Oral presentation | Turbulent flow

Turbulent flow-I

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[6-B-04] Parametric Study of Distributed Roughness Effects for Transitional Flow

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Parametric Study of Distributed Roughness Effects for Transitional Flow

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1 Introduction

Innovative technologies to improve aircraft aerodynamics are needed to reduce environmental impact and achieve sustainable air transportation in the face of future aviation demand growth. In general, surface friction drag is one of the most significant aerodynamic drag farm for commercial aircraft. Therefore, it is expected that methods to radically reduce surface friction drag will be developed. Tani proposes that hydrodynamically smooth roughness (Distributed Micro Roughness, DMR) has the effect of reducing friction drag [1]. The smooth roughness is the roughnesses lower than low viscosity ($Re_k < 6$) . In recent years, with the development of numerical and measurement techniques, the characteristics of distributed micro roughness (DMR), including smooth roughness, has been analyzed. Several studies have been shown that changes in friction drag are greatly affected not only by the height of the DMR but also by its shape. [2] have been analyzed the mechanism by which DMR reduces friction drag by performing DNS for the spanwise uniform sinusoidal roughness surface, the sandy roughness surface based on the actual sandpapers, and the randomly arranged roughness surface based on the Gaussian distribution. The results suggest that there is a certain relationship between the wavelength of roughness and the growth rate of Tollmien-Schlichting (T-S) wave. On the other hand, artificially creating a roughness shape that exceeds the friction drag reduction effect of a rough surface on sand by sandpaper has not yet been realized. In this study, a parametric study of the flow over the distributed roughness will be performed. From the analysis of DNS data, the mechanism by which the DMR reduces friction drag is clarified and the shape of roughness that is more effective in reducing friction drag is proposed.

2 Problem Settings

The analysis targets are the flow near the wall surface with the smooth surface and the DMR. Figure 1 shows an overall flow field. The Reynolds number is set to $Re_{\delta_s} = 3535$ based on the boundary layer thickness at the inlet boundary δ_s. Note that the physical quantities with subscript δ_s are normalized by δ_s. The lengths in the streamwise, spanwise, and wall-normal direction are set to $L_{x,\delta_s} = 56.5$, $L_{y,\delta_s} = 11.3$, and $L_{z,\delta_s} = 28.3$, respectively. At the inflow boundary, a artificial disturbance is added to induce T-S wave. Each roughness is randomly distributed in the range of $2.8 \leq x_{\delta_s} \leq 42.4$. The density of roughness is expressed as ρ_{δ_s}, the number of roughness vertices per standard area. The shape of roughness is defined by a Gaussian function. Therefore, the wall shape of DMR is expressed by the following equation using the height h from the reference surface. In the present study, the diameter and height for each roughness are set to $\phi_{\delta_s} = 1.0$ and $h_{\delta_s} = 0.141$, respectively. The density of roughness are set to $\rho_{\delta_s} = 1, 4, 9, 25$.

$$h(x, y) = \sum_{i=1}^{N} \alpha_i \exp\left(- \frac{(x - x_i)^2 + (y - y_i)^2}{2\sigma^2} \right) \tag{1}$$

3 Numerical Methods

The governing equations the fluid dynamics are the unsteady three-dimensional compressible Navier-Stokes equations. In-house code LANS3D is used for solving the equations. Figure 1 shows computational grids used in this study. The number of grid points in Zone 1 for the entire computational domain and Zone 2 for the area near the DMR are approximately 60 and 80 million, respectively. The Volume Penalization (VP) method is used for represent the complex three-dimensional shape of the DMR [3]. The vertical wall velocity is added as a artificial disturbance to induce T-S wave.

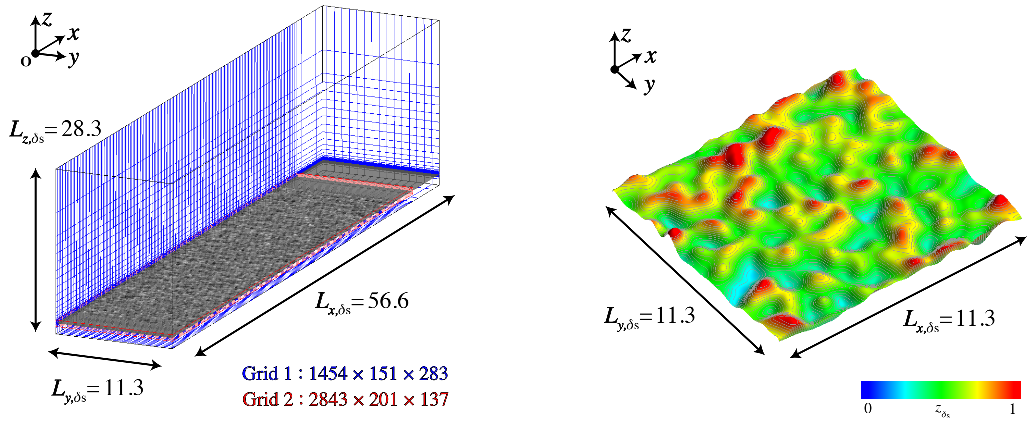

Figure 1: Computational grids and an example of gaussian roughness surface ($\phi_{\delta_s} = 1.0$, $\rho_{\delta_s} = 1.0$)

4 Results and Discussion

Figure 2 shows the turbulent kinetic energy (TKE) and friction drag coefficient (C_f) integrated along the wall-normal direction at each position in the streamwise direction. In each case of DMR, TKE and C_f are lower toward to the downstream than the case of flat plate. Thus, the effect of C_f reduction by DMR is confirmed. This is due to the promotion of the turbulent transition by DMR. In addition, an approximate positive correlation between ρ_{δ_s} and C_f can be observed. This tendency suggests that ρ_{δ_s} must be lower to obtain a lower C_f. However, a DMR with $\rho_{\delta_s} \sim 0$ is equivalent to Flat Plate. Therefore, a more detailed understanding of the mechanism is essential for the adjustment.

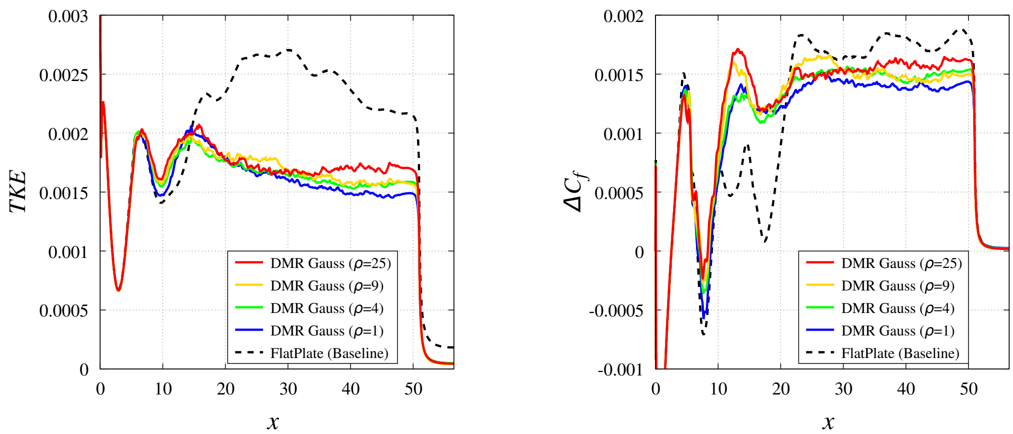

Figure 2: Friction drag coefficient (C_f) and Turbulent kinetic energy (TKE) integrated along the wall-normal direction at each position in the streamwise direction.

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