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Numerical Study of Turbulent Drag Reduction over Riblet Surface

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ABSTRACT

The paper focuses on numerical investigations of the characteristics of turbulent drag reduction over longitudinal riblet surface plate using the commercial software Fluent. The effects of riblet shape, depth and space, which are the main factors affecting drag reduction, are further analyzed after the numerical model is validated using the theoretical results and experimental data. Through numerical modeling, the distribution of velocity and vortices in near-wall fluid field are gotten, which are combined with the "Second Vortex" theory to analyze the mechanism of the turbulent drag reduction over riblet surface.

KEY WORDS: Numerical simulation; Turbulent boundary layer; Riblet surface; Drag reduction; the "Second Vortex" theory; RSM; Drag reduction efficiency

INTRODUCTION

Applying riblet surfaces is an effective method to reduce turbulent drag. NASA Langley research center started his research work on tiny longitudinal riblet reduction (Walsh & Anders, 1989). This observation broke the traditional opinion that smoother surface result in smaller drag. Walsh and his co-worker firstly started to study turbulent drag reduction over riblet surfaces (Bacher etc. 1985; Fletcher, 1988; Walsh, 1982, 1983). Based on the measured velocity distribution, Bscher and Smith (1985) numerically simulated this problem through integral of the momentum along the boundary layer. They concluded that the riblet surface may result in a neat drag reduction of 25%. In a similar way, Coustols also concluded that the riblet surface could achieve 10%～15% drag reduction. The technology of applying riblet surfaces has been and is being gradually implemented in practice. For example, AIRBUS Corporation affixed riblet films on the surface of A320 experimental airplane, which saves 1%～2% fuel usage (Li, 2006). In addition, the Germany manufacturer of airplane employed riblet-surface fuselage (Li, 2006). This technique makes planes save 8% fuel comparing to normal ones. In the paper, a mathematical model is established to study the characteristics of turbulent drag reduction over longitudinal riblet surface plate using Fluent.

TURBULENT STRUCTURE AND THE SECOND VORTEX THEORY

The turbulence widely exists in nature and engineering, for instance, the boundary-layer turbulence, pipe and canal turbulence, which are all called wall turbulence. The wall turbulence is directly affected by the wall boundary. Due to the restriction of the wall, the fluid particles near walls, under the action of the viscous stress and the turbulent stress, not only undergo a pulsation along the flow direction, but also undergo a transversal turbulent diffusion. The boundary layer along the normal distance of the wall can be divided into two regions: wall and core field. The former can be further divided into viscous bottom, transition layer and logarithmic rule layer. The field between viscous bottom and transition layer is called near wall region, whose thickness approximately equals twenty percents of the thickness of the boundary-layer. The formation and development of turbulence mainly appear in this region Therefore, it is reasonable to analyze the mechanism of the drag reduction over riblet surfaces through studying the characteristic of the flow in the near-wall.

The most important characteristics of the turbulent structure in the near wall region is the burst phenomenon (Fletcher, 1988). The burst comprises five stages: the low speed fluid ejected from the wall region, the rising of low speed fluid, vibration, burst and sweeping. The burst consumes the energy of the flow over the walls. The basic idea of turbulent boundary layer drag reduction is to avoid the streamwise concentration of low-speed streak, to restrain turbulent bursting and to reduce turbulent dynamic energy.

As indicated above the riblet surfaces may result in lower drag than smooth surfaces, the reason may be explained by using the "Second Vortex" theory, which is based on generation mechanism of turbulence and the turbulent structure in the near-wall field (Li, 2006). For smooth surfaces, the turbulence near the wall generates longitudinal vortexes which may concentrate fluid along spanwise direction and, therefore, reduce the fluid velocity. As a result, a low-speed streak appears and the outward burst occurs. However, the longitudinal riblet surface and the reversely rotating vortex pairs can affect each other. The interaction between them generates a second vortex (as sketched in Fig.1). The development of second vortex could prevent the streamwise