CHAPTER VII

RECOMMENDATIONS

To enhance the applicability of the design optimization strategy to open-channel design, several areas of further research are proposed. First, this design process has been applied to several types of channel transitions that can be simulated with the shallow water equations, but several design issues have not been addressed. For instance, the confluence of two channels, channels with multiple design flows and channels with multiple transitions have not been studied. Second, for two-dimensional simulation of open-channel flows, the results in Appendix E indicate that the boundary conditions based on Manning's friction equation are inadequate, predicting normal depth that is too large. Thus, research into more accurate and consistent boundary conditions and Reynolds stress terms should be considered. Third, this design optimization strategy should be applied to existing three-dimensional free-surface codes **[67,68]** that can simulate flow in a wider range of channels. In some existing codes, fractional step methods have been used to separate the pressure term from the convective terms. Integrating discrete sensitivity analysis within this type of framework where there are multiple Jacobian matrices makes this problem more challenging and remains to be investigated.

To convert this design optimization strategy into a tool that can actually be used by designers, a grid generation interface must be built. In this interface, the user must be able to specify wall boundaries and inflow boundaries. The user must be able to specify fixed boundaries and movable boundaries that are determined by the design variables. Using this information, a structured or unstructured grid should be generated, and all the information should be stored. Special care must be made to generate high precision grids because small perturbations of the design variables are necessary. In this regards, research into the variety of perturbation propagation methods can reduce the computational expense of regenerating these grids for the perturbed design variables, especially for three-dimensional grids, without dramatically reducing the accuracy of the resulting design space derivatives.

In regards to the design optimization strategy presented in this research, the complex Taylor's series expansion method (CTSE) should be applied to an existing explicit flow solver so as to generate the Jacobian matrix. By using CTSE to generate the Jacobian matrix for explicit solvers, the application of discrete sensitivity analysis to explicit codes may be easier and less time consuming than the application of continuous sensitivity analysis to such problems. This combination holds much potential especially because explicit codes are easily parallelized. Thus, the most efficient design optimization strategy may involve the use of a parallel implementation of an explicit flow solver to obtain the steady-state solution for a design, CTSE to generate the Jacobian, which can be done in parallel, and the use of discrete sensitivity analysis to determine the design space derivatives, which can again be parallelized.

The design optimization problem studied in this dissertation is a steady-state design problem. As such, the discrete sensitivity analysis in conjunction with the complex Taylor's series expansion method, may be the most computationally efficient method that yields accurate design space derivatives and that is relatively easy to implement. For unsteady, periodic, or time-dependent problems, research is needed to re-evaluated these methods to consider the computational costs of each method under these different circumstances. A preliminary investigation into the application of discrete sensitivity analysis to time-dependent problems is presented in Appendix A.7.

In this research, the Gauss-Newton method has been used almost exclusively because of the structure of the objective function. Since a satisfactory objective function can be constructed that measures the non-uniformity of the flow in a least-squares sense, the Gauss-Newton method is an obvious choice. For other design applications, such as maximizing the lift coefficient for airfoils, the objective function may not be easily expressed as the sum of squares, and the Gauss-Newton method can not be applied. Thus, Hessian update methods, such as the BFGS method, should be studied, especially focusing on the use of a Levenberg-Marquardt constant. Furthermore, these optimization algorithms need to be re-evaluated for use within time-dependent optimization. Finally, for more sophisticated design problems, constraints will probably be placed on the design variables. Hence, research into efficient constrained optimization is recommended.

The areas of design optimization and of physically accurate two-dimensional and three-dimensional modeling are of great interest in current computational fluid dynamics research. Thus, there are many areas of research to which this design optimization strategy can be applied and many aspects of discrete sensitivity analysis need to be investigated.