論 文 の 内 容 の 要 旨

論文題目　Wind Tunnel Testing Using Multi-Objective Design Exploration and Its Application to DBD Plasma Actuator
(多目的設計探査を用いた風洞実験とプラズマアクチュエータへの適用)

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Wind tunnel testing (WTT) has been the mainstay for aeronautical design since the beginning of the field itself. For example, optimum shape of reusable sounding rocket is studied in Japan Aerospace Exploration Agency (JAXA) using its transonic/supersonic wind tunnel. Our study deals with the dielectric-barrier discharge (DBD) plasma actuator, a promising Active Flow Control device. However, there are a large number of parameters to be determined such as voltage, burst frequency, burst ratio, etc. Traditional design approach using WTT is inefficient because of its trial-and-error method or full grid search which is very time-consuming.

On the other hand, framework of multi-objective design exploration (MODE) is proposed in CAE in 2000s. In MODE, multi-objective evolutionary computation (MOEC) is used to capture Pareto-optimal designs and data-mining techniques are used to extract useful information from those designs. MODE's capability has been shown when it was coupled with numerical simulations and applied to real-world design optimization problems.

Therefore, objective of this study is to propose and demonstrate wind tunnel testing based on MODE and to characterize optimum control settings of plasma actuator for post and deep stall flow conditions using MODE. Experiments are conducted using 2D Low Speed Wind Tunnel at ISAS/JAXA at Reynolds number 63,000 with NACA0015 airfoil. The study is composed of three parts.

The first part deals with the feasibility of MODE framework applied to DBD plasma actuator compared to the traditional Grid Search method. The evaluation criterion are : 1) Maximization of lift, dC_l; and 2) Minimization of drag, dC_d while the design variables are : 1) Voltage, V_{pp}; 2) Number of on waves, N_{on}; 3) Number of off waves, N_{off}; and 4) Base frequency, f_{base}. These two techniques are compared at deep stall condition. Results show that MODE outclasses Grid Search by a large margin : MODE solutions improve each generation to finally form an approximate Pareto-front and most of its solutions are in the vicinity of the front. On the other hand, Grid Search solutions are concentrated in the low performance region and only one of its solution is close to the Pareto-front of MODE.

For the following parts, the evaluation criterion are : 1) Maximization of lift, dC_l; 2) Minimization of drag, dC_d; and 3) Minimization of power, P while the design variables are : 1) Voltage,

V_{pp}; 2) Burst frequency, F^+; and 3) Burst Ratio, *BR*. In the second part, the MODE framework is applied to post stall condition. In this case, flow control authority is achieved rather easily as the voltage required is low and all solutions found are effective. For the majority of cases, the increase of V_{pp} beyond 5kV and of BR beyond 11% does not show any benefit. Best performance of the plasma actuator is achieved by non-dominated solutions have which medium V_{pp}~5kV, F^+ between 6.5 to 12 and *BR* from 5.4 to 68%.

Lastly, MODE is applied to deep stall flow condition. The control phenomenon is vastly different as two modes are present : 1) Solutions with F^+ = 0.5 that use large vortex that significantly increase lift at the cost of higher drag; 2) Solutions with higher F^+ > 4 that utilize finer vortices that reduce drag but have less of lift increase then F^+ = 0.5 solutions. As F^+ increases, both lift and drag decrease. Obviously, F^+ is the main factor determining the type of control regime. Generally, solutions with highest V_{pp}~7.5kV and medium *BR* (<30%) are effective, especially for high F^+ solutions. As the flow condition is more severe than before, it can be expected that optimal V_{pp} is close to maximal value.

PIV experiments were performed to characterize the laminar separation bubble for key solutions for both post and deep stall conditions and data mining of the obtained results was done.