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Study on Acoustically Transparent Test Section of Aeroacoustic Wind Tunnel

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Abstract

On the purpose of accurate data acquisition for the aeroacoustic testing mostly in open jet test section of aeroacoustic wind tunnel, the large scale anechoic chamber is specifically designed to build the low background noise environment. A newly acoustic test section is presented in this paper, of which the contour is similar as the closed test section, and the wall is fabricated by the fiber fabric, both the characteristics of closed and open jet test section of conventional wind tunnel are combined in it. By thoroughly researching on the acoustics and aerodynamics of this acoustically transparent test section, significant progress in reducing the background noises in test section and improving the ratio of energy of the wind tunnel and some other aspects have been achieved. Acoustically transparent test section behaves better in acoustics and aerodynamics than conventional acoustic test section because of their high definition in detecting the sound sources and great performance in transmitting sounds.

Keywords

Aeroacoustic Experiment, Sound Transparent Property, Acoustic Test Section, Low Background Noise, Sound Identification

1. Introduction

Aeroacoustic experiments are mostly conducted in aeroacoustic wind tunnel with open jet test section for a long period, and the large-scale anechoic chamber must be used around the test section to reduce the background noises to simulate far-field environments as truly as possible [1]. Aeroacoustic wind tunnel has two obvious problems because of its nozzle and a collector structurally. First, the jet shear boundary layers caused by the large eddies formed near the nozzle and entrain air from around the wind tunnel. At the point where the jet re-enters the tunnel, this leads to a source of instability and noise. The second problem is that fluid in open jet test section is notoriously sensitive to the interferences from surrounding environment. Interferences elimination becomes very complicated especially in analyzing the sound reflection under a load. Researchers in China Aerodynamic Research and Development Center (CARDC) have carried out a series of experiments to eliminate the noises caused by the open jet in the aero-acoustic wind tunnel. For example, installing slenders at the exit of the nozzle, adjusting the opening of collector and adding the plush coverage on the surface of collector [2] [3]. Although the methods mentioned above have made some effects, the main noises of open jet test section of wind tunnel are still caused by shear layer.

The closed test section has better performances in resisting the interferences and shows good aerodynamic performances, but it also has many disadvantages in aeroacoustic experiments. The acoustic attenuation and reflection on solid walls are too high and the noise interferences in boundary layers become obvious. These drawbacks limit the application of closed test section in aeroacoustic experiments. As one of the main two noise sources, boundary layer noise has caught a lot of attentions from the laboratories all over the world and a series of experiments have been conducted by them. According to M. V. Lowsonalgorithm [4], the boundary layer noise level in closed test section could reach to 103 dB at the flow speed of 30 m/s. This kind of noise caused by the walls of test section influences the aeroacoustic experiments directly.

The wall of acoustically transparent test section is fabricated by the fiber materials, with which the test section is closed aerodynamically and opens acoustically. The researchers in Virginia Tech University have conducted similar experiments [5] [6]. They decoupled the aero and acoustic problems by application of aramid fiber acoustic test section and relevant anechoic chamber. However, the noise attenuation of aramid fiber is low when the noise frequency level is below 25 kHz. The experiment results of NACA0012 giraffe shows that the aerodynamic performances of this test section are nearly the same as the conventional hard-wall test section and the lift interference corrections are less than half those expected in an open-jet wind tunnel.

In recent years, the constructions of wind tunnels aim at frontier field of aerodynamics. The study on acoustic characteristics of acoustically transparent test section and exploration on acoustic and aerodynamic performances could greatly help to promote the experimental ability of relevant wind tunnels, broaden the range of experimental wind speed, and reduce the energy consumption as well as the background noises.

2. Facility Overview

The study was conducted on a small scale aeroacoustic wind tunnel which was built in 2007 and located at CARDC. It is also the pilot wind tunnel of the large scale aeroacoustic wind tunnel in CARDC whose test section size is 5.5 m (width) × 4 m (high). Both the open jet test section and the closed test section are configured for this pilot wind tunnel. When using the open jet test section, it comes with an anechoic chamber. The aerodynamic and the acoustic parameters of it are listed as follows:

1) The test section size: 0.55 m (width) × 0.4 m (high).

2) The maximum flow speed: 100 m/s.

3) The pressure loss coefficient of the wind tunnel with open jet test section: 0.312.

4) The pressure loss coefficient of the wind tunnel with closed test section: 0.09.

5) Background noise level: ≤78 dB (A) (The measuring point is 2 m away from the fluid in the wind tunnel with open jet test section).

6) Cut-off frequency of the anechoic chamber: 100 Hz.

The new acoustically transparent test section with 0.55 m (width) × 0.4 m (high) × 1.44 m (length) flow path cross section was re-designed and processed to match the wind tunnel. The stainless steel orifice plate was used as braced frame to fasten the transparent fiber fabric (**Figure 1**).

3. Aerodynamic Performance of the Acoustically Transparent Test Section

In order to compare the pressure loss between the acoustically transparent test section and conventional test sections, the pressure rise of fan section is measured under the same conditions. From the **Figure 2**, it can be seen that the pressure rise of closed test section is the minimal compared with the other two test sections at the same wind speed. And the pressure rise of open jet test section is the maximum. In general, high pressure rise corresponds to high power consumption. It will need more energy to drive the fluid in wind tunnel with open jet test section. In other words, the acoustically transparent test section behaves better than the open jet test section in enhancing the energy ratio of wind tunnel. Although the wind tunnel with closed test section has the lowest energy loss, it is not suitable for aeroacoustic experiment.

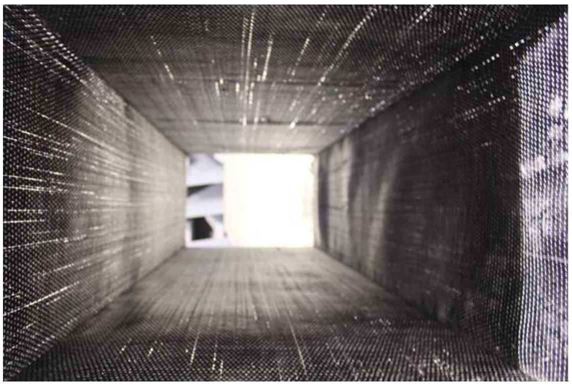


Figure 1. The acoustically transparent test section.

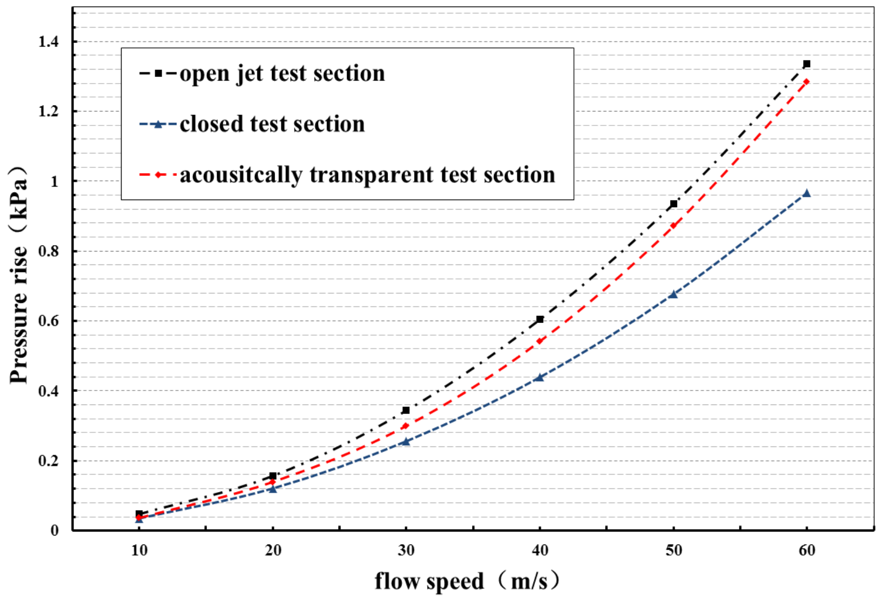


Figure 2. The pressure rise of fan section.

4. Acoustic Performance of the Acoustically Transparent Test Section

To comprehensively and accurately evaluate the acoustic performances of acoustically transparent test section, the sound intensity method and sound power method were both adopted. The **Figure 3** shows the measurement plate in the anechoic chamber. It is parallel to the side wall of the test section and is 2150 mm side away from the axis. In the vertical plane, 49 measuring points are arranged as the 7 × 7 dot matrix. The distance between the left and right adjacent points is 300 mm.

4.1. Theoretical Analysis of Sound Intensity Method

Sound intensity is defined as the power carried by the sound waves per unit area. It is equal to the product of sound pressure and particle velocity [7].

$$I(t) = p(t)u(t) \tag{1}$$

The sound intensity component in the specified direction is defined as:

$$I_0 = p(t)u_0(t) \tag{2}$$

$u_0(t)$ —Velocity component in the specified direction

In the direction of sound propagation (r), the particle velocity and the sound pressure gradient are satisfied with the relationships as follows:

$$\frac{\partial u_r(t)}{\partial t} = -\frac{1}{\rho_0}\frac{\partial p(t)}{\partial r} \tag{3}$$

$$u_r(t) = -\frac{1}{\rho_0}\int \frac{\partial p(t)}{\partial r}\mathrm{d}t \tag{4}$$

Thus, the particle velocity could be calculated by the time integration of the

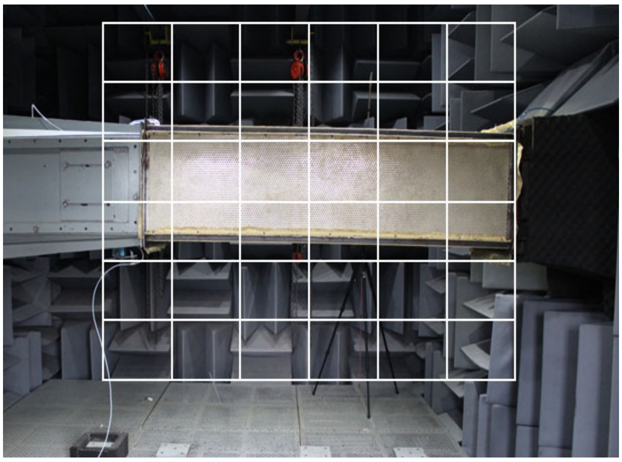


Figure 3. The dot matrix of measuring points.

pressure gradient measured at some point from the sound field. When the Δr is small enough (far less than the wavelength), the pressure gradient in the equation can be instead of the differential form. The sound intensity could be measured by the probe consisted by two properly installed microphones.

Sound intensity means sound power density. The sound power of the measuring plane could be calculated by the integral of the sound intensity times the area. The sound power could be more accurately indicate the rule of the sound generation in the test section. One research object of this paper is to measure and analyze the sound power of the measuring plane. Due to the directivity of the sound intensity, the spatial distribution of the sound intensity will be confirmed by measuring the sound intensity of a series of test points in a specific plane, and it is easier to analyze it by drawing the sound intensity map.

$$W = \iint_S I_n \mathrm{d}S \tag{5}$$

W—Sound power.

I_n—Sound intensity component in the normal direction of dS.

S—The measuring area.

4.2. The Background Noise in the Test Section

Figure 4 illustrates the distribution of sound sources in the aeroacoustic pilot wind tunnel with open jet test section. From the noise cloud picture it can be found that the energy increases dramatically around nozzle and collector which are the main noise sources in that kind of wind tunnel. But the noises in the test section remain low, which contributes to collect noise data of the test model.

Figure 5 shows the contour of sound intensity of the acoustically transparent test section. Sound filed becomes much more steady than that in open jet test section, and the strong noise area around the nozzle and collector disappears. **Figure 6** shows that the sound pressure level (SPL) of the new test section and sound power level (SWL) of certain test plane decrease greatly in contrast to open jet test section. The tiny noise signal radiated from the model can be easier

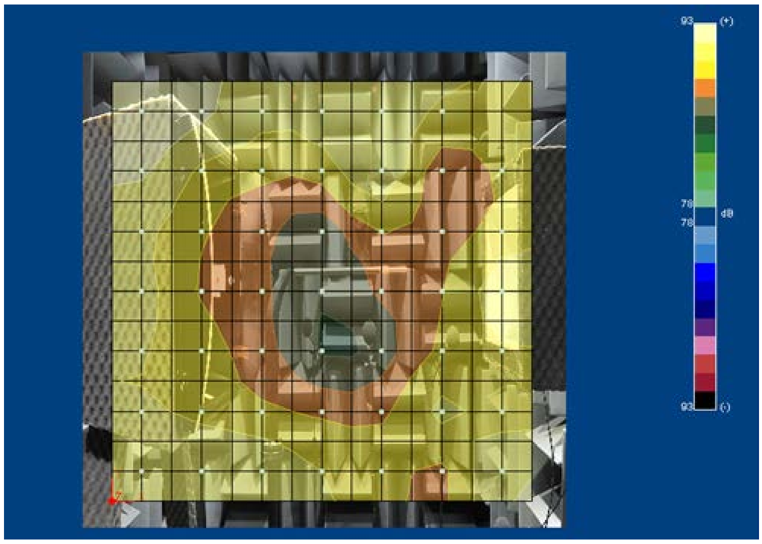


Figure 4. The sound intensity contour of open jet test section.

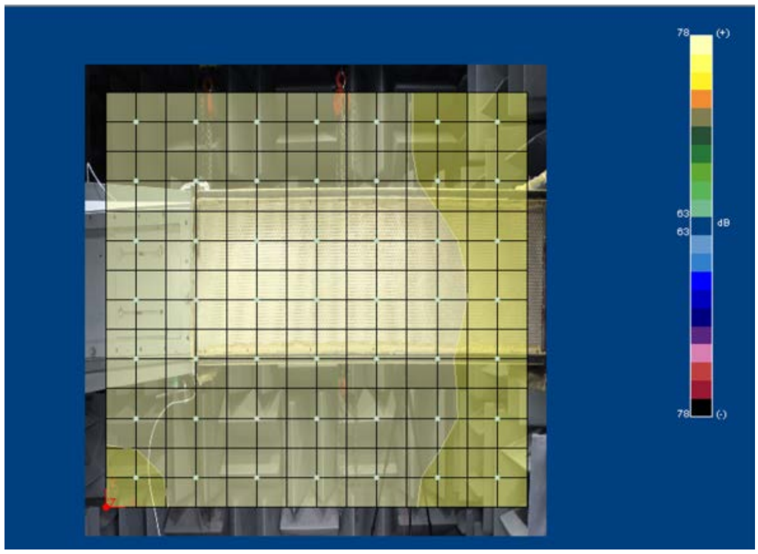


Figure 5. The sound intensity contour of acoustically transparent test section.

captured when the noise energy in the anechoic chamber is reduced. It is still a problem worth to be explored whether the aeroacoustic test could be conducted in the acoustically transparent test section because of the extremely great differences in comparison with the conventional open jet test section in which the aeroacoustic experiments are conducted.

The sound field in the chamber of aeroacoustic wind tunnel, namely the anechoic chamber is nonuniform. The reason why large wind tunnel must be equipped with a large-scale anechoic is that the noise distributed above the cut-off frequency of the anechoic chamber could be absorbed by the silencing wedge on the walls. It is easy to recognize the position of sound source because the influence of reflection waves is reduced. The jet noise and the boundary noise formed from the process that the flow re-entered the wind tunnel circuit

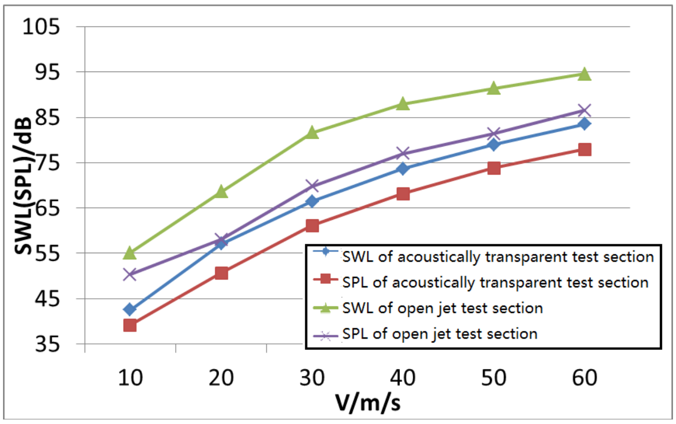


Figure 6. The acoustic performances of acoustically transparent test section and open jet test section.

from the collector could be clearly seen from the noise contour picture, which is benefit from the above function of anechoic chamber. The new test section eliminates these two strong noise sources fundamentally which are meaningless for the aeroacoustic experiments. And the noise level in test section is dramatically reduced without the introduction of any other new noise sources.

4.3. Sound Identification

Installing the acoustically transparent test section could reduce the background noise in anechoic chamber. The main reason is that the influence of nozzle and collector were avoided. But another possibility that the wall of that test section will affect the sound transmission can't be ignored. If that possibility exists, the acoustically transparent test section used in aeroacoustic experiment is unsuitable.

In order to rule out the possibility, two simple sound sources were put into the test section to evaluate the sound transmission performance of the material used in the experiment. The sound sources were produced by two 2.5 mm diameter steel wires inserted into the upper and lower walls of test section. The experiment results indicated that it is easy to distinguish those two simple sound sources, and their locations were able to be distinguished roughly from the noise cloud map. The total sound power of the measuring plane is increase by 4.8 dB after installed the steel wires. The sound sources produced by the steel wires were typical dipole resources; its frequency satisfies the following equation [8]:

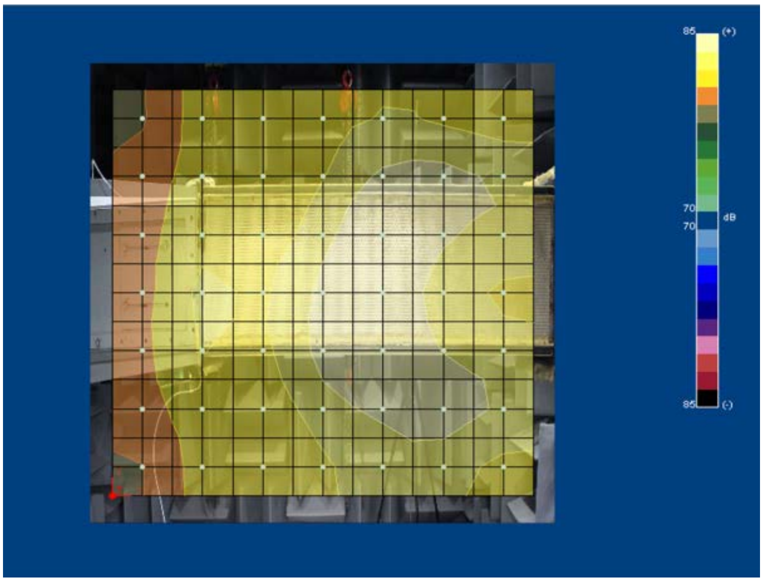
$$f_p = \beta \frac{V}{d}$$

β —Strouhal number, the value of it is 0.2 here.

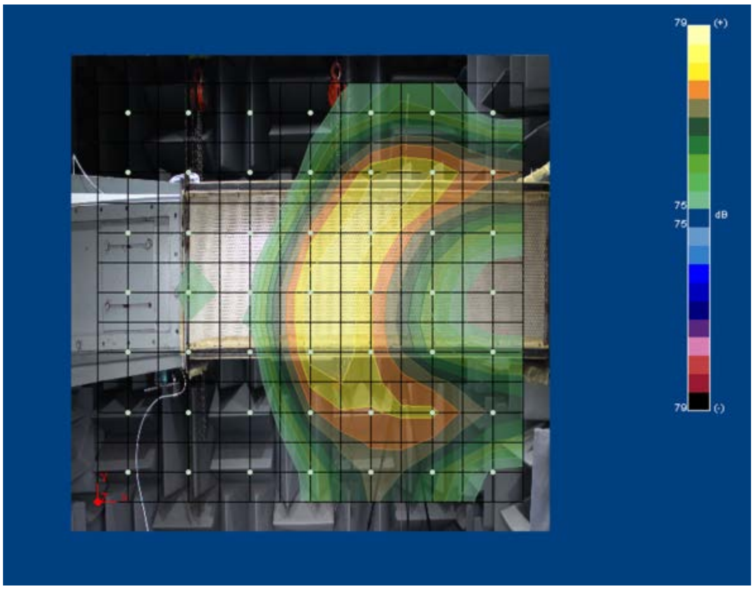
V—airflow velocity, m/s.

d—characteristic length, m.

The sound frequency spectrum that the above steel wire generated is 4800 Hz, and the experiment result is 5000 Hz (see in **Figure 7**). The **Figure 8** shows the experiment result of the same sound sources put into the open test section. It can be seen from the figure that the frequency of the strong interference noises



(a)



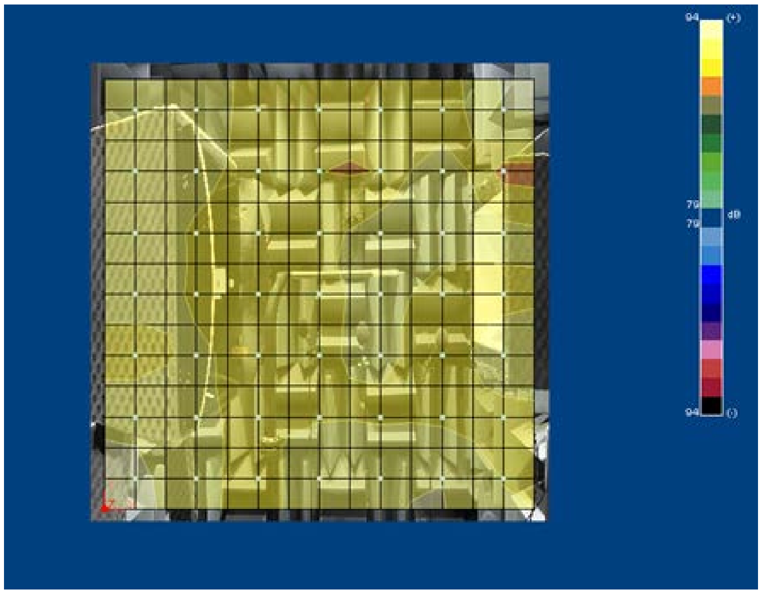
(b)

Figure 7. The sound power contour of acoustically transparent test section with sound sources. (a) 25 - 10 kHz; (b) 5 kHz.

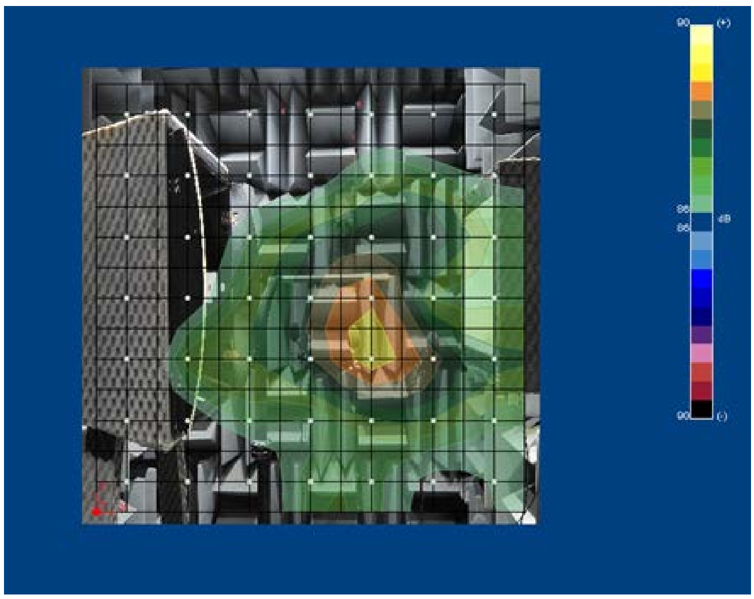
level is lower than 1000 Hz (the cut-off frequency of the anechoic chamber), which appeared around the boundary of the measuring area. The identification precision of sound sources in open jet test section is obviously inferior to that in acoustically transparent test section.

5. Conclusion

Through a series of intensive study of the acoustic and aerodynamic performances of acoustically transparent test section, the conclusions can be addressed as follows:



(a)



(b)

Figure 8. The sound power contour of open jet test section with sound sources. (a) 25 - 10 kHz. (b) 5 kHz.

1) In aerodynamic performance, the equivalent pressure loss coefficient of acoustically transparent is smaller than that of the open jet test section. The energy ratio of wind tunnel could be increased by using the new test section in some extent.

2) The background noise of the test section could be significantly decreased by using the acoustically transparent test section for the reason that the noises of the nozzle and collector are completely restrained.

3) Due to the excellent sound transmission performance of fiber material, the weak noise could penetrate it and be captured by the measuring equipment with

high resolution.

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