8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

MATHEMATICAL MODEL OF TURBULENT SHEAR LAYERS WITH HARMONIC PERTURBATIONS

*** Yuli Lifshitz and David Degani**

Faculty of Mechanical Engineering
Technion - Israel Institute of Technology, Haifa 32000, Israel
E-mails: ylifshitz@tx.technion.ac.il, degani@tx.technion.ac.il

Key Words: *Mixing Layer, Harmonic Perturbations, Mathematical Model.*

ABSTRACT

Because turbulent shear layers are sensitive to artificial periodic disturbances, they may be used for active flow control. As it is known today, such a control has high potential benefits to many applications (e.g., increase of maximum lift; drag reduction; improvement of aircraft performance, stability, and control; etc.). The objective of this work is the presentation of mathematical model for understanding the main physics of turbulent shear layers with weak oscillatory forcing. The model under consideration is based on the splitting of the ensemble-averaged flow parameters (velocity, pressure) into a mean and a coherent part connected with the forcing frequency. The governing equations for both parts of the flow are derived from the unsteady RANS equations, assuming eddy-viscosity equivalence for the random part of the flow.

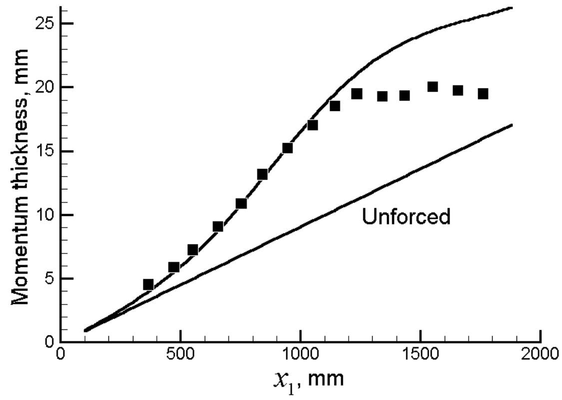

Figure 1. Variation of the momentum thickness: lines – results of calculation, symbols – experiment [2].

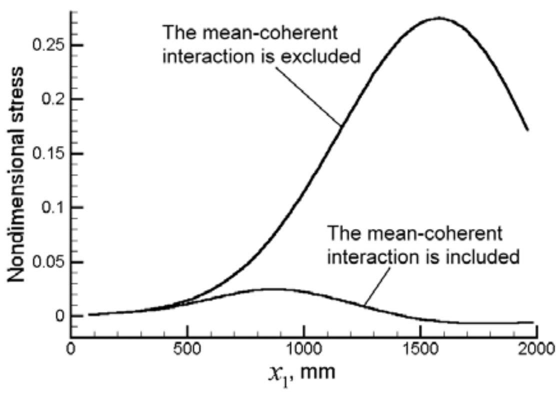

Figure 2. Variation of the coherent Reynolds stress.

In this representation, the mean-flow equations consist of additional terms originated from correlations of the coherent velocity components. These coherent Reynolds stresses (CRS) change the mean flow. The CRS are calculated from the solution of the coherent-flow problem which is the boundary-value problem for the linearized Navier-Stokes equations, at least for the eddy-viscosity closure and small-amplitude perturbations. The wave propagates in the mean field is determined by the CRS, and iterations are used to provide a coupled solution of the problem as a whole.

Because of the several assumptions mostly for the turbulence closure for the mean and the coherent problems, the model needs validation. For this purpose, we use experimental data for turbulent shear layers harmonically excited by oscillating flap: wake past a flat plate, mixing layer between two parallel streams, and boundary layer subjected to highly adverse pressure gradient [1-3]. Besides, the role of the mean-coherent interaction must be studied. The overall amplification of the coherent wave intensity in the mixing layer has been compared with data of Ref. [4], measured in limited region. The good correlation of the results shows that our eddy-viscosity closure satisfactorily represents the development of coherent-flow intensity. Variation of the mixing layer momentum thickness in wider region is shown in Fig. 1. Results of calculations well agree with experimental data upstream of the region, where momentum thickness saturates. Corresponding variation of the CRS at the mixing layer center line is presented in Fig. 2 for calculations with and without the mean-coherent interaction. The interaction changes the mean-flow velocity profiles in such a manner that the growth of mixing layer increases, and the CRS decreases. The flow becomes less unstable in contrast to laminar shear layer, where the interaction increases the instability. A parametric analysis shows that the interaction is the most important nonlinear process following the wave propagation in a turbulent shear layer.

.

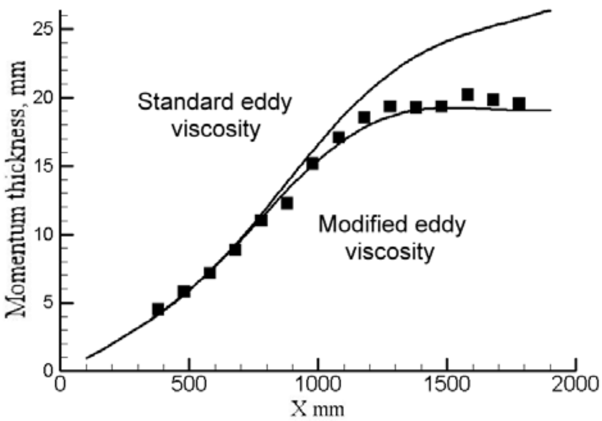

Figure 3. Variation of the momentum thickness by the standard and modified eddy-viscosity models: lines – results of calculation, symbols – experiment [2].

Downstream, the CRS becomes negative but it is not enough to saturate the mixing layer growth. Here the turbulent Reynolds stress is grossly overestimated by the conventional eddy viscosity model. This signifies a noticeable impact of the random-coherent interaction on the turbulent Reynolds stress, which cannot be expressed by a closure relation comprising the mean-flow parameters only, and explains why our mathematical model is in rather poor agreement with the experiment. We propose another eddy-viscosity closure that takes into account the decrease of turbulent shear stress caused by the coherent wave. The new model results in much better agreement with the experiment as it is shown in Fig. 3.

REFERENCES

[1] B. Marasli, F. Champagne, I. Wygnanski, Phys. Fluids A. 3, (1991), 665-674.
[2] D. Oster, D., I. Wygnanski, J. Fluid Mech., 123, (1982), 91-130.
[3] K. Elsberry, J.L. Loeffler, M.D. Zhou, I. Wygnanski, J. Fluid Mech., 423 (2000), 227-261.
[4] M. Gaster, E. Kit, I. Wygnanski, J. Fluid Mech., 150 (1985), 23-39.