The correlation matrix for the beam's flexural rigidity EI for case A is

$$[\rho_{\mathrm{EI}}] = \begin{bmatrix} 1 & -0.1361 & -0.4930 & 0.0316 & -0.1551 \\ -0.1361 & 1 & 0.8678 & -0.9931 & -0.9532 \\ -0.4930 & 0.8678 & 1 & -0.8331 & -0.7422 \\ 0.0316 & -0.9931 & -0.8331 & 1 & 0.9768 \\ -0.1551 & -0.9532 & -0.7422 & 0.9768 & 1 \end{bmatrix}$$

The correlation matrix for the beam's flexural rigidity EI for case B is

$$[\rho_{\mathrm{EI}}] = \begin{bmatrix} 1 & -0.1311 & -0.4844 & 0.0283 & -0.1559 \\ -0.1311 & 1 & 0.8712 & -0.9933 & -0.9545 \\ -0.4844 & 0.8712 & 1 & -0.8376 & -0.7489 \\ 0.0283 & -0.9933 & -0.8376 & 1 & 0.9774 \\ -0.1559 & -0.9545 & -0.7489 & 0.9774 & 1 \end{bmatrix}$$

The present method has been shown to solve successfully the probabilistic model update/refinement problem using experimentally measured modal data on a cantilever aluminum beam.

Conclusions

A method has been presented to improve the robustness characteristics of current FEM updating methodologies by introducing the concept of probability theory. Measured statistical changes in natural frequencies and mode shapes, along with an initial analytic deterministic FEM are used to assess the integrity of the original model. Only the stiffness matrix was updated during the procedure and the mass matrix was assumed unchanged. The structural parameters of the system were modeled as correlated normal random variables. Stochastic expressions for SRFs were obtained that led to determination of estimated updated stiffness statistics. The method was applied using experimental data from a cantilever aluminum beam. The method was successfully able to adjust the stiffness parameters of an initial best-guess deterministic FEM to correct it using statistical data of experimentally measured modal properties. Two test cases were investigated where the initial model underpredicted (65.075 GPa) and overpredicted (71.925 GPa) the actual mean modulus of elasticity by 5.0%. For both scenarios, the method aptly corrected the under- and overpredictions. Overall, the method was successful in probabilistically updating the stiffness matrix of the experimental beam data.

Acknowledgments

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A. Berman
Associate Editor

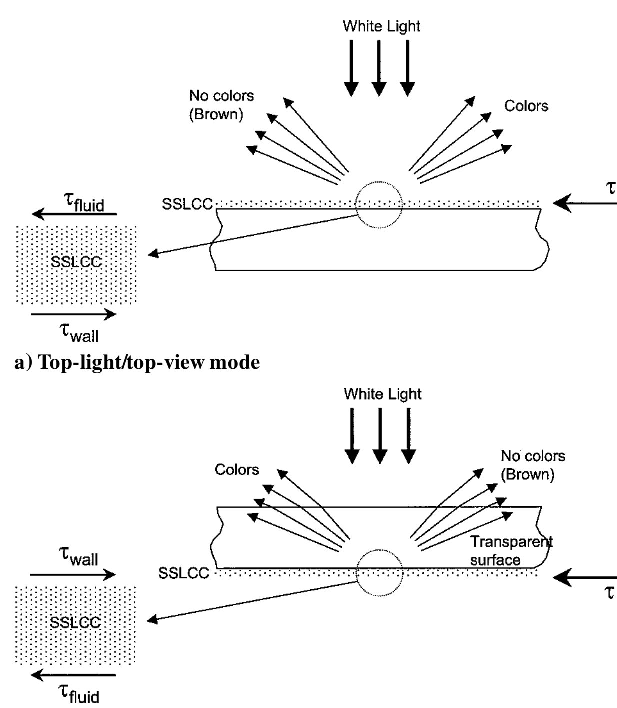
Shear-Sensitive Liquid Crystal Coating Method Applied Through Transparent Test Surfaces

Daniel C. Reda* and Michael C. Wilder†
NASA Ames Research Center, Moffett Field, California 94035-1000

I. Introduction

THE objective of the present experiment was to explore application of the shear-sensitive liquid crystal coating (SSLCC) flow-visualization method through a transparent test surface. In this previously untested back-light/back-view mode, the exposed surface of the SSLCC was subjected to aerodynamic shear stress while the contact surface between the SSLCC and the solid, transparent surface was illuminated and viewed through the transparent surface. Figure 1a shows schematically the geometrical arrangement utilized in the conventional top-light/top-view mode,[1–3] and the new back-light/back-view mode is shown in Fig. 1b.

The optical properties of the liquid crystal molecular arrangement are reviewed in Refs. 4–6. Shear-sensitive cholesteric (chiral nematic) liquid crystal coatings are composed of helical aggregates of long, planar molecules arranged in layers parallel to the coated surface. Each layer of molecules is rotated, relative to the layer above and below it, about an axis perpendicular to the coated surface. The longitudinal dimension along the helical axis (the pitch) is on the order of the wavelengths of visible light. This layered, helical structure causes such materials to be extremely optically active. White light



a) Top-light/top-view mode

b) Back-light/back-view mode

Fig. 1 Two SSLCC operational modes and the macroscopic view of the forces applied to the coating.

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*Senior Staff Scientist, Space Technology Division. Fellow AIAA.
†Senior Research Scientist, ELORET. Member AIAA.

incident normal to the coating surface is selectively scattered at a wavelength proportional to the pitch of the helix. Under applied shear at either boundary of the coating, the local pitch of the helical structure is altered, and the local helical axis is tilted relative to the no-shear state. The net result is that the incident light is reflected in a highly directional manner, as a three-dimensional color spectrum in space.

In the top-light/top-view mode, color-change response of a 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.[2] 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 the order of 30 deg. 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-alignedorientation 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[1] and measurement[2,3] of continuous shear stress vector distributions.

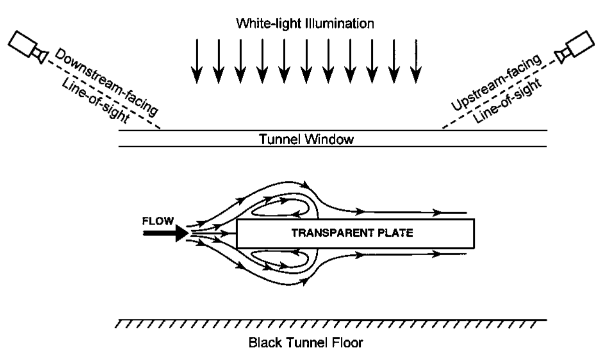

Fig. 2 Schematic of experimental arrangement.

II. Experimental Arrangement

Figure 2 shows a schematic of the experimental arrangement and resultant flowfield. A 12 × 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 microinches 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 × 4 ft test section. Test conditions were a total pressure

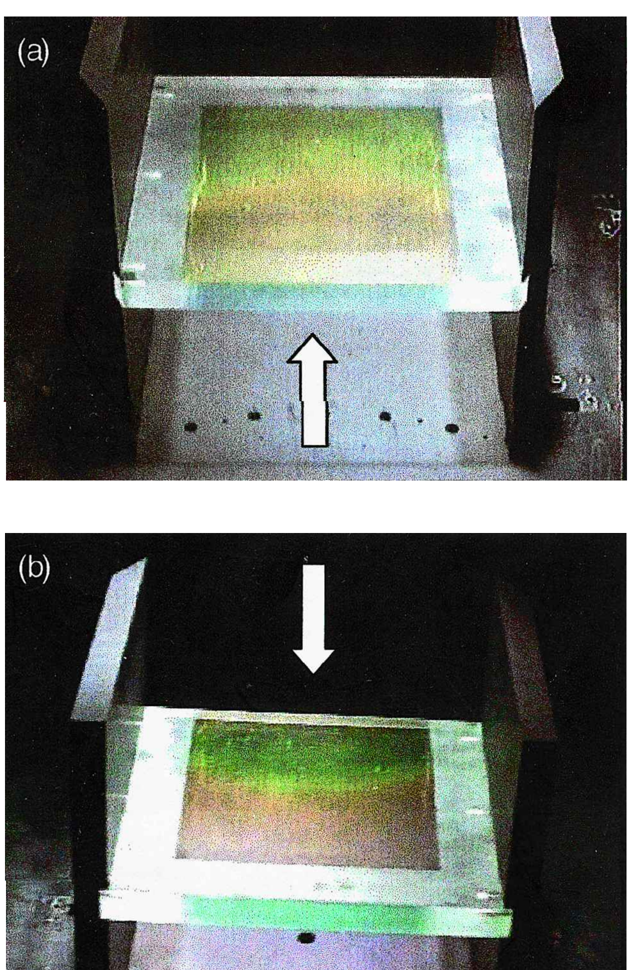

Fig. 3 SSLCC on upper surface, top lit and viewed with a) downstream-facing camera and b) upstream-facing camera.

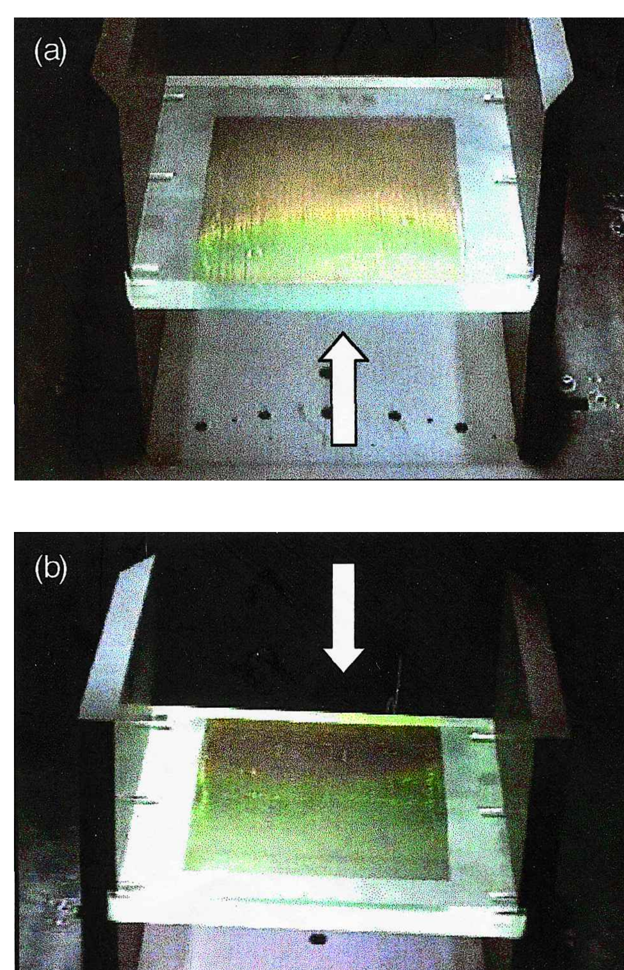

Fig. 4 SSLCC on lower surface, back lit and viewed with a) downstream-facing camera and b) upstream-facing camera.

of 1 atm, a total temperature of 72°F, and a freestream velocity of 180 ft/s. As shown in Fig. 2, a large-scale separated flow region formed over both the upper and lower plate surfaces immediately downstream of the blunt leading edge. The streamwise extent of the reverse-flow region was slightly larger on the upper, unbounded surface of the plate. 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 flowfield 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. The coating was illuminated and viewed through a 1-in.-thick plexiglass window.

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 and remounted between the sidewalls. Flow was reestablished, and the color-change response for the back-light/back-view deployment of the same coating was recorded.

III. Results and Discussion

Figures 3a and 3b show the top-light/top-view color-change responses, and Figs. 4a and 4b show the corresponding back-light/back-view results. First, consider the top-light/top-view images of Fig. 3. In Fig. 3a, 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. 3b, 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. 3a with 4a and Fig. 3b with 4b clearly show that the color-change responses recorded for the back-light/back-view mode were opposite to those recorded in the conventional top-light/top-view mode. On the macroscopic level, this finding can be explained by analyzing a free-body diagram of an elemental area of a thin, nonflowing coating (see again Fig. 1). 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.

IV. Conclusions

The present results clearly demonstrate that the SSLCC flow-visualization method can be extended to the back-light/back-view mode. This mode makes the SSLCC method applicable to the study of a new class of fluid-dynamic problems. First, the method can be utilized to visualize 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. Second, visualization 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 nontransparent appendages or protuberances onto the test surface. Extension of the shear-vector measurement aspect of the SSLCC method to the back-light/back-view mode should next be explored.

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R. P. Lucht
Associate Editor

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