Experimental research on collector effect on operating characteristics of high-speed free-jet wind tunnel

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Abstract. Collector is one of the key parts of the high-speed free-jet wind tunnel, which directly affects the performance of wind tunnel. In this paper, a small high-speed free-jet wind tunnel is used as the test platform to carry out the start-up and operation characteristics test of wind tunnel. Start-up pressure characteristics were obtained at various Mach number, and the influence of the collector throat heights and collector positions on start-up pressure and matching pressure was preliminarily studied. The results show that the high collector throat height can meet the requirements of wind tunnel start-up and pressure matching. The closer the collector is to the nozzle, the smaller the corresponding starting pressure and matching pressure. However, this trend weakens with the decrease of Mach number, which lays a foundation for the development of large high-speed free jet equipment.

1. Introduction
Due to the strict restriction of the high percentage blockage of wind tunnel model in closed test section, the large-scale model, wide angle of attack and integrated research of the aircraft are seriously affected. The high-speed wind tunnel in the closed test section has become one of the bottlenecks restricting the independent development and development of China’s advanced high maneuvering aircraft. Design and construction of high-speed free-jet test equipment will be an effective technology to solve the above problems.

The high speed free-jet test equipment in foreign countries almost appears in the same period as the closed high speed wind tunnel. In the 1930s～1940s, the United State, the Soviet union and other countries, in order to meet the requirements of the advanced aircraft design, development and test, to solve problems that the closed high-speed wind tunnel could not afford at that time, such as the integration of air intake and exhaust, aero-engine performance assessment and defect investigation, and the research and development of high angle of attack aerodynamic force and control technology, successively built a number of high-speed free-jet test equipment. For example, the 16-inch × 16-inch test equipment (Mach number range 0.3～5) of the U.S. navy weapon center, the Ohio state university transient free-jet wind tunnel, the Texas university supersonic free-jet test equipment (Mach number range 1.25～4) [1-6], and the TPD 1.05 meter free-jet test equipment (Mach number range 0.3～4) of TsAGI [7].

In this paper, a wind tunnel is used as the test platform to conduct the pilot test of high-speed free-jet test equipment. The influence of different collector throat heights and collector positions on operating
characteristics of wind tunnel is compared and studied. The relevant research results are obtained, which provides technical support for the design and debugging of large-scale high-speed free-jet wind tunnel.

2. Test equipment

2.1. Test platform

Fig. 1 shows the overall outline of test platform, mainly including the control valve, large-angle diffusion section, settling chamber, contraction section, nozzle section, test section, supersonic diffusion section, subsonic diffusion section and the exhaust muffler. The test section is in the form of half opening free-jet. The rear part of nozzle, the inlet section of supersonic diffusion and the test section are contained in a plenum chamber, which is equipped with observation window and the rear part is equipped with exhaust section. The free-jet inlet size is 80mm×80mm, and the length of the open free-jet area is 180mm.

![Figure 1. Outline drawing of small high-speed free jet wind tunnel](image1)

Three sets of collectors are equipped with two-stage contraction, in order to meet the needs of the research. The full angle of first stage and second stage are 30 degree and 15 degree, respectively, and the area ratios of the throat to the nozzle exit are 1.23, 1.5 and 2.4 respectively, numbered 1#, 2# and 3#.

The test device has the functions of axial, left and right, up and down shift measurement, and the axial shift measurement is external, which is realized by hand wheel; the up and down, left and right are manually adjusted, and Fig. 2 shows the photograph of shift measuring device.

![Figure 2. Photograph of shift measuring device](image2)

2.2. Measurement and control system

During the test, the total pressure of settling chamber, the static pressure of the nozzle exit, the total and static pressure of the rake, the static pressure of plenum chamber, the static pressure of the collector and the static pressure along the collector throat are monitored. The measuring equipment mainly includes
the probe, the pressure sensor and a 16 channel electronic scanning valve, and the accuracy is better than 0.1%.

The control system implements closed-loop control through the pressure regulating valve and the precision is better than 0.3%.

3. Test contents

According to the references [1-3] and the preliminary tests, two key parameters, that is to say, start-up pressure and matching pressure, are needed to be determined for the normal operation of the free-jet wind tunnel. The start-up pressure can be defined as: according to the time-varying curve of various pressure, when the static pressure at the nozzle exit suddenly reduces to a certain degree, the corresponding total pressure at the settling chamber is called start-up pressure; matching pressure: after the flow field is established, adjusting the total pressure at the settling chamber, so that the static pressure at the nozzle exit matches the static pressure of the plenum chamber, and the total pressure corresponding to the minimum difference is called matching pressure.

These two parameters are very important for the aerodynamic design and test of large-scale free-jet equipment. According to the references [3] [4], the collector throat height has a great influence on the start-up and operation performance of the wind tunnel. Moreover, considering that the collector of large-scale high-speed free-jet equipment needs to have the function to move back and forth, this paper focuses on the study of the influence of different collector throat height and different collector location (from the nozzle) on the start-up pressure and matching pressure of small free-jet wind tunnel. The test conditions are shown in Table 1.

| Number | collector number | collector position/mm |
|--------|------------------|-----------------------|
| Case01 | 1#               | 180                   |
| Case02 | 2#               | 180                   |
| Case03 | 3#               | 180                   |
| Case04 | 3#               | 120                   |
| Case05 | 4#               | 160                   |
| Case06 | 5#               | 200                   |

4. Test results discussion

4.1. Influence of the collector throat heights

Fig.3 ~ Fig.5 shows the operation pressure test diagram of case01 ~ case03 at Mach number 3.0 condition. It can be seen that when the total pressure of the settling chamber rises to a higher state, i.e. above 700kPa, the pressure of the plenum chamber has been stable at about 93kPa, thus the supersonic flow field cannot be established. After eliminating the causes such as air leakage, it is considered that the throat size of 1# collector is too small, and the shock wave cannot enter the downstream through the throat, so the supersonic flow-field cannot be established.

The reason analysis is as follows: under ideal state, the minimum allowable cross-sectional area $A'_c$ of collector throat required for the wind tunnel to complete the start-up process is [8, 9]:

$$A'_c = \frac{Ma^{\frac{\gamma+1}{2}}}{\left(1 + \frac{\gamma - 1}{2} Ma^2\right)^{\frac{\gamma}{2}}} \left(\frac{\gamma - 1}{\gamma + 1}\right)^{\frac{1}{2}} \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{2\gamma-1}}$$
Where $A$ is the cross-sectional area of the test section, and the nozzle exit cross-sectional area is taken in the paper; $Ma$ is the Mach number of the test section; $\gamma$ is the specific heat ratio. The minimum allowable cross-sectional area of the collector throat obtained by the above formula is the theoretical calculation value; considering the influence of boundary layer friction and separated flow, the actual minimum allowable cross-sectional area of the collector throat should be about 1.25 times of the above theoretical calculation value. In this paper, 1# collector throat cross-sectional area is 1.16 times of the theoretical calculation value, which is less than the actual design value, so 1# collector throat size of the collector is too small and the wind tunnel fails to start.

In case 02 and case 03, the static pressure at the nozzle exit decreases first and then rises with the increase of the total pressure, and then rapidly decreases to a lower pressure. The supersonic flow field is basically established, and the total pressure in the settling chamber corresponding to the lower static pressure of the nozzle is the start-up pressure.

Since 1# collector failed to establish supersonic flow field in Mach number 3.0, the matching pressure test was mainly carried out for 2# collector and 3# collector.

According to Fig.4 and Fig.5, the difference between the nozzle exit static pressure and the plenum chamber static pressure remains 10kPa~20kPa within a large pressure range (600kPa~700kPa) of 2# collector, failing to achieve pressure matching. But for 3# collector, the nozzle exit static pressure and the test chamber static pressure curve formed a cross within the same pressure range (600kPa~700kPa), indicating pressure matching. The total pressure of the settling chamber corresponding to the cross point is the matching pressure.
4.2. **Influence of the collector position**

Fig. 6—Fig. 7 show the influence curve of different collector positions (distance from the nozzle exit) on the start-up and matching pressure of the wind tunnel at different Mach numbers.

It can be seen that change of collector position has little effect on start-up and matching pressure at low Mach number; with the increase of Mach number, the farther the distance between collector and nozzle exit, the larger the corresponding start-up and matching pressure, but the increase level is small. When the collector position increases to a certain distance, the change of pressure parameters tends to be stable. The research results are basically consistent with the reference [9].

5. **Conclusion**

In this paper, a pilot test is carried out on a small free-jet wind tunnel. The effects of collector throat height and collector position on the start-up and operation performance of the wind tunnel are studied. The main conclusions are as follows:

1) Larger collector size can meet the requirements of wind tunnel start-up and pressure matching, but too large collector size is not conducive to improving the operation efficiency of the equipment, which needs to be optimized by later test;

2) The farther the collector away from the nozzle exit, the smaller the start-up pressure and matching pressure increase, but the trend decreases with the decrease of Mach number;

3) The research results provide data for the design and debugging of large-scale free-jet equipment.

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