Numerical Modeling of External 3-D CFD Problems on the Parallel Computers and Aerodynamic Shape Optimization

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Introduction

This paper is devoted to development of mathematical models, numerical methods and parallel algorithms for aerodynamic design problems focused on multiprocessing computing systems.

Up to recent time the computational fluid dynamics (CFD) studied flows about moving bodies of rather simple shape. Numerical modeling of flow fields past bodies of the real form is much more difficult. There are many problems connected with design of geometry, grid generation, construction and implementation of numerical methods. One of the basic problems at the solution of aerodynamics problems is creation of the most full computer models of geometry. For fluid dynamics problems it's useful to represent the surface by algebraic methods. This approach used for optimisation problems.

One of the basic problems is the grid generation that takes into account geometrical and physical features of flow field. It allows obtain the solution with required accuracy at restriction on amount of grid points. Next methods of grid generation used: algebraic, differential and with the help of the theory of functions complex variable. Two different methods based on solution of partial differential equation used.

Numerical methods of calculation of 3-D flows are considered within the framework of full unsteady Navier-Stokes equations and submodels from the point of view of parallel calculations. Numerical methods are based on a finite-difference, finite-volumes methods and S.K.Godunov's schemes ([1-3]). Use of technology of parallel calculations on multiprocessing computer facilities will proceed a qualitatively new approach at the solution of aerodynamic designing problems ([4]).

Methods, variables of optimization, solution of governing equation

The solution of optimization problems includes the following sub-problems: definition of cost function and the major parameters subject to optimization, direct minimization. Aerodynamic properties that defined by cost function are functional of variable flows and geometry. Changing of the aerodynamic shape results in pressure distribution upon surfaces and, hence, of cost function. The problem of designing now is examined as a task of management, where function of management - geometry, which gets out to minimize the function of cost subordinated to restrictions determined by the gas-dynamics equations. Sometimes governing CFD equations changed by an adjoining problem.

As algorithm of optimization the descent method is used. In view of the huge expenses connected to calculation of criterion function, the determined methods of optimization based on gradient methods and the analysis of sensitivity, in our opinion, are more preferable. At indignation of variables of designing with the help of numerical methods value of criterion function is calculated, there are functional increments. The direction of search is determined the further process repeats until variations do not tend to zero. After finding of a minimum of cost function process stops.

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The solution of gas dynamics problem consists in separate parts: geometry design, grid generation, numerical method. For construction of geometry of the complex form various methods are used: 1) algebraic, 2) spline-approximations, 3) NURBS - non-uniform rational Bezier-splines. It is convenient to set a surface analytically, approximating initial data by elementary surfaces. Advantage of such technique consists in that it can be used at all design levels. The analytical presentation of geometry is convenient in the respect that it allows to define a surface by finite number of parameters.

As methods of calculation governing equations the different methods were used: updating method the S.K.Godunov-marching procedure, S.K.Godunov's method for the unsteady equations and a method of "predictor-corrector" for calculations 3-D Euler and Navier-Stokes equations in so-called "thin" layer approximation([5-6]). This approximation contains all members of Euler and boundary layer equations. The offered approach allows to take into account within the framework of the uniform equations both inviscid and the main viscous effects, and as result an influence of viscosity on aerodynamic characteristics.

To find an increment of cost function it is necessary to solve a gas dynamics problem for new values of optimization parameters, i.e. to set new geometry, to construct a grid and to find new values of aerodynamic characteristics. Thus the grid generator will be used repeatedly. Number of required grid constructions is proportional to number of design variables. For complex 3-D configurations the grid generation differential equations in partial derivatives are solved by iterative methods. From computing point of view these repeating procedures of grid generation is time consuming. Then certainly optimization methods are used for definition of cost function. For grid generation the updating of the parabolic generator offered in work /1/ is used. Further methods of adaptation are used. One of such approaches consists in use of the special equations near to borders.

Domain decomposition. Parallel implementation of algorithm. Numerical tests and results

Basically the given report consists in use of opportunities of simultaneous calculations on the parallel architecture computer, in acceleration of process of optimization, effective realization of a multiprocessing method. The CFD problems are solved by a decomposition domain, optimization of communication between processors and with use of standards of system MPI (message passing interface). Choice MPI as library is determined according to the requirement, that the resulting program was applicable to various parallel computing platforms to homogeneous and heterogeneous networks of the automated workplaces.

We shall assume, that completely organized, checked up and tested algorithm of calculation of a supersonic flow of a body of the arbitrary form for the personal computer is used. Time of calculation of a problem for the modern computer of type"Pentium-4" depends on used algorithm, an accuracy of a method and grid number points.

Besides methods of optimization and parallel implementation algorithm the basic strategy for the solution of problems of aerodynamic design on the computer with parallel architecture consists in decomposition of area on a sub-domain in the basic algorithm of calculation. The consecutive algorithm is broken into independently working blocks for which interaction of two additional operations are entered: reception and data transmission. Calculations were carried out with the help of computer complex PARAM 10000 constructed on 12 computing units, each of which is equipped with 2 processors Ultra-Sparc II, thus, total of processors in the given computer complex equally 24.

Finally it's displayed some of results of the CFD applications. The numerical algorithm was constructed in view of use multiprocessors of a complex: on different units variants simultaneously paid off with various initial parameters of a configuration of the aircraft, then aerodynamic characteristics combine on the main processor where the analysis of the received results was carried out. Such algorithm allows not only to reduce time of the calculation, but also facilitates process of the receiving data. Some results of calculations of aerodynamic characteristics are submitted. They show the basic laws of influence of parameters of the shape on its aerodynamics.

The conclusion

Two versions of the codes simulating the flow fields developed: sequential and parallel.

Simulation of 3-D gas flow are carried out within the framework of different mathematical models: inviscid gas, laminar and turbulent boundary layer, a "thin" layer approach that contains all members of Euler and a boundary layer equations, and also on the basis of full Navier-Stokes equations. Solutions of supersonic problems past the conic and blunted bodies under an angle of attack obtained (fig.1).

Reliable and effective parallel computing systems using distributed memory is a key for optimization of complete configurations with repeated recurrence of calculations for the linear and nonlinear restrictions and received at reasonable expenses of time.

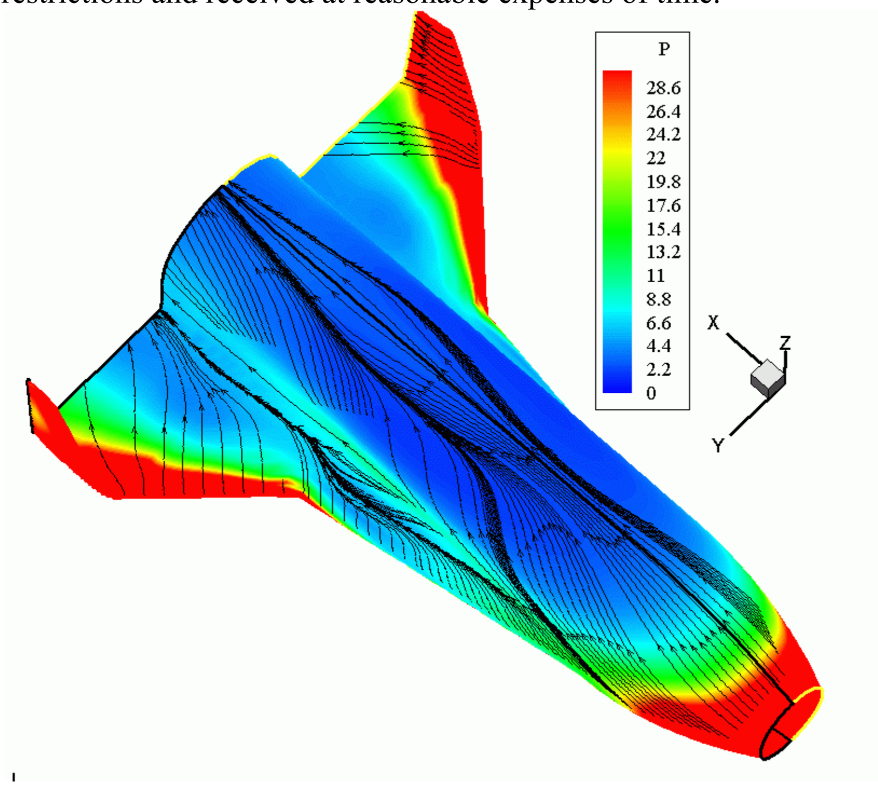

Fig. 1. Pressure distribution and streamlines on leeward side of model of Reusable Launch Vehicle : M=24, $\alpha=15^{o}$.

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