Fluid Flow Analysis By A Modified, Sharp Focussing, White Light Lau Interferometer

P. Waddell, M. Stickland, S. Mason, S. McKay

Department of Mechanical Engineering, University Of Strathclyde, Glasgow, Scotland

L. Mair

Department of Energy and Environmental Technology, Caledonian University, Glasgow, Scotland

Abstract

This paper presents a sharp focussing schlieren system based upon a modified Lau interferometer. A method of reducing the depth of focus of the system is demonstrated and the development of the system to study large fields of view by the incorporation of flexible membrane mirrors is discussed

1 Introduction

Transonic and supersonic flows which contain shockwaves, convective flows, and chemical reactions are often visualised by optical techniques which utilise the change in the refractive index of the fluid. These optical techniques; such as shadowgraphy, Schlieren, Mach Zender and Moiré interferometry are well known and have been developed over many years. However, the basic applications of these techniques all have one flaw. They represent the three dimensional flow field they are interrogating on a two dimensional plane.

Attempts have been made to design a Schlieren system which could display disturbances from only one, thin, pre-selected plane inside the fluid volume. In such a system no disturbance within the flow field, other than in the plane of interest, would be observed. Fish and Parnham (1951) detail a number of such systems. The prohibitive expense of very large aperture, small focal length, small F number, optics has been the prime reason that they are not extensively used.

This paper describes a novel sharp focussing system, based on a Lau Interferometer, that enables two dimensional slices of a three dimensional flow field to be interrogated. Examples of the images produced by such a system are presented. The system is suitable for the incorporation of flexible membrane mirror technology. These membrane mirrors are extremely low cost when compared to equivalent conventional glass optics. The inclusion of membrane mirrors within the visualisation system would allow large flow fields to be examined with small depth of focus.

This paper also describes a novel technique for rapidly decreasing the depth of focus of the system, by stopping out the centre of the optics.

2. Modified Lau Interferometer

The original Lau (1948) interferometer used self imaging of one straight line grid on to a second similar grid. The modified Lau interferometer uses lenses as in figure 1, rather than self imaging. An extended white light source S is imaged by lens L_1 on to a low density straight line grid G_1. G_1 has a pitch d and a clear space width w. Figure 1 shows that the diffracted orders leaving the slits at position A are collimated by lens L_2 and pass through the disturbed fluid, crossing the axis at O, and are refocused by L_3 at position B on grid G_2. Lens L_3 is identical to L_2, a matched and well corrected pair. The plane at O and the plane at I are conjugate, as light passes through L_3 and L_4. This optical system will produce a limited depth of focus in the image plane at I, corresponding to a limited depth of field in the object plane. This can be evaluated using conventional optics theory.

3. Effect of stopping the optics

If the grid G_1 has a finite width of 2h, and the grid pitch is d. Light from the entire width of G_1 is collected and deviated after collimation by L_2 into a cross over zone of width 2a'. If the central region of G_1 is stopped out, the depth of the cross over zone is reduced to 2a because the incidence angle, θ, is not allowed to become small. Light is diffracted into the first order at an angle ϕ by grid G_1 where

$$\tan \phi = \frac{\lambda}{d} = \frac{x}{f}$$

x is the displacement at L_2. For small angles

$$\tan \theta = \frac{h}{f} = \frac{x}{a}$$

where

$$a = \frac{fx}{h} = \frac{f}{h}\frac{f\lambda}{d}$$

let h=Nd where N is the number of lines on G_1

$$a = \frac{f^2\lambda}{dh} = \frac{f^2\lambda}{d^2 N}$$

The total depth of the interference zone is 2a. Examination of this equation reveals the following: In order to achieve a small depth of interference zone (2a) one must use short focal length (f) lenses, and gratings which have a large pitch (d) and a large number of lines (N). To achieve small values of a it is essential to use grids which have a large number of lines and a large spacing. Since large grids are required this will also require the use of large optics.

Figure 2 shows two photographs taken of a fine jet from an aerosol spray. In the photographs shown, the depth 2a can be calculated approximately as

$$2a = \frac{2f^2\lambda}{d^2N} = \frac{2(0.145)^2(5x10^{-7})}{(4x10^{-4})^2(125)} = 1mm$$

Figure 2 shows the bias fringes being distorted by the fine jet. The effect is shown of moving the object away from the centre of the interference zone where it is in focus, to a point 15 mm closer to L_2.

4. Membrane mirrors

The Sharp focussing modified Lau system, described above, is a feasible system for analysing 3D flow fields however, the limitations of the optics available precluded its application to large scale flow fields and it is therefore more of an interesting lab experiment rather than a useful engineering tool. To develop a sharp focussing system to analyse large scale flow fields required low F.No., large diameter optics, to provide a small depth of focus, and a reasonable field of view. The authors intend to utilise off axis plastic membrane mirrors to develop such a system. The four feet diameter, plastic membrane, mirrors are capable of operating at any F.No. from a flat mirror to a concave mirror with an F.No. of 1.0 and allow the possibility of focussing Schlieren on a large scale.The characteristics of these mirrors may be found in the papers by Waddell et al (1994) and (1999). This will be reported in a subsequent paper

5. Conclusions

The modified Lau interferometer appears to offer great potential for the examination of thin slices of phase distorted fluids. Test results as illustrated in this paper show fringes of reasonable contrast. Stopping out the centre of a lens or mirror dramatically decreases the depth of focus of the optics.

It is believed by the authors that combinations of large diameter small F.No. membrane mirrors and the modified Lau system as described will allow very thin two dimensional slices of three dimensional flow field to be analysed

6. References

Fish R. W. and Parnham K., Focusing Schlieren Systems, Ministry Of Supply, Aeronautical Research Council, H.M.S.O., 1951.

Waddell P, Stickland M, Mason S, McKay S, "History of Strathclyde University's White Light Optical Imaging Plastic Membrane Mirrors", Optical Society of America Annual General Meeting, Baltimore, USA, 4-9 October 1998

Waddell P. and Stickland M. and Mair L., Checking The Symmetry of Stretchable Plastic Membrane Mirror Using A Lateral Shearing Interferometer, European Symposium On Optics For Productivity In Manufacturing, Frankfurt, June 1994.

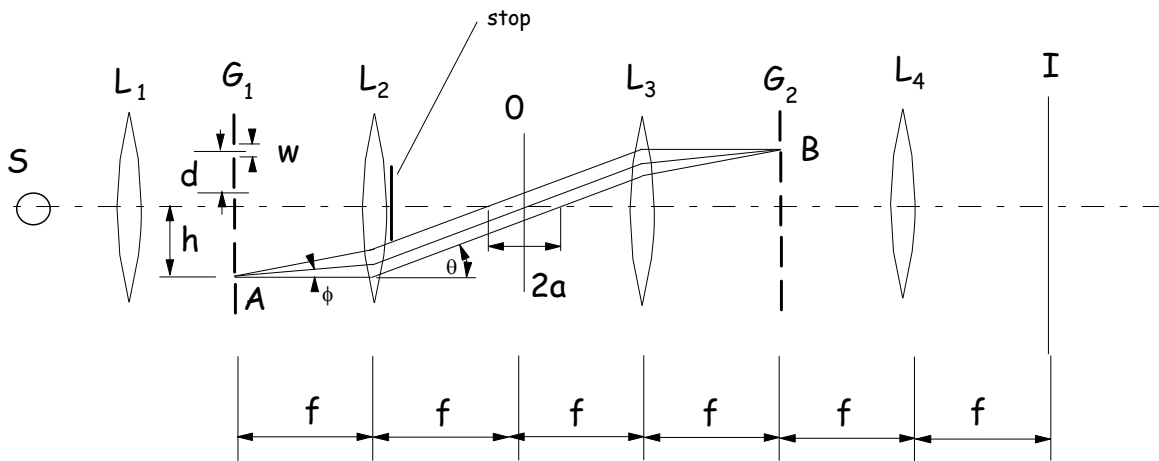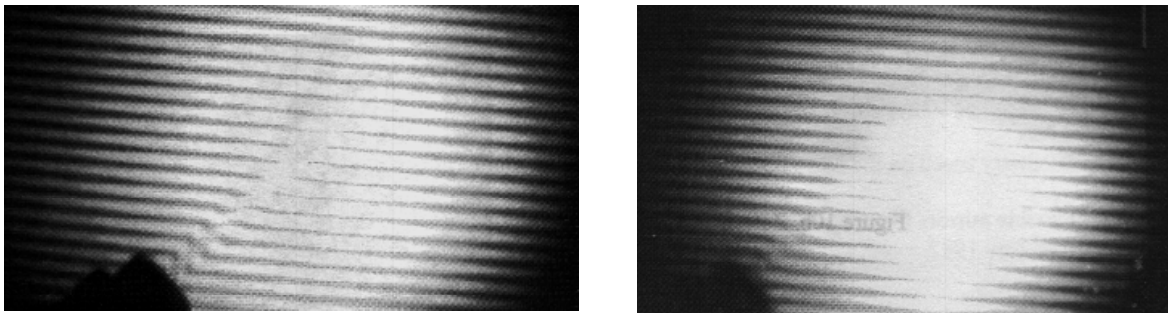Lau E., "Interference phenomenon on Double gratings", Ann. Phys.6, p417, 1948.

Figure 1: Optical setup

Figure 2: jet in focus left, out of focus, right.