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A NEW METHOD FOR LAMINAR BOUNDARY LAYER
TRANSITION VISUALIZATION IN FLIGHT - COLOR
CHANGES IN LIQUID CRYSTAL COATINGS

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**A NEW METHOD FOR LAMINAR BOUNDARY LAYER TRANSITION VISUALIZATION IN FLIGHT
- COLOR CHANGES IN LIQUID CRYSTAL COATINGS -**

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INTRODUCTION

The visualization of laminar to turbulent boundary layer transition plays an important role in flight and wind-tunnel aerodynamic testing of aircraft wing and body surfaces. Visualization can help provide a more complete understanding of both transition location as well as transition modes; without visualization, the transition process can be very difficult to understand.

In the past, the most valuable transition visualization methods for flight applications included sublimating chemicals and oil flows. Each method has advantages and limitations. In particular, sublimating chemicals are impractical to use in subsonic applications much above 20,000 feet because of the greatly reduced rates of sublimation at lower temperatures (less than -4 degrees Fahrenheit). Both oil flow and sublimating chemicals have the disadvantage of providing only one good data point per flight. Thus, for many important flight conditions, transition visualization has not been readily available.

This paper discusses a new method for visualizing transition in flight by the use of liquid crystals. The new method overcomes the limitations of past techniques, and provides transition visualization capability throughout almost the entire altitude and speed ranges of virtually all subsonic aircraft flight envelopes. The method also has wide applicability for supersonic transition visualization in flight and for general use in wind tunnel research over wide subsonic and supersonic speed ranges.

LIQUID CRYSTALS

Originally discovered in 1888, liquid crystals have been applied in aerodynamic research only within the past twenty years (refs. 1-6). Those previous efforts involved use of liquid crystals for aerodynamic investigations in wind tunnels for supersonic and hypersonic heat transfer and boundary-layer transition measurements.

Liquid crystals are a peculiar state of matter between solid and liquid, in which the molecules are elongated in one direction. Although they appear as oily liquids, they have certain mechanical properties which are similar to solid crystals. In particular, liquid crystals scatter light very selectively. The molecules possess a helical structure; fortuitously, the pitch length of the helixes can occur at the same wavelengths as visible light. Thus when subjected to certain physical influences, the helix pitch

length changes and the wavelength of reflected light changes accordingly. In this fashion liquid crystals change colors in response to changes in shear stress, temperature, pressure, ferromagnetism, and in the presence of chemical vapors. Since the fundamental chemical structure is unaffected by these changes, a liquid crystal coating will respond repeatably to the same physical changes. Thus, the color changes are reversible virtually indefinitely. Liquid crystals will also reflect other non-visible wavelengths in the electromagnetic spectrum, such as X-ray and infrared (ref. 7). Liquid crystals have been widely used for temperature measurements, and have the capability to resolve temperature by color changes to within 0.18 degrees F (ref. 8). These materials have also been used in medical applications, as well as for electronic displays (digital watch displays being the most common). Other applications include non-destructive testing for flaws or fatigue in materials, and malfunction detection in electrical circuits. In nature, liquid crystals are present as fatty acids in animals and provide colors in some insect wings and shells (ref. 9).

USE IN AERODYNAMIC TESTING

Previous wind-tunnel work on the applications of liquid crystals in aerodynamic testing is reported in references 4-6 and 10-14. Many of the past applications, especially those at high speeds, utilized encapsulated liquid crystals to provide coatings which would respond to temperature and not to shear. For flight applications, the liquid crystals must operate in aircraft skin surface temperature ranges between near -30 degrees F and +300 degrees F. The lower surface temperatures occur at stratospheric altitudes at compressible subsonic speeds. For example, for flight at Mach = 0.8 at 45,000 feet pressure altitude, the total (i.e. skin surface) temperature is about -3 degrees F even though the static temperature is near -60 degrees F. At supersonic speeds, where compressible heating of the skin surfaces is even more significant, surface temperatures can approach +300 degrees F at Mach = 2.7 in the stratosphere. The temperature range over which known liquid crystals operate is from -22 degrees F to +480 degrees F. Thus, in theory liquid crystals are available which will operate at virtually all altitudes and speeds of interest for subsonic and supersonic flight applications. Two types of liquid crystals were used in the present flight experiments, cholesteric and chiral nematic.

Although much is known about liquid crystals as thermoindicators, relatively little information exists in the literature about their use for quantitative shear-stress or boundary layer transition indicators. Previous studies of liquid crystals for quantitative shear stress measurements are described in references 5 and 6. For use in aerodynamic flight testing, unencapsulated liquid crystal formulations were sought which would provide a color change in response to skin friction differences between the laminar and the turbulent boundary layers. Liquid crystals can be formulated to change colors across the entire visible spectrum, from red to violet, over a temperature range as small as 1.8 degrees F or as large as 90 degrees F (see ref. 8). For flight applications it is usually desirable to use formulations with as wide a temperature band as possible, so that transition measurements may be made over a large range of altitudes or Mach numbers during one flight. The wide temperature band formulations are chosen to minimize sensitivity to temperatures. In order for a liquid crystal coating to indicate laminar

boundary layer transition, the operating temperature of the coating must be within the temperature range in which color is present. The coating then develops different colors in the laminar and turbulent boundary layers or develops a color pattern at the transition location, depending on the temperature band of the formulation used. Outside of the temperature band for the coating, no color may be present. Selection of the specific liquid crystal formulation for a given test condition requires "a priori" knowledge of the range of the test surface temperatures expected. The best test surface is an adiabatic one; that is, one which is well insulated. If the test surface has substructure which acts as a heat sink, these locations may be visible in color changes or as colorless areas; a knowledge of the structures is therefore important to avoid misinterpretation of coating patterns in such areas. With care, the liquid crystals can also be used to indicate the locations of such aerodynamic phenomena as shock locations and laminar separation bubbles.

The time response of a liquid crystal coating can be better than 0.2 second (ref. 3). During the recent flight testing, very rapid time response of the liquid crystal coatings was observed by watching turbulent wedges emanating from artificial roughness (grit) installed near lifting surface leading edges. As the roughness passed between being subcritical and subcritical, the resulting turbulent wedge was observed to change from laminar to turbulent colors very rapidly.

APPLICATION TECHNIQUES

Various application techniques are effective. The best visual and photographic results have been obtained by using the liquid crystal coatings applied over a flat black surface, but good transition patterns have been observed on other dark-colored backgrounds as well. The liquid crystal material can be applied by hand, with a brush, or it can be sprayed on. It is important that the coating be uniform in thickness for maximum clarity in transition pattern development. For brushing or spraying, thinning is accomplished using such solvents as 1,1,1 trichloroethane, acetone, or Freon (TMC). When using compressed air spray equipment, a solution of one part liquid crystal to 8 parts solvent can be sprayed on using 25 psi air pressure. When applied in this ratio, one quart of solution will cover about 100 square feet of surface area. Undiluted liquid crystal can be applied at a rate of about one milliliter per square foot of surface area. This coverage will provide adequate thickness for good color response; coatings which are too thin will not develop color responses to shear. Coatings which are too thick will run under aerodynamic loading, and the thickness of the coating can affect the transition location. A single coating can be used repeatedly from flight to flight for transition measurements. Liquid crystals are sensitive to ultraviolet light, however, and after extended exposure (days or weeks) can cease to operate. For health and safety reasons, the spray application procedure should only be conducted in a well-ventilated area using a half-face mask carbon-filter type respirator.

RESULTS

The photograph in figure 1 is an example of transition visualization in flight using a chiral nematic liquid crystal coating on a flat-black background. This particular liquid crystal formulation had a temperature response range beginning at -22 degrees F. The flight condition is Mach = 0.8 at an altitude of 48,000 feet. The coating is on the right winglet of a Gates Learjet Model 28/29 business transport airplane. Percent-chord location markings are at the lower edge of the black region, and transition is indicated by a color change near the 60-percent chord location. Thus in the laminar flow region on the forward part of the airfoil where the skin friction is very low, no color is present; in the aft turbulent flow region where the skin friction is several times higher, colors appear in the liquid crystal coating. The crisp line of demarcation between the two regions is where transition occurs. A wedge-shaped turbulent region appears near the winglet tip, caused by an intentional roughness trip. Excellent correlations have been observed between transition indicated by liquid crystals and transition indicated by other methods, including sublimating chemicals, oil flow and hot films. Results can be recorded either photographically, or on video tape, but the quality of the recorded image will depend on both the quantity of light available for illuminating the coating, and the angle at which the light strikes the surface under examination. The best results were obtained with lighting emanating from behind the viewer and camera onto the coated surface in front of the eye. The use of a polarizing filter on the camera lens provides improved color rendition and minimum spectral reflections under many lighting conditions. Even with less than optimum lighting angles for the camera, the human eye can still discern color changes associated with transition location.

CONCLUDING REMARKS

Some recent exploratory NASA flight experiments have shown that liquid crystals offer a solution to the limitations of previous transition visualization method for flight applications. The advantages of the liquid crystals include reversibility, rapid time response, nontoxicity, ease of application, and low cost. The primary disadvantages are that the data are real time only - that is some means of photographic recording is necessary - and that the coatings are sensitive to temperature discontinuities in the surface. Care must be taken to avoid the effects of heat sinks in aerodynamic surfaces such as occur over fuel cells or major structural components such as spars.

Use in this report of names of manufacturers does not constitute an official endorsement of products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration. A partial list of candidate suppliers is given in the Appendix; additional companies unknown to the authors may also supply the liquid crystal materials.

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APPENDIX

LIQUID CRYSTAL SUPPLIERS

1. Atomergic Chemetals Corp.
100-T Fairchild Avenue
Plainview, NY
2. Damert Co. Dept. T
900 75th Street
Oakland, CA
3. Davis Liquid Crystals, Inc.
14692-T Wicks Blvd.
San Leandro, CA 94577
415 351-2295
4. Eurand America, Inc.
1464-A Miamisburg-Centerville Rd.
Dayton, OH
5. General Electric Co.
Fairfield, Cr 06431
518 438-6500
6. Hall Crest Products/Liquid Crystal Technology
1820-T Pickwick Lane
Glenview, IL 60025
312 998-8580
7. Har Chemicals Inc.
15840-T Joleen Way
Morgan Hill, CA
8. Liquid Crystal Applications, Inc.
990 Raritan Road
Clark, NJ 07066
201 574-1496
9. Liquid Crystal Industries, Inc.
Dept. TR
P. O. Box 8124
Pittsburgh, PA
10. PCI, Inc.
2455 Augustine Drive, P. O. Box 58097
Santa Clara, CA
11. Practical Products Co.
7820-T Concord Hills Lane
Cincinnati, OH
12. Qmax Technology Group, Inc.
P. O. Box 1509
125 Bacon Street
Dayton, OH 45402
513 228-2817

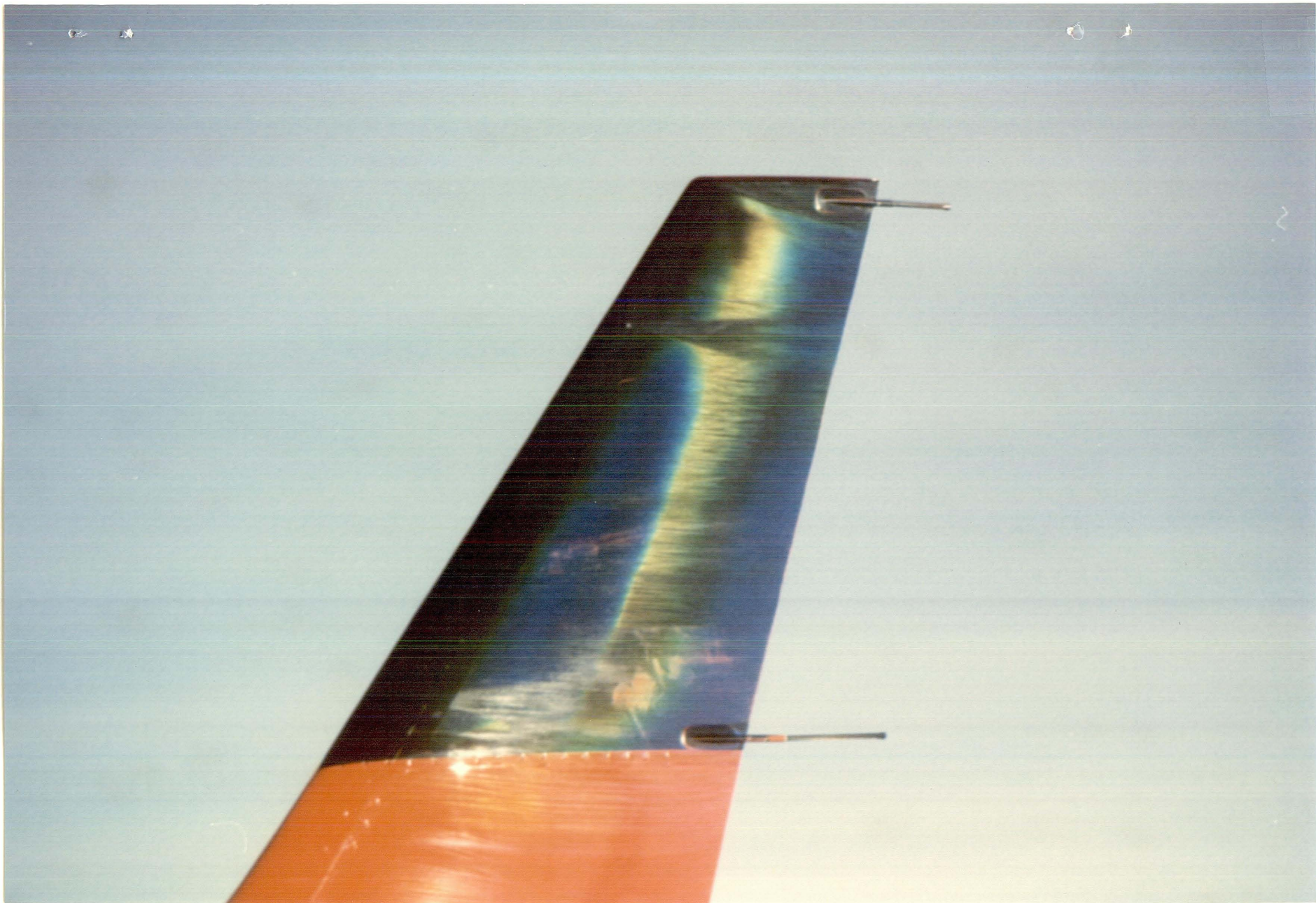


Figure 1. - Transition visualization using liquid crystals on winglet of Lear 28/29
Airplane. Pressure altitude = 48,000 ft., $M = 0.8$; leading edge
sweep = 31° .

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