GAs for aerodynamic shape design I: general issues, shape parameterization problems and hybridization techniques

D. Quagliarella, A. Vicini
C.I.R.A., Centro Italiano Ricerche Aerospaziali
Via Maiorise — 81043 Capua (Italy)

Abstract

This lecture is focused on the use of genetic algorithms for aerodynamic shape design: some of the important issues related to shape parameterization and representation problems, and the improvement of the genetic search process efficiency. Several shape parameterization techniques are described, and their advantages and disadvantages are outlined. The efficiency issue of genetic search is addressed through the introduction of hybrid search techniques. A description of the hybridization of a genetic algorithm with a gradient based search technique is given. The application examples are related to airfoil and wing design problems.

1 Introduction

Genetic algorithms are quickly becoming a standard tool for aerodynamic shape optimization, due to their interesting features of flexibility, robustness and easiness in setting up a complex design problem. A wide range of design applications has been produced [1, 2, 3, 4, 5, 6], as genetic algorithms are gaining increasing favor and popularity in industrial environments. Nevertheless their widespread application is still hampered by a substantial lack of computational efficiency. Indeed, efficiency, in terms of minimization of computational effort, is a critical issue of aerodynamic shape design, and it is one of the driving forces of technological developments in this field. On the other hand, other desirable aspect of aerodynamic shape design procedures are flexibility and robustness. In terms of development cost of a new product, both efficiency and flexibility play an important role, but, unfortunately, high efficiency is often contrasting with high flexibility in a design tool. This is especially true in aerodynamic shape design problems, where fitness evaluation is the most important part of the global computational effort. Thus genetic algorithms, and in general evolutionary procedures, although offering great robustness and an unparalleled flexibility in setting up the design problem, do not compare favorably with more specialized techniques, such as adjoint based approaches [7, 8], when computational efficiency matters. On the other hand, specialized techniques often lack of flexibility and easiness of use, and are often plagued by poor performance when applied to problems that significantly differ from the ones for which they have been tuned.

Basically, the challenge for the research in design optimization with genetic algorithms is, therefore, the improvement of computational efficiency. Several approaches are currently under investigation, that range from parallel algorithms, to approximated fitness evaluation, to hybrid techniques.

Shape parameterization and handling also plays an important role in aerodynamic design, as it has a deep impact on the efficiency and the effectiveness of any aerodynamic design procedure determining the design space where optimum solutions are looked for.

The present work is focused on the choice of shape description techniques that are best suited for the evolutionary optimization approach to aerodynamic shape design, and on hybrid techniques that may significantly improve computational efficiency.

2 Geometry representation and handling

Shape definition and handling is one of the critical points in any design procedure. Indeed, the number and nature of design variables, as well as the number and type of geometrical constraints that have to be imposed, strongly depend on the technique chosen for geometry definition. At the same time, they univocally determine the design space that will be explored by the search procedure, so that their choice is of fundamental importance for the success of any optimization technique. The 'ideal' shape representation minimizes the number of necessary variables and avoids the imposition of constraints to maintain the shape feasible while preserving a large search space with a sufficient number of dimensions.

Evolutionary procedures, and especially genetic algorithms, are particularly exposed to these problems, as they usually start from a population of randomly generated individuals. Hence, if the shape description technique may easily produce unfeasible individuals, it may become difficult (or computationally expensive) to initialize properly the starting population. Another critical point is the number of variables, that has a direct impact on population size [9]. Therefore, although genetic algorithms can usually cope with problems of big size, a proper shape representation can greatly improve their computational performance.

Of course, an optimal shape representation technique does not exist, and the choice is every time the result of a compromise. Nevertheless some basic criteria can be traced that each suitable method has to satisfy:

- Easy handling of shape perturbation.
- Flexibility in constraint imposition.
- Easiness in local and global changes of the shape.
- Minimal number of design variables requested.

Furthermore, the aerodynamic shape has often to satisfy severe continuity requirements on the derivatives that might be imposed by flow quality problems. The careful consideration of these aspects in the context of the particular problem at hand leads to the choice of the optimal geometry perturbation method.