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# Large-Aperture Interferometer Using Local Reference Beam

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Scientific and Technical  
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## SUMMARY

An interferometer has been devised and assembled which uses amplitude division of an object beam to construct an information-free reference beam by low-pass spatial filtering. It is shown that this interferometer can be used to convert a schlieren system into an interferometer without limiting the useful aperture of the schlieren system, which may be very large, and without constructing a reference beam around the test section.

Two versions of the interferometer are demonstrated: one employing 12.7-cm (5-in.) diameter schlieren optics and the other employing 30.48-cm (12-in.) diameter parabolic mirrors in an off-axis system. The latter system requires the addition of a cylindrical lens to correct for astigmatism. Satisfactory results were obtained by replacing a decollimating lens in the reference-beam arm by a zone plate. Attempts to increase the flux and uniformity of irradiance in the reference beam by means of a diffuser are discussed, and photographs of the reference beam are shown.

## INTRODUCTION

Optical interferometric studies of nonuniform fluids are most frequently undertaken using the Mach-Zehnder interferometer (refs. 1 and 2) shown in figure 1. This interferometer uses wave-amplitude division to provide two separate, coherent, light beams, namely, an object beam, which traverses the fluid to be evaluated, and a reference beam, which circumvents the fluid. The two beams are subsequently recombined to produce an interference pattern whose deformities permit evaluation of the condition of the fluid, especially its refractive index distribution.

The Mach-Zehnder interferometer suffers from several limitations; for example,

(1) Although interferometer apertures up to 1 m (36 in.) in diameter are possible, actual interferometer apertures have been limited to less than

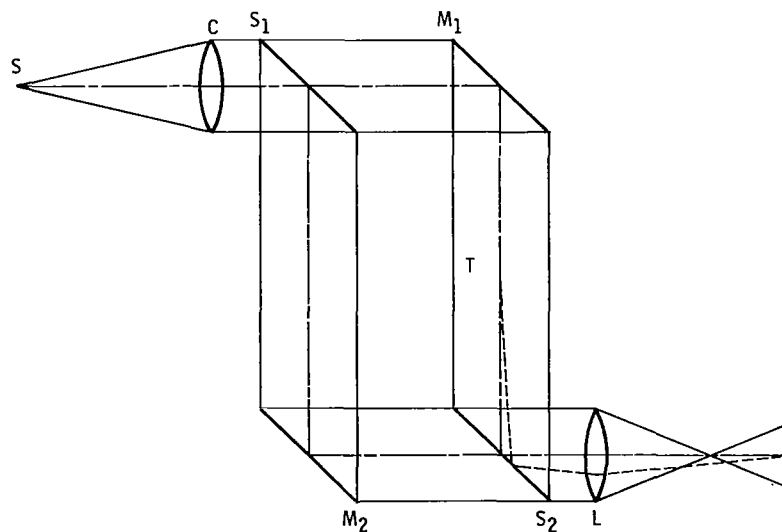


Figure 1. - Mach-Zehnder interferometer. S, Monochromatic source; C, collimating lens; S<sub>1</sub>, S<sub>2</sub>, splitter plates; M<sub>1</sub>, M<sub>2</sub>, mirrors; T, test section; L, camera lens; I, image plane.

0.3 m (12 in.) in diameter by the difficulty, and especially by the cost, of manufacturing large, defect-free, transmitting optics.

(2) The long separation of object and reference light paths in larger facilities may be inconvenient and allows extraneous disturbances, such as vibration and random refractive-index fluctuations, along each path to introduce spurious fringe distortions.

Various alternatives to overcome these difficulties (see, e.g., refs. 3 to 8) reduce the required number of large optical elements, but also

(1) Greatly reduce the field of view to as little as one-half the maximum aperture, or

(2) Retain the long reference path, or

(3) Retain the long reference path while worsening random refractive-index fluctuations along it by including it as part of the object path, or

(4) Introduce fundamentally new optical aberrations in the system.

This report describes an interferometer that ameliorates these problems. The interferometer uses wave-amplitude division of the object beam to construct a reference beam. This interferometer can be added to a schlieren apparatus. The resulting system allows very large schlieren optics to be combined with relatively small interferometer optics to convert the schlieren into an interferometer with large aperture at potentially low cost while eliminating or minimizing the problems cited above.

After this report was first written two important references (refs. 9 and 10) were located which pertain to closely related devices, a holographic system (ref. 9) and an interferometer (ref. 10). Comparisons of these devices and the interferometer described herein are presented in the section entitled "Comparisons With Other Devices".

## DESCRIPTION OF INTERFEROMETER

The system consists of a local-reference-beam interferometer in series with schlieren optics, minus the usual schlieren knife edge. (A reference beam constructed from an object beam, that is, from a beam which has traversed the object space, has been called a local reference beam (ref. 11).) Two versions of the local-reference-beam interferometer are delineated. The first uses lenses in the schlieren system (fig. 2); the second uses parabolic mirrors (fig. 3).

### Lens Version

The front end of the system, the schlieren portion, consists of a laser, monochromatic source,  $S$ , followed by a beam expander (microscope objective  $E$ ), and spatial filter (pinhole)  $F_1$ . The expanded beam is collimated by a collimator,  $C$ , having any desired aperture. (The irradiance of the beam across the aperture is approximately uniform.) The collimated beam traverses a test section,  $T$ , containing any desired transparent fluid and objects for study, and then is focused by a decollimator,  $D_1$ , having an aperture equal to, or less than, that of the collimator  $C$ . Decollimator  $D_1$  is at a distance from the test section equal to, or slightly greater than, the decollimator focal length in order to minimize vignetting by the subsequent interferometer section of light refracted and diffracted in the test section. The more this object distance exceeds the decollimator focal length, the less will be the ultimate image magnification at the final recording plane.

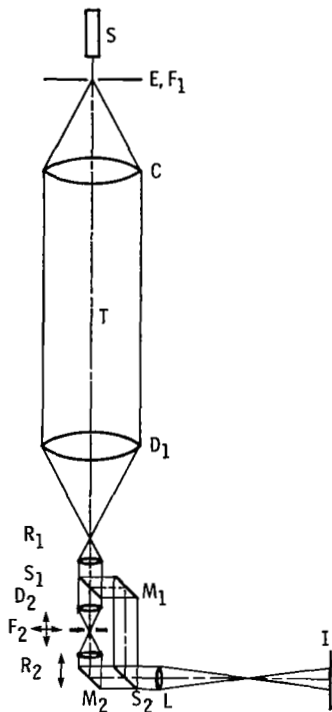


Figure 2. - Local reference beam interferometer coupled with schlieren optics. E, beam expander;  $F_1, F_2$ , spatial filters;  $D_1, D_2$ , decollimators;  $R_1, R_2$ , recollimators.

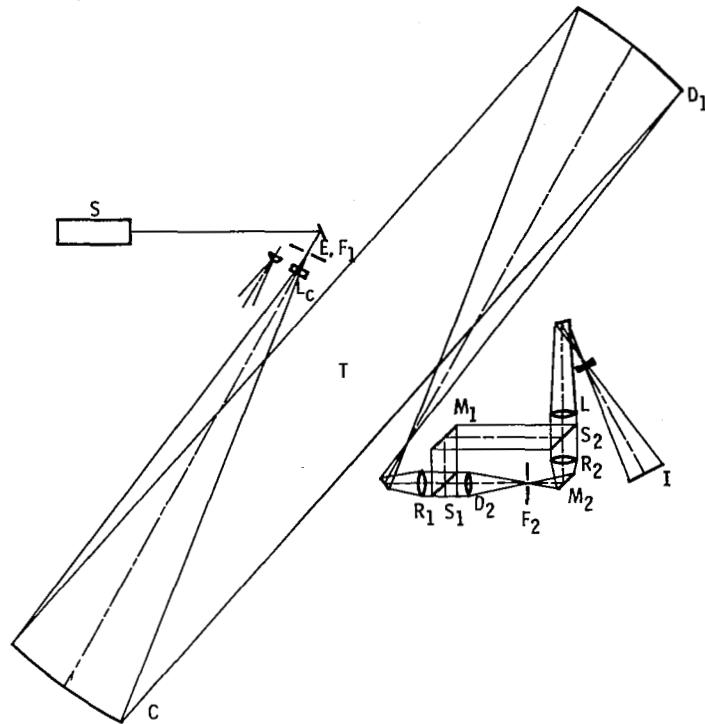


Figure 3. - Local reference beam interferometer coupled with schlieren mirror optics.

The rear end of the system, which corresponds to that in reference 9 looks like a Mach-Zehnder interferometer with additional optics in one beam. In detail, the light source image formed by the schlieren section is recollimated by  $R_1$ . This is done to allow production of straight fringes at the final image plane and to minimize aberration of the beam transmitted through the first splitter plate,  $S_1$ . The second collimator  $R_1$  may have a much smaller aperture than the schlieren optics, but should have an  $f$ /number equal to, or preferably less than, that of decollimator  $D_1$  in order to gather light refracted and diffracted in the test section. The recollimated light beam is next split into two coherent beams, an object beam reflected from splitter  $S_1$ , and, ultimately, a reference beam constructed from the beam transmitted through splitter  $S_1$ . The final object beam is always reflected from splitter plates to avoid introducing the aberration of refracted or diffracted light in the image of the object. Also, the splitter plates are slightly wedged to eliminate the spurious interference pattern produced by parallel splitter-plate surfaces as well as to dispense with overlapping multiple images.

The object beam is transmitted in one arm of the interferometer via reflection from a front-surface mirror,  $M_1$ , and a second splitter plate,  $S_2$ , to a long-focal-length camera lens,  $L$ , which images the test section at the final image plane,  $I$ . A long-focal-length camera lens is used to achieve sufficient magnification of the test section image  $I$ .

In the other arm of the interferometer, a reference beam is constructed from the object beam by decollimating the object beam using lens  $D_2$ ,

transmitting the beam through a low-pass, spatial-frequency filter (pinhole,  $F_2$ ), and then recollimating the beam through a similar lens,  $R_2$ . Lens  $R_2$  should match lens  $R_1$  so that the interfering wavefronts (at the image plane), in the absence of disturbances in the test section, will be as closely matched as possible. Lens  $D_2$  should match lens  $R_2$  and, hence,  $R_1$ , in order to maximize the intensity of the reference beam. Not only should all three interferometer lenses be matched, they should also each possess the shortest practical focal length and lowest possible f/number in order to minimize the interferometer size and maximize the flux it transmits. The reflectance of splitter plates  $S_1$  and  $S_2$  should be kept low - they may even be uncoated - in order to retain maximum relative flux in the reference beam. This is necessary because of potential flux loss at pinhole  $F_2$  due to aberrations by the preceding optics ( $C$ ,  $D_1$ ,  $R_1$ , and  $D_2$ ) plus refraction and diffraction of light by disturbances in the test section. In fact, the greater the blockage of the object field by objects and disturbances in the test section, the less flux gets transmitted through pinhole  $F_2$ .

Pinhole  $F_2$  and lens  $R_2$  in the reference beam should be capable of fine axial translation;  $F_2$  so that it may be located at the image of the light source, and  $R_2$  so that the reference-beam wavefront may be made plane to match the object beam wavefront in the absence of disturbances and, hence, produce the infinite-fringe condition or straight fringes. If the reference beam, or the object beam, is not collimated, then the fringes are circular, or circular arcs. In addition to axial translation, pinhole  $F_2$  must be capable of lateral translations so that it may be centered on the image of the light source. Mirror  $M_1$  and splitter  $S_2$  along the object beam should each be capable of fine rotational motions about two perpendicular axes in order to obtain straight fringes with controlled spacing and orientation. It may be possible to form the first image of the test section at splitter  $S_1$ , mirror  $M_1$ , or at the distance of mirror  $M_2$  from splitter  $S_2$  in order to permit fringe orientation at the image plane,  $I$ , by rotating only one plate, namely, the splitter plate  $S_1$ , mirror  $M_1$ , or mirror  $M_2$ , respectively. However, fringe orientation control by rotating splitter  $S_1$  is undesirable because it may cause too much lateral displacement of the light source image at filter  $F_2$ .

The optical path lengths of the separated object and reference beams should be approximately equal to obtain interference. However, because of the high coherence of lasers, the path lengths need not be precisely equal to obtain satisfactory fringe visibility.

The optics should be of high quality to obtain an infinite fringe with uniform phase because inversion of the reference beam eliminates one-to-one correspondence between points on the interfering wavefronts.

Because the off-axis contribution to the imagery is generally limited to light refracted through small angles in the test section, the optical system need only be aberration-free for small off-axis angles; that is, it need only be corrected for coma, at most, in addition to the axial correction for spherical aberration at the operating wavelength of the laser.

### Mirror Version

This version is the same as the lens version, except that the schlieren lenses are replaced by parabolic mirrors (fig. 3). The aperture of the lens version of the schlieren system is limited to less than 0.3 m (1 ft) diameter by the difficulty and cost of manufacturing large aberration-free

lenses. Much larger parabolic mirrors can be manufactured at lower cost. However, to achieve an unobstructed mirror version of the schlieren system requires that the mirrors be used in the off-axis configuration shown in figure 3. In this configuration an astigmatic image of the light source is formed at the front focus of lens  $R_1$ , unless the mirrors are the more expensive off-axis parabolas. Thus, the wavefronts "recollimated" by lens  $R_1$  are not plane, so that the infinite-fringe condition or uniformly spaced straight fringes are not obtainable at the image plane I. In addition, the secondary image of the light source at filter  $F_2$  is enlarged and astigmatic, so that most of the radiant flux in the reference beam may be blocked when using a pinhole.

The astigmatism can be removed by installing a cylindrical lens,  $L_c$ , in the divergent beam from spatial filter  $F_1$ , thus substituting a virtual astigmatic source and ideal image for the original ideal source and astigmatic image (ref. 12). With the astigmatism eliminated the mirror system operation is similar to that of the lens version.

## CONSTRUCTION OF INTERFEROMETER

### Lens Version

To demonstrate the proposed technique, the interferometer shown in figure 4 was assembled mostly from optics already available. The use of lenses rather than mirrors in the schlieren portion of the system permitted demonstration of the interferometer, but not of a large ratio of schlieren aperture to interferometer aperture. Using lenses, rather than mirrors, also avoided the problem of astigmatism, which prevents sufficient light



Figure 4. - Interferometer with lens assembly.

flux from being transmitted by spatial filter  $F_2$ . Thus, the lens configuration provided a basis for comparison with other variations of the system. The following specific optics were used in the initial system:

Laser, S.	15-mW helium neon
Light source pinhole aperture, $F_1$	25- $\mu$ m diam
Schlieren collimator lens C	62.9-cm (24.75-in.) focal length, 12.7-cm (5-in.) diam objective lens
Schlieren decollimator lens $D_1$	
Interferometer collimator, lenses $R_1$ and $R_2$	
Interferometer decollimator, $D_2$	30.5-cm (12-in.) focal length, f/2.5 Kodak Aero Ektar aerial camera lens
Splitter plates, $S_1$ and $S_2$	30.6-cm (12-in) focal length, f/2.5 Kodak Aero Ektar aerial camera lens
Mirrors, $M_1$ and $M_2$	15.2-cm (6-in.) diam, 50 percent reflectance with 30-min. wedge angle
Reference beam pinhole, $F_2$	15.2-cm (6-in.) diam
Camera lens, L	10- $\mu$ m diam
	34.3-cm (13.5-in.) focal length, f/3.5 Kodak Aero Ektar, aerial camera lens followed by negative lens to obtain a telephoto system

For an idea of the size of the system, note that in figure 4 the holes in the table top form 1-in. squares.

### Mirror Version

The mirror system shown in figure 3 was assembled as shown in figure 5. The optics were essentially the same as in the lens system, except that the objective lenses were replaced by 30.5-cm (12-in.) diameter, 244-cm (96-in.) focal-length, parabolic mirrors with a 6.5-cm-focal-length cylindrical lens near the initial source point to correct the astigmatism. In some tests the Aero Ektar decollimator  $D_2$  was replaced by a holographic zone plate having a focal length of 27.9 cm (11 in.) and diameter of 8.1 cm (3.2 in.).

The system is obviously not restricted to mirrors 30.5 cm (12 in.) in diameter, or less. The selected mirrors were simply the largest readily available.

## RESULTS AND DISCUSSION

### Lens Version

With the particular optics used (fig. 4), a 10- $\mu$ m-diameter spatial filter  $F_2$  was the largest that would provide reasonably uniform irradiance in the reference beam while eliminating the information in the original object beam. The introduction of an object into one side of the field of



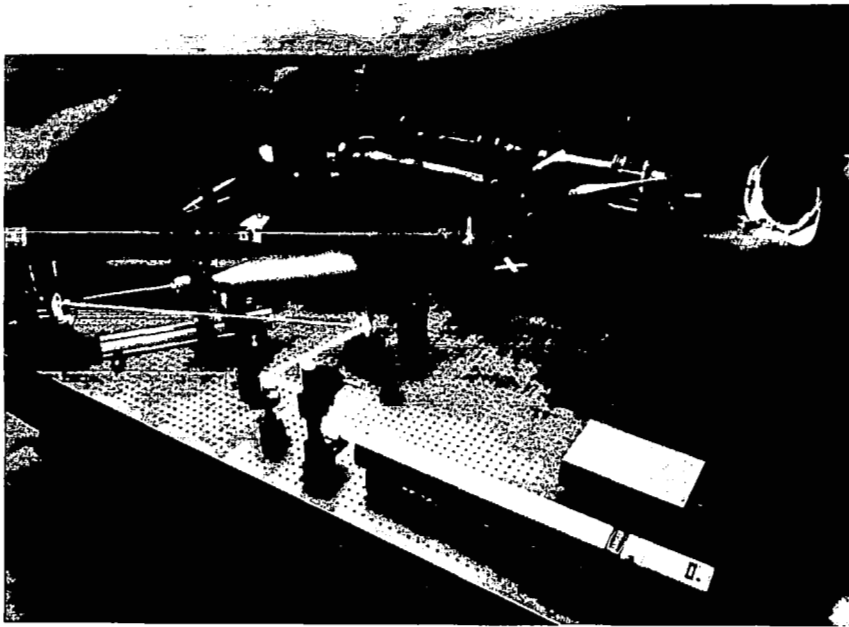
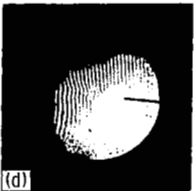
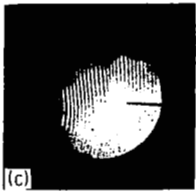


Figure 5. - Interferometer with mirrors assembly.

view in the test section provided a good test for information elimination. In the space following final splitter plate  $S_2$ , the interferometer causes one beam, say the reference beam, to be inverted relative to the other, object, beam. Hence, if the reference beam contains information about the test section two images of the object in the test section can be seen at  $I$ , one image upside down and backwards relative to the other. However, if aperture  $F_2$  is small enough, the test section information is filtered out, and the second image is missing.

The results obtained using the demonstration interferometer are presented in the following series of photographs. Figure 6(a) shows the interference pattern formed when the low-pass spatial filter  $F_2$  was removed from the reference beam and the interferometer was adjusted for the infinite-fringe condition. The residual fringes are of high contrast. The maximum phase variation over the 12.7-cm (5-in.)-diameter aperture corresponds to two to three fringes. A soda straw used as the jet-exit nozzle from a can of compressed air within the test section extends into the field of view from the right side. The existence of the second, reversed, image of the straw indicates that information regarding the test section has not been removed from the reference beam. When the 10- $\mu$ m-diameter pinhole,  $F_2$ , is introduced in the reference beam, the interference pattern appears as in figure 6(b). The reversed image of the straw is eliminated. Hence, the reference beam now contains negligible information pertaining to  $T$ . Both the visibility contrast and phase variation across the field are reduced. The corresponding finite-fringe interferogram with no jet flow is shown in figure 6(c). With choked-jet flow the interferogram appears as shown in figure 6(d). The minimum available exposure of 1 millisecond, limited by a focal-plane shutter, was, of course, insufficient to freeze turbulence-produced, high-frequency fluctuations of the fringes. However, the disturbed fringes, averaged over a millisecond, are, nevertheless, distinct. The fringe shifts are small because the jet diameter was small (approx. 0.3 cm



- (a) Infinite-fringe configuration without spatial filter.
- (b) Infinite-fringe configuration with low-pass spatial filter (10- $\mu\text{m}$  diam).
- (c) Finite-fringes with spatial filter (10- $\mu\text{m}$  diam).
- (d) Choked jet; spatial filter (10- $\mu\text{m}$  diam).

Figure 6. - Interferograms obtained by schlieren with lenses.



- (a) Hot soldering iron.
- (b) Incandescent light bulb.

Figure 7. - Interferograms obtained by schlieren with lenses. Pinhole diameter, 10 $\mu\text{m}$ .

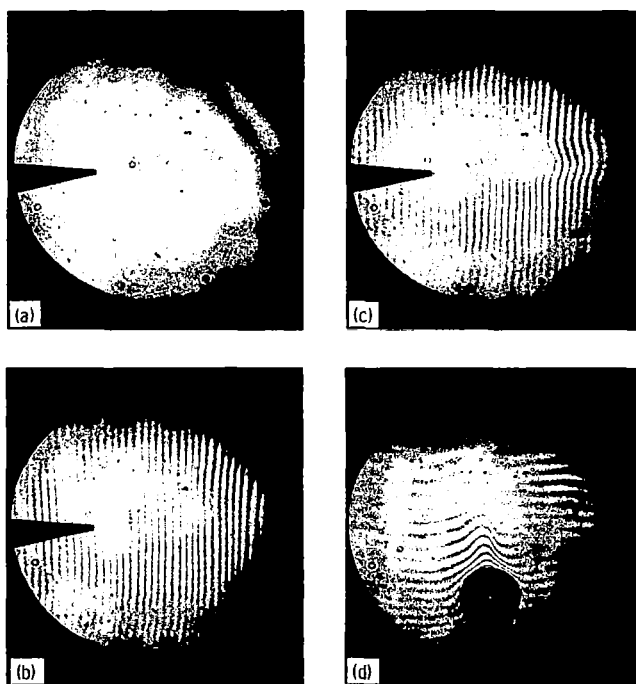
diam (1/8 in.)). In both the preceding and following interferograms, the defects, small circular fringes, result from diffraction by air bubbles within the Aero Ektar lenses, especially the recollimator  $R_1$ .

Additional interferograms of various objects were obtained at an image I magnification of 0.6, rather than the value 0.25 used in recording the previously described interferograms. Some results are shown in figure 7. Figure 7(a) displays a hot soldering iron oriented vertically. Figure 7(b) shows heat rising from an incandescent light bulb.

The irradiance in the reference beam was marginal for high-speed photography because of limited laser power. In an attempt to increase the irradiance while simultaneously destroying the information from the test section T, the pinhole  $F_2$  was replaced by a diffuser at the focal point. This would permit retention of flux previously blocked by the pinhole aperture. Increased irradiance was obtained by introducing a ground-glass diffuser. However, the resulting reference beam was severely speckled. Moreover,

information concerning the test section was not sufficiently destroyed. The ground-glass diffuser was replaced either by a small optical disk coated with a thin layer of polystyrene latex microspheres or by a layer of microspheres sandwiched between two optical disks. The coating could be applied more uniformly using the latter configuration. The microsphere diameters used were nominally either 0.109 or 0.624  $\mu\text{m}$ . Uniformity of the irradiance of the reference beam was then comparable with that obtained with the 10- $\mu\text{m}$ -diameter pinhole ( $F_2$ ). Moreover, by using the microsphere diffuser and reintroducing a pinhole immediately following the diffuser, the pinhole diameter could be increased from 10 to 25  $\mu\text{m}$  without introducing appreciable information into the reference beam. As a result, the total flux in the reference beam was significantly increased.

The interferograms in figure 8 were recorded with the microsphere sandwich and 25- $\mu\text{m}$ -diameter pinhole replacing the 10- $\mu\text{m}$ -diameter pinhole. It is evident that information on the test section T has been removed from the reference beam. This was not achievable when the 25- $\mu\text{m}$ -diameter pinhole was used without the microspheres. In addition, with the new spatial filter  $F_2$ , the reference beam, always weaker than the object beam, possessed greater irradiance than before. Hence, the image intensity, as well as the interference fringe visibility, was increased. Figure 8(a) shows the nozzle from the can of compressed air projecting into the field of view with the interferometer adjusted for the infinite fringe condition. The finite



(a) No flow; infinite fringe.

(b) No flow; finite fringes.

(c) Choked jet.

(d) Incandescent light bulb.

Figure 8. - Interferograms obtained by schlieren with lenses. Spatial filter; diffuser with 25- $\mu\text{m}$  aperture.

fringe condition without flow is displayed in figure 8(b). This is followed in figure 8(c) by an interferogram of choked jet flow recorded at a 1-milli-second exposure. Finally, the effect of heated air above an incandescent light bulb is shown in figure 8(d).

It is noteworthy that in some of the preceding figures, especially figure 8(b), fringe visibility is reduced in an annulus about the center of the field of view and around the periphery of the field. This results primarily from a similarly shaped nonuniformity of the irradiance in the reference beam, as shown in the split-field photograph (fig. 9) and in the infinite-fringe interferogram (fig. 8(a)). The nonuniformity of the reference beam is shown in photographs (fig. 10), taken with the pinhole at various axial positions, to result from residual spherical aberration of the light-source image formed at the pinhole (fig. 11).

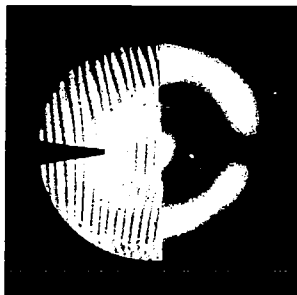
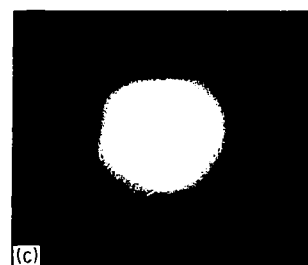
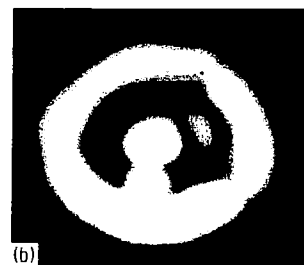
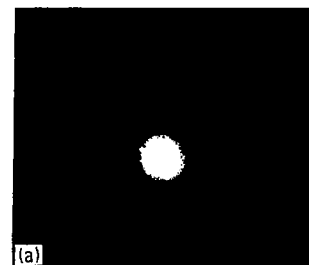


Figure 9. - Comparison of interfering beams (left) with reference beam (right).



(a) Inside focus of decollimator  $D_2$ .  
 (b) At focus of decollimator  $D_2$ .  
 (c) Outside focus of decollimator  $D_2$ .

Figure 10. - Nonuniformity of reference beam. Schlieren with lenses. Recollimated reference beam with spatial filter (25- $\mu$ m diam).

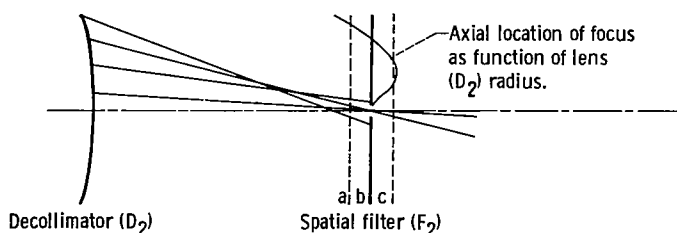


Figure 11. - Ray paths in reference beam derived from figure 10. (Plane a, fig. 10(a); plane b, fig. 10(b); plane c, fig. 10(c).)



Figure 12. - Interferogram obtained by schlieren with mirrors. Infinite-fringe configuration without spatial filter.

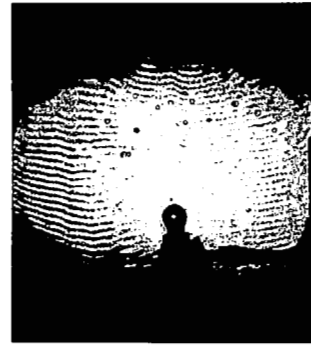


Figure 13. - Interferogram obtained by schlieren with mirrors. Incandescent light; spatial filter (25- $\mu$  diam.) plus polystyrene-DVB-microsphere (5- $\mu$ m diam.) diffuser.

### Mirror Version

Results obtained using the 30.5-cm diameter (12-in.) mirror system are displayed in figure 12 and all subsequent figures.

Figure 12 shows the best obtainable infinite-fringe configuration in the absence of a spatial filter. With a spatial filter added, figure 13 shows the effect of heat rising from a lighted incandescent bulb. The greatly increased size of the optical system can be seen by comparing this interferogram with that in figure 8(d), in which the same light bulb is shown. In obtaining figure 13 the 25- $\mu$ m-diameter pinhole was combined with a glass-plate diffuser coated with 5- $\mu$ m-diameter polystyrene divinylbenzene (DVB) microspheres.

All interferograms displayed thus far contain considerable coherent noise, most of which was attributable to air bubbles and dirt in the Aero Ektar recollimator,  $R_1$ . This particular lens was removed and replaced by the Aero Ektar originally used as the decollimator ( $D_2$ ). Since all information is to be removed from the reference beam, it was deemed possible to use an available  $f/3.5$  holographic zone-plate as decollimator  $D_2$ . Consequently, much of the coherent noise was removed from the system, and the zone plate served as a very satisfactory decollimator.

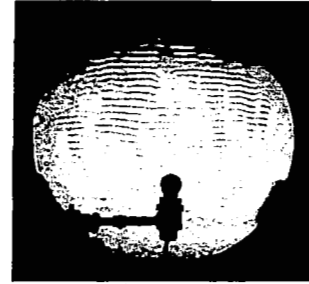
The infinite fringe configuration, obtained using the zone plate but without a spatial filter or diffuser, is shown in figure 14. The interference field does not cover the entire available aperture because the  $f/3.5$  of the zone plate did not match the  $f/2.5$ , of the Aero Ektars. Two interferograms of the light bulb are shown in figures 15(a) (light off) and 15(b) (light on). In these interferograms the spatial-filter aperture was increased even more than before, to  $10^3$ - $\mu$ m (0.04-in.) diameter, in combination with a diffuser of polystyrene DVB microspheres. Some indication of information in the reference beam is evidenced by a weak inverted shadow of the light bulb apparatus at the top of the interferograms.

### Appearance of the Reference Beam

The desired reference beam is characterized by irradiance equal to that in the object beam, uniform irradiance, and absence of information regarding the test section. The reference beam obtained following the splitter  $S_2$



Figure 14. - Interferogram obtained by schlieren with mirrors. Infinite-fringe configuration with zone-plate decollimator  $D_2$  and without spatial filter.



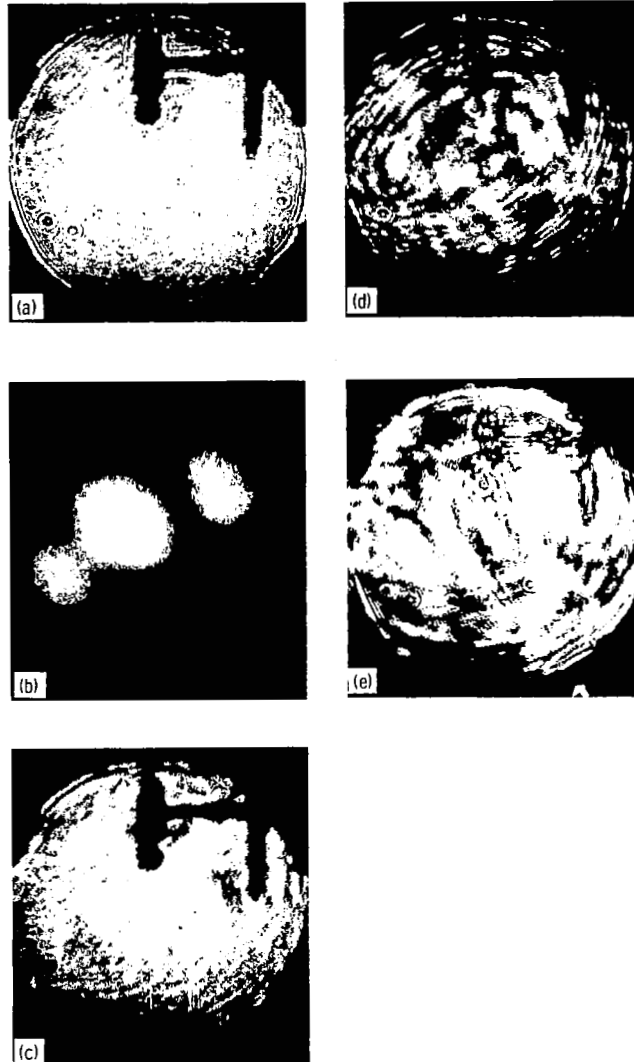
(a) Incandescent light off.  
(b) Incandescent light on.

Figure 15. - Schlieren with mirrors. Zone-plate decollimator  $D_2$ . Spatial filter,  $10^3 \mu\text{m}$  (0.040 in.) diameter plus polystyrene DVB diffuser.

using the schlieren mirror system, the Aero Ektar decollimator,  $D_2$ , and no spatial filter,  $F_2$ , is shown in figure 16(a). This is obviously an unsatisfactory reference beam because of the prominence of information on the light bulb and its fixture. With the addition of a  $25\text{-}\mu\text{m}$ -diameter spatial filter the test-section information is eliminated but the reference beam is very weak and nonuniform, as in figure 16(b) which shows only the brightest areas of the beam. The exposure to obtain this image was twice that for the preceding figure 16(a). With the  $25\text{-}\mu\text{m}$ -diameter pinhole replaced by a  $10^3\text{-}\mu\text{m}$ -diameter pinhole and the exposure the same as that for figure 16(a), the flux is increased, and irradiance is more uniform; but information on the test section reappears, as is displayed in figure 16(c).

A diffuser consisting of microspheres coated on an optical glass disk was felt to be an easy way to eliminate information from the reference beam while increasing its irradiance by enlarging the aperture of the spatial filter. With  $0.624\text{-}\mu\text{m}$ -diameter polystyrene latex microspheres coated on glass the transmitted test section information is largely obscured, even in the absence of a spatial filter (fig. 16(d)). As shown in figure 16(e), a diffuser consisting of transparent,  $5\text{-}\mu\text{m}$ -diameter, polystyrene DVB microspheres yielded the maximum loss of information and at only one-half the exposure required for figure 16(a).

The main difficulty in using microspheres was in obtaining a uniform coating and, hence, a reference beam with uniform irradiance free of information. There are undoubtedly better ways to accomplish this, in particular, by using holographic optical elements.



(a) No filter.  
 (b) Spatial filter, 25 $\mu$ m diameter. Exposure two times that in part (a).  
 (c) Spatial filter, 10<sup>3</sup> $\mu$ m (0.040 in.) diameter. Exposure same as in part (a).  
 (d) Polystyrene latex diffuser (0.624 $\mu$ m diam.) without spatial filter. Exposure same as in part (a).  
 (e) Polystyrene DVB diffuser without spatial filter. Exposure one-half that in part (a).

Figure 16. - Schlieren with mirrors. Reference beam.

### Remaining Problems

In its present state of development as a quantitative instrument the assembled large aperture, local-reference-beam interferometer suffers from three shortcomings, namely,

- (1) Optics of too low quality to obtain uniform phase of interference or straight fringes over the field of view in the absence of disturbances.
- (2) Inadequate flux and nonuniformity of irradiance over the aperture of the reference beam while eliminating information regarding the test section.
- (3) Coherent noise.

Fortunately, all of these problems are practical and solvable in that they do not result from conceptual defects. Thus, considerable improvement of the system may be expected if higher quality optics are used.

### Comparisons With Other Devices

As mentioned in the Introduction, two references on related devices have been found (refs. 9 and 10). The former device (ref. 9), shown in figure 17, is an apparatus for holography, rather than interferometry.

Whereas for interferometry the subject beam and local reference beam need only have comparable amplitudes, for satisfactory holography the amplitude of the reference beam must be several times that of the object beam. This is not as easily achieved. Uncoated splitters, used in the configurations shown in figures 2 and 3, and an efficiently focused reference beam should help increase the relative amplitude of the reference beam while removing information. However, a lens focusing light on a pinhole, as described in the patent (ref. 9), is not likely to be a satisfactory flux transmitter, especially when the test is of an extended reflecting object (fig. 17, as in the patent) unless a very-high-intensity source is used and a neutral filter is added to reduce the relative amplitude of the object beam. (Note that, if the reflecting object has a finite extent, the focus at the spatial filter  $F_2$  will also be laterally extended, rather than being a point.) In addition, since the distance of the reflecting object from the holographic device is likely to be finite, axial translation of the filter  $F_2$  will be necessary to account for changes of object distance.

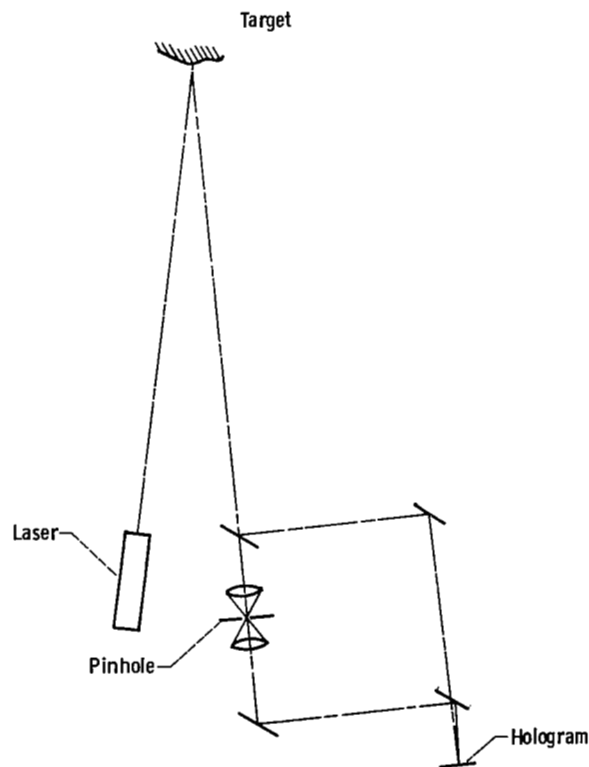


Figure 17. - Local reference beam generation for holography (ref. 9).



A system with a reflecting object, similar to that described in the patent and shown in figure 17, was also tested in the present study as an interferometer system before the discovery of the existence of the patent. The test failed for the reasons just cited. With the transmission (rather than reflection) application described herein, a holographic system may be more readily achieved. Additional, easily manufactured, off-axis holographic optics may be added, especially to replace lens  $R_2$  and mirror  $M_2$  in the reference beam.

The latter device (ref. 10), shown in figure 18, consists of the local-reference-beam interferometer without the collimation feature. This simpli-

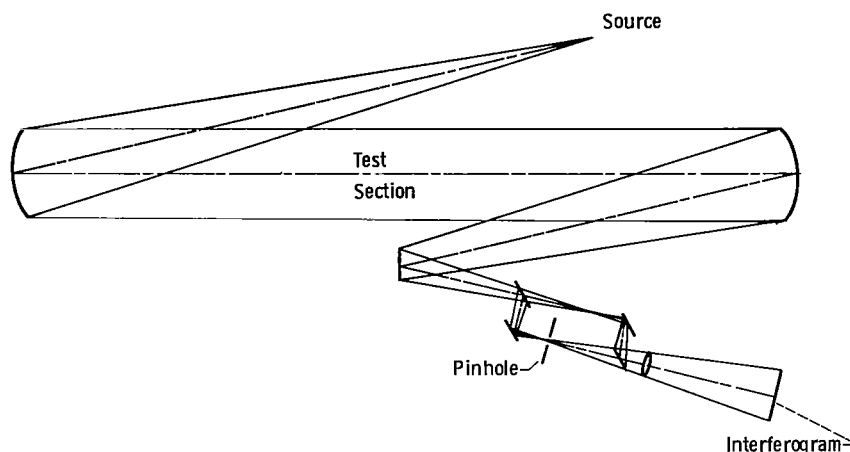


Figure 18. - Lensless local-reference-beam interferometer with schlieren (ref. 10).

fication yields interference between spherical, rather than plane, waves. To achieve the infinite-fringe condition requires that the interfering spherical waves be identical in radius and propagation direction. Otherwise curved, nonuniformly spaced fringes result. In addition, since this configuration involves transmission of convergent and divergent light through tilted plates (i.e., the splitters) spherical and chromatic aberration, coma, and astigmatism are introduced. This further complicates the problem of achieving the infinite-fringe condition and changes the curvature and spacing nonuniformity of fringes if the wavefronts are not superimposed.

A system almost identical to that shown in the figure 18 was demonstrated as a first step in developing the local-reference-beam interferometer described herein. The system was abandoned for the reasons described above.

## CONCLUSION

An interferometer has been devised which utilizes amplitude division of an object beam to construct an information-free, reference beam by low-pass spatial filtering. It is shown that this interferometer can be used to convert a schlieren system into an interferometer without limiting the useful aperture of the schlieren system, which may be very large, and without constructing a reference beam around the test section. The interferometer can employ very large schlieren optics in conjunction with relatively small interferometer optics.

Two versions of the interferometer were demonstrated, one employing 12.7-cm diameter (5-in.) lenses in the schlieren portion, and the other

employing 30.48-cm diameter (12 in.) parabolic mirrors in an off-axis schlieren system. The latter system required insertion of a cylindrical lens near the light source to correct for astigmatism. Satisfactory results were also obtained by replacing a decollimating lens by a zone plate in the reference-beam arm of the interferometer. Attempts to enlarge the aperture of the information-removing spatial filter by means of a diffuser, although only partially successful, showed promise as a means of increasing the irradiance of the reference beam.

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## REFERENCES

1. Schardin, H.: Theory and Applications of the Mach-Zehnder Interference-Refractometer. Rept. T-3, Defense Research Lab., Univ. of Texas, 1946. (Translation from Z. Tech. Phys., vol. 12, 1931, p. 436 ff.).
2. Ladenburg, R.; and Bershader, D.: Interferometry. Physical Measurements in Gas Dynamics and Combustion, R. W. Ladenburg, ed. Princeton Univ. Press, 1954, pp. 47-78.
3. Buchele, Donald R.; and Day, Pierce B.: Interferometer with Large Working Field Utilizing Schlieren Optics. NACA RM E50I27, 1951.
4. Temple, Edward B.: Quantitative Measurement of Gas Density by Means of Light Interference in a Schlieren System. J. Opt. Soc. Am., vol. 47, no. 1, 1957, pp. 91-100.
5. Murty, M.V.R.K.: Common Path Interferometer Using Fresnel Zone Plates. J. Opt. Soc. Am., vol. 53, no. 5, 1963, pp. 568-570.
6. Smartt, Raymond N.: Zone Plate Interferometer. Appl. Opt., vol. 13, no. 5, 1974, pp. 1093-1099.
7. Merzkirch, Wolfgang: Flow Visualization, Academic Press, 1974, pp. 102 ff.
8. Pollock, N.: A Simple Laser Interferometer for Wind Tunnel Flow Visualization. J. Phys. E. vol. 13, no. 10, 1980, pp. 1062-1066.
9. Cathey, W. T., Jr.: Local Reference Beam Generation for Holography. U. S. Patent 3,415,587, Dec. 10, 1968.
10. Kulesh, V. P.; and Orlov, A. A.: Use of Coherent Optical Filtering in Forming a Reference Wave Front in Interferometry. Sov. J. Opt. Technol., vol. 41, no. 5, 1974, pp. 257-260.
11. Cathey, W. Thomas: Local Reference Beam Holograms. Handbook of Optical Holography, H. J. Caulfield, ed., Academic Press, 1979, pp. 219-224.
12. Prescott, Rochelle; and Gayhart, E. L.: A Method of Correction of Astigmatism in Schlieren Systems. J. Aeronaut. Sci., vol. 18, no. 1, 1951, p. 69.

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