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TURBULENT FLOW COMPUTATION FOR COMPLEX THREE-DIMENSIONAL DUCTS

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Abstract

The computational prediction of flow through a complex three-dimensional duct whose axis undergoes a series of smooth changes in direction is complicated by the appearance of significant secondary or transverse velocities in addition to the primary or axial velocity. The secondary motion can be interpretated by the rotation of the direction of the axial flow. This type of interpretation is appropriate in both the upstream invicid core/viscous boundary layer region and in the downstream fully merged region.

For viscous flows with a dominant flow direction, it is often possible to cast the governing equations in a form where specific terms can be neglected. For steady flows, this raises the possibility that the mathematical character of the governing equations may change from elliptic to non-elliptic with respect to the dominant flow direction. If this occurs, stable computational algorithms can be constructed that permit the solution to be obtained in a single downstream march [1].

For slightly elliptic flows, computational strategies based on a few downstream marches are effective. For flows that do not meet the requirements for a non-elliptic reduced form of the original governing equations, it is still possible to use an equivalent non-elliptic algorithm to obtain an approximate solution very efficiently [2]. This solution provides the initial data for an iterative solution of the actual governing equation. In this way, more efficient overall iterative techniques can be constructed.

In this paper, a repeated marching algorithm will be described based on using the axial momentum equation to obtain the pressure distribution. The transverse velocity components are obtained from the transverse momentum equations and the axial velocity component is chosen to satisfy continuity. The incompressible Navier-Stokes equations are presented in general tensor notation and discretised to construct the repeated marching algorithm.

An efficient numerical method for the prediction of internal flow within ducts of arbitrary geometry is implemented. The method derives its efficiency mainly from the combination of a marching scheme along the main flow direction and Multi-grid technique. The use of general tensorial form in the algorithm is essential to the successful sequential solution of all the equations. Firstly, the physical flow domain is transformed onto a regular computational domain and the governing equations are transformed accordingly. Secondly, the equations expressed in general coordinates are solved in a sequential way by implementing the marching scheme in the main convection direction. Finally, the Multi-grid method is incorporated to further increase the convergence rate. An effective grid generating method used here is also an important part of this algorithm's robustness in dealing with irregular boundary shape of ducts.

Several very interesting applications for using this method to predict flow within ducts and over bumps are presented. Recirculating areas are well predicted and comparison between experimental results and the computed turbulent average velocity and pressure shows that this robust method is accurate and computationally economical.

This computational method is being developed for turbulent three-dimensional internal flows through ducts of complex shape and with axis curvature. Results will be presented for the transition of swirling pipe flow to rectangular duct flow and the flow over a bump in a rectangular duct.

References

[1] C.A.J. Fletcher: Computational Techniques for Fluid Dynamics, Vol. 2, Springer-Verlag, Heidelberg, Chap. 16, 1988.

[2] C.A.J. Fletcher and Z. Zhu: Efficient Internal Flow Solver Using Reduced Navier-Stokes Equations, ISCFD Proceedings, Okayama, Japan, September, 1988.

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