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APPLIED PRIMARILY OF FOCUSING SCHLIEREN VISUALIZATION SYSTEM IN THE SHOCK WIND TUNNEL

XIE Ai-min[1], HUANG Jie, SONG Qiang, XU Xiang, LU Zhi-guo

ABSTRACT

For the sake of satisfying with the quantitative measurement of flow density, 3D flow and large field flow visualization, the focusing schlieren system has been developed in the shock tunnel. The system has the characteristic of focusing on some plane, and the information gotten from the flow by the system is mainly decided by the focusing plane. The technique introduced in this paper includes the theory, the composition, the debug and the result of tunnel test.

Test results show that: (1) The sensitivity of the system is high, and the image gotten by the system is clear and not disturbed by the diffraction and interference though the light source is laser; (2) The system can get the image at the condition that the sharp focus depth is less than 5mm, the measurement field diameter is about 100mm, the system can get the focusing image of different plan by changing the place of image plane; (3) Quantitative flow density of some test region can be gotten by disposing the gray degree between the static and dynamic focusing schilieren image.

Keywords: Focusing schlieren; Flow visualization, Shock tunnel, Schlieren, Quantitative measurement

INTRODUCTION

Flow visualization is one of the important means to obtain the test data while testing in the wind-tunnel [1], conventional shadowgraph, schlieren, interferometer, give information which is related to refraction of the light along the entire optical path, they can’t give a certain flow region message, so these methods can't be used to show three-dimension flow and complicated flow effectively. Focusing schlieren has the following characteristic:

In the conventional schlieren, the parallel light beam crosses the test flow field; it provides information along an integrated path. The focusing schlieren method, however, can focus on a certain flow field through focusing lens, images can be recorded density gradient change from only one planar region at a time, the information of other planar regions is recorded as uniform background, and thus the focusing schlieren method can reflect detail structure of field flow even more.

As to some complicated field flows, for instance, the high temperature flow, because the convection is strong, different information of planar regions mantles each other, conventional shadowgraph, schlieren,

[1] Corresponding author: China Aerodynamics Research and Development Center (CARDC), China

interferometer can't describe the flow structure clear, as the focus characteristic of focusing schlieren, the defect of convection interference can be overcome.

Also, because of the focus characteristic, different planar region information can be gotten through changing the focus planar region in the test, so as to show the three-dimension flow. At the same time, the method can combine the laser holographic through changing the focus planar region as reconstructing; the three-dimension flow information can also be gotten in one test. According to the relevant principle of focusing schlieren, the density value of a certain focusing planar region can be gotten by processing the focusing schlieren image.

Just because of the characteristics of focusing schlieren method above-mentioned, the technique after this technical development has been widely used as flow visualization method in the wind-tunnel in many countries.

IMAGING PRINCIPLE OF FOCUSING SCHLIEREN

Conventional schlieren

The measurement principle of flow on the basis of the optics method (shadowgraph, schlieren, and interferometer) is that: The light beam changes the direction of density increasing as it crosses the transparent test medium. In the schlieren, the edge of a knife is put during testing visual field and a screen of flow image, and blocks some light beam. Fig. 1 shows the basic layout of a conventional schlien system using lens. The light intensity change has reflected the density gradient change along the vertical direction of the edge of a knife, we define this quantity as

$$\text{Measurement signal} \propto \int_{z1}^{z2} \sigma(z) \frac{\partial \rho(x,y,z)}{\partial s} dz \qquad (1)$$

$\sigma(z)$ is expand function and is related with the focusing system and test position, z1 and z2 are that the light beam enter and depart from the test flow field along the optical axis (such as Fig. 2), the direction which is perpendicular to the edge of a knife is " s ", ρ is the density value, the knife edge direction in this paper is set as " y ".

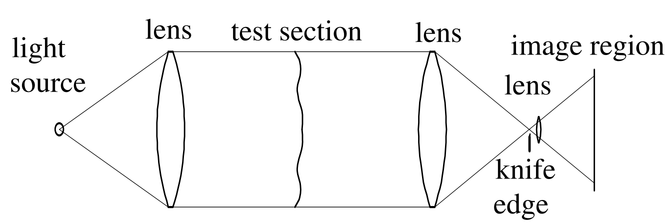

Fig.1. Optical diagram of conventional schlieren

In conventional schlieren, one point light source produce the parallel light beam behind the mirror through collimation, the parallel light beam crosses the test region, the edge of a knife is put at the planar region of light source image, the principle of this system has been confirmed that the flow information of different planar region can't be distinguished with on the image picture. The expansion function of equation (1) is one invariable value between the test areas from z2 to z1; therefore density gradient is an integration value along the optical axis in whole test region, the light intensity change on the image picture is described as the quantity

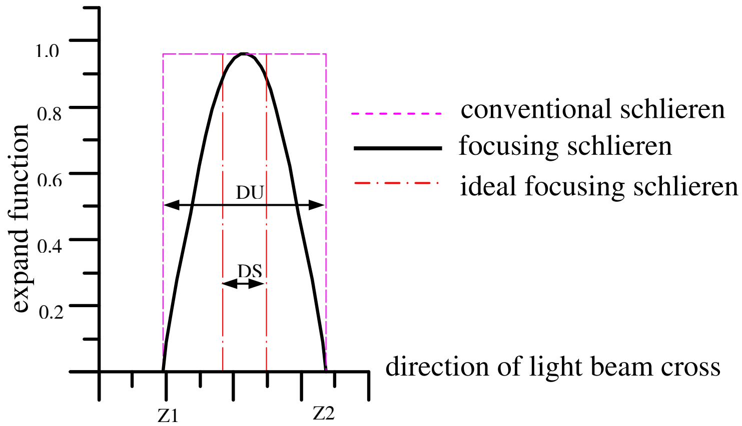

Fig.2. Spread function of schlieren

$$\frac{\Delta I}{I_0} = \frac{KF}{a} \int_{z_1}^{z_2} \frac{\partial \rho}{\partial x} dz \qquad (2)$$

Where the light intensity change on the image picture with the change of density gradient in the test region, $I = I - I_0$, K is the Gladstone-Dale constant, F is the focal length of the lens 3 in the Fig.1, or the focusing lens in Fig. 3, a is the height of light source image above cut off. If the different field information is different especially such as injection flow, the information of each planar region mantles each other; the flow image can't reflect the true flow structure.

Focusing schlieren

The principle of focusing schlieren was proposed firstly by Burton, R. A. in 1949, by 1991, after U.S.A. Weinstein, L. M. carried on this technology supplementarily and perfected, this technology tends to be ripe, and the technique is widely used as the method of flow visualization in the wind-tunnel of many countries from then on, and is called one of most promising flow methods. Fig. 3 shows a schematic diagram of a typical focusing schlieren system, the common characteristics with conventional schlieren is that they have used the light source and the edge of a knife; The difference is that the light source can be a wide light source, the non- parallel light beam crosses and tests the area, the edge of a knife is a cut off grid, at the same time, it have not a collimation sphere mirror necessary in the conventional schlieren, and that replaced is to use fresnel lens, source grid, focusing lens, and cut off grid, etc..

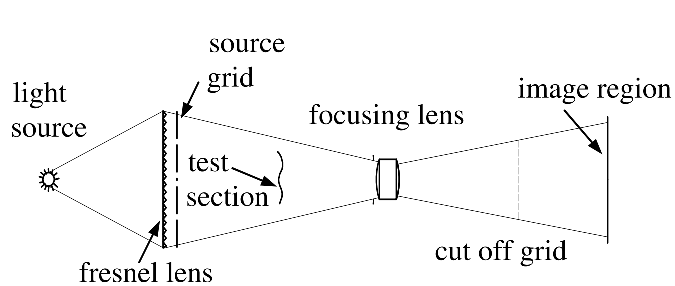

Fig.3. Optical diagram of focusing schlieren

As everyone knows, the object image is clear as focusing on the object plane, the image of other plane fuzzy when the depth of field is much smaller for the ordinary camera. In the focusing schlieren system, the focusing lens has been used, it can focus on a certain plane, the focusing thickness, or the depth of field of focusing lens is defined as "sharp focus depth", or for short name "DS", the flow information of image is mainly derive from the DS, other planar region is reflected by one of formation of image with the uniform background. As the ordinary camera, the information derived from other planar regions also influence on the information of image, the planes are called as the depth of unsharp focus, or for short name "US". It is not an invariable value in the whole expansion function of testing region in the focusing schlieren system, but one function of advancing gradually, in sharp focus planar in maximum; it diminishes gradually as far away from sharp plane. If the focus characteristic is more obvious, the expand function is more precipitous, the sharp focus depth DS is less accordingly (see Fig. 2).

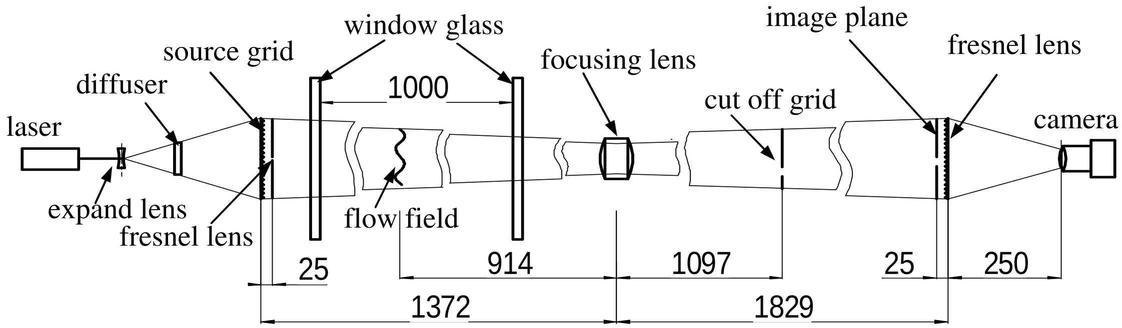

Fig.4. Optical diagram of focusing schlieren in the 0.6m shock tunnel

In the schematic diagram of the focusing schlieren system (see Fig. 4), laser light source (or other wide light source) , after expanding a expand lens, diffuser screen, cross the fresnel lens and the close source grid, the light illuminates to testing region again. Similarly, the focusing lens focuses the source grid on the region of the cut off; the flow image is record by camera.

Can be found out from the schematic diagram , the focusing schlieren system has used the edge of a knife of compounding, has replaced single the edge of a knife of conventional schlieren; The testing field depends on the diameter of the fresnel lens and the position relation between test object and the focusing lens. Because large diameter of the fresnel lens and the source grid can be processed conveniently, so the test field of the focusing schlieren system can be very large.

DESIGN OF FOCUSING SCHLIEREN

Though focusing schlieren system can be used to the large field visualization, quantitative measurement of density field and three-dimension flow visualization etc., these characteristics can be satisfied in a certain specific focusing schlieren system. Such as the sharp depth of focus of the large field focusing schlieren system is too large to be unsuitable for three-dimension flow visualization. The system described here is mainly used to quantitative measurement of the flow density, but the result of the measurement will be described in the paper afterwards.

Fresnel lens

Special light railing, wave bands of odd or even numbers are blocked to call fresnel wave band slices, which is bar or square slice. Because its spotlight function is similar to a piece of ordinary lens, and it is similar to the ordinary lens in formation of image, also called the fresnel lens, but it can be used as a diffraction screen similar to the grating, which makes the light source shine to the testing area evenly .

Made the mould with the copper first in processing, then made process of pressurizing etc. to the plastics one.

Source grid

It is made up of a series of light and shade and alternate stripes, is dyed after carving the line on the optical glass directly at the time of processing, expect very much the precision of interval of stripe and stripe straight line degree. The light and shade size of stripe that we adopt is 2mm and 6mm respectively, its diameter is 300mm like size of the fresnel lens, its material object picture is showed in Fig. 5.

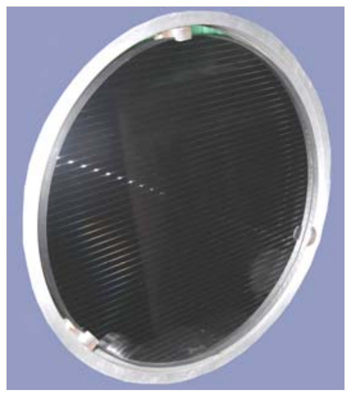

Fig.5. Picture of source grid

Cut off grid

Adopt the method to reduce the source grid in certain proportion to make into the negative, and duplicate in the optical glass to get the cut off grid, the sharpness and definition reduced to the source grid while duplicating are expected very much. The size of the proportion is decided by the focusing lens and the mutual position. The proportion size of source grid and cut off grid used here is about 10/1.

Focusing lens

The image formula of focusing lens is similar to the ordinary lens, the essential aberration of the lens must be correct. Focus position of testing region and other optics component can position according to the formula of focusing lens. In the following examples, a 440mm focal length with a 100mm clear aperture was used according to the structure of testing flow and depth of field.

Imaging equipments

For meet the request of high resolution, a big size aviation film, 100mm diameter, with high resolution is placed on the image plane of flow.

TEST AND APPLICATION

Principle verification testing

Have finished the installation and debugging of the focusing schlieren system in the laboratory at first, the images of candle flames were gotten, whether the light source is an incandescent lamp, Fig. 6 shows the focusing schlieren image with two candle flames for two different planar region. The small perturbations of the air current can be find out from the the strong light and shade change of the photo, also, it is obvious to find out the focus characteristic, namely the candle air current that is not focusing on the position is reflected by one of formation of image as the even background basically, thus prove the focus characteristic of this system obvious, the principle experiment is successful.

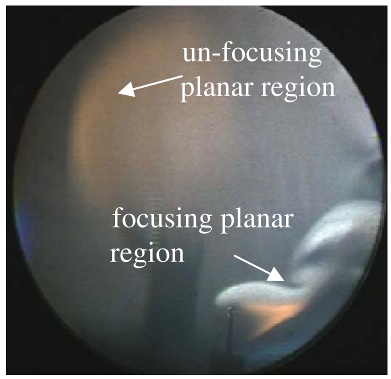

Fig.6. Focusing schlieren image of two candles burning at different plane

Applications study in shock tunnel

Preliminary applications of focusing schilieren system have been finished in the 2m shock tunnel and 0.6m shock tunnel in the hypervelocity institute of CARDC. In the 2m shock tunnel, in order to observe the bow-shaped shock wave, we focus on the centre of one model head. The distance between two viewing window glasses of this wind-tunnel is 3m, source grid and focusing lens is 5m, the sharp focus depth DS of the focusing schilieren system according to the relevant formula is about 11mm, the unsharp focus depth DU is about 56mm. In the 0.6m shock tunnel, source grid and focusing lens is 3m, the sharp focus depth DS is about 4.6mm, the unsharp focus depth DU is about 50mm. The pulse width of the laser light soure used in the system is 10ns with the highest pulse energy about 20mJ.

Experimental condition

The test model in the 2m shock tunnel is an awl body with a ball head which radius is 7.5mm, the flow Mach number is 9.3, flows, the nose angle is 10 degree, the free flow density is 6.05e-2kg/m^3. The test model in the 2m shock tunnel is an the model with unsmooth step, its nose angle is 0 degree, the flow Mach number is 6.386, the free flow density is 0.182kg/m^3.

Test result

Photographs were made with the awl body in the 2m shock tunnel, the focus plane is in the model centre, and the results are shown in Fig. 7. This photograph has reflected clearly the bow-shaped shock and the surface layer of the flow around the awl body, thus prove that the system has very high sensitivity. Though the system has used the laser light source and change into the wide light source, unavoidable diffraction and interference stripe when the source used in the conventional schlieren is not appearing in the picture, it is obvious to explain the wide light source characteristic for focusing schlieren.

Fig. 8 shows that the image gotten in the 0.6 shock tunnel with a protruding step awl model, the focus plane is in the model centre. The flow structure of this picture is clear, and the surface layer characteristic is obvious.

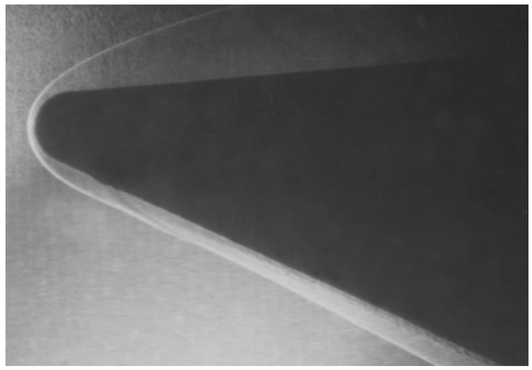

Fig.7. Focusing schlieren image gotten in the 2m shock tunnel

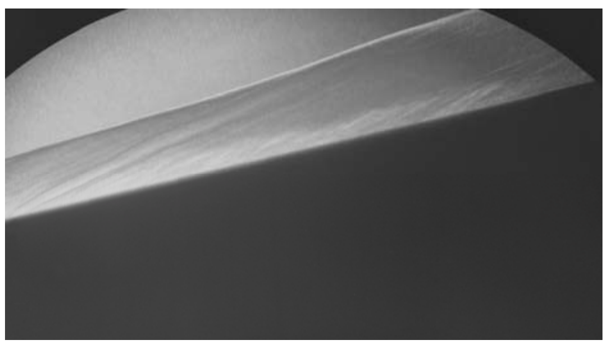

Fig.8. Focusing schlieren image of convexity model gotten in the 0.6 m shock tunnel

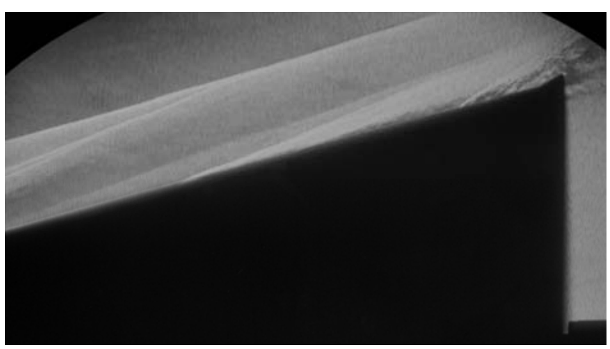

Fig.9. Focusing schlieren image of concavity model gotten in the 0.6 m shock tunnel

Fig.9 shows that the image gotten in the 0.6 shock tunnel with a concave step awl model, the focus plane is from the model centre sectional 16mm. Can be found out from this picture, the whirlpool structure of the flow field is clear. According to the different gray value of the pictures between having flow and no flow, through pattern process method the size of grey level change on a certain focus surface can be gotten, the data will establish the foundation for the quantitative analysis of density value.

CONCLUSION AND FUTURE WORK

(1) The focusing schlieren system has been constructed in the hypervelocity institute of CARDC, the focusing schlieren pictures have been obtained firstly in the shock tunnel with the system, the flow structure, the surface layer close model and the whirlpool structure characteristic of field flow are clear from the pictures;

(2)The quantitative value of density of flow field could be gotten accord with the relevant focusing theory of focusing schilieren;

(3) It is possible to develop a large field flow visualization system; its diameter is greater than 1m, for the optical components are easy to process;

(4) Next goal in research: Combine together focusing schileren with holographic technology, in order to expect that focusing schlieren pictures of different focusing plane can be gotten in one test, realize to record the instantaneous three-dimension image in a wind tunnel.

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