Rewiew of Drag Reduction on Ribs

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Abstract

This paper introduces the current mainstream drag reduction technology on ribs. his structure is rarely used in actual situations in China, so more experiments should be done to compare with simulation. The processing of special structures is more difficult, making it possible to propose new processing techniques. It can be simulated by adding actual working conditions to make the simulated data more reliable, and compared with other drag reduction methods to find the best method for drag reduction.

Keywords

Fluid; Drag Reduction; Rib; Bionic.

1. Introduction

In the ocean, huge but fast-swimming sharks have attracted widespread attention because of the tight and orderly arrangement of scales with a certain regular shape on the skin surface. The scales are lined with fine rib-like structures. Studies have shown that this small rib-like structure can effectively reduce the fluid resistance in the flow.

With the advancing of the times, mankind has gradually abandoned the traditional concept of "the smoother the object, the lower the resistance". Nowadays, more and more studies have shown that there are certain grooves and fins with special structures than smooth surfaces. The drag reduction effect is better. Coupled with its excellent practicability, the structure of various grooves has also become the key for scientists to study how to reduce fluid resistance.

In today's society, with the gradual exhaustion of fossil fuels, improving energy efficiency and protecting the ecological environment have gradually become hot issues. All regions of our country also actively responded to the government's call and actively contributed to energy conservation and emission reduction. Surface drag reduction technology is one of its key research objects. At present, research on reducing fluid surface resistance has attracted more and more attention from domestic and foreign researchers, experts and scholars. Therefore, the simulation application research on trench drag reduction is of great significance to solve my country's energy problems. This article provides an overview of existing research and makes assumptions about further developments in this area.

2. Research status at home and abroad

At present, with the continuous research on shark scales, the application of the bionic structure of the turtle scale groove structure is mainly concentrated in the following areas:

2.1 Surface of aircraft

The shark scale groove structure has excellent performance in reducing drag and improving efficiency, and has a wide range of applications. Airbus has shark-like scale films on 70% of the fuselages of its A320 and A340 models. Practice has proved that the scale groove drag reduction structure can save
fuel in a small margin. When the flying speed is 0.7 Mach, the flight resistance is reduced by about 5% [1].

2.2 Pipeline transportation
K. Koeltzsch [2] applied a bifurcated groove structure to the inner wall of the pipe to test its flow properties. After the application, the fluid transmission speed of the pipeline is greatly increased, while the volatility is significantly reduced.

2.3 Sports equipment

![Fig. 1 Change curve](image)

**Drag decreasing case** ($s^+ = 25.2$)

**Drag increasing case** ($s^+ = 40.6$)

*Fig. 1 Change curve*
The famous sports equipment manufacturer SPEEDO combines swimsuits with shark scales to create a bionic shark skin swimsuit. When the athlete puts on the shark skin swimsuit, it greatly reduces the resistance caused by the water when the athlete moves forward. Achieved excellent results\cite{3};

In 1980, scientists discovered the structural characteristics of the non-smooth scales of the rough skin of sharks for the first time, and conducted experimental studies on them, and found that they did reduce the resistance of their fluids\cite{4}. Subsequently, many scientists began to study various aspects of the characteristics of its scales (Figure 1).

Boomsma\cite{5} in the United States compared the drag reduction effect of grooved bionic shark skin surface and microgrooved bionic shark skin surface through numerical simulation. The results show that under the low Reynolds number, the groove surface drag reduction rate can reach 5.2%, and when the scale structures are arranged neatly, the force will increase by 44%, and when the scale structures are staggered, the resistance will increase by 50%.

Walsh M J\cite{6} conducted a hot-wire experimental study on a series of longitudinal grooves on a low-speed turbulent boundary layer, and found that the range of h* and s* is h* ≧ 25, s* ≧ 30, and the symmetrical V-shaped ribs are at h* = s* = 12, the maximum drag reduction rate is 8%.

Lee\cite{7} of Pohang University of Science and Technology in South Korea conducted a visualization experiment on a wing with a V-shaped micro-groove surface. The results show that when the wind speed is 3 m/s and the Reynolds number is 1.54x10^4, the drag reduction rate of the V-shaped micro-groove surface can reach 6.6% relative to the smooth plane; and when the wind speed is 9 m/s, the Reynolds number is 4.62 x10^4, the surface of the V-shaped micro-groove did not show the drag reduction effect, but the drag increased by 9.8%. At the same time, the synchronous tobacco method and velocity field measurement technology were used to study the flow field on the surface of the rib with semicircular grooves. The free flow velocity is set to 3 m/s and 5 m/s, respectively, corresponding to the conditions of reducing resistance (s* = 25.2) and increasing resistance (s* = 40.6).

In the case of reduced resistance, since the large-scale longitudinal vortices are larger than the column ridge spacing s* = 25.2, most of the flow vortices stay above the column ridges, and the flow inside the column valleys is sufficiently calm. The vorticity center of the flow vortex is mostly located above the virtual origin, mainly concentrated near the ridge tip. Velocity fluctuations and turbulent flow energies have small values in the viscous sublayer (y*<5). The outer layer (y*<30), they are almost equal to or slightly smaller than those on a smooth plate. However, when the resistance increases (s* = 40.6), the size of the longitudinal vortices is smaller than the ridge spacing, most of the flow vortices stay in the ridges and valleys, and the high-speed disturbance ratio often penetrates into the ridges and valleys. Inside the valley, the flow vortex actively interacts with the increased wetted surface area and increases surface friction. The velocity fluctuation and turbulent flow energy above the rill are larger than that of a smooth flat plate.

German Bechert\cite{8} et al. used a test board with a ridged structure on shark scales for tubing drag reduction test experiments, in which the scaly structures were staggered, as shown in the figure. It was found that the three-dimensional ridged surface can reduce the wall shear stress by 7.3% compared with the smooth plane. At the same time, it was found that the lower the height of the ridge structure, the more obvious the drag reduction effect (Figure 2).

Agrim Sareen of the University of Illinois\cite{9} applied the ribs to the airfoil turbulence zone to study the changes of the turbulent boundary layer under the action of the ribs. The results show that the resistance reduction caused by the ribs depends on factors such as the size and position of the rib membrane, the angle of attack and the Reynolds number. Despite the variables involved, there is an optimal rib size that produces the greatest resistance reduction. Analysis found that the optimal rib size was found to be 62μm. It shows that the ridgeline theory based on flat plate boundary layer can also be applied to airfoil. When applied to turbulent areas, the optimal size of ribs can reduce drag by 4%. In addition, non-ideal rib sizes can increase resistance by 10-12% in some cases. It is also observed that as the rib diameter increases, the most effective Reynolds number of the rib decreases. For different ridge geometry, such as zigzag and skip-tooth arrangement, the optimal ridge size and
performance may also vary. Therefore, making full use of the well-designed airfoil of the rib film technology and carefully selecting the best size ribs based on the understanding of the operating conditions can make it possible to use the ribs and effectively apply them to practical problems (Figure 3).

Greidanus of Delft University [10] verified the existence of different flow regimes through PIV measurement and concluded that the flow regime strongly determines the friction coefficient and resistance performance of the rill. In the Taylor vortex type, the fins create additional drag compared to a smooth surface. For full turbulent flow, the application of thin ribs can reduce the measured torque by 5.3%; the PIV measurement at Reynolds number Res=4.7x10^4 shows that the application of ribs on the inner surface of the cylinder will change the azimuth velocity profile. The velocity gradient of the inner cylinder wall is significantly reduced, which is related to the reduction of turbulence. Under the condition of complete reverse rotation, the change of resistance will produce a rotation effect. The maximum drag reduction rate observed on the inner wall of the cylinder was 5.3%, and the average azimuthal velocity changed by 1.4%.

Zhou Hao of the Chinese Academy of Sciences [11] found that in turbulent conditions, the increase in rib height and the decrease in rib spacing can bring better drag reduction effects. When the rib height = 0.4 mm and the rib spacing = 1.5 mm, the drag reduction effect can reach 33%.

Meng Kunyu of Shanghai Jiaotong University [12] and others used numerical simulation methods to study the drag reduction of wave wall turbulence with different wave amplitudes. The results show that the corrugated wall can reduce the surface resistance within a certain width and wavelength range. Different wavelengths have different drag reduction effects. The wavy wall surface in the downstream direction has a certain drag reduction effect.

Liu Zhihua from the Naval University of Engineering [13] studied the influence of the peak shape of the V-shaped groove on the drag reduction effect, the velocity distribution in the turbulent boundary
layer, and the shear stress of the groove wall. The calculation results show that the smaller the fillet radius at the peak of the groove, the better the drag reduction effect, and the maximum drag reduction rate can reach 6.6%; the wall stress in the middle and lower part of the groove slope decreases with the decrease of the fillet radius, but the local wall stress at the peak will increase accordingly.

Wang Jinjun of Beijing University of Aeronautics and Astronautics [14] embedded a section of grooved plates of different sizes in the smooth flat plates. By analyzing the changes in the velocity distribution and turbulence characteristics of the flow field before and after the grooved plate. It is concluded that the viscous bottom layer of the turbulent boundary layer of the grooved plate is thicker than the upper and downstream smooth plates, and the local friction resistance of the grooved plate is smaller, and the grooved plate has a drag reduction effect. The local resistance is reduced by as much as 13% to 26%. And the maximum local drag reduction is $h^*=16.9$ and $s^*=59$ (Figure 4).

You Lianqing [15] used a numerical simulation method to calculate the drag reduction performance of the groove surface and found that the drag reduction rate was 11% when the top angle of the V-shaped groove was 60°.

Cong Qian [16] of Jilin University and others analyzed the flow field characteristics of the non-smooth surfaces of the triangle, fan and edge grooves, and studied the velocity field and turbulence statistics of the $z=3$ mm plane at the center of the computational domain. The influence of different groove shapes on the drag reduction effect is discussed. Under the condition that the three grooves have the same characteristic size, the apex spacing $s=0.1$ mm, and the height of the groove tip to the bottom of the groove, the drag reduction effect is 3.1%, 9.1%, and 9.7%, respectively, compared with the smooth surface.

Fu Huiping [17] of Northwestern Polytechnical University analyzed the drag reduction characteristics of the striped film and proposed the design criteria for the V-shaped striped film with the best drag reduction effect. The results show that when the small tendon inclination angle $\theta$ is approximately equal to 60. When the stripe film has the best drag reduction effect, the drag reduction can reach 11%.

Tang Shaomeng et al. [18] studied the drag reduction effect in the pipe under different structural parameters and found that $h$ (rib height) = $s$ (rib width) = 0.51 mm symmetrical V-ribbed gas pipeline at a flow rate of 12.5 m/s has the optimal drag reduction effect of 6.5%, and $h=s=0.90$ mm symmetrical V-ribbed gas pipeline starts to increase the drag when the flow rate increases to 7.5 m/s, and at the flow rate At 5 m/s, the optimal drag reduction effect is 2.9% (Figure 5).
Yu Yang et al. [19] found that at the same gas inlet velocity, the shear stress at the top of the V-shaped rib is greater than the shear stress at the bottom of the rib, and the local turbulent kinetic energy near the bottom of the rib is smaller.

3. Conclusion

(1): This structure is rarely used in actual situations in China, so more experiments should be done to compare with simulation;
(2): The processing of special structures is more difficult, making it possible to propose new processing techniques;
(3): It can be simulated by adding actual working conditions to make the simulated data more reliable;
(4): It can be compared with other drag reduction methods to find the best method for drag reduction.

References