Technical University of Denmark

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Fernández-Gámiz, U.; Velte, Clara Marika; Egusquiza, E.

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NUMERICAL SIMULATIONS ON A TWIN-PLATE WAKE

U. Fernández-Gámiz[1] (unai.fernandez@ehu.es), P, Clara M. Velte[2] (cmve@dtu.dk), and E. Egusquiza[3] (egusquiza@mf.upc.edu).

[1] *University of the Basque Country, Nuclear Engineering and Fluid Mechanics Department, Nieves Cano 12, 01006 Vitoria-Gasteiz, Araba, Spain.*

[2] *Section of Fluid Mechanics, Coastal and Maritime Engineering, Department of Mechanical Engineering, Technical University of Denmark, Nils Koppels Allé, 2800 Kgs. Lyngby, Denmark.*

[3] *Technical University of Catalonia, Fluid Mechanics Depart., Av. Diagonal, 647 Barcelona Spain.*

Abstract

In this work, a detailed numerical analysis of two dimensional mean velocity profiles downstream of two parallel flat plates was carried out at a Reynolds number of $3.2\text{x}10^4$ (based on the plate length and free stream velocity) using Reynolds Averaged Navier-Stokes (RANS) and have been compared with experimental data. Furthermore, a self-similar study of the wake behind the twin plate was carried out based on the computer simulations. The main objective is to investigate how well the simulations can reproduce the physics of the flow behind a twin plate.

Keywords: twin-plate, wake, self-similarity, CFD, computational fluid dynamics.

1. INTRODUCTION

Research of the flow field near the trailing edge of submerged bodies has attracted significant interest of researchers over the years. The free turbulent mixing procedure is an inevitable and vital process in numerous realistic phenomena of aerodynamics, Townsend [1], Harsha [2] and Patel et al. [3]. Prabhu et al [4] and Narasimha et al. [5] conducted some experiments on plane turbulent wakes undergoing transition from an initial equilibrium state to a different final one. These experiments showed evidence of self-similar behaviour of the wake behind different wake generators. Later, Hebbar [6] and Wygnanski et al. [7] investigated the boundary layers and wakes on various wake generators where detailed measurements of two-dimensional profiles of static pressure, mean velocity, turbulence intensity and Reynolds shear stress were analyzed. Fernández-Gámiz et al. [8] and Velte [9] also investigated numerical and experimentally the self-similar manners of the wake on a rectangular vortex generator on a flat plate.

A flow is said to be self-preserving if solutions to its dynamical equations and boundary conditions exist for which, throughout the evolution of the wake, all dynamical parameters have the same relative value at the same relative position, George [10]. These parameters are sketched in Figure 1, where U_∞ is the free stream velocity, u_0 the convection velocity and W_0 and δ the defect velocity and the half-defect thickness, respectively. Therefore, according to Narasimha et al. [5], an equilibrium wake state is defined as one in which the mean velocity and the turbulent stresses exhibit similarity with identical length and velocity scales.

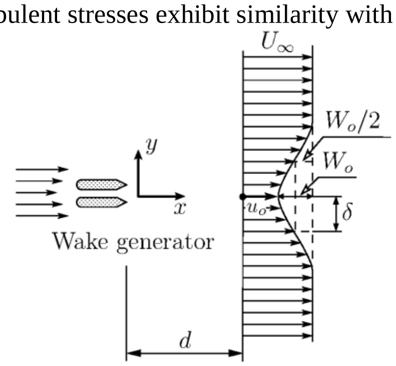


Fig. 1: Sketch showing the main wake parameters behind a twin-plate.

The purpose of this work is to study the manner in which computational simulations of a twin-plate (see Figure 1) at moderate Reynolds numbers approach the self-preserving state described in Sreenivasan et al. [11]. For this purpose, a twin plate 2D computational configuration was performed.

2. EXPERIMENTAL DATA

The experimental setup is the one of Sreenivasan et al. [11]. The experiments were conducted in an open circuit suction type wind tunnel with a Reynolds number Re=3.2x10^4 based on the twin plate length L (see Figure 1) and a free stream velocity U_∞=21.3 m/s. The free stream turbulence level at this velocity was measured about 15%. The wind tunnel test section was about 30 cm square and 4.27 m long with a contraction ratio of about 10:1. Less than 1.5% of variation in the wind speed along the test section was obtained by applying suitable divergence for the boundary layer growth. All mean velocity measurements were made with a pitot-static tube. Constant current hot-wire measurements with suitable frequency compensation.

3. COMPUTATIONAL CONFIGURATION

In this study, two-dimensional steady state simulations were carried out and compared to the previous experimental observations. These computations were performed using a structured finite-volume flow solver utilising, in this work, the Reynolds-Averaged Navier-Stokes equations. The *k-ω SST* (Shear Stress Transport) turbulent model developed by Menter [12] was used.

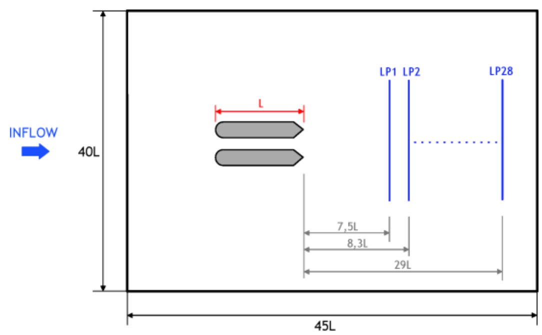


Fig. 2: Computational domain.

Figure 2 illustrates the computational setup with the current settings consisting of a twin-plate with a length L = 23.4 mm. The thickness of the plates is 1.59 mm, constant along the x direction, with rounded off leading edge and with a sharp trailing edge, as described in Sreenivasan et al. [11]. The computational domain normalized by the twin-plate length (*45L x 40L*) is also displayed in figure 2. The twin plate was aligned with the inflow and the Reynolds number based on the length of the twin-plate is Re= 3.2x10^4, using an inflow velocity of 1 m/s and a density of 1 kg/m^3. The computational setup of the CFD simulations consists of a mesh of one million 2D square cells with the first cell height ($\Delta y/L$) of 5.85x10^{-5} normalized by the twin plate length. In order to obtain an optimal mesh, three refined volume meshes have been created, two of them around the plates and the third one behind the trailing edge of the plates, see Figure 3. In the immediate vicinity of the plates, the mesh has 0.5x10^6 cells, while the mesh downstream of the twin plate for capturing the wake has approximately 0.35x10^6 cells. In order to resolve the boundary layer, cell clustering has been used close to the wall and the dimensionless distance from the wall is less than 2 (y^+ <2), as is required by the SST turbulence model. Verification of sufficient mesh resolution was performed by a mesh independency study. Results obtained for the finest mesh were compared with the results for a standard and a coarse mesh. The deviation between coarsest and finest meshes indicates a difference of approximately 5% in the centreline wake defect velocity W_0.

Data in the computational simulations were extracted in 28 streamwise lines, normal to the flow direction and located *x/L*=7.5-29 plate lengths downstream the trailing edge of the twin-plates, as illustrated in Figure 2.

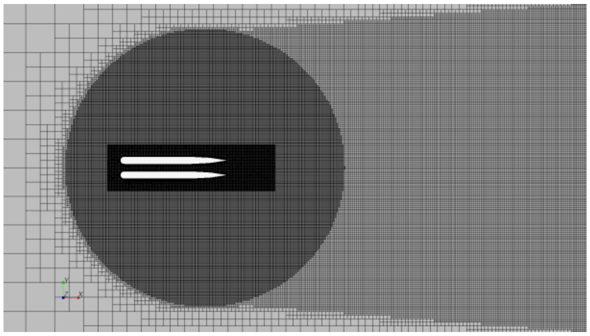


Fig. 3: Mesh around the Twin-Plate.

4. RESULTS

A two dimensional numerical analysis was performed for the study of the twin-plate wake generator. Figures 4 and 5 represent the axial velocity field and the pressure field respectively. The plates were aligned with the oncoming flow in order to have an aerodynamic fashion lay-out and subsequently compared with the wind tunnel experiments and the analytical model described in Sreenivasan et al. [11]. The extraction of the velocities from the computations was conducted in a similar way to the experimental procedure, downstream of the twin-plate and applying cartesian coordinates to the velocity profiles with the origin in the middle point of the trailing edges of the plates.

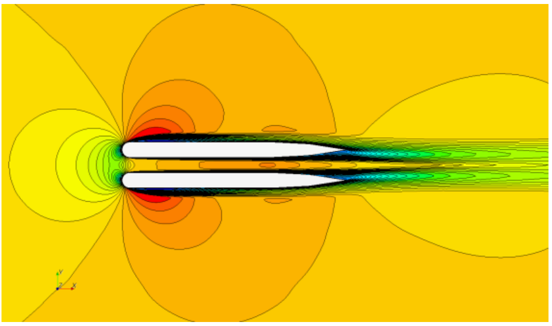


Fig. 4: Axial Velocity field on a Twin Plate.

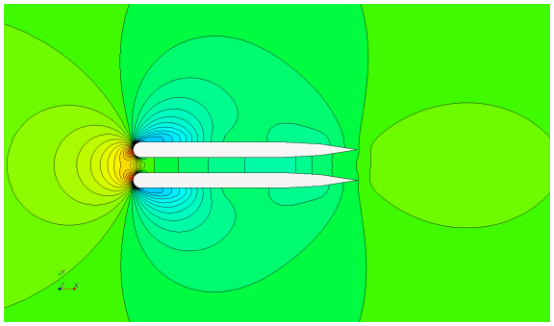


Fig. 5: Pressure field on a Twin Plate.

4.1 Comparison with experimental data and analytical model.

Table 1 lists mean parameters of the twin-plate wake generator used in the experiments of Sreenivasan [13] for a comparison with the computational results. The momentum thickness θ is defined by the equation (2), where w is the wake velocity deficit and U is the stream velocity outside the wake:

$$\theta = \int_{-\infty}^{+\infty} \frac{w}{U}\left(1 - \frac{w}{U}\right) dy \qquad (2)$$

The drag coefficient value of the computations matches quite well with the experimental one and the averaged momentum thickness is also very similar for both cases.

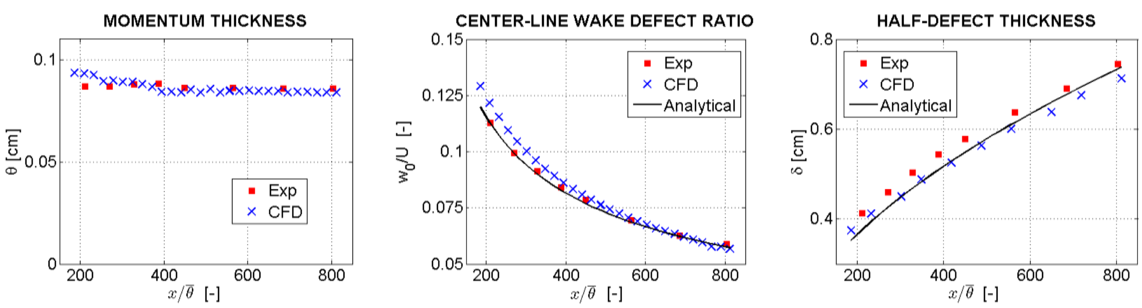
TWIN-PLATE CASE	*Drag coef. C_D*	*Momentum Thickness $\bar{\theta}$*	*Aspect Ratio*	*L(cm)*	*Re_L*
Exp.	0.0740	0.874 mm	64	2.33	3.2x10^4
CFD	0.0729	0.869 mm	64	2.33	3.2x10^4

Table 1: Mean twin-plate wake parameters.

Additionally, the analytical model presented in Sreenivasan et al. [11] is considered for comparison. It is useful to consider the development of two-dimensional turbulent wakes in term of the parameters described in the equations (1a) and (1b) as a growth-rate expression (see also White [14]):

$$\delta \approx 0.30(x\bar{\theta})^{1/2} \qquad (1a) \qquad\qquad \frac{W_0}{U} \approx 1.63\left(\frac{\bar{\theta}}{x}\right)^{1/2} \qquad (1b)$$

where δ is the half-defect thickness, w_0/U is the center-line wake defect ratio and $\bar{\theta}$ the averaged momentum thickness measured in 28 line probes downstream of the twin plates.



(a) (b) (c)

Fig. 6: Wake developments parameters. Comparison between the experimental data (■), numerical simulations (x) and analytical model (—).

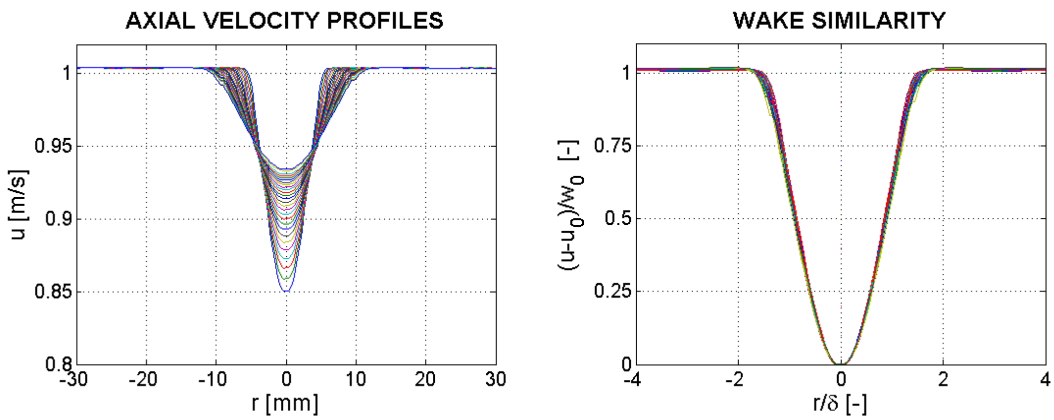
Figure 6(a) displays the momentum thickness simulation results in a 2D wake behind a twin-plate of the computational simulations (x) and the comparison with experimental data (■). Note that, in the computations, a stable momentum is reached about 220 averaged momentum thicknesses downstream the dual-plate, while in the experiments the momentum was stabilized at about $x/\bar{\theta}$ =200. Figures 6(b) and 6(c) display a comparison between the experimental and computational results for the calculations of the center-line wake defect and the shear layer half-defect thickness, respectively. In addition, the analytical model previously presented in the equations (1a) and (1a) has been represented. In both cases, a strong agreement it is observed between the computational results and the ones of the experiments and the analytical model.

4.2 Self-similarity on two-dimensional twin-plate turbulent wake.

The twin-plate wake velocity components were extracted in 28 cross-planes positioned from 7.5 to 29 twin-plate lengths downstream of the trailing edges of the plates. Figure 7(a) shows the velocity profiles for all downstream positions with no scaling. Figure 7(b) illustrates that, if the twin-plate wake velocity profiles are correctly scaled, self-similarity is achieved. A self-preserving state basically means that the mean velocity and the Reynolds shear stress distribution must be independent of the streamwise position when normalized by the same velocity and length scales. The developed self-similar region seems to grow from an apparent origin just behind the plates, between the trailing edges of the twin-plates. Far downstream self-similarity is reached when:

$$\frac{w}{w_0(x)} = fcn\left[\frac{y}{b(x)}\right] \tag{3}$$

It was observed in the computations that about 220 momentum thicknesses behind the dual plate the velocity profiles become self-similar, which is quite similar to the value found in the experiments carried out by Sreenivasan [11]. Since there is no significant streamwise pressure gradient, the wake momentum thickness θ remains constant at each line probe position.



(a) (b)

Fig.: 7: Computational velocity profiles at positions *x/L*=7.5-29. (a) Axial velocity profiles no scaled. (b) Axial velocity profiles scaled by self-similarity variables

5. CONCLUSIONS

The two-dimensional turbulent wake behind a twin-plate has been numerically studied. Computational RANS simulations at Reynolds number $Re=3.2\text{x}10^4$ have been carried out and compared with experimental data and an analytical model.

The self-similar behaviour wake generated by the twin-plate was tested at 28 line positions *x/L*=7.5-29 plate lengths downstream the trailing edge. It was established that the wake equilibrium was reached about 220 momentum thicknesses downstream of the twin-plate. From the point of view of self-similarity, computational simulations are able to reproduce the physics of the flow behind the twin-plate with considerable reliability. The CFD results in Figure 6 match the experimental observations reasonably well, as well as the analytical model presented in [11].

For future investigations, it would be highly interesting to investigate the self-similar behaviour and the stability of the wake behind the twin-plate at higher Reynolds numbers and in three dimensions.

6. ACKNOWLEDGEMENTS

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