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Use of the Schlieren Technique to Observe the Still Air Layer Above the Surface of Fabric Covering a Heated Flat Plate

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THE insulating properties of fabrics have often been associated with "still" air layers which exist over the surface of the fabric and add to its insulating value. This phenomenon was recognized early in the 19th century [3]. One of the early guarded-ring hot plates developed for testing fabrics [2] was provided with a hood so that the equipment could be operated in a room without disturbance of the "still" air layer by ambient air currents. Measurements of this air layer were made in the past by indirect methods [4]. To date the examination of the "still" air has been difficult since techniques for making this air visible have not been explored by investigators studying the thermal properties of fabrics. The Schlieren technique [7], whereby differences of air density can be made visible [1, 5], suggests the possibilities of photographing the air layer so that it can be accurately measured and its behavior observed in different environmental conditions.

This paper describes the preliminary experiment to demonstrate the feasibility of the application of the Schlieren technique. Further work, using motion pictures and color photographs, gives promise of explaining in greater detail the role of the "still" air layer in the insulation provided by a given fabric or combination of fabrics. A refinement of this technique to simulate the thermal condition of a human body should provide much valuable information. In fact, quantitative data regarding the limits of boundary layer, surface temperature, and heat-transfer rate are possible. Such data will be useful in designing better cold-weather ensembles by answering questions about the relative insulating value of different fibers and the most effective relative positions for rough or smooth surfaces to achieve maximum insulation.

The optics of the Schlieren apparatus are shown in the schematic diagram, Figure 1. Light is directed from point L to a parabolic concave mirror, K_1, from which it is reflected in parallel rays to a similar mirror, K_2. This mirror is so slanted as to, in turn, reflect the beams to a camera, P, at the other side of the mirror system. A knife edge, B, is set at the focal point of the converging rays as they are reflected from the mirror, K_2, to the camera, P.

With this system, if the air density in the path of the parallel light is uniform, moving the knife edge, B, into the ray of light would produce a uniform darkening of the mirror surface. The specimen, S, which in this investigation consisted of a fabric covering a thermal plate, is positioned between the mirrors. As the heat flowing from the plate changes the air density in the light path, the camera, with the knife edge properly positioned in front of it, photographs the differences in density between the hot air directly along the fabric and the cooler ambient air. The hot-air layer appears on the photograph as a darkened area.

Figure 2 (A–E) shows photographs of 4 fabrics taken by the Schlieren technique at the David Taylor Model Basin of the U. S. Navy. A laboratory thermal plate was used. (No special apparatus was designed for the heat source.) The laboratory thermal plate was selected to fit in the space provided for this in the Schlieren system. The temperature of the thermal plate could be controlled at about 250°F. A check of its surface temperature indicated that the

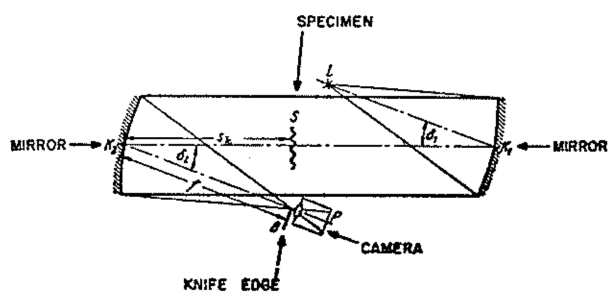

Fig. 1. Schematic diagram of apparatus for Schlieren photographs [7].

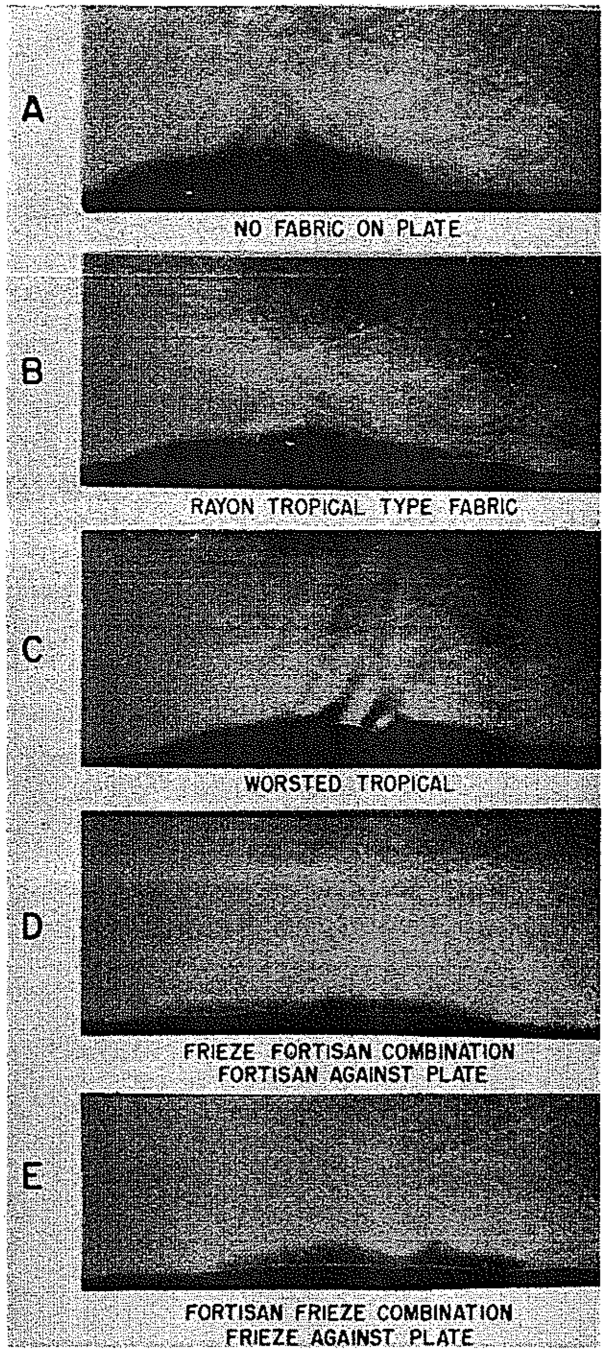

Fig. 2. Fabrics photographed by Schlieren method.

thermostat maintained the temperature between 235° and 260°F. The measurements were made on a hot July afternoon with the room temperature at 92°F. Thus, the effective temperature differential was about 160°F.

Four fabrics were tested in this exploratory investigation. Two were relatively thin fabrics of approximately equal weight and thickness but of different fiber content: a rayon tropical suiting and a tropical worsted. The third was wool frieze, a thick double-faced loop-pile fabric, and the fourth was 1.6-oz Fortisan lining fabric. The first two fabrics were tested separately; the third and fourth were tested as an ensemble, duplicating the standard liner formerly used in Army cold-weather clothing. The ensemble was tested in two ways, frieze side up and then Fortisan side up, to determine the effect on the height of the air layer of the radically different surfaces.

The thermal plate was placed in a 9-in. wind tunnel which formed an integral part of the Schlieren system used to make the measurements reported here. The gates of the tunnel were shut to provide a closed chamber.

Figure 2*A* shows the thermal plate at 250°F with no fabric covering. The boundary surface of the "still" air layer is clearly shown here. It extends 0.75 in. above the plate at the high point near the center.

With the rayon tropical sample on the plate, as shown in Figure 2*B*, the dark portion of the photograph, indicating the "still" air layer, measures 0.60 in., a loss in thickness of 0.15 in. Because of its smoothness, the rayon fabric can be considered similar in surface character to the thermal plate itself. It is assumed that, in general, for similar surfaces, the height of the air layer is directly related to the differences in temperature between the exposed surface and the ambient air. The difference between the height of the air layer over the bare plate and that over the rayon tropical fabric, therefore, indicates that the temperature at the surface of the fabric is less than that at the surface of the bare plate, and hence, that the fabric provides some degree of insulation. The less efficient the fabric is as an insulant, the higher the temperature at the fabric-air interface would be, and the thicker the air layer.

In Figure 2*C*, the plate was covered with tropical worsted fabric. After the photograph was taken, it was discovered that the fabric was not properly smoothed, and the photograph shows a break in the air layer where the fabric was not flat against the plate. Elsewhere, the air layer is 0.50 in. thick, slightly less than that over the rayon fabric. Further testing would be required to determine whether the difference between the two is significant. The disappearance of the air layer over the part of the sample raised above the plate may be a substantiation of the value of an air space between the body and the fabric.

Figures 2*D* and 2*E* show the frieze-Fortisan ensemble. With frieze side up (Figure 2*D*), the air layer measured 0.30 in. With the Fortisan up (Figure 2*E*), the air layer thickness was 0.40 in. It should be borne in mind, however, that in the case of the frieze-Fortisan combination with the frieze side exposed to air the base line of the fabric is approximately 0.10 in. below the loop height. In the photograph, measurement of the air layer was made from the top of the loop to the outside boundary surface of the air layer. Here it is difficult to draw the line as to what constitutes the boundary layer of the fabric, the top of the loop or the top surface of the base fabric which holds the loop in place. It may well be that the two air layers' thicknesses are alike if the top of the base fabric is taken as a point for measurement. The fact remains, however, that the overall height of the assembly and air layer is lower when the frieze side is exposed to air than when the Fortisan side is so exposed. That is, for equivalent assemblies and test conditions, the air layer over a rough surface (such as frieze) is not as thick as the air layer over a smooth surface (such as the Fortisan fabric). It may be that further experiments with the technique will provide a clue to the possible value of napping and other treatments which roughen fabric surfaces for the purpose of improving insulation properties.

The data collected in this preliminary experiment are summarized in Table I. In all instances, the "still" air layer was seen to build up rapidly above the fabric. A slight circulation was noted, which was seen as a constant swirling action along the periphery of the heated layer. This circulating air was seen to rise to the top and center of the layer, where it then trailed off into the chamber atmosphere. A momentary blast, at 30 mph, when jetted across the fabric lowered the thickness of the air layer to the upper surface of the projecting fibers. When the jet was shut off, the layer rapidly regained its size and shape.

These few experiments have shown that the Schlieren method is well suited for investigating the thermal properties of the "still" air layer. Moreover, its applications can be categorized as follows:

TABLE I: THICKNESS OF STILL AIR MASS OVER SURFACE OF HEATED FABRICS

SAMPLE	ARRANGEMENT OF SAMPLE	WEIGHT OZ./SQ.YD.	THICKNESS OF FABRIC (")		THICKNESS OF AIR LAYER
			AT 0.01 PSI	AT 0.1 PSI	
NO FABRIC	HOT PLATE	—	—	—	0.75
RAYON TROPICAL	HOT PLATE	6.7	—	0.020	0.60
TROPICAL WORSTED	HOT PLATE	6.7	—	0.020	0.50
FRIEZE FORTISAN	HOT PLATE	16.0 1.8	0.29 —	— 0.007	0.30
FORTISAN FRIEZE	HOT PLATE	1.8 16.0	0.29	0.007	0.40

a. A study of a "still" air layer around the surface of fabrics and fabric assemblies.

b. A quantitative evaluation of the temperature field defining the limits of the boundary layer, surface temperature, and heat-transfer rate.

These two categories for studying air layers offer a wide latitude for investigators working on thermal problems; for example, the study of conditions necessary for entrapping air in cold-weather clothing and dissipating the insulating air layer for hot-weather clothing. The design of garments can also be effectively studied from the standpoint of functional properties. Study can be made on scale models for the optimum design to accommodate subjects when at rest and also at high levels of activity.

Future plans using the Schlieren technique include the following series of studies:

a. Refinement of techniques to include temperature measurements by density measurements on the photographic plate. This will provide quantitative information not only on the boundary layer, but also on the measurement of the heat-transfer rate through the clothing system.

b. A study of individual fabrics, fabric layers in contact, and fabric layers artificially spaced at different thicknesses [6] to arrive at an optimum combination of fabric air for good insulation.

c. A pore-size study to determine hole size and shape in insulating material for retaining heat at low levels of motion and dissipating heat at higher levels of motion.

d. A study of the effect of air permeability of fabrics on the insulating properties of the garments.

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