures of the flow. Then, the Navier-Stokes equations are projected onto this basis, obtaining a Galerkin projection model [2] which allows for reducing the computational. Then, integrating in time the Galerkin-model equations, it is possible to reconstruct the flow snapshots at the specified time instants. Fig. 2 exemplifies the procedure for a turbulent jet.

3 RESULTS
A fluidic pinball is a test case to validate the model and consists of a cluster of three cylinders [1]. The flow field is measured at specific instants of time obtaining time-independent snapshots. Then, using the Galerkin model, the flow evolution between snapshots is reconstructed. As it can be observed in Fig. 3 the Galerkin reconstruction captures well the main structures of the flow.

All in all, a dynamic model based on Galerkin projection has been developed to recover time-resolved measurements from time-independent snapshots. The preliminary results show the effective reconstruction of the velocity fields.

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