FLIGHT TEST POLAR MEASUREMENTS OF MODERN SAILPLANES

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During recent years it appears that an insufficient amount of accurate flight performance polar measurements have been made and published for the many new high performance sailplanes that have become available. Manufacturer's polars are generally optimistic estimates whetted by a need to present a superior brochure for marketing purposes, and for this reason they are seldom reliable.

Good valid measurements are an important and interesting facet of the sport, and it is not so difficult that it cannot be undertaken by many people throughout the world. To those persons this paper is dedicated as a guide and encouragement to undertake similar measurement tests themselves. Those who try it will likely later agree that they learned much more than just the actual polar values they initially sought, and they may become addicted to it as I have during the many years since working with August Raspet at Mississippi State University.

This paper will touch separately on each of three important phases of flight performance testing. These are:

A. The calibration of airspeed indicators.

B. The flight calibaration of airspeed systems.

C. The flight test sink rate measurements.

A. Calibration of Airspeed Indicators

Good functioning and well calibrated airspeed indicators are the very heart of the instrumentation necessary for gathering creditable flight test polar data. For this reason a brief review of the airspeed indicator calibration procedure is appropriate here.

First of all it eases one's thinking to realize that all airspeed indicators are simply sensitive differential pressure gages, marked in velocity units instead of pressure units. Long long ago, the instrument manufactuers and engineers apparently decided to design the flight airspeed indicators to read true airspeed on a standard temperature and pressure day at sea level. This was and still is done by connecting the indicator's pressure sensing element to a pitot tube placed facing forward in the airstream, and its static side connected to a suitable static source.

The theory and general equations can be found in any basic aero or fluid dynamics reference book. The only thing really needed by a sailplane flight tester is to know which height of a water column corresponds to various airspeeds. A mercury column is used by most airplane instrument calibration shops in the U.S.A., but at the lower sailplane airspeeds the mercury column does not usually provide sufficient resolution for accurate low airspeed calibrations. For this reason I prefer to use my own simple home constructed water manometer, shown sketched in Figure 1.

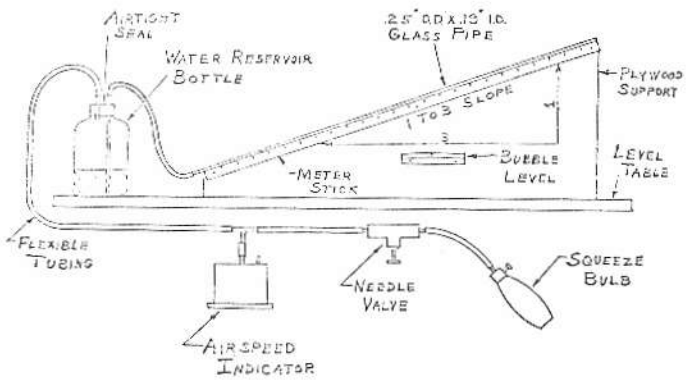

Figure 1. - Manometer Airspeed Test Stand Sketch.

A squeeze bulb and a valve control the air flow that pressurizes both the indicator and water column thru a tee connection. The basic water column height versus knots calibrated airspeed is:

$$V_c = \sqrt{24.573}\sqrt{H_20 \text{ column height in cm}}$$

Find and carefully calibrate a high quality master airspeed indicator, to be used for future flight test work. It should have low hysteresis and should have dial airspeed marks for each one or two knots of airspeed. The instrument marks do not have to be exactly where they should be at each speed because by using the water manometer and the above equation an exact correction chart can be prepared. For best results a small electric motor vibrator should be mounted on or near the instruments to keep them free, both during ground and flight testing.

Figures 2 thru 4 show calibrations that were made on several German and Polish manufactured airspeed indicators using the above described water manometer and velocity equation. Little average deviation is shown in any of the various countries instruments; so we all apparently agree on airspeed indicator calibrations.

B. The Flight Calibration of Airspeed Systems

This next phase is very important to the gathering of accurate performance polar data. It covers the flight calibration of the sailplane airspeed system, which is not difficult but needs to be done correctly and with care to assure the desired degree of accuracy.

What is done here is to temporarily install a complete but separate known calibrated

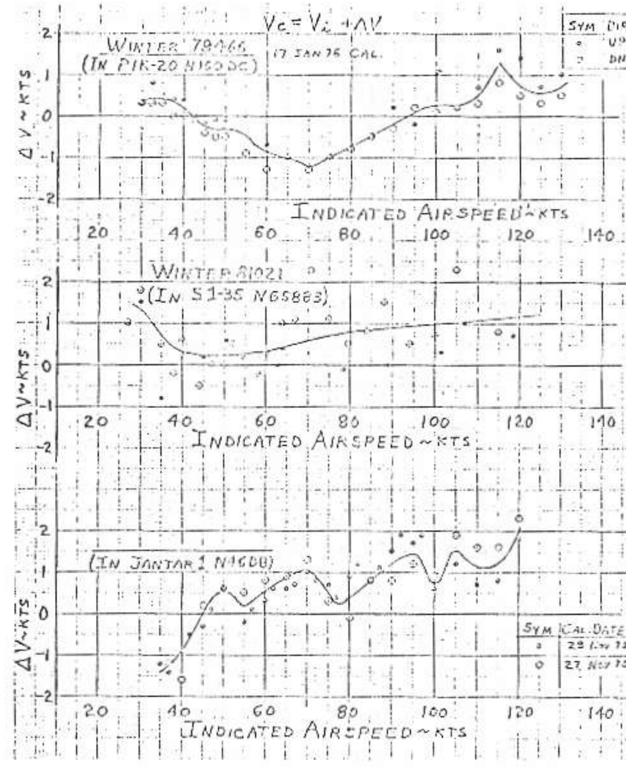

Figure 2. - Airspeed Indicator Calibrations.

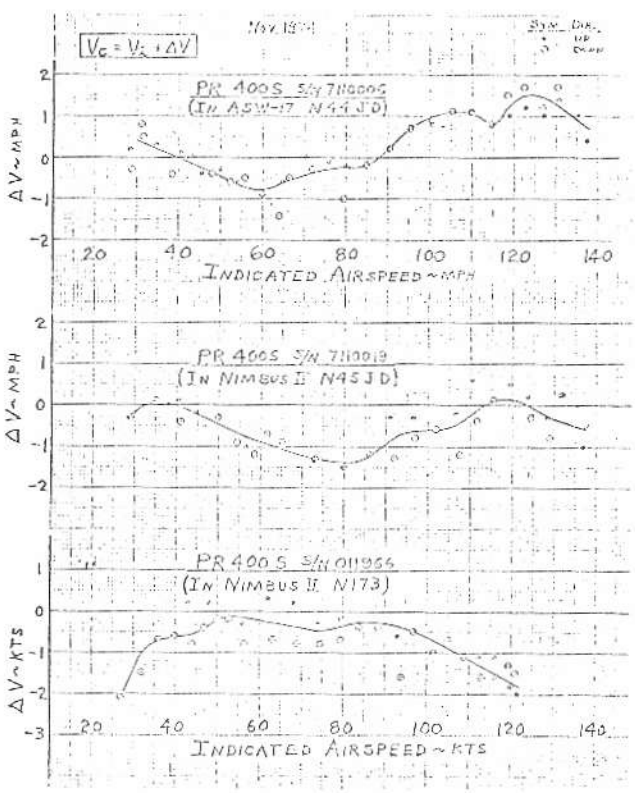

Figure 3. - Airspeed Indicator Calibrations.

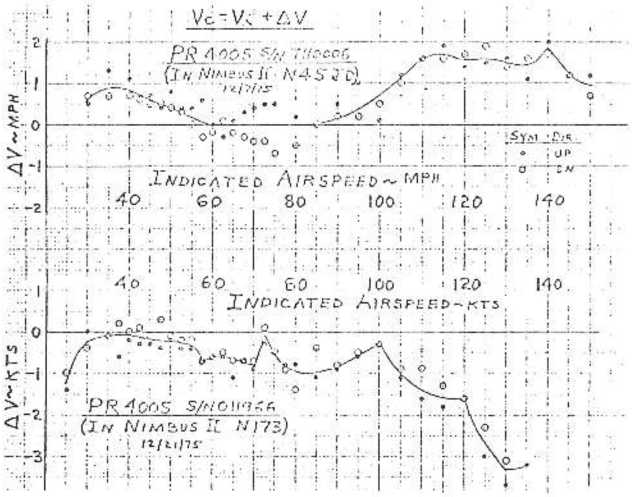

Figure 4. - Airspeed Indicator Calibrations.

airspeed system in the sailplane to be calibrated, and compare readings in flight. The temporarily installed calibrating airspeed system is comprised of three items: the carefully calibrated airspeed indicator, described in section A; an error free pitot; and an error free or known error static source.

The error free pitot is quite easily made from a few small pieces of brass tubing, soldered together as shown in Figure 5. I normally install this temporary pitot with adhesive tape, on the canopy itself, usually at a forward corner of the side ventilation window. This hooded pitot tube is called a Kiel tube. It is relatively insensitive to being misaligned with the airstream, but try to install it pointing as directly into the airstream as you can, to minimize any possible error source here. Connect the Kiel tube outlet to the pitot side of the calibrated airspeed indicator with a short length of plastic tubing.

The third item, the error free or known error static source, is the most critical item, and is not as easily obtained as the pitot source. Any aircraft in flight achieves its lifting and maneuvering forces by airframe induced changes to the static air pressures over its exterior surfaces. That means it is practically impossible to find a reliable static source on the sailplane itself that will be free of error throughout the entire flight test airspeed range. Aft fuselage static vents located about half way between the wing and the tail usually come close to being error free, but seldom are they perfect enough for the data accuracy desired here.

To ensure a good reliable static source, it is necessary to locate it a fair distance from the sailplane itself. I recommend using a trailing static "bomb," such as the one shown sketched in Figure 6. The static bomb is connected to the static side of the calibrated airspeed indicator by about 15 meters of 5/32" I.D. by 1/32" wall thickness flexible tubing. When the sailplane is at test altitude, the static bomb is carefully lowered out of the side vent window to the full length of the tubing. Care must be taken so that no kinks occur in the tubing. Run the cockpit end of the tubing thru a U shaped piece of 1/4" I.D. metal tubing to prevent the plastic tubing from being pinched at the edge of the cockpit window while supporting the trailing bomb.

Now with the Kiel tube pitot, calibrated airspeed indicator, and trailing static bomb temporarily installed in the sailplane, it is ready for calibrating the sailplane's air-

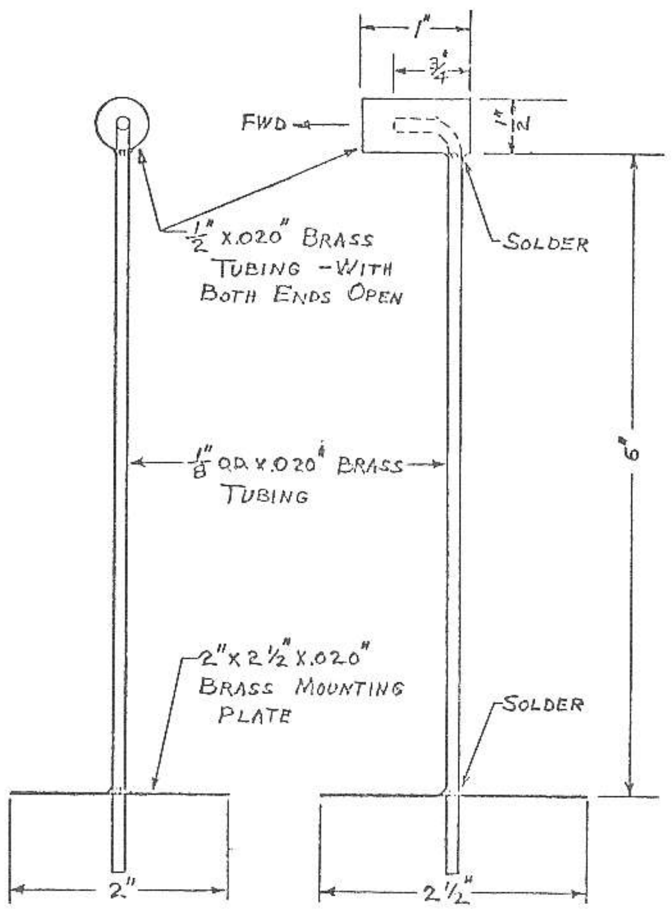

Figure 5. - Kiel Tube Sketch.

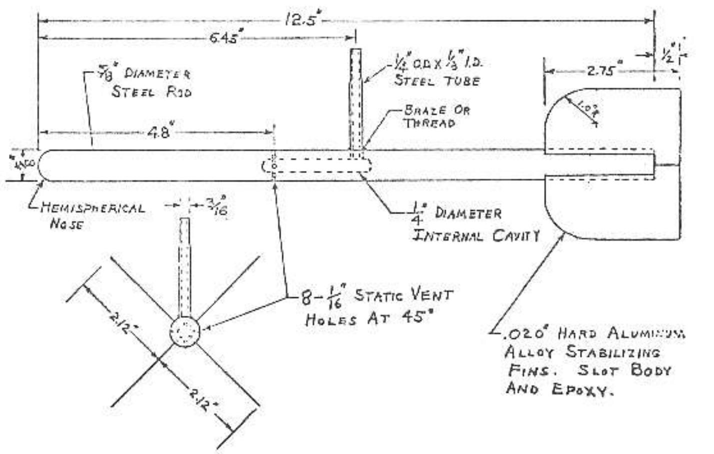

Figure 6. - Trailing Static Bomb Sketch.

speed system. A moderately high tow in smooth air is needed. The sailplane is flown steadily for a short period of time at each airspeed for which a calibration point is wanted. Both the sailplane's airspeed indicator speed and the temporarily installed calibrating airspeed indicator readings are recorded at each test speed. The sailplane's calibrated airspeed, at each point, is whatever the calibrating airspeed indicator says it is, corrected of course for its own manometer measured errors. This assumes that there are no errors in the Kiel tube pitot or the trailing bomb static, which I believe is the case for the units shown in Figures 5 and 6.

Altitude and air temperature readings are not necessary here because they do not have any effect upon the airspeed system calibrations. Usually only one flight is needed to obtain a full calibration of a sailplane's airspeed system. After this is completed, the calibrating airspeed indicator, Kiel tube and static bomb may be removed.

Examples of several sailplane airspeed system calibrations are shown in Figures 7 thru 9. These airspeed system calibration data shown have been corrected for indicator errors; so they represent a system with a perfectly marked airspeed indicator. The sailplane's ASI can be removed and calibrated with the manometer, or it can alternately be calibrated while mounted in the instrument panel by connecting its pitot side to the calibrating ASI, and pressurizing both with the squeeze bulb and valve discussed earlier.

C. Performance Polar Measurements

Now that the sailplane's airspeed system has been calibrated, the hardest work is over. All that remains to be done is to tow the sailplane to high altitudes when the air is smooth and measure its sink rate when flying steadily at various airspeeds.

Items needed to make these sink rate measurements are smooth air, a stop watch, a calibrated altimeter, and an air thermometer. Typically, the errors in a good grade sensitive altimeter are relatively small, amounting to only 2 or 3 percent error over a 500 foot descent interval, which I generally use in sink rate tests. Sometimes, however, an apparently good altimeter will possess up to a 50 foot incremental error change over a 500 foot interval, and this will introduce a 10 percent sink rate error if not correct. For this reason I strongly recommend that a carefully calibrated altimeter be used when good quality data is wanted. Here, I find that an aircraft instrument calibration shop can provide an adequate calibration. However, you must tell them exactly what you need, which is a careful, descending only calibration with check intervals of not more than 500 feet.

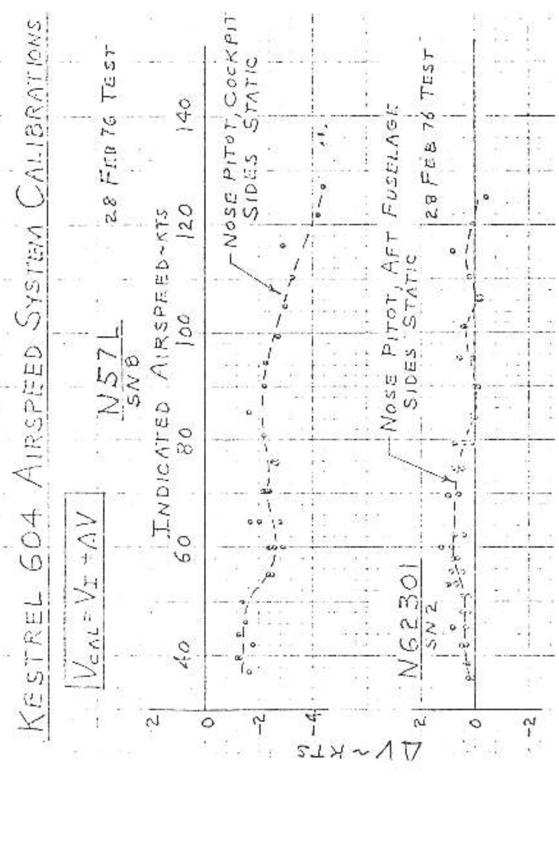

Figure 7. Airspeed System Calibrations.

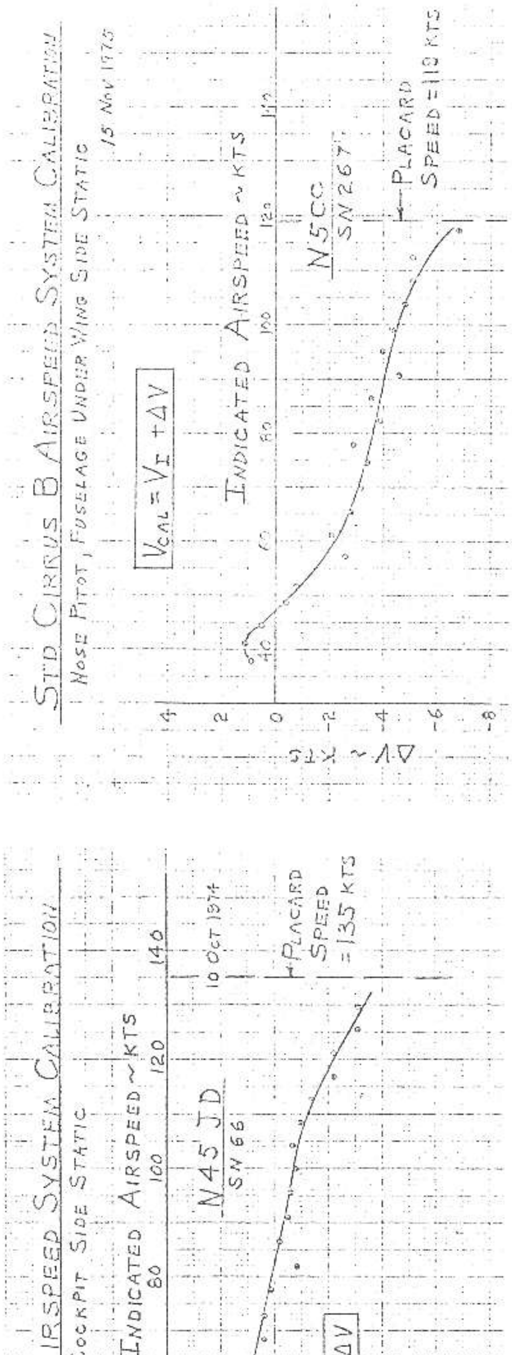

Figure 8. Airspeed System Calibrations.

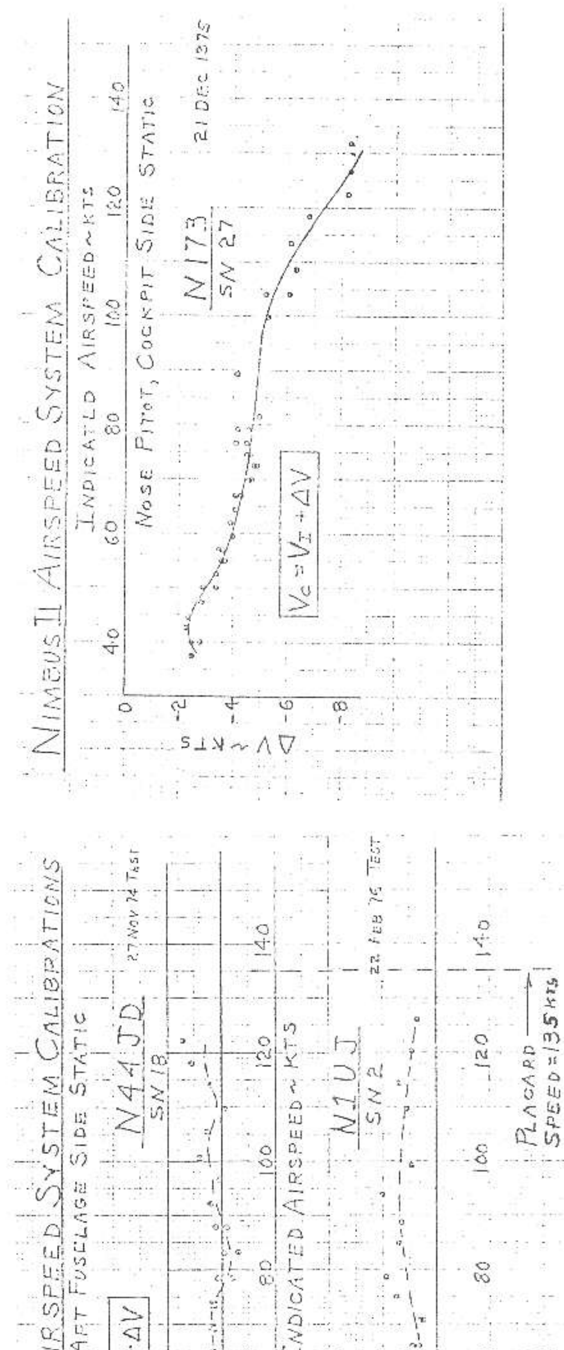

Figure 9. Airspeed System Calibrations.

If the calibration shows a badly zig-zagging error curve, the instrument should be replaced or overhauled, if it is to be used for sink rate testing. I have my own favorite instrument that I move to each sailplane being tested. Its calibration shows only small changes in error with altitude, such that over a 500 foot interval, the error would amount to only 1 to 2 percent, even if uncorrected. Altimeter errors alone do not degrade the data quality, provided they are smooth progressions with altitude, and a repeatable and accurate calibration is achieved.

The altimeter is really just a sensitive pressure gage, just as the airspeed indicators are. However, the altimeter measures only absolute pressures, and therefore has only one pressure line; whereas the airspeed indicator has two pressure lines and measures differential pressures.

The altitude unit marks on an altimeter correspond to absolute pressures existing at various altitudes in a so called standard atmosphere. The standard atmosphere is an internationally agreed upon average air temperature and pressure versus altitude, throughout the world. Seldom are actual flight test atmospheres close enough to standard to ignore these errors, and atmosphere corrections, in addition to the altimeter indicator corrections must be made. A detailed explanation of why and how these altitude corrections are made is given in Reference A. To prevent this paper from becoming too lengthy, only the final necessary equation will be given here.

Either have the towplane make the outside air temperature measurements during the tow to test altitude, or temporarily tape an OAT gage out the sailplane canopy window and record temperatures during tow. A 3° C error here will introduce only about 1 percent error in corrected sink rate; so these measurements do not have to be very exact. I normally measure the OAT at each 500 feet of altitude during tow. The long climb to test altitude tends to be a bit boring, and recording air temperatures gives the sailplane pilot a useful occupation.

When test altitude is reached, remove the OAT gage, set the altimeter to standard day sea level pressure at its index window, close the air vents, turn on the instrument virbrator, and position the data pad and stop watch for use. Set the airspeed upon the first planned test speed, and record the altitude at which the stop watch is started, and again the altitude at which the watch is stopped. I normally use 500 feet indicated altitude change as a test descent interval. Larger descent intervals improve data accuracy but provide fewer data points per tow. Everyone has to make his own judgements there. At the high test airspeeds where high sink rates are experienced, I usually extend the test altitude intervals to about 600 to 1000 feet to improve accuracy.

If the air would ever be completely free of any vertical motions, a reliable polar could be measured in just one flight. However, this is practically never the case. Even though the air feels perfectly smooth, there is often evidence of gentle clear air waves, even over flat lands far from mountains. These show up as sink rate data scatter, and for this reason, several test flights should be made, preferably on different days, to obtain sufficient data to establish a reliable polar curve. Sometimes a test flight will show excessive data scatter over a portion or all of the test altitudes. When this happens, throw out the bad data and try again on another day. Be careful not to keep the low sink points and just throw out the high ones. This will result in overly optimistic polar measurements, and perhaps is the method by which some enthusiastic designers justify their performance claims.

Once an adequate amount of sink rate data is acquired, it is corrected to sea level standard atmosphere conditions, because that is the customary way to present performance polar data. The equation used to so reduce the flight test sink rate data is:

$$R/S_{SL} = \frac{\Delta H}{\Delta t} \times \frac{T}{T_S} \sqrt{\frac{P}{P_{S_{SL}}} \times \frac{T_{S_{SL}}}{T}}$$

Where:

R/S_{SL} = Measured rate of sink, corrected to sea level standard atmosphere.

ΔH = Altimeter measured altitude interval, corrected for instrument errors.

Δt = Time required to sink thru the test altitude interval.

T = Measured absolute air temperature at midpoint of test altitude interval.

T_s = Standard absolute air temperature interval.*

P = Air pressure at midpoint of test altitude interval.*

$P_{s_{sL}}$ = Standard sea level air pressure.*

$T_{s_{sL}}$ = Standard sea level absolute air temperature.*

The above sink rate data reduction equation corrects for the test air density being other than standard day sea level. It permits the flight test calibrated airspeeds, discussed in Section B to be used directly as the data point airspeeds on the final polar plots.

The sink rate correction equation is not difficult to solve, and can be done quite quickly with a small electronic pocket calculator. If very much testing is to be done, programming a larger computer can save time and also be used to prepare final data plots and tables.

A collection of recent polar data measurement plots are shown in Appendix 1 of this paper. Most of these data plots were prepared by a computer plotter device, programmed by Bob Gibbons of the North Dallas Glider Club. He also devised the least squares curve fit computed line thru the flight test data, shown drawn on most of these plots. This curve fit line is that calculated for a theoretical parabolic drag curve that best matches the flight test data. The equation used for the curve fit line is:

$$R/S = AV^3 + B/C + C/V^3$$

Where:

A = The sailplane profile drag constant.

B = The induced drag constant.

C = An arbitrary stall region drag constant.

V = Airspeed at sea level.

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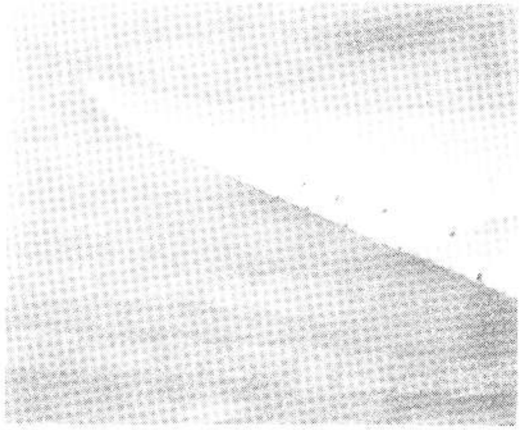
* These values are obtained from I.C.A.O. Tables.

This curve provides a fairly good fit to most of the flight test data, provided that the sailplane's profile drag coefficient remains relatively constant throughout the test airspeed range, and it appears to be adequate for some of the sailplanes tested. For others, the unmodified Nimbus II N173 for example, the above parabolic curve does not follow the test data well in the 80 to 105 knot speed range. Apparently a fairly sharp profile drag increase at around 95 kts exists there, and a more complex computer equation is needed to follow N173's data. Likely the wing is leaving its low drag laminar "bucket" rather rapidly at that point. It is appreciated that better data curve fitting needs to be done to rigorously follow the sink rate data obtained on sailplanes whose profile drag coefficients vary significantly with airspeed. Work on this is now being done.

The parabolic curve fitted the smoothed wing Nimbus II N45JD data much better, apparently because the additional wing smoothing kept its wing at lower profile drag levels at the higher airspeeds. Wing wake rake profile drag measurement testing needs to be done to verify this.

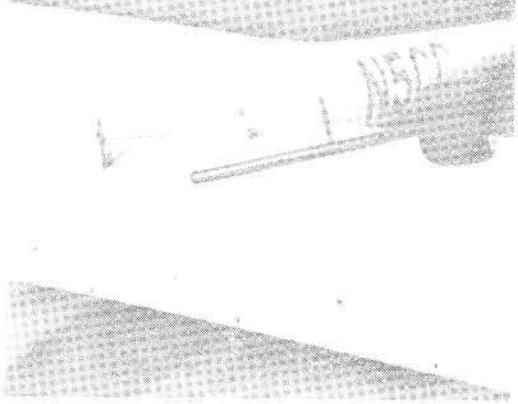
It has always been customary to measure a sailplane's performance polar with its surfaces as clean and smooth as possible. As a result, the sailplane's performance polar is at its best. However, average flying in and between thermals involves sharing the air with flying insects, especially in countries with moist climate. Collisions with these small insects occur, and gradually the leading edges of all the sailplane's surfaces are roughened. Laminar flow is soon lost and the sailplane is exhibiting a much difference polar than it did during its clean configuration flight tests.

For this reason it was judged that the sailplane polars should be measured with rough leading edges as well as smooth. To roughen the leading edges systematically, a pattern of small square pieces of fabric tape, about .25 mm thick and measuring about 5 mm on the sides, were adhered to the wing leading edges. A pattern was used where one "insect" was placed each 15 cm directly on the wing leading edges, a second row in between and about 2.5 cm above the leading edge, and a third row also in between the first, and about 1.25 cm below the leading edge. This pattern placed a total of 20 tape squares per meter span along each leading edge.



"Bugs" on Kestrel 604 Wing
During Flight Test

Tape "Bugs" on Nimbus II
Wing Leading Edge



Kiel Tube and Static Bomb
on "Bugged" Std. Cirrus Wing

Wave Gage on Kestrel 604 Wing

This bug installation is perhaps somewhat too dense to be representative of average USA flight conditions, but for much of Europe the summertime thermal insect population is high and a 20 bugs/meter impact density may be achieved within one or two hours of flight.

The flight test polar data measured with the 20/meter "bug" pattern on the wing are shown in Appendix 2. Significant increases in sink rates are shown for all the sailplanes tested, and stalling speeds were increased by 2 to 3 knots by the bug installation. The sailplanes that were most severely affected by the bugs were those which showed the lowest drag levels when in the clean configuration, notably the Nimbus II and the ASW-17. Apparently the leading edge roughening disrupted practically all the laminar flow on the wing and left only turbulent flow.

The designers and pilots usually do not think of their sailplane's performance in terms of what it really is, when roughened by a normal load of insects. As a result, many competition pilots may be using speed rings and final glide computers that are much too optimistic. A "fast" speed ring with a buggy wing can quickly take the pilot to uncomfortably low altitudes between thermals, and the problems on final glide are obvious.

Just how many insect impacts a good sailplane wing can tolerate without losing most of its low drag laminar flow has not been determined, at least during the Dallas testing. Nimbus II tests are planned soon where 5 bugs/meter and perhaps 10 bugs/meter will be tested. If these tests are completed in time for inclusion in this paper, their data plots will be included in Appendix 2. It is speculated that since laminar flow is normally lost over a 14° included angle behind each rough point, the effect of 10 bugs/meter on the wing leading edges will be almost as severe as the 20 bugs/meter. Also, that even the 5 bugs/meter are likely to show quite significant increases in sink rates.

It should be appreciated that due principally to atmospheric air motions, it is practically impossible to obtain completely error free sink rate data measurements. This requires that a fairly large number of measurements need to be made, and the results averaged. Here I think the computer curve fit to the data is a good tool. It saves the test engineer time and money by requiring fewer data points to establish a polar curve with fairly good accuracy. If the tow resources are available without restraint, I prefer to obtain about 50 data points to establish the polar of an average sailplane. However, I often find little change to the computer fitted curves after obtaining 15 to 20 points.

It is hoped that thru this paper others will be motivated to conduct flight tests of their own, and that meaningful discussions and better understanding of sailplane polars will result.

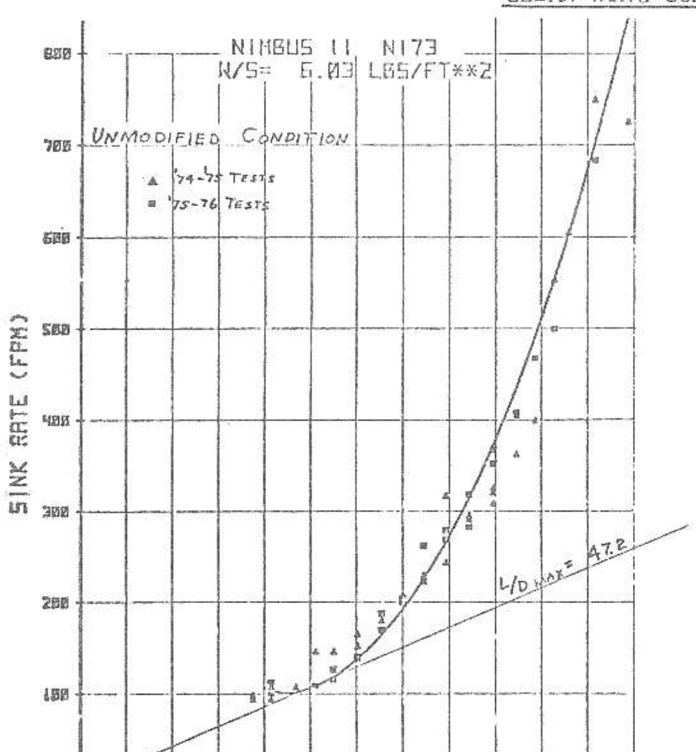
The author is indebted to the Dallas Gliding Association for providing the many high airplane tows needed to obtain the data presented here. Also, to the many owners who donated the use of their sailplanes and their time toward the conduct of these tests, and to Bob Gibbons, who assisted with the data reduction and prepared the computer polar data plots.

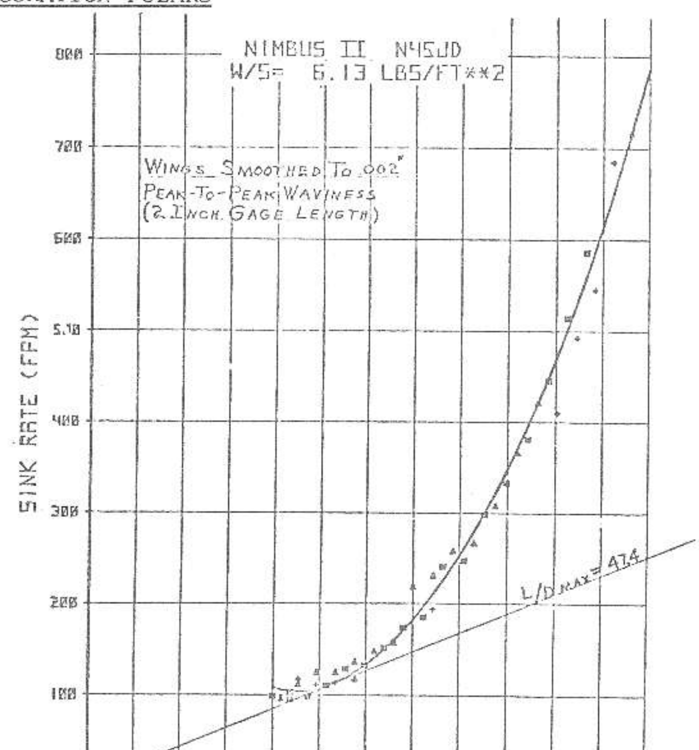
REFERENCES

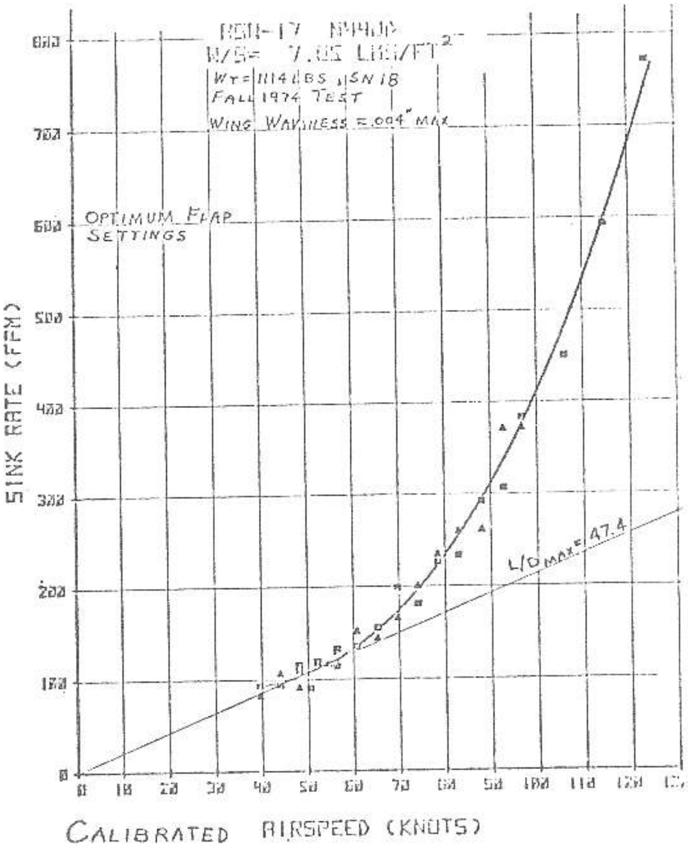
Johnson, R.H. Sailplane Flight-Test Performance Measurement. *Soaring*, 1968, April, 10-16.

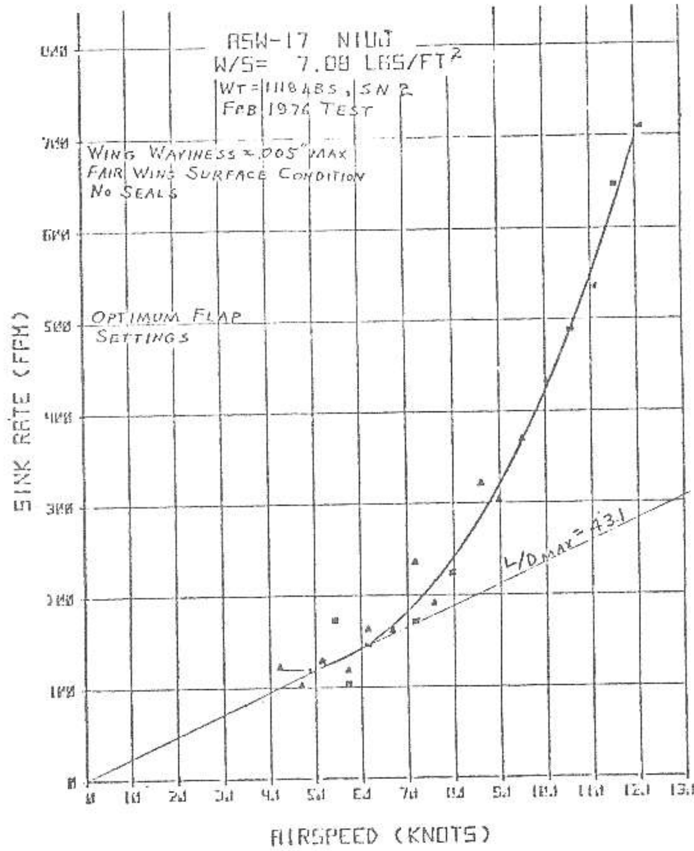
APPENDIX I

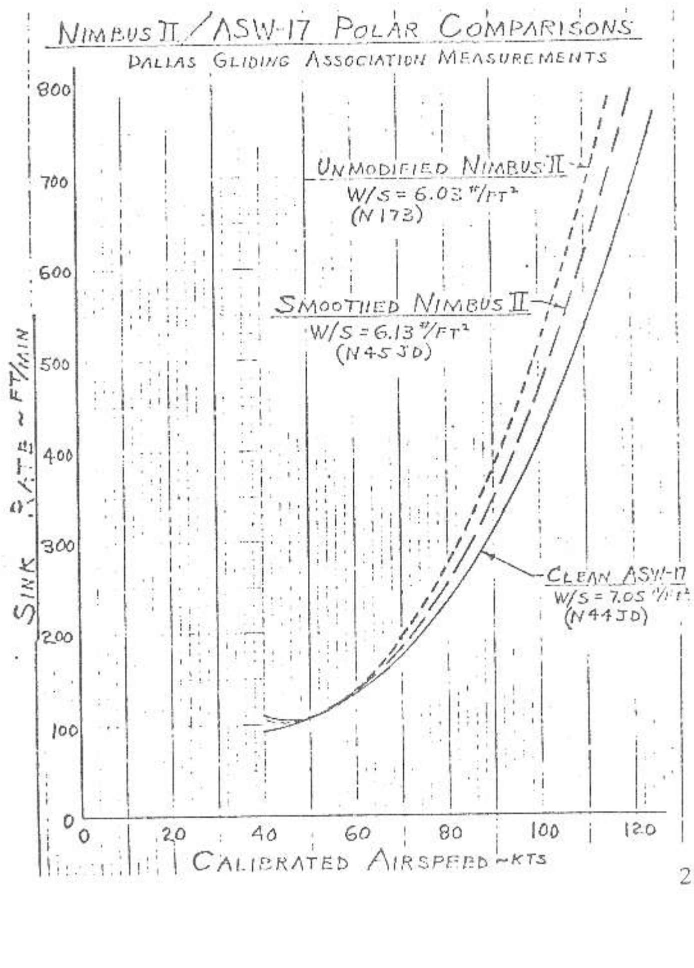
CLEAN WING CONFIGURATION POLARS

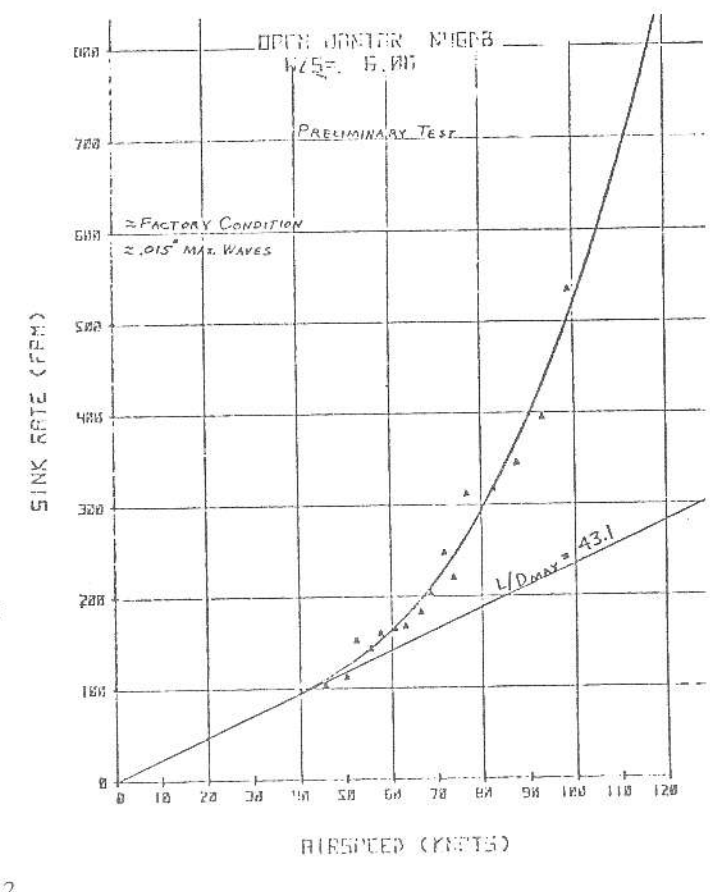


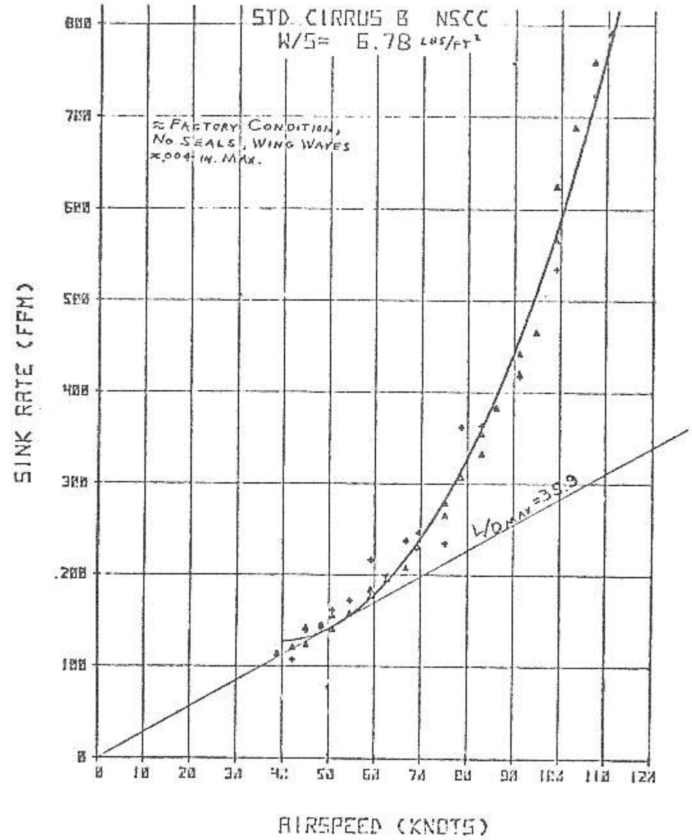


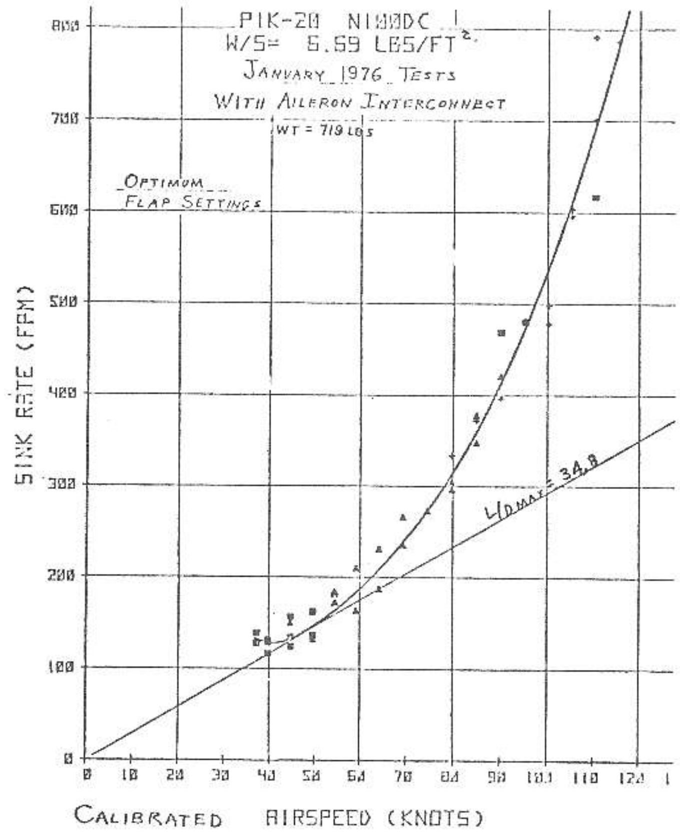

FALL 1974 TEST
WING WAVINESS ≈ .004" MAX
OPTIMUM FLAP SETTINGS
L/D MAX = 47.4
SINK RATE (FPM)
CALIBRATED AIRSPEED (KNOTS)

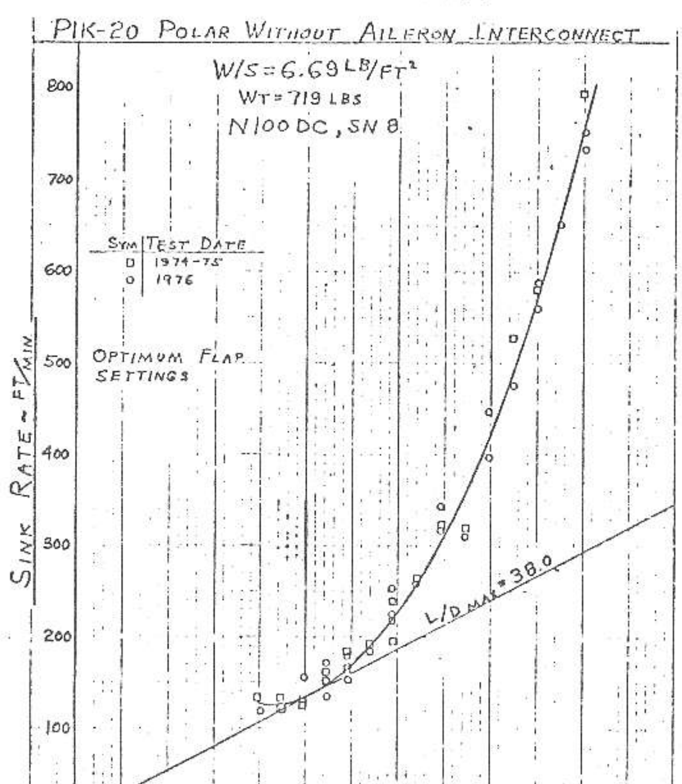

W/S= 7.08 LBS/FT²
FEB 1976 TEST
WING WAVINESS ≈ .005" MAX
FAIR WING SURFACE CONDITION
NO SEALS
OPTIMUM FLAP SETTINGS
L/D MAX = 43.1
SINK RATE (FPM)
AIRSPEED (KNOTS)

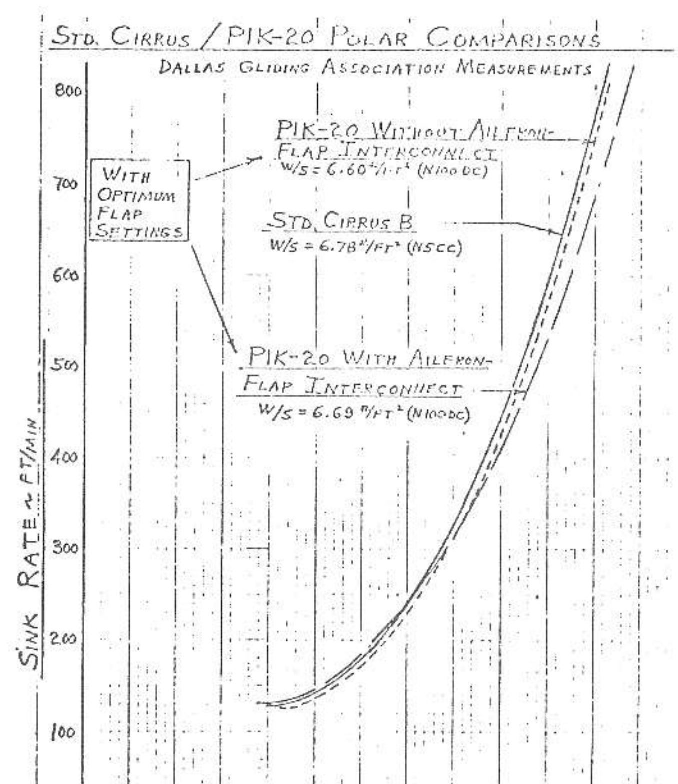

NIMBUS II / ASW-17 POLAR COMPARISONS
DALLAS GLIDING ASSOCIATION MEASUREMENTS
UNMODIFIED NIMBUS II
W/S = 6.03 #/FT²
(N173)
SMOOTHED NIMBUS II
W/S = 6.13 #/FT²
(N45JD)
CLEAN ASW-17
W/S = 7.05 #/FT²
(N44JD)
SINK RATE ~ FT/MIN
CALIBRATED AIRSPEED ~ KTS

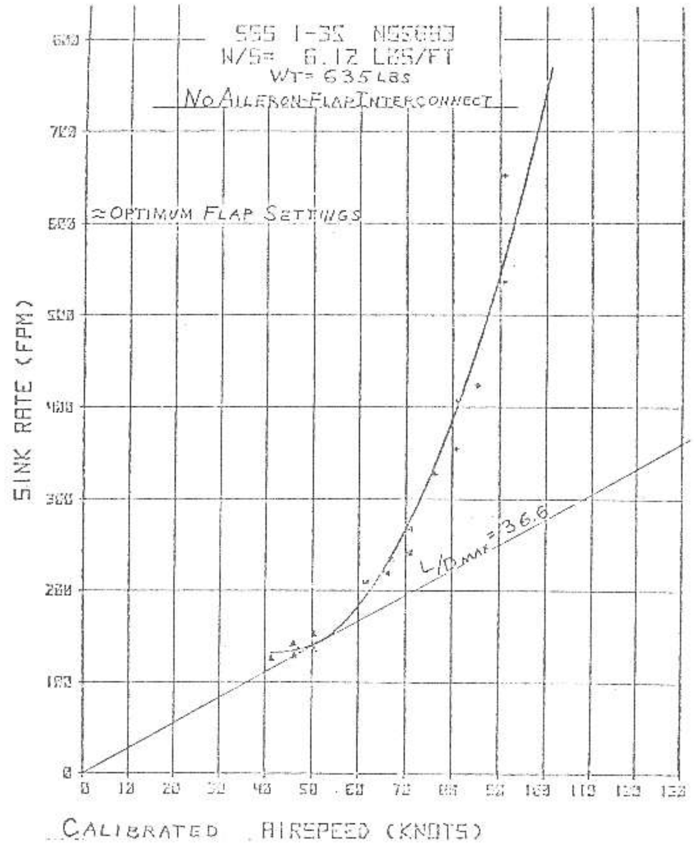

PRELIMINARY TEST
≈ FACTORY CONDITION
≈ .015" MAX. WAVES
L/D MAX = 43.1
SINK RATE (FPM)

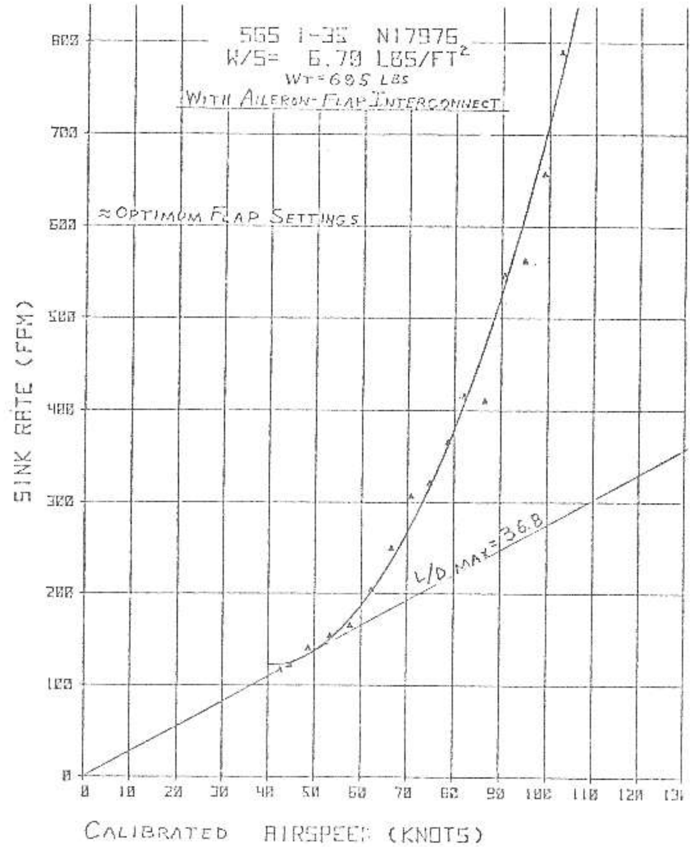

STD. CIRRUS B NSCC
W/S= 6.78 LBS/FT²
≈ FACTORY CONDITION, NO SEALS, WING WAVES ≈.004 IN. MAX.
L/D MAX = 35.9
SINK RATE (FPM)
AIRSPEED (KNOTS)


PIK-20 N100DC
W/S= 6.69 LBS/FT²
JANUARY 1976 TESTS
WITH AILERON INTERCONNECT
WT = 719 LBS
OPTIMUM FLAP SETTINGS
L/D MAX = 34.8
SINK RATE (FPM)
CALIBRATED AIRSPEED (KNOTS)


PIK-20 POLAR WITHOUT AILERON INTERCONNECT
W/S = 6.69 LB/FT²
WT = 719 LBS
N100DC, SN 8
SYM TEST DATE
□ 1974-75
○ 1976
OPTIMUM FLAP SETTINGS
L/D MAX = 38.0
SINK RATE ~ FT/MIN
CALIBRATED AIRSPEED ~ KTS

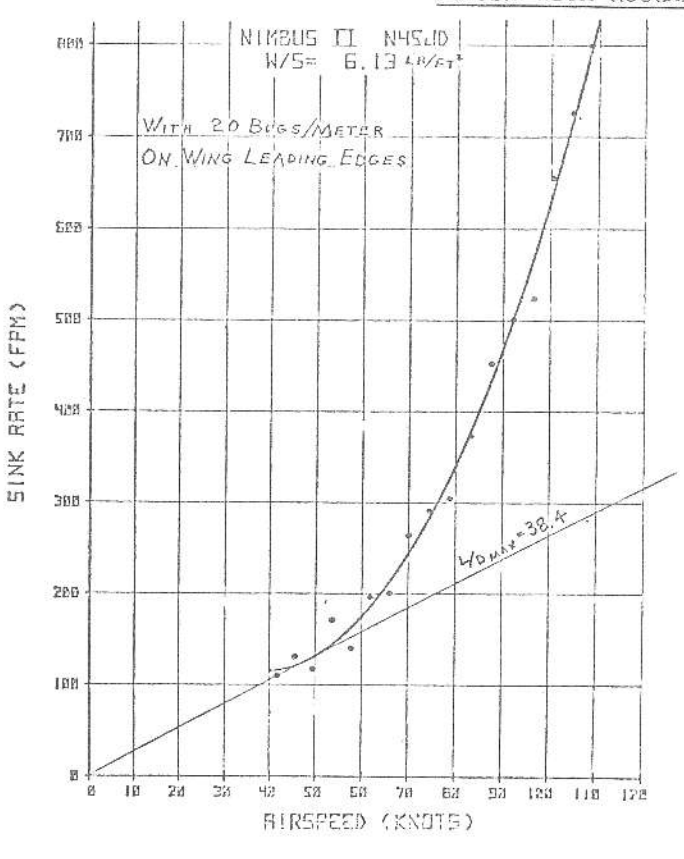

STD. CIRRUS / PIK-20 POLAR COMPARISONS
DALLAS GLIDING ASSOCIATION MEASUREMENTS
WITH OPTIMUM FLAP SETTINGS
PIK-20 WITHOUT AILERON-FLAP INTERCONNECT
STD. CIRRUS B
W/S = 6.78 #/FT² (NSCC)
PIK-20 WITH AILERON-FLAP INTERCONNECT
W/S = 6.69 #/FT² (N100DC)
SINK RATE ~ FT/MIN
CALIBRATED AIRSPEED ~ KTS

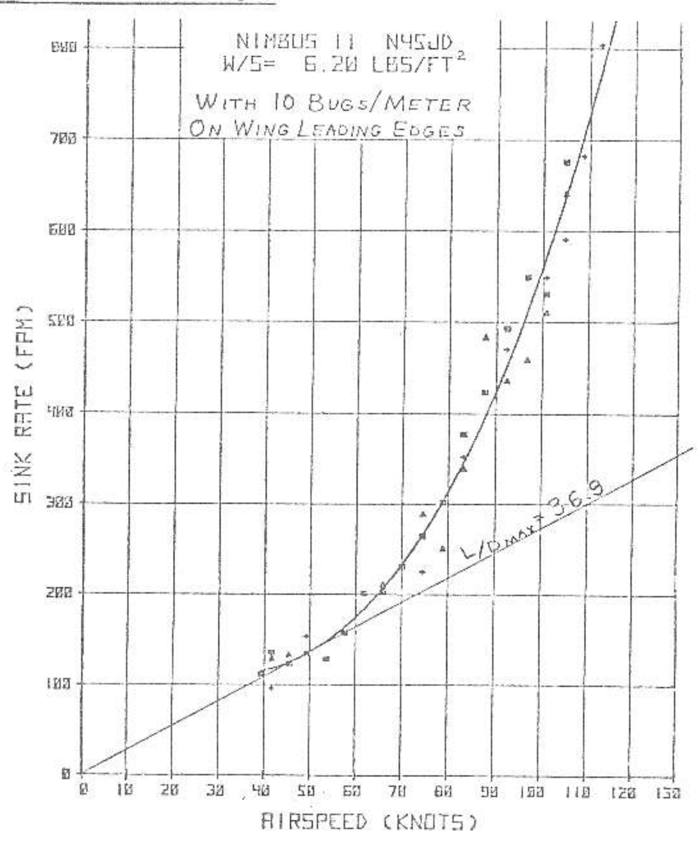


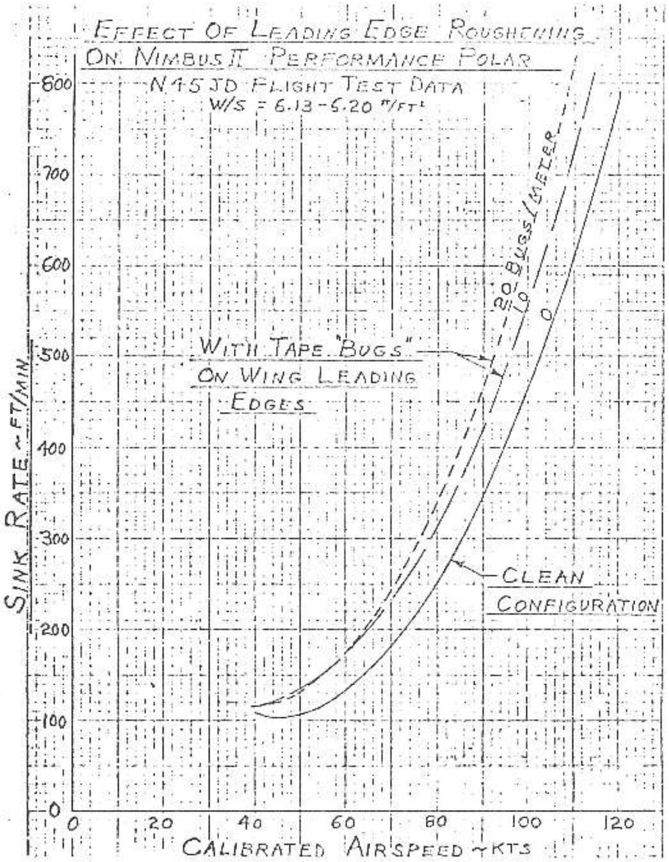


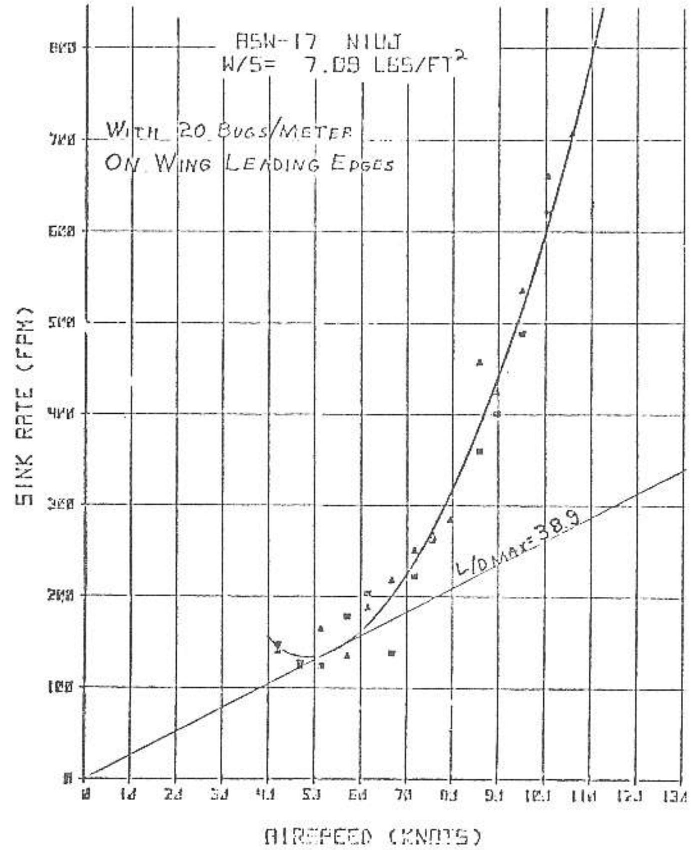
APPENDIX 2

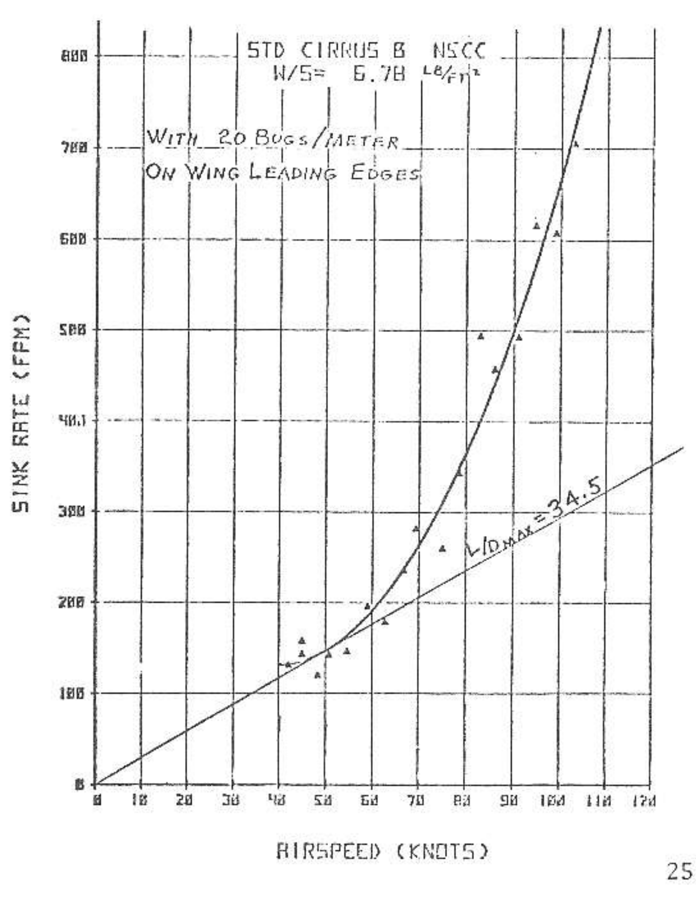
POLARS WITH ROUGHENED WING LEADING EDGES

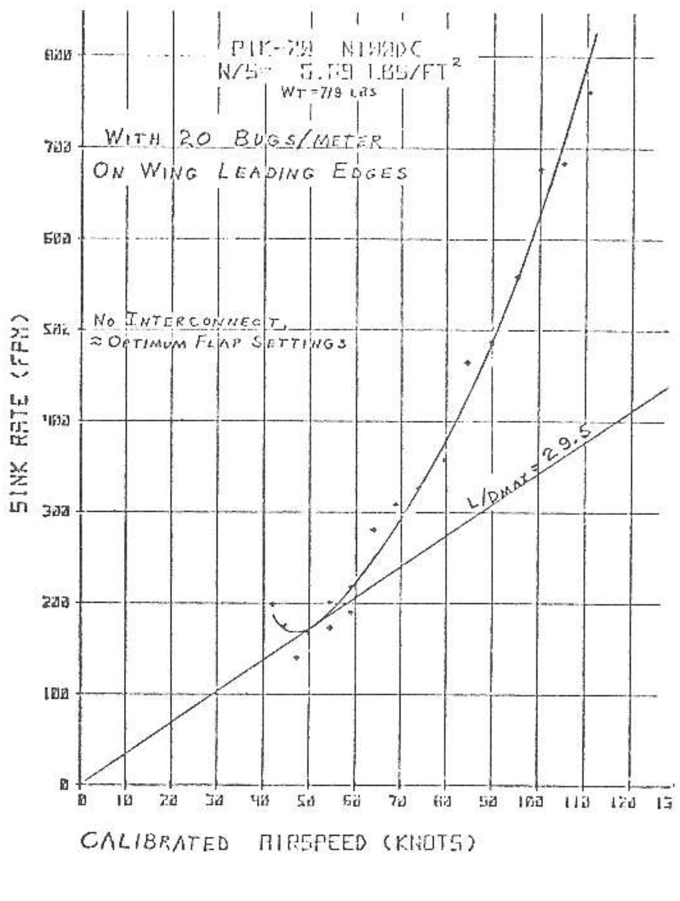


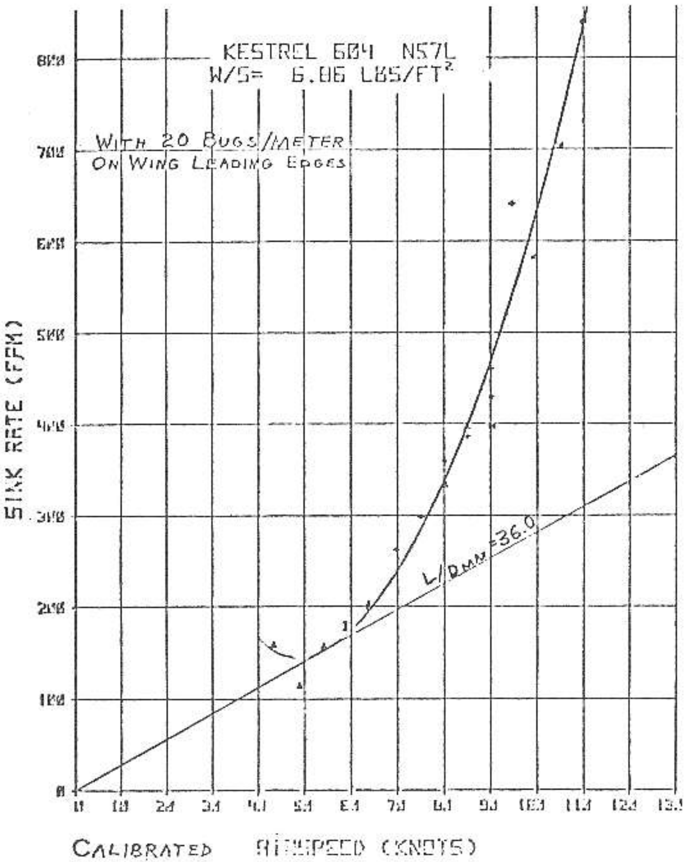


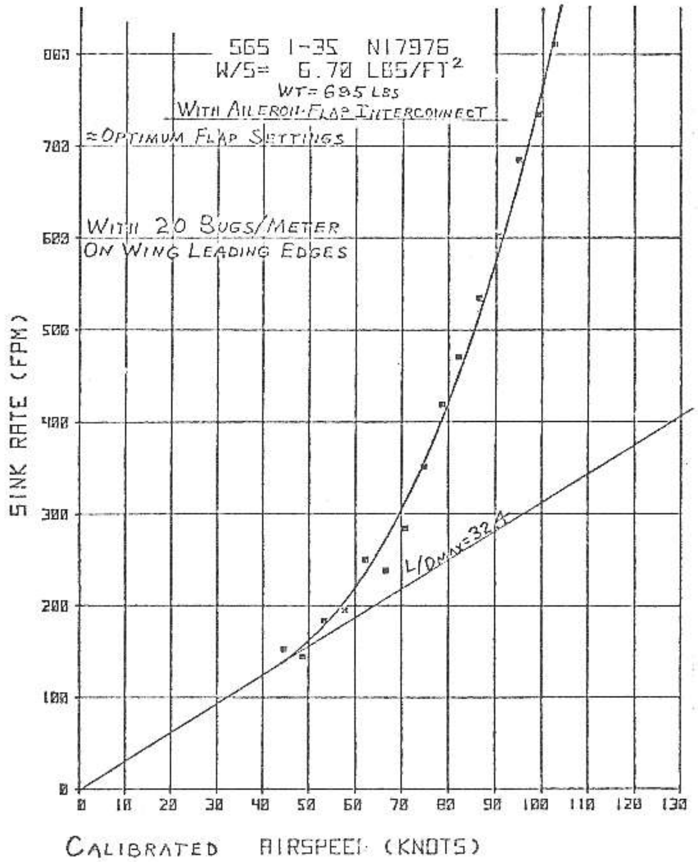

EFFECT OF LEADING EDGE ROUGHENING
ON NIMBUS II PERFORMANCE POLAR
N45JD FLIGHT TEST DATA
W/S = 6.13 - 6.20 #/FT²
20 BUGS/METER
10
0
WITH TAPE "BUGS"
ON WING LEADING
EDGES
CLEAN
CONFIGURATION
SINK RATE ~ FT/MIN
CALIBRATED AIRSPEED ~ KTS


ASW-17 N1UJ
W/S= 7.09 LBS/FT²
WITH 20 BUGS/METER
ON WING LEADING EDGES
L/D MAX=38.9
SINK RATE (FPM)
AIRSPEED (KNOTS)


STD CIRRUS B NSCC
W/S= 6.78 LB/FT²
WITH 20 BUGS/METER
ON WING LEADING EDGES
L/D MAX=34.5
SINK RATE (FPM)
AIRSPEED (KNOTS)


WITH 20 BUGS/METER
ON WING LEADING EDGES
NO INTERCONNECT,
≈ OPTIMUM FLAP SETTINGS
L/D MAX=29.5
SINK RATE (FPM)
CALIBRATED AIRSPEED (KNOTS)





Ship	No. Pts.	LEAST SQUARES CURVE FIT DATA A	B	C	Max L/D	Speed for L/D Max (knots)	Speed for 6 FPM Sink (knots)
			Clean Wing Data				
Nimbus II N45JD	45	4.457784E-04	1.518574E+03	2.730008E+06	47.4	53.0	91.0
ASW-17 N44JD	37	3.795699E-04	3.350214E+03	9.329395E+05	47.4	51.5	95.0
Nimbus II N173	54	5.024578E-04	8.199601E+02	3.463737E+06	47.5	51.0	88.0
ASW-17 N1UJ	24	3.875257E-04	3.212967E+03	1.106780E+06	43.1	56.5	94.0
Std Cirrus B N5CC	43	5.531463E-04	3.434047E+03	4.168375E+05	35.9	51.0	83.0
SGS 1-35 N17976	17	6.926850E.04	1.510947E+03	2.669085E+06	36.8	48.5	78.5
SGS 1-35 N55883	20	7.498795E-04	-1.195301E+03	8.967441E+06	36.6	52.0	78.0
			Roughened Leading Edges				
Nimbus II N45JD	17	6.007870E-04	3.403578E+03	1.105043E+06	38.4	48.5	81.5
ASW-17 N1UJ	29	5.904513E-04	-6.977934E+01	7.705988E+06	38.9	54.5	83.5
Std. Cirrus B N5CC	18	6.338962E-04	2.922656E+03	1.135903E+06	34.5	49.5	79.5
Kestrel 604 N57L	21	6.207683E-04	2.723723E+02	7.776531E+06	36.0	54.5	82.0
SGS 1-35 N17976	16	7.207369E-04	4.381031E+03	-1.981943E+06	32.4	44.0	75.0