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Calculation of Merging Turbulent Wakes

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Introduction

THE work described here can be regarded as an extension of that of Cebeci et al.[1] and Chang et al.,[2] who performed calculations for wall boundary layers and wakes, respectively, and assessed the relative merits of eddy-viscosity hypotheses based on the algebraic formulation of Cebeci and Smith[3] and on the two-equation model of Hanjalic and Launder.[4] These investigations showed that the results obtained by the two turbulence models were similar and agreed well with experiments.

Flows considered in this Note represent a further step towards the flows of aircraft; on this occasion the merging of multiple wakes downstream of a high-lift arrangement of flaps. They involve a series of scales characteristic of the neighboring wakes and jets and present challenge for calculation methods. As described in the following section, the two-equation model can be used in the same form as for the earlier work,[4] but the algebraic expression requires modification to deal with the interactive region between wakes. The results allow consideration of the advantages of the two approaches, one with added algebraic complications but cheap and easy to formulate and use, and the other requiring no change to the turbulence model but more expensive and less convenient to use.

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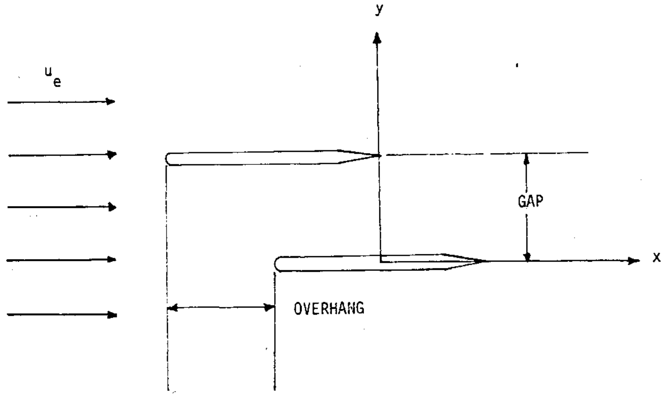

Fig. 1 System configuration and coordinate.

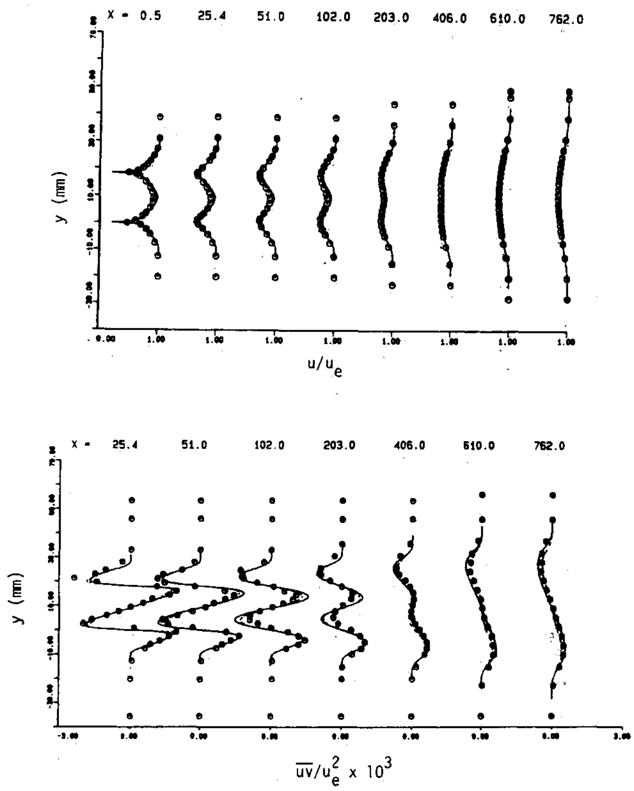

Fig. 2 Velocity profiles for overhang of 0.0 mm and gap of 19.0 mm.

Equations

The flow configuration is shown on Fig. 1 together with the notation of the following equations and results. It corresponds to the merging of wakes with different origins and has been examined experimentally by Nakayama et al.[5]

The boundary-layer form of equations for momentum, turbulence energy, and dissipation rate were solved with Keller's box scheme[6] for specified freestream velocities or boundary conditions and with the measured streamwise velocity profile at the trailing edge of the flat plate. The static pressure was assumed constant, and the initial profile of dissipation rate was obtained from the relationship in which the production and dissipation rates are the same. Edge boundary conditions for kinetic energy and dissipation rate corresponded to reduced forms of the conservation equations with zero cross-stream gradients and known values of external velocity u_e.

The algebraic eddy viscosity expression for the wake is that of Chang et al.[2] which, with B_1 given by $(x - x_{te})/20\delta_{te}$, is

$$\epsilon_m = \epsilon_w + (\epsilon_{te} - \epsilon_w)e^{B_1} \tag{1}$$

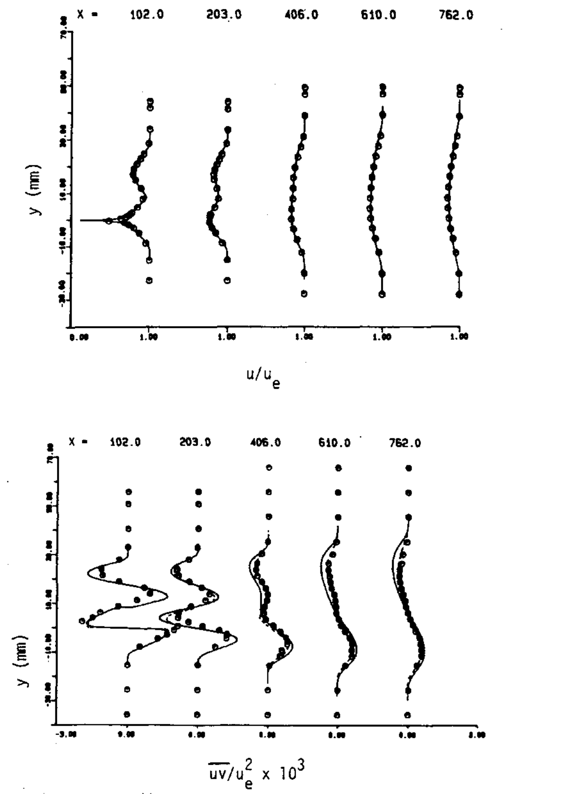

Fig. 3 Velocity profiles for overhang of 102.0 mm and gap of 19.0 mm.

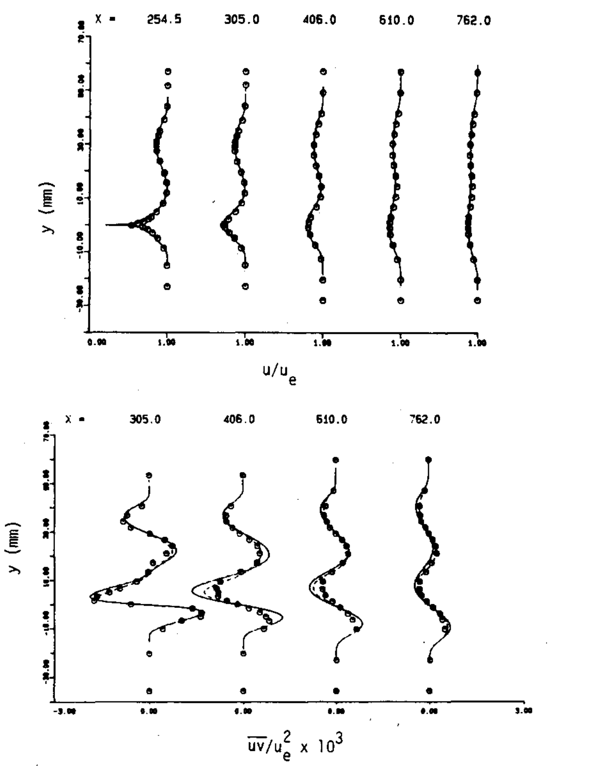

Fig. 4 Velocity profiles for overhang of 254.0 mm and gap of 19.0 mm.

Here x_{te} corresponds to the trailing edge, δ_{te} denotes the boundary-layer thickness at x_{te}, and ϵ_W represents the eddy viscosity of the far wake given by the maximum of ϵ_w,L and ϵ_w,U defined by

$$\epsilon_{w,L} = 0.064 \int_{-\infty}^{y_{\min}} (u_{e,L} - u)\,\mathrm{d}y, \qquad \epsilon_{w,U} = 0.064 \int_{y_{\min}}^{\infty} (u_{e,U} - u)\,\mathrm{d}y$$

Here the subscript L and U denote the lower and upper wakes, respectively, and $y_{\min}$ corresponds to the normal distance where $u = u_{\min}$.

The eddy-viscosity expression for the interactive region between the two wakes is similar to that given by Eq. (1) provided that we replace ϵ_{te} with ϵ_{mg} and B_1 with B_2 defined by $B_2 = (x - x_{mg})/20\delta_{mg}$. Here x_{mg} corresponds to the distance where merging takes place, and δ_{mg} and ϵ_{mg} denote the boundary-layer thickness and the eddy viscosity calculated from Eq. (1) at that location, respectively. The merging location is defined to be the edge of the boundary layer (at $0.995 u_e$) of two adjacent inner wakes which cross over.

Results and Conclusion

The experiments of Nakayama et al.[5] correspond to turbulent wall boundary layers on the two plates of Fig. 1. A sample of the results is shown on Figs. 2–4 with symbols representing experimental data, solid lines the algebraic turbulence model, and dashed lines the transport model.

Figure 2 represents the case of zero overhang and displays the poorest agreement between measured and calculated profiles of velocity in the near field, due to the confined nature of the flow and the need to adjust the turbulence model to deal with this arrangement. The results of the two models are virtually identical and the agreement with experiment improves with downstream distance. Figures 3 and 4 correspond to flows with two values of the overhang distance and show that the results obtained with the two models are in excellent agreement with experiment.

The results allow the same conclusion to be drawn for multiple wakes as Cebeci et al.[1] and Chang et al.[2] reported for wall boundary layers and single wakes. The two turbulence models provide essentially the same results and the use of the transport model has a cost penalty, in terms of computer run time, of a factor of three.

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Magnetization-Vector Analogy as a Reformulation of the Equations of Fluid Dynamics

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Introduction

SEVERAL numerical methods of solving the incompressible Euler and Navier-Stokes equations in two dimensions

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