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The research on propeller noise prediction method for turboprop aircraft

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Abstract: Three methods of propeller noise prediction for turboprop aircraft are introduced: the NASA method, the SAE method and the ESDU method .Combined with the noise test results of a turboprop aircraft, the prediction results of different methods are compared and analyzed, including the first five orders sound pressure levels at passing through frequency and the total sound pressure levels. The results show that the SAE method is more suitable for predicting propeller noise. The propeller noise prediction program is written based on the prediction method, which can improve the calculation efficiency and accuracy. The distribution of propeller noise along fuselage is studied. The results show that the propeller rotating plan has the biggest noise, and the farther the focus position from the rotating plane, the smaller the total sound pressure level is.

Keyword: propeller noise, prediction methods, prediction program

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1 Introduction

Cabin noise is a very important index in aircraft design, manufacture and maintenance. The noise environment in the cabin directly affects the comfort of the ride and the safety of the aircraft. On the one hand, the noise environment affects people's conversation and easily causes fatigue of drivers and passengers. On the other hand, the noise environment in the cabin has an impact on the airborne equipment and electronic equipment. The latter may lead to the failure of important equipment and other emergency situations. The turboprop aircraft has low fuel consumption rate, good economy and is suitable for long distance flight. However, the problem of noise in the cabin of turboprop aircraft has always been difficult to solve. This noise control problem of turboprop aircraft has been paid more and more attention by researchers. The propeller noise of turboprop aircraft has the characteristics of low frequency and high energy. There are the dominant factors affecting the cabin noise of turboprop aircraft. At present, the methods to obtain propeller noise load can be divided into three kinds: test method, CFD numerical calculation method and semi-empirical engineering prediction method. The test method cannot overcome the problems of locating sound source, difference between test and real environment and high-test cost. In terms of numerical calculation, it involves unsteady flow field simulation, flow separation and other acoustic source flow field simulation. This method is difficult, time is tight, and accuracy is difficult to guarantee. Semi-empirical engineering prediction method refers to the empirical noise prediction method summarized on the basis of a large number of tests combined with theoretical analysis. Semi-empirical engineering prediction method has a certain theoretical basis, the prediction results are relatively reliable, and the efficiency is very high, which is a very useful method for aircraft engineers.

This paper studies the current propeller noise is expected to NASA, SAE and ESDU methods, combining with the turboprop aircraft propeller noise test data, analysis of the calculation results of different forecast methods, and according to the theory method, compiled the propeller noise is expected to procedures, can be used to guide the turboprop aircraft noise control design.

1 Propeller noise characteristics

The aerodynamic noise of propeller includes periodic noise component and wide-band noise component. The periodic noise refers to the noise at the passing frequency of blade and its multiple frequency, which is caused by the interaction between blade and periodic flow. The broadband noise is caused by the interaction between the blade and the random pulsation of the surrounding flow field.

In general, propeller noise has the following characteristics:

a) the contribution of periodic noise is significantly higher than that of wide-band noise;

b) The main parameters determining propeller noise level are shaft power and tip speed;

c) Under the condition of constant power, increasing the number of blades can increase the blade passing frequency and reduce the propeller noise;

d) In the subsonic range, the increase of tip speed will lead to the increase of noise;

e) Propeller noise has obvious directivity; the maximum noise appears in the latter half at subsonic speed and moves forward to the rotation plane at supersonic speed;

f) Propeller noise in ground driving condition is greater than that in flight condition.

2 Propeller noise engineering prediction method

At present, the commonly used methods for propeller noise prediction include NASA method, SAE method and ESDU method The NASA method, which originated in the Hamilton Standards Division of United Aircraft Corporation, estimates sound pressure levels using a series of curves derived from ground and flight test data, including ground tests for electric drives, and ground and flight tests for piston and turbine engines The method provides a periodic noise correlation curve at the blade passing frequency (thrust and torque noise), which consists of two parts:

Evaluation of near-field noise of propeller

Evaluation of noise in the far field of the propeller (beyond one diameter of the propeller tip)

The definitions of near-field noise and far-field noise are independent of each other.

This method provides all the necessary steps to read the data from the chart, ignoring some factors that may affect noise generation, including:

a) air turbulence interference;

b) flow distortion generated by wings and compressors;

c) Propeller flow and interactions between wings and nacelles;

d) Reflection and diffraction of the fuselage to propeller noise;

e) Compressibility effects of flows

The ESDU 76020 provides a rapid method for the assessment of propeller noise in the early design phase, using test data mostly from bench tests. The scope of application is as follows:

a) Discrete frequency noise of a single propeller or rotor;

b) Ground start-up and low speed flight of helicopters and propeller-driven aircraft;

c) Excluding noise contributions from engine, wing, fuselage and ground reflection;

d) The calculated distance is not more than 150 meters.

The SAE AIR1407 report provides near-field and far-field noise prediction methods for a wide range of propeller aircraft, from small utility aircraft to large commercial transport aircraft. The difference between the calculated maximum sensory noise level (PNdB) and the test is usually within 3PNdB, and the agreement between the calculation and the test is good for aircraft with good aerodynamic design. Generally, aircraft noise is sound pressure level (dB), and its perceived noise level can be obtained by iso-noise curve. When predicting propeller noise, SAE method also divides near-field noise into far-field noise. The definitions of near-field noise and far-field noise are the same as those of NASA method.

3 Computational analysis and application

Based on the aircraft test data in the literature "Research and Verification of Laboratory Simulation Technology of Turbine Aircraft Propeller Flow/Noise", three analysis methods were adopted to calculate the propeller noise of a turboprop aircraft as the analysis object. The results are shown in Fig. 1 and Fig. 2.

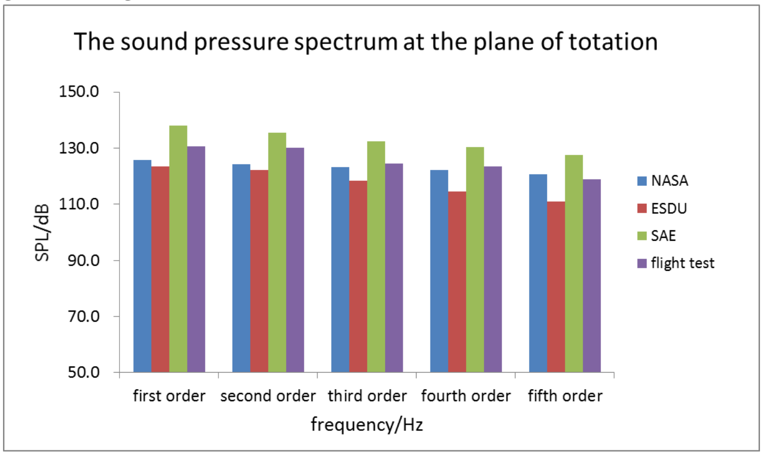

Fig1 comparison of the first five sound pressure levels

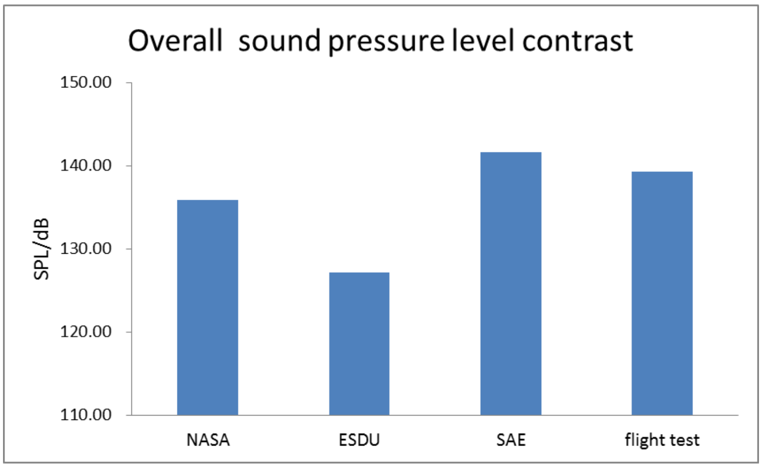

Fig2 overall sound pressure level contrast

The relative errors between the total sound pressure levels calculated by NASA, ESDU and SAE methods and those measured by flight are 2.44%, 8.97% and 1.65%, respectively. All the three methods meet the requirements of engineering application.

At the propeller rotation plane, the sorting results of SPL are as follows: SAE method > flight measurement >NASA method >ESDU method.

Compared with the other two methods, ESDU method has a great difference. The analysis shows that the data of ESDU method are mostly from the ground bench test of propeller, which is mainly applicable to ground driving or low-speed flight. Moreover, the installation effect of propeller and the influence of wing and fuselage reflection effect are not taken into account, so the calculated results are small.

Both the SAE method and the NASA method take account of the effects of airframe reflection, and the calculated results are close to those measured in flight. The SAE method is more conservative, and the total sound pressure level is 2.3dB larger than that measured in flight, while the NASA method is 3.4dB smaller than that measured in flight. From the perspective of spectrum distribution, the first five order noise attenuation of NASA method is relatively gentle, the difference between the first order noise and the fifth order noise is 5dB, the difference between the first order noise and the fifth order noise of SAE method is 10dB, and the difference between the first order noise and the fifth order noise of flight measurement is 12dB. It can be seen that the variation trend of SAE method is in better agreement with the flight measurement.

Through the comparison and analysis of the noise prediction results of propeller engine in flight, the SAE method is relatively conservative and has little error with the measured data. Therefore, this method can be used to evaluate propeller noise of turboprop aircraft. Based on the research results, a calculation program is compiled, and the interface is shown in Figure 3.

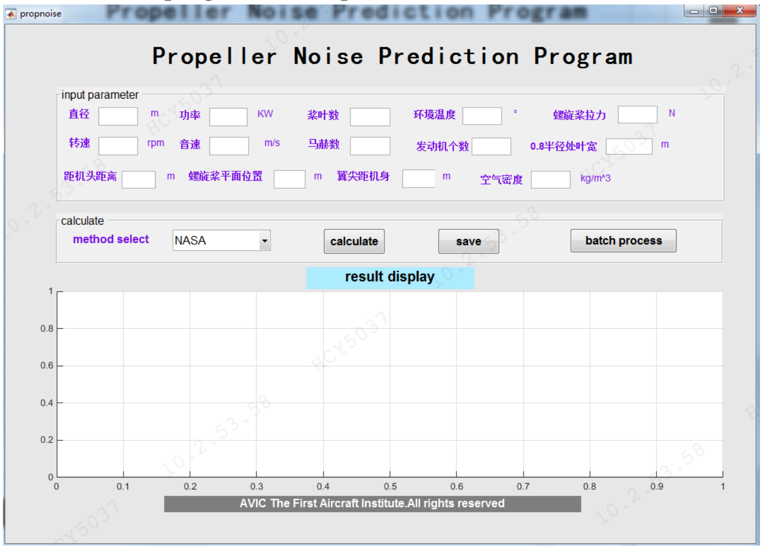

Fig3 program interface

Based on this calculation program, the noise distribution of the aircraft propeller can be quickly given. Fig. 4 is a comparison diagram of the variation of the noise of an aircraft propeller with the distance from the nose based on the SAE method. According to the calculation results, the noise level of the propeller rotating plane is the largest, and the farther from the propeller rotating plane, the smaller the noise level is.

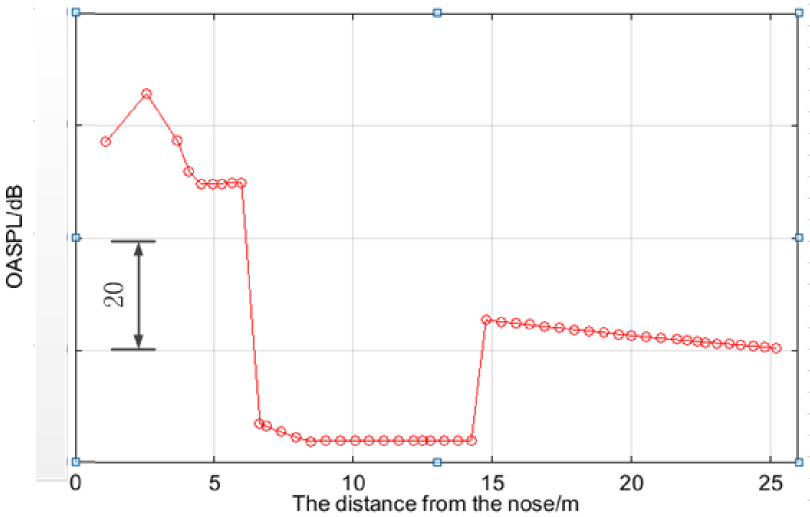

Fig4 The sound pressure level varies with the distance from the nose

4 Summary

According to the noise characteristics of turboprop aircraft, this paper studies the dominant propeller noise and compares and analyzes the commonly used prediction methods of propeller noise in engineering. The SAE method is more suitable for the prediction of propeller noise of turboprop aircraft. Based on the theoretical prediction method, the propeller noise prediction program is compiled, which can improve the calculation efficiency and accuracy Based on the results of the program, the distribution of propeller noise along the fuselage direction is studied, which provides a reference for the design of aircraft noise control.

References

[1] Estimation of the surface pressure fluctuations in the turbulent boundary layer of a flight vehicle，ESDU 75021-2011

[2] Large Civil Tilt Rotor (LCTR2) interior noise predictions due to turbulent boundary layer excitation，NASA/CR-2013-218005

[3] A Review of Aerodynamic Noise from Propellers, Rotors, and Lift Fans，NASA/CR-107568

[4] Prediction Procedure for Near-Field and Far-Field Propeller Noise，SAE AIR1407

[5] Estimation of the maximum discrete frequency noise from isolated rotors and propellers，ESDU 76020

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