High-Fidelity Multidisciplinary Design Optimization of Wing Shape for Regional Jet Aircraft

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Abstract. A large-scale, real-world application of Evolutionary Multi-Criterion Optimization (EMO) is reported in this paper. The Multi-disciplinary Design Optimization among aerodynamics, structures and aeroelasticity for the wing of a transonic regional jet aircraft has been performed using high-fidelity models. An Euler/Navier-Stokes (N-S) Computational Fluid Dynamics (CFD) solver is employed for the aerodynamic evaluation. The NASTRAN, a commercial software, is coupled with a CFD solver for the structural and aeroelastic evaluations. Adaptive Range Multi-Objective Genetic Algorithm is employed as an optimizer. The objective functions are minimizations of block fuel and maximum takeoff weight in addition to difference in the drag between transonic and subsonic flight conditions. As a result, nine non-dominated solutions have been generated. They are used for tradeoff analysis among three objectives. One solution is found to have one percent improvement in the block fuel compared to the original geometry designed in the conventional manner. All the solutions evaluated during the evolution are analyzed by Self-Organizing Map to extract key features of the design space.

1 Introduction

Recent researches on Multidisciplinary Design Optimization (MDO) have been conducted for aircraft design[1, 2]. Pure aerodynamic optimization shows wings with a low thickness-to-chord ratio and a high aspect ratio. These wings suffer undesirable aeroelastic phenomena from the low bending and torsional stiffness. Aerostructural interacted optimization is needed to overcome these phenomena and to perform a realistic aircraft design[3]. This multi-criterion optimization will provide a good application field for EMO.

The project to develop a more environmentally suitable, highly efficient transonic regional jet aircraft has been founded by Ministry of Economy, Trade and

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Industry (METI) since 2003. Mitsubishi Heavy Industries, Ltd. (MHI) is the prime contractor for the project. The aim of this project is to build a demonstrator with advanced technologies, such as low drag wing design, light weight composite structures which are necessary for reduction of environmental burden. The initial aircraft geometry has been obtained from a conventional design method.

The objective of this study is to optimize the three-dimensional wing shape for the proposed regional jet aircraft using evolutionary multi-objective optimization with high-fidelity simulations as a collaboration between Institute of Fluid Science (IFS), Tohoku University and MHI. From the optimization results, tradeoff analysis has been performed among the three objectives. Moreover, by using a data mining technique, the aerostructural design knowledge for transonic regional jet aircraft has been obtained.

In the present study, high-fidelity simulation tools such as Reynolds-averaged Navier-Stokes solver for aerodynamics, NASTRAN, a versatile and high-fidelity commercial software, for structures and aeroelasticity are coupled together for MDO. Although the Euler/N-S solver may be still too expensive for the real-world design environment, it will predict complex and nonlinear flow phenomena such as shock wave and separation more accurately. Such nonlinearity will provide a severe test case for EMO. With the aid of rapid progress in computer hardware, the demonstration in this paper will become a standard design practice soon.

2 Multidisciplinary Design Optimization

2.1 Objective Functions

In this study, because the target range for the regional jet is given, the minimization of the block fuel derived from aerodynamics and structures is selected as an objective function instead of the range maximization commonly used for aircraft design. The block fuel is defined as the minimum fuel mass for the fixed range. In addition, two more objective functions are considered as the minimization of the maximum takeoff weight and the minimization of the difference in the drag coefficient between transonic and subsonic flight conditions.

2.2 Geometry Definition

The design variables define the aerodynamic geometry. Structural optimization and aeroelastic transformation are performed using NASTRAN under the given aerodynamic geometry after aerodynamics, structures and flutter are evaluated, the objective functions are calculated.

The design variables are related to airfoil, twist and wing dihedral. The airfoil is defined at three spanwise cross sections using the modified PARSEC[4] with nine design variables (x_{up}, z_{up}, $z_{xx_{up}}$, x_{lo}, z_{lo}, $z_{xx_{lo}}$, α_{TE}, β_{TE} and $r_{LE_{lo}}/r_{LE_{up}}$) per cross section shown in Fig. 1. The twists are defined at six spanwise locations, and then wing dihedrals are defined at kink and tip locations. An entire wing