# Sailplane Performance Flight Test Methods

*by Richard H. Johnson*

The need for flight testing goes back to the first aircraft ever designed, which makes it the second oldest profession in aviation. It was important from the very beginning for the aircraft designers to learn how the test data agreed with their predictions, and it is even more so today.

The glide performance of a sailplane is defined by what is called its polar. That is, simply, a plot of its sinking speed versus its calibrated airspeed. To keep all polars on a common comparison basis, they are all corrected to sea level altitude/standard 15 degrees C day conditions. At altitude both the sailplane's sink rates and true airspeeds are higher by an equal factor, which amounts to roughly 1.5 percent per 1000 feet. Theoretically, however, the glide angles remain unchanged with altitude; just the speeds get faster.

Basically, there exist about five different methods today by which creditable sailplane polar measurements can be made, at least in my opinion. Those methods are listed in Figure 1.

**FIG. 1**

SAILPLANE POLAR MEASUREMENT METHODS

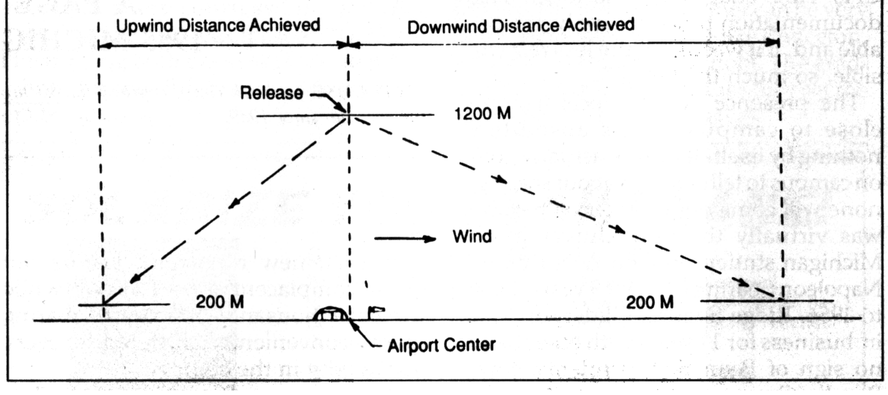
1. Achieved Distance Glides.
2. Sink Rate Measurements
   - A. Altimeter vs Time Method.
   - B. Comparison With Calibrated Sailplane.
3. Flight Path Descent Angle Measurements.
   - A. Trailing Angle Bomb.
   - B. Nose/Wing Boom Mounted Angle Instrumented Vane.
4. Level Flight Tow Drag Measurements.
5. Deceleration Measurements.

### METHOD 1

The first method is depicted in Figure 2. It is perhaps the most rudimentary in that the only instrumentation required is an airspeed indicator and a calibrated altimeter. The glide angle measurements are those actually achieved in still calm air, preferably early mornings.

A dedicated crew is needed to retrieve each test flight, which necessitates an outlanding for accurate distance measurements. Since there are always some winds aloft, at least two test runs will be needed at each airspeed to average the upwind and downwind distances and ground speeds. Because of the time, manpower, and large number of outlandings required to accurately determine a sailplane's polar, this method had not been popular, at least in recent years.

**FIG. 2** METHOD 1 ACHIEVED DISTANCE METHOD




### METHOD 2

The second two methods used for measuring sailplane performance polars do not require outlandings, and are essentially unaffected by wind. However, they do require that the flight test atmosphere be smooth and reasonably free of any convection or waves. There are two accepted methods for performing the sink rate measurements, as listed in Section 2 of Figure 1.

### METHOD 2A

The first method, 2A, involves only

FIG. 3

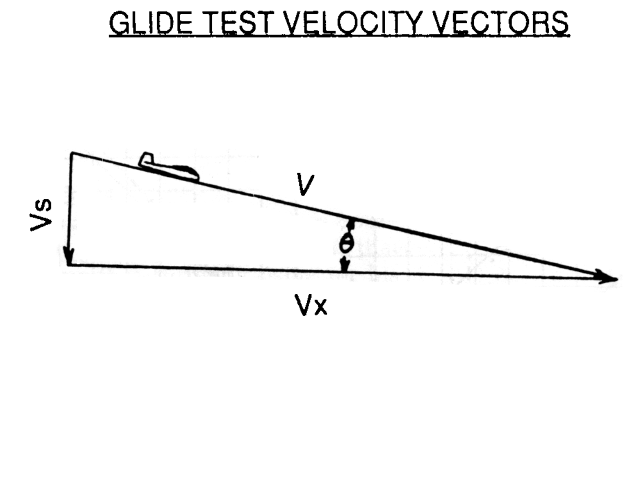
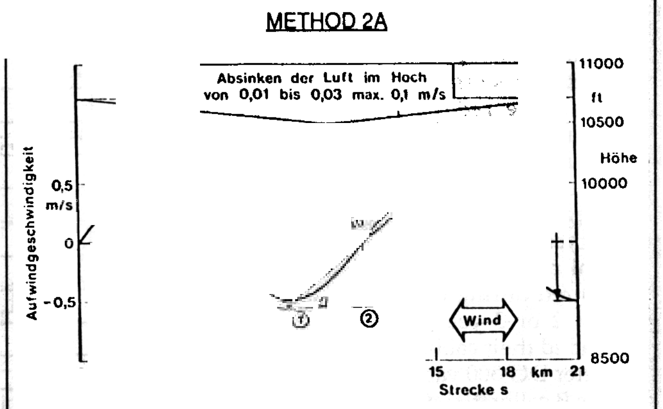
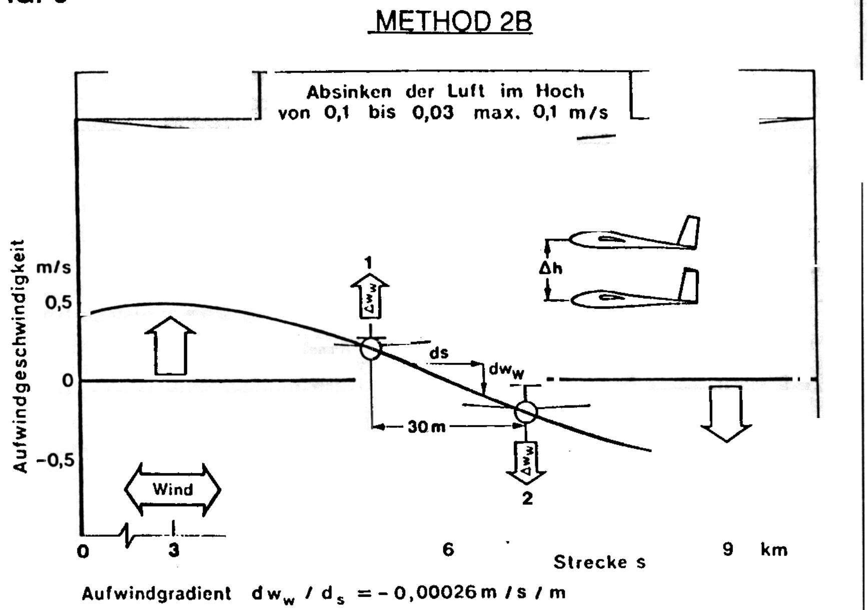



FIG. 4




Einfluß der Luftbewegung auf das Höhenstufenverfahren
From G. Stich, "Flugmessungen An Einigen Modernen Segelflugzeugen".

FIG. 5




Einfluß der Luftbewegung auf das Vergleichsflugverfahren
From G. Stich, "Flugmessungen An Einigen Modernen Segelflugzeugen".

the single test sailplane, where careful and repeated measurements are made of its sinking speed at various calibrated airspeeds, via a calibrated altimeter and stop watch. Figure 3 depicts that flight test condition. It is a simple and reliable method, provided no vertical air motions are present. Wind shear induced waves are the largest concern when performing this type of testing, because they cause incorrect sink rate indications, as shown in Figure 4.

The shear waves can generally be avoided by restricting the flight test days to those where the test atmosphere winds aloft are less than 20 knots, and do not change direction rapidly with altitude. Observing the steadiness of variometer readings during test runs, will provide a good indication of any wave action.

**METHOD 2B**

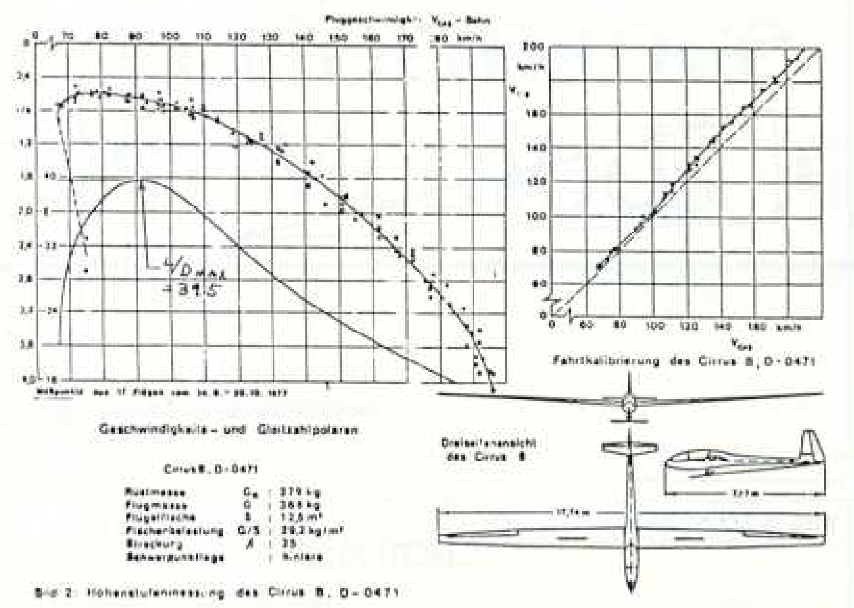
The second method, 2B, involves two sailplane comparison testing to measure the differences in sink rate at each test airspeed. One sailplane has been previously calibrated, and the two sailplanes compare sink rates while flying one to two wingspans apart. The calibrated sailplane is sometimes called the "sacred cow," and its polar must have been carefully measured beforehand, usually by the Method 2A described above.

The 2B comparison method requires that the "sacred cow" remain unchanged in its performance and condition, once it is calibrated. Normally, two towplanes are required for the high altitude test tows needed to perform the sink rate comparisons. The advantage of this method is that althrough vertical air motions do affect the measurement results somewhat, it is to a much smaller degree because both sailplanes fly in essentially the same air, except for their 1, to 2 wingspan separation. As shown in Figure 5, some sink rate measurement error can exist, because the two sailplanes do not fly in exactly the same air, but separated by about 30 meters. Also, any changes to the "sacred cow's" configuration such as continued age warping and roughness impacts of insects on its wing leading edges during tow, will add some data distortion. That becomes very serious if the calibrated sailplane develops any bi-stable polar characteristics, as our DGA measurements have recorded with several sailplanes.

Figure 6 shows Cirrus B sailplane D-0471 that was used by the German Idaflieg as their calibrated sailplane for many years. Also shown are its Method 2A sink rate polar data that was carefully measured during the summer of 1977. About 2 or 3 years ago, the Idaflieg upgraded their calibrated sailplane to a 17-meter DG-300 variant. Note that the Cirrus B calibrated polar shows an L/D max of only 39.5; whereas, its original sales brochures claimed about 44. It was common in the 1960's and 1970's for sailplane performance capability claims to be exaggerated by as much as 5 to 10 percent. Almost everyone except the Poles were guilty of that at times.

FIG. 6

METHOD 2B-CALIBRATED SAILPLANE



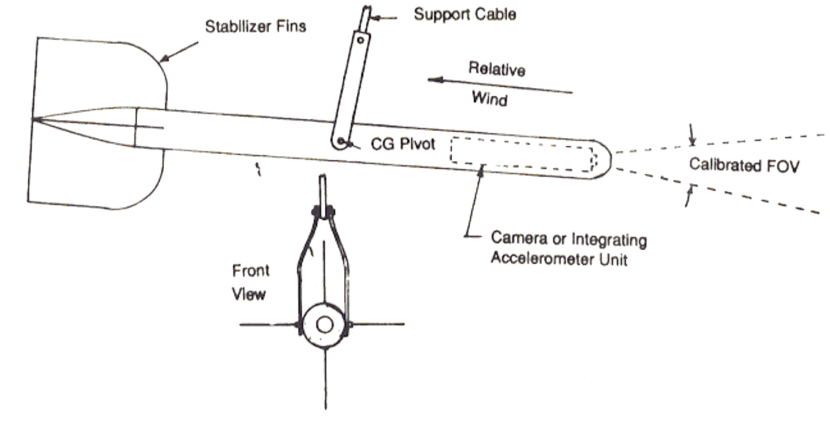

**METHOD 3A**

A direct measurement of flight path glide angle is not a commonly used method for determining a sailplane's flight polar. However, it does have the potential to do so more quickly and easily than the above discussed sink rate measurement methods. One instrumentation configuration considered for flight path angle measurement is like that shown in Figure 7. There, an instrumented fin stabilized and mass balanced body is lowered about 1 wingspan or so below the test sailplane. Its pitch attitude, relative to the horizontal, is measured at each test airspeed by either a calibrated field-of-view camera or an integrating longitudinal accelerometer.

The calibrated FOV camera would need a clear smooth horizon to view, but the longitudinal accelerometer sensing unit will work without a visible horizon, because it merely senses the glide angle relative to gravity. A data correction for the added drag of the instrumentation installation would need to be included. The attractiveness of this type of system is that correct still air glide angle measurements can be made without concern for any vertical or horizontal air movements.

FIG. 7

METHOD 3A
Instrumented Angle Measurement Vane




**METHOD 3B**

This method works on the same principle as 3A above, except that the angle measurements are made directly through a nose or wing boom mounted to pitch plane airflow angle vane. The vane's angle relative to a true vertical would need to be recorded at each test airspeed. It is difficult to mount a nose or wing boom long enough to be completely outside the test sailplane's airflow disturbance field; therefore, some theoretical angle corrections would likely need to be included. Corrections for the instrumentation drag and the boom flexibility would also need to be included.

**METHOD 4**

As depicted in Figure 8, this is a simple and straightforward method that Dick Brandt is currently using for his Nimbus 3 drag reduction program. As with Methods 1 and 2A, it does require still air free of vertical motion.

After aero towing to test altitude, the tow pilot merely flies straight and level at various test airspeeds, while towline tension force measurements are averaged. To reduce the towline tare magnitudes a secondary, very thin drag force measurement towline is attached to the test sailplane, in addition to its normal towline. The heavier normal towline is released from the sailplane after reaching test altitude and only the fine tensiometer instrumented towline is used thereafter.

This drag measurement method is quite effective for measuring incremental changes to the sailplane's drag, as Dick uses it so successfully. However, its airspeed test range is limited to those available from the towplane. Also, if absolute drag values are to be measured, and from those polar curves constructed, difficult corrections would need to be made for the towplane's propeller wake and wing downwash, in addition to the small towline drag correction.

**METHOD 5**

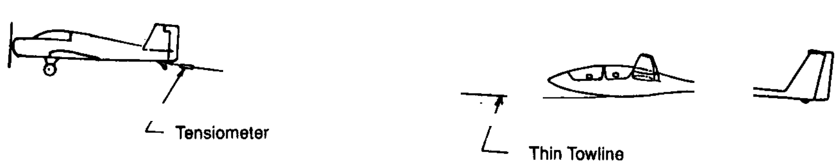
The sailplane deceleration method is not a new idea, but its practical implementation may be approaching, thanks to modern, accurate, and relatively low cost electronic inertial measurement units that are now becoming available. The plan here is to dive the sailplane to near $V_{max}$ and then level out of the dive and carefully measure the sailplane's rate-of-change in velocity as it slows down. From that, the sailplane's drag can be computed directly as a function of airspeed by simply using the basic Newtonian F=ma equations.

This method is attractive, because it can be quickly performed from relatively low airplane tows, and possibly from moderately high ground tows. No doubt a number of test runs would be needed to average data measurements, but its simlicity is outstanding. Its instrumentation can be carried internally so no instrumentation drag or towplane wash corrections need to be included.

In earlier days, before modern electronic inertial measurement units were available, it was planned to track the sailplane during its level light deceleration run with multiple phototheodolite tracking cameras. That was an expensive and laborious technique, and, therefore, never atempted with sailplanes, to my knowledge.

FIG. 8

METHOD 4
Level Flight Tow With Tensiometer




**METHOD 2A DETAILS**

For most persons wishing to perform their own flight test measurements, the basic steady airspeed sink rate measurements is the most practical. All that is required is a good calibrated altimeter and airspeed indicator, along with a stopwatch and an air temperature thermometer. Basically, the procedure that needs to be followed is that outlined in Figure 9.

If you do not have the equipment or the time to perform an airspeed system calibration, nor a calculator to fully reduce the sink rate data to sea level conditions, you can arrive at a reasonably close polar by using the simplified equations shown in Figure 10. The reduced sink rate test data, when plotted versus calibrated airspeed, should look somewhat like those shown in Figure 11.

For those who desire a more rigorous test data reduction and theorectical analysis, the final portion of this report is offered. The glide test force vectors that are involved in the polar determination are those shown in Figure 12. Note that the sailplane's drag force must be exactly countered by the sailplane's weight times the sin of its glide angle. That is true, even if the sailplane is flying in rising or descending air, except that in those cases the descent angle is that relative to the air, and not the ground.

Figures 13 and 14 present the derivation of the sink rate data reduction equations, but the last equation is the only one that you will need to use. The flight test run midpoint air temperatures need to be in absolute Rankine units, though the equation can just as easily be converted to Kelvin units as well. P stands for absolute air pressure, also at the flight test data run mid-point, and it needs to be in inches of mercury. Read that from a standard atmoshere pressure versus altitude table or plot. Again, metric absolute pressure units can be

**FIG. 9**

**METHOD 2A**
**Flight Test Procedure-Sink Rate**

1. Check Airspeed System For Leaks.
2. Install Instrument Panel Vibrator (Optional).
3. Install Air Temperature Gauge on Side Window.
4. Set Altimeter to 29.92 In-HG(Std. S.L. Setting).
5. Tow High While Recording Air Temp. at Each 500 Ft.
6. Stow Thermometer After Tow Release.
7. Stabilize Airspeed at Desired Speed.
8. Use a Stopwatch to Time Descent Through 1000 Ft.
9. Change to Next Airspeed and Repeat 7 and 8.

**FIG. 10**

**SIMPLIFIED APPROXIMATE DATA REDUCTION EQUATIONS**
**≈ SEA LEVEL TO 8000 FT, STANDARD ATMOSPHERE**

1. AIRSPEED = INDICATED + FACTORY HANDBOOK CORRECTION

$$V_c = V_i + \Delta V$$

(*NO ALTITUDE CORRECTION NEEDED*)

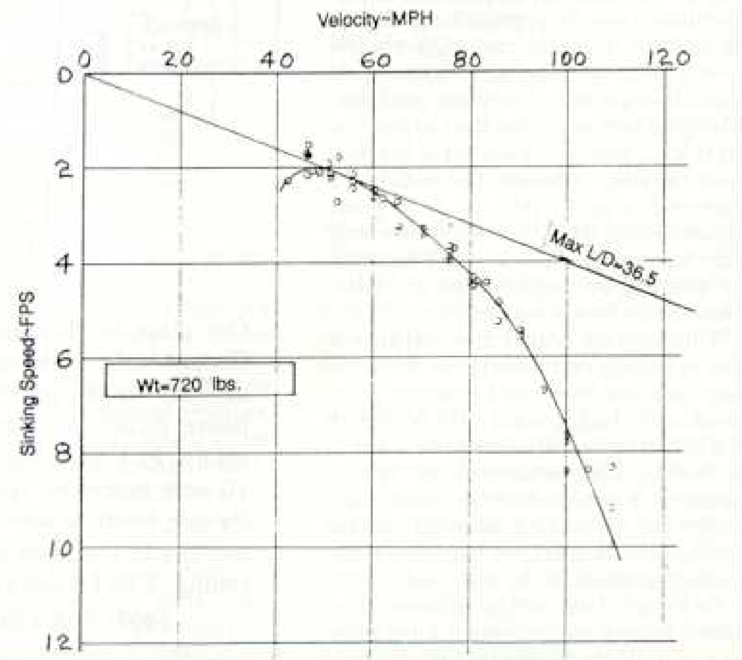
2. RATE OF SINK CORRECTED TO SEA LEVEL

$$R/S = \frac{H_1 - H_2}{\Delta t}$$

$$R/S_{SL} = \frac{H_1 - H_2}{\Delta t}\left(1 - .015xH_{AVE} \sim K\,FT\right)$$

FIG. 11

TYPICAL SAILPLANE FLIGHT TEST POLAR
Test Data Corrected to S.L. Std. Conditions



## GLIDE TEST FORCE VECTORS
Steady Level Flight

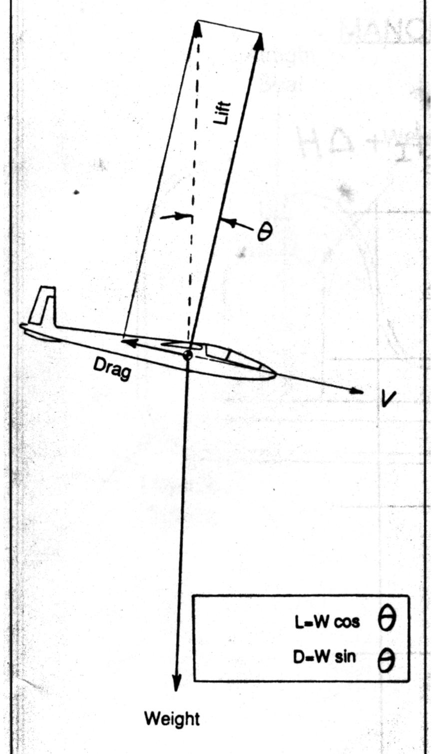



FIG. 12

## GLIDE ANGLE CALCULATIONS

1. $\theta = \text{Sin}^{-1} \frac{V_s}{V}$
2. Glide Ratio $= \frac{V_x}{V_s}$
3. $V_x = V \cos \theta$
4. Glide Ratio $= \frac{V \cos \theta}{V_s}$
5. $V = \frac{V_c}{\sqrt{\frac{\rho}{\rho_o}}}$
6. $\sqrt{\frac{\rho}{\rho_o}} = \sqrt{\frac{\rho}{\rho_o} \times \frac{T_o}{T}}$
7. $V = \frac{V_c}{\sqrt{\frac{\rho}{29.92} \times \frac{518.7}{T}}}$
8. $\Delta\rho = \Delta h \times \rho_{AVE}$
9. $\Delta h = \frac{\Delta\rho}{\rho_{AVE}}$
   $= \Delta h_i \frac{T}{T_s}$
10. $V_s = \frac{\Delta h}{\Delta t}$

FIG. 13

## DATA REDUCTION TO STANDARD SEA LEVEL CONDITIONS

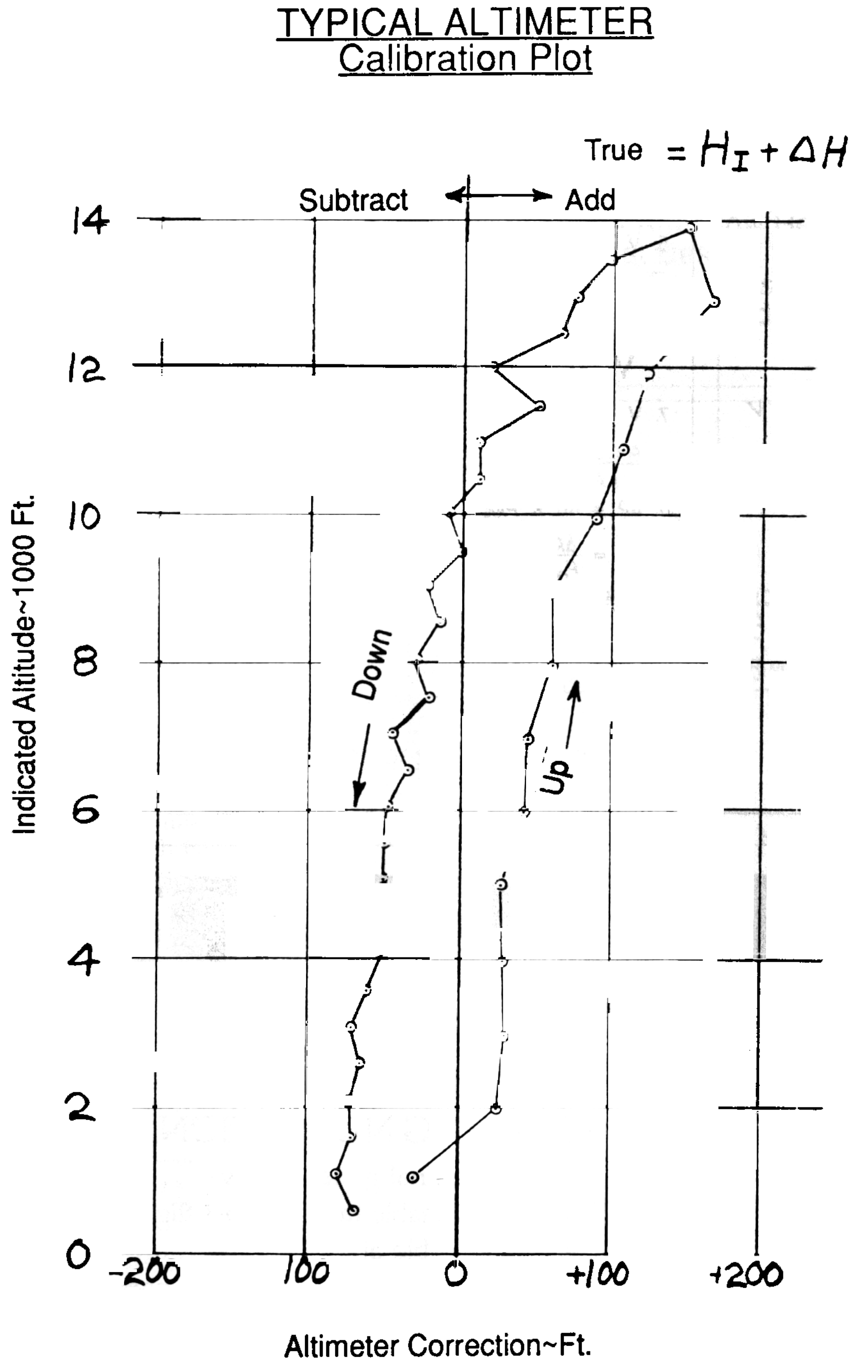
11. Altitude Factor $= \frac{1}{\sqrt{\frac{\rho}{\rho_o}}}$
12. Std. S.L. Cond. = 29.92" $H_G$ + 59°F
13. $V = \frac{V_c}{\sqrt{\frac{\rho}{\rho_o}}}$
14. $V\sqrt{\frac{\rho}{\rho_o}} = V_c$
15. At Std. S.L. Cond. $V = V_c$
16. $V_{s_O} = V_s \sqrt{\frac{\rho}{\rho_o}}$
    $= V_s \sqrt{\frac{\rho}{\rho_o} \times \frac{T_o}{T}}$
    $= V_s \sqrt{\frac{\rho}{29.92} \times \frac{518.7}{T}}$

### SUMMARY

17. $V = V_c$
18. $V_{s_O} = \frac{\Delta h_i}{\Delta t} \times \frac{T}{T_s} \times \sqrt{\frac{\rho}{29.92} \times \frac{518.7}{T}}$

FIG. 14

FIG. 15




used just as well, provided the 29.92 value is changed to the standard sea level metric unit.

**ALTIMETER CALIBRATION**

For good data accuracy, the flight test altimeter needs to be calibrated by a professional aircraft instrument service. It should be calibrated at roughly 500 foot intervals, for both ascending and descending altitudes, such that an error plot similar to that shown in Figure 15 can be constructed. No need to calibrate above the maximum flight test altitudes.

**AIRSPEED INDICATOR CALIBRATION**

To do a good job of calibrating the sailplane flight test airspeed indicator, it is probably necessary to construct a simple water manometer test stand, such as that shown in Figure 16. The professional aircraft instrument services normally use mercury manometers that do not give adequate resolution at sailplane low end airspeeds. The basic water column height versus knots calibrated airspeed is:

$$V_c = 24.573 \sqrt{H_2O \text{ column weight in centimeters}}$$

When completed, the airspeed indi-

FIG. 16

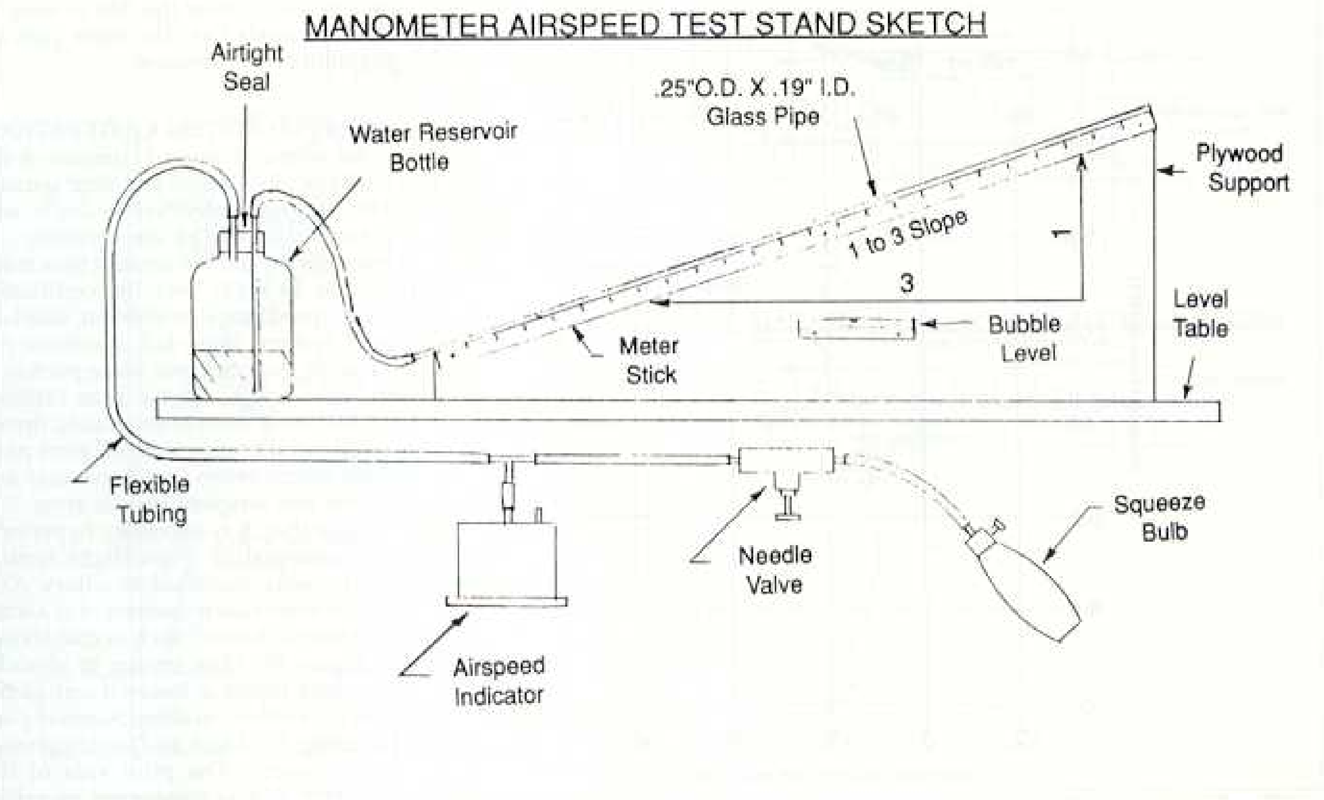
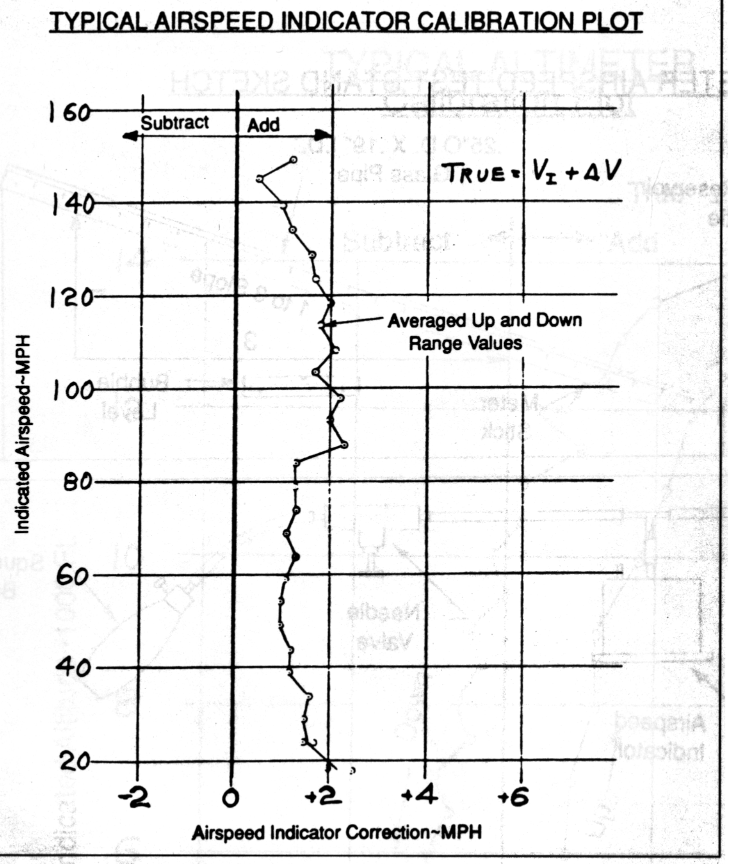

MANOMETER AIRSPEED TEST STAND SKETCH
Airtight Seal
Water Reservoir Bottle
.25"O.D. X .19" I.D. Glass Pipe
Plywood Support
1 to 3 Slope
1
3
Level Table
Bubble Level
Meter Stick
Flexible Tubing
Needle Valve
Squeeze Bulb
Airspeed Indicator

FIG. 17




cator calibration plot should be similar to that shown in Figure 17. A small vibrator of some sort needs to be attached to or near the ASI to keep its striction levels low. The same goes for the altimeter calibration.

## AIRSPEED SYSTEM CALIBRATION

An airspeed system consists of the indicator plus its pitot and static sources. The airspeed system errors due to sailplane static sources are generally not insignificant and can amount to as much as 8 to 10 knots over the certificated flight speed range. In addition, sailplane pitot systems often fail to achieve full dynamic pressure over some portion of the speed range. Rather than calibrate each of those sources separately, time is saved by calibrating the total pitot-plus-static source errors simultaneously and calling that airspeed system error.

To do that, it is necessary to perform one moderately high flight with a temporarily installed auxillary ASI, whose static side is connected to a static calibration "bomb," such as that shown in Figure 18. After towing to altitude, the static bomb is lowered out of the canopy window on about 50 feet of plastic tubing to obtain an "uninfluenced" static source. The pitot side of the auxillary ASI is connected to a Kiel

FIG. 18

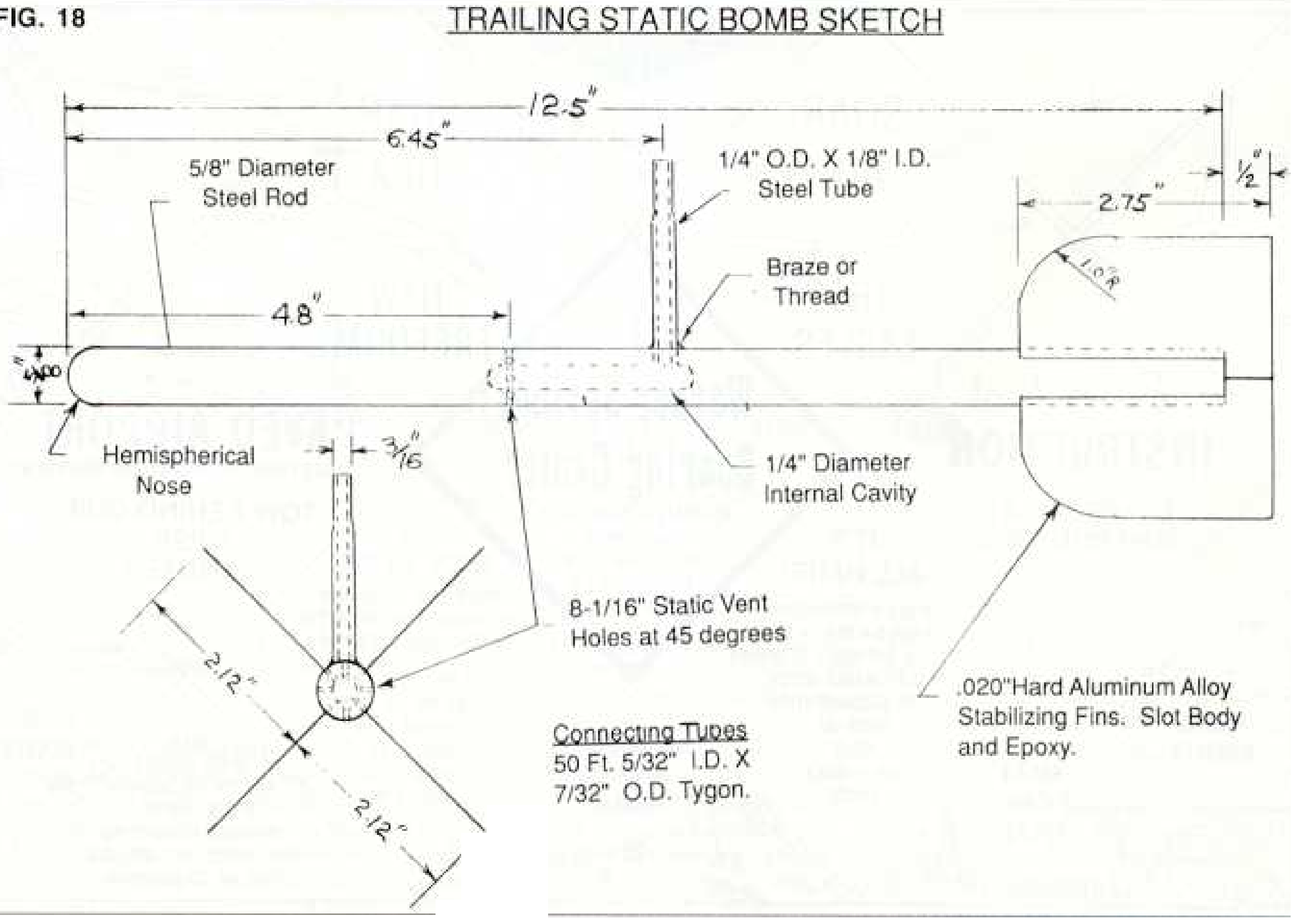


FIG. 19

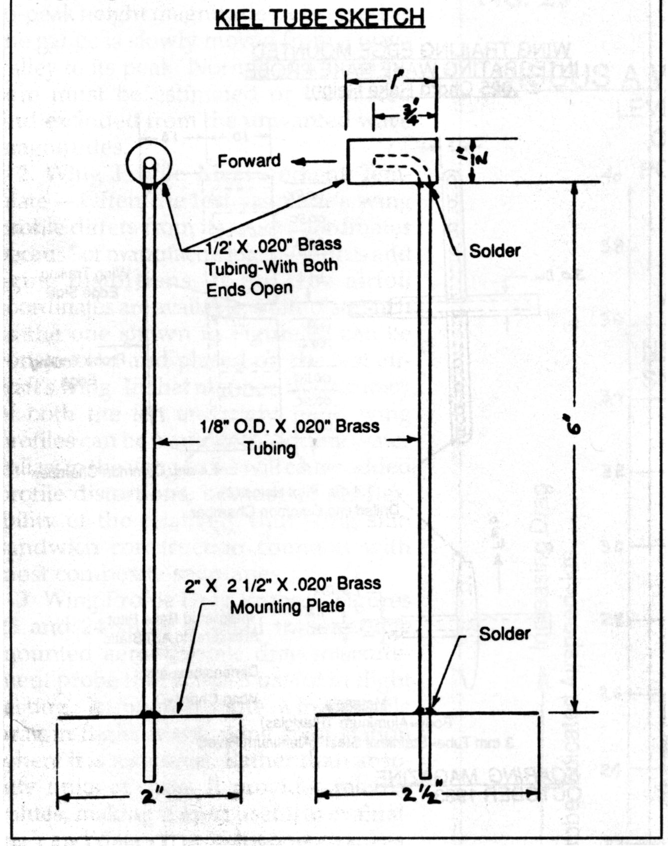
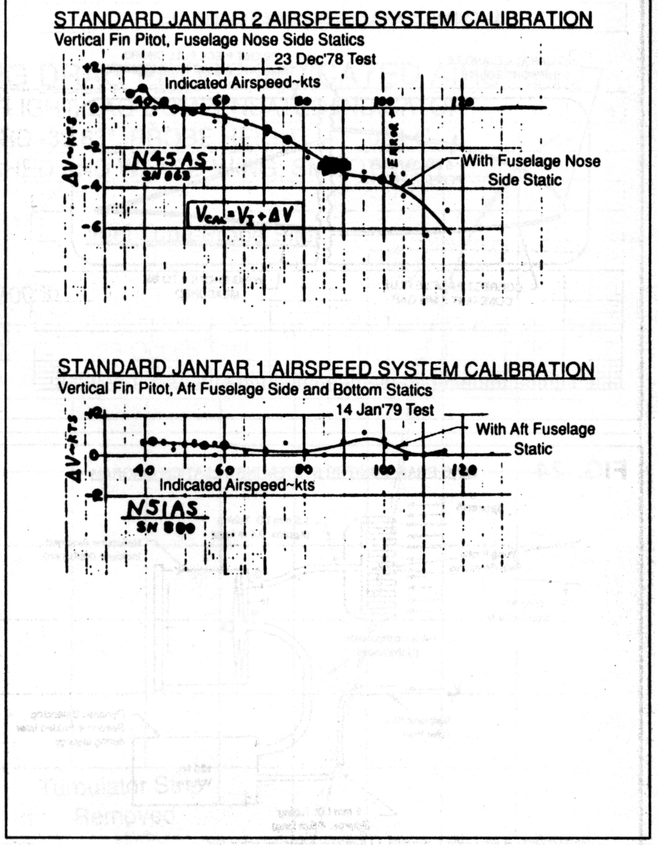



FIG. 20




tube, such as that shown in Figure 19. The Kiel tube is a shrouded pitot pressure source that has essentially no error below 15 or 20 degrees angles of attack or yaw. The Kiel tube mounting plate is taped to the canopy at one corner of a partially opened window.

The sailplane's airspeed system is then calibrated by comparing the essentially errorless readings of the temporarily installed auxillary ASI to those read from the sailplane's normal ASI. Care must be taken to correct both ASI instruments for their inherent indicator errors, via the Figure 16 manometer test stand.

When completed, the airspeed system calibration plot should look something like those shown in Figure 20. The airspeed system calibration normally requires only one smooth air test flight. No sink rate data are taken during the ASI calibration flight, because of the added drag of the trailing static bomb and Kiel tube installations. Pull the static bomb back into the cockpit before landing. Reference 1 contains additional information on the procedures used in these data measurements.

**AUXILLARY MEASUREMENT EQUIPMENT**

When making flight test performance measurements, it is often worthwhile to make a few other measurements to help describe the test sailplane's wing surface condition. Some useful gauges and instruments are as follows:

1. Wing Surface Wave Gauge — As shown in Figure 21, this simple instrument is useful for measuring the height of chordwise waves on test sailplane wings. A small machinist's dial gauge with indicator marks at approximately each .001 inches will do, along with an aluminum or plastic mounting base.

FIG. 21

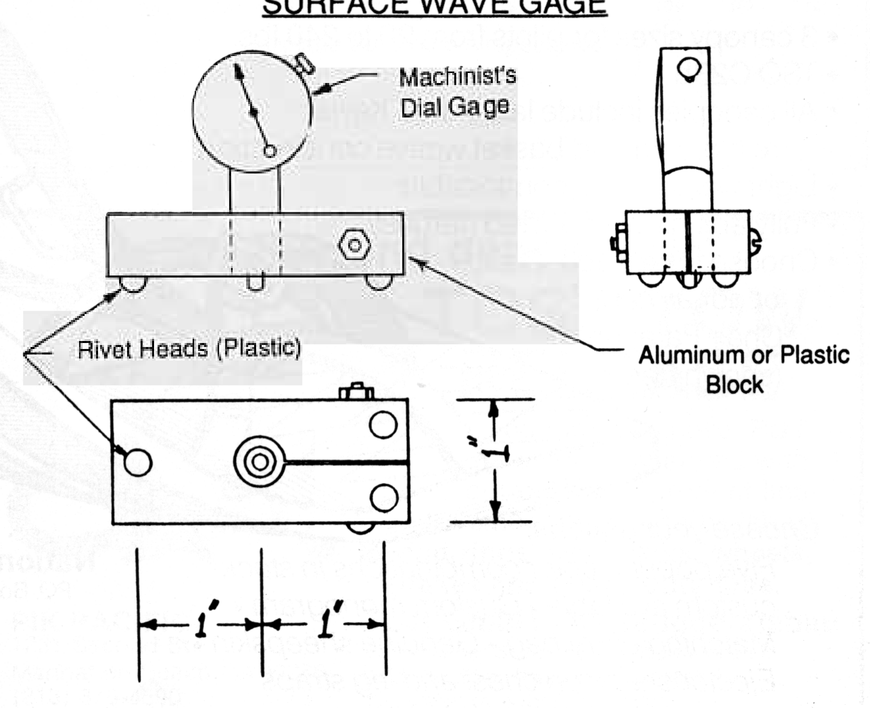


FIG. 22

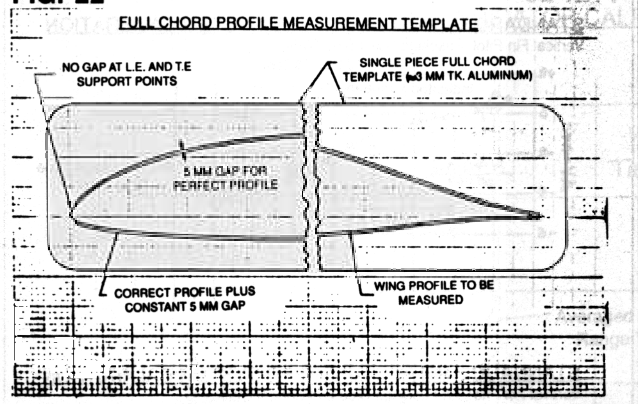



FIG. 23

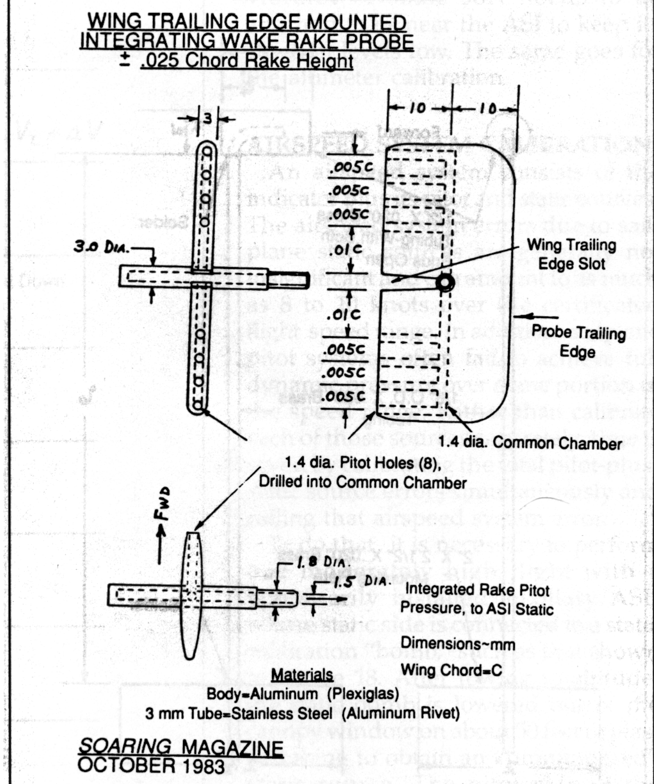
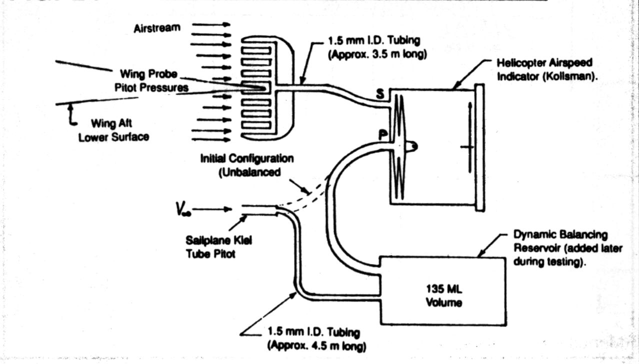



FIG. 24



Waves are generally called out as peak-to-peak height magnitudes, observed as the gauge is slowly moved from a wave valley to its peak. Normal airfoil curvature must be estimated or calculated and excluded from the unwanted wave magnitudes.

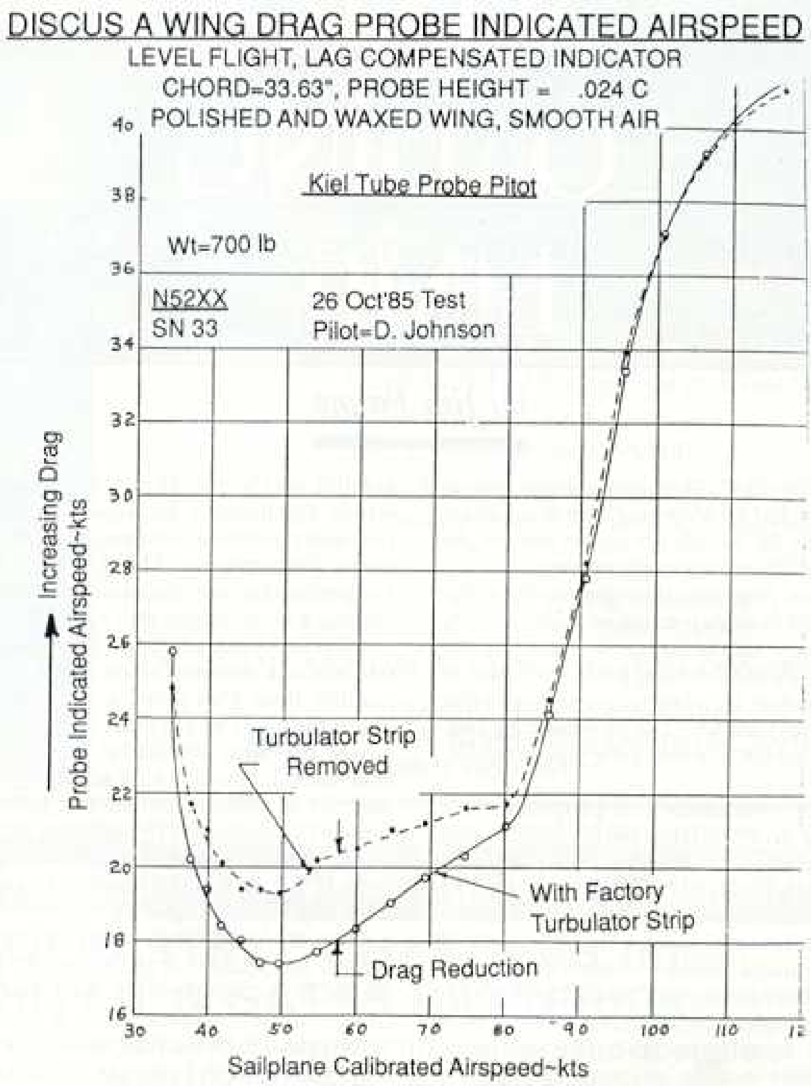
2. Wing Profile Measurement Template — Often the test sailplane's wing profile differs from its exact coordinates because of manufacturing tolerances and aging distortions. If the true airfoil coordinates are available, a template such as the one shown in Figure 22 can be constructed and placed on the test aircraft's wing. In that manner, the accuracy of both the left and right hand wing profiles can be evaluated. Adding water ballast to the wing tanks will cause added profile distortions, because of the flexibility of the relatively thin wing skin sandwich construction common with most composite sailplanes.

3. Wing Profile Drag Probe — Figures 23 and 24 show a small trailing edge mounted aerodynamic drag measurement probe that is often useful in flight testing. It measures the wing profile drag in flight at any wing span station where it is mounted. Rather than absolute units of drag, it provides relative values, making it most useful in evaluating candidate drag reduction changes, such as turbulator tapes and blow hole effectiveness.

One advantage of such a single wing station measurement device is that only about 2 feet (.6M) of wing span needs to be altered to evaluate a section change. Figure 25 shows an example where the Discus A wing profile relative drag was measured, first with the factory turbulator strips installed, and then with a 2 foot (.6M) length of the turbulator tape ahead of the probe removed. The results were dramatic in that they show that the installation of the turbulator tape really does reduce drag, and over a large airspeed range.

Using this simple drag probe is a quick, easy way to evaluate turbulator tape installations, profile smoothing, waxing and sanding effects on wing rag. Reference 2 contains additional information on the drag probe design and operation.

FIG. 25

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2. Johnson, R. H., "At Last, An Instrument That Reads Drag," *Soaring* October, 1983. ■