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AN INVESTIGATION OF TURBULENCE MODELS

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The accuracy to which a turbulent boundary layer or wake can be predicted numerically depends on the validity of the turbulence closure model used. The modeling of turbulence physics is one of the most difficult problems in computational fluid dynamics (CFD). In fact, it is one of the pacing factors in the development of CFD.

In general, there are three main approaches to the description of turbulence physics. First is turbulence modeling in which the Reynolds averaged Navier - Stokes equations are used and some closure approximation is made for the the Reynolds stresses. The various closure models are based partly on theory and partly on experiment. Included in this category are the eddy viscosity models in which the Reynolds stresses are equated to a coefficient times the local mean rate of shear. This eddy diffusion coefficient depends on a length scale and a velocity scale. The eddy viscosity models can be be further broken down into algebraic, one equation and two equation models. In the algebraic models, such as Prandtl's mixing length model, the eddy viscosity is related by algebraic equations to the properties of the local mean flow. Turbulence, however, is a non-local phenomenon and there are strong history effects. The algebraic models are not capable of treating history effects. The one and two equation models attempt to correct for this by making use of transport equations for the velocity and length scale in the eddy viscosity. The algebraic models work well for attached boundary layers. It is expected that the one and two equations models should work better for separated and re-attached boundary layers. There are also a class of turbulence models in which the Boussinesq approximation of an eddy viscosity is not made. Instead, the Reynolds stresses are modeled directly by means of transport equations. These equations require a closure assumption on the third order velocity correlations.

A second approach to turbulence is large eddy simulation (LES) in which the computational mesh is taken to be fine enough that the large scale structure of the turbulence can be calculated directly. An empirical assumption must be made for the small scale sub - grid turbulence. The third approach is direct simulation. In this technique the Navier-Stokes equations are solved directly on a mesh which is fine enough to resolve the smallest length scale of the turbulence. The Reynolds averaged equations are not used and no closure assumption is required. These last two approaches require extensive computer resources and as such are not engineering tools. They are useful for providing important checks for the engineering turbulence models.

The purpose of the work this summer was to investigate the various engineering turbulence models for accuracy and ease of programming. This involved the comparison of the models with each other and with experimental data. It was decided to choose a simple geometry with which to test the turbulence models. Therefore a computer program was written to solve the two dimensional, incompressible boundary layer on a flat plate at zero incidence. The flat plate has the added advantage that there is a wealth of good experimental data available for comparison. The governing equations were written in integral form and applied to a control volume consisting of a basic cell. This led to a set of finite difference equations for the tangential and normal components of velocity. The x momentum equation was solved by a Runge-Kutta scheme with the diffusion terms treated implicitly. The program was written in such a way that different eddy viscosity models can be easily inserted. At present the program is successfully running with an algebraic turbulence model. The results have been compared with empirical curve fits for turbulent boundary layers and the agreement is very good.

There are several areas where work needs to be done to advance the study. First, various iterative solution schemes should be tried to speed the convergence rate of the finite difference solution. The present scheme converges but is slow. Secondly, one and two equation turbulence models should be incorporated into the program so that comparisons can be made for accuracy and ease of programming. Third, compressibility should be added to the model so that transonic flows can be studied.

It is expected that all of the turbulence models should give fairly similar results for attached boundary layers. This is not the case for separated boundary layers. Therefore, it will be useful to extend the code so that it can model separation. This will require some additional terms in the momentum equations since the boundary layer equations are singular at a point of separation. This aspect of the problem should be investigated in the future.