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The Application of Fluid Mechanics in Engineering

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Abstract. Whether an item is popular or not depends largely on its cost performance. For manufacturers, it is very important to create the most high-quality items with the least amount of money. For example, in the case of the same material, what kind of bridge structure is the most material-saving and long-life, what specific design can make the car more fuel-efficient and faster, and what kind of special pipeline design can make the flow of water resources more efficient are problems that manufacturers need to constantly explore, and fluid mechanics can help and solve these problems to a large extent. This paper mainly introduces the application of fluid mechanics in bridge engineering, automobile design, and agricultural production. The author analyzes the working principle of fluid mechanics, including some speculations on the future development direction of fluid mechanics.

Keywords: fluid mechanics, bridge engineering, automobile engineering, agricultural, water circulation.

1. Introduction

From the stone arch bridge that can only cross the creek to the Hong Kong Zhuhai Macao bridge that can cross the sea, and from the initial 0.9-horsepower car with only three wheels to the supercar now at a speed of hundreds of horsepower, it can be seen that the progress of the times is obvious. Comparing these objects, it is not difficult to find that their shapes have undergone thorough changes, and these changes are also closely related to fluid mechanics. Fluid mechanics is a branch of mechanics that studies fluids. Objects, under the general temperature and pressure conditions, can be divided into three states: gas, liquid, and solid. Gases and liquids are collectively called fluids. Many engineering techniques related to fluids regard fluid mechanics as an important scientific theoretical basis, such as the techniques related to aerospace, aviation, navigation, atomic bomb, water conservancy, meteorology, bridges, transportation, power machinery, civil construction, metallurgy, oil and natural gas, and chemical industry. The theoretical basis of these engineering technologies is inseparable from fluid mechanics [1]. This paper explores the relationship between fluid mechanics and the fields of bridge engineering, automobile design, and agricultural production. It also analyzes the application of fluid mechanics in these three fields, which helps to further sort out and supplement the working principle and development prospects of fluid mechanics.

2. Application of fluid mechanics in bridge engineering

The bridge is always subject to the impact of water and wind, and these two fluids will also bring great harm to the bridge. In 1940, Tacoma Bridge collapsed due to vibration. At that time, the bridge was only subjected to a low wind speed of 18m/s [2]. The reason for its collapse is the flutter (large amplitude vibration of an elastic structure caused by coupling of aerodynamic force, elastic force, and inertial force in uniform airflow) and buffeting (irregular vibration of structure or part of structure caused by boundary layer separation or turbulence) [3]. These vibrations are due to the unstable load excited by the shape of the bridge itself and the gusty pulsation of the wind itself. These vibrations will continue to wear and destroy the bridge structure until the service life of the structure is exhausted. At present, the common bridge has a service life of at least 100 years.

Wind resistance is a standard to measure the quality of bridges. A bridge with good wind resistance will be more durable and can experience greater wind erosion. Besides, the wind resistance of the bridge can be greatly improved by changing the design of the bridge. The improvement methods include: (1) the width-to-height ratio of the cross-section of the bridge structure can be increased; (2) the cantilever length is supposed to be increased. The aerodynamic performance of the cantilever section is better than that of the blunt section, and the stability of the bridge structure is proportional to the length of the cantilever; (3) air vents shall be added at the bridge deck. Slotted ventilation can help long-span bridges or bridges with low natural frequencies maintain their aerodynamic stability; (4) restrictors and deflectors should be added. This can change the air flow pattern and reduce the probability of buffeting of the bridge structure.

After implementing these wind resistance measures, the flutter critical wind speed calculation formula (1) can be used to check the wind resistance of the bridge [4].

$$U = \alpha[1 + (\frac{\varepsilon}{\omega} - 0.424\sqrt{\frac{r}{b}\mu})]\omega b \tag{1}$$

U is the critical wind speed, α is the section attenuation coefficient, ε is the torsional frequency of the bridge, ω is the vertical bending frequency, r is the inertia radius, μ is the air mass ratio of the main beam, and b is the half-bridge width.

At the same time, the wind resistance design of different bridge structures is also different. For example, for suspension bridges, wind nozzles can be set at the edges of both sides of the deck to make the section more streamlined, so as to improve the airflow pattern and improve flutter stability; The central slot is used to increase the air permeability of objects, reduce the contact area and force between the bridge deck and the wind, and improve the service life of the bridge. For cable-stayed bridges, when the bridge height is moderate, in order to ensure the integrity and aesthetics of the bridge body, anti-vibration cables and friction sliders can be used to replace the central slot design. When the bridge is too high, dampers can be used to reduce the deck sway, and air nozzles or deflectors can also be used to improve the gas flow pattern.

3. Application of fluid mechanics in automotive design

3.1. Application of fluid mechanics in reducing resistance

The earliest cars adopted a design similar to that of carriages, obtaining a large amount of internal space, but only driving at a low speed. So, people began to study new shapes in an attempt to achieve higher speeds. In 1937, Fernand Porsche designed the "Beetle Car". Later, cars with streamlined bodies were created. From the perspective of appearance, it can be found that the car’s shape has undergone tremendous changes. In fact, these changes are only made to reduce the air resistance suffered by cars [5].

$$F_w = \frac{1}{2}\rho \cdot C_w \cdot S \cdot V^2 \tag{2}$$

In the formula (2), V is the vehicle speed, S is the area contacting the vehicle body with the wind, C_w is the wind resistance coefficient, and ρ is the air density. According to the calculation, the wind resistance coefficient of the old Beetle car is about 0.49 due to its large contact area with the wind, while the wind resistance coefficient received by the streamlined body of the flat sports car is 0.2-0.25.

According to formula (2), it is known that the air resistance is proportional to the wind resistance coefficient, so when the speeds are the same, the air resistance suffered by sports cars is only half of that of the Beetle car. With more advanced engines and transmission systems, the limit speed of the vehicle can be greatly improved.

3.2. Application of fluid mechanics in strengthening stability

When the vehicle is running at a high speed, it will sway from side to side due to the turbulent airflow. At this time, the safety of the vehicle is very important. How to improve the stability of the vehicle at a high speed has become a problem for engineers to consider. According to F=mg and f=μF (f is the friction force, μ is the friction coefficient, and F is the pressure on the ground), it is known that, under the same road surface, the heavier the object is, the greater the friction will be, so that the car can fit the ground more closely and be more stable. On the premise of not sacrificing the speed, it is necessary to create a downward force to increase the friction between the car and the ground, and the downward force is the downward pressure. The airplane also uses a similar principle. By using the Bernoulli effect, the airplane can obtain an upward lift. The upper part of the wing has a certain range compared with the lower part of the wing, so the airflow through the upper part is fast, while the lower part is slow. In this way, the pressure below the wings will be high and the pressure above the wings will be low, thus creating pressure from bottom to top. The front wing of a car can be regarded as the reverse wing of an airplane, so the car will get pressure from top to bottom, thus obtaining greater stability. Taking a race car as an example, its wing is a crucial aerodynamic device. A rear wing that seems like a spoiler is shaped like a wing of an airplane turned upside down [6]. Its main objective is to provide sufficient downforce or negative lift so that the vehicle has increased traction and the vehicle does not lift off at higher speeds [7].

4. Application of fluid mechanics in agricultural production

4.1. Application of the ventilation system

Agriculture includes the production of food crops, cash crops, feed crops, green manure, and other crops. Water and air are indispensable for the survival of crops. In the process of greenhouse planting, the ventilation system will be used to ensure crop yield. It is usually a low-cost method to control the greenhouse climate by detecting the difference between the wind speed and indoor and outdoor temperature to control whether the system starts the fan. In summer, the ventilation system is mainly used to reduce temperature and increase humidity, while in winter, it is used to reduce excessive humidity to ensure the survival rate of crops. In a closed environment, the position of the air inlet and outlet directly affects the gas circulation in the environment and it is an important factor in determining ventilation.

4.2. Application of the siphon principle

In the process of irrigating crops, the difference in terrain often leads to the problem that water resources cannot be easily transported. At this time, a hydrodynamic phenomenon known as siphon can be used. Siphon phenomenon is a common unstable flow phenomenon. The siphon flow channel is widely used in engineering because it has the advantage of obtaining the force source by using the level height difference of liquid [8]. It refers to using the force of liquid level height difference to fill an inverted U-shaped tubular structure (called siphon) with liquid, and then placing the high opening end in a container filled with liquid, so that the liquid in the container will continue to flow out through the siphon to the lower position. As shown in Figure 1, it is a long bent pipe that is used to transfer liquid from a reservoir at a higher elevation to another reservoir at a lower level when the two reservoirs are separated by a hill or high-level ground [9]. Using the siphon principle, water from other water sources can be introduced to irrigate crops or other plants. In addition to agriculture, siphon also plays an important role in other fields. For instance, the rainwater drainage system of buildings, the siphon toilet (water level difference formed by S-shaped drainage pipes), gastric lavage (gastric lavage with gastric tube and siphon solution), etc.

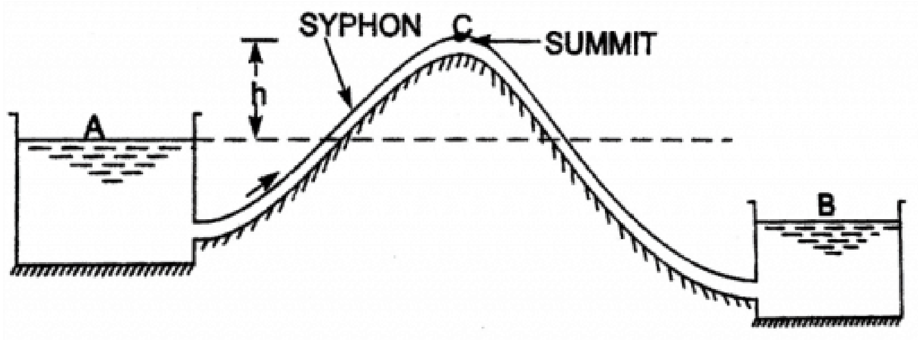

Figure 1. The application of siphon principle in agriculture [9].

5. Conclusion

With the continuous development and research of human civilization, more and more new knowledge is slowly applied to all aspects of life. This paper mainly analyzes the application of fluid mechanics in bridge engineering, automobile design, and agricultural production. In conclusion, fluid mechanics plays a crucial role in the wind resistance design of bridges, drag reduction design and stability enhancement design of automobiles, as well as ventilation and irrigation in agricultural production. Based on the current development of fluid mechanics, it can be inferred that fluid mechanics may be applied in more fields in the future. In addition to the most basic fluid, the abstract data flow (which can improve the computational ability of the fluid itself with the aid of artificial intelligence algorithms and provide a well-documented prediction for the next step. In addition, with the help of the blockchain comprehensive application method, it can realize the interaction between the fluid itself and the outside world and comprehensively measure the fluid walking path), the traffic flow (combined with the traffic flow and relying on fluid mechanics, a transportation model with its own characteristics can be built. According to the time-space characteristics, the scientific attributes of fluid mechanics are embedded into the current traffic, to guide and predict the traffic trend, and to plan ahead for the transportation of subsequent needs), and the electronic flow (whether the chip is designed independently or the integrated circuit is safe and controllable, it can be attributed to the meticulous design of the "electronic flow". The potential energy effect of electric power flow can be quantified and optimized by using the thermodynamic law of fluid mechanics) may also become branches of fluid dynamics in the future. Consequently, fluid mechanics is bound to play a more important role in the future.

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