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【論文の内容の要旨】

To realize innovative supersonic transport (SST), design knowledge to reduce aerodynamic drag and the impact of sonic booms is required. However, few studies have been conducted on the planform dependency on supersonic wing’s for low aerodynamic drag and low sonic booms. To enhance knowledge on supersonic wings, a highly efficient design method is desirable because simultaneous evaluations of the aerodynamic drag and sonic boom tend to be time-consuming. Thus, this dissertation has two main objectives. The first objective is to understand the planform dependency on a supersonic wing to simultaneously reduce the aerodynamic drag and sonic-boom under cruise conditions. The second is to apply the design method with improved efficiency, which integrates the multi-fidelity approach and the concept of multi-additional sampling, to solve the optimum design problem. This dissertation is divided into five chapters.

Chapter 1 introduces the studies that motivated this study. It also surveys the global situation surrounding SST research and development and optimization methods for aircraft design.

Chapter 2 focuses on drag reduction for two supersonic wing planforms: a cranked arrow wing with a large backward-swept angle and a tapered wing with a small backward-swept angle. For each planform, the optimal airfoil distributions along the span direction were designed under supersonic and transonic cruise conditions. In the design process, the efficient global optimization (EGO) method using a Kriging surrogate model was employed. To realize minimum drag in the entire cruise, the objective functions were the pressure drag coefficients at Mach 1.6 (over sea) and Mach 0.8 (over ground). The design results show that, for both planforms, no trade-off occurred between the objective functions. According to the functional analysis of variance, for both planforms, the design variable contributing the most to drag reduction at Mach 1.6 was the camber height at the kink. However, the design value contributing the most to drag reduction at Mach 0.8 differed between the planforms. In the cranked arrow wing case, it was the camber height at the kink, whereas in the tapered wing case, it was the twisted angle or camber height at the tip.

Chapter 3 presents the study developed based on Chapter 2. It discusses the optimal airfoil distributions for the cranked arrow wing and tapered wing while considering the aerodynamic interference between the engine, fuselage, and wing. The design problems were solved using a multi-fidelity approach consisting of a hybrid surrogate model assisted by evolutionary computation. To evaluate the aerodynamic performance, the compressible Euler equation was used to consider spatial pressure propagation and linearized compressible potential equation to acquire the surface pressure distribution were employed as high- and low-level fidelity solvers, respectively. The objective function was the pressure drag coefficient during the Mach 1.6 level flight. Several geometric parameters of modified PARSEC methods were used as the design variables. By design optimization, the contributions of different cross-sectional parameters to drag reduction were determined. It was found that for both wing planforms, shape of the forward camber and twist angle around the middle of the wing had the most significant influence on drag reduction because most of the aerodynamic force was generated near the wing mid-span. For a wing with a large backward-swept angle, a cross-sectional geometry involving a small positive camber at the leading edge and a small twisted angle were optimum. For a wing with a small backward-swept angle, a cross-sectional geometry involving a negative camber at the leading edge, a small leading-edge radius, and a higher twisted angle than those for a large backward-swept wing were optimum because of the generation of a shock wave at the leading edge.

Chapter 4 focuses on the simultaneous reduction of the drag and sonic boom. A parametric study was performed to investigate the relationship between the sonic boom performance, and backward-swept/forward-swept angle. Using the knowledge gained from these parametric studies, optimal airfoil distributions for the forward-swept and backward-swept wings were designed to determine the planform dependency on a low-drag, low-boom wing while considering the airfoil distribution. For the sonic-boom evaluation, the augmented Burgers equation and multipole analysis were applied to the near-field pressure distribution calculated with the Euler simulation to evaluate each sample. However, this process was extremely time-consuming. Thus, a new multi-fidelity approach was developed, which was integrated with a multi-additional sampling concept and was more efficient than the conventional multi-fidelity approach for application to the design problem. Low-drag and low-boom solutions were then obtained for both planforms. It was found that the forward-swept wing can reduce the sonic boom and aerodynamic drag more efficiently than the backward-swept wing. Based on the functional analysis of variance, the design variables that contributed to the reduction of the various objective functions were different.

Finally, Chapter 5 discusses the conclusions of the series of studies. By solving the optimal design problems for several planforms, knowledge regarding the planform dependency on a supersonic wing for the simultaneous reduction of aerodynamic drag and sonic boom during cruising was obtained. In addition, the multi-additional-sampling, multi-fidelity approach was proven to solve these optimization problems more efficiently.