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Study on wing-tip device technology

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Abstract. Aircraft wings are designed to make airflow to travel faster on top and slower on bottom. The lift force is generated by the pressure difference between the top and bottom of the wing due to the Bernoulli principle. The downwash also provides lift due to Newtons' third law. The wake vortex is the consequence of the production of lift. The spinning turbulent flow at the wing tip creates induced drag, and decreases the total aerodynamic efficiency of the aircraft. A wing tip device is a piece of extension of the wing attached to the wing tip vertically upward or downward. The idea of a wing tip device comes from nature, where engineers reference the wings of different types of birds. The main purpose of this design is to counter and reduce the total drag, allowing aircraft to optimize its aerodynamic performances to reduce fuel consumption. Different wing tip devices based on their structure design have various positive impacts on the aviation industry. In this article, the origin and the applications of wing-tip devices are discussed, offering a reference for the development of wing-tip devices.

Keywords: Wing-Tip Device, Winglet, Global Warming.

1. Introduction

The principle of flight is to create a pressure difference and generate lift that allows the aircraft to levitate in the air. Apart from the pressure difference, modern jet aircraft also change the angle of attack to generate downwash to push the aircraft upward according to Newton's third law. However, designing an aircraft is not that simple. Optimizing aerodynamic efficiency is critical to the aviation industry since the drag will increase the total amount of fuel consumption and carbon dioxide emission, which accelerates global warming.

Global warming is currently a major threat to humans. It is estimated that human activities are responsible for the increase in global temperature compared with pre-industrial levels. It is believed that the increase in temperature is likely to reach 1.5 degrees Celsius in 2030 [1]. Global warming means risk for people near the coastline. Melting glaciers may lead to rising sea levels, causing flooding and forcing people to migrate to other places. There are also impacts caused by wind change and extreme weather. The aviation industry is one of the major contributors to global carbon dioxide emissions which is the main factor in global warming. In 2013, about 5 million barrels of oil are consumed by the global aviation industry every day. This number will become larger due to the continued growth in air traffic flow. For every gram of fuel, there will be an emission of 3.15 grams of carbon dioxide gas [2]. Taking the Boeing 737-400 as an example, the amount of carbon dioxide emission is 115g per passenger per kilometer. If the airplane is cruising at a speed of 780km/h, this is equal to 90 kg of carbon dioxide emission per passenger per hour. The main material for aviation fuel is petroleum, which is a non-

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renewable resource that will eventually run out one day. Modern days, humans rely on air transportation completely. It is important to control the amount of fuel consumption to minimize the harm to our future unless a new power source is invented or humans come out with a cheap way to duplicate petroleum. Providing possible devices that could reduce the total amount of drag exerted on every aircraft is a way of reducing fuel consumption. In this article, the origin and the applications of wing-tip devices are discussed, offering a reference for the development of wing-tip devices.

2. Negative Effect Induced by Lift

When thrust is generated from the engine, it helps the aircraft to move forward, the air will be split at the wing. The air above the wing will travel faster and the air under the wing will travel slower. According to Bernoulli's principle, the pressure under the wing is higher than the pressure above the wing. The pressure difference between the wing surfaces will generate lift to counter the aircraft's weight. Moreover, downwash also contributes to the generation of lift, since the direction of the wing is not designed completely parallel to the ground. According to Newton's third law, the air that goes down also generates some lift for the aircraft. It is known that Bernoulli's principle won't apply under turbulent flow since it has wake vortexes. Compared with the laminar flow, which is stable, and smooth, the turbulent flow is not stable at all, it spins around and does no benefits in the process of generating lift. As a consequence of the product of the lift, the wake vortex increases the amount of drag exerted on the airplane. Since the pressure is lower on top and greater at the bottom, the airflow at the tip will start to spin around causing induced drag, and has influenced the aviation industry for years. Wake vortex also plays a significant role in influencing the operation of aerospace utilities [3]. The wake vortex is invisible and perilous to aircraft during the take-off and landing phases. These two phases share a couple of analogous traits such as low speed, and close to the ground. Since generating lift is difficult when air is influenced by a wake vortex, the chance of stalling is considerably increased. Under this circumstance, there is barely room for error considering there is very little margin for reclamation [4,5]. The wake vortex can be measured with tomography and coherent Doppler lidar (CDL). Both methods are approved by the International Civil Aviation Organization (ICAO) [4]. To prevent airplanes from flying into rolling spinning air, separations are required because the wake vortex won't remain in the air forever. For different plane types, there are different regulations. Take the interval in China as an example, CCAR-93TM-R6, which has been effective since the first of January 2023. It clearly states that, if there is an A380-800 in front of a mid-size aircraft, the separation between them should not be less than 13.0 km.

On the single piece of wing, there are numerous different devices to help the aircraft maximize its aerodynamics. Flaps are used during low-speed operation, leading-edge slats are used to increase laminar flows, and spoilers are used to maximize braking efficiency and assist speed reduction in the air [6]. The wing tip devices such as winglets are designed to reduce the effect caused by the wake vortex.

3. Wing-tip devices for Drag Reduction

The purpose of any wing-tip device is to reduce induced drag since it can counteract 20% of the total drag [7]. The tip device is a piece of upward or downward extension at the wing tip [8,9]. Due to the condition of airport limitations, wing-tip devices are preferred to bend upward. Even though it means extra weight, the amount of thrust needed to counter the induced drag is significantly greater than the thrust needed to deal with these extra weights. Whitcomb brought out the concept of winglets in the late 1970s. He gets his inspiration from birds in an article which is about the flight characteristics of soaring birds and their use of tip feathers to control flight and shows that some birds' wings bend at the tip to reduce the induced drag [8]. Large land birds such as vultures may spread their hand wings, in this way the large wake vortex at the wing tip will turn into many smaller wake vortices that eradicate less energy, meaning a reduction in induced drag [8].

The blended winglet is a type of wing-tip device, which is invented by Boeing. It is an extension of the wing upward vertically attached to the main structure of the wing. The blended winglets are currently used on airplanes like Boeing 737, Boeing 757, and Boeing 767. With blended winglets, there will be a 3-5% reduction in drag. However, the winglet will add about 300 lbs to the aircraft [7].

On the Boeing 747, the wing-tip device is called the canted winglet. The canted winglet is extended upward like winglets but shorter in contrast. They can also be found on the A330 and A340. However, Boeing 747 and A340 are slowly retired and disappear. Spotting this type of winglet is rare [10].

Airbus has its own version of winglets named sharklets. In 2001, a program called the AWIATOR (Aircraft Wing with Advanced Technology Operation) is conducted by the European Union to solve the problem of drag caused by the wake vortex and fuel burn. In 2011, Airbus finally provides the sharklets. Sharklets are used on the A320 family. Airbus also uses the idea of sharklets in the A350 series, even though it is less sharp than sharklets, and extends the total wingspan, bringing more flexibility and better efficiency to the aircraft. For the A320 and the A380, Airbus has another wing-tip device called the wing-tip fence which is invented before the sharklets. Compared with the winglets, the wing fence is smaller in size, and most of the passengers even cannot notice the existence of this device. The wing-tip fence is extended both upward and downward.

There is also similar wing-tip device that works as same as the blended winglet. The Raked wing tip, which has been used on the Boeing 777 series, provides a better drag reduction compared with the winglets. The Raked wing tip is not designed like the winglet device, instead adds an extension at the wing tip vertically, The Raked wing device is connected to the wing tip with a higher angle of sweep compared to the main wing. By doing this, the wake vortex is mitigated and the aspect ratio of the wing is increased [7].

4. Benefits Brought to Aircraft by Wing-Tip Devices

The extra energy will be needed to counter the induced drag caused by the wake vortex, which means much more fuel burn in one flight. Airliners would not like to spend unnecessary money on something like this. Boeing announced that more than two billion gallons of fuel are being saved due to the APB (Aviation Partners Boeing) blended winglet in 2010. They also estimate that in 2014, the invention of the winglets could save 5 billion gallons of fuel. Reducing the amount of fuel burned also means a massive reduction in carbon emissions. Boeing 737 is one of the most successful series of narrow-body civil aviation airliners in the history of civil aviation. Evidence shows that the APB blended winglet on B737 will increase the total range of flight by 5-7% since the amount of drag has been moderated [7]. The blended split winglet or the split scimitar winglet which is an enhanced version of the originally blended winglet has an upward and downward extension at the wing tip. Both of them are designed like backward hooks. This wing tip can provide 1.6% to 2.2% of fuel savings. Based on the split scimitar winglets, the eponymous MAX winglets for the special 737 MAX series have a simpler design. The eponymous MAX winglet basically looks like the split scimitar winglets but without a backward-hook structure. This kind of winglet has a gentler angle to the main wing horizontally [10, 11].

Sharklets, which is the Airbus version of winglets, can also help reduce the effect of the wake vortex for the A320 family and later used on the A350. This device will reduce 3.4% of the total fuel burn and it also responds to 700 tons of carbon emission per aircraft in a year [7]. This device contributes significantly to slowing down global warming.

The Raked wing-tip device is designed by Herrick. The advantage of this device is that it helps to reduce induced drag to save fuel consumption. This device manages to provide a 2% decrease in fuel burn and if conducted to numbers, it is about 1.3 million tons of fuel saved and 3.9 million of carbon dioxide won't be emitted into the atmosphere per year [7]. This device can also reduce take-off field length, allowing the aircraft to land or take off at some of the smaller airports that are equipped with shorter runways making travel more convenient. However, this device has some disadvantages too. Compared with winglet or sharklet devices, the Raked wing tip will add extra length to the wing which means the total wingspan is longer. Making it a problem for Boeing 777 to park at some of the small airports. The plane will need to taxi longer distances to reach some special gates. If two parallel taxiways are designed to have a small separation, when a Boeing 777 is using one of the taxiways, the other one cannot be used, causing airport congestion that can decrease airport efficiency. This also adds limitations

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to the airplane itself, since the airplane cannot accept missions to small airports or airports that are designed with close distance between gates.

Since jet fuel costs highly, and more importantly, it releases extra carbon into the atmosphere. The global aviation industry is responsible for about 915 million tons of carbon dioxide emissions per year [12, 13]. Just reducing a small amount of fuel consumption on every plane will save a massive amount of money and be more environmentally friendly to the earth. Even in different areas such as navigation, cutting the total distance that a plane needs to cover per flight also reduces the amount of carbon emission and fuel consumption. The International Air Transport Association aims to achieve a 50% reduction in carbon dioxide emissions by 2050, making plane travel cleaner[2].

5. Conclusion

Aviation fuels are made from petroleum. Since petroleum is a nonrenewable resource, the costs of aviation fuel are rising constantly. Finding solutions to reduce drag is critical to the entire aviation industry. Aircraft equipped with wing tip devices have better aerodynamic performance than those without. The wing-tip device can reduce a large amount of induced drag, saving the total amount of fuel consumption, and making flight more environmentally friendly and economical. Reducing the total amount of drag also leads to further ranges that the aircraft can travel without redesigning and developing a new aircraft.

Even though devices like sharklets or winglets provide a huge amount of benefit to the aircraft itself, the downside of any wing tip device is the increase in total wingspan. Foldable wing tip technology like the one Boeing 777X used is a good direction for the next stage. This gives aircraft the ability to retract wing tip devices on the ground and extend them before entering the runway. Allowing heavy-weight aircraft to fit in more gates around the world. Wing-tip devices also add extra weights to the aircraft, further research on lighter and stronger materials is also needed.

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