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AN INVESTIGATION OF DESIGN OPTIMIZATION USING A 2-D VISCOUS FLOW CODE WITH MULTIGRID

by

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Computational fluid dynamics (CFD) codes have advanced to the point where they are effective analytical tools for solving flow fields around complex geometries. There is also a need for their use as a design tool to find optimum aerodynamic shapes. In the area of design, however, a difficulty arises due to the large amount of computer resources required by these codes. To carry out a design optimization involving multiple parameters and constraints would most likely lead to a prohibitively large drain on computer resources. It is desired to streamline the design process so that a large number of design options and constraints can be investigated without overloading the system. There are several techniques which have been proposed to help streamline the design process. My work this summer involves an investigation of the feasibility of one of these techniques.

The technique under consideration is the interaction of the geometry change with the flow calculation. Consider the problem of finding the value of camber which maximizes the ratio of lift over drag for a particular airfoil. This is an optimization problem involving one parameter. A starightforward approach to this problem would be to carry out a number of solutions to a flow code for different values of camber over a range of cambers. At each value of camber, the flow code would have to be carried out a sufficient number of iterations so that the solution is fully converged. The computed lift over drag for each solution could then be plotted versus camber. Probably ten different values of camber would be sufficient to generate a curve. The optimum camber could then be found from the curve by inspection. This process requires roughly ten applications of a grid generation program and ten fully converged flow solutions.

Now consider the same problem, but this time, instead of running the flow code to complete convergence after each change in camber, we carry out only a few iterations of the flow solution so that it is only partially converged. This partially converged flow solution is then used as the starting solution for the next grid. In this way, the design process of changing the body geometry is brought inside the flow iteration loop. In the straightforward method described above, the geometric boundary change is made outside of the flow iteration loop. If the lift and drag are fairly well established after a small number of iterations, then this procedure should yield a good approximation to the optimum camber with less computational effort.

In order to test out this technique, a particular optimization problem was tried. We considered a NACA 0012 airfoil at free stream Mach number of 0.5 with a zero angle of attack. Camber was added to the mean line of the airfoil. The goal was to find the value of camber for which the ratio of lift over drag is a maximum. The flow code used was FLOMGE which is a two dimensional viscous flow solver which uses multigrid to speed up convergence. This code was developed by Charles Swanson, Eli Turkel and Antony Jameson. A hyperbolic grid generation program was used to construct the grid for each value of camber.

First the grid was generated for six values of camber betweeen 0 and 12.5 percent. The flow solution was carried out to convergence at each value of camber. The resulting plot of lift over drag vs camber showed that a maximum value of L/D of 67.5 was obtained at a camber of 9.0 percent. It was found that 50 multigrid cycles on the finest mesh were required for convergence. Next the flow solution was run with only ten multigrid cycles on the finest mesh. This solution was used as the starting solution for the next grid. This process was carried out for the same six values of camber as above. The resulting curve showed a maximum L/D of 66.1 at a camber of 9.3 percent. The total CPU time for this case including grid generation was one-third of the time required for full convergence. Thus, a good answer to the optimization problem could be found with a savings in computer effort of a factor of three. The partially converged solutions were also carried out with five and two multigrid cycles. The case with five cylces gave comparable results. The two cycle case was not close to the converged curve although it showed the right trends.

From the above results it appears that the method of incorporating the boundary geometry change into the flow iteration loop is promising and should be given further study. Another area which needs further investigation is the development of a method for moving the interior grid points when a change in boundary shape is made. In the above test case, the grid generation code was run each time a change in camber was made. This is not an efficient way to redistribute the grid points. It would be desirable to have an efficient way to move the interior grid points smoothly when a change in boundary shape is made. One method under consideration was developed by John Batina for treating unsteady flows. In this method, the grid points are considered to be a series of masses connected by springs. The stiffness of each spring is inversely proportional to the distance between points. In this model, the grid is treated as a deformable elastic truss. The method has worked well for triangular meshes. It is hoped that it will prove useful for moving meshes made up of quadrilaterals.