# Technical Support Package for

# LAR-13319

# Continuous Multi-Element Hot-Film Transition Gage

## National Aeronautics and Space Administration

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### INTRODUCTION

The accurate measurement of the location where a laminar boundary layer transition to turbulent serves many purposes. In basic research and in developmental testing, this information is needed for validation of theory and design. For example, a complete understanding of performance and stability and control of a laminar flow airplane requires knowledge of transition locations on wing surfaces, empennage surfaces, fuselage and nacelles.

Several methods, visual, acoustic, and electronic, are capable of providing transition information. These methods may utilize sensing devices mounted either on the test surface or through the skin surface from the interior to the exterior of the test surface. Each of the various transition measurement methods has advantages and disadvantages.

One very useful device for large-scale wind tunnel and flight applications is the thin, surface-mounted hot-film gage. Hot films indicate transition by responding to the different heat transfer in laminar versus turbulent flow. These gages are approximately the size of a postage stamp and are applied to the test surface using conventional strain-gage installation techniques. The advantages of these

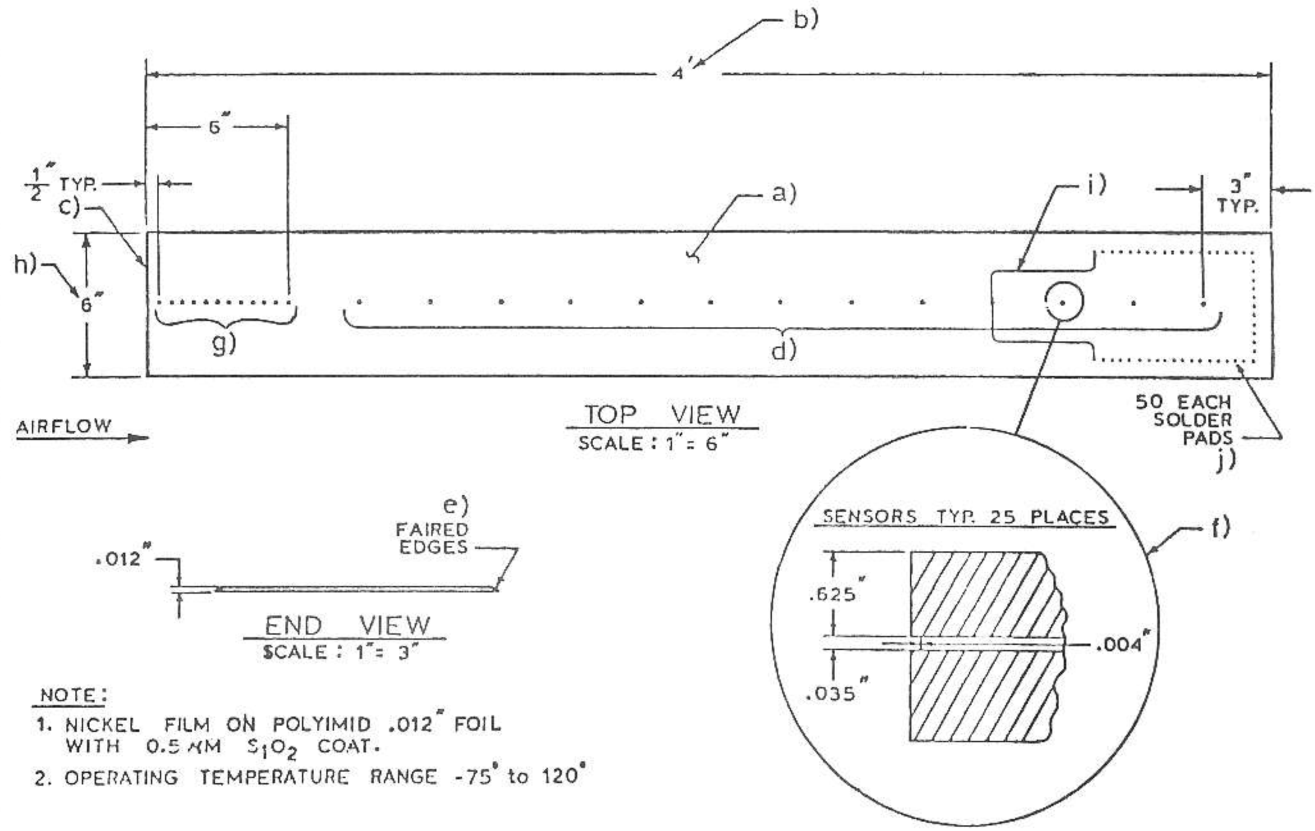


**FIGURE 1: Continuous Multi-Element Hot-Film Transition Gage**

gages relate to installation flexibility and durability. Since the gages and associated wiring are entirely surface-mounted, they may be used on test surfaces which do not permit through-the-surface types of instrumentation. In addition, with care, it is possible to remove and reposition gages for reuse in other locations. Installed gage thicknesses will not be large enough to cause transition for testing at sufficiently large model scales. However, the wiring attached to the downstream end of each gage will be large enough to cause a transition wedge (emanating downstream at about 7° half angle). Thus these individual gages must be staggered to avoid turbulent contamination of a downstream gage from a neighboring upstream gage. This need for staggering is the source for the most significant disadvantages of individual hot-film gages.

Dedicated electronic circuitry is typically connected to the postage stamp-size gages using coaxial cables which are necessary to provide a low D.C. resistance, constant A.C. impedance connection. However, the diameter of these coaxial cables is sufficiently large to disturb the airflow in the vicinity of the gages. The exact placement and means of attachment of these cables relative to the local airflow and gages require careful attention.

The continuous multi-element hot-film transition gage, or multi-element hot-film boundary-layer transition sensor, has been developed to overcome the disadvantages of individual hot-film gages by integrating the required number and distribution of hot-film sensing elements into a long, continuous, thin sheet. Transition data acquisition is accomplished using an electronic switching system which allows rapid switching of all sensing elements into the data recording system.

## SYSTEM DESCRIPTION AND OPERATION

The continuous multi-element hot-film transition gage is shown in Figure 1. The continuous thin sheet, 1(a), of a particular length, 1(b), covers the area of interest for transition measurements beginning at the leading edge, 1(c), and continuing to downstream of the transition region, 1(d). For example, on an airplane wing of 10 feet chord length, the gage may be as much as 7 to 8 feet in length. The leading edge, 1(c), of a gage mounted on the upper surface of a wing would wrap around and beneath and downstream of the wing leading edge. In this fashion, no disturbance from the film leading edge will cause turbulent wedges to disturb the hot-film sensors in the transition region. A technique for installation of the sensor is described in the section, "Multi-Element Hot-Film Transition Sensor Installation Procedures."

Conventional hot-film manufacturing techniques produce films thin enough that sideways-facing steps at the gage lateral edges, 1(e), do not cause turbulent wedges at most test conditions on large-scale test surfaces. For situations where the lateral edges would cause transition, the

FIGURE 2: 4 x 1 Electronic Switch Matrix

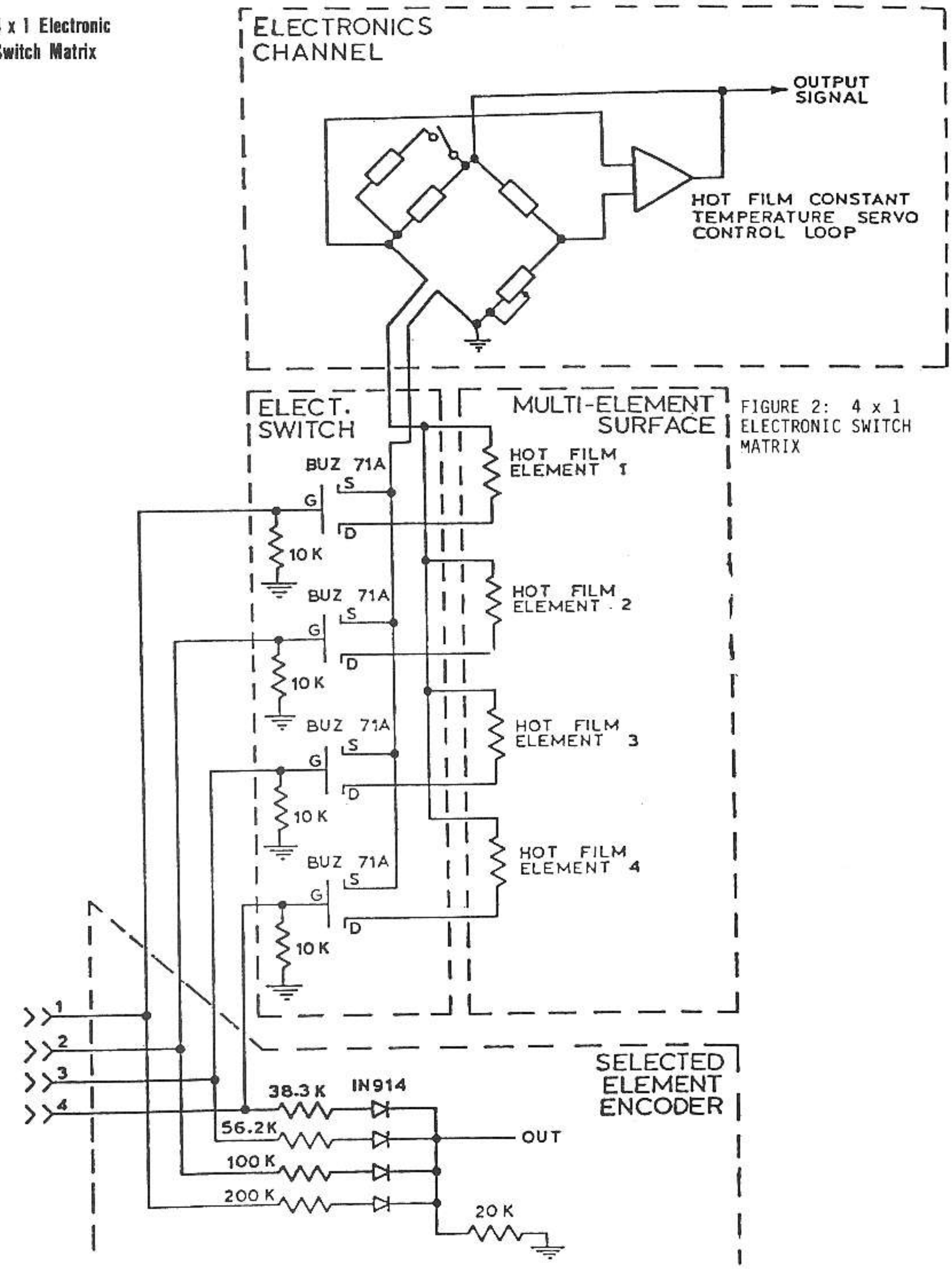


FIGURE 2: 4 x 1 ELECTRONIC SWITCH MATRIX

edges may be filled and faired, 1(e), to correct this difficulty. A method to accomplish this is described in the installation procedures. The gage incorporates as many hot-film sensing elements, 1(f), as needed, distributed as needed along the length of the sheet. By closely spacing the elements along the upstream end of the sheet, 1(g), stagnation or attachment line location can be documented. Further downstream, 1(d), the elements are more widely spaced for transition location measurement. The width, 1(h), of the sheet provides space for the signal leads, 1(i), to be carried laterally away from each hot-film element and longitudinally to the downstream end of the sheet where external wiring attachments, 1(j), are made.

The gage utilizes improved circuitry in the form of an electronic switch. The switch is a power MOSFET (metal oxide semiconductor field effect transistor) device capable of switching far greater currents (10 A) than the hot-film elements require. The result is that the "ON" D.C. resistance in the switch is very small, on the order of 0.018 ohm. This resistance is repeatable and will not be affected

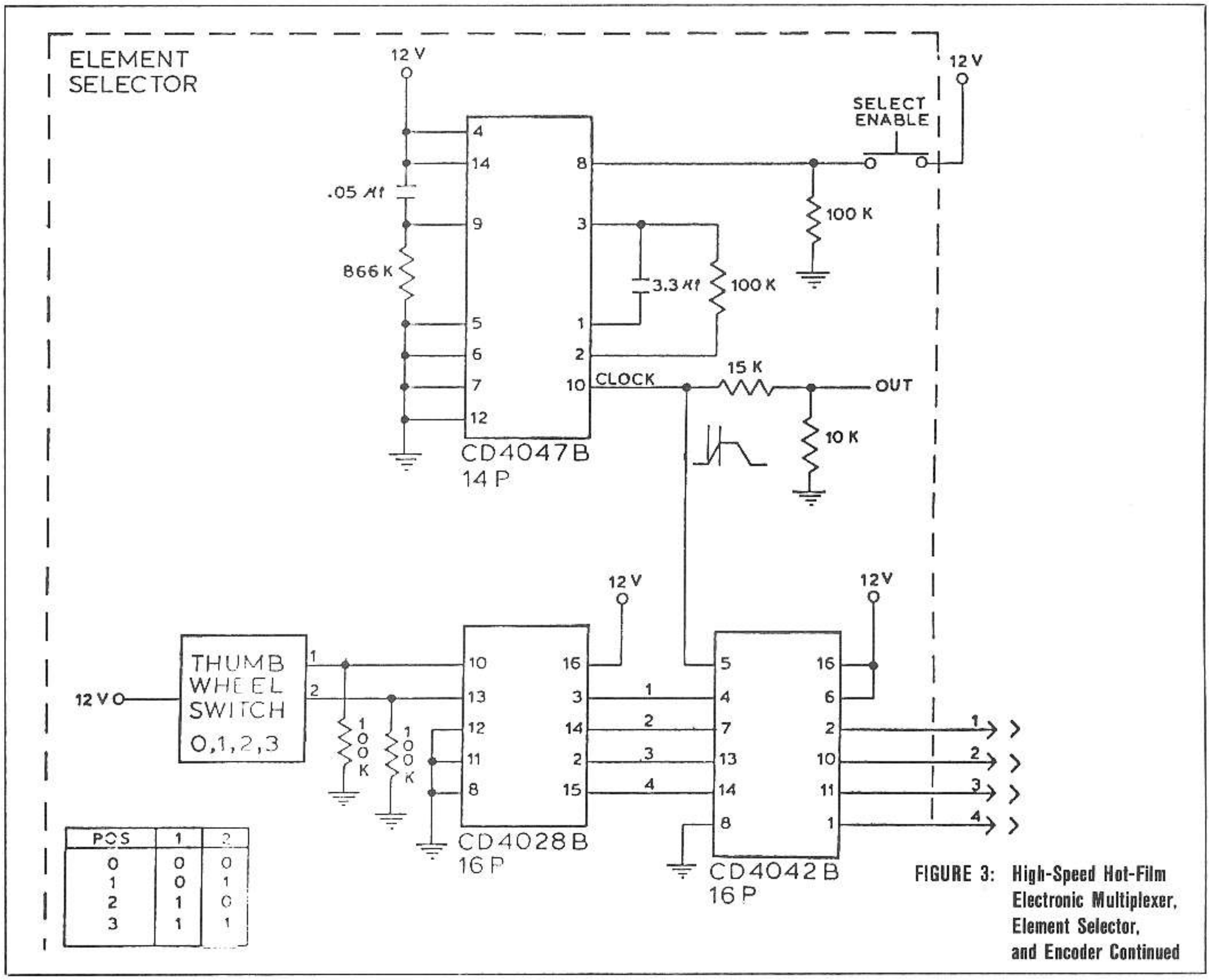


FIGURE 3: High-Speed Hot-Film Electronic Multiplexer, Element Selector, and Encoder Continued

by aging or the number of switching cycles. The MOSFET switch will not oxidize as do conventional contacts, and it is not affected by vibration or accelerations and is not position sensitive. The MOSFET switch also has a very rapid switching speed which allows sensor elements to be switched into the servo loop at very high rates without damage to the sensors.

A 4 x 1 electronic switch matrix is shown in **Figure 2**. Hot-film elements 1 through 4 are electronically selected in any sequence for inclusion into the hot-film constant temperature servo control loop. An element selector circuit, **Figure 3**, consists of a thumb wheel digital selector switch and an electronic channel decoder which directly drives the power MOSFET switches. Figure 2 also contains an element encoder for determining and recording which hot-film element is activated at any time.

Alternative embodiments of the gage include variations of the geometry (length and width) of the gage such as a continuous sheet which covers both the upper and lower surfaces of a wing to provide simultaneous transition measurements on both surfaces. Another possibility is the substitution of very thin pressure sensing elements for the hot-film elements (or co-installation of the two sensing devices) to provide chordwise measurement of static pressure distributions simultaneous and co-located with transition information.

Location of electronic switches near sensor elements significantly reduces the number of wires required to sense, acquire, and record data. The number of hot-film elements which can be multiplexed into a constant temperature anemometer system depends only on the number of switches in combination with the number of wideband servo channels that are available in a given system.

## SUMMARY

Installed on a laminar flow surface, the continuous multi-element hot-film transition gage provides boundary layer transition information in the streamwise direction. The gage allows simultaneous measurement of stagnation or attachment line position aligned in the streamwise direction with the transition measurement. With this gage, detailed studies are possible concerning the effects of three-dimensional flow fields on laminar flow behavior. Thus, the gage provides a unique means for acquiring accurate boundary layer data in situations where sensing instruments must be installed on the exterior of a test surface. The gage performs the functions of previous systems with greater simplicity and saves time, space, and cost for laminar boundary layer data acquisition systems.

The electronic circuitry allows switching of elements into the servo control loop at faster rates than was previously possible. The electronic MOSFET switch provides a very low resistance which will remain repeatable throughout the aging of the circuit, and the switch will not be affected by vibration, accelerations, oxidation or life cycle. The rapid switching speed permits significantly more data to be gathered than prior art circuitry.

## MULTI-ELEMENT HOT-FILM TRANSITION SENSOR INSTALLATION PROCEDURES

*All brand names mentioned in the instructions are brands used and can be substituted with an equivalent product.*

### List of Materials

Dupont Prep-Sol 3919S
Johnson Kit Paste Wax
Pen, Permanent Sanford's Sharpie
Paper Wipers
3MY9460 Adhesive
Permacel P252 Electrical Tape
Paper Masking Tape
Dow Corning RTV 732 Adhesive/Sealant
Cellulose Acetate, Clear .020 thick
Chevron Hy-Jet IV Hyd. Fluid
Everhard Products Hand Roller 2 x 2 Hardrubber
Plastic Squeegee (Auto Body Filler Type)
Putty Knife (1 inch Red Devil)

### Multi-Element Hot-Film Transition Sensor Installation Procedures

1. Wash wing surface area with Dupont 3919S Prep-Sol Solvent where the Hot-Film Sensor is to be installed. Wipe dry with clean lint-free cloth.
2. Wax entire Hot-Film Sensor area with pre-softened paste wax (Johnson's Kit). All residue wax must be removed.
3. Using a black permanent ink pen (Sanford's Sharpie), mark the prepared surface with two sets of alignment marks. One set for the width and length of 3MY9460 adhesive and one set for the width and length of the Hot-Film Sensor. All marks should be at the angle the Hot-Film Sensor is to be installed.
4. Cut a length of 3MY9460 adhesive sufficient to cover area previously marked.
5. This step requires two people. Apply Dupont 3919S Prep-Sol Solvent by hand to completely wet area marked for adhesive placement. While area is still wet with solvent apply adhesive by holding adhesive above Hot-Film Sensor placement area. Using the adhesive alignment marks as a guide press approximately one inch of adhesive width to wing surface while 2nd person holds remaining adhesive strip above surface. Working to the person holding adhesive strip, slowly press adhesive to the surface with a plastic squeegee using care to remove all trapped air and solvent by working attached adhesive with the squeegee. Once entire length of 3MY9460 adhesive strip is attached continue to work out trapped air and solvent. Wipe excess solvent from edges of adhesive with clean lint-free cloth. Paper backing will absorb some of the solvent along edges. Use a needle to puncture any remaining air bubbles to remove trapped air and solvent. Again use clean lint-free cloth to wipe away solvent.
6. Allow adhesive to dry 1 hour minimum at 75°F. Check adhesive paper backing if solvent absorbed by backing is dry, paper backing can be removed. Starting at one end of adhesive strip slowly peel paper backing away from adhesive. Be careful not to lift adhesive from wing surface. Best procedure is to hold backing almost flat over against remaining attached backing when peeling away and pull very slowly. Once paper backing is removed, Hot-Film Sensor should be installed immediately.
7. During installation of Hot-Film Sensor, again two people are required. While holding Hot-Film Sensor above adhesive, using sensor alignment marks as a guide, place one inch of sensor width to adhesive. Then use a plastic squeegee to press remaining sensor to adhesive; work towards the person holding the unattached portion of Hot-Film Sensor above adhesive. Hot-Film Sensor should be applied very slowly to keep sensor flat and smooth against adhesive.
8. After the Hot-Film Sensor is attached to adhesive, remove excess adhesive from border of sensor. This can be accomplished by rubbing excess adhesive with fingers. The adhesive is easy to remove at this stage of curing. Make sure all excess adhesive is removed from border of Hot-Film Sensor.
9. Fair the border of Hot-Film Sensor with Dow Corning 732 RTV Adhesive/Sealant as follows: The RTV should not exceed .002 inch height protrusion above the Hot-Film Sensor or the wing surface ⅝th inch away from sensor edge.
   a) Place one layer of one inch wide Permacel P252 Electrical Tape directly on top and along the lateral borders of Hot-Film Sensor. Make sure to stay even and parallel to the sensor edges.
   b) Place one layer of one inch wide Permacel P252 Electrical Tape on wing surface parallel to and ⅝ inch away from Hot-Film Sensor border.
   c) Place one layer of masking tape directly on top of Permacel P252 previously installed on wing surface. This layer of masking tape should be installed leaving ⅛th inch of Permacel P252 Tape showing on edge nearest to Hot-Film Sensor. The masking tape will act as a guide for putty knife when spreading RTV.
10. Squeeze out a bead of Dow Corning RTV 732 Adhesive/Sealant sufficient to fill the ⅝th inch space

between Hot-Film Sensor and tape on wing surface. Using a 1¼ inch putty knife (Red Devil 4302) spread RTV in a fillet manner along the entire length of Hot-Film Sensor border. Once RTV is spread and area between Hot-Film Sensor and wing surface tape is filled, remove the Permacel P252 tape from Hot-Film Sensor and wing surface leaving RTV layer.

11. Lay a piece of clear cellulose acetate, .020 thick by 1¼ inches wide and length sufficient to extend 3 inches beyond both ends of Hot-Film Sensor, on top of RTV fillet layer. Make sure the outer edge of cellulose acetate is even with RTV edge ⅝ inch from Sensor against wing surface. Use a 2 inch by 2 inch hard rubber hand roller (Everhard Products) to roll cellulose acetate against RTV.

    Continue rolling until excess RTV is pressed from underneath cellulose acetate and a good smooth fillet is formed from Hot-Film Sensor to wing surface. Try to maintain a ⅝ inch width and a maximum of 0.002 protrusion of RTV above the sensor and wing surface. Wipe away excess RTV as area is rolled.

    Once cellulose acetate is smooth against RTV use masking tape on the 3 inch overlapping ends to hold cellulose acetate tight against RTV fillet and to wing surfaces for drying. Allow minimum of one hour drying time and test pull one end of acetate; acetate should pull away from RTV easily and leave a smooth surface. Excess cured RTV can be trimmed away after cellulose acetate is removed.

12. Place one layer of one inch Permacel P252 Electrical Tape over the RTV fillet allowing an even overlap on Hot-Film Sensor and wing surface approximately 1/8 to 3/16 inch on each side. This tape acts as a smooth surface over RTV and allows surface to be cleaned and chemical agents to be sprayed on for flight.

13. Sensor is ready for use.

## Removal of Hot-Film Sensor

1. Remove Permacel P252 Tape overlapping RTV 732 from border of sensor.
2. Slowly remove Hot-Film Sensor by peeling away from 3MY9460 adhesive.

## Clean Up of 3MY9460 Adhesive and RTV 732

1. Place a paper wiper against the exposed 3MY9460 adhesive, covering all adhesive. Paper wiper will readily stick to adhesive.
2. Saturate the paper wiper with Skydrol Hydraulic Fluid (Chevron Hy Jet IV). Wipe away all excess fluid from surface around paper wiper and allow to stand for a minimum of 15 minutes.
3. After time period the paper wiper will loosen and easily lift away from adhesive.
4. Using a plastic or wooden scraper, scrape away the gummed adhesive.
5. Once all gummed adhesive is removed, wash away all remains with Dupont Prep Sol 3919S to wash away remaining RTV 732 film.