# Aerodynamic Surface
# Pressure Measurement using Deflectometry

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**Abstract.** In order to obtain full-field pressure information on a surface under dynamic loading from an impinging jet, a deflectometry setup was combined with the Virtual Fields Method (VFM). The high sensitivity of deflectometry allows slope measurements of the order of several $mm\,km^{-1}$ on the investigated reflective surface. Using the VFM, pressure reconstruction from the obtained data is possible with relatively small computational effort. Compared to other commonly used means of pressure measurement, like pressure transducers and pressure sensitive paints, this method does not require alterations of the investigated surface, as long as it is sufficiently plane and specular reflective.

## Introduction

Combining full field optical measurement with the Virtual Fields Method (VFM) allows determination of pressure distributions on a thin plated impinged by an air jet. Knowledge of thus obtained surface pressure information is of great value for material testing, component design and investigations of flow-surface interactions. The method stands out in that it allows obtaining full-field surface pressure information with an optical setup that only requires the sample to be specular reflective and plane.

## Methodology

**Measurement.** Deflectometry is an optical technique for measuring full-field surface slopes [1]. The method has been used in the past *e.g.* for damage detection in composites [2] and the identification of stiffness and damping parameters of vibrating plates [3]. Deflectometry requires an accurately printed hatched grid, a specular reflective surface, a light source and a high resolution camera. Measuring the reflection of a test grid on the specular reflective surface of this sample allows calculating the slopes from the grid shift on the loaded surface. Surface curvatures and accelerations then follow from these slopes.

**Setup.** A jet impinging on a thin sample plate causes variations in the surface slopes. Fig. 1 shows the experimental setup. Impinging jets show characteristic, roughly Gaussian mean pressure distributions [4] on the impingement plate as well as a range of turbulent structures [5]. The flow depends on the initial flow conditions, *i.e.* nozzle diameter, downstream distance, initial mean and turbulence characteristics and Reynolds number [6]. This makes them suitable for experiments aiming at initial validation as well as determining the suitability of the method for investigation of turbulence.

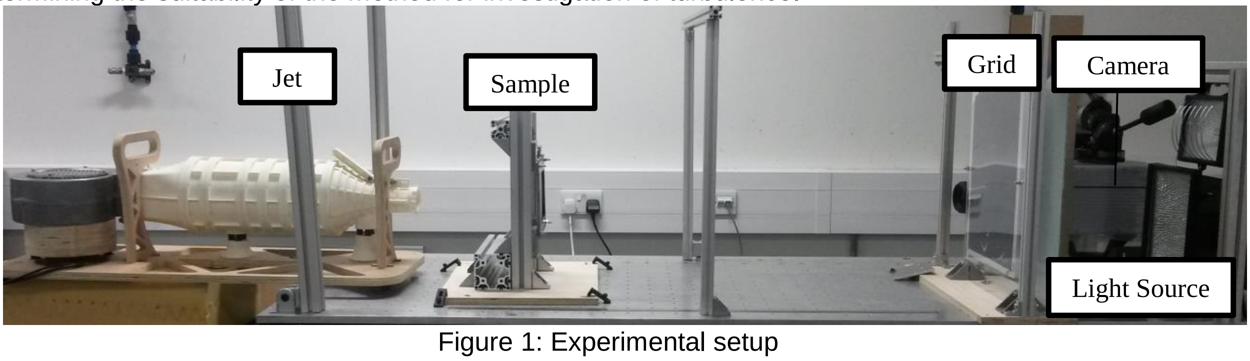


Figure 1: Experimental setup

**Pressure Reconstruction.** The VFM is a technique to identify constitutive material parameters from full-field kinematic measurements using the principle of virtual work [7]. Force and pressure field reconstruction has recently also been shown to be feasible [8]. Compared to other approaches like Finite Element Model updating, it does not rely on iterative procedures to match numerical and experimental results, and knowledge of the boundary conditions is not required [9]. Here, the curvatures and accelerations obtained from deflectometry measurements were used to reconstruct pressure using the principle of virtual work for a thin plate in pure bending.

Eq. 1 describes the equilibrium of an isotropic, homogeneous plate through the principle of virtual work [10], assuming pure bending and linear elasticity [11].

$$\int_S q(t_i) \cdot w^* dS = \rho h \int_S a(t_i) \cdot w^* dS + \int_S \kappa^* \cdot D \cdot \kappa(t_i) dS \quad (1)$$

Here, $q$ is the investigated load, $t_i$ a point in time, $S$ the surface area, $\rho$ the material density, $h$ the plate thickness, $a$ the acceleration, $D$ the bending stiffness matrix and $\kappa$ the curvature. $w^*$ and $\kappa^*$ are the virtual deflections and curvatures. Since the material parameters are known from the chosen sample, $q$ is determined by the measured quantities $a$ and $\kappa$ once suitable $w^*$ and $\kappa^*$virtual fields are chosen. 4-node Hermite 16 element shape functions as used in FEM [12] are perfect to expand the virtual fields for the investigated case of a thin plate in pure bending, as they provide $C^1$ continuity of $w^*$ and therefore, $C^0$ continuity on the virtual slopes, which is required for the VFM [7]. Pressure was reconstructed within a window of four Hermite elements of a chosen size which is then moved over the investigated field of view.

## Results

First tests were conducted for a range of flow conditions and test plates. Fig. 2 shows reconstructed instantaneous pressure values for a glass mirror sample of 3*mm* thickness and an impinging jet with nozzle diameter of 5*cm*, exit dynamic pressure of 340*Pa* and 15*cm* distance between nozzle and sample. The surface slopes measured for this case were of the order of several hundred $mm\ km^{-1}$. The pressure distribution and magnitude agrees well with the expectations from literature [5].

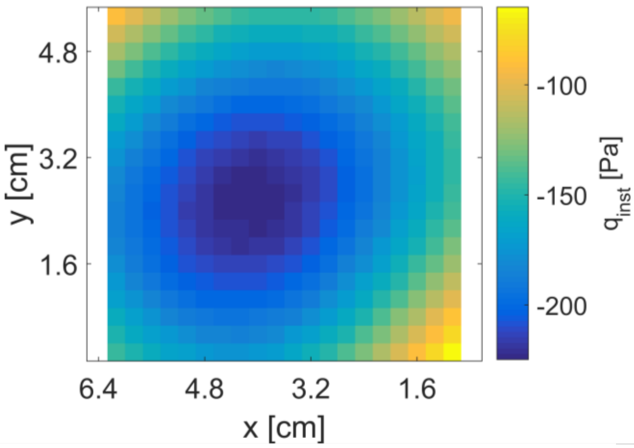


Figure 2: VFM pressure reconstruction using 10 data point window with 5 data point overlay.

## Conclusion

Surface slopes were measured on a thin plate bending under an impinging jet using deflectometry. Surface pressure was reconstructed from those slopes using the VFM. These results will be validated using pressure transducers and numerical models. The aim is to apply the method for investigating dynamic wall interactions between the sample and a turbulent flow using high speed imaging.

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