DATA REDUCTION METHOD BASED ON INTERFEROMETRIC AND PIV MEASUREMENT RESULTS

P.Šafarik
Czech Technical University in Prague, Faculty of Mechanical Engineering, Prague, Czech Republic

M.Matejka
Czech Technical University in Prague, Faculty of Mechanical Engineering, Prague, Czech Republic

ABSTRACT

The paper describes the modified data reduction method for the application of results from interferometric and PIV measurements. The method is designed to evaluate the representative aerodynamic parameters when distribution of the mean density ρ(y) measured by interferometry and the distributions of the component velocities $w_x(y)$ and $w_y(y)$ obtained by PIV are applied in the same measuring plane. Limits for the proposed data reduction method are discussed.

INTRODUCTION

The main objective of the data reduction method is to determine the representative parameters in the traversing plane from the distributions of aerodynamic parameters obtained during the investigations of flow fields downstream of blade cascades. Originally, the method was developed for evaluation of traversing pneumatical probe measurements where two-dimensional flow was taken into account. A system of five equations was derived (one equation for the balance of mass, two equations for the balance of momentum for the two components, one equation for the energy balance, and one equation of state for ideal gas). This system was solved by a well-known procedure [1] in which a biquadratic equation for nondimensional velocity is derived. The original data reduction method was extended in [2] for total temperature distribution measurements. Further development of the data reduction method was carried out in [3], where the representative aerodynamic parameters for the case of another gas injection were solved. Another contribution to the development of the data reduction method for three-dimensional transonic flow measurements was presented in [4].

The paper presents the data reduction method for the case when experimental data in the traversing plane are obtained from interferometric and PIV measurements. Due to interferometry two-dimensional approach based on a consistent balance of mass, momentum and energy in the proposed data reduction is applied.

RESULTS OF INTERFEROMETRIC AND PIV MEASUREMENTS

The set of data from the measurements in the traversing plane (Fig. 1) consists of the distributions of density ρ(y) obtained by interferometric measurements, the velocity component normal to the traverse path $w_x(y)$, and the velocity component parallel to the traverse path $w_y(y)$ obtained by PIV measurements. Adiabatic flow is assumed, $T_{01} = T_{02}$ = const. in the whole flow field.

DATA REDUCTION METHOD

The proposed data reduction method is based on the consistent balances of mass, momentum and energy of ideal gas flow in the traversing path 2. The reference parameters are static pressure p_2, static density ρ_2, velocity components w_{x2}, w_{y2}, static temperature T_2. The parameters are determined for the traversing path 2 in the region of one pitch length from y = 0 to y = t. Further reference parameters are total pressure p_{02}, flow direction α_2, velocity vector value w_2, and Mach number M_2. By comparing these parameters with the reference parameters upstream of the blade cascade in the plane 1 it is possible to determine the kinetic energy loss coefficient ζ, isentropic exit Mach number M_{is2}, entropy incerease, etc.

An important aspect of the data reduction method is the solution of integrals for the experimental aerodynamic measurements. The integrals are the following:

Mean mass flux

$$I_M = \frac{1}{t}\int_0^t \rho(y) w_x(y)\,dy \tag{1}$$

Mean momentum flux normal to the traverse path

$$I_A = \frac{1}{t}\int_0^t \left[\rho(y) w_x^2(y) + p(y)\right] dy \tag{2}$$

where

$$p(y) = \rho(y)\left\{ rT_o - \frac{\kappa - 1}{2\kappa}\left[w_x^2(y) + w_y^2(y) \right] \right\} \tag{3}$$

Mean momentum flux parallel to the traverse path

$$I_C = \frac{1}{t}\int \rho(y) w_x(y) w_y(y)\, dy \tag{4}$$

The set of 5 equations (1 mass balance, 2 momentum balance, 1 energy balance, 1 equation of state for ideal gas) forms the basis of the proposed data reduction method:

Mass balance

$$\rho w_x = I_M \tag{5}$$

Momentum balances

$$\rho w_x^2 + p = I_A \tag{6}$$

$$\rho w_x w_y = I_C \tag{7}$$

Energy at T_0 = const.

$$T_0 = T + \frac{w_x^2 + w_y^2}{2 c_p} \tag{8}$$

Equation of state

$$p = \rho R T \tag{9}$$

where all parameters (except the constant specific heat capacity at constant pressure c_p, and the specific gas constant R, and integrals I_M, I_A, and I_C (Eqs. (1), (2), (4))) are the representative aerodynamic data. The set of equations (5) to (9) contains 5 unknowns, and can be solved by a well-known procedure described in [1] and modified in [4]. The analysis described in [3] and [5] can be applied. After some algebra using the following substitution

$$z = I_A - p = \frac{I_M^2}{\rho} \tag{10}$$

the following quadratic equation is derived:

$$\left(1 - \frac{R}{2c_p}\right) z^2 - I_A z + T_0 R I_M^2 - \frac{R}{2c_p} I_C^2 = 0 \tag{11}$$

Equation (11) has the following solutions:

$$z\big|_{1,2} = \frac{I_A \pm \sqrt{I_A^2 - 4\left(1 - \frac{R}{2c_p}\right)\left(T_0 R I_M^2 - \frac{R}{2c_p} I_C^2\right)}}{2\left(1 - \frac{R}{2c_p}\right)} \tag{12}$$

where – (minus) holds for all subsonic solutions, and transonic and supersonic solutions under the limit load regime, and + (plus) should be accepted in the case of transonic and supersonic solution exceeding the limit load regime.

The representative parameters follow from the above:

Static pressure

$$p\big|_{1,2} = I_A - z\big|_{1.2} \tag{13}$$

Static density

$$\rho\big|_{1,2} = \frac{I_M^2}{z\big|_{1,2}} \tag{14}$$

Static temperature

$$T\big|_{1,2} = \frac{p\big|_{1,2}}{\rho\big|_{1,2} R} \tag{15}$$

Velocity components

$$w_x\big|_{1,2} = \frac{I_M}{\rho\big|_{1,2}} \tag{16}$$

$$w_y\big|_1 = w_y\big|_2 = \frac{I_C}{I_M} \tag{17}$$

VERIFICATION OF THE PROPOSED DATA REDUCTION METHOD

The data reduction method based on distributions of density and velocity components was verified for a data on the compressor blade cascade. The interferogram is shown in Fig.2 and was taken at inlet Mach number M_1 = 0.513 and isentropic exit Mach number M_{2is} = 0.448. The PIV data were substituted by assumptions pressure distribution p(y) = const. and distribution of ratio $w_x(y)/w_y(y)$ = const. Both constants were evaluated from the interferogram (Fig.2). Two distributions of density ρ(y) were evaluated through neighbour wake as shown in Fig.2. The proposed data reduction method gives values of the kinetic energy loss coefficient $\xi = \frac{\lambda_{2is}^2 - \lambda_2^2}{\lambda_1^2}$ (λ is nondimensional velocity) for 1st pitch 0.305 and for 2nd pitch 0.270.

DISCUSSION AND CONCLUSION

In its principle, the data reduction method simplifies the results of the measurements in order to obtain the representative aerodynamic parameters. The formulation of the procedure is based on the fundamental balance laws. However, the method suffers from inaccuracy of the input data. The interferometric method projects the flow field into a two-dimensional picture from which the distribution of density ρ(y) along the traversing path is evaluated. The PIV measurement results obtained in the traversing plane describe the three dimensional flow field and they are transformed into the data for the two-dimensional flow field by determining the distributions of the velocity components $w_x(y)$ and $w_y(y)$, see Fig. 3. The transformation based on averaging of the velocity components w_x and w_y in a narrow strip is questionable. Because this approach is correct only for the case of incompressible fluid (ρ = const.), the inaccuracy of transformation of the PIV data to the 2D case presents a limitation for the proposed data reduction method. The method offers good results for the reference parameters for subsonic velocities. Further development of the method, namely for transonic and supersonic velocities, will be based on three-dimensional pneumatic and PIV measurements.

An indivisible part of the application of the data reduction method is the analysis of the results. The analysis determines which of the two solutions of Eq. (12) should be taken into account for further evaluation of the reference parameters in the region of transonic and supersonic velocities. It has been proved in [5] that the sign + (plus) in Eq. (12) has to be accepted when the limit load regime is exceeded.

Two topics should be studied in the future development of the data reduction method: the first is the analysis of uncertainties (the data reduction method should not be a strong source of uncertainties or one should know, how the data reduction method amplifies the uncertainities of the input data) and the second is the entropy analysis (the second law of thermodynamics or entropy production by the data reduction method).

ACKNOWLEDGMENTS

The research was supported by the Research Centre of the Ministry of Education, Youth and Sports of the Czech Republic No. 1M0659, and by the Grant Agency of the Academy of Sciences of the Czech Republic, grant No. IAA200760504.

REFERENCES

[1] J. Amecke: Data Reduction of Wake Flow Measurements with Plane Cascades, AVA-Report 76 A 49, Göttingen, 1967 (in German)
[2] M.L.G. Oldfield, D.L. Schultz, J.H. Nicholson: Loss Measurements Using a Fast Traverse in ILPT Transient Cascade, Paper No.17, pp. 0-25; In: Proceedings of 6th Meeting on Measuring Techniques in Transonic and Supersonic Flows in Cascades and Turbomachines, Lyon, 1981
[3] J. Amecke, P. Šafařík: Data Reduction Method of Wake Flow Measurements with Injection of an Other Gas, DLR-Forschungbericht No. 95-32, Göttingen, 1995
[4] P. Šafařík, M. Luxa, J. Benetka, J. Michálek: Data Reduction Method for Three-Dimensional Transonic Flow Measurements, Paper No. 2; In: The 17th Symposium on Measuring Techniques in Transonic and Supersonic Flow in Cascades and Turbomachines, Proceedings, KTH, Stockholm, 2004 (CD-ROM)
[5] P. Šafařík: Multicomponent Mixture Flows in Machine Parts, Thesis, Prague, 1999 (in Czech)

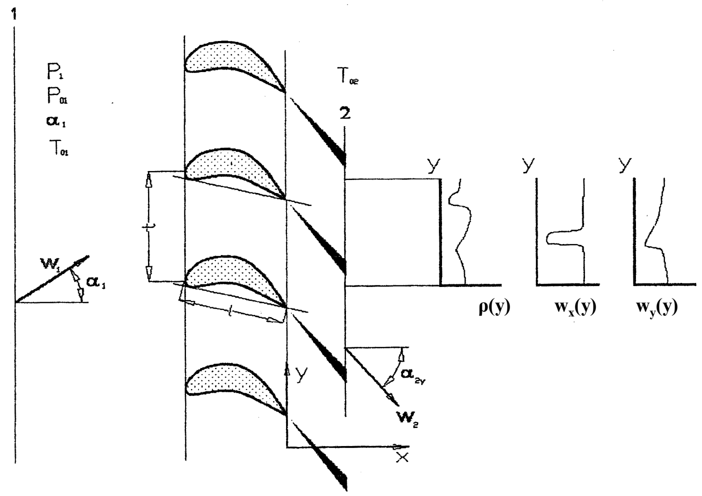

Fig. 1 Distribution of flow field parameters along the traversing path

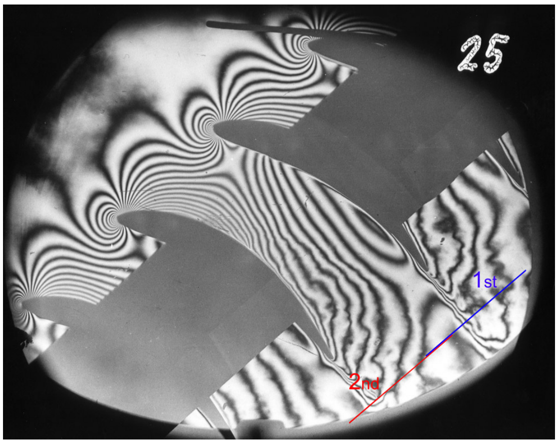

Fig. 2 Interferogram of flow past a compressor blade cascade
(inlet Mach number M_1 = 0.513, isentropic exit Mach number M_{2is} = 0.448)

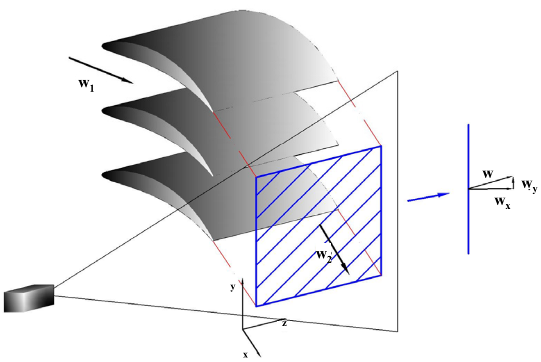

Fig. 3 Transformation of PIV results