Proceedings of the 3rd International Conference on Computing Innovation and Applied Physics
DOI: 10.54254/2753-8818/26/20241049

Study on vortex generator on automobile and airplane

Songlin Li[1], Junwen Shao[2], Yuze Sun[3, 4]

[1]Tsinglan School, Shenzhen, China
[2]Chengdu Foreign Language School, Chengdu, China
[3]Hangzhou No.4 High School International School, Hangzhou, China

[4]18768132206@163.com

Abstract. A vortex generator is a compact device that can be installed on automobiles and airplanes to enhance aerodynamic efficiency. The use of vortex generators on automobiles and airplanes is briefly described in this study. It begins by outlining the working theories and categorizations of vortex generators, which reactivate the boundary layer to postpone airflow separation. Second, this study examines the use of vortex generators on automobiles and trucks, positioned at the back of these vehicles to reduce air drag and improve fuel efficiency. Studies show that vortex generators can increase vehicle fuel economy by 10% to 20%. This study examines how vortex generators improve airplane efficiency and lift by controlling the airflow above the wings. In general, if a vortex generator's design is appropriate for automobiles and airplanes, it can improve aerodynamic performance. This article lists several sources regarding the use of vortex generators and their benefits. In short, the future development of vortex generators will tend to be intelligent, material optimization, and environmental protection, aiming to provide more efficient, reliable, and intelligent fluid control solutions, and bring greater economic and social benefits to various industrial applications.

Keywords: Vortex generator, boundary layer, airflow separation, drag, efficiency

1. Introduction

In fluid mechanics, when the fluid flows through the object at a certain velocity, due to the viscosity of the fluid, the closer the fluid surface, the slower the fluid speed until it approaches zero, and the same is true of gas. This transition region from zero to velocity is called the boundary layer. As the flow distance becomes longer, the flow velocity in the boundary layer slows down, and the transition region also becomes thicker and thicker. When the thickness reaches a certain level, this layer of slow air is difficult to maintain its own state, and the high-speed air is mixed together to form turbulence. Without boundary layer maintenance, the force of air flow on the object is obviously reduced. However, aircraft need high-speed airflow to maintain lift, especially when taking off at high Angle of attack, boundary layer separation is very easy due to the occlusion of leading edge wing. A vortex generator is a compact device that can be installed on automobiles and airplanes to enhance aerodynamic efficiency. The use of vortex generators on automobiles and airplanes is briefly described in this study. It begins by outlining the working theories and categorizations of vortex generators, which reactivate the boundary layer to postpone airflow separation. Second, this study examines the use of vortex generators on automobiles and trucks, positioned at the back of these vehicles to reduce air drag and improve fuel efficiency. Studies

DOI: 10.54254/2753-8818/26/20241049

show that vortex generators can increase vehicle fuel economy by 10% to 20%. This study examines how vortex generators improve airplane efficiency and lift by controlling the airflow above the wings. In general, if a vortex generator's design is appropriate for automobiles and airplanes, it can improve aerodynamic performance. This article lists several sources regarding the use of vortex generators and their benefits.

2. Related works

2.1. Principle and classification of vortex generators

Early common vortex generators were small aspect ratio wings mounted vertically at a certain mounting angle on the fuselage surfaces (the outer wing section of the airplane, the root of the wing, and the center). The vortex generator can produce wingtip vortices in the oncoming airflow because it artificially generates two airflows, high and low pressure, which create a strong spin when they meet at the edge. The relative strength of these generated wingtip vortices is stronger due to the smaller spreading ratio of the vortex generator itself. This vortex, which is close to the airfoil, can run the full length of the large airfoil because of its better stability [1]. One of the key factors of the vortex generator is the relationship between its height and the thickness of the local advective surface layer, with the turbulent boundary layer thickness below 0.2 being the main region of viscous action. As the velocity increases from zero to about 75% of the outflow velocity, the combined effect of viscous and counterpressure gradients causes the boundary layer to separate in this region [2]. As soon as the flow velocity in this region increases, the boundary layer resistance to separation increases. Therefore, the vortex generator can bring high-speed airflow into the attached surface layer, thus bringing the energy in the external airflow into the attached surface layer and accelerating the airflow flow in the attached surface layer. Thus, the airflow separation of the wing at large head-on angles is delayed.

Depending on the vortex generator controlling the separation of the attached surface layer, it can be categorized into passive and active types. The most widely used type is the passive vortex generator. This type of vortex generator is installed at specific locations. However, it can only delay the airflow separation of the attached surface layer under specific circumstances and play the role of increasing the lift resistance. If there is no airflow separation of the attached surface layer, this vortex generator produces additional resistance. Active vortex generators are vortex tubes that are installed at a certain distance, at a specific angle to the flow direction, with a specific tube diameter, and at a specific jet velocity, in front of an area that is susceptible to flow separation. The vortex generator can control flow separation by adjusting the jet pipe jet speed according to the different operating conditions at the time [2].

Vortex generators are categorized into three types according to their size: normal vortex generators, sub-surface layer vortex generators, and miniature vortex generators. General vortex generators are usually large in size and shape, and some have a height equal to or greater than the thickness of the surface layer in the scene. Although they provide good control of the surface layer, these vortex generators generate high resistance if the surface layer is not separated. Due to its limitations, the normal vortex generator is not used today. The sub-surface layer vortex generator and micro vortex generator size relative to its attached surface layer is smaller, after many experiments, the data results show that its delayed attached surface layer of fluid flow separation effect with the ordinary vortex generator produces a comparable effect, and the resulting resistance is also much smaller than the ordinary vortex generator.

2.2. vortex generators for automotive applications

The Subaru WRX STI has a row of radome-like vortex generators at the rear end of the top of the body, which serves to prevent airflow from separating and creating vortices as it flows down the slope of the roof, thus reducing driving resistance. On some cars and pickup trucks, the vortex generators are mainly used in the rear end of trucks. The rear end of a truck tends to be square, and the edges are essentially sharp. So as the truck is traveling, the airflow through the bay breaks through the boundary layer at the

DOI: 10.54254/2753-8818/26/20241049

edges of the rectangle and creates a vortex. This creates a low-pressure area at the rear of the truck. Such a low-pressure zone significantly increases the resistance of the vehicle while traveling and increases fuel consumption [3]. The main sources of drag in a truck are the underbody, the gap between the front and rear of the semi-trailer, and the rear of the truck. This makes it necessary to apply vortex generators to these areas of the truck. Currently, there are several types of vortex generators for trucks, namely cylindrical vortex generators, elliptical vortex generators, wedge-shaped vortex generators, and fork-shaped vortex generators. All these types can reduce the low-pressure area at the rear of the truck to varying degrees, but which one reduces it more needs to be determined on a case-by-case basis [4].

Airtab USA, for example, can provide vortex generators for large vehicles. A row of vortex generators on the rear side of the cab at the front of their semi-trailers allows airflow to flow more smoothly through the vehicle body, minimizing the amount of vortex generated. Vortex generators can also be applied to the rear of a motorhome, allowing low-speed turbulence at the rear to be directed away from the body to reduce air resistance. Several American truckers have purchased this product and are using it on their trucks.

For vans, a vortex generator is a device that is used to delay gas separation and reduce air resistance in a van. It is usually mounted on the side of the van's body and improves the aerodynamic performance of the van while traveling. A vortex generator works by reducing air resistance by delaying gas separation and reducing the speed of airflow around the van body. It does this by creating a series of vortices on the surface of the bodywork that pulls the air around the bodywork to the surface, thereby delaying gas separation.

The application of vortex generators in trucks can effectively reduce air resistance and fuel consumption. By generating an upward airflow, this small device can create aerodynamic lift when the vehicle is moving, thus reducing tire friction and air resistance, and ultimately reducing fuel consumption. According to relevant studies, the fuel efficiency of trucks can be increased by 10% to 20% after the installation of vortex generators. In addition, the vortex generator can also improve the stability and safety of the vehicle by changing the direction and speed of the airflow, reducing the aerodynamic bumps of the vehicle, and improving driving comfort.

2.3. *Vortex generators in aircraft applications*

For airplanes, a vortex generator can improve the performance of an airplane by increasing its lift and efficiency during flight. First, the vortex generator can produce strong vortices, and this vortex can effectively increase the lift of the airplane. Due to the presence of the vortices, the airflow on the surface of the airplane is disturbed, which results in an increase in the lift force on the airplane. This increase in lift allows the airplane to climb to a higher altitude at the same speed, or to reduce its speed at the same rate of climb, thus making it easier to fly over mountain ranges or enemy lines.

Secondly, vortex generators can also increase the efficiency of an airplane. An airplane generates drag when flying, and this drag drains the energy from the airplane, thus limiting the range and endurance of the airplane. The vortex generator, however, can effectively direct the airflow of the airplane to the rear of the fuselage, thereby reducing drag and increasing the efficiency of the airplane. This increased efficiency allows the airplane to fly farther on the same amount of fuel, or to use less fuel for the same range, thus accomplishing its mission more economically.

In the civil aircraft field, most of the vortex generators are located on the fairings of jet airliner engines and at the front of the wings. During takeoff, the aircraft needs to achieve sufficient lift at a relatively low speed to reduce the distance required for taxiing. Therefore, the pilot needs to increase the angle of approach of the airplane's wings during takeoff. When the angle of approach is greater than a certain value, the air at the rear of the wing is more likely to separate from the surface of the wing, creating a vortex. Such a vortex causes the wing to lose lift and also destabilizes the aircraft. Thus, to stabilize the airflow in the upper part of the wing, a vortex generator can be applied to civil airliners based on the principle of a vortex generator. The vortex generator induces a high-energy airflow outside the boundary layer and brings this airflow close to the surface, replacing the low-energy airflow inside the boundary layer. The airflow close to the surface of the wing is boosted and properly tuned by the

DOI: 10.54254/2753-8818/26/20241049

vortex generator so that the airflow in the boundary layer is less likely to separate. This makes the airplane with the vortex generator less likely to stall at airspeeds and angles of approach that would otherwise cause the wing to stall [5].

Using a vortex generator as the fin on the engine nacelle is also applicable. When the airplane takes off, the engines are elevated above the upper surface of the wing, so the engines block the airflow over the wing, creating turbulence. This fin then acts as a vortex generator to squeeze the air and make it flow more smoothly over the wing. This fin can reduce an airplane's takeoff distance by tens of meters. There are also vortex generators on the wing surface to prevent the airflow from separating from the wing surface [6]. In conclusion, an analysis of the effects of vortex generators on airplanes shows that they can be effective in improving the performance of airplanes by increasing their lift and efficiency.

2.4. New developments in vortex generators

Foldability is an important consideration when disassembling and assembling a vortex generator, as it allows for easy storage and transportation of the device. To realize the folding of vortex generators, some designers have come up with some innovative solutions. For example, a collapsible vortex generator utilizes a multi-folding sheet structure that folds and unfolds through rotational motion. This design allows the device to be easily folded into a smaller size for storage and portability when not needed [7]. There are also vortex generators that utilize bendable materials such as flexible metal sheets or plastics that can be bent or folded when needed. This bendable vortex typically offers greater flexibility and can be adapted to different experimental conditions and needs [8]. Overall, the foldability of vortex generators is important for their utility and convenience. Designers are constantly exploring new techniques and materials to realize more flexible and collapsible vortex generators for experimental and industrial applications.

3. Discussion

A vortex generator is a device used to create vortex currents in a fluid. In the last few decades, vortex generators have been widely used in many fields. The advantages of vortex generators are that they can generate strong eddy currents and control the flow of fluids, which can improve the efficiency and performance of equipment and reduce fuel consumption by reducing air resistance [9]. In addition, it can significantly improve the turbulence of the fluid, making the flow of the fluid more uniform in the pipeline, avoiding dead zones, and thus improving heat transfer efficiency. Moreover, the installation of a vortex generator on the heat transfer surface is a common way of passive enhancement technology of convective heat transfer. The use of a vortex generator to induce vortices to destroy the fluid boundary layer is an effective way to enhance the gas-side heat transfer [10]. However, vortex generators have some limitations. First of all, the operating conditions are highly required, and there are strict restrictions on the speed, viscosity, density, and other parameters of the fluid. Secondly, it requires precise design and manufacturing to ensure its efficiency and safety. The design of a vortex generator needs to consider many factors, such as fluid characteristics, device structure, operating environment, and so on, which increases the complexity of its design and use [11]. Furthermore, the airflow generated by a vortex generator may have adverse effects on the surrounding environment, such as noise and airflow disturbances [12]. In addition, the manufacturing and maintenance of vortex generators also require a lot of resources and manpower. Its manufacturing cost is high [13]. Professional technicians are required for installation and maintenance [14]. At the same time, due to the serious fluid erosion and wear in the working process, it needs to be overhauled and replaced regularly, which undoubtedly increases the use cost. Besides, the performance of the vortex generator is greatly affected by the fluid characteristics. For viscous, corrosive, or precipitable fluids, the working effect will be greatly reduced, and even the equipment may be damaged in serious cases. Therefore, when using the vortex generator, it is necessary to select the appropriate model and operating parameters according to the actual application scenarios. Finally, vortex generators may be limited under certain environmental conditions, such as high temperatures and pressures [15].

DOI: 10.54254/2753-8818/26/20241049

4. Conclusion

Overall, vortex generators in airplanes and trucks are a potential energy-saving technology. In addition, vortex generators are also widely used in various industrial fields, such as petroleum, chemical, pharmaceutical, food processing, energy, and environmental protection. It can be used not only for heating and cooling equipment but also for gas-liquid mixing, dispersion, and emulsification processes. The use of vortex generators can improve the efficiency of equipment, reduce energy consumption, and improve product quality, to achieve energy conservation and emission reduction and sustainable development of industrial production. However, further research and development is needed to fully utilize its advantages and address its limitations. In recent years, with the continuous progress of science and technology, the future development prospect of vortex generators is very broad. First of all, with the continuous development of digital technology, eddy current generators will gradually realize intelligence. The future vortex generator will realize more accurate control and regulation of fluid through advanced sensors and algorithms, and improve the utilization rate of fluid and energy saving effect. Secondly, with the continuous development of material science, the material of the vortex generator will be further optimized. The new material will make the vortex generator more portable, durable, and economical, and can meet the needs of more complex and demanding working environments. Finally, the future development of vortex generators will also focus on green environmental protection. With the continuous improvement of global environmental awareness, future vortex generators will pay more attention to environmental protection and energy-saving design to reduce the impact on the environment. In short, the future development of vortex generators will tend to be intelligent, material optimization, and environmental protection, aiming to provide more efficient, reliable, and intelligent fluid control solutions, and bring greater economic and social benefits to various industrial applications.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] G.Vasantha Kumar, K.Sathiya Narayanan, S.K.Aravindhkumar, S.KishoreKumar. Comparative Analysis of Various Vortex Generators for a NACA 0012 Aerofoil. International Journal of Innovative Studies in Sciences and Engineering Technology (IJISSET). 2(5), 6, 2016.

[2] Huang Hongbo, Lu Fang. Development of eddy current generator applications. Journal of Wuhan University of Technology (Transportation Science & Engineering). 35(3), 611-612, 2011.

[3] Sanjay D. Patil, Vikas T. Mujmule, Ajay P. Mahale, Suhas A. Jagtap, and Ganesh S. Patil, “Effects of Vortex Generators on Aerodynamic Drag Force in the Hatchback Type Car”, ARAI J. Mobi. Tech., 2(2), 183–191, 2022.

[4] K. M. Hsu, & K. M. Fan. Effects of eddy current generator on aerodynamic drag reduction characteristics of heavy trucks. Journal of Chongqing University. 012, 043, 2020.

[5] Tsipenko, V. G., & Shevyakov, V. I. About the Use of Vortex Generators to Improve Aircraft Aerodynamics. Russian Aeronautics, 65(1), 165-172. 2022.

[6] Tsipenko, V. G., Sagaydak, M. V., & Shevyakov, V. I. The use of vortex generators to improve the take-off and landing characteristics of transport category aircraft. Научный вестник Московского государственного технического университета гражданской авиации, 25(4), 83-95. 2022.

[7] Ding Yonggang, Zhao Kaixuan. A Scalable Eddy Current Generator and Its Operating Method: CN110541869A[P]. 2019.

[8] Zhou Guobin. Enhanced Heat Transfer Element of a Diagonal Cylindrical Wing Vortex Generator: CN101532798B[P]. 2011.

[9] Xu Jianmin. The Influence of Eddy Current Generator on Heavy Truck’s Aerodynamic Drag Reduction Characteristics [J]. Journal of Chongqing University, 12, 41-58. 2020.

[10] Wang Jiali. Study on the effect of vortex generator on flow and heat transfer Dis Hebei University of Technology.

DOI: 10.54254/2753-8818/26/20241049

[11] Zhang Lei et al "Parameter design of eddy current generator based on numerical model", Chinese society of Engineering Thermophysics, 2011.
[12] Han Zhangjing. The Influence of Eddy Current Generator on the Aerodynamic Performance and Noise of Wind Turbines [D]. North China Electric Power University, 2020.
[13] Li Shaowu, Rong Xinghan, Liu Zhiyi. "Application progress of wind turbine vortex generator." Wind Power 5, 6. 2014.
[14] Sergei Nikolaevich nizov. Aerodynamic surfaces, vortex generator arrays, and methods for installing turbine generator arrays. 2021.
[15] Zhang Jinfeng, Wang Jiansheng, Sun Jian. "Heat transfer enhancement characteristics and mechanism of small-scale vortex generators." energy saving technology 24, 3. 2006.