THE APPLICATION OF HOLOGRAPHIC INTERFEROMETRY FOR WIND TUNNEL WINDOWS TESTING

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The basic principles of the holographic interferometry have been given. The air flow around aerodynamic models is a very complex phenomenon. In optical sense, fluid flow field is a transparent object with complex light refraction index distribution. The method of holographic interferometry is very often used for qualitative and quantitative flow testing. The holographic images contain the summation of the flow and window contributions. The internal stresses of klirit wind tunnel windows have been tested with holographic interferometry. These results are very important for interpretation of flow field visualization effects obtained in wind tunnel experiments.

INTRODUCTION

The holographic interferometry is an optical contact-free method enabling a complete diagnosis of different transparent object and flow field of fluids (1-12). Very large literature exists on holography and holographic interferometry. Its applications in aerodynamic testing goes back some twenty years ago. Air flow around aerodynamical models is a very complex phenomenon. In optical sense, fluid flow field is a transparent object. Light beam passes through test section, suffers phase changes and carries information as phase modulation.

The basic assumption in flow field visualization by holographic interferometry is that only changes due to aerodynamic effects around the tested model are recorded. All other effects are neglected (3,4,6,9).

This article deal with the case when aerodynamic effects are combined with the influence of plastic deformation produced on wind tunnel windows made of plexiglas (klirit). False conclusion about flow field could be made, if these holograms have been for analysis. In some cases, due to windows bad quality, the visualization is impossible. Then, the special filtering method must be used to eliminate the influence of windows deformation and internal stresses on final images.

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EXPERIMENT DESCRIPTION

In order to help is complex flow field testing, the experiments are performed in three sonic wind tunnel. Wind tunnel test section size 25oX25o X 25o mm,with windows in standard version, made of BK7 glass. These windows are not suitable for tested 2D flow. For this case, the special 2D models and windows have been made to be able to ensure model fixation and change of the angles of attack (9). While the holographic interferometer shown in Fig. 1 is used in realization of this experiment. The obtained interferograms are of very bad quality (Figs. 3,4). A system without a ground glass plate and with a parallel beam through test section has been used for the first interferogram. A diffusing plate is placed in the interferometer in the front of the test section, for the interferogram shown in the Fig. 4. A two dimensional NACA 0012 airfoil is tested for $M_{\infty}=0.89$. The localization of interferometric fringes is a problem when is used a diffusing light, but the reconstructed scene may be examined from different points of view.

The ruby laser (2) is used for recording, while He-Ne laser (3) is for hologram reconstruction. The holograms have been recorded on a AGFA GEVAERT 8E75 plates (9). Tho coherent collimated monochromatic laser light is divided at beam splitter (5) into two parts as the test beam and reference beam. The object beam is reflecting from mirror (6) (Fig. 1), passes through the test section (10), focusing from another mirror (6) and arrives to the plate (9). Other part of light beam is conducted across wind tunnel (11) and sent to holographic plate (9).

The main problem in the beginning, was the wind tunnel windows quality. They were full of inhomogeneities. To obtain the good quality interferograms, with described system is practically impossible. The modification of interferometer has been made, after that the system can be used. The modulation has been made in the receiving part of the interferometer. The new version is shown in Fig. 2.

DISCUSSION AND ANALYSES OF RESULTS

The basic principle of the double exposure holographic technique has been well known (1-4). Two exposure are made on the same plate, with and without air flow through the test section. When the double exposed hologram is reconstructed, interference patterns due to changes in optical path length between the two exposures is displayed. Holographic interferograms have been used for numerical calculation of flow field parameters.

Light intensity distribution recorded in holographic reconstructed image could be presented with the following approximate formula:

$$I(x,y)=2\{1+[\phi_2(xy)-\phi_1(xy)]\},\quad \Delta\phi(x,y)=\phi_2(xy)-\phi_1(xy)$$

For two dimensional models: $\Delta\phi(xy)=[n_2(x,y)-n_1(xy)]L$

$\Delta\phi(x,y)$-phase difference depending on light refraction index n, L-path length (wind tunnel test section width).

Gladstone-Dale equation is the basic relation connecting flow field optical and other physical parameters, $n-1=k\rho$.

It is known that for light interferometric fringes

$\Delta\phi(x,y)=N(x,y)\lambda$ $\quad N=0,1,2...$ $\quad \lambda$ wave length.

The combination of the presented equations gives:

$$\rho_2(xy)-\rho_1(xy) = \frac{N(xy)\cdot\lambda}{K\cdot L}$$

The interferogram processing can be made by comparison two different points in the images. If ρ_∞ (density in the undisturbed flow) is known, then the density ρ in any field point will be:

$$\rho(xy)=\rho_\infty \pm \frac{N(xy)\cdot\lambda}{K\cdot L}$$

The density ρ is connected with other field parameters as follows:

$$P(xy)=P_o\left(\frac{\rho(xy)}{\rho_o}\right)^{\gamma} ; \quad T(xy)=T_o\left(\frac{\rho(xy)}{\rho_o}\right)^{\gamma-1} ; \quad \gamma=c_p/c_v$$

$$V(xy)=\sqrt{2c_pT_o\left(1-\frac{\rho(xy)}{\rho_o}\right)^{\gamma-1}} ; \quad M(xy)=\sqrt{\frac{2}{\gamma-1}\left[\left(1-\frac{\rho(xy)}{\rho_o}\right)^{\gamma-1}-1\right]}$$

where P(xy) denotes pressure, T(xy) temperature, V(xy) velocity and M(xy) Mach number.

The experiment has been made in two parts. The first is testing the flow field around 2D models and the second is the klirit windows investigation by double exposure method.

In the past few years, laser holographic interferometry has been shown to be a valuable diagnostic tool for wind tunnel studied and transparent object (3,4,6,7,12). The entire density fields can be visualized and mapped qualitatively without disturbances, since only light is used to probe the flow. For the special case of infinite fringes inteferograms of two dimensional flows, the fringe lines become lines of constant density. Thus, density contours are obtained directly. That method is used for presented experiments. The holographic interferograms (Figs. 3,4,5a,5b,6a,6b) show real isodensity; line configuration around 2D model NACA 0012 and cone with top angle of 30 deg. Optical imperfection near the edge of model airfoil is the result of windows inhomogeneities and internal stress produced during polymerization and windows manufacturing.

During wind tunnel running sub pressure was produced in the test section. Because of that, windows were attracted towards the model. The window materials was deformed in the top area of the model. Additional inside strains were induced in the windows.

The repeated test with the same model (cone) has done the differential interferometric fringes distribution (Fig. 6b). Beside the aerodynamical effects the elliptical fringes are located in the top area of cone. They are produced of plastic, rheological, windows deformation during the tunnel running. The parasite effects could give false information about the flow field. For quantitative interferograms processing it is necessary to eliminate this parasite effect by filtering of picture .

The fundamental problem was to produced good quality tunnel windows. The models were mounted in the plastic windows with a gap at each end of 1 mm. The montage could be ensure model fixation and positioning the angle of attack.

Klirit is obtained from methyleter of metacrilic acid (monomer) the synthesis of which is generated by hydrocyanic acid and acetone. The monomers are featured by long chain structure composing high molecular compounds. The blocks used for windows was 30 mm of thickness, with physical and optical properties as follows: specific weight 1190 kg/m^3, refractive index n=1.49, light transmittance t=92%, tensile strength 70 MPa, compression strength 100 MPa, modulus of flexure 315 MPa, impact strength 25 kJ/m^2, Rockwell hardness (M-scale) 100, deformation temperature 105^{o}C.

These material properties promised the good quality of tunnel windows, but the interferograms show that there are a lot of inhomogeneities in the block because of polymerization defects and additional stresses during manufacture of the windows specially in the central area (4,5,9,1,12).

Testing the windows quality has been made by holographic interferometry double exposure method. The interferometers were made without and with the windows (open and closed wind tunnel). In the time of the first exposure, object beam traversed through test section without amplitude and phase modulation. They stay constants. During the second exposure, the tunnel windows were closed and the object beams traverse through them.

The holographic images were reconstructed and the photos were taken. The Fig. 7 and 8 show the interferograms of central windows parts. The distribution and number of fringes indicate the presence of the strong density gradient. That is the evidence why the interferograms have bad quality in the middle of the field around the edges of the models (NACA 0012).

CONCLUSION

The results of these experiments are used for qualitative investigation of wind tunnel windows. The interferograms are very compligated to be quantitative processing. The looking of the windows interferograms is more complicated when the second exposure is made in the moment of tunnel rub. The second problem is to connect the picture and object coordinate system.

The results of the flow field testing around 2D models and tunnel windows show the advantages of holographic interferometry method compared with classical one.

The presented configuration, klirit windows and 2D models, is not satisfactory because of material properties. The numerical processing of flow field interferograms needs the determination of the defects and theirs interferograms are subtracted from the final holographic inteferograms of flow field around tested models.

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Fig. 1

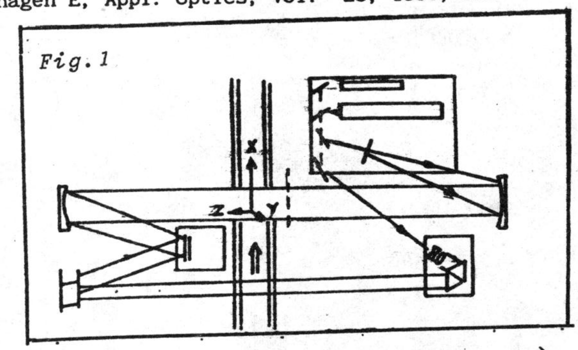
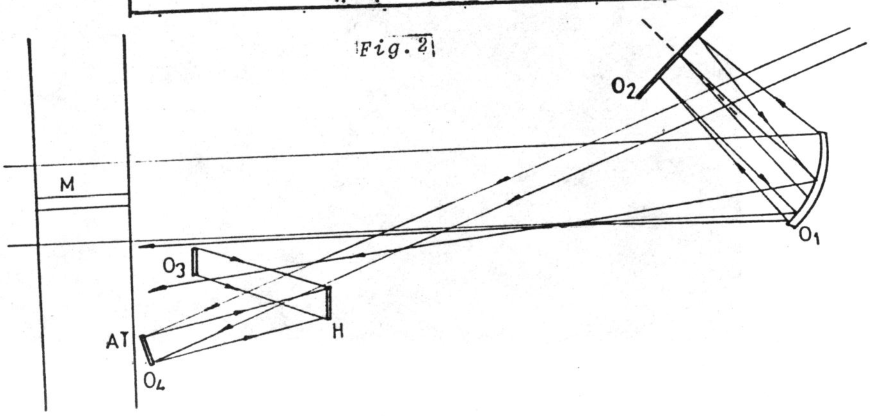
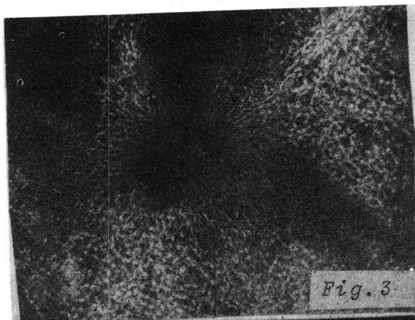


Fig. 2

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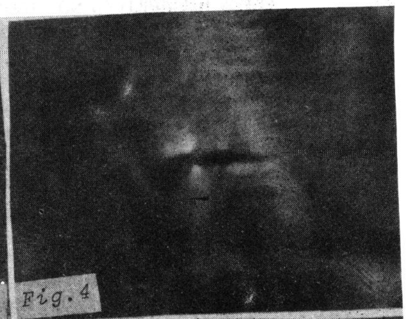
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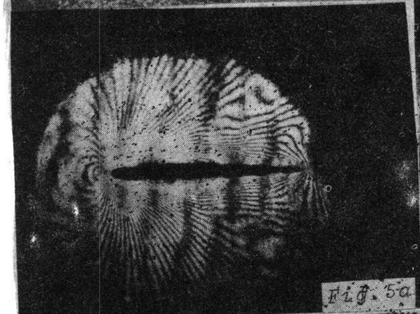
Fig.5a

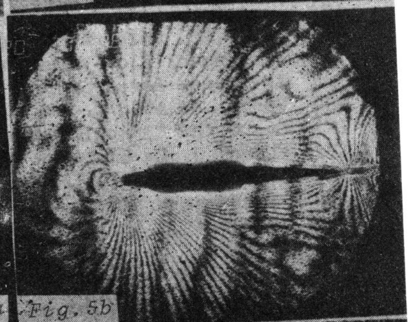
Fig.5b


Fig.6a


Fig.6b


Fig.7

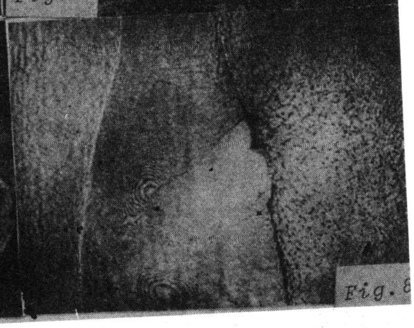
Fig.8