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主 論 文 の 要 旨

論文題目: **Numerical Simulation of a New Method for Vortex Shedding Suppression on Turbine Blades**
(タービンブレードにおける新しい渦はくり抑制法に関する数値計算)

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論 文 内 容 の 要 旨

The performance of a gas turbine can be improved by minimizing component losses. The wakes of a turbine blade have an unsteady characteristic called vortex shedding. Vortex shedding contributes different loss mechanisms and is significant under high-speed conditions. Losses can be reduced by optimizing the blade geometry (shape) or by employing additional flow control techniques.

This research started with the development of CFD numerical code. The three-dimensional, Reynolds-averaged, compressible unsteady Navier–Stokes equations are solved. The Spalart–Allmaras turbulence model with Delayed Detached Eddy Simulation is used. Pre-processing of this simulation has been carried out using Gridgen Version 15, and post-processing has been visualized using Fieldview Version 16. The configuration of the blade is similar to the

experiment conducted by Professor C.H Sieverding from Von Karman Institute, Belgium. The numerical method is validated by comparing the numerical results with experimental data obtained by Sieverding et al. The validation process gives a good agreement with the experimental results.

In chapter 3, a method for suppressing vortex shedding by connecting the pressure side and suction side via a series of micro through-holes is proposed. The chapter focuses on the effect of the size and location of the multiple micro holes at the trailing edge region on wake vortex shedding. First, the location of the hole was fixed at S/D = ± 0.62, and three different hole diameters, D_h were tested; 0.054D, 0.065D and 0.094D. The flow through each micro-hole is modeled using the Hagen–Poiseuille equation. The result shows that at a fixed location of S/D = ± 0.62, the hole diameter of 0.094D is the most effective among the three diameters. D_h = 0.094D reduced the wake loss by a maximum of 10%, increased the trailing edge pressure distribution by 14% and gave a reduction in wake velocity profile thickness by a maximum of 24% as compared with the base (no hole) case. In addition, a series of micro-holes suppresses the vortex and reduces the pressure drop in the wake at lower distances of x/D. Then, the effect of a fixed diameter hole of 0.094D at three different locations; S/D = ± 0.73, ± 0.62 and ± 0.58 was studied. The best location was obtained at S/D = ± 0.62, where the maximum reduction of average wake loss of approximately 2.6% was achieved, in comparison to the base case (without hole case). The wake loss is sensitive to the size and location of the hole. A micro-hole series of D_h = 0.094D at S/D = ± 0.62 showed the best result among others, and the flow field also showed the suppression of vortex downstream of the blade wake.

In chapter 4, the effect on a number of steady jet holes and their arrangement has been studied in a high subsonic turbine blade. This study focuses on the effect of single, double and triple rows of steady jets on wake vortex shedding, and the pressure around the blade and at the wake. The reaction of the steady jets has been validated with established data under a condition of: transonic flow at Mach Number of 0.8, Reynolds number of 3.0×10^6, and angle of attack of 1.0°. The result revealed that the location of the hole is important: employing a series of steady jet slot-holes at the location of significant pressure difference can reduce the wake loss by a maximum of 13% and increase the trailing edge pressure distribution. Additionally, a double slot-hole series is beneficial in terms of pressure, where the concentrated pressure drop is reduced and surface pressure coefficient, $C_{P,sur}$ is increased by a maximum of 53%. The wake loss is also reduced by 46% in the case of double slots, and the flow field showed that the pressure drop at the wake was successfully eliminated, which led to a reduction in wake loss. In addition, the instantaneous vorticity also showed the strength of the wake vortex was reduced in all jet cases. The findings show that the double slot-hole series is more effective in reducing wake loss and pressure drop than the single or triple slot-hole series.

Chapter 5 describes techniques of making the slot-hole series. One of the techniques suitable for making a micro-hole on a turbine blade is the use of electrical discharge machining (EDM). A turbine blade is normally coated with a non-conductive coating in order to operate under high temperature conditions. In order to perform the EDM process, a conductive layer coating must be applied at the trailing edge area, since EDM requires a conductive surface. The full-scale simulation of this coating process is presented in this chapter. A hybrid computational method, combining FVM (Finite Volume Method) for solving the high-speed flows of compressible gas, and MPS (Moving Particle Semi-implicit) for solving the deformation of the droplet, has been developed. This hybrid method is extended to simulate the plasma spray solving the compressible and viscous gas flow, heat transfer between the droplet and the substrate, and phase change of the droplet. This extension is an innovation, performed for the first time in the present study. The plasma spray processes have been simulated, from the acceleration to the solidification of the droplet on a substrate. The unsteady three-dimensional compressible Navier-Stokes equations are solved. As a result, a new method, coupling FVM and MPS via a virtual boundary method, has successfully been developed. The processes from the acceleration and deformation of a droplet under the influence of the ambient gas flow to the solidification of the droplet on a substrate have successfully been observed. The trend of flatness at the initial temperature of 300K is proportional to $Re^{0.26}$, which is consistent with the experimental result ($Re^{0.2\text{-}0.3}$). The splat shape results also agree well with the results of previous studies using the VOF method.