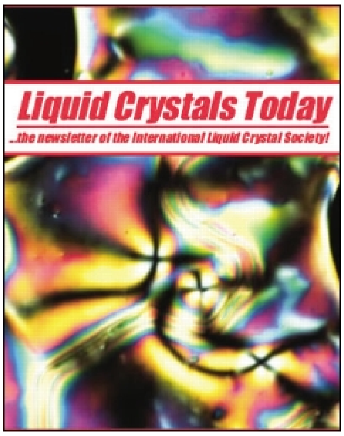

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AERODYNAMIC and HEAT TRANSFER testing

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AERODYNAMIC and HEAT TRANSFER testing

from Terry Jones, Department of Engineering Science, University of Oxford, UK.

Liquid crystals have now achieved some maturity in aerodynamic and heat transfer testing [1]. Their main use in the field is as a surface temperature indicator. Cholesteric material in micro-encapsulated form mixed with a suitable binder is sprayed onto the surface to form a layer of approximately 20 microns thickness. With suitable calibration the temperature can be found to an accuracy rivalling thermocouple measurements or other techniques. Temperatures above 150°C are difficult to monitor in this manner due to encapsulation problems; however the neat material may be used in some of these situations. In their simplest application the thermochromics may be coated on a suitable thin insulator so as to trace the passage of hot air flow. The encapsulated material itself may be suspended in liquids such as glycerin or silicone oil and give vivid displays of the natural convection temperature fields. Neat (unencapsulated), liquid crystal may also be dispersed as small droplets in certain liquids so as to produce similar effects [2].

The heat transfer coefficient distribution on a surface is given by the flow of air over the body. Global distributions of heat transfer coefficient on models may be found using thermochromic layers on top of thin electrical heater films. For a given electrical heating the regions of high heat transfer will be cool relative to those with low heat transfer coefficients and this is reflected in the colour display of the liquid crystal. High heat transfer usually occurs in the stagnation regions at the leading edge of bodies whereas low heat transfer is present where the flow has separated from the surface. The state of the thin boundary layer which is present on all aircraft also dictates the heat transfer, being low where the boundary layer is laminar and high when this becomes turbulent. Indeed this may be used to detect the state of the boundary layer and such a technique is to be employed to determine the transition from laminar to turbulent states on a jet engine nacelle in a European flight test programme [3]. The nacelle is shown in ***Fig 1*** where the heater strip can be seen. This heater strip is integrated in the carbon fibre structure and is covered by liquid crystal which is to be viewed by cameras in flight. Significant protection from ultra-violet and rain has to be provided in this application.

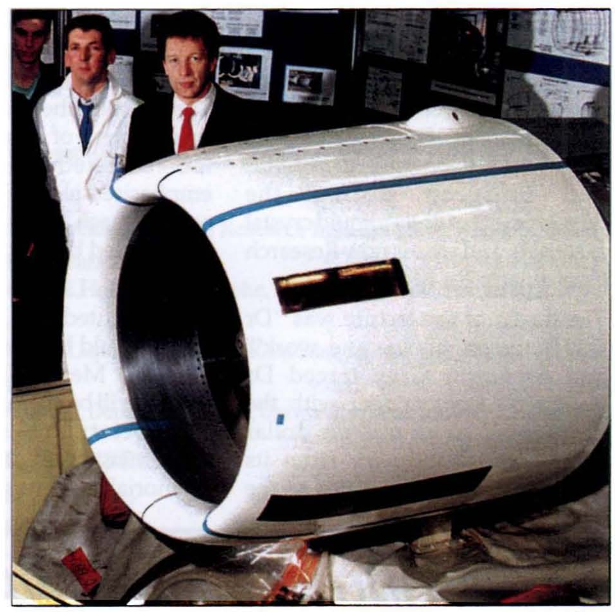


Fig 1: The jet engine nacelle to be tested in the European Laminar Flow Flight Demonstrator Programme. The liquid crystal heater section can be seen as the lower and larger of the two dark strips on the nacelle.

It has been established practice to use transient testing methods in heat transfer experiments and also in situations where power requirements or other restrictions do not permit continuous aerodynamic testing. Liquid crystals have also found great application in this area. Models are machined from an insulator such as perspex (plexiglas) and this is sprayed with encapsulated thermochromic liquid crystal. Models may typically be aircraft, rockets, turbine blades, or heat exchangers which are tested in airflows so as to simulate the correct non-dimensional flow and heat transfer conditions. Thus temperature levels may be much less severe than those occurring in practice. The model is suddenly exposed to the hot flow and the colour display is seen to move over the model as this heats up. It can be appreciated that lateral conduction in these insulating models is very small and the surface temperature rises according to the local heat transfer. Hence isotherms indicated by colour contours give contours of constant heat transfer coefficients and all points on the model will be covered. An example of a test of a channel containing a cylindrical heat transfer promoter typical of those used within turbine blades is shown in ***Fig 2.*** Infra-red cameras could perform a similar function in measuring surface temperature; however they are subject to the uncertainties associated with surface emissivity and absorption in wind tunnel windows.

In these transient tests the liquid crystal has to respond rapidly to changes in temperature. Measurements at Oxford and DRA (Electronics Division) have shown that the time for the cholesteric helical pitch to respond to changes in temperature can be as fast as 3 milliseconds [4]. In some shock tunnels and gun tunnels the running times may be approximately 10 to 100 milliseconds and very high heat transfer rates are present. The latter causes extremely high temperature gradients of the order of one million degrees per metre and it is this

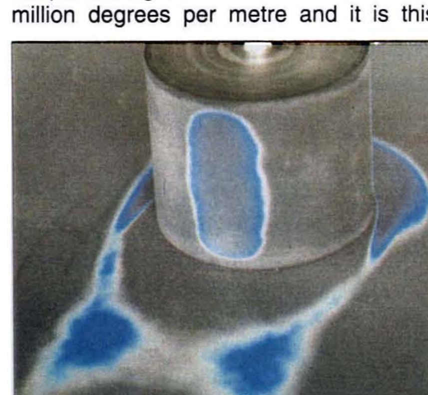


Fig 2.: The thermochromic colour play at a particular time in a transient test. The cylinder in a channel is viewed from downstream and the horseshoe vortex can be seen wrapping round this. The flow separates at the edges of the cylinder but reattaches to give high heat transfer at the rear.

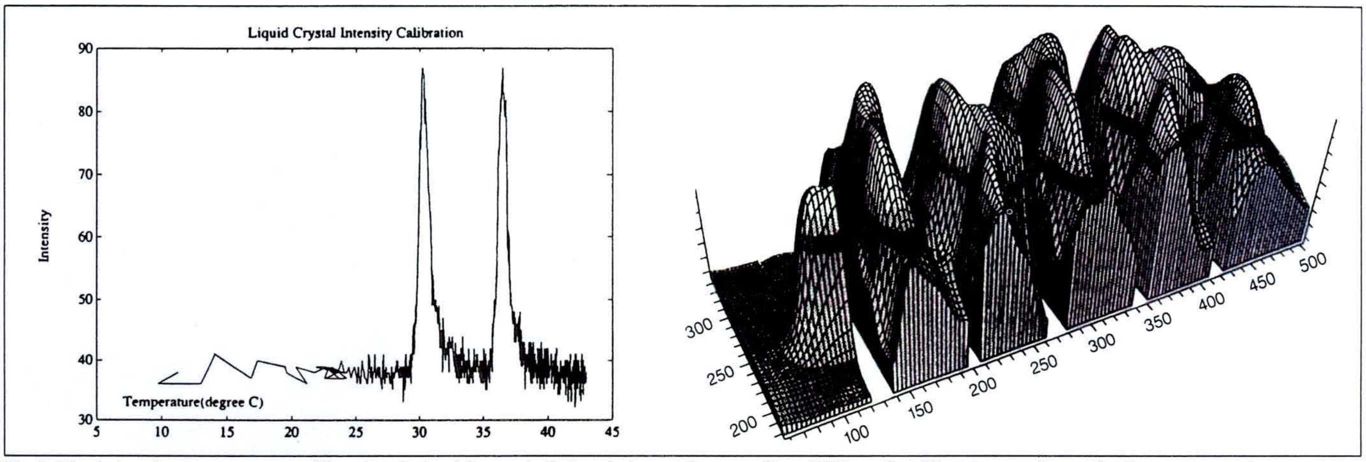


***Fig 3:** The intensity-temperature calibration derived from pixel signals in a video recording. With such calibrations and complex image processing contours of heat transfer may be derived such as that given for a duct with rib roughness and suction through holes downstream of the ribs.*

which restricts the use of the thermochromics in this class of wind tunnel. If materials with a narrow colour play band are employed then the resulting pitch gradients disrupts the structure such that no colour is visible. On the other hand if a wide band material is used then even though colours may be seen the temperature resolution is inadequate. In these cases it has been found possible to use a cholesteric material insensitive to temperature and observe the cholesteric to isotropic transition. Thus an isotherm can be seen as a change from colourful to colourless. Fast temperature measurements may also be performed using the temperature dependence of the birefringence of aligned nematic layers in contact with the surface [5].

Video recording and analysis of the liquid crystal experiments has been the subject of considerable work over recent years. Optical filters have been employed to identify an isotherm and monochromatic illumination used for the same purpose. However, it is convenient for most engineering applications to analyse the selectively reflected colour and hence infer the temperature from the red, blue and green signals which originate from the video camera (RGB signals). In fact this corresponds to using three relatively wide band filters and in general signals which are composites of the RGB values are used. Hue, a colour attribute derived from the RGB values, has been used with fair success, although use of the green intensity has also proved useful. A combined RGB signal which reflects the overall intensity has been used at Oxford and this rises to a peak and then diminishes as the colour play is traversed. A typical output from a model covered by a layer containing two encapsulated liquid crystals is shown in ***Fig 3*** exhibiting two such peaks. These signals, whether hue or intensity, may be image processed so as to give a complete distribution of heat transfer coefficients over a complex model. Due to the vast amount of information in such a recording this processing may take 100 hours on a present day workstation. An example of the results from a converging ribbed cooling duct with flow also extracted through small circular holes in given in ***Fig 3.***

Liquid crystals in their neat form have also been used to measure surface shear stress. The response of aligned cholesteric liquid crystal layers to shear is a distortion of the helical structure and in turn a change in the colour of the selective reflection. In general the purity of the colour is degraded. Thus colour change may be interpreted in terms of shear stress. At present due to the complexity of the process no quantitative measurements have been derived from this method but changes in shear stress are readily seen and the response is fast [5,6]. For some years NASA have used this effect to identify the laminar to turbulent transition on wings and fins in flight trials [7]. Two quantitative methods have been developed at Oxford which are suitable for short duration wind tunnel testing. The first, devised by Bonnett [5], renders a thin layer of neat cholesteric material into the focal-conic texture by heating into the isotropic state and then cooling. The wind tunnel is then started and the time taken for the material to flow align back to the Grandjean texture is measured. This is clearly visible as the material changes from a colourless diffuse scattering state to a bright colourful surface. The times range from seconds to minutes and this may be directly related to the shear stress by calibration. The other variables of temperature and hence viscosity and solid surface state may be controlled. The shear necessary to cause the texture change as found from optical and electrical measurements is only approximately 4:1. A typical result is shown in ***Fig 4*** where the high shear region of a turbulent wedge generated by a surface element can be seen in an otherwise laminar boundary layer.

A transient technique employing nematic liquid crystals was devised by Walton. Microgrooves are produced in the surface of a plastic model by rubbing with tissues and these align the nematic director when this is applied in a 20 micron layer on the surface. The liquid crystal is doped with a dichroic dye so as to act as a polarising layer. When exposed to an airflow at an angle to the microgrooves the upper director rotates so as to align with the imposed flow direction. Thus a twisted nematic structure is created and serves to rotate the plane of polarisation of transmitted light. This effect is easily seen by viewing through an analyser and the time for the rotation to take place is a measure of the surface shear stress and may be calibrated. Changes in material viscosity so as to measure different ranges of shear stress may be produced by using additives. The method is robust and has been used in various studies [8].

The developments in liquid crystal materials will continue to be followed by aerodynamicists eager to use them as convenient sensors. Their ability to give a continuous measure of surface flow properties over models and aircraft is of great importance. The exciting possibility exists that other surface measurements such as pressure may also be a candidate for liquid crystal technology.

(Acknowledgements and References on p 6)

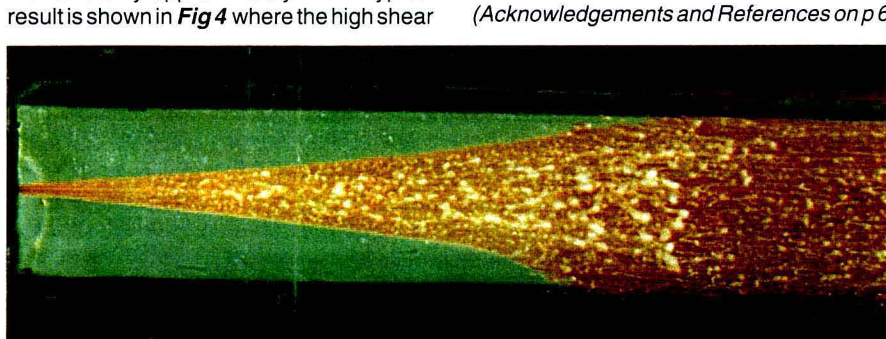
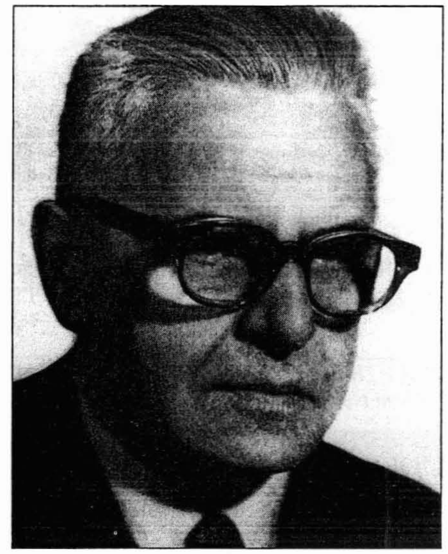


Fig 4: The focal-conic to Grandjean texture change technique for measuring shear stress. A laminar boundary layer has been established on a flat plate in a wind tunnel, and a small surface roughness placed close to the leading edge. This causes a turbulent wedge to be formed with high shear stress in which the texture change has occurred earlier than in the laminar region. The plate is 1 metre in length.

PROFESSOR MARIAN MIESOWICZ, 1907—1992:
A Scientific Appreciation

from Professor J A Janik,
Institute of Nuclear Physics, Kraków, Poland



Professor Marian Miesowicz

Marian Miesowicz, former Professor at the Mining Academy and the Institute of Nuclear Physics at Kraków, died on April 5th, 1992.

Professor Miesowicz was born in Lwów on November 21, 1907. He studied physics at the Jagellonian University in Kraków. As a young graduate researcher he became interested in liquid crystals, under the inspiration of Mieczyslaw Jezewski, then Professor of Physics at the Mining Academy. His peak achievement in this research, carried out during the 1920s and 30s, was the discovery of the anisotropic viscosity in nematic liquid crystals.

During the Second World War, Miesowicz changed his field of interest in physics. He left the field of liquid crystals and became involved in problems of cosmic radiation, which later on transformed into the broad field of high energy and elementary particle physics. He remained faithful to this field until his death. However, liquid crystal matters interested him during his whole life, and I remember many interesting discussions with him on that subject. Miesowicz also participated in two International liquid crystal conferences: in Bordeaux in 1978, and in Bangalore in 1982.

As I have mentioned before, Miesowicz' main achievement in liquid crystals was his discovery in 1935 of the anisotropy of viscosity. He then suggested an exceptionally clever and convincing experiment, which he afterwards realised for the nematic PAA and PAP. In this experiment one observed a decreasing amplitude of oscillations of a balance, whose one arm carried a quartz plate immersed in the nematic substance. The direction (or motion) (up and down) of the plate was parallel to the plate surface. From the damping decrement of the oscillations one was able to calculate the viscosity coefficient. By carrying out the experiment in a magnetic field orienting the sample it was possible to determine the viscosities for a direction parallel to the nematic director, **n**, for a direction parallel to the velocity gradient in the nematic liquid, grad **v**, and for a direction perpendicular to both vectors, **n** and grad **v**. These three components of the viscosity tensor — η_1, η_2, and η_3 — have an important property: their definition (as introduced by Miesowicz) is very clear and natural. In the officially accepted terminology these coefficients are called "the Miesowicz viscosities". Their values for PAA at 122°C (in the nematic phase) are: $\eta_1 = 2.4 \pm 0.05$; $\eta_2 = 9.2 \pm 0.4$; and $\eta_3 = 3.4 \pm 0.3$ centipoise, as determined by Miesowicz. It is worth noting that the accuracy of Miesowicz' experiments was so good that no significant improvement has been reported until the present time.

Let me make a historical remark at this point. It is well known that the nematic PAA (as also PAP) looks like an ordinary liquid, and one should remember that in the 1930s a paradigm claiming that the properties of liquids are isotropic was generally accepted. In connection with this Miesowicz related a story: When an outstanding physicist from Kraków, Professor Konstanty Zakrzewski, was informed about Miesowicz' results, he could not believe that they were correct since they were in conflict with the above mentioned paradigm. He changed his mind after spending several days with Miesowicz in the laboratory. Then he realised that it was the paradigm that had to be rejected.

Miesowicz' results on viscosity were published in 1935 in the relatively little known Bulletin of the Polish Academy of Sciences and Letters, in German. After the Second World War, Miesowicz published a new version of that work in *Nature*, **158**, 27 (1946). Then the Miesowicz viscosities became widely known. Every year until now — almost half a century later — references and quotations appear to what was originally viewed as a violation of the paradigm.

Editorial note: *An interesting perspective on Miesowicz' work is given in "Liquid Crystals in my Memories and Now — The Role of Anisotropic Viscosity in Liquid Crystals Research", M Miesowicz, Mol. Cryst. Liq. Cryst., 1983,* ***Vol 97,*** *pp1-11.*

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REFERENCES

[1] T V Jones, "The Use of Liquid Crystals in Aerodynamic and Heat Transfer Testing", Keynote Paper, *Proc. 4th Int. Symp. Transport Phenomena in Heat & Mass Transfer*, Sydney (1991).

[2] N Akino, T Kunugi, A Kurosawa, Y Asano, S Saiya and M Nakanishi, "Thermo-chromatic Characteristics of Liquid Crystal Suspensions", *ASME Annual Winter Meeting*, Atlanta (1991).

[3] P P Shipley, N T Birch, H Riedel, K H Horstmann and P Lucking, "A European Collaborative NLF Flight Demonstrator", *Ist European Forum on Laminar Flow Technology*, Hamburg, (1992).

[4] P T Ireland and T V Jones, "The Response Time of a Liquid Crystal Surface Temperature Thermometer", *J. Phys. E:Sci. Instrum.*, pp 1195-1199, (1987).

[5] P Bonnett, T V Jones and D G McDonnell, "Shear Stress Measurements in Aerodynamic Testing Using Cholesteric Liquid Crystals", *Liquid Crystals*, **Vol 6**, No 3, pp 271-280, (1989).

[6] D C Reda, "Observations of Dynamic Stall Using Liquid Crystal Coatings", *AIAA J.*, **Vol 29**, No 2, pp 308-310, (1991).

[7] B J Holmes and P D Gall, "Liquid Crystals for High Altitude in Flight Boundary Layer Flow Visualisation", *AIAA Gen. Aviation Techn. Conf. Paper* 86-2592, (1986).

[8] T V Jones and T W Walton, "Reynolds Analogy in Film Cooling", *Proc. 10th Int. Symp. on Air Breathing Engines*, Nottingham, pp1263-1269, (1991).