Combining Experiment and Simulation

Combining Measurement and Simulation

Measurements can give quantitative insight into flows relevant for aircraft and spacecraft aerodynamics. Where Leonardo da Vinci had to rely on his observational skills to study turbulence in water flows, today fully three-dimensional quantitative measurements of a flow velocity field can be made by a technique called tomographic PIV (Ebina et al. 2006). However, the experimentalist has to deal with measurement noise and errors and hardware limitations on for example sampling rates.

In this project it is proposed to alleviate measurement limitations by augmenting the measurement results with knowledge of the flow physics and modern computational fluid dynamics.

Reducing Measurement Rate Requirements

An instantaneous measurement freezes an unsteady flow in time. For example, a transitional jet flow shown below, measured using four cameras by tomographic PIV.

Vortices in a circular jet (Violato and Scarano 2011)

Application of knowledge about the fundamental physics governing the flow in the three-dimensional measurement volume may allow to start time again. To time-supersample the measurements and reconstruct temporal fluctuations in the flow from instantaneous measurements.

Physics based interpolation

Employing an approximation of the flow governing equations in form of the vorticity transport equation, a physics based interpolation is proposed between two consecutive tomographic PIV measurements.

The time-supersampling technique has demonstrated reconstruction of temporal velocity fluctuations, even when data was sampled at less than half the frequency typically required (figure below).

Redefining Nyquist by physics based interpolation

(Results from Schneiders et al. 2014a)

Application: Launcher Aerodynamics

The dynamic loads induced by separated flow in the base region of a launcher is a topic of interest to prevent response of the structural modes. To evaluate pressure in the flow field, typically the temporal velocity derivatives need to be measured, which is in this high speed flow only feasible by dual tomographic PIV systems requiring 8 to 12 cameras and two high-power lasers

Temporal Derivatives from a Single Snapshot

An alternative is given by the proposed time-supersampling approach, which when extended to single-snapshots can potentially approximate the temporal velocity derivatives and pressure from an instantaneous velocity measurement.

Instantaneous Pressure Evaluation

The procedure is applied to the results from a tomographic PIV experiment on a base flow model (figures top right) at Ma=0.7. From the measured velocity vector field, pressure is evaluated by solving the momentum equation with temporal derivatives approximated by time-supersampling. For preliminary validation, the mean result is shown to be in good correspondence with mean pressure reported in literature (figure below).

Instantaneous tomo-PIV velocity measurement

Instantaneous pressure evaluated from the single velocity snapshot by time-supersampling

Average afterbody surface pressure coefficient

(Results from Schneiders et al. 2014b)

Publications