Experimental Study on High Speed Two-dimensional Airfoil Based on Conventional High Speed Wind Tunnel Test

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Abstract. The wind tunnel test of two-dimensional airfoil is usually carried out in the special wind tunnel for the airfoil test, but this kind of wind tunnel is usually small in size and low in Reynolds number. On the contrary, the conventional wind tunnel test is generally large in size, in which higher test Reynolds number can be obtained, but there is wall interference and other problems to overcome at the same time. In this study, the RAE2822 airfoil was used to carry out the wind tunnel test of high-speed two-dimensional airfoil in FL-3, which is a large-scale conventional high-speed wind tunnel and the section pressure coefficient was measured. Experimental data after calculation and correction comparing with the standard model data shows that it is practically possible to carry out airfoil wind tunnel test in conventional high-speed wind tunnel.

Keywords: Conventional high speed wind tunnel; RAE2822; Airfoil; Pressure measurement.

1. Introduction
Two-dimensional airfoil wind tunnel test still plays an important role in aircraft development [1], fan blade design [2,3] and ground vehicle design [4]. It is particularly important to carry out wing wind tunnel testing with high Reynolds numbers [5]. The two-dimensional airfoil wind tunnel test is usually carried out in a special airfoil wind tunnel (height of the test section is larger than the width), but this kind of wind tunnel is usually smaller in size and has a lower Reynolds number, which is quite different from the in-flight aircraft airfoil Reynolds number. On the contrary, the conventional wind tunnel is generally large in size. How to use the conventional wind tunnel to carry out the wind tunnel test of two-dimensional airfoil to obtain a higher test Reynolds number and better meet the needs of traffic tools development agencies is a engineering concerned branch in aerodynamic research.

Previous research carried out on the low-speed test of NASA GA (W) - 1 airfoil in FL-12 obtained ideal test results [6]. In the aspect of high-speed wind tunnel test, due to the high-speed energy consumption, the general test section size will be more restricted. On the other hand, some conventional high-speed wind tunnels (the width of the test section is greater than or equal to the height dimension) that undertake the task of aircraft development are large in size, and can be pressurized, through which a large test Reynolds number can be obtained, and more real simulation and verification for the designed airfoil can be carried out.

In this study, RAE2822 airfoil was used to carry out the wind tunnel test of high-speed two-dimensional airfoil in FL-3 high-speed wind tunnel in Aerodynamics Research Institute. Through reasonable design of test scheme together with appropriate calculation and correction of test data, the test results close to
RAE2822 airfoil reference data are obtained, which shows that it is practically possible to carry out high-speed airfoil test in the conventional high-speed wind tunnel.

2. Test Plan
The main purpose of this study is to make RAE2822 high-speed two-dimensional airfoil model with large aspect ratio by using the publicly released RAE2822 airfoil form [7], and to carry out pressure distribution test measurement in FL-3 wind tunnel. By comparing the pressure distribution results measured under typical test conditions with the publicly released pressure distribution results [7], the technology of high-speed two-dimensional airfoil test in conventional high-speed wind tunnel FL-3 is studied for its feasibility.

FL-3 wind tunnel test section is 1.6m in height and 1.5m in width, and the height is slightly larger than the width, which is good for the wind tunnel test of two-dimensional airfoil. The chord length of the airfoil is 0.34m, the span length is 1.5m, and the ration of model span to chord can reach 4.41, which is good for the realization of two dimensional flow on the surface of the model. At the same time, adding end airfoil plates at both ends of the model can ensure that the two-dimensional airfoil has good flow characteristics in the middle region. In order to reduce the influence of the front pressure tappings on the rear pressure tappings and accurately measure the pressure distribution of the airfoil, Three lines of pressure holes in syncline section with $15^\circ$ deflection angle are arranged on the airfoil model. The overall scheme of the model installation in the wind tunnel is shown in Figure 1.

![Figure 1. Installation of high speed airfoil test in FL-3 wind tunnel.](image)

3. Test Equipment and Models

3.1. Wind Tunnel
FL-3 wind tunnel is a blow down transonic wind tunnel. The Upper and lower wall plates of subsonic and transonic test sections plug-ins are straight hole wall plates with opening closing ratio of 22.5%, and both sides are parallel solid walls. The highest pressure in the settling chamber is 0.4MPa, and the highest Reynolds number at Mach 1.0 is $9.5 \times 10^6 (L = 0.1\sqrt{A})$. In this test, a 4.2m-long porous wall test section for subsonic and transonic conditions was used.
3.2. Measurement and Control System

Four psi8400 electronic pressure scanning modules are used in the test. The pressure tubes of the two-dimensional airfoil model are led out from the left and right rotating windows and connected with the electronic scanning modules placed in the chamber to measure the pressure of each pressure measuring point on the airfoil. The range of the electronic scanning module is -15psi ~ 15psi, the working temperature range is -25 °C ~ 80 °C, and the pressure measurement accuracy is ±0.05% of the full range. The total pressure P0 control system has a voltage regulation accuracy of better than 0.25%, M number control accuracy is about 0.002, attack control system range of the half model is -30 ° ~ 30 ° with the accuracy of better than ±2'.

3.3. Model and Support System

The chord length and span length of RAE2822 standard airfoil are 0.34m and 1.5m respectively. There are three chord syncline sections on the airfoil. There are 37 pressure measuring points on the upper surface and 26 pressure measuring points on the lower surface of each profile. 189 pressure measuring points in total. The pressure tubes with an inner diameter of 0.4mm ~ 0.6mm are selected for the airfoil test. In FL-3 wind tunnel, the degree of blockage of the model at α = 0 ° is about 2.5%.

In this test, the layout of the test model pressure measuring points is divided into three categories, five sections: 1. Three oblique sections are arranged along the chord direction of the airfoil, with an angle of 15 °, the middle section is located in the center of the model, and the distance between the left and right chord direction sections is 0.185m; 2. One spanwise section is arranged along the span direction of the airfoil, with a chord position of 40%, and one pressure measuring point is arranged between every 0.03m. This section is only arranged on the upper wing surface of the airfoil; 3. A chord section is arranged along the chord direction of the airfoil. The spanwise position is 0.08m away from the middle of the model. There are three pressure measuring points in total. The chord positions are 34%, 40% and 46% respectively. This section is only arranged on the upper wing surface of the airfoil. See attached Fig. 3 for the photos of pressure measuring points and Fig. 2 for the layout plan of pressure measuring section of model.

![Figure 2. Schematic diagram of model pressure profile layout.](image)

In this test, a circular boundary layer partition board is arranged 0.07m away from the tunnel wall at both ends of the model. The thickness of the partition board is 0.015m, the diameter is 0.7m, and the edge has a cutting angle of 20 °. The upper and lower cover plates of the simulated airfoil are used between the diaphragm and the tunnel wall to ensure the smooth air flow. See Figure 3 for the details of the side end plate of the attachment:
4. Test Method and Content

4.1. Test method
In this experiment, the fixed transition mode is adopted, and the cylinder roughness element with height of 0.1mm is pasted at 5% of chord direction of airfoil model. The Mach number was calculated by controlling the ratio of the total pressure of the settling chamber to the static pressure of the reference point of the chamber. A pitch pause model of attack angle motion is adopted.
In order to prevent the error caused by the torsion deformation of the model, an angle of attack sensor is installed at the active end and the driven end respectively to monitor and measure the accurate angle of attack due to the model large span and load.

4.2. Test Content
The test contents mainly include airfoil pressure test. According to the test status as indicated in the open literature sources ‘aerofoil RAE2822 - pressure distributions, and boundary layer and wake measurements’ (see Figure 4), three test conditions (case1 \ case2 \ case7) were selected for comparative test research.

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Figure 3. Diagram of side end plate scheme.
Figure 4. Test conditions of RAE2822 standard model test. Also see Table 1 for the test conditions in FL-3 wind tunnel.

Table 1. Test conditions of RAE2822 airfoil in FL-3 wind tunnel.

| Conditions number | Mach number | Angle of attack | Chordal position of transition zone (X/C) | transition zone height (mm) |
|-------------------|-------------|-----------------|------------------------------------------|-----------------------------|
| case1             | 0.676       | -2°~5°          | 0.07                                     | 0.1                         |
| case2             | 0.676       | -2°~5°          | 0.07                                     | 0.1                         |
| case3             | 0.725       | -2°~5°          | 0.07                                     | 0.1                         |

5. Data Processing
The data processing formula in this study is as follows:

(1) Pressure coefficient of each point:

\[ C_{pl} = \frac{P_l - P_{cl}}{q} \]  \hspace{1cm} (1)

All the bad data points are calculated by interpolation or extrapolation, and replaced by the nearest pressure measuring points.

(2) Normal force coefficient of body axies:

\[ C_N = \int_0^1 (C_{pl} - C_{pu}) \, d\bar{x} \]  \hspace{1cm} (2)

Among them:  
\( C_{pl} \) -- pressure coefficient of lower wing surface  
\( C_{pu} \) -- pressure coefficient of upper wing surface
6. Test Results and Discussion
According to the measured test results, the comparisons between the test results of case 1, case 2, case 3 in FL-3 and the reference data which (English translation from reference 2) are shown in Fig. 5-7. The measurement test results are marked with exp, the reference data are marked with Ref, and the following numbers correspond to the angle of attack measured in the test. There is a certain difference between the measured angle of attack and the angle of attack of the standard model test, because there is no wall interference correction for the angle of attack in this test, but the same normal force coefficient is used to ensure the consistency of the compared statuses.

![Figure 5](image1.png)

Figure 5. Comparison between case 1 CP test measurement and standard model test results.

![Figure 6](image2.png)

Figure 6. Comparison of case 2 CP test measurement and standard model test results.
According to the comparison results, there are limited bad data points in FL-3 wind tunnel test results, including data points at 12.5% of chord length of upper wing surface and 85% of pressure points of lower wing surface. After eliminating these bad data points, the results of CP measured in FL-3 under the three compared conditions are in good agreement with reference data in the literature.

In case 7, the position of shock wave measured in FL-3 is a little ahead of the reference data results, which may be related to the different transition simulation types of the two tests.

Through the above comparison, it can be shown that it is feasible to carry out high-speed two-dimensional airfoil measurement test in FL-3 wind tunnel test.

7. Conclusion

A higher Reynolds number can be obtained by using conventional high-speed wind tunnel for high-speed airfoil wind tunnel test. In this study, the high-speed airfoil wind tunnel test of RAE2822 airfoil was carried out in FL-3 wind tunnel. Through the reasonable design of test scheme, the test model with good quality was manufactured, and the reasonable wind tunnel data correction and data processing were applied, the pressure distribution of RAE2822 at three typical test conditions was obtained. Compared with the reference results of RAE2822 airfoil model which are from literature, it shows that the pressure distribution obtained by FL-3 wind tunnel is credible, and it also shows that it is feasible to carry out high-speed two-dimensional airfoil test in FL-3 wind tunnel.

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