Multi Criteria Decision Aiding Techniques to Select Designs After Robust Design Optimization

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Abstract. Robust Design Optimization is the most appropriate approach to face problems characterized by uncertainties on operating conditions, which are peculiarity of aeronautical research activities. The Robust Design methodology illustrated in this paper is based on multi-objective approach. When a Pareto approach is used, a Multi Criteria Decision Method is needed for selecting the final optimal solution. This method is tested on an aeronautic case: the design of a transonic airfoil with uncertainties on free Mach number and angle of attack. The final solution is compared with a well known airfoil: the new design performs as the original one , especially concerning lift and drag stability.

Keywords: Robust Design, uncertainties, Multi-Objective, Multi Criteria Decision Making, airfoil.

1 Introduction

Multidisciplinary Design Optimization (MDO) is getting more and more important, especially in the aerospace community. The AIAA Association (American Institute of Aeronautics and Astronautics) has organized several sessions dedicated to the MDO (last session, AIAA 2004) and recently the First Session of MDO for specialists (AIAA, 2005). Consequently the development of numerical methodologies to solve this kind of problems is increasing in importance, in order to help industry during the phases of complex design. It seems useful to remark that designs, in particular in aeronautic fields, are extremely complex, because of the physic model and the huge number of input and output parameters.

One important aspect in industrial design is the management of uncertainties, to find solutions which are not sensitive to stochastic fluctuations of parameters. The name of this design model is Robust Design.

The need of Robust Design method appears in many contests, especially in Multi Disciplinary Design. In fact it is possible to find uncertainties in many different cases. During the preliminary design process the exact value of some input parameters could be unknown or the input parameters could change in the next design phases. Consequently the aim is to look for a solution as less dependent as possible on unknown parameters. Other concerns are to find out solutions which are insensitive to the tolerance manufacturing parameters, to fluctuations in operative conditions or numerical fluctuations in the high fidelity simulation models.

S. Obayashi et al. (Eds.): EMO 2007, LNCS 4403, pp. 619–632, 2007.

The present paper shows a new optimization method that look for solutions which are insensitive to fluctuations, any source they are caused by. The method refers to the statistical definition of stability and is based on a multi objective approach, in particular on Game Theory. It is able to find good solutions for stability and performances.

Finally an important aspect of multi disciplinary optimization is presented: the selection of the most interesting design among those obtained by a Multi Objective Optimization. It is known that a co-operative Game Theory gives a set of solutions (Pareto frontier). In order to choose the final design a Multi Criteria Decision Making (MCDM) algorithm has been adopted.

MCDM is both an approach and a set of techniques, with the goal of providing an overall ordering of designs, starting from the most preferred to the least preferred one. Obviously no one alternative design will be the best in achieving all objectives; in addition, some conflict or trade-off is usually evident among the objectives: costs and benefits typically conflict. MCDM is a way of looking at (and solving) complex problems that are characterized by both costs and benefits. In this work we used an outranking method that allows ranking the alternatives from the best to the worst one.

2 The Idea of Robust Design in Aeronautics

The study of uncertainties in engineering begins with Taguchi (Taguchi, 1978), who codified the methodology for the quality engineering. Taguchi divides the design in three different phases: the firsts one, called system design, determinates the most feasible region for the following numerical optimizations, the second phase, called robust design, determinates the optimal parameter for maximizing the final quality of considered system, and in the third final phase, called tolerance design, a parameter tuning is performed to reach the best possible final solution.

The necessity to study uncertainty is well known in aeronautics; in fact it is possible to cite the definition of uncertainty given on AIAA Guideline (AIAA, 1998):

Definition 1.2. *Uncertainty: A potential deficiency in any phase or activity of the modeling process that is due to lack of knowledge.*

Notice that the uncertainty is defined how a lack of knowledge, which obviously leads to the need of a different approach for studying the model.

From a numerical point of view the study of a model affected by uncertainties could be defined as:

$f: A \times B \rightarrow \Re$ where

- $a \in$ A represents the design parameters chosen by the designers
- $b \in$ B represents the input parameters permeated by uncertainties consequently not controllable by designers.

In (Trosset, 2005) the common uncertainties (parameter b) for external aerodynamic are well described, in particular in the case of two dimensional airfoil design:

1. Uncertainties on geometry parameters due to manufacturing tolerance ε which modifies the geometry parameters in a-ε This situation is deeply explained in (Welch, 1989), where an airfoil with minimum drag over geometrical uncertainties is designed.