A laser holograph for investigation of two-dimensional transonic cascade flow

by
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The task was to construct and to apply a simple optical arrangement with a laser as a light source for interferometrical and holographical measurements.[1)] A cascade test-section was given.

During the measurements the essential optical elements of the interferometer or holograph must be at rest each against the other. But it is very difficult to realize this restriction if the measurements are made on a measuring arrangement with a large charge at high velocity. In this case the measuring arrangement produces floor vibrations and a strong sound field in the ambient atmosphere. Both of them give rise to undesirable vibrations of the elements of the interferometer. To avoid detrimental mirror vibrations it is nessesary to diminish the generation of vibration and of sound caused by the test facility. This was done by constructive provisions. Further the interferometer must be constructed stable and the installation of the interferometer must be so, that floor vibrations are absorbed.

Fig. 1 shows one of several possible arrangements of the optical elements. The interferometer is formed only by two mirrors like a Fabry-Pérot interferometer. This is the simplest form that is possible. The mirrors are supported Cardanic and they can be inclined. Mirrors with different reflecting and transmitting behaviour can be mounted easily. Thus the optical arrangement can be used in a great manner: it can be used as a multiple-beam interferometer or as a holograph; the phase object can be observed in the reflecting light or in the transmitting light.

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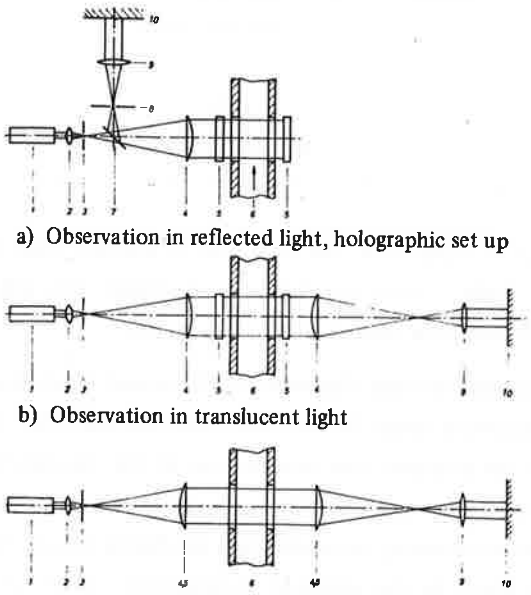
1) The author has reported this problem also at Euromech Colloquium No. 55 on "Optical Interferometry in Experimental Gasdynamics", Bochum, 25.-26. March 1974



a) Observation in reflected light, holographic set up

b) Observation in translucent light

c) Observation in translucent light; non-spherical lens and mirror of interferometer are one optical unit.

1) He-Ne-Laser
2) Microscope objective
3) Spatial filter
4) Non-spherical lens
5) Mirror of interferometer
6) Test section
7) Beam splitter/mirror
8) Diaphragm
9) Objective
10) Plane of image

Fig. 1 Optical arrangement of the holograph

For the investigation of the cascade flow the optical arrangement is a double-exposure holograph (Fig. 1). A microscope objective focuses the laser beam on a very fine hole in a screen, the patial filter. It follows a non-spherical lens with a focal length of one meter and with a diameter of two hundred millimeters. The lens generates a collimated beam. The interferometer reflects the light and a second beam splitter decouples the light for the image on the negative. The total reflecting mirror of the interferometer is normal to the light beam. It reflects

beam splitter of the interferometer generates the reference beam. It is inclined by a small angle, about two degrees. Then a row of light-source images appears in the focal plane after the second beam splitter.

The image from the reference beam and the first image from the measuring beam are selected with an aperture. The result is a two-beam interference in the negativ.

The interferometer is an optical resonator as the laser. The length of the interferometer can be tuned to the resonator of the laser. Then the coherence length of the laser light can be smaller than the path difference between the measuring beam and the reference beam. That is, the laser must not work in mono-mode.

An objective focuses an optical sharp image on the negativ. This has an important consequence. During the reproduction of the hologram the image appears in the plane of the hologram. Thus the size of the image is independent of the wavelength and the hologram can be reproduced with nonmonocromatic white light. A mercury-vapour lamp was used.

Another essential aspect is the following one. The laser is a helium-neon laser with a power of two milliwatts. The exposure time is one millisecond and the sensibility of the film is eighteen DIN. About fifty lines per millimeter are in the negativ. Thus the use of special holographic films is needless.

To avoid detrimental vibrations the interferometer itself was constructed very stable. The simple symmetric form of the interferometer has here a further favourable behaviour. If the interferometer is moving, the two mirrors are overcome the same conditions and the relative position of the mirrors is nearly unchanged by the motion. The interferometer is placed on a concrete block with a weight of 1.5 metric tons (Fig. 2). The block is placed on four springhousings with several helical springs. All natural vibration frequencies of the system are about one Hz. The whole system is something like a seismograph.

Acryl-glass windows are mounted in the test-section. This gives rise to some serious problems.

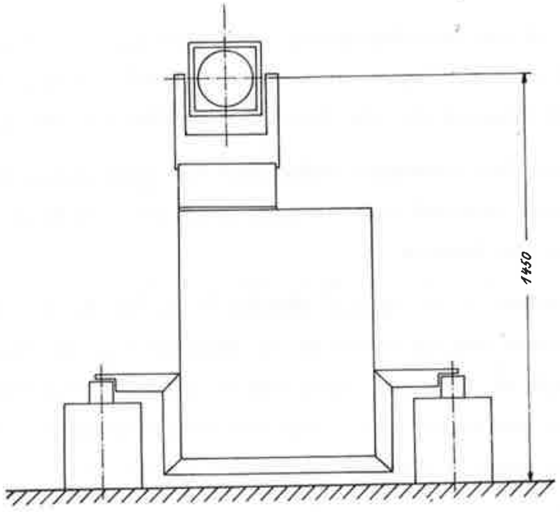


Fig. 2 Mechanical installation of the holograph

At first, the optical path length through the acryl-glass varies considerably, especially at any boundary of the acryl-glass plates. The double-exposure technique eliminates the influence from all inhomogeneities on the path length, but the double-exposure technique does not eliminate the optical deformation of the geometrical field due to the associated light deflexion. This leads to measuring faults. To avoid this the acryl-glass plates were examined interferometrically and then so combined, that the result was a minimum in deflexion.

Secondly, the acryl-glass plates have internal, inherent tensions. These tensions twist the light vector slowly. But interference is only possible between parallel components of light vectors. Therefore the contrast of the fringes is reduced and the fringes vanish if the turning angle reaches ninety degrees. Hence the plates were examined also with photoelastic methods.

Fig. 3 shows the tension field in a quadratic plate. The same plate after working on the turning bench is to see in Fig. 4. Now the conditions on the boundary are changed and therefore the whole field is changed. After drilling the result is the unfavourable picture in Fig. 5.

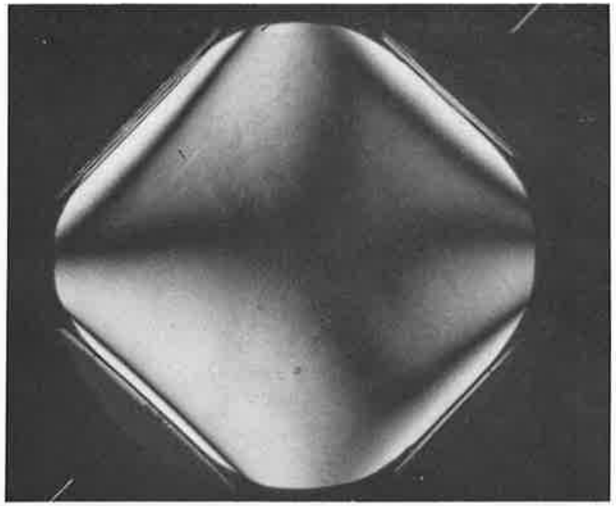


Fig. 3 Tension field in a quadratic acryl-glass plate

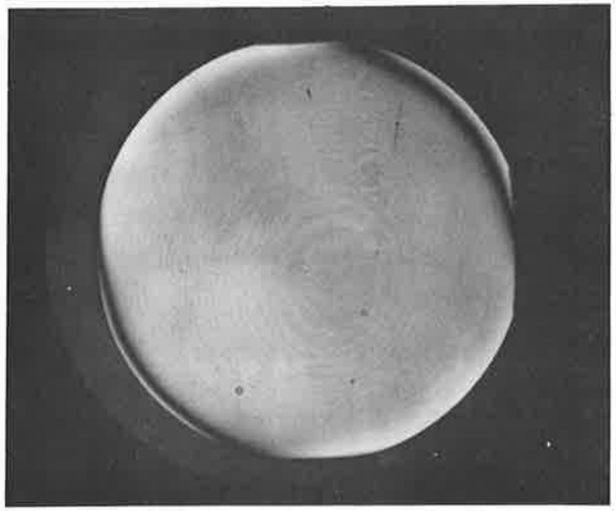


Fig. 4 Tension field in a round acryl-glass plate

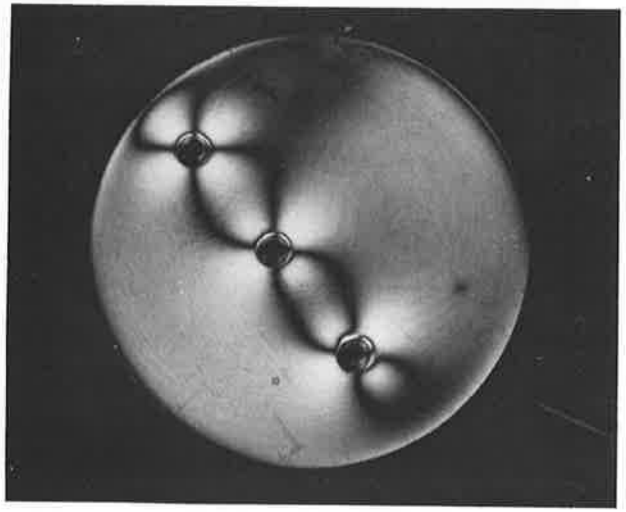


Fig. 5 Tension field around drilled bores

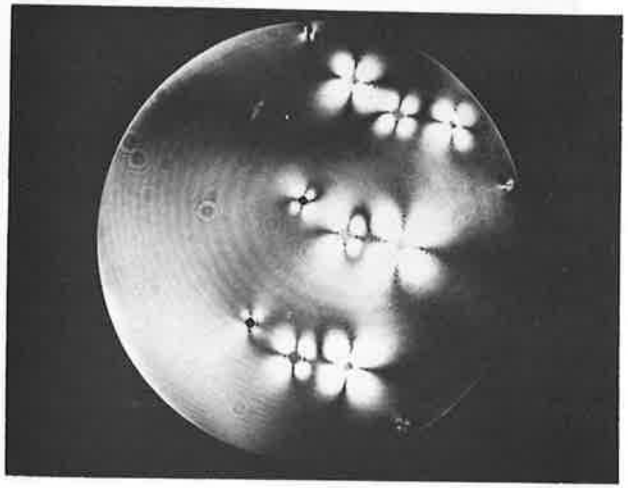


Fig. 6 Tension field around several well drilled and badly drilled bores

Several bores are to see in Fig. 6. The intensity of the tensions varies from bore to bore. Well drilled bores lead to weak tension fields and badly drilled bores lead to strong tension fields. The consequence is: the acryl-glass windows must be prepared carefully.

It gives one more problem. This is the change of the tension field with time. The fringes in Fig. 7 are lines of constant optical path length around a well worked bore. After some days the picture is changed unfavourable (Fig. 8). Now it gives a high density of fringes around the bore.

The application of acryl-glass windows gives rise to some serious difficulties. But with carefully selected and workes windows all difficulties were overcome and the interferograms in Fig. 9 and Fig. 10 were obtained. The fringes are lines with constant velocity.

In Fig. 9 the flow is nearly incompressible. Worth mentioning is, that the periodicity is very good. Consequently the relative positions of the mirrors were unchanged during the two exposures. All stagnation points are white. This means, the position of the hologram was unchanged in the time between the two exposures.

In Fig. 10 the flow is transonic. The dash lines mark the sonic lines. On the nose of the profile is a local supersonic region with two weak shock waves. The second sonic line begins on one profile and ends on the other profile. The dash-and-dot line marks the trailing-edge shock wave.

Also the whole flow field was calculated numerically[2]. The difference between the measured and the calculated lines of constant velocity is about a half of the distance between the fringes in the picture. This means, the accuracy of the measurements is as good as the accuracy of the calculation.

2) Schmidt, E.: Numerische Berechnung und experimentelle Untersuchung des transsonischen Strömungsfeldes in stark umlenkenden Schaufelgittern.
Dissertation an der Universität Stuttgart. Dez. 1976

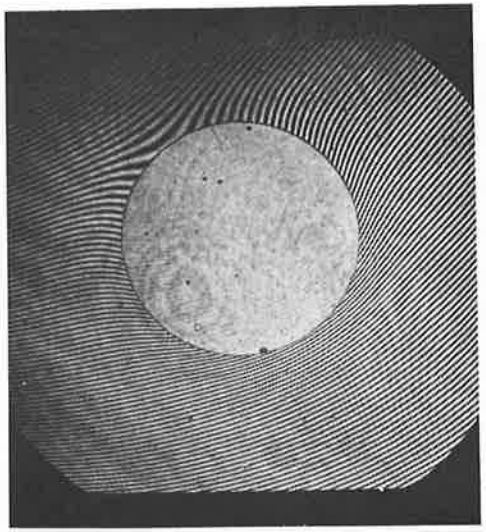


Fig. 7 Lines of optical path length in a acryl-glass plate just after working the bore

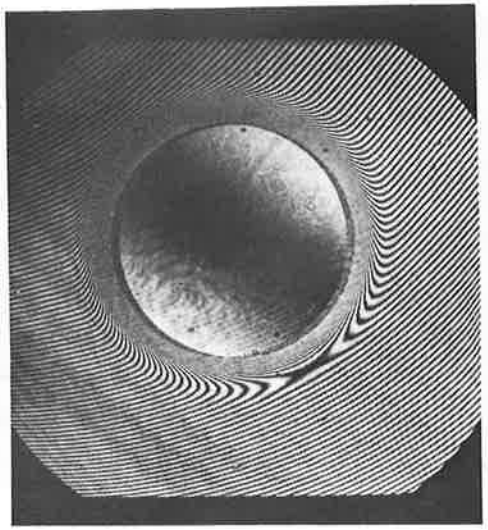


Fig. 8 Lines of optical path length in a acryl-glass plate some days after working the bore

Fig. 9 Lines of constant velocity in a nearly incompressibel flow

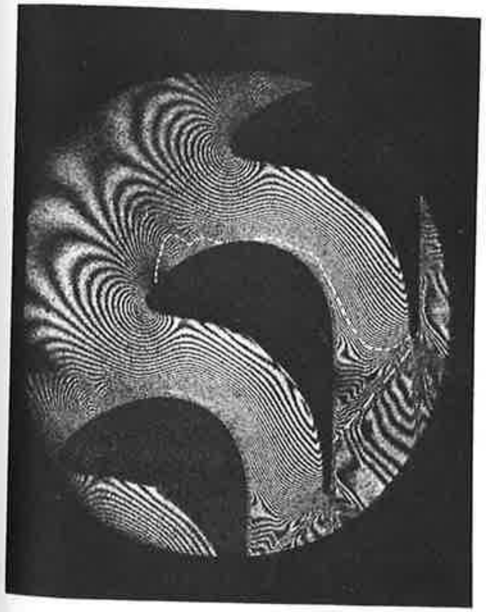


Fig. 10 Lines of constant velocity in a transonic flow