Wing Design Using Evolutionary Algorithms

By

Akira Oyama

A dissertation submitted to the Department of Aeronautics and Space Engineering of
Tohoku University in fulfillment of the requirements for the Degree of Doctor of Philosophy

Department of Aeronautics and Space Engineering

March 2000

Abstract

Although Evolutionary Algorithms (EAs) have become increasingly popular in aerodynamic design problems, the previous applications of EAs are restricted to more or less simplified problems involving not more than 10-30 design parameters. In contrast to that, in real-world design problems, a large number of design parameters must be handled – for example, a wing shape for a generic transonic aircraft usually parameterized by more than a hundred of design parameters. Since such problem has a highly multidimensional search space and extremely complicated objective function distribution, standard EAs would fail to find a globally optimum. This research develops a new, robust, and efficient numerical design method applicable to such real-world aerodynamic design problems.

One of the most important difficulties in real-world aerodynamic shape design problems is their highly multidimensional design space. To develop a robust and efficient EA applicable to such design problems, the real-coded ARGAs have been developed by incorporating the idea of the binary-coded ARGAs with the use of the floating-point representation. The performance of the proposed EAs was demonstrated by applying to a typical test function minimization problem and an aerodynamic airfoil shape optimization problem. The real-coded ARGAs consistently found better solutions than the conventional real-coded GAs do.

Because the flow field is governed by a system of nonlinear partial differential equations, objective function landscape of an aerodynamic optimization is often multimodal and nonlinear. To improve EAs' capability of finding a global optimum in such a problem, a crossover operator based on the structured coding has been proposed. The coding structure of the design variables is constructed according to the interaction information among design parameters analyzed by the experimental design. Aerodynamic optimizations of a transonic wing demonstrated that the crossover based on the structured coding was more efficient than the traditional one.

To ensure the capability of the present EA in handling large-scale aerodynamic design optimizations, the real-coded ARGA coupled with the crossover based on the structured coding is applied to an aerodynamic design optimization of a transonic wing shape for generic transport aircraft. Aerodynamic performances of the design candidates are evaluated by using the three-dimensional compressive Navier-Stokes equations to guarantee an accurate model of the flow field. Structural constraint is introduced to avoid an apparent solution of zero thickness wing for low drag in high speeds. To overcome enormous computational time necessary for the optimization, the computation is parallelized on NWT. The designed wing had a good L/D value satisfying the given structural constraint on wing thickness.

Finally, an EA is applied to an aerodynamic wing shape design for a supersonic transport to examine the feasibility of the EA-based optimization in supersonic wing design optimizations. The optimum design obtained from the present approach yielded both the minimum induced drag and the minimum volume wave drag in the given design space. The design also indicated the most important features of supersonic wing design as compared with conventional transonic wing design as follows:

1) Warp geometry based on camber line and twist angle distributions plays a more important role than spanwise thickness distribution because the thickness becomes simply as thin as possible.
2) Because the wing thickness constraint comes from the wing structure, a practical structural constraint will be required.

Acknowledgements

First of all, I would like to thank my thesis advisors, Dr. Kazuhiro Nakahashi and Dr. Shigeru Obayashi for their guidance, support, and encouragement over the last six years. You've guided, supported, and continually motivated me since I belonged to Nakahashi Laboratory. I genuinely feel fortunate to have you as mentors. Thanks are also due to Dr. Hisao Hukunaga for advising me on structural modeling of a wing. I thank Dr. Ian Fejtek of deHavilland Inc. for his help and guidance.

I wish to thank everyone at National Aerospace Laboratory in Japan. In particular, I thank the following key persons to my doctoral dissertation: Mr. Takashi Nakamura, who assisted me for Parallelization on the Numerical Wind Tunnel, Dr. Naoki Hirose, who graciously provided FLO-27 code for aerodynamic evaluations in Chap. 3, and Dr. Kenji Yoshida, who shared his expertise and knowledge in connection with the design of supersonic transport.

I thank my father and mother for their love and support. I would especially like to thank my wife Junko for her patience and encouragement. I also thank my many friends and colleagues for their help and friendship.

Finally, I acknowledge that this research is funded by the Japan Society for the Promotion of Science.

Table of Contents

List of Figures

Figure

List of Tables

Table