Sailplane Performance Flight Testing

D.J. Marsden
Department of Mechanical Engineering
University of Alberta
Edmonton, Canada
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ABSTRACT

The traditional partial glide method of measuring glide performance is simple in principle, but requires a high degree of accuracy. Scatter in results arise from two sources, limitations in resolution of instrumentation and from movement of the air.

Use of high resolution pressure transducers together with electronic data recording reduces the first source of scatter to a minimum and provides easy access to statistical analysis using a computer. In addition, the theoretical shape of the polar curve can be used to obtain a better fit than can be obtained by fitting an arbitrary line through measured points. A value of maximum L/D can be obtained from a statistical analysis of the complete polar curve that will provide a meaningful figure of merit of aerodynamic performance.

INTRODUCTION

Measurement of glide performance is simple in principle, requiring only the measurement of sink speed for a series of steady forward speeds. The difficulty lies in obtaining sufficient precision and accuracy in these measurements.

There are two basic sources of scatter, resolution of instrumentation and movement of the atmosphere. While the problem of resolution and accuracy of instrumentation can be overcome with modern equipment and careful experimental technique, movement of the atmosphere can only be dealt with on a statistical basis. Essentially we have to make a large number of measurements and average them. This process can be improved considerably if we make use of theoretical knowledge about the shape of polar curves in general.

In any case, a large number of experimental measurements are required. These tests will be greatly facilitated if data can be recorded directly into the memorry of a microprocessor and data processing handled on a small computer with only minimal manual input.

INSTRUMENTATION

Pressure transducers were used to measure airspeed, atmospheric static pressure (altitude) and rate of change of static pressure as a measure of sink speed. Ambient temperature was also recorded in order to be able to

calculate air density, $\rho = P/RT$, where P is absolute static pressure, R is the gas constant and T is absolute temperature. Output from an electric variometer was recorded on an available fifth channel. A multiplexer was used to make these five measurements in sequence repeated each 1.64 seconds.

Voltages from the transducers were converted directly to digital values. These were stored in memory in the microprocessor, which has enough capacity for 45 minutes of continuous data recording. The memory of the microprocessor can be read directly into the HP-85 computer at the end of each flight for storage on tape and processing.

The most difficult measurement is that of sink rate since changes in static pressure have to be measured that are very small compared to total atmospheric pressure. Sensitivity was obtained by using a 0.2 p.s.i. differential pressure transducer to measure changes from a reference static pressure captured at the start of each data run. A schematic of this system is shown in Figure 1. The manually
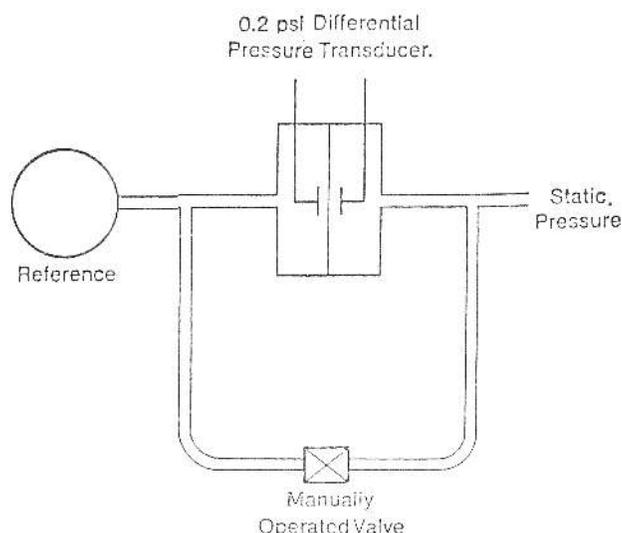
operated valve is closed at the beginning of a run to hold a constant reference pressure, and opened again to equalize pressure before the beginning of the next run.

DATA ACQUISITION SYSTEM

A schematic of the data acquisition system is shown in Figure 2. Transducers measuring air speed, change in pressure altitude, absolute static pressure, variometer sink rate, and outside air temperature are recorded in sequence.
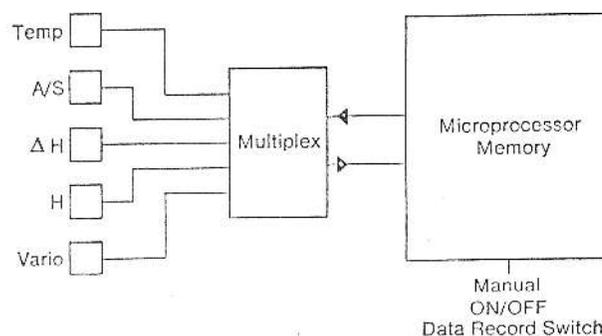

Figure 2. Data Acquisition System

In measuring a single data point, a steady gliding speed is established, the pressure reference valve is closed and data recording switched on. After a steady run of 20 to 30 seconds duration the data recording switch is set to stop and the pressure reference valve opened. A new speed is then established for the next data run.

The microprocessor records data starting with channel 1 and ending with channel 5 so that complete sets of 5 readings are recorded. When the data switch is turned off the current row is completed and a final row is recorded consisting of the run number in sequence followed by four zeros to indicate the end of a data run.

Figure 1. Sensitive Height Transducer

ANALYSIS

The analysis of the raw data is automated as much as possible to reduce the time needed between test flight and final results. Data is stored in the memory of a microprocessor that is part of the flight test data acquisition system. After the flight test the microprocessor is removed from the aircraft and taken to the HP-85 computer where the data is transferred to computer memory and stored on magnetic tape. The HP-85 then proceeds with data reduction, applying previously stored calibration factors.

Position error corrections are applied to air speeds which are interpreted as sea level equivalent. Sink rates obtained from the differential pressure transducer are corrected to sea level equivalent by multiplying by the square root of the density ratio.

Each data run contains approximately 15 individual measurements of forward speed and sink rate. Scatter arises from two sources, instrument resolution and movement of the air. This scatter can be reduced by averaging the 15 values measured, or averaging can be accomplished by allowing a longer time between measurements so that a larger change of height is divided by a longer time interval. A combination of these two can be accomplished in the computer software by specifying a "skip interval". For example, if a skip interval of 3 is specified, height intervals between measurements 1 and 4, 2 and 5, etc are divided by 3 X 1.640 seconds to provide measured sink rates. These can be averaged to provide a final value for this run. The standard deviation can be calculated as a useful indication of scatter.

Variation of airspeed during a data run could produce significant errors in rate of sink measurements. Errors from this source can be eliminated by calculating energy height using the measured airspeed, and basing sink rate of change of energy height.

RESOLUTION

The resolution of instrumentation used in these tests is very much better than that of standard flight instruments. Resolution of the airspeed is ±0.04 knots and resolution on measurement of height intervals is ±0.17 feet.

With such excellent resolution, most of the scatter in the results can be attributed to movement of the atmosphere.

STRATEGY FOR FLIGHT TEST MEASUREMENT

The atmosphere is never completely still. Even quite small movements up or down have a large effect when sink rates of only a few feet per second are being measured. For example, an air movement of only 1/4 fps would result in 8.3% error on a measured sink rate error of 3 fps.

Air movement can be averaged out in one of two ways. The first is to measure sink rate for a long period of time while the aircraft flys through varying rising or sinking air. The second is to make a number of measurements of sink rate at different times, possibly even on different days, and average the results, in order to sample a wider range of air conditions and be less susceptible to a persistent patch of up or down. Good instrument resolution and computer aided data reduction make it practical to adopt this second strategy.

ANALYSIS

Statistical analysis of measured data is needed to reduce the uncertainty in any one measurement. Simply averaging a number of measurements of sink

rate at one particular forward speed will provide a better value than any single measurement as well as an estimate of probable accuracy of that averaged result. A typical set of measurements is shown in Figure 3. Grouping

At high speed, and again at low speed when transition moves forward reducing the amount of laminar flow on the wing, drag increases more than indicated by the above equation. If we drop points measured at airspeeds
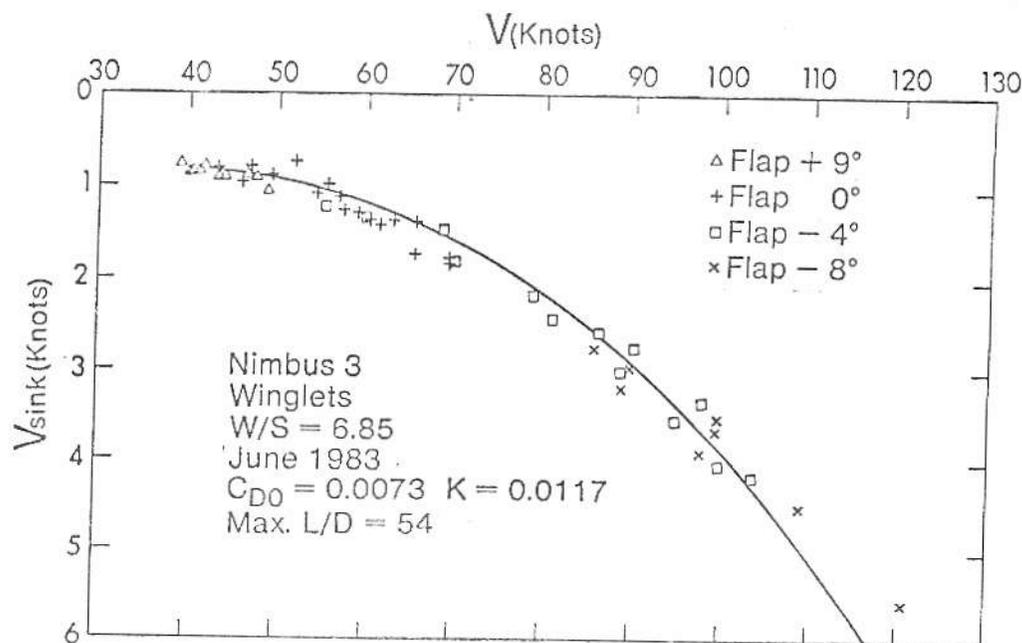

Figure 3. Typical Results Showing Scatter

points which are close to the same speed and taking average sink rates will produce a polar curve. However, since we know from aerodynamic theory that the polar curve should have a particular form we may be able to use all the data to get a better fit.

The quadratic polar,

$$C_D = C_{Do} + KC_L^2 \qquad (1)$$

is known to be a good approximation for sailplanes over the middle part of their speed range.

C_{Do} is the zero lift drag, or drag component independent of lift. The constant K represents drag dependent on lift made up of induced drag together with the lift dependent part of skin friction drag. Thus K consists of two components, one related to aspect ratio and the other depending on the wing section characteristics [1].

outside the speed range for laminar flow on the wing the remaining points should fit a quadratic polar. Plotting C_D vs C_L^2 and using a linear regression least squares fit will immediately yield values of C_{Do} and K together with an estimate of probable error in the values obtained. Some examples are shown in Figures 6(a), 6(b), and 6(c). The value of maximum L/D can be simply obtained from these results as [2]:

$$\text{Max L/D} = \sqrt{\frac{1}{4C_{Do}K}} \qquad (2)$$

This value is a good index of overall performance because it is derived from data taken over the whole of the primary operating speed range rather than just from measurements made at speeds close to the speed for maximum glide ratio.

Finally, we can add in the points measured at the high speed

and low speed ends of the polar curve and extend the fitted polar.

Figure 4 shows a flow chart for the computer program used in data reduction.
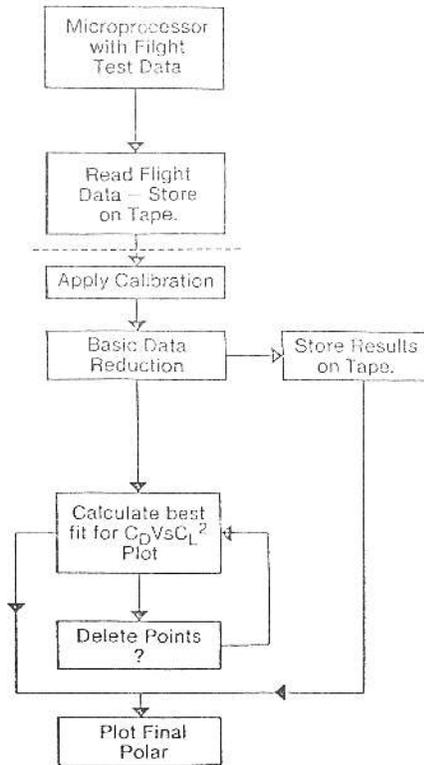

Figure 4. Data Reduction Program

SAILPLANES WITH FLAPS

Chamber changing flaps are used to extend the speed range over which the wing is operating in its low drag regime with extensive laminar flow on both top and bottom surfaces. If the current speed range for each flap setting is known, the overall polar can be measured directly by coordinating flight speed with flap settings.

NIMBUS 3 FLIGHT TEST RESULTS

Flight tests were conducted on Dick Brandt's Nimbus 3 (N2737F) which was being prepared for the World Contest at Hobbs. Since time available for flight tests was short, results from Dick Johnson's tests were used for position error and to choose airspeed ranges for each flap position. Johnson's[3] results showed that position error was less than 0.5 knots over the entire speed range when rear fuselage statics were used.

Three configurations were tested, the 24.5 metre version with factory long tips, a 25 metre version with tip extensions patterned after Schuemann's suggestions[4], and a 22.9 metre version with 12 inch high winglets developed at the University of Alberta.

The size and general shape of the winglet can be seen in Figure 5. The planform area of each winglet is 0.4 ft compared to 2.5 ft for the tip extension they replace.
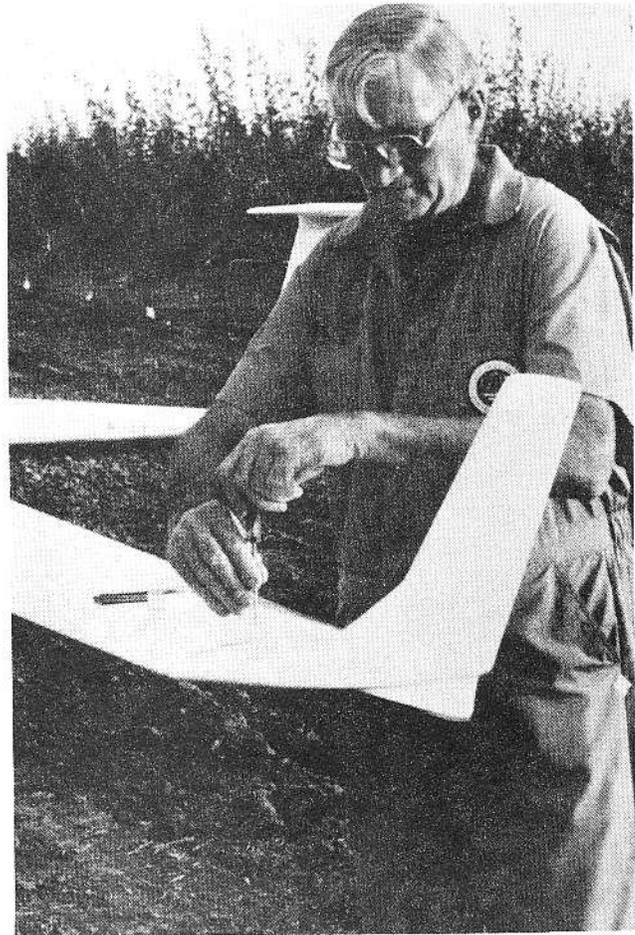

Figure 5. Winglet fitted to the Nimbus 3

Results of C_D vs C_L^2 are shown in Figures 6(a), 6(b) and 6(c) for factory long tips, Schuemann long tips and winglets, respectively, along with values of C_{Do}, K, and maximum L/D determined by a regression best fit line. Note that the uncertainly in C_{Do} of approximately 0.0005 is fairly large compared to C_{Do} (7%) while the uncertainty in K is relatively smaller (3%). The value of maximum L/D is 55:1 for the two long wing configurations and 53:1 for the 22.9 metre span with winglets.

Glide polars are shown in Figures 7(a), 7(b) and 7(c) with the solid line representing the quadratic polar given by values of C_{Do} and K. These curves give a good fit with the possible exception that the curve representing the winglets shows too much sink at the high speed end. If the value of C_{Do} is reduced to C_{Do} = 0.0073 (within the statistical uncertainty) the solid curve is a better fit at the high speed end as shown in Figure 3 and maximum L/D is raised to 54:1.

Comparing the three configurations, the glide polars are nearly identical. The slightly higher value of C_{Do} in the case of the winglets is partly due to the reduction in wing area, but this is compensated by the small increase in wing loading.

The value of K is the same for all three configurations. This is particularly significant for the configuration with winglets because it implies that the effective aspect ratio is the same as that of the long wing version.

COMPARISON WITH JOHNSON'S FLIGHT TESTS

A comparison of these test results with those reported by Johnson is shown in Figure 8. Johnson's results have been adjusted for the difference in wing loading.

Agreement between the two sets of test results is as good as can be expected for two aircraft of the same type. Better high speed performance measured here may be a reflection of work done to prepare this Nimbus 3 for a world contest.

CONCLUSION

An integrated flight test system has been assembled which uses an electronic data acquisition system and computer processing to provide efficient sailplane performance flight testing. The traditional partial glide method is used to gather data, but the process is made more efficient by use of high resolution instrumentation to obtain accurate sink rate measurements from relatively small height loss intervals. Computer data reduction makes statistical analysis easy. Use of the whole polar to determine a value of best L/D provides a reliable figure of merit by which to judge aerodynamic efficiency.

Flight test measurements on a Nimbus 3 indicated a maximum L/D of 55:1. Use of winglets with the 22.9 metre span configuration proved the effectiveness of the winglets in providing performance substantially equal to the 24.5 metre span configuration.

ACKNOWLEDGEMENTS

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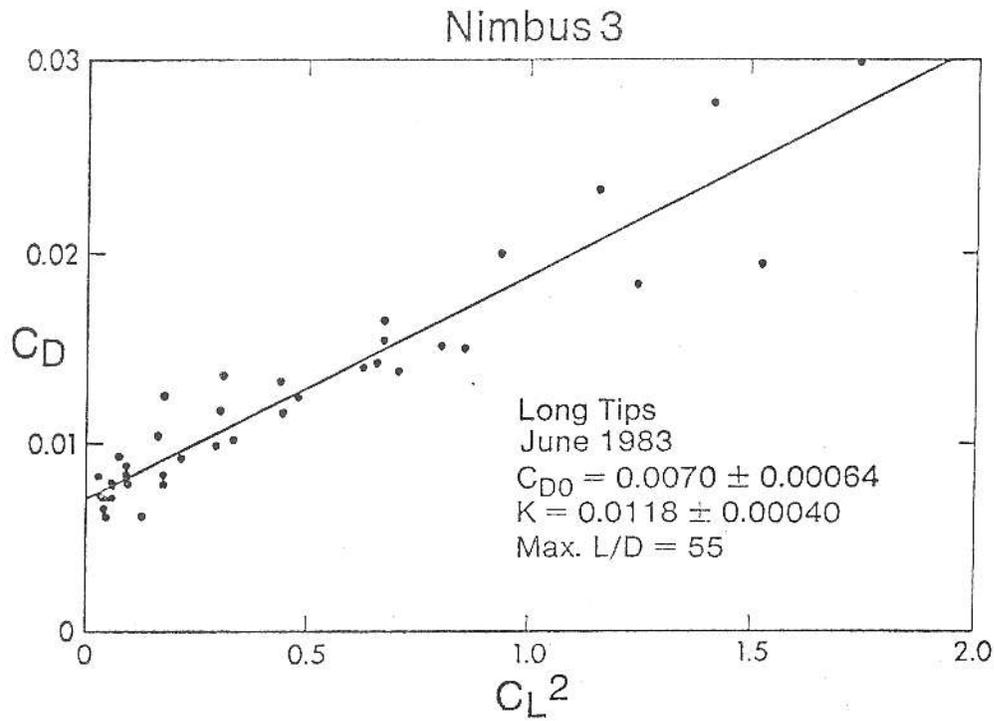
Nimbus 3

Long Tips
June 1983
$C_{D0} = 0.0070 \pm 0.00064$
$K = 0.0118 \pm 0.00040$
Max. L/D = 55

Figure 6(a). C_D vs C_L^2 For 24.5 m Span

Nimbus 3

New Long Tips
June 1983
$C_{D0} = 0.0070 \pm 0.00053$
$K = 0.0118 \pm 0.00033$
Max. L/D = 55
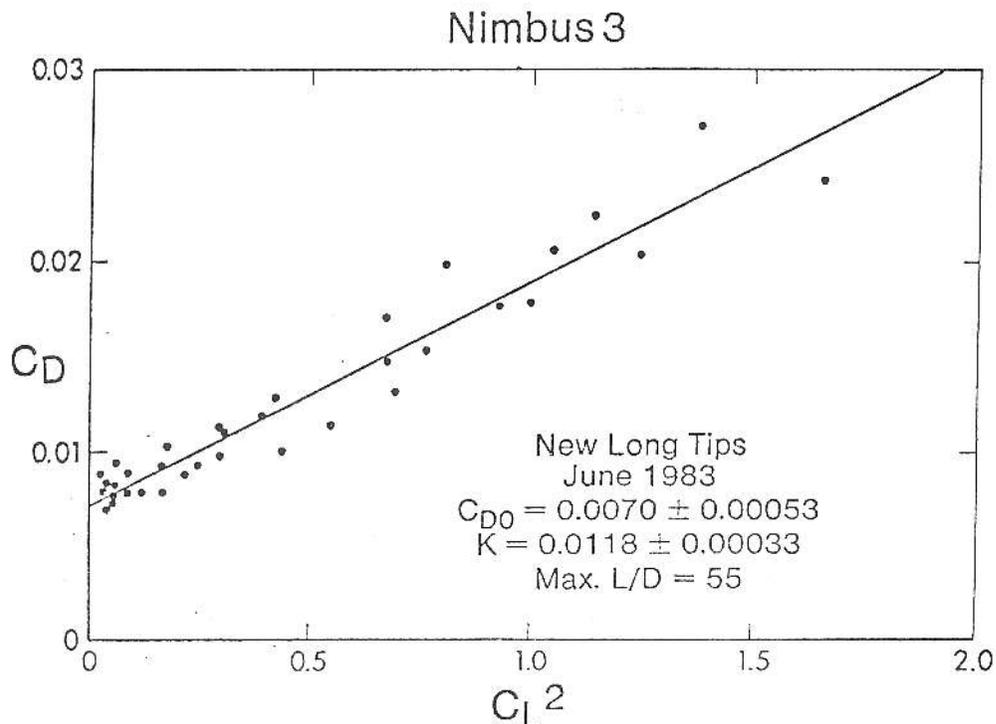
Figure 6(b). C_D vs C_L^2 For 25 m Span

Nimbus 3

Winglets
June 1983
$C_{DO} = 0.0076 \pm 0.0032$
$K = 0.0117 \pm 0.00023$
Max. L/D = 53
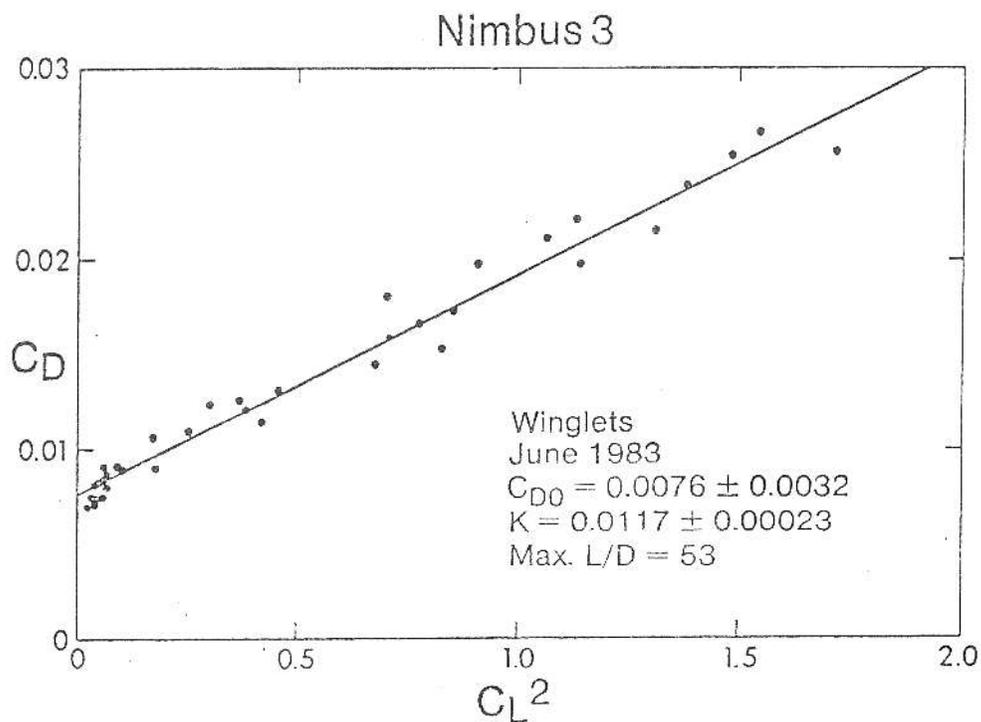
Figure 6(c). C_D vs C_L^2 For 22.9 m Span With Winglets

△ Flap + 9°
+ Flap   0°
□ Flap − 4°
× Flap − 8°

Nimbus 3
Long Tips
W/S = 6.6
June 1983
$C_{DO} = 0.0070$ $K = 0.0118$
Max. = L/D = 55
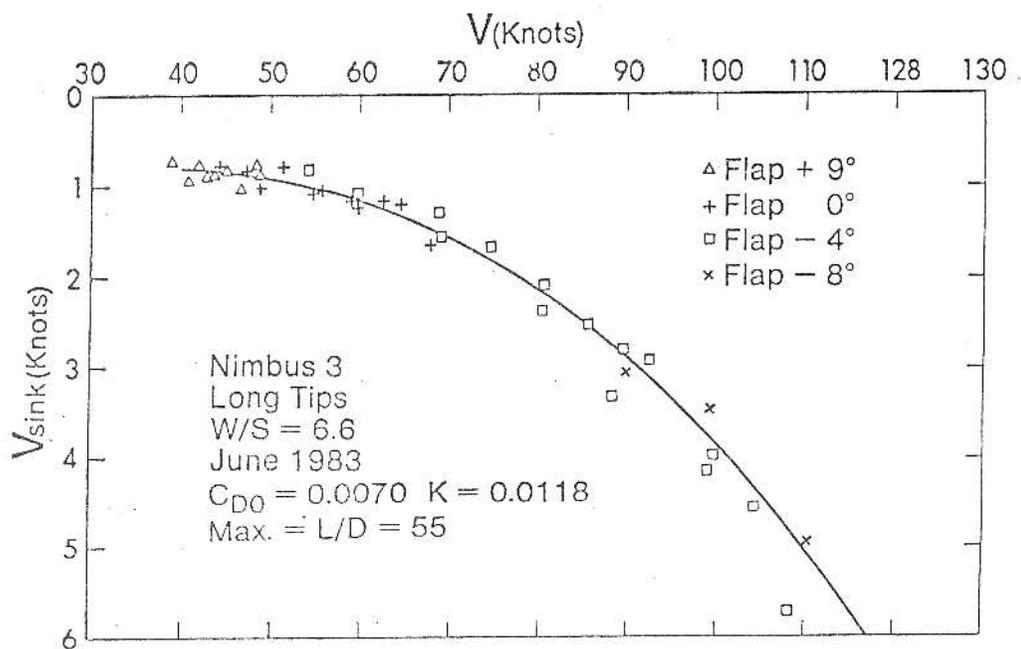
Figure 7(a).   Polar With 24.5 m Span

V (Knots)

V sink (Knots)

Nimbus 3
New Long Tips
W/S = 6.6
June 1983
$C_{DO} = 0.0070$ K = 0.0118
Max. L/D = 55

△ Flap + 9°
+ Flap   0°
□ Flap − 4°
× Flap − 8°
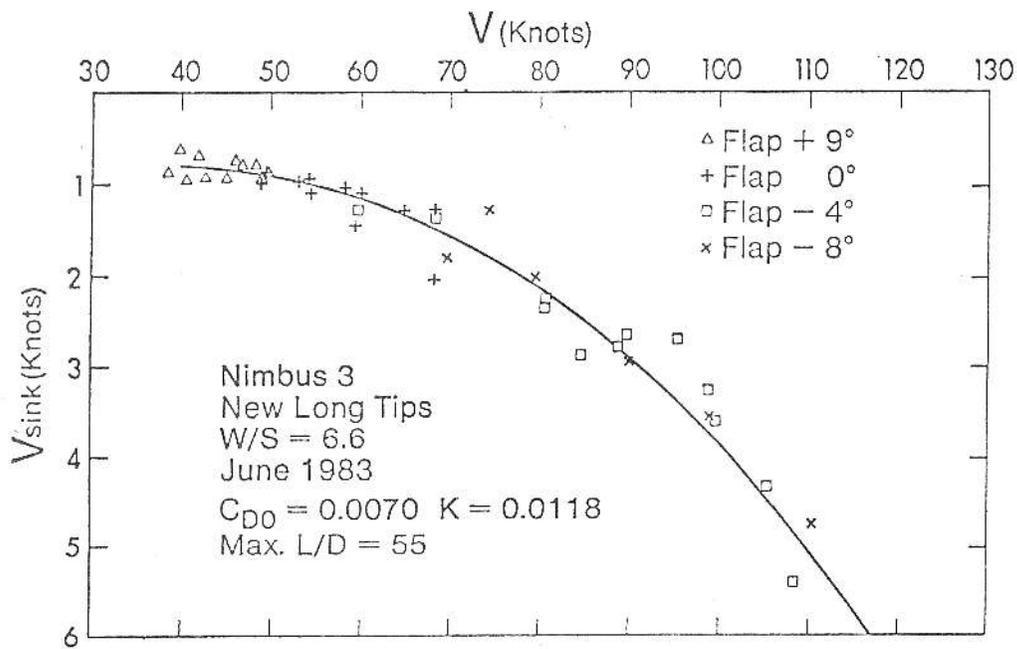
Figure 7(b).   Polar With 25 m Span

V (Knots)

V sink (Knots)

Nimbus 3
Winglets
W/S = 6.85
June 1983
$C_{DO} = 0.0076$ K = 0.0117
Max. L/D = 53

△ Flap + 9°
+ Flap   0°
□ Flap − 4°
× Flap − 8°
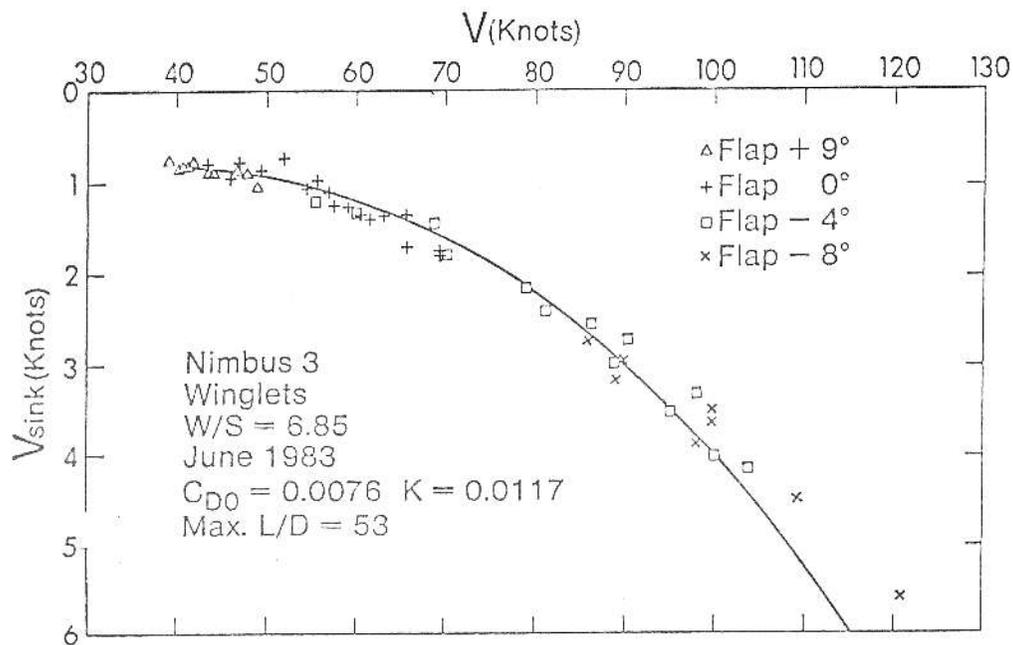
Figure 7(c).   Polar With 22.9 m Span and Winglets
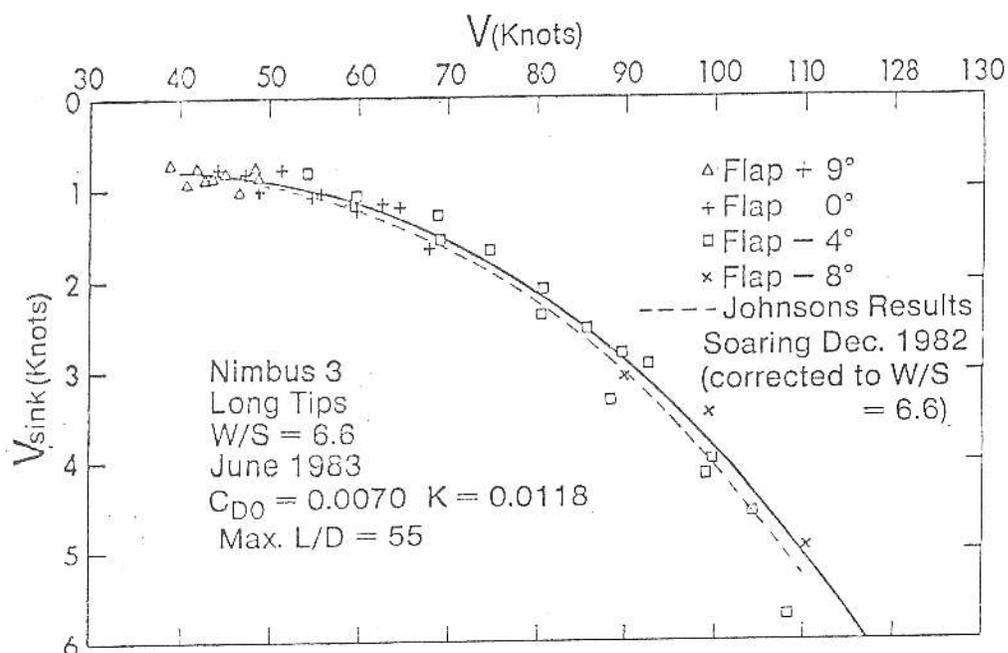
Figure 8.   Comparison with Johnson's Test Results