Aviation environmental technology and science

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Abstract: Expatiating on the impact of aviation on the environment and aviation environmental protection projects are expounded, and analyzing on the atmosphere pollution and effects on the aviation noise of aircraft discharge. Researching the approach to control aircraft exhaust pollution and noise pollution, and proposing the technology and management measures to reduce air pollution.

Key words: aviation; aircraft; environment; discharge; noise

1 Introduction

With the development of aviation undertaking, the effect caused by aircraft to the environment is increasingly growing. As aircraft are flying at high altitude, the pollution discharged as a result has more obvious effect on the environment than that discharged on the ground, and more easily leads to greenhouse effect and change of the global climate. As the environment protective consciousness of people is intensified, people pay more and more attention to aircraft noise and pollution discharge. Some regulatory departments are formulating even stricter technical standard, so as to reduce aircraft noise and pollution discharge, thus bringing about a new challenge to the development of aviation technology. At present, people have used technology of aerodynamics, structures and engines, etc., to greatly reduce noise of the jet aircraft, improve flying efficiency and reduce pollution discharge.

In recent 100 years, aviation technology has grown out of nothing, and is continuously perfected. Aircraft are widely used in the areas of communication, transport, military affairs and trade, etc., creating enormous benefit to the society, and promoting the development of the global economy and social progress. According to the statistics by relevant authorities, main airlines across the world own totally 15 271 civil aircraft at present. Although affected by the "9·11" terrorist attack, in 2001, passenger traffic volume of scheduled flights reached 1.62 billion person times, and volume of freight transport reached 29 million tons across the world. According to the forecast made by Boeing Company, in the future 20 years, the passenger traffic volume would be increased at a rate of 4.9 % annually, and the volume of freight transport at 6.4 % in the world civil aviation industry. By 2021, main airlines of the world would own 32 495 aircraft in total[1].

However, with the continuous development of the aviation undertaking, the effect caused by aircraft to the environment is growing increasingly. According to the statistics by Intergovernmental Panel on Climate Change (IPCC) under the United Nations, transport industry accounts for 20 % of the fossil fuel consumed across the world, and the aviation transport accounts for 12 % of the fossil fuel consumed by the transport industry across the world (Fig. 1)[2]. That is to say, carbon dioxide generated by aviation transportation accounts for about 2.4 % of the total volume of carbon dioxide generated through using fossil fuel by humankind. The aviation transport is one of the important factors that contribute to the increase of carbon dioxide content in the atmosphere.

With the increase of people's environment protective consciousness, ground vehicles such as automobiles are gradually using electric power, natural gas and other green energies, and proportion of aviation fuel in the oil consumption across the world will increase every year. As aircraft pollutant is discharged at high altitude, its effect on the atmosphere becomes even greater. Therefore, people pay more and more attention to the environment protective performance of aircraft. For this reason, International Civil Aviation Organization (ICAO) and some governmental organizations are gradually enhancing the regulation standards with respect to the environment protective performance of aircraft. On January 30, 2002, EU Aviation Commission announced that from April 1, civil aircraft as Tu-134, IL-62, IL-76 and IL-86 made by Russia would be prohibited to enter into EU countries because their noise levels were not in conformity with the EU standard. This decision has caused a

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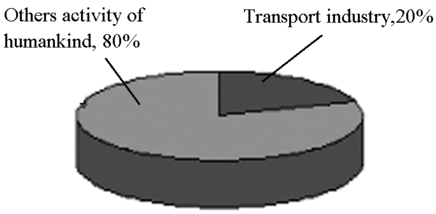
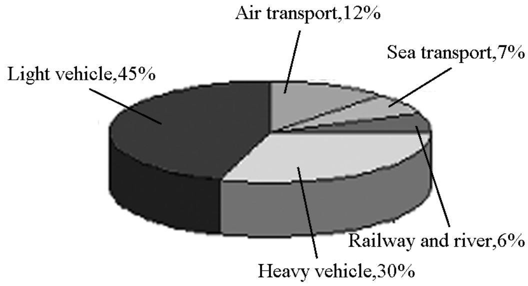
great loss to the Russian aviation manufacturers and transport industry.



The proportion of transport industry to total volume of using fossil fuel by humankind



The proportion of carbon dioxide generated by the aviation transport to world

Fig. 1 Aviation transport is one of the important factors that contribute to the increase of CO_2 content in the atmosphere

In order to promote the implementation of sustainable development strategy and protect the common homestead of humankind, it is necessary to further improve the technological level of aircraft, so as to meet the environment protection requirements of people.

2 Aircraft effect on the environment

Aircraft effect on the environment is mainly reflected by its exhaust pollution and noise. As aircraft are flying at high altitude, pollutant discharged thereof has more serious effect on the atmosphere than that discharged on the ground, and more easily leads to greenhouse effect and change of the global climate. According to calculations, total greenhouse effect created by humankind is about 1.5 times bigger than that of created by carbon dioxide generated by humankind, while the total greenhouse effect created by aircraft is about 2 ~ 4 times bigger than that of caused by carbon dioxide of equal magnitude on the ground. The main reason for this difference is that aircraft emissions such as hydrocarbon, nitric oxides and vapor at high altitude have more evident greenhouse effect than those on the ground.

2.1 Effect of aircraft emissions on the environment

Fuel used by aircraft is aviation fuel. Its exhaust gas is mainly composed of carbon dioxide, nitric oxides, vapor, hydrocarbon, carbon monoxide, oxysulphide and small carbon particles. The main effect of these gases on the environment is to generate greenhouse effect of the atmosphere, and which will in turn affect the change of the global climate.

2.1.1 Carbon dioxide

According to the molecular constitution of the aviation fuel, the aviation fuel of specific mass after it is burnt will produce about 3.15 units of carbon dioxide. The carbon dioxide discharged by aircraft in 1992 was about 514 million tons, which accounted for 2.4 % of the total volume of carbon dioxide generated by all the fossil fuel consumed that year, or 2 % of the carbon dioxide generated by humankind that year. By 2050, total volume of carbon dioxide generated every year by the aviation industry will reach 1 468 million tons, which accounted for 3 % of the total volume of carbon dioxide generated by humankind. Carbon dioxide is the main gas that causes greenhouse effect[3].

2.1.2 Nitric oxides

Nitric oxides are a byproduct generated during burning. It is mainly composed of NO, NO_2 and N_2O, etc. NO is colorless and scentless, and it has a stronger ability to integrate with hematoglobin than CO, thus it more easily causes human body to run short of oxygen. NO_2 is a brown gas, and it can reach the depth of the lung during breathing, causing disease to the respiratory system. Furthermore, NO_2 can also form acid rain, causing damages to the environment.

2.1.3 Vapor

Vapor generated by aircraft can form the wake of cooled particles and high altitude cloud cluster. The wakes and cloud clusters, like greenhouse gases, can partially prevent solar energy reflected by the ground from radiating to the space, thus resulting in greenhouse effect. If there are also sulphate and carbon black generated during burning, the blocking radiation effect of vapor will be reinforced.

2.1.4 Hydrocarbon

Hydrocarbon is more capable of creating greenhouse effect than carbon dioxide. Especially aircraft are normally flying over troposphere or in stratosphere, and the greenhouse effect created by hydrocarbon discharged by them is more evident.

In order to control the effect of aircraft-discharged pollution, in May 1981, ICAO amended the content in Annex 16 of "International Civil Aviation Convention" by adding relevant regulations on pollutant discharged by civil aviation aircraft to the Annex, and required that engines produced after January 1, 1986 should meet these requirements.

These discharge standards mainly involve aircraft takeoff, landing, climbing, approaching and ground taxiing periods, and no specific regulations was set for aircraft cruising period. Since these standards are implemented, carbon monoxide and hydrocarbon discharged by aircraft have been greatly reduced, but nitric oxides discharged by aircraft have not been reduced much (Fig. 2). The main reason for these phenomena is that temperature and pressure in the combustion chambers of engines have a development tendency to increase gradually. To increase the combustion temperature of engines will be helpful for engines to improve their operating efficiency and promote complete fuel combustion, thus reducing the discharge of carbon monoxide and hydrocarbon. However, because of the higher combustion temperature, nitric oxides produced by engines have been increased.

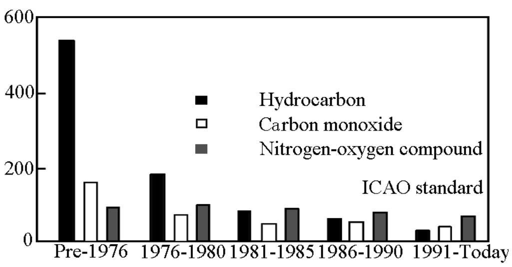


Fig. 2 Percentage of aeroengine's pollution discharge in relation to the ICAO requirements in 1996

In order to reduce aircraft discharge of nitric oxides, ICAO, based on the suggestions of its subordinate body, Committee on Aviation Environmental Protection (CAEP), revised the original aircraft discharge standards. The revised standards didn't change the discharge standards for carbon monoxide, hydrocarbon and soot, but reduced the discharge volume of nitric oxides by 20 %. In 1999, ICAO again raised the discharge standards for nitric oxides, and required that engines produced after January 1, 2004 should further reduce their discharge volume of nitric oxides by 16.5 % on the basis of the standards of 1993 (Fig. 3). Meanwhile, in view of the fact that although an engine of high compression ratio may increase the discharge of nitric oxides, it is contributing to the improvement of the engine overall performance and reduction of carbon dioxide discharge, hence it is permitted to relax the discharge standard of nitric oxides for engines with compression ratio of over 30.

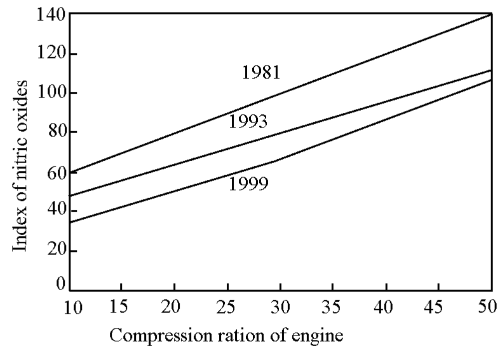


Fig. 3 Evolution of standard set by ICAO with regard to engine discharge amount of nitric oxides

2.2 Effect of aircraft noise on the environment

Based on the different affected targets, aircraft noise can be classified as interior noise and exterior noise. Interior noise not only affects the comfort and health of passengers and flight crew on board, but also produces very strong noise load to the aircraft structure. When sound pressure level of the noise load exceeds 130 dB, it will result in fatigue damages to the structure. The higher the sound pressure level acts on the aircraft structure, the longer the sound pressure level lasts, and the greater damages it will cause to the structure.

Exterior noise mainly affects normal life of the residents near airports or air routes. Generally speaking, exterior noise can be categorized into low frequency noise and high frequency noise. High frequency noise brings more vexation to people than the low frequency noise, and yet most of noise generated by jet aircraft is exactly high frequency noise. Therefore, to control aircraft exterior noise has great significance for improving the living quality of people around the airport.

In addition to the ordinary noise, aircraft sometimes also produces an exterior noise called "sonic boom". Sonic boom takes place mainly because of the shock wave generated during the supersonic flying. The shock wave has very strong energy even after it reaches the ground, so it gives off thunder-like explosive sound. Sonic boom normally lasts very short period, about 350 ms for large supersonic aircraft, and about 100 ms for fighters. If sonic boom is transmitted into a room, it will last longer because of sound resonance caused by multiple reflections. Some high strength sonic boom even can damage the glasses of buildings, causing even greater damages to infrastructures on the ground.

In order to control aircraft noise, FAA formulated aircraft noise airworthiness regulation FAR 36 as early as in 1969. In 1971, ICAO specified aircraft noise standards for application of airworthiness certificates before October 6, 1977 and after October 6, 1976 respectively in Chapter 2 and Chapter 3 of Annex 16 of "International Aviation Convention". Afterwards, ICAO revised and perfected these standards, and required all states to meet the requirements set forth in the standards. With the implementation of these standards and enhancement of the aviation technological level, aircraft noise has evidently taken a turn for better (Fig. 4).

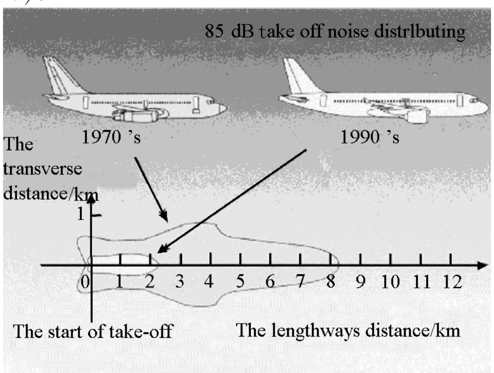


Fig. 4 Development of aviation technology improving aircraft exterior noise

In October 2001, ICAO adopted a new proposal by CAEP to further improve aircraft environment protective performance, and as a result, the requirements on aircraft environment protective performance have been further enhanced. For example, according to the newly formulated standards in Chapter 4, Annex 16 of "International Civil Aviation Convention", aircraft designed after January 1, 2006, their noise level should be further reduced by 10 dB on the basis of the standard set forth in Chapter 3 of Annex 16.

3 Technology of controlling aircraft discharge pollution

In order to reduce aircraft discharge pollution, work can be done from many areas such as technology, management and tax policy. But the most important one is to constantly improve the technological level of aircraft to reduce pollution fundamentally. Among various technologies to reduce aircraft discharge pollution, technologies with respect to engines, aerodynamics, and structure and air traffic control are the most important ones.

3.1 Engine

Since pollution discharged by aircraft is directly from engines, therefore to improve the performance of engines and enhance combustion efficiency can greatly reduce aircraft fuel consumption and greenhouse gases discharge. From 1976 to 1994, with the improvement of aircraft structural design and engine technology, and increase of aircraft seat occupancy, aircraft fuel consumption per seat-kilometer was decreased by 50 % (Fig. 5), which meant that aircraft pollution discharge was also decreased. The improvement of engine technology contributes a major half for this achievement.

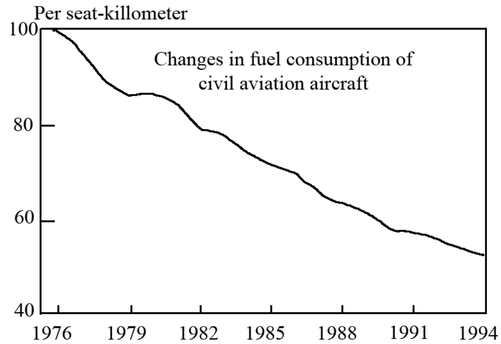


Fig. 5 Changes in fuel consumption of civil aviation aircraft

In the past forty years, technology of aeroengines has made great progress. From turbojet engines to the present turbofan engines of the third generation, fuel consumption of engines has been cumulatively reduced by 40 %. By using new types of engines, fuel efficiency of aircraft can be evidently improved, and carbon dioxide discharge per seat-kilometer can be reduced. Especially for long-haul aircraft, the result is even more evident. As for the short-range route, aircraft with advanced turbo propeller engine is more efficient than aircraft powered by jet engine. The carbon dioxide discharge per seat-kilometer of the former is lower than that of the latter by 20 %.

At present, a new generation of engine with high bypass ratio is being developed; its fuel consumption is expected to be further lower than the present engines by 12 % ~20 % (Fig. 6). However, there is an important technological challenge in developing new type of aeroengines, which is the discharge of nitric oxides. In order to improve engine's operating efficiency, it is necessary to increase engine's compression ratio and combustion chambers' temperature; however, with pressure and temperature increasing in combustion chambers, it is inevitable to lead to increase of nitric oxides (Fig. 7).

Researches show that production of nitric oxides is related to combustion chamber's temperature, pressure and the time period that fuel gas passes through the chambers. By improving flow field of the combustion chamber and fuel-spraying mode, it is possible to reduce nitric oxide discharge by 20 % ~40 %. In addition, by rationally controlling engine's ratio of fuel to air, it is possible to decrease flame temperature and increase airflow velocity, thus reducing the time that the fuel gas dwells in the chambers and production of nitric oxides.

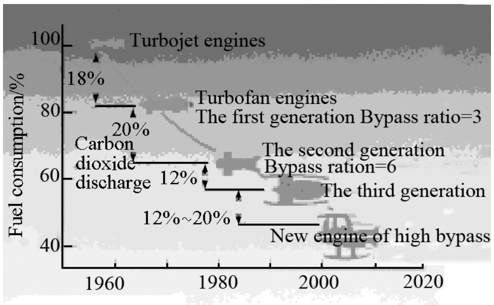


Fig. 6 Change in fuel consumption and carbon dioxide discharge of engines in different ages

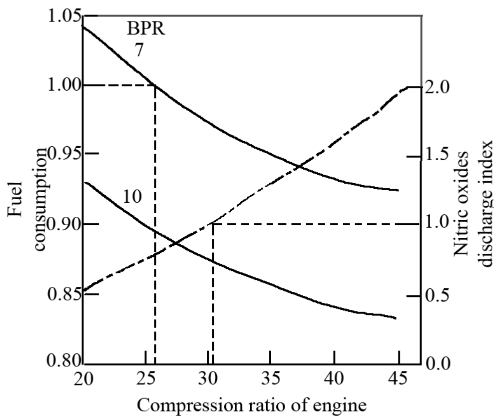


Fig. 7 Relationships between engine fuel consumption and nitric oxides discharge amount and changes of compression ratio

At present, USA and Europe are all energetically developing highly efficient and clean engines. According to the NASA working plan, in the next 10 years, nitric oxides discharge amount of aircraft is expected to be reduced to 1/3 of the present value, and carbon dioxide discharge amount reduced to 75 % of the present value; in the next 25 years, nitric oxides discharge amount shall be reduced to 1/5 of the present value, and carbon dioxide discharge amount reduced to 50 % of the present value[4].

In order to resolve aviation fuel problem after petroleum becomes depleted, people now have already started looking for substitute fuel (e. g. hydrogen) for aviation kerosene. By using these fuels, it will be helpful to solve the aircraft pollution discharge problem. However, there are also some insurmountable problems to use these fuels, for example, the unit volume calorific value of liquid hydrogen fuel is only 23 % of aviation kerosene, for aircraft of the same fuel consumption, its fuel tank will be three times as big as the kerosene tank. Moreover, it is necessary to make a completely new design of aircraft, and replace the present fuel supply, distribution and storage infrastructure fundamentally. Since presently there is no practical alternative option to replace aviation kerosene, therefore, to improve aircraft fuel efficiency is still the key measure to reduce aviation pollution discharge.

3.2 Aerodynamic contour

Advanced aerodynamic technology can reduce aircraft aerodynamic resistance, thus achieving the aim of saving fuel and reducing pollution discharge amount. At present, people are intensifying research work on laminar flow technology and aerodynamic layout of blended wing-body, so as to improve the aerodynamic performance of aircraft. In addition, in the area of aerodynamic contour, technology conducive to the improvement of aircraft efficiency and reduction of aircraft pollution discharge also includes: using advanced passive flow field controller (e. g. vertex generator) to increase aircraft lift, adding winglet to the wing tip, using super critical airfoil to improve and optimize aircraft lift-drag ratio during cruising, using the design method of computational fluid dynamics to carry out aerodynamic design, and using advanced manufacturing technology to improve smoothness of aircraft surfaces, etc. According to NASA's estimation, lift-drag ratio of subsonic civil aircraft in the 21^{st} century will increase by one time than the present, reaching 40.

3.3 Aircraft structure

To reduce aircraft structural weight is conducive to reduction of aircraft fuel consumption, thus reducing aircraft pollution discharge. In future aircraft, more aluminum lithium alloy and composite materials will be used. And aluminum lithium alloy is mainly used in wings and main force-bearing structure of fuselage, and composite materials are mainly used in some secondary structure of aircraft.

In addition to adoption of new materials, to reduce some of not-much-required components of aircraft can also decrease the weight of aircraft. For example, some people proposed to remove thrust reverser from some aircraft. Although thrust reverser can improve takeoff and landing performance of aircraft, it is obviously superfluous for flight missions in well-built airports. If the device is removed, the maximum takeoff weight of aircraft will be reduced by approximately 0.3 % ~1 %, and moreover removal of thrust reverser can also improve the flow field characteristics within the engine. Currently, this proposal is being studied.

Another way to reduce aircraft weight is at the expense of passengers' comfort and enjoyment, for example, to cancel aircraft portholes and recreational equipment, or to reduce the aisle's width and seat pitch, etc. This way of reducing weight may be feasible for short-haul aircraft, but it needs further study to see whether it will be satisfied and accepted by passengers.

In addition, if active noise reducing technology is successful, it is possible to remove some decorations and sound insulation devices from the inside of aircraft, thus reducing aircraft weight.

It is estimated that after these weight reducing measures are comprehensively adopted, the takeoff weight of a medium range wide-body aircraft can be reduced by 2 000 kg. This is approximately equivalent to 1 % increase of engine fuel efficiency.

3.4 Air traffic control

With traffic flow increasingly growing, many airports and air routs across the world have experienced congestion of different degrees. In addition to the insufficient airports and other infrastructures that contribute to the congestion, there is also another important reason, that is, air traffic control systems need further improvement. In Europe, airlines suffered loss of about $ 5 billion in 1999 because of flight delays. Half of the delays were caused by air traffic control system.

At present, with rapid development and gradual application of satellite communication and "free flying" technology of navigation, it is possible to increase air route capacity, shorten aircraft flight range and reduce aircraft waiting time both on the ground and in the air. And as a result, aircraft fuel consumption is decreased.

Since improvement of air traffic control system involves airports, airlines and air traffic managing authorities in many countries, so all states are required to work hand in hand. According to a report by ICAO, if governments of all the countries can formulate proper aviation management framework and improve air traffic control system, the present fleets for international flights will be able to reduce fuel consumption and carbon dioxide by 6 % ~12 % for each flight.

Furthermore, to improve the operating modes of airlines can also reduce aircraft fuel consumption and decrease aviation impact on the environment. At present, main methods can be applied by airlines are as follows: to reduce unnecessary weight on board, to increase aircraft full-load rate, to optimize aircraft flying velocity, to limit use of APU and to shorten aircraft taxiing distance, etc. Generally speaking, these fuel saving measures can reduce aircraft fuel consumption and carbon dioxide discharge by 2 % ~6 %.

4 Technology of reducing aircraft noise

In order to reduce jet aircraft interior noise, it is necessary to reduce its engine noise and airframe noise. As for propeller aircraft and helicopters, it is also necessary to reduce propeller noise in addition to the aforesaid noises. The main method to reduce damages caused by aircraft exterior noise is to rationally plan the land around airports, use even quieter aircraft and adopt noise-reducing means in operation.

4.1 Reduction of engine noise

Engine noise mainly includes turbine noise, combustion chamber noise, fan noise and jet noise, etc. As for turbojet engine, because the airflow exhausted from its jet nozzle has high velocity, so nozzle noise is a main source of the engine noise. Since turbofan engine replaces turbojet engine, the airflow velocity in the exhaust nozzle has been greatly reduced. With the increase of engine bypass ratio, nozzle noise has been gradually reduced. In order to reduce compressor noise, people have adopted such methods as elimination of the guide vanes in the air inlet duct, reduction of the number of fan blades and of rotating speed and improvement of aerodynamic design of blades, etc. And people also have properly selected the number of fan blades and stator vanes to control frequency of compressor noise, so that it will not easily be transmitted to the outside of engine nacelle to form noise. Furthermore, noise liners are also used on engines, so that engine noise has been greatly reduced.

In order to meet even higher environment protective requirements, German Aerospace Institute (DLR) is making researches on active noise control technology (ANC). They are planning to use a system that can generate counter sound wave to reduce the sound wave of the main airflow produced by fan propeller. DLR states that this technology is expected to make the attenuation rate of short passage engines bigger than the conventional passive sound-absorbing device. The American company GE is making researches on a new type of jet nozzle, which, through continuous mixing of hot gas with the ambient atmosphere, can make the energy of high speed jet flow reduce by 50 %, thus reducing noise by 3.5 dB.

4.2 Reduction of airframe noise

During flying, the airframe has friction with the air, changing the air movement. As a result, airframe noise is produced. Airframe noise level is related to aircraft aerodynamic contour, surface roughness and flying velocity. Since 1970s, with the reduction of engine noise, airframe noise has gradually become the main source of aircraft noise. It is impossible to further reduce aircraft noise just by reducing engine noise, and some people even regard the airframe noise as the lower limit of aircraft noise, stating that it is almost impossible to reduce airframe noise.

Until recent ten years, with the help of the powerful tool of computational fluid dynamics, people have had a clear picture about the flow field distribution and change around the key structural components that produce aircraft noise. And people are therefore able to fairly systematically understand the generating and controlling mechanism of airframe noise, so as to seek for solutions to reduce airframe noise. At present, NASA has already used these research achievements to design low noise flaps, and achieved success in model experiment. At next stage, NASA plans to make researches on low noise undercarriages, followed by researches on methods to reduce overall airframe noise.

Furthermore, people are now also making researches on active or passive method to reduce aircraft interior noise. Principle of reducing noise by active method is to place some loudspeakers in certain areas of the aircraft, then use computers to control these loudspeakers to generate sound whose phase is opposite to that of noise signal, thus offsetting the noise. Although this noise-reducing method has now made some progress, there are still some difficulties to overcome. The passive way to reduce airframe noise mainly includes use of sound absorbing materials and shock absorption, sound insulation devices and dynamic mufflers, etc.

4.3 Reduction of propeller noise

Propeller noise is an important source of aircraft noise for helicopters and propeller aircraft. At present, the main method to reduce propeller noise includes increase of propeller blades, reduction of diameters of propeller blades and improvement of profile of propeller blades, etc. Moreover, by increasing the number of propellers, it is also possible to increase frequency of propeller noise. Since high frequency noise attenuates fast in the air, this feature can be used to reduce propeller noise. Fig. 8 shows the relationship between number and diameter of the propeller blades and the far field deci-sound pressure level FL2. From this figure, it can be noticed that under fixed power, with the increase of the number of propeller blades and the diameter of the blades, rotating speed of the propeller has been reduced, hence the deci-sound pressure level decreases rapidly. As for aircraft with multiple propellers, using synchronized technology of propellers can offset noise generated by each propeller, and avoid mutual overlapping, thus reducing overall noise of aircraft.

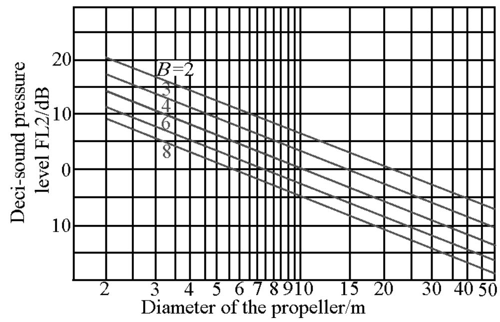


Fig. 8 Relationship among sound level FL2 and rotor blade number *B* and diameter

5 Conclusions

With the social progress and economic development, aviation will play even more important role in the life of human society. Meanwhile, aviation will have bigger and bigger effect on the environment. States across the world have higher and higher requirements on the environment protective performance of aircraft, and ICAO is also formulating new standards on aircraft discharge and noise. This is an opportunity and a challenge as well for the development of our aviation undertakings.

As long as we make early efforts, increase investment in scientific researches, actively develop new high efficient, environment protective and energy saving aviation technologies, and make use of the opportunity created by the entry of WTO to more actively carry out international cooperation, we will be able to reduce aircraft effect on environment to the minimum, and promote the development of national economy and improvement of people's living standards in China.

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