Shear-Sensitive Liquid Crystal Coating Method Applied Through Transparent Test Surfaces

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I. Introduction

Research conducted at NASA Ames Research Center[1] has shown that the color-change response of a shear-sensitive liquid crystal coating (SSLCC) to aerodynamic shear depends on both the magnitude of the local shear vector and its direction relative to the observer's in-plane line of sight.

In conventional applications, the surface of the SSLCC exposed to aerodynamic shear is illuminated with white light from the normal direction and observed from an oblique above-plane view angle of order 30 deg. In this top-light/top-view mode, shear vectors with components directed away from the observer cause the SSLCC to exhibit color-change responses. At any surface point, the maximum color change (measured from the no-shear red or orange color) always occurs when the local vector is aligned with, and directed away from, the observer. The magnitude of the color change at this vector-observer-aligned orientation scales directly with shear stress magnitude. Conversely, any surface point exposed to a shear vector with a component directed toward the observer exhibits a non-color-change response, always characterized by a rusty-red or brown color, independent of both shear magnitude and direction. These unique, highly directional color-change responses of SSLCCs to aerodynamic shear allow for the full-surface visualization[2, 3] and measurement[4-6] of continuous shear stress vector distributions.

The objective of the present research was to investigate application of the SSLCC method through a transparent test surface. In this new back-light/back-view mode, the exposed surface of the

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SSLCC would be subjected to aerodynamic shear stress while the contact surface between the SSLCC and the solid, transparent wall would be illuminated and viewed in the same geometrical arrangement as applied in conventional applications. It was unknown at the outset whether or not color-change responses would be observable from the contact surface of the SSLCC, and, if seen, how these color-change responses might relate to those observed in standard practice.

II. Experimental Arrangement

Figure 1 shows a schematic of the experimental arrangement and resultant flow field. A 12 in. x 12 in. plate, 1 in. thick, of transparent acrylic plastic was used as the model. One surface of this plate was bead blasted to a "frosty" surface finish to enhance SSLCC adhesion. Surface roughness, measured with a diamond-tip stylus apparatus, was 30 μ in., rms. The other surface was unaltered from its original, smooth/clear state.

A 0.003 in. nominal thickness coating of Hallcrest SSLCC compound CN/R3 was spray painted onto the bead-blasted test surface. The model was mounted between two 12 in. high, sharp-leading-edge, sidewalls with the plate chord 6 in. above, and parallel to, the tunnel floor; the flow-exposed spanwise dimension of the test surface was 11.5 in. The blunt leading edge of the model was thus positioned perpendicular to the freestream velocity vector.

Experiments were conducted in an in-draft subsonic wind tunnel with a 3 ft. x 4 ft. test section. Test conditions were a total pressure of 1 atm., a total temperature of 72 °F, and a freestream velocity of 180 ft/s. As illustrated in Fig. 1, a large-scale separated flow region formed over both the upper and lower plate surfaces immediately downstream of the blunt leading edge. Reattachment occurred downstream of each reverse-flow zone, resulting in a high-shear, attached, turbulent boundary layer flow over the downstream extent of each surface.

White-light illumination of the SSLCC was supplied by a quartz-arc lamp (5600 K). SSLCC color-change responses to this flow field were recorded with two 30 frame/s color video cameras, one facing downstream and one facing upstream, each positioned at a 30 deg. above-plane view angle. Shear vectors both toward, and away from, each camera thus existed simultaneously on both horizontal plate surfaces.

After the SSLCC color-change response was recorded for the top-light/ top-view deployment, flow was turned off and the plate was rolled 180 deg. about the freestream velocity direction. Flow was re-established and the color-change response for the back-light/back-view deployment of the same coating was recorded.

III. Results and Discussion

Figures 2a,b show the top-light/ top-view color-change responses, while Figures 3a,b show the corresponding back-light/ back-view results. First, consider the top-light/top-view images of Fig. 2. In Fig. 2a, the downstream-facing view, shear vectors beneath the reverse-flow zone were toward the observer and a non-color-change response (brown) was seen, while shear vectors downstream of reattachment (outlined by the thin yellow arc) were away from the camera, resulting in a green color-change response (the no-shear color for this compound being a reddish orange). In Fig. 2b, the upstream-facing view, shear vectors beneath the reverse-flow zone were away from the observer, and a green color-change response was seen. Attached-flow vectors downstream of reattachment were toward the observer and the non-color-change (brown) response resulted.

Cross comparisons of Fig. 2a with 3a and Fig. 2b with 3b clearly show that the color-change responses recorded for the back-light/ back-view mode were directly opposite to those recorded in the conventional top-light/top-view mode. (Note: the streamwise extent of the reverse-flow zone was slightly larger on the upper, unbounded surface of the model.)

On the macroscopic level, this finding can be explained by analyzing a free-body diagram of a thin, non-flowing coating. Applying Newton's second law of motion, the shear stress exerted on the coating by the fluid is equal to and opposite from the shear stress exerted on the coating by the solid surface. The physics of light scattering from the liquid crystal molecular structure is beyond the scope of this technical note. References 7 and 8 provide some insight.

These results show that the SSLCC method can be utilized to study surface shear stress patterns in internal-flow problems. Examples include biomedical applications, such as flows in heart-assist devices; race-car applications, such as flows under inverted wings in close ground (or moving-belt) proximity; and aerospace applications, such as flows within engine inlets. In addition, visualization and/or measurement of surface shear stress distributions on external surfaces of test bodies such as fuselages, hulls, keels, etc., can be accomplished through transparent ports using lights/cameras placed inside of these structures. Finally, this new back-light/back-view deployment mode overcomes surface obscuration limitations associated with mounting non-transparent appendages or protuberances onto the test surface.

References

1) Reda, D.C., and Muratore, J.J., Jr., "Measurement of Surface Shear Stress Vectors Using Liquid Crystal Coatings," *AIAA Journal*, Vol. 32, No. 8, 1994, pp. 1576-1582.

2) Reda, D.C., "Method for Determining Shear Direction Using Liquid Crystal Coatings," U.S. Patent 5,394,752, March 1995.

3) Reda, D.C., Wilder, M.C., and Crowder, J.P., "Simultaneous, Full-Surface Visualizations of Transition and Separation Using Liquid Crystal Coatings," *AIAA Journal*, Vol. 35, No. 4, 1997, pp. 615, 616.

4) Reda, D.C.,, "Method for Measuring Surface Shear Stress Magnitude and Direction Using Liquid Crystal Coatings," U.S. Patent 5,438,879, Aug. 1995.

5) Reda, D.C., Wilder, M.C., Farina, D.J., and Zilliac, G., "New Methodology for the Measurement of Surface Shear Stress Vector Distributions," *AIAA Journal*, Vol. 35, No. 4, 1997, pp. 608-614.

6) Reda, D.C., Wilder, M.C., Mehta, R.D., and Zilliac, G., "Measurement of Continuous Pressure and Shear Distributions Using Coating and Imaging Techniques," *AIAA Journal*, Vol. 36, No. 6, 1998, pp. 895-899.

7) Fergason, J.L., "Liquid Crystals," *Scientific American*, Vol. 211, Aug. 1964, pp. 76-85.

8) De Gennes, P.G. and Prost, J., "*The Physics of Liquid Crystals*," 2nd edition, Oxford University Press, Oxford, U.K., 1993.

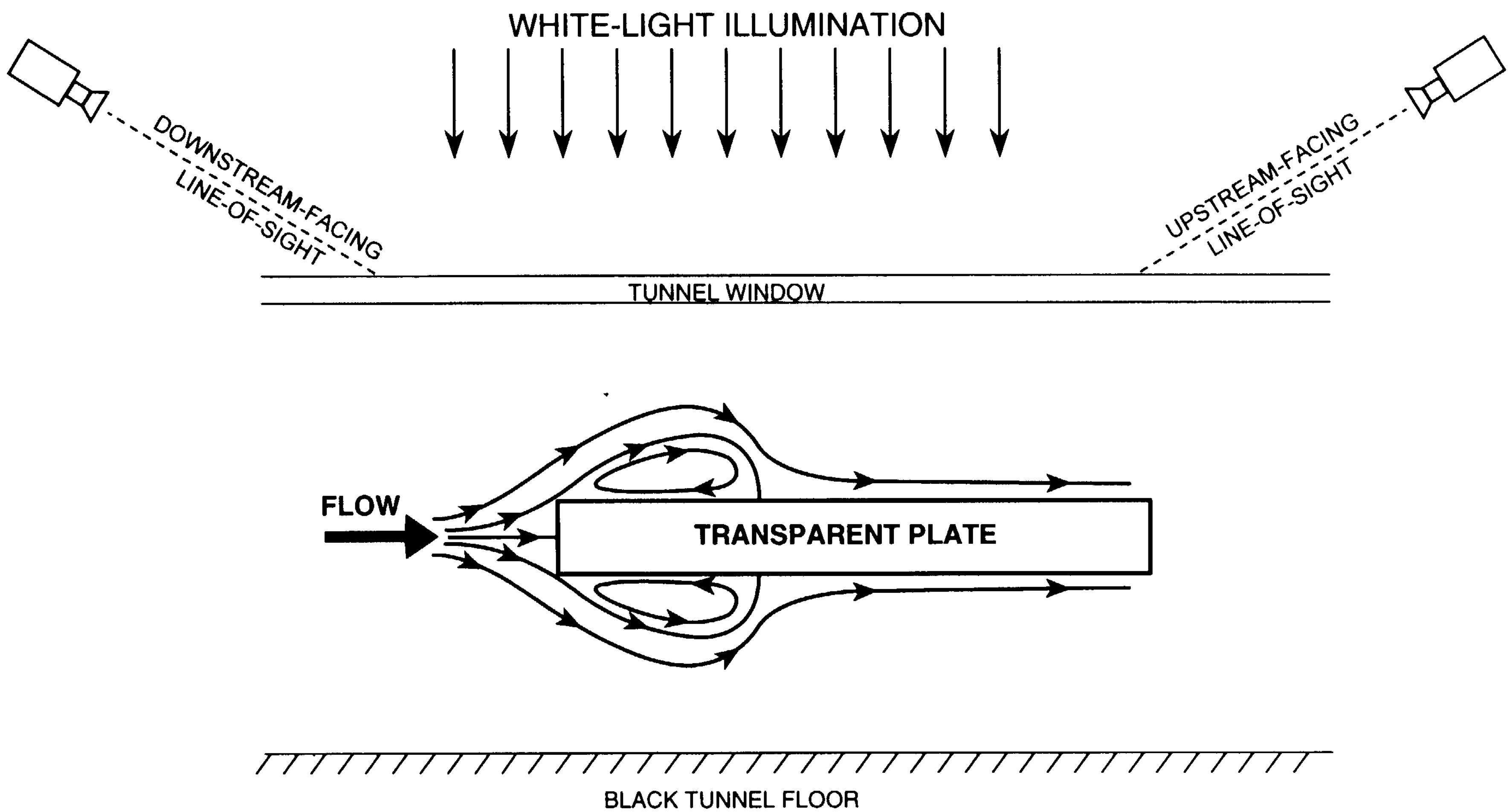

Fig. 1. Schematic of experimental arrangement.

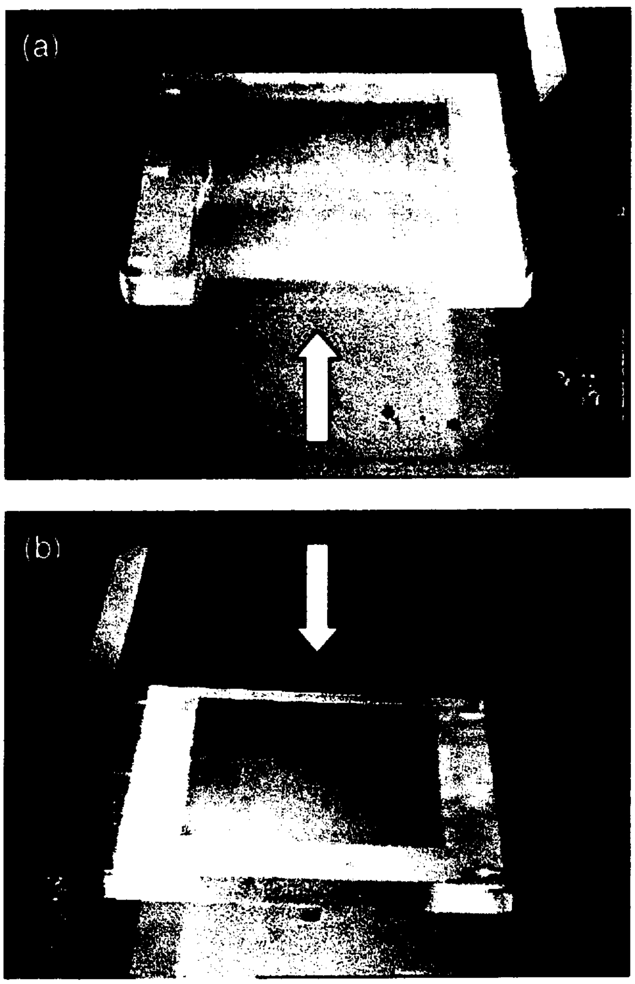

Fig. 2 SSLCC on upper surface, top lit and viewed with, (a) downstream facing camera, (b) upstream facing camera.

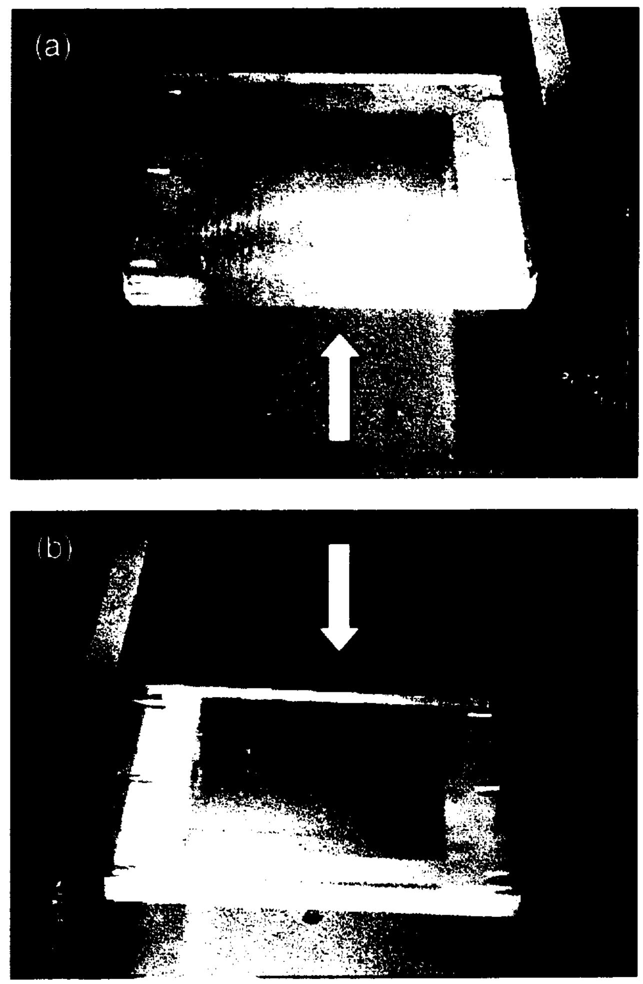

Fig. 3 SSLCC on lower surface, back lit and viewed with, (a) downstream facing camera, (b) upstream facing camera.