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Computer Program for Calculating Laminar, Transitional, and Turbulent Boundary Layers for a Compressible Axisymmetric Flow

Accurate methods for calculating boundary layer growth and boundary layer separation are needed for the analysis and design of aircraft and propulsion system components. Nacelles, turbomachinery blading, nozzles, ducts, splitter rings, and airfoils are examples of some of the aircraft components that require information on the properties of boundary layer flow. The ability to use boundary layer methods enables one to replace much testing with calculations that consume less time and result in more detailed information.

A finite-difference computer program has been developed for calculating the viscous compressible boundary layer flow over either planar or axisymmetric surfaces. The flow may be initially laminar and progress through a transitional zone to fully turbulent flow, or it may remain laminar, depending on the imposed boundary conditions, laws of viscosity, and numerical solution of the momentum and energy equations. The flow may also be forced into a turbulent flow at a chosen spot by the data input.

The available techniques for solving the boundary layer equations can be divided into two general methods. The first includes the explicit integral method which requires a procedure for solving ordinary differential equations for "integral" properties of the boundary layer. The second method of solution of boundary layers is the finite-difference method, which provides a procedure for solving the partial differential equations of mass, momentum, and energy.

The finite-difference boundary layer techniques developed here are an extension of those of Herring and Mellor. In order to solve the partial differential equations for turbulent flow, an expression for the turbulent effective viscosity is required. Mellor and Herring, in formulating their effective viscosity hypothesis, divide the boundary layer in terms of an inner layer, an overlap layer, and an outer layer. The viscosity of each region is based on experimental data and is uniquely determined by values of a pressure gradient parameter and a displacement thickness Reynolds number. The effective viscosity hypothesis as used in the program includes the influence of longitudinal wall curvature.

Theoretical investigations into the process of transition from laminar to turbulent flow are based on Reynolds' hypothesis that transition occurs as a consequence of an instability developed within the laminar boundary layer. The transition region is defined as the region between the instability point (or critical point) and the fully turbulent point. The instability point is the point on the surface at which amplification of an individual disturbance begins and proceeds downstream. The boundary layer becomes fully turbulent some distance downstream of the instability point since the disturbance takes time to be amplified to fully developed turbulent flow. The basic formulation of the transition equations used was developed by H.J. Herring.

Once the basic equations describing the flow are formulated, a modified Crank-Nicolson scheme is used to reduce them to finite-difference form. Since the momentum and energy equations are decoupled, a solution of the momentum equation can be obtained without solving the energy equation in many cases of interest. The decoupling thus may lead to shorter execution time. The flow may be initially laminar and progress through a transitional zone to fully turbulent flow, or it may remain laminar, depending on the imposed boundary conditions, laws of viscosity, and numerical solution of the momentum and energy equations. The solution may start from an initial Falkner-Skan similarity profile, an approximate equilibrium turbulent profile, or an initial arbitrary input profile. The program can calculate variable property flows with arbitrary pressure gradients and heat transfer. The input may contain the factors of arbitrary Reynolds number, free-stream Mach number, free-stream turbulence, wall heating or cooling, longitudinal wall curvature, wall suction or blowing, and wall roughness.

(continued overleaf)

Notes:

1. The program is written in FORTRAN IV for use on an IBM 7094/7044 direct-coupled system.
2. Inquiries concerning this program should be directed to:

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