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5.3 Use of a Pitot Probe for Determining Wing Section Drag in Flight

Edwin J. Saltzman
NASA Flight Research Center

(A status report of development work of Lawrence C. Montoya and Paul F. Bikle)

Introduction

This paper presents the status of recently completed development work on the wake traverse method of obtaining section drag at low speeds. The method of B. M. Jones, Reference 1, has been applied to wake profile data obtained from the wing of a sailplane.

Though the sailplane provides a quiet and relatively vibration free environment, and a very clean and smooth high aspect ratio wing, it is limited to a dynamic pressure range from about 6 psf to somewhat above 20 psf. These low dynamic pressures are a severe challenge for the wake traverse method.

This paper is intended not only to rekindle interest in the wake traverse approach of defining profile drag, but it is also intended to demonstrate techniques for increasing reliability and minimizing certain bias errors when dealing with relatively low differential pressures. The thought which accompanies this paper is that if acceptable accuracy in section drag can be obtained at these low dynamic pressures, even better profile drag definition could perhaps be obtained for applications on general aviation aircraft where higher pressures would prevail.

Airplane and Test Conditions

The sailplane was a T-6 having a modified Wortmann FX-61-163 airfoil. The modification consisted of a straightening of the underside cusp region at the rear portion of the section. A sketch of the wing profile is shown in Figure 1.

The surface finish of the wing was very smooth and the maximum waviness was about 0.003 inches in a two-inch section of surface. At the semispan station of the wake traverse tests the waviness was less than this.

The wake measurements were made 9.6 inches behind the wing trailing edge which corresponds to about 32 percent of the 29.9 inch local chord. Data were obtained for speeds from about 40 knots to 125 knots which provided chord Reynolds numbers between 10^6 and 3×10^6.

Indicated airspeed was held constant during each data run and six "total-pressure" wake traverses were made during each run followed by three "static-pressure" wake traverses. This sequence of nine traverses took approximately one minute. Data been obtained for deflected flap conditions but the data to be shown herein are for zero flap deflection. The majority of the data were obtained for very smooth air conditions but some data were obtained for air that would be considered somewhat rough.

A photograph of the sailplane with the wake traverse probe installed is shown in Figure 2. A Kiel probe can be seen mounted ahead of the drive unit package on the right wing. The dark colored tape running parallel to the wing trailing edge covers and holds down the wiring harness which connects the drive unit package to the recording package inside the fuselage.

Instrumentation

Probe and Drive Unit: A closer view of the probe and drive unit, and some of the reference probes, is provided in Figure 3. The Kiel tube is used as the reference for the transversing total pressure probe and the trailing boom provides a static reference for the traversing static pressure probe. The trailing boom orifices are located about 5 feet behind the wing and are calibrated against the ships static system, which is in turn a system which has been calibrated for position error.

The traversing probe (with total and static heads) and drive unit are shown again in Figure 4(a) and in closer detail in Figure 4(b) where some of the parts have been labeled. The probe traversed to about 8 inches above and below the wing trailing edge. The probe travel rate was a little less than 3 inches per second. The hardware which is shown in Figure 4 weighed about 3 pounds.

A very important part of the unit was the switching valve which permitted the same pressure transducer to measure the wake station total pressure decrement, in one mode, and the difference between wake static and trailing boom static pressure, when in another mode. More detail will be provided about this feature in following figures.

Recorder Package: The recording package consisted of a tape recorder, battery and a component box which housed a pressure transducer and two amplifiers. This package was mounted on a shelf behind the pilot's head rest as can be seen in Figure 5. A closer view of this hardware is shown in Figure 6, after a covering hatch has been removed. The weight of this package is about 40 pounds. The switch shown in Figure 6 is also an important element in obtaining in-flight tare readings on the transducer which records "ships q."

Switching Features: Figure 7 will be used to show schematically how the switching feature mentioned in the previous section works. As sketched in Figure 7, the switch is in the "zeroing mode." When the pilot places the switch in this mode, freestream total pressure exists on each side of the pressure transducer element, thus providing an in-flight tare reading which minimizes the bias error of this transducer. When the switch is placed in the "q mode" (toggle to the left) there is freestream total pressure on one side of the transducer and ships static on the other side. This, of course, provides a record of "ships q." Because the ships static system has been calibrated for position error the appropriate corrections are applied and a true freestream dynamic pressure can be calculated as a function of time for correlation with the pressures recorded in the wake and the probe position in the wake. The airspeed indicator allows the pilot to hold "ships q" steady for a sufficient period of time to permit up to nine successive wake traverses to be made under quasi-steady state conditions.

Another switching feature involves the switching valve which was identified in Figure 4(b). In Figure 8, a slide valve is shown in schematic form to illustrate how this switching valve can be used to direct Kiel tube pressure (freestream total) to one side of the transducer and wake total pressure to the other side. Thus the transducer senses the total pressure defect, ΔP_T, in the wake. When the wake probe moves beyond the wake, the transducer experiences freestream total pressure on both sides of the sensing element which thereby provides inflight tare readings for the transducer. This feature minimizes the bias error for this transducer.

Another mode for this switching valve is illustrated in Figure 9. In this case the valve arrangement provides trailing boom static pressure to one side of the sensing element and wake station static pressure on the other side. As mentioned before, the trailing boom static pressure has been calibrated against the ships static system which in turn has been calibrated for position error. Therefore the true decrement between wake station static pressure and freestream static can be calculated. It is this corrected decrement, ΔP, which appears as an adjustment in the Jones expression for calculating section drag from wake measurements. The Jones equation follows:

$$C_d = \frac{2}{c} \int \sqrt{\frac{q\ \text{wake}}{q}} \left(1 - \sqrt{\frac{q\ \text{wake} + \Delta P}{q}} \right) dy$$

where

q, freestream dynamic pressure, from ships transducer plus position error correction

$\Delta P_{T_{wake}}$, total pressure decrement in wake, from probe transducer

ΔP , difference between freestream and wake static pressure, from probe transducer

dy, from probe position potentiometer

c, wing chord at wake survey location

$q_{wake} + \Delta P$, from $q - \Delta P_{T_{wake}}$

q_{wake} , from $(q_{wake} + \Delta P) - \Delta P$

or $(q - \Delta P_{T_{wake}}) - \Delta P$

It is important that the same transducer, through the switching valve feature just described, provides both $\Delta P_{T_{wake}}$, and ΔP because thereby the parameter ΔP has bias error minimization in the same way as has been described for the $\Delta P_{T_{wake}}$ measurement.

It is also important to note that six $\Delta P_{T_{wake}}$ traverses and three ΔP traverses are made in succession while indicated airspeed, and consequently q , is held constant. Section drag coefficients to be presented in a following section are the average of six such traverses for each Reynolds number condition.

Results

Profiles of $\Delta P_{T_{wake}}$ plotted as a function of distance above and below the wing trailing edge plane are presented in Figure 10. These are obtained from six consecutive traverses through the wake over a period of about 40 seconds. The airspeed was about 44 knots which resulted in a section lift coefficient of about 1.0. Note the low "delta pressures" with which the instrumentation must contend at these speeds. Some part of the apparent dispersion of the six profiles is random scatter; however, a part of it is caused by small changes in airspeed during the 40 seconds of run time. Therefore, a part of the apparent dispersion will be eliminated when each profile is normalized by the appropriate mean q for that traverse. As mentioned before, the six normalized profiles are then averaged when calculating section drag coefficients by Jones' equation.

Another set of profiles is shown in Figure 11 for an airspeed of about 42 knots which provided a lift coefficient near maximum. In this case only, four profiles are shown. The profile with triangular symbols is the first of the sequence and is similar in appearance to those shown in Figure 10. The following profiles in their order of occurrence (diamonds and squares) progress toward local stall (circles) as speed was reduced ever so slightly. Earlier flying with flow visualization indicated that this region of the wing was indeed stalling at these speeds.

Section drag coefficients plotted as a function of chord Reynolds number are shown in Figure 12. Also shown are curves from Blasius and Schlichting representing fully laminar and turbulent flow over the upper and lower surfaces as if they were flat plates.

The circles represent three flights (each point is the average of 6 traverses) for natural transition. The wing surface was exceptionally smooth and clean for these runs.

The squares represent flight with the boundary layer tripped 5 percent behind the leading edge for both the upper and lower surfaces. The trip material was distributed grit of 0.035 inches mean height above the skin surface.

The results obtained to date have been encouraging and suggest several possibilities which may deserve to be included in follow-on flights. Some of these possibilities are listed below:

(a) 400 grit sanding of the local surfaces
(b) 200 grit sanding of the local surfaces
(c) add waves, up to 0.008" per 2 inches
(d) restore to best finish (fill, sand, rub)
(e) tape over flap gap
(f) insect roughness (bugs) on leading edges
(g) install wake traverse unit on several general aviation aircraft.

Closing Remarks

The experience reported has provided progressively improving accuracy in defining section drag for flight at low dynamic pressures. The accuracy is about 3 to 4 percent for the lower dynamic pressures and somewhat better than 3 percent at the higher dynamic pressures. It should be emphasized, however, that such accuracies were obtainable only by resorting to the detailed procedures described herein (especially the in-flight switching and tare evaluations) and by conducting all phases of the testing with the utmost care. Also of great importance was the precise position error calibration which had been accomplished on the ships airspeed-altitude system prior to the wake traverse work.

It is believed that with proper care and attention to detail, comparable or perhaps even more accurate section drag coefficients could be obtained on general aviation aircraft, considering the higher dynamic pressures encountered in general aviation.

References

Reference 1. Jones, B. M., Measurement of Profile Drag by the Pitot-Traverse Method, Cambridge University Aeronautics Laboratory, Rand M. No. 1688, 1936.

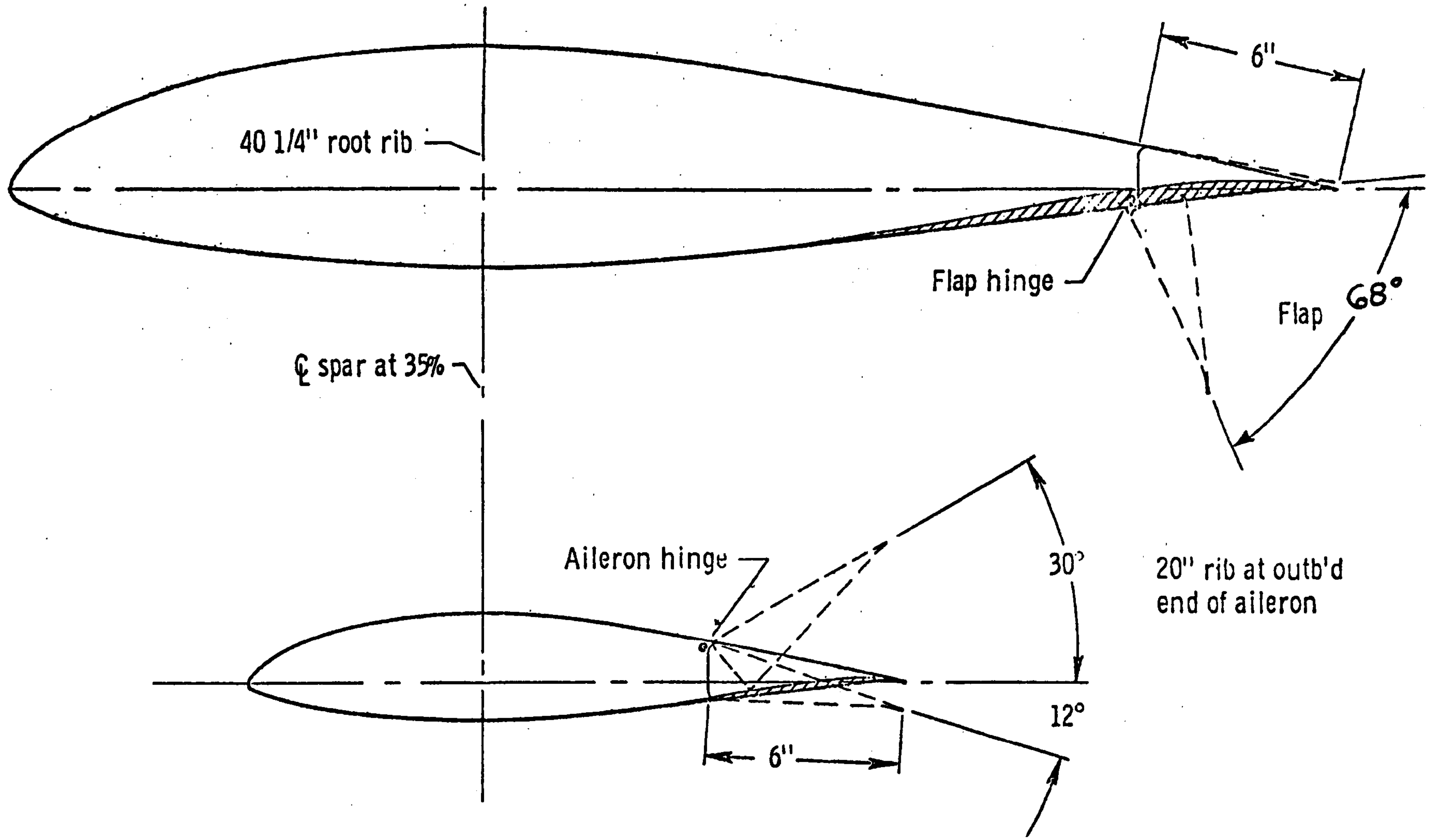

Figure 1. Example of Wortman FX-61-163 Airfoil

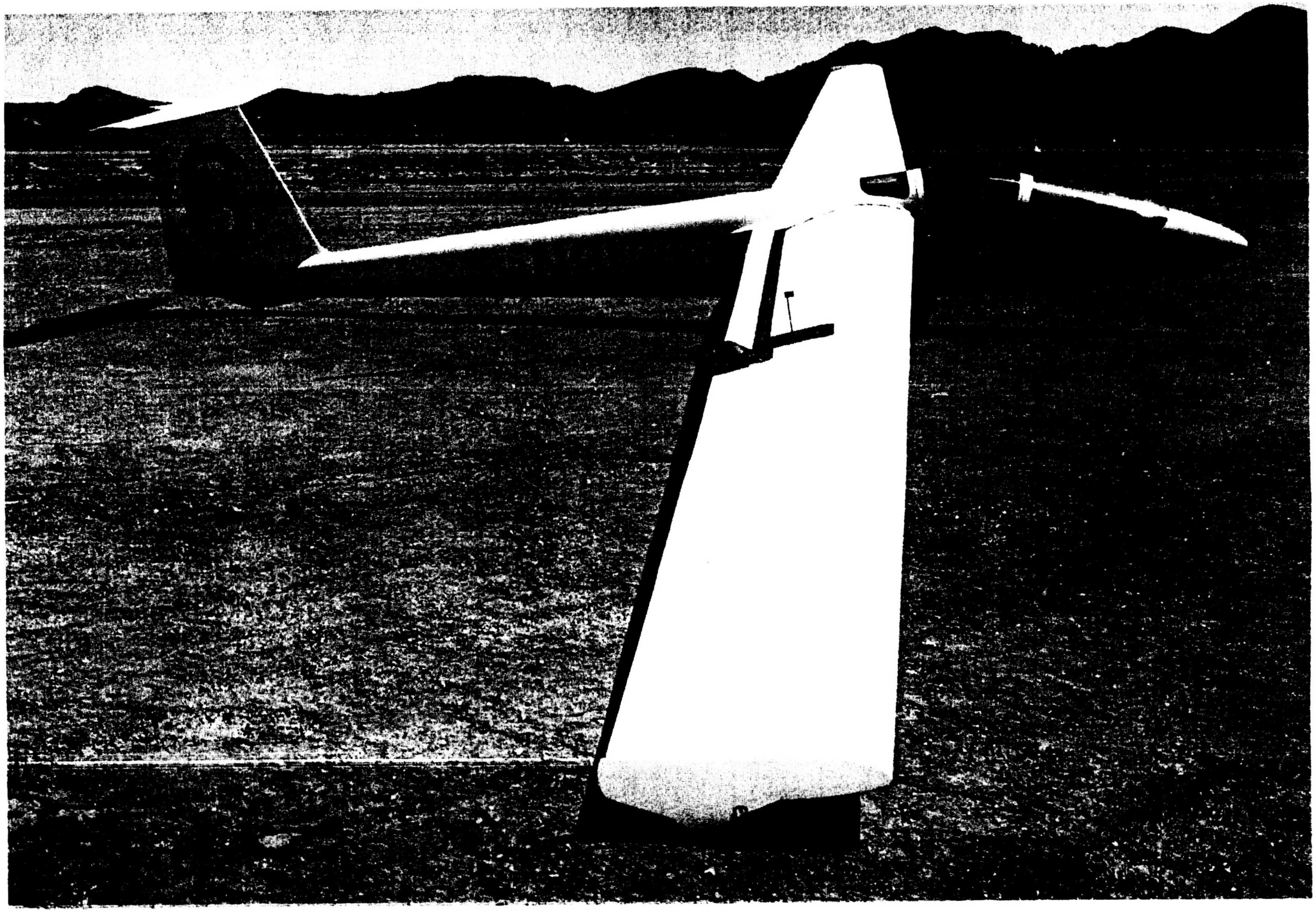

Figure 2. Example of Wake Traverse Probe Installation

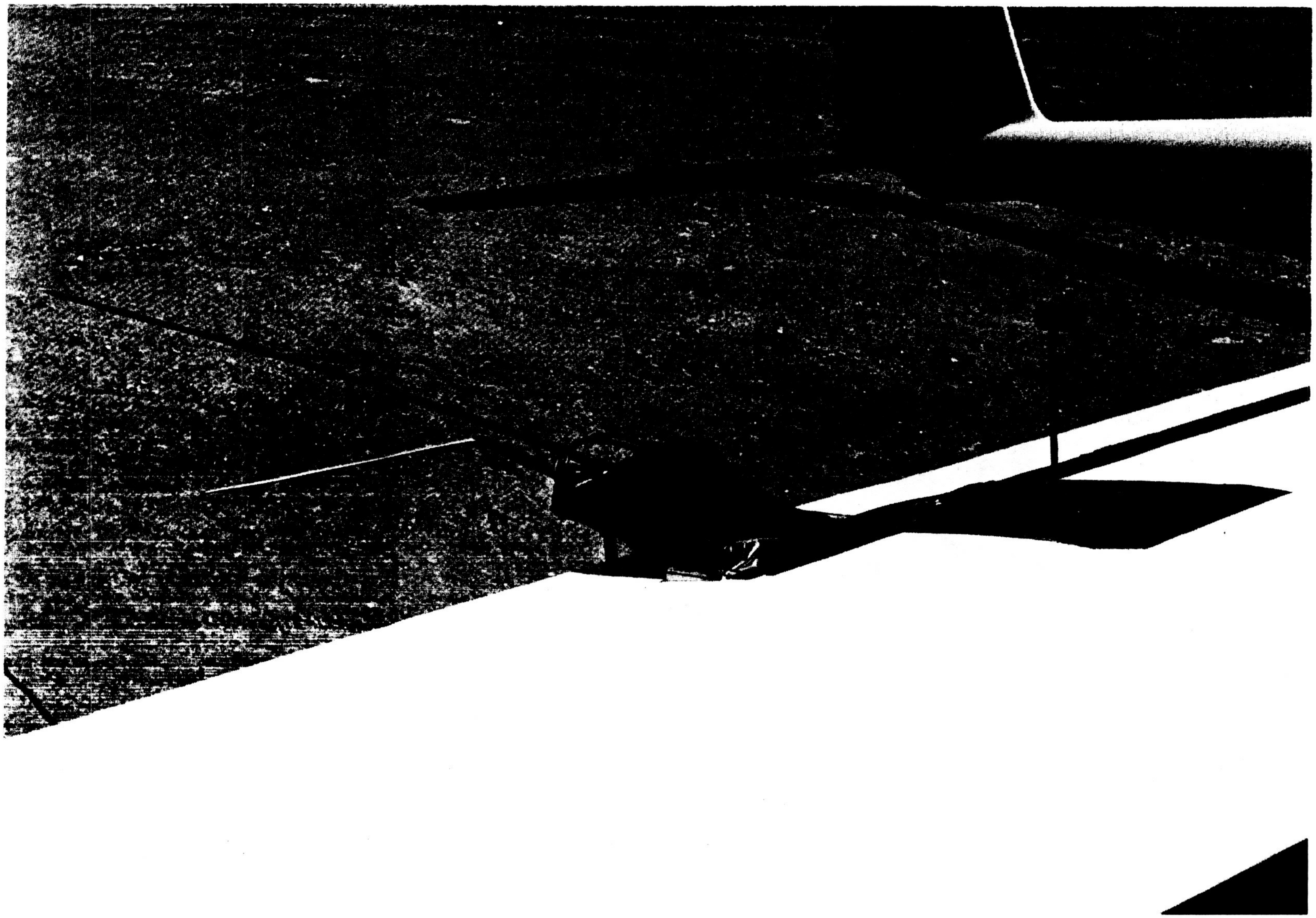

Figure 3. Close-up of Probe and Drive Unit and of Reference Probes

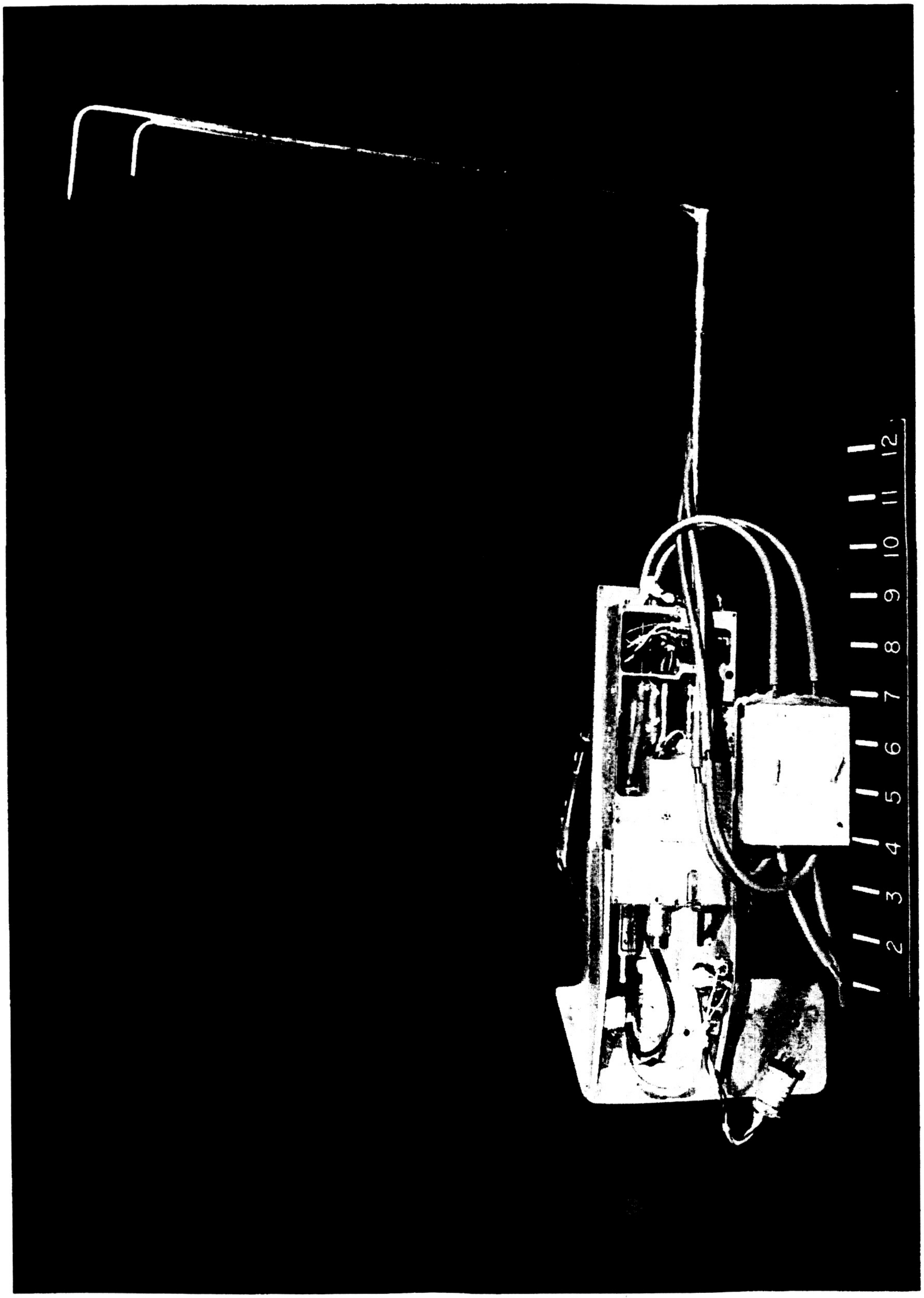

Figure 4(a). Traversing Probe in the Drive Unit

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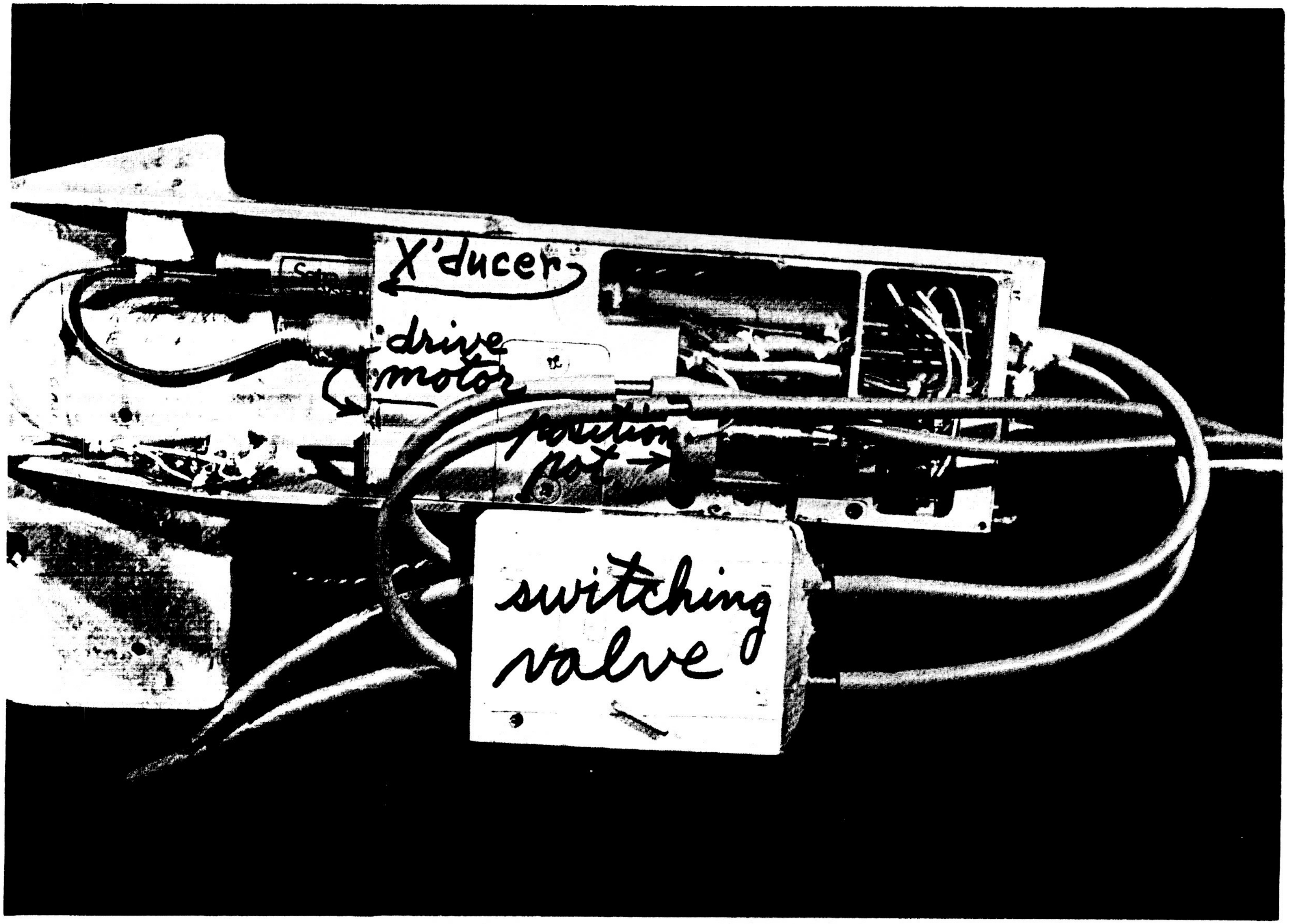

Figure 4(b). Transversing Probe and Drive Unit: Close-Up

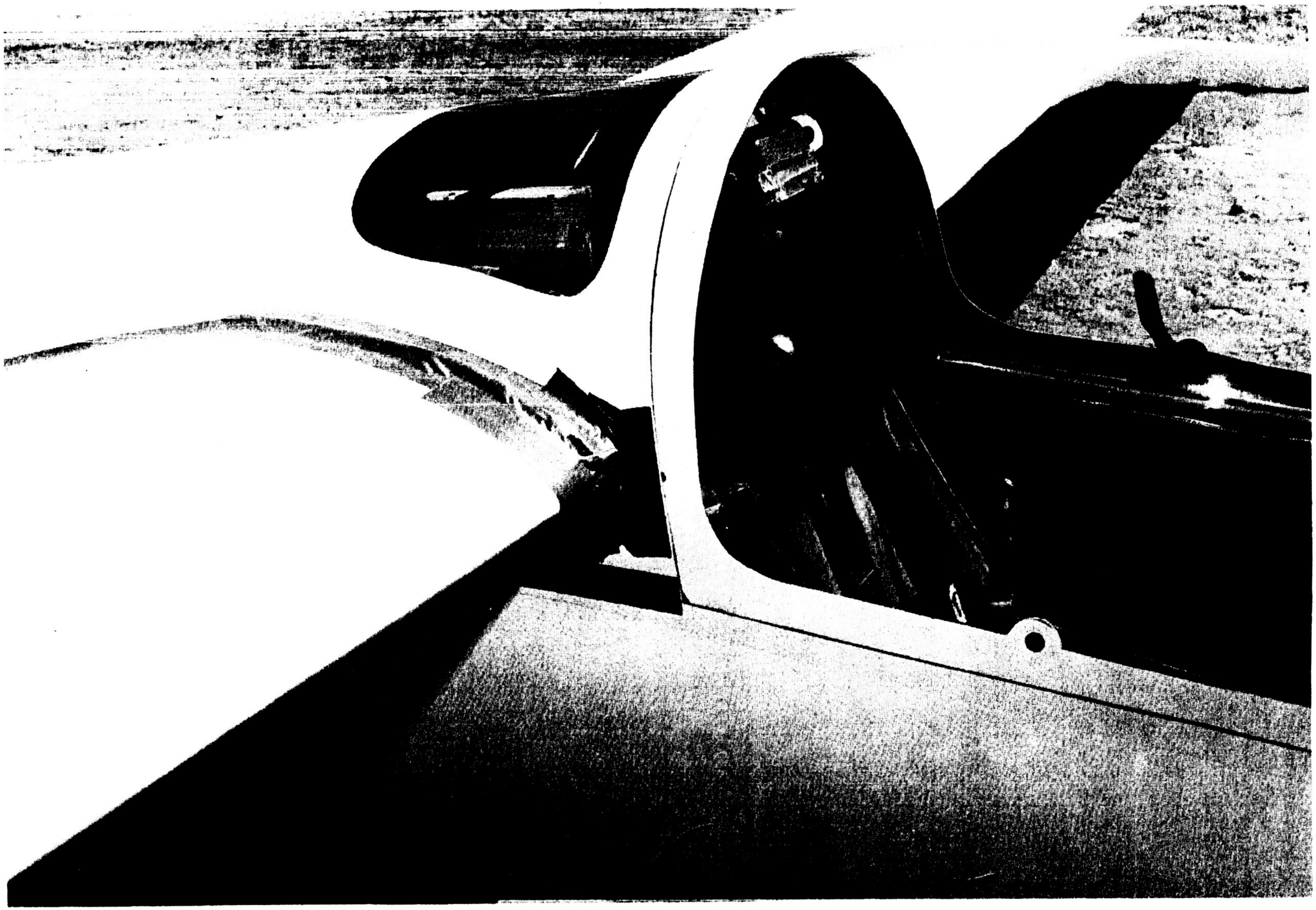

Figure 5. Recorder Package Installed behind Pilot's Headrest

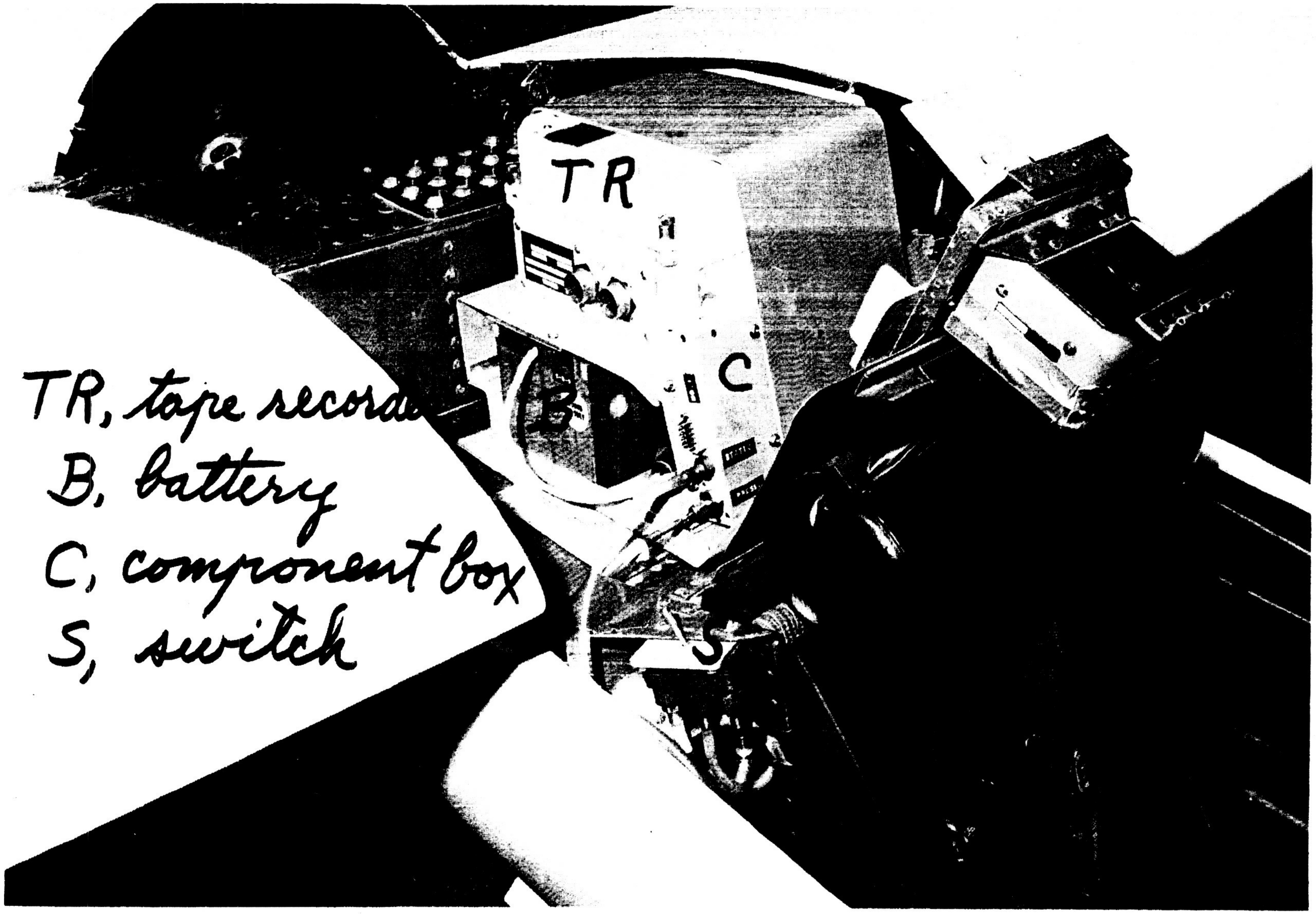

Figure 6. Recording Package: Close-Up

FREE STREAM "q" SCHEMATIC

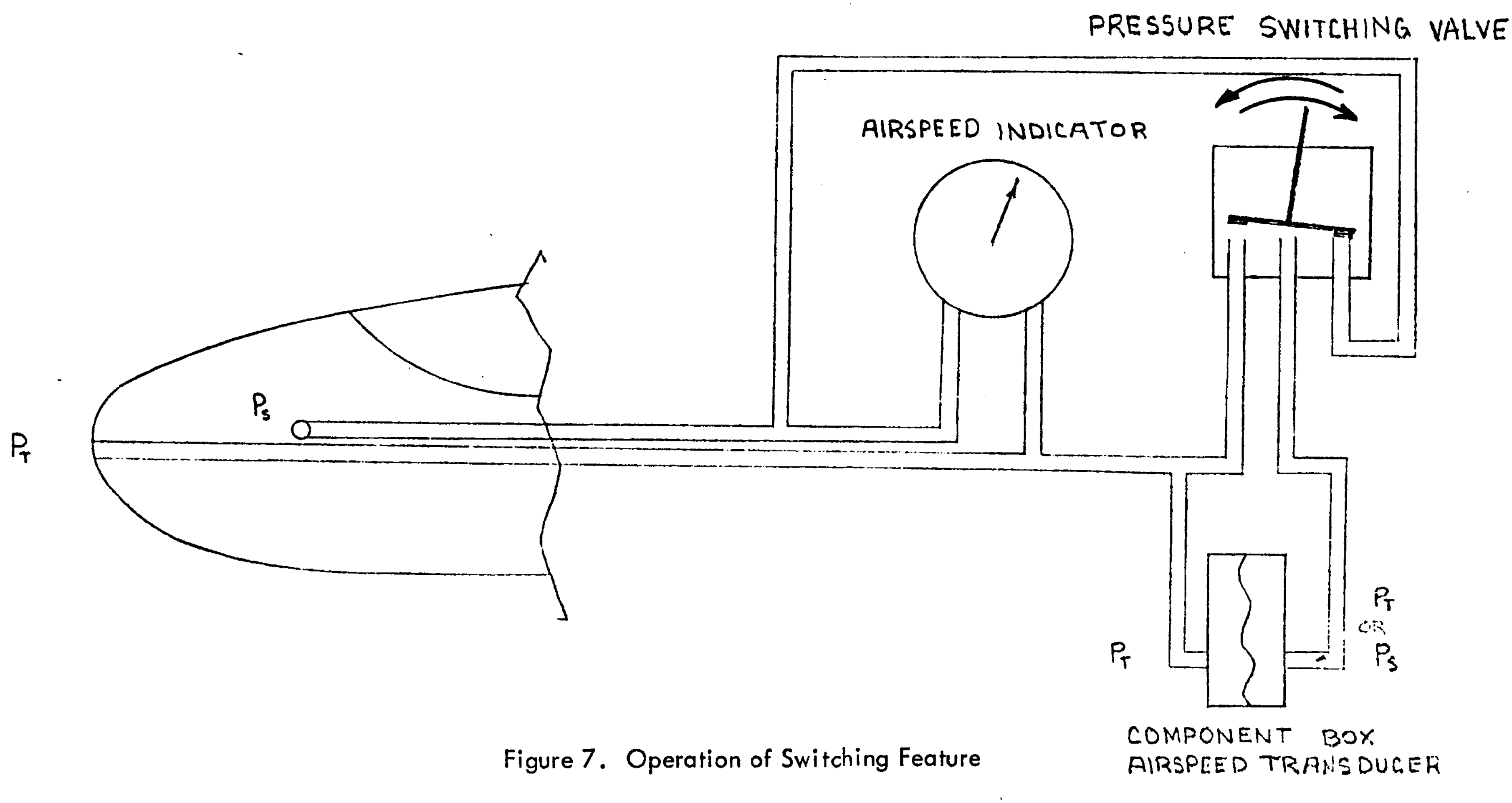

Figure 7. Operation of Switching Feature

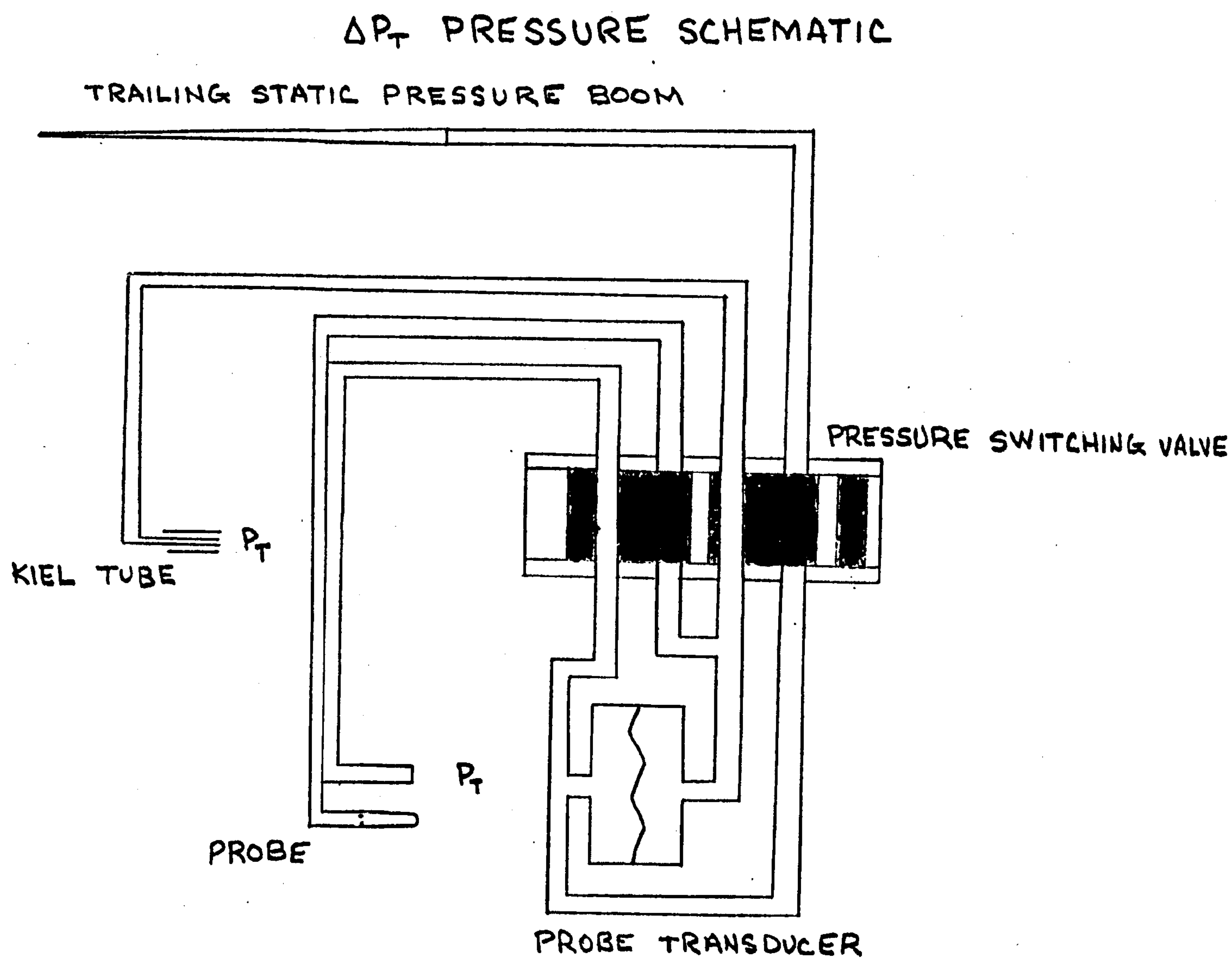

Figure 8. Slide Valve Used in Switching Feature (First Mode)

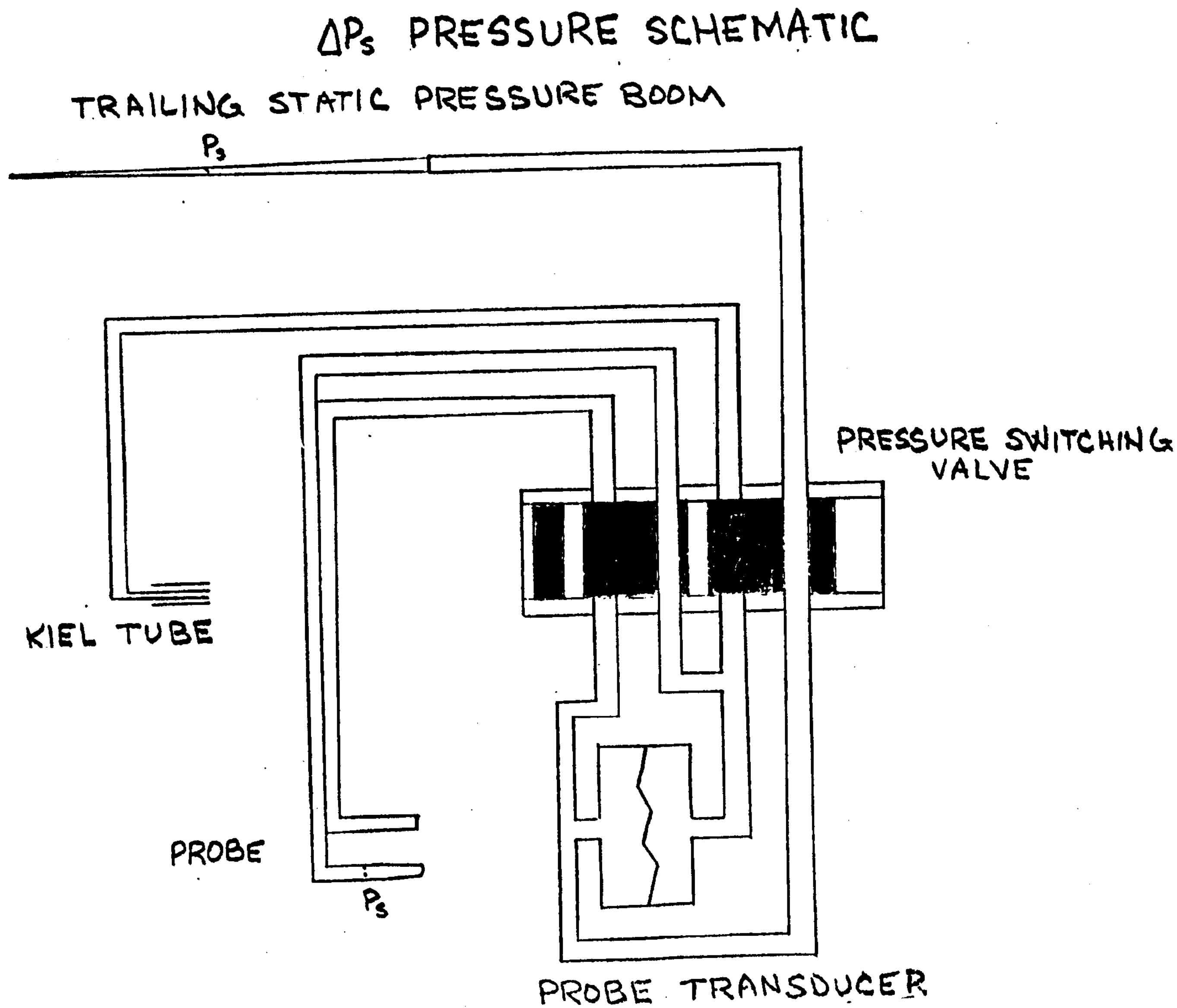

Figure 9. Slide Valve Used in Switching Feature (Second Mode)

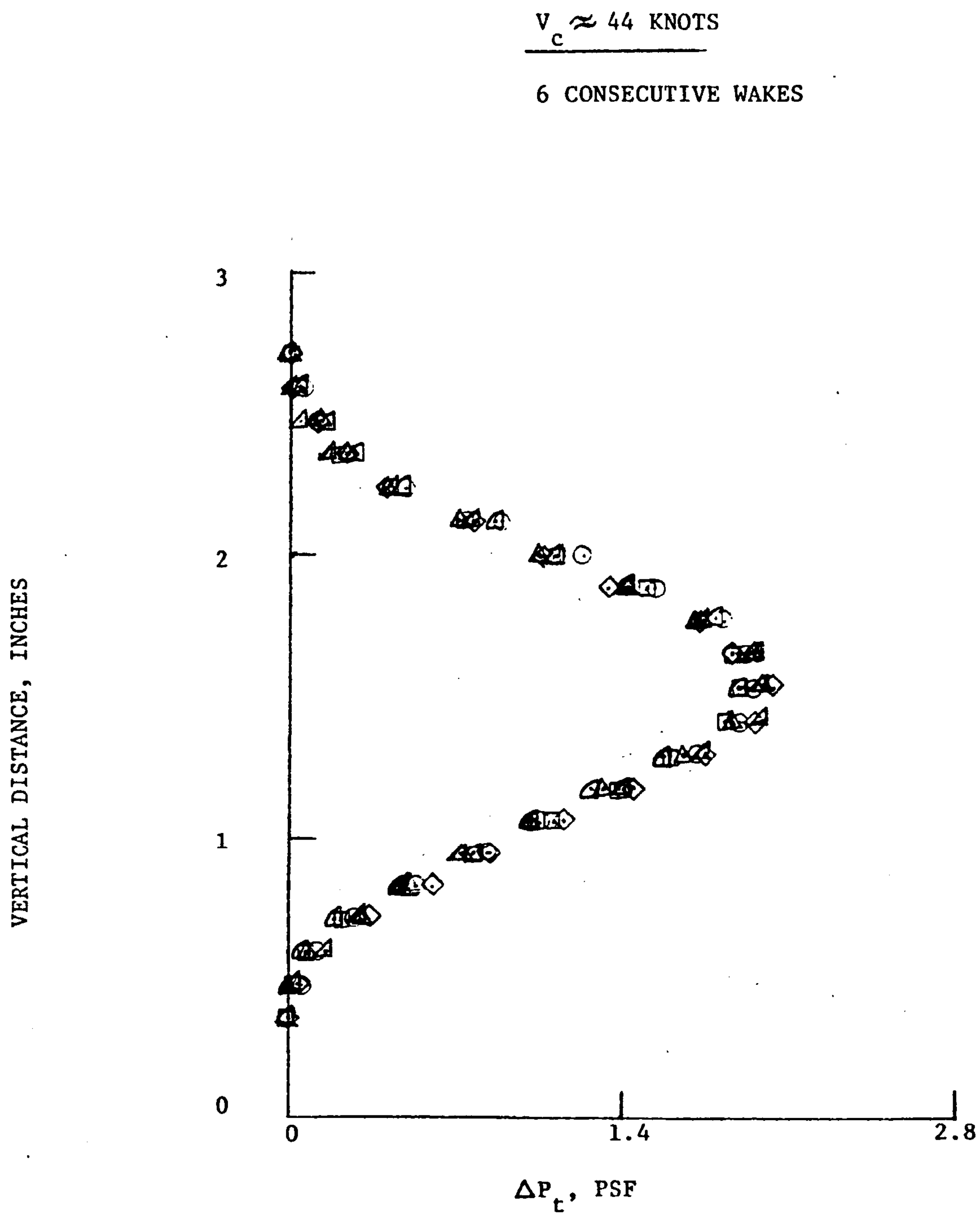

Figure 10. Example Wake Pressure Profiles (44 kts)

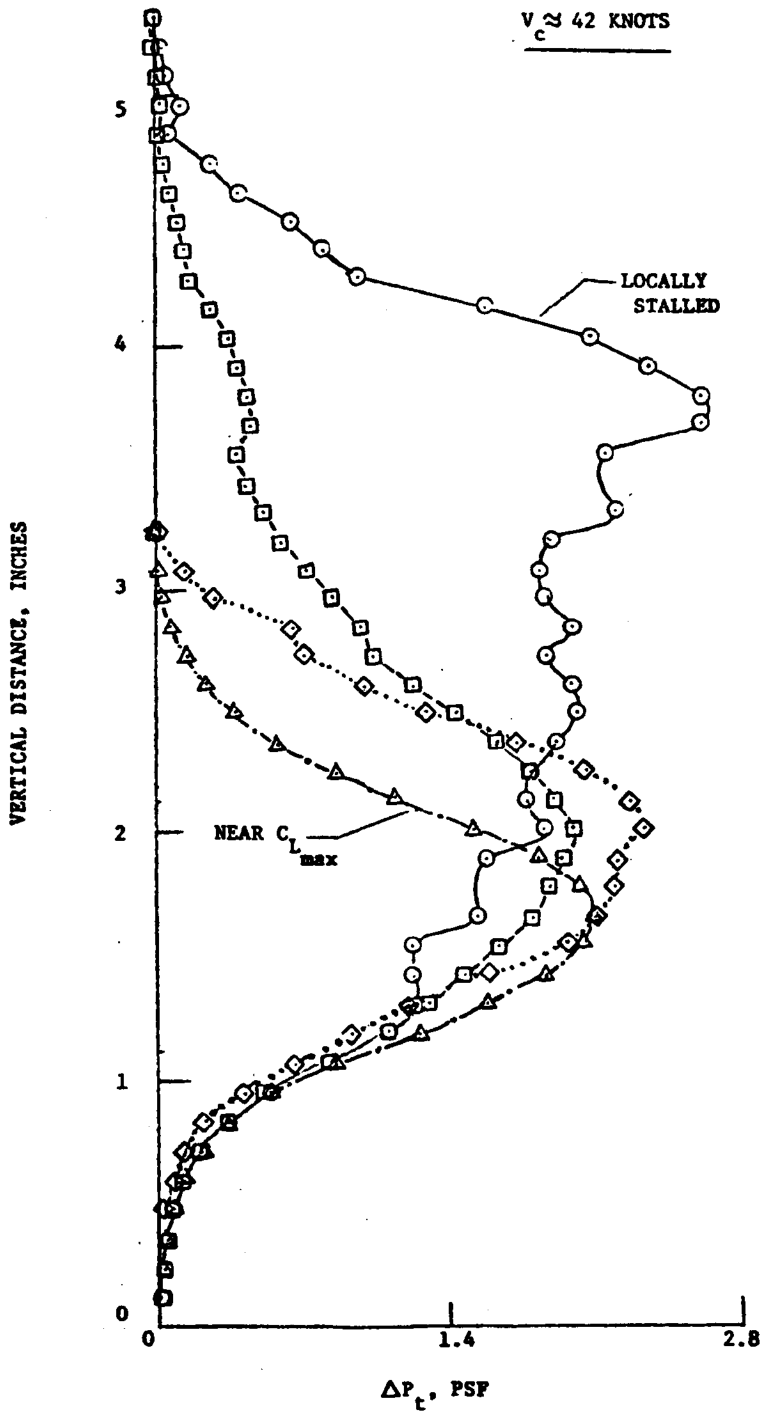

Figure 11. Example Wake Pressure Profiles (42 kts)

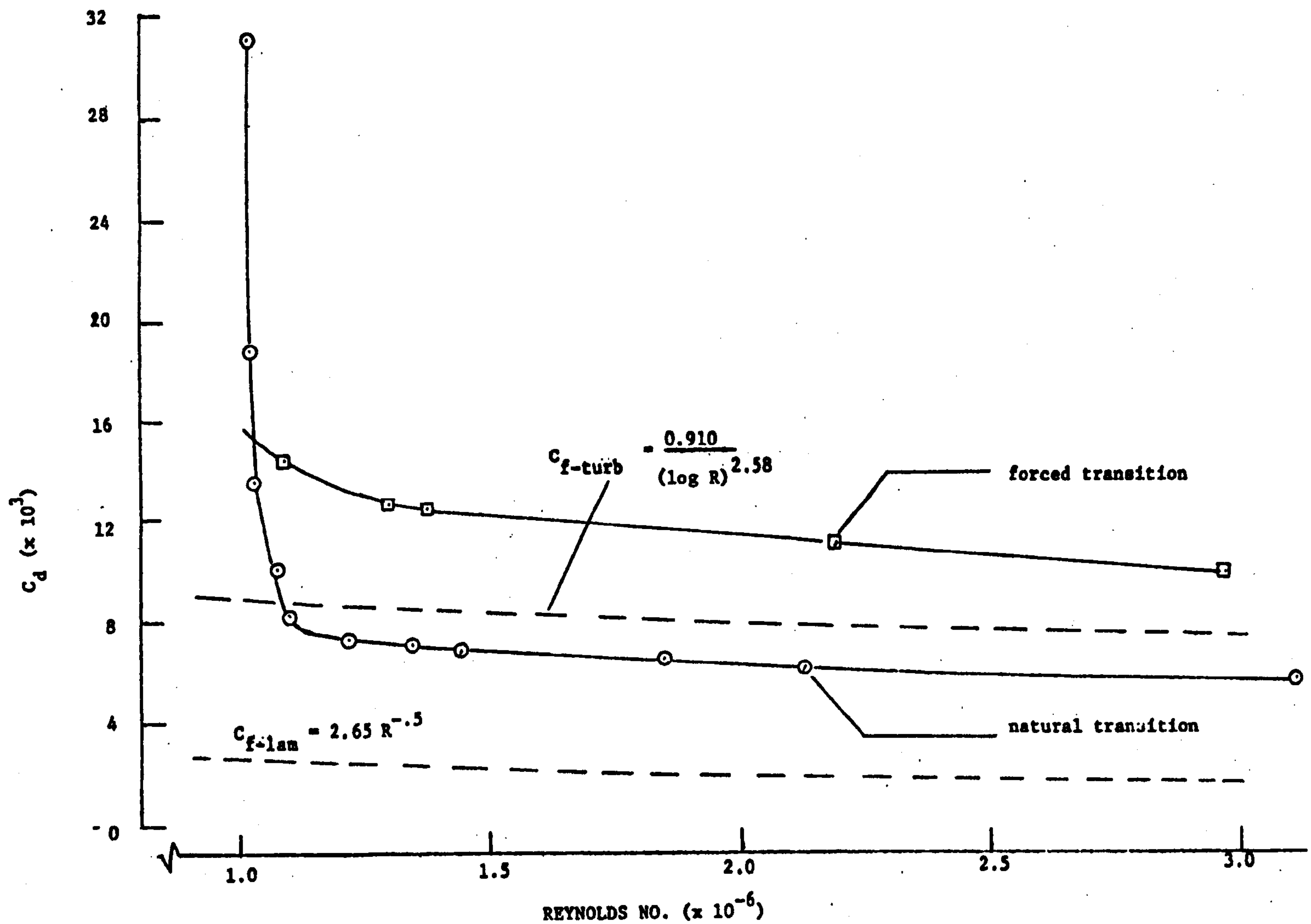

Figure 12. Section Drag: Measured Compared to Theoretical