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State of the Art of Color Interferometry at ONERA

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Abstract : At ONERA-Lille center a lot of studies have been conducted to characterize complex flows using an optical method based on differential interferometry with Wollaston prism and white polarized light source. Several applications are presented in two-dimensional and axisymmetric flows and in a gaseous mixture where the two gases interface is submitted to acceleration. Then, real-time color holographic interferometry (RCHI) has been developed to obtain the refractive index itself in two dimensional wake flow. The last improvements concern the extension of this method for analyzing three dimensional flows. The authors present a specific setup defined in a single sight direction, the aim being to reproduce the same optical setup along several sight directions, each shifted by a given angle. This optical technique uses reflection holograms where the diffraction efficiency of plates is strongly influenced by the variations in the gelatin thickness produced during the holograms treatment. Problems are discussed and solutions are proposed to control the gelatin shrinkage for two different types of used holograms. The results obtained in a one sight direction make it possible to build in the future an optical setup allowing several simultaneous line-of-sight optical measurements.

Keywords : High speed interferometry, Color holography, High speed flow, Panchromatic hologram.

1. Introduction

At the Lille center of the Office National d'Etudes et de Recherches Aérospatiales (ONERA), the fine characterization of complex flows has been a specificity known for more than twenty years, starting with an existing system, developing an optical method based on differential interferometry using Wollaston prism and a source of polarized white light. A schlieren interferometer has been built to make possible high speed differential interferometry using Wollaston prism and a polarized white light source (Desse, 1990; Desse et al., 2005). A lot of studies have been conducted where the unsteady pressure measurements have been simultaneously recorded with visualizations in order to be able to synchronize high speed interferograms and pressure variations (Rodriguez, 1984; Desse, 1991; Sieverding et al., 1997; Desse, 1998).

The development of color interferometry to high speed flows and several applications are presented. The adaptation of the optical setup to two-dimensional subsonic flows, axisymmetric flows are detailed, as well as different results that have been obtained. An application also concerns the study of a gaseous mixture and the evolution of two gases interface submitted to acceleration (shock wave). All the applications of color interferometry are not described here, but one can note that the properties of color interference fringes have been used to evaluate the skin friction coefficient. The interference fringes obtained under white light by a thin oil film have been used to measure the distribution of the skin friction coefficient on a flat plate (Desse, 2003). The analysis of the interferograms used to be conducted manually and heavily hampered the method. A quasi-automatic processing of interferograms has been developed, based on the modeling of interference fringes versus the optical path difference. This modeling allows identifying the color of the pixel under analysis by a value of the refractive index, so that each pixel can be replaced by an optical path difference (Desse, 1997).

Finally, as differential interferometry produces the first derivative of the refractive index, real-time color holographic interferometry (RCHI) has been developed to obtain the refractive index itself. The method has been successfully applied in the ONERA wind tunnel to analyze the two dimensional wake flow around a circular cylinder at Mach 0.4 where high resolution panchromatic holograms have been recorded by transmission. Currently, our work aims at extending this method for the analysis of the three dimensional flows. In order to make that, the specific setup has been defined in a single sight direction, the aim being to reproduce the same optical setup along several sight directions, each shifted by a given angle. Contrary to the optical setup developed for the analysis of 2D flows, in the one proposed for 3D flows, reflection holograms are used and the diffraction efficiency of plates is strongly influenced by the variations in the gelatin thickness produced during the holograms treatment. Solutions are proposed to control the gelatin shrinkage and tests are presented for two different types of holograms: Russian plates (Slavich) and French plates (Gentet). Finally, high speed interferograms obtained in a one sight direction are presented.

2. Application of Color Interferometry

2.1 Application of Color Interferometry to Two-Dimensional Unsteady Flows

The optical setup is based on differential interferometry in polarized white light using one or two Wollaston prism and the principle is discussed in details by Gontier (1957). In this example, the unsteady wake flow is analyzed behind schematic turbine blades at Mach 0.4 (Sieverding, 1997). The unsteady pressure signals are simultaneously recorded around the trailing edge in order to be able to synchronize pictures and pressure variations. A dozen interferograms covering about one period of the vortex street have been analyzed for the three tested models. Two successive interferograms and the gas density field are given for model C in Fig. 1. The gas density ρ is referenced to the upstream gas density ρ_∞. With this model, the trailing edge is circular and 15 mm in diameter and the boundary layer state is quasi-laminar. In fact, because of the shifting of the two interfering rays, the interferograms cannot be analyzed down to the model wall. For example an analysis conducted following a vertical line is only possible until one of two interfering rays is blocked by the model. In the conditions of the optical setup, the analysis is made down to 1.57 mm from the model wall and the gas density at the wall is obtained through extrapolation of the data. The density fields of Fig. 1 show the vortices as concentric rings, with density decreasing toward the center. These vortices pass through a formation phase where the density decreases in the vortex center and a dissipation phase where the density and the size of the vortex increase.

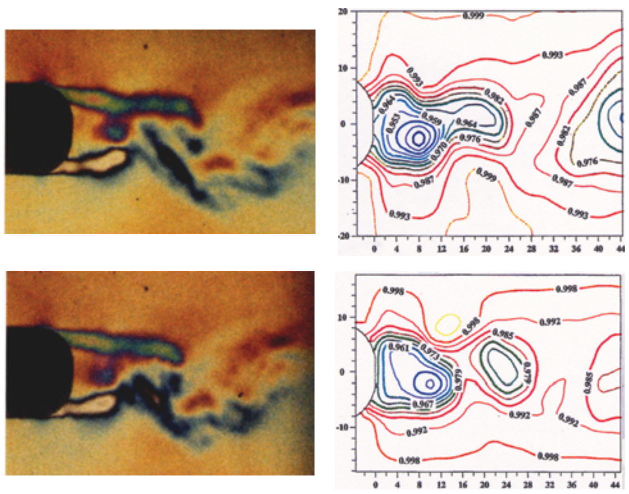


Fig. 1. High speed interferograms and gas density field reconstruction – Δt = 50 µs, M = 0.4.

2.2 Application of Color Interferometry to Axisymmetric Wake Flows

The structure of a supersonic hot jet at Mach 1.8 injected into a coaxial supersonic flow at Mach 1.5 has been analyzed by differential interferometry because it is a non-intrusive technique particularly well suited to investigation of phenomena related to compressibility and high temperatures (Rodriguez et al., 1997). The unsteady character of the flow is taken into account by adapting the exposure time of the recordings to some characteristic time scale. The method is sufficiently sensitive to be able to make a quantitative analysis to reconstruct the local density field. This operation is possible from a single interferogram provided the flow is two-dimensional or axisymmetric. The interferograms recorded were analyzed assuming that the structure was axisymmetric.

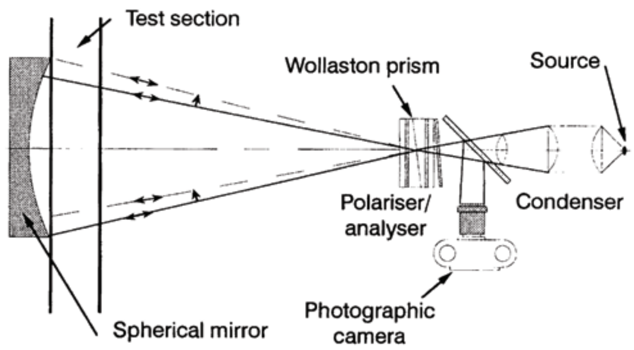


Fig. 2. Experimental setup modified for axisymmetric flows.

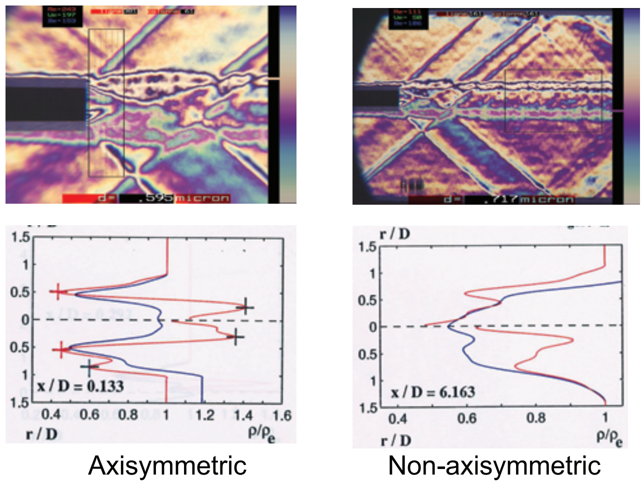


Fig. 3. Radial distribution of the gas density.

Figure 2 shows the optical setup modified to analyze the axisymmetric flow. The two waves issued from the Wollaston prism (4° pasting angle) cross the test section and are returned by a spherical mirror at the same location in the Wollaston prism. A beam splitter inserted in the optical axis returns the rays on the photographic camera. The technique was extended to the analysis of rapidly varying phenomena by substituting a flash source for the initial continuous light source. In our case, the fluid velocity in the jet was around 685 m/s. The interferogram exposure time therefore had to be very short. The exposure time of the flash source used, equal to 0.3 µs, corresponds to a fluid displacement of around 0.2 mm.

Figure 3 shows two interferograms recorded for $P_1/P_2 = 2.74$ and 3.38 at the same temperature ratio $T_1/T_2 = 1.67$. The subscripts 1 and 2 are relative to the external flow and to the jet flow respectively in the injection plane. The radial density distribution was determined by spectrum analysis of the colors in the upper and lower half-planes. If the flow is strictly axisymmetric, the two profiles should be identical. In Fig. 3 and for the axisymmetric case, the profiles of the optical thickness (blue line) and the gas density (red line) obtained near the nozzle exit section are relatively symmetric about the flow axis. In the non-axisymmetric case, the analysis made far downstream provides relatively contrasted density profiles which reflect the presence of local turbulences in the flow. Finally, the density profiles measured in the jet were superimposed on the flow image. They showed that, close to the jet exit, the density minima were always positioned on the boundary between the potential cone and the reflected shock wave while, further downstream, they are on the boundary separating the internal and external parts of the jet. This structure was observed in all the cases and indirectly validates the analysis method.

2.3 Application of Color Interferometry to the Gaseous Mixture

Differential interferometry has also been used to analyze the stability of the interface separating two fluids of highly different densities when it is impacted by an incoming shock wave. Tests were made at the Commissariat à l'Energie Atomique (Galametz, 1994). For that, a shock tube has been built to visualize the evolution of these diffuse interfaces, the light gas being above the heavy one. The shock tube is vertical in order to keep the interface stable before the arrival of the shock wave. Several diagnostic techniques have been used: X-ray densitometry and differential interferometry. With the X-ray technique, one can obtain the partial gas density profile of one of the two gases from a careful calibration if the gases pair is air/xenon. In the case of SF6/air, both gases are transparent to X-rays and the radiography can not be used. Only differential interferometry can yield a SF6 repartition in air.

The optical setup requires two Wollaston prisms installed head to foot and two "Clairaut" achromatic lenses, 800 mm in focal length and 120 mm in diameter. The Wollaston prisms are pasted with an angle of 0.5°, which generates a shifting of 0.157 mm between the two interfering rays. To focus the interference fringes and the test section central plane on the film, the middle of the test section is at the focal length of the second lens near the camera.

In the case of two gases mixture, the Gladstone-Dale relation can be extended if the Gladstone-Dale constants of each gas are known. Then, the analysis of interferogram yields the partial density profile of one of two gases across the interface. Figure 4 shows three interferograms recorded at different times. In interferogram (a), the shock wave has already crossed the interface, has reflected from the tube end wall and is about to again impact on the modified interface. Picture (b) has been taken shortly after this second impact and the wave is seen to have been partly transmitted into SF6 and partly reflected into air. On picture (c) the transmitted wave can be seen close to the bottom of the picture while the reflected part has again reflected from the end wall and is about to impact on the interface. The SF6 partial density profiles have been obtained through the interface by averaging a dozen of interferograms. The abscissa x = 0 is defined when the partial density of SF6 is equal to 0.5. For the xenon/air gases pair, xenon partial density profiles compared to those obtained with the X-ray technique show that the two techniques yield very similar results.

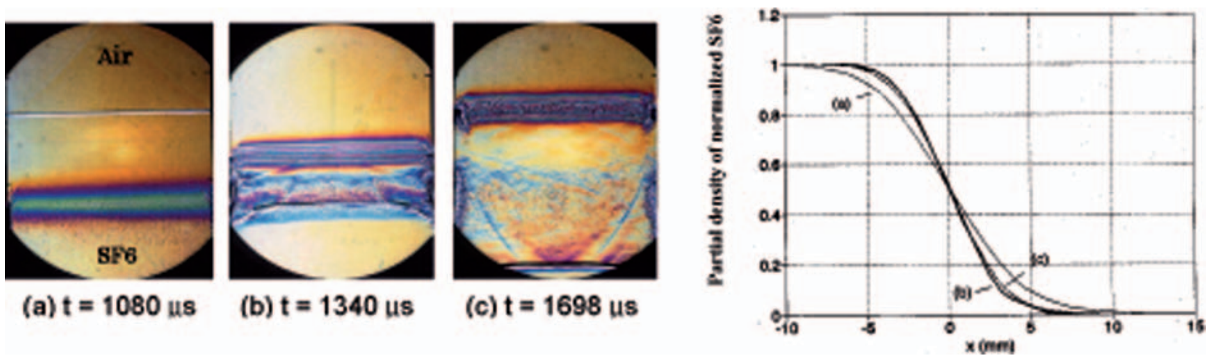


Fig. 4. Gas density profiles of SF6 - Interface: SF6 – Air, Ms = 1 .45.

2.4 Measurement Sensitivity and Accuracy

The technique of differential interferometry is limited by the minimum phase difference δ_{min} that can be detected. To determine δ_{min}, it is possible to refer to the Newton color scale as a function of the phase difference Δ in the Wollaston prism when the polarization axes of the polarizer and the analyzer are perpendicular. In this scale, the smallest phase difference (30.10^{-9} m) is found between the warm red and the purple of tints of the first order. For example, if the setup is such that the path crosses the test section twice, the optical thickness difference ΔE is half the phase difference. The refractive index reference Δn is given by $\Delta n = \Delta E/e$ in which e is the test section width. The Gladstone-Dale relation, $n-1 = K\rho/\rho_s$ in which ρ_s is a reference value and K a constant, relates ρ to n.

For a two-dimensional flow in a test section of width e = 42 mm, $\Delta\rho_{min}$ = 1.57.10^{-3} kg/m^3, while for e = 200 mm, $\Delta\rho_{min}$ = 1.57.10^{-3} kg/m^3. If, for a given value of e, the gas density gradients are smaller than $\Delta\rho_{min}$, they will not be detected. One should mention that the minimum detectable phase difference is deduced from a visual criterion, i.e. the change of tint in the interferometer scale. This criterion can be often improved by automatic processing of the interferogram.

3. Real-Time Color Holographic Interferometry

3.1 Application to 2D Flows

Our latest work has thus led us to develop true color real-time holographic interferometry which combines the advantages of differential interferometry with those of monochromatic holographic interferometry. With this, not only small path differences but also large ones can be measured because the interference fringe diagram obtained is very broad and well-contrasted. Also, as opposed to monochromatic holographic interferometry that can provide only relative data, color holographic interferometry generates the achromatic fringe and also provides absolute data throughout the entire field of observation and its feasibility has been demonstrated in the Franco-German Saint-Louis research institute (Desse et al., 2002).

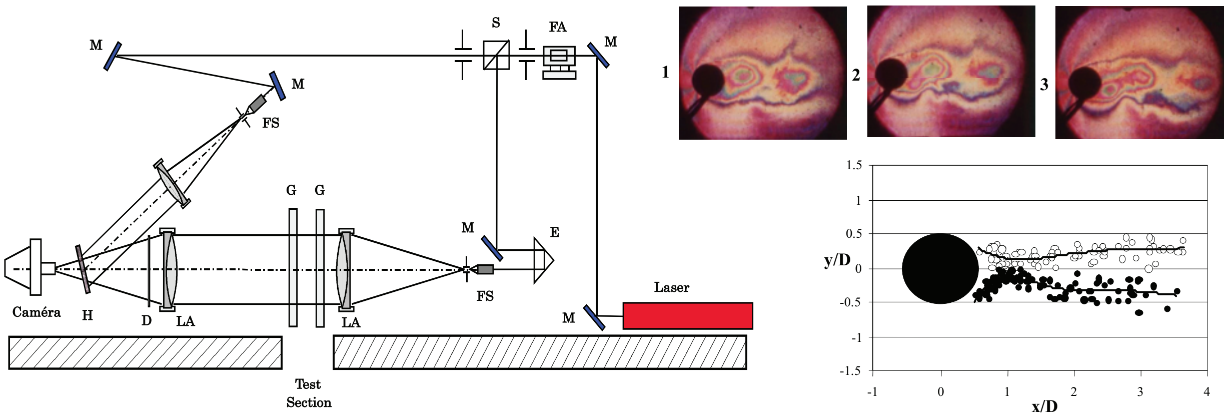


Fig. 5. Interferograms and results obtained with real-time color holographic interferometry setup.

The optical setup shown in Fig. 5 has been implemented around Onera's wind tunnel at the Lille center. For reference, this wind tunnel is equipped with a 2D test section 200 mm high and 42 mm across. The flow studied was the unsteady flow downstream of a cylinder of diameter D = 20 mm placed crosswise in the test section. An argon and krypton mixed gas laser emits the ten lines in the visible simultaneously. The beam power as it leaves the laser is 1.20 W when the Fabry Perot etalon is tilted. The red, green, and blue lines we want are diffracted by an acousto-optic cell (FA) and the three patterns that are generated by three appropriate frequencies. Beam splitter cube (S) splits the reference beams and three measurement beams. The three reference beams pass over the test section, and they are expanded by a microscope objective lens and an achromatic lens (FS) then, an achromatic lens is used to illuminate the hologram with a parallel light beam of 60 mm in diameter. The three measurement beams are collimated in the same way to form three parallel light beams between the two achromatic lenses (LA) and cross the test section. Hologram (H) is thus illuminated on the same side by the three parallel reference beams and the three convergent measurement waves. A diaphragm is placed in the focal plane just in front of the camera in order to filter out any parasitic interference. That is, the hologram is first illuminated in the absence of flow (2s) and is then developed and placed back in exactly its original position.

The holograms are then subjected to treatments to harden the gelatin, develop it, and bleach it. When the hologram is put back in place, the light power at the camera entrance is 1.5.10^{-3} Watt at the focal point, which is sufficient to record interferograms at an ultra-high rate of 35,000 frames per second with an exposure time of 750 nanoseconds per shot. Figure 5 gives three successive interferograms shifted by 100 µs of the flow around the cylinder at Mach 0.37. The vortex formation and dissipation phases can be seen very clearly, along with the fringe beat to either side of the cylinder. Several types of measurements were made by analyzing a sequence of some 100 interferograms. First, the vortex center defined by the center of the concentric rings was located in space for each interferogram, which made it possible to determine the mean paths for the vortices issuing from the upper and lower surfaces (Fig. 5). The "o" symbols represent the positions of the

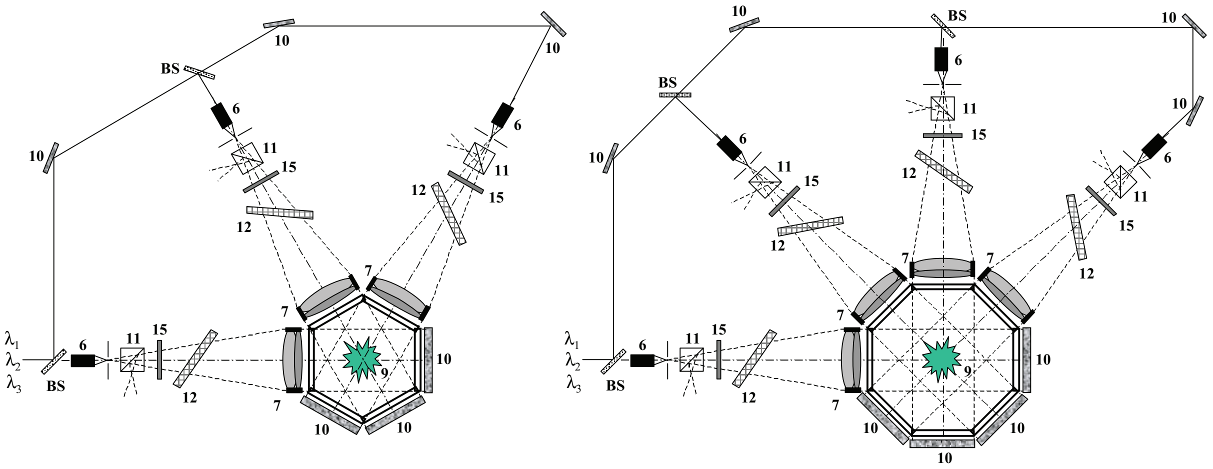


Fig. 6. Optical setups considered with three or four crossings of the test section.

vortex centers from the upper surface, and the "•" symbols those of the lower surface. Remarkably, the two paths exhibit a horizontal symmetry about the x = 0 axis passing through the cylinder center. We may also point out that even at x/D = 4 downstream of the cylinder, the upper and lower vortex paths do not come together and line up. The gas density at the center of the vortices has been also measured in order to see how ρ/ρ_0 varies for the vortices emanating from the upper and lower surfaces. The trend curves plotted show the same variations (Desse et al., 2004).

3.2 Application to 3D Flows

3.2.1 Real-Time Color Denisyuk Holographic Interferometry

Currently, our last work concerns the definition and the feasibility of real-time color Denisyuk holographic interferometry setup for analyzing unsteady 3D flows. It should be based on several crossings of the flow along different view angles as shown in Fig. 6 and it is very evident that the optical setup defined for analyzing 2D flows cannot be reproduced three or four times. As the optical differences to measure are smaller in 3D flows than in the 2D case, it is preferable that each optical ray crosses the phenomena twice in order to increase the sensitivity. To simplify the setup, all the optical pieces are located on the same side of the wind tunnel, except the flat mirror which reflects the light rays back into the test section.

Due to these considerations, an optical setup based on real-time color Denisyuk holographic interferometry has been designed and the feasibility has been shown in one sight of view. Figure 7 shows the optical setup which has been tested. The light source used behind the interferometer is constituted by a laser argon and krypton mixed the red line (647 nm) and the green line (514 nm). A Diode Pump Solid State produces the blue line at 457 nm. An half wave plate (1) is used to rotate the polarization of the blue line and a dichroic plate (3) allows the mixing of the three lines. An acousto-optical cell (4) diffracts the unwanted lines of the argon and krypton laser in the light mask (5) and does not deviate the three wanted patterns that are generated by three appropriate frequencies. The amplitude of each frequency can be adjusted to modify the luminous energy on the hologram and the exposure time is given by an adjustable electronic shutter. A spatial filter (6) constituted by a microscope objective lens (x 20) and a very small hole (25 µm) and an achromatic lens (7) then, are used to illuminate the hologram with a parallel light beam of 120 mm in diameter. A flat mirror (10) located just behind the test section containing the 3D object (9), returns the three beams on the hologram. Hologram (12) is thus illuminated on the two sides by the three divergent reference beams and the three convergent measurement waves. In this setup, a beam splitter polarizing cube (11) is inserted between the spatial filter (6) and the hologram (12). The half quarter plate (15) turns the waves polarization twice so that, when the rays are returning, the beam splitter cube returns the rays towards the screen (14). A diaphragm (13) is placed in the focal plane just in front of the camera in order to be able to filter out any parasitic interference.

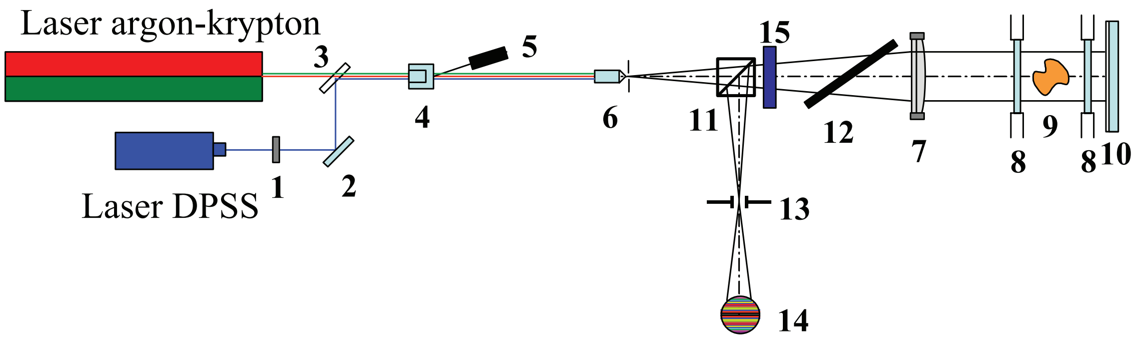


Fig. 7. Real-time color holographic interferometry setup type "Denisyuk".

That is, the hologram is first illuminated in the absence of flow and is then developed and placed back in exactly its original position. If variation in the refractive index exists in the test section, color interferences fringes (14) can be observed on the screen. The advantage lies in the small number of optical pieces which are used. The reference beams and the measurement beams are co-linear and there is just a flat mirror behind the test section. A main inconvenience resides in the fact that it is not possible to adjust the luminous intensity between the reference and measurement beams. The unique solution to solve this problem consists in a specific treatment of the surface of the flat mirror if the diffraction efficiency of the hologram is not near 50 %.

3.2.2 Problems of Gelatin Skrinkage

As shown in Fig. 7, the hologram is now working in reflection and not in transmission. In transmission, the interference fringes are put down perpendicular to the plate and a small variation in the gelatin thickness caused by the chemical treatment of the hologram does not modify the three interfringes. On the other hand, in reflection, the interference fringes are recorded parallel to the plate surface and the interfringes are very sensitive to a small variation of the gelatin thickness.

Two types of holograms have been tested: Russian plates from Slavich and French plates from Gentet. Concerning the first ones, a specific treatment proposed by Kim et al. (2002) has allowed obtaining a gelatin contraction smaller than 20 nm by mixing 2 ml of glycerol in the last bath of ethanol (100 % ethanol drying). We can mention that the treatment applied to the Russian plates includes about ten steps and it is very sensitive to the temperature and the PH solutions. About the French plates, we have also obtained basically no variation in the gelatin thickness and the treatment of these plates is very easy because only two baths are used: developer and bleaching and the products are no carcinogenic.

Figure 8 shows the spectrum diffracted by Gentet and Slavich plates when they are illuminated in white light. In two graphs, the dashed lines represent the spectrum of white light diffracted by the holograms when no solution is brought for the treatment of the plates. We can observe a shifting of about 1.8 % with Gentet holograms and about 1.1 % with Slavich holograms which is not acceptable. It can be also seen that the spectrum diffracted by Gentet holograms shows bell curves wider than the spectrum diffracted by Slavich holograms. For example, if one looks at the red line at a normalized intensity of 0.4, the width of the curve is near to 16 nm and 27 nm for the Slavich and Gentet holograms respectively. It is of 10 nm and 17 nm for the blue line. Gentet holograms show a response wider that is an advantage if a small variation of the gelatin thickness is left. A bad adjustment of the Fabry-Perot etalon in the argon-krypton laser cavity explains the weakness of the green response in the Salvich graph.

When no shrinkage exists, the bell curves are basically centred on the three different lines of the lasers and the best diffraction efficiency of hologram is reached. The three different gratings inscribed in the hologram gelatin diffract very well the three different wavelengths (blue, green and red) of the emitted laser source. In fact, the response of the hologram is the best one because the bell curves are centered on the three laser rays. In these conditions, there is basically no difference in the gelatin thickness before and after the chemical treatment of the plates. Moreover, if the power of the three reference and measurement wavelengths are the same, it is possible to obtain very well luminous and contrasted fringes.

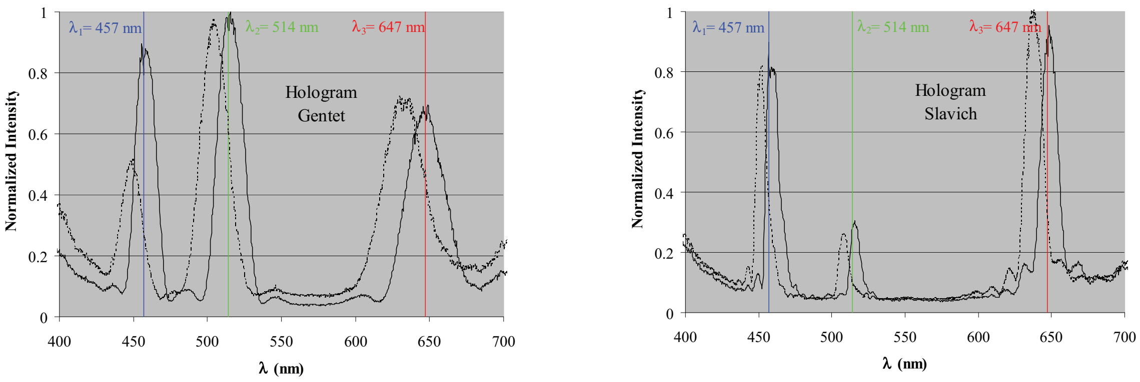
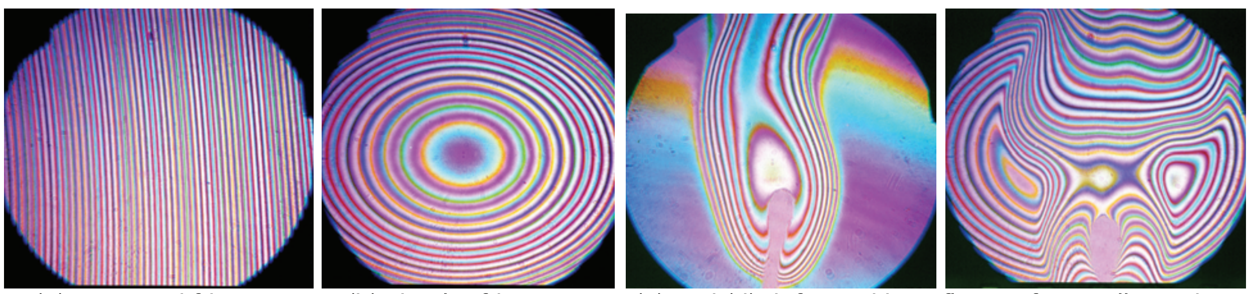


Fig. 8. Measurement of the gelatin shrinkage – Gentet and Slavich holograms.

Finally, Fig. 9 shows some interferograms obtained when the specific treatments are applied to avoid the gelatin shrinkage. The two first ones are obtained with no variation in the refractive index and the two last ones when the fringes are deformed by the flame of a small match. Here, the diffraction efficiency of holograms is about 35 % to 40 %.
Similar results have been obtained with the Slavich plates.



(a) narrowed fringes (b) circular fringes (c) and (d) deformed by a flame of a small match

Fig. 9. Real-time color denisyuk holographic interferograms.

4. Conclusions

It has been shown that the high speed two-dimensional flows can be analyzed by differential interferometry using Wollaston prism and a polarized white light source. Described applications show the large capability of the technique to measure the variation of the refractive index in complex flows and in gaseous mixtures.

As differential interferometry produces the first derivative of the refractive index, real-time color holographic interferometry has been developed to obtain absolute measurements of the gas density.

By using three different wavelengths, a white central fringe representing the zero order is obtained on the interferogram. An application is given in two-dimensional flow represented by the unsteady flow around a circular cylinder at Mach 0.37.

Concerning the analysis of 3D flows, an optical setup based on real-time color Denisyuk holographic interferometry has been designed in one sight of view where reflection holograms have to be used. Problems raised by the chemical treatment which induces shrinkage of the gelatin have been mastered to increase the diffraction efficiency and the true colors restitution. Finally, real-time true colors holographic interferometry type "Denisyuk" exhibits significant interferograms with high contrast and saturated colors. Next work will consist to implement an optical setup with three or four crossings of the test section.

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References

Desse, J. M, Albe, F. and Tribillon, J. L., Real-time color holographic interferometry, Applied Optics, 41-25 (2002), 5326-5333.
Desse, J. M., Albe, F. and Tribillon, J. L., Real-time color holographic interferometry devoted to 2D unsteady wake flows, Journal of Visualization, 7-3 (2004), 217-224.
Desse, J. M. and Bourez, J. P., High speed differential interferometry used for analyzing Aerooptic aberrations, Journal of Visualization, 8-2 (2005), 87.
Desse, J. M., Effect of time-varying wake flow characteristics behind flat plates, AIAA Journal, 36-11 (1998), 2036-2043.
Desse, J. M., Instantaneous density measurement in two-dimensional gas flow by high speed differential interferometry, Experiments in Fluids, 9 (1990), 85-91.
Desse, J. M., Oil-film interferometry skin-friction measurement under white light, AIAA Journal, 41-12 (2003), 2468-2477.
Desse, J. M., Recording and Processing of interferograms by spectral characterization of the interferometric setup, Experiments in Fluids, 23 (1997), 265-271.
Desse, J. M., Whole-field measurement of gas density from two simultaneously recorded interferograms, Experiments in Fluids, 12 (1991), 1-12.
Galametz, I., Visualisation et mesure de masse volumique dans un mélange gazeux en tube à choc, (1994), Thèse de doctorat, Université de Lille.
Gontier, G., Contribution à l'étude de l'interférométrie différentielle à biprisme de Wollaston, Publication Scientifique et Technique du Ministère de l'Air, 338 (1957), Paris.
Kim, J. M., Choi, B. S., Choi, Y. S., Kim, J. M., Bjelkhagen, H. I. and Phillips, N. J., Holographic optical elements recorded in silver halide sensitized gelatin emulsions. Part 2., Reflection holographic optical elements, Applied Optics, 41-8 (2002), 1522-1533.
Rodriguez, O., Desse, J. M. and Pruvost, J., Interaction between a supersonic hot jet and a coaxial supersonic flow, Aerospace Science and Technology, 6 (1997), 369-379.
Rodriguez, O., The circular cylinder in subsonic and transonic flow, AIAA Journal, 22-12 (1984), 1713-1718.
Sieverding, H, Cicatelli, G, Desse, J. M., Meinke, M. and Zunino, P., Experimental and numerical investigation of time varying wakes behind turbine blades, Notes on Numerical Fluids Mechanics, 67 (1997), Ed Vieweg.

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Jean-Louis Tribillon: Doctor/Engineer, famous specialist in color holography. He has a very large experience in color holography using continuous and pulsed lasers and he has recorded a lot of large color holograms known in the entire world. He is working at the Délégation Générale à l'Armement, Direction des Systèmes de Forces et de la Prospective, Mission pour la Recherche et l'Innovation Scientifique.