SAILPLANE PERFORMANCE MEASURED IN FLIGHT

Paul Bikle, Lancaster, California, U.S.A.

Presented at the 12th OSTIV Congress, July 1970
Alpine, Texas, U.S.A.

In the past year, members of the SSA Flight Test Committee have completed a portion of a continuing test program to measure the performance of a number of sailplanes. The long-range goal is to provide a body of performance data which will at least be consistent within itself and, hopefully, also be sufficiently accurate to be of interest in terms of absolute performance. A 100-hr test has essentially been completed on the T-6, a modified HP-14 sailplane; this sailplane was then used as a basis for comparative tests to establish the performance of seven other sailplanes. This summary report describes the T-6, the performance data obtained, the test techniques and data reduction procedures, and then briefly covers the comparison tests and results obtained for the other seven sailplanes.

External aerodynamic design of the T-6 is essentially the same as the HP-14T except for an additional 15-in. tip on each wing, which makes the span an even 57 ft. Twenty inches on the outboard end of each flap have been converted to ailerons. Generally, the sailplane is of all metal construction; has a shoulder-high wing, a retractable gear, simple hinged flaps with no speed brakes or tail chute; and is of medium aspect ratio and wing loading. Construction and assembly techniques were modified significantly to eliminate the use of pop rivets and a number of changes were made in the flight control system and flap actuation linkage. As a "homebuilt," it was more convenient to register it as a T-6 with obvious reference to the tee tail and the big number six painted on the vertical tail and on the underside of the right wing.

Figure 1 is a photograph of the sailplane. Side, top, and front views are shown in Fig. 2, and more detailed information is listed in Fig. 3. Profiles in Fig. 4 show the extent of the modification to the basic FX 61-163 airfoil and also the use of a constant 6-in. chord flap and aileron along the span of the tapered wing. Filling in the cusp on the lower surface (cross-hatched area) permitted the use of a deeper, constant cross section for the rear spar, flap, and aileron which greatly simplified the construction and is a standard feature of several HP designs.

As might be expected, the casual modification of an airfoil for the sake of simplified construction is not achieved without some loss in aerodynamic efficiency. The magnitude and character of this reduction in efficiency has only become apparent as the testing has progressed. In analyzing the performance data for the T-6, it is apparent that filling in the cusp has removed an effective part of the camber or curvature from the back of the wing so that the wing must be flown at about one or two degrees more nose up with relation to the air in order to provide the same lift. Also, the maximum lift

FIGURE 1

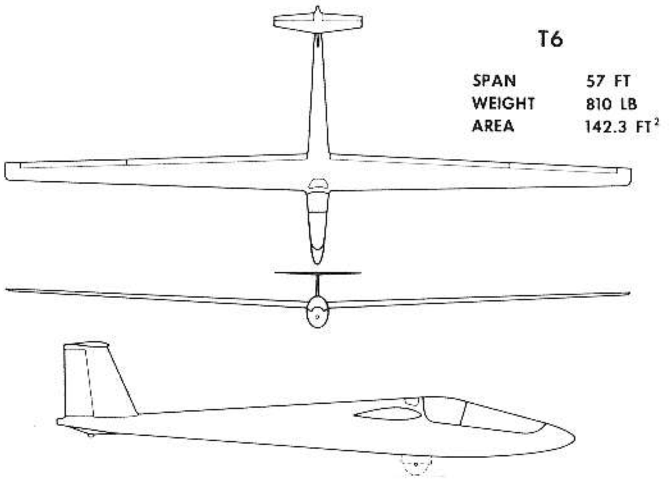
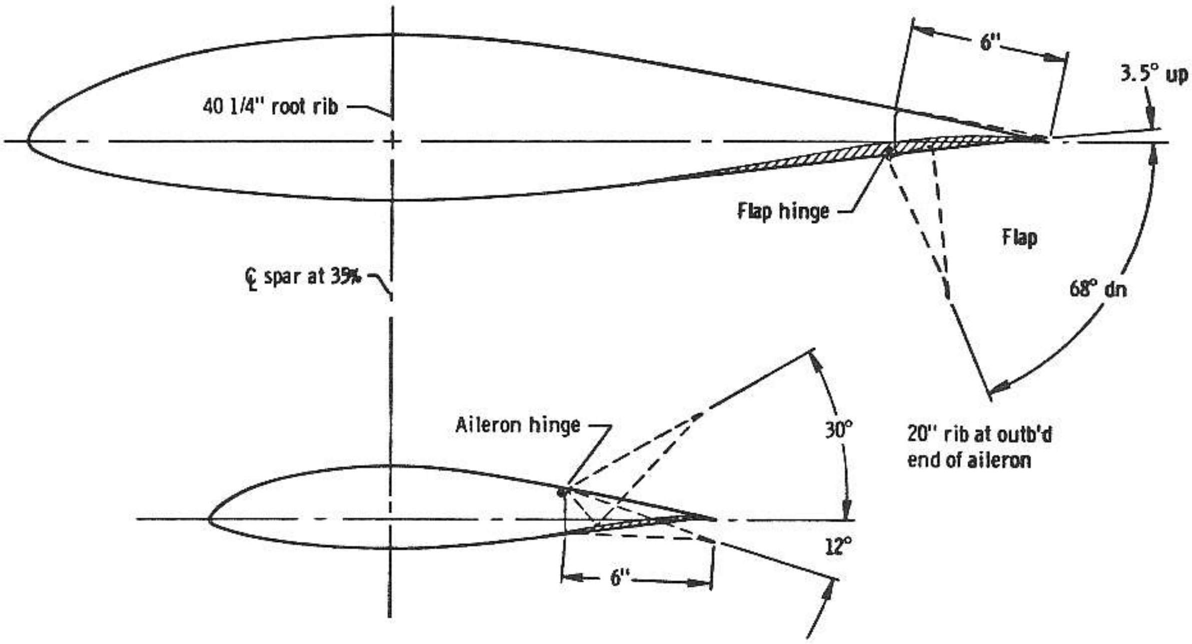


FIGURE 2

T-6 AS TESTED - 1969 & 1970

Wing		**Horizontal Tail**	
Span	57' 0"	Span	102.7"
Area	142.5 ft^2	Area (inc. elev.)	11.4 ft^2
Root chord	40.6"	Elevator hinge line at	60 percent
Tip chord	19.4"	Aspect ratio	6.4
MAC	30.0"	Incidence	-2.6°
Aspect ratio	22.8	Elev., deg up	17°
Incidence	0.5°	Elev., deg down	12.5°
Dihedral (static)	2.1°	**Vertical Tail**	
Sweep (35 percent)	0°	Height	42"
Twist	0°	Area (incl. rudder)	9.3 ft^2
Taper ratio	2.09	Rudder area	3.9 ft^2
Thickness (percent)	16.5	Rudder hinge line on left side	
Airfoil	Mod. FX61-163	Degrees left	24.8°
Flap		Degrees right	25.0°
Span (each)	16' 6"	**Fuselage**	
Chord	6"	Length	23' 6"
Area (each)	8.25 ft^2	Depth at cockpit	32.8"
Avg. percent chord	17.7 percent	Width at wing	24"
Degrees up	3.5°	Landing gear	Retractable
Degrees down	68°	Wheel	5.00 × 5
Actuation	Manual	Brake	Hydraulic
Aileron		Tow hook	Retractable
Span (each)	9' 8"	**Weights**	
Chord	6"	Wings	330 lb
Area (each)	4.8 ft^2	Fuselage and tail	260 lb
Avg. percent chord	23.5 percent	Gross (as flown)	810 lb
Degrees up	30°	c.g. (as flown)	32.5 percent
Degrees down	12°		

FIGURE 3



Wing profiles with cross hatched areas showing HP-14 modification of basic FX 61-163 airfoil and flap and aileron detail

FIGURE 4

that can be obtained is about 15 percent less than would have been anticipated with the basic airfoil. Normally, the original characteristics of the airfoil might be substantially restored by some small flap deflection to approximate the camber of the unmodified airfoil. Tests with flaps down 7 deg show that the maximum lift and angle-of-attack relationships of the sailplane are about the same as for the unmodified airfoil. Measurements of section profile drag with a traversing probe located behind the trailing edge, now in progress, show that the section drag of the wing is reduced to about the level that would be obtained with the unmodified airfoil when about 4 deg of down flap is used. However, the performance of the sailplane is deficient at the slower speeds and use of even the 4-deg flap setting only increases the drag at all usable flying speeds down to one or two knots above the stall.

This is not too surprising considering that the flaps extend over only part of the wing span and that the constant 6-in. flap chord is 21 percent of the wing chord at the outboard end of the flap and about 15 percent of the wing chord at the root end. Also, the ailerons do not move with the flap so that any use of flaps creates an unfavorable and nonuniform change in the distribution of lift along the span which results in increased induced drag. The net result is that the drag is greater than it should be at slower speeds as a result of filling in the lower surface cusp and that the reduction in profile drag that is obtained with small flap deflections at these speeds is more than offset by higher drag due to lift because of the poor span lift distribution with use of flaps. The sailplane is quite efficient at high speeds but deficient at the slower speeds. The wing loading is kept low to obtain acceptable slow-speed performance and the high-speed performance then suffers because of the low wing loading.

Wing angle of incidence or angle with relation to the fuselage is only one-half degree which would be about right for a flapped wing with the unmodified airfoil. The increase in angle-of-attack caused by the airfoil modification and the inability to use the flap at slow speed for best performance results in a nose high attitude in slow flight and thermalling which is apparent, and looks inefficient, even to the casual observer. Overall sailplane performance could be improved by linking the ailerons to the flap and providing for segmented differential operation of the flaps. A better approach would involve a new wing with an airfoil selected for good performance with flaps and with both flaps and ailerons designed to move in such a way that a more uniform span lift distribution would be maintained.

Measurements of wing surface waviness have been made at 20 stations along the span of the wing. Data obtained with a surface gauge showing surface curvature in increments of one-thousandth of an inch over a 2-in. arc are plotted in Fig. 5 (gauge shown in Fig. 5a). Surface waves appear as departures from the mean or average dashed line drawn for each station. Waves of several thousandths of an inch are apparent in the forward 30 percent of the wing chord and the outer portions of the wing show a larger wave near the spar at 35 percent chord. Metal skins of the type used in this wing might also be expected to change contour in flight. At the moment, the degree to which this occurs is unknown, but one recheck was made at station (12) on the top of the right wing with the wing loaded statically to represent a 1-g flight load (triangle points plotted in Fig. 5). There was no measurable change in contour at this station at least.

The wing appears to be very smooth and all gaps are well sealed. Yet it would be unreasonable to expect large areas of laminar flow with the degree of waviness that exists and the wave near the spar in the outer wing panels could even be suspected as a source of flow separation. On the other hand, the flow on the wings was observed in flight, Fig. 6, with every indication that the flow did not separate but stayed attached at all speeds of interest. Section profile drag tests with a probe traversing the wing wake behind the trailing edge have also demonstrated that some laminar flow does exist, particularly at the higher speeds, at the wing stations where the tests were made.

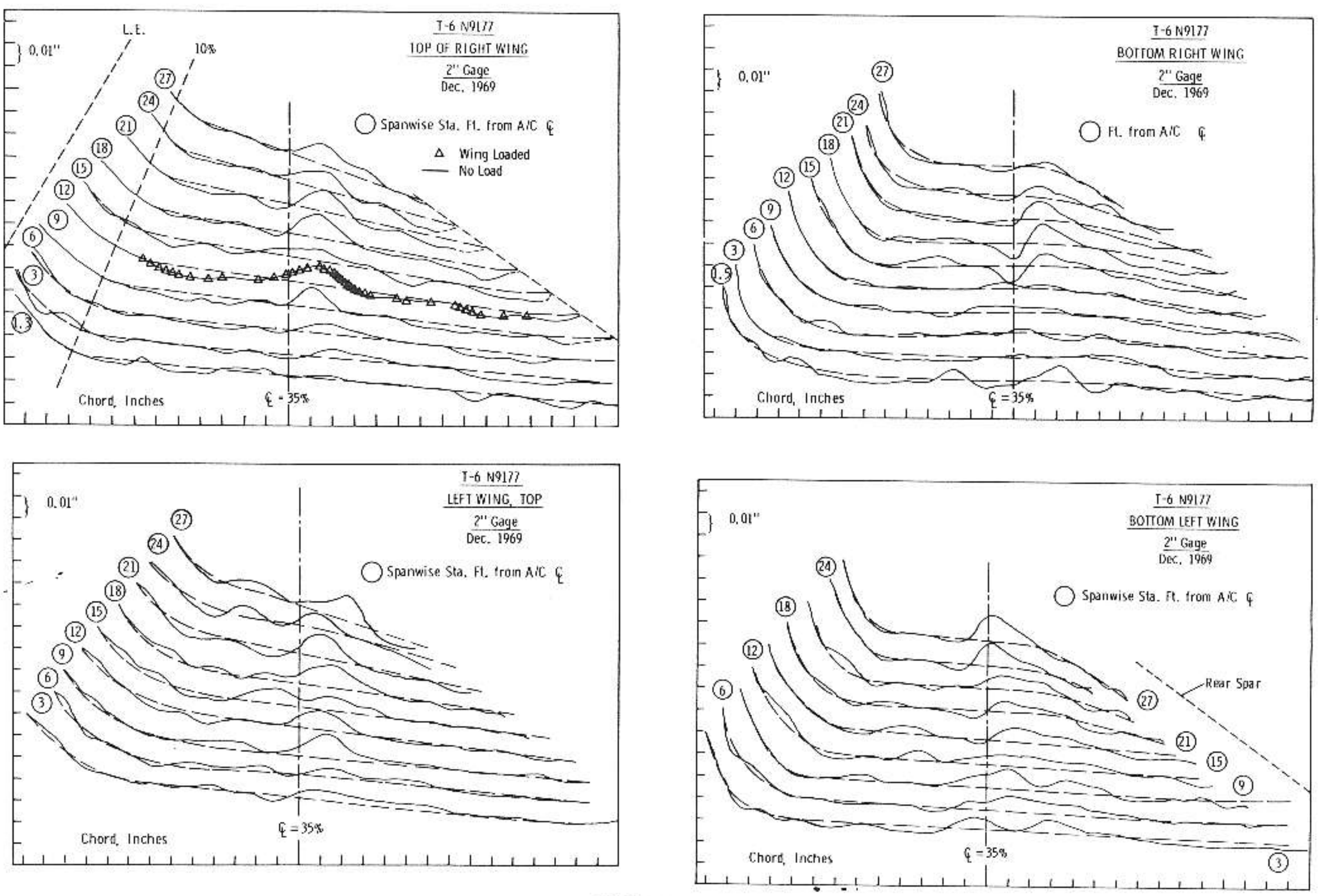


FIGURE 5

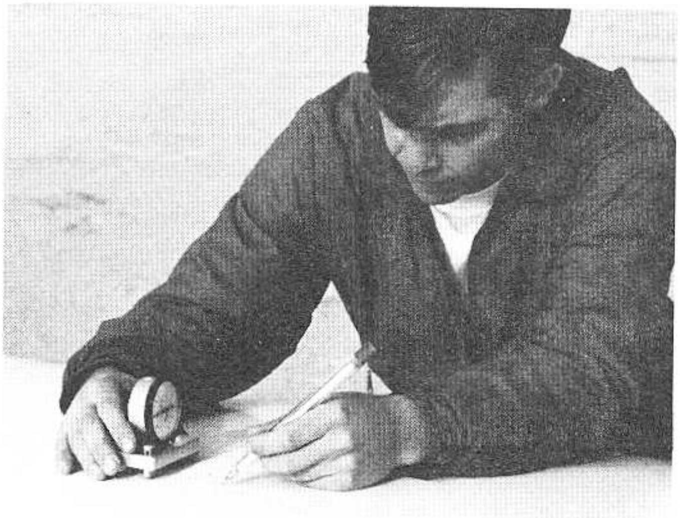


FIGURE 5a

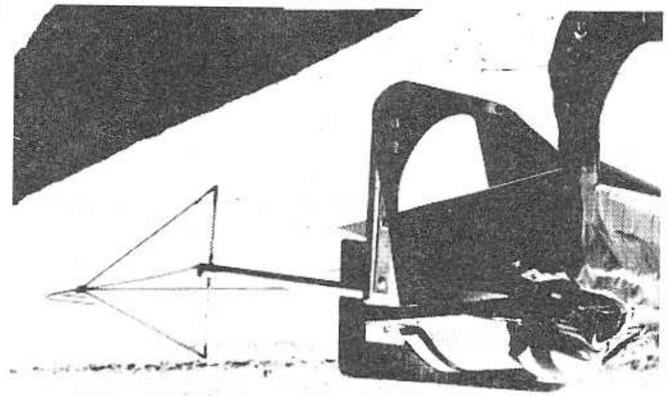


FIGURE 5b

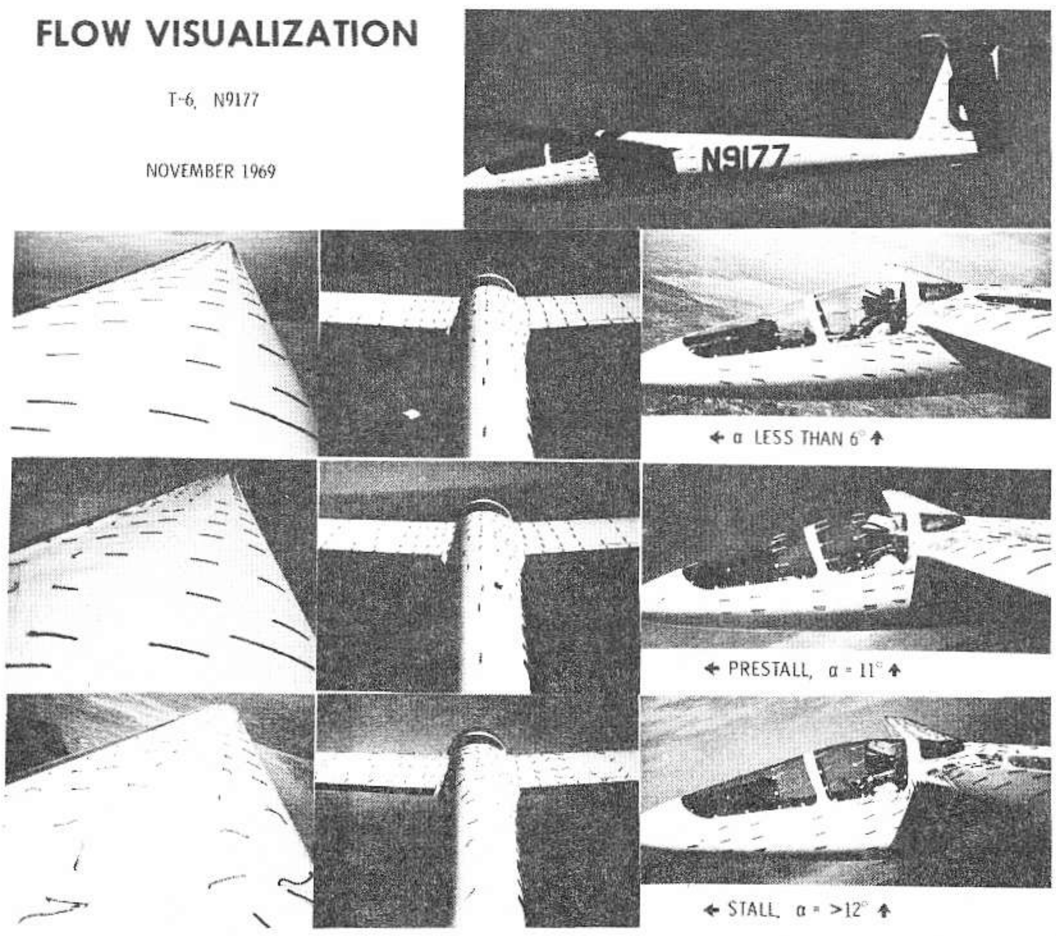


FIGURE 6

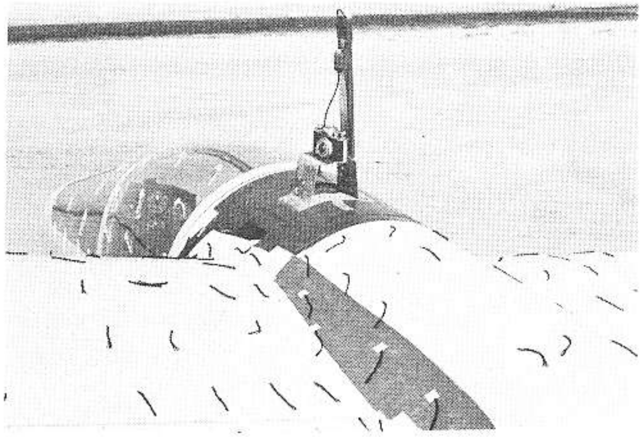


FIGURE 6a

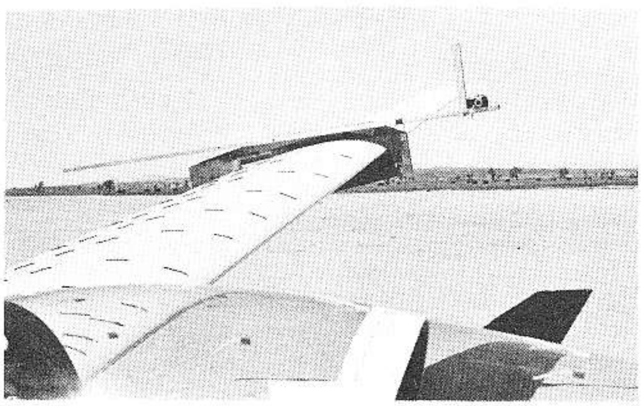


FIGURE 6b

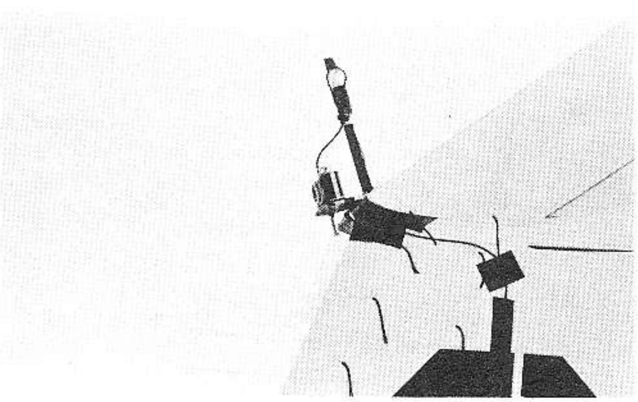


FIGURE 6c

So far, the discussion involving the flaps has only touched on the fact that these particular flaps, along with the filled-in airfoil cusp, were not particularly efficient in the speed range near minimum sink. It would be wrong to infer that flaps should not be used. In most other respects, the flaps are one of the best features of the sailplane; they are very effective in reducing the stall speed, providing more than adequate approach path control, and as air brakes at high speed.

Some concern has been expressed about the possible accident potential involved in using flaps for approach path control if an inexperienced pilot might pull up the flaps to extend the glide when flying at a speed below the flaps-up stall speed. Obviously, one should maintain a safe speed for flaps-up flight if this is the case; but, in doing so, some of the advantage of a slow approach and a minimum flare distance and touchdown speed is sacrificed. Flap actuation on the T-6 is provided by two handles as shown in Fig. 7: one handle is used to set the flaps to an approach setting (30 deg) when entering the pattern; the second handle is identical in location, function and operation to a speed brake handle and is used for approach path control using the remaining 40 deg of flap available as required by the pilot. Stall speed is reduced from 38 knots (0-deg flap) to 32 knots with the flaps set in the approach position. Normal pattern speeds of from 45 to 50 knots may be used with performance generally falling between that of a 2-22 and a 1-26. Use of the remaining 40 deg of flap as required for speed or height control provide much greater effectiveness than available with the 1-26 speed brakes and has less than 2 knots effect on the stalling speeds. Measured data defining flap characteristics in terms of lift, drag, angle-of-attack, loads, and hinge moments are shown later in the performance summary.

Figure 8, showing the T-6 in a normal steep approach, conveys the correct impression of an outstanding capability to land over obstacles into small fields. The steep approach, good view over the nose, short flare distance, and low touchdown speed (30 knots) couple with a large, rugged, shock-strut-supported retractable landing gear and a powerful hydraulic brake to give an overall short field performance superior to any other sailplane with which we are familiar. The extended

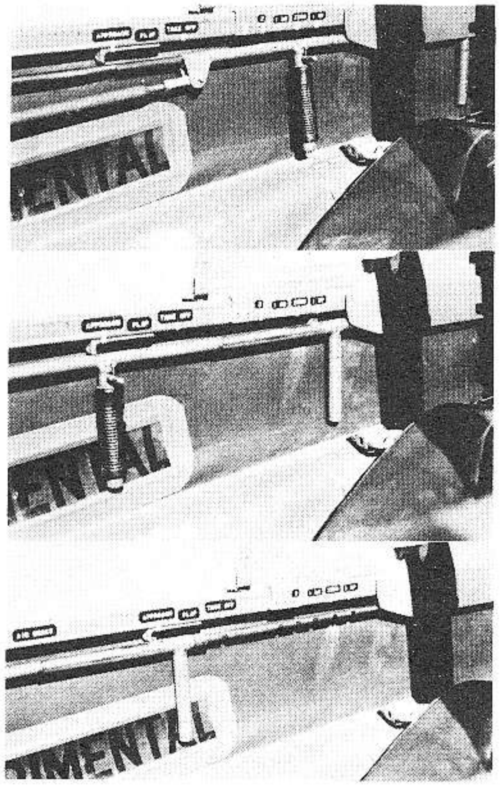


FIGURE 7

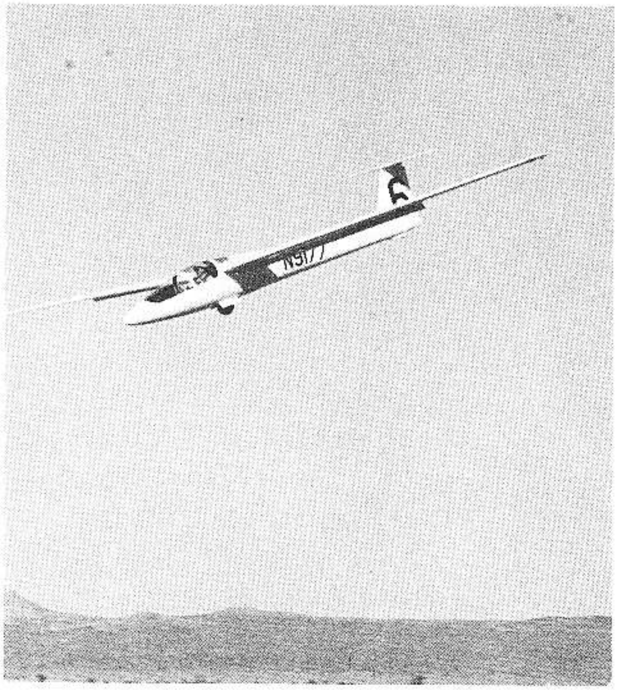


FIGURE 8

landing gear may be seen in the same picture; there is plenty of ground clearance and the doors are well out of the way of ground objects.

During the comparison tests, it was possible to obtain direct comparisons of the performance of the T-6 with the landing gear extended and with the gear retracted to measure the difference in rate of sink attributable to the landing gear at a series of speeds. Results of these tests are shown in Fig. 9. The incremental drag very nearly approaches 10 percent of the zero lift drag of the sailplane. Component drag data of this type are of considerable value as a reference for designers to complement the more general drag references such as those in Hoerner's Fluid Dynamic Drag (13-4-5).

Even for this large and very dirty extended gear, the increase in rate of sink is only about 4 ft/min at 40 knots, 15 ft/min at 75 knots, and 55 ft/min at 110 knots. Obviously, the drag of a smaller, well-faired, and sealed fixed wheel buried in the fuselage would be a small fraction of that shown in Fig. 9. The great advantage of the retractable gear is not reduction of drag over that of a clean fixed gear installation; but, rather, the adequate ground clearance, reduction in wing incidence, ability to

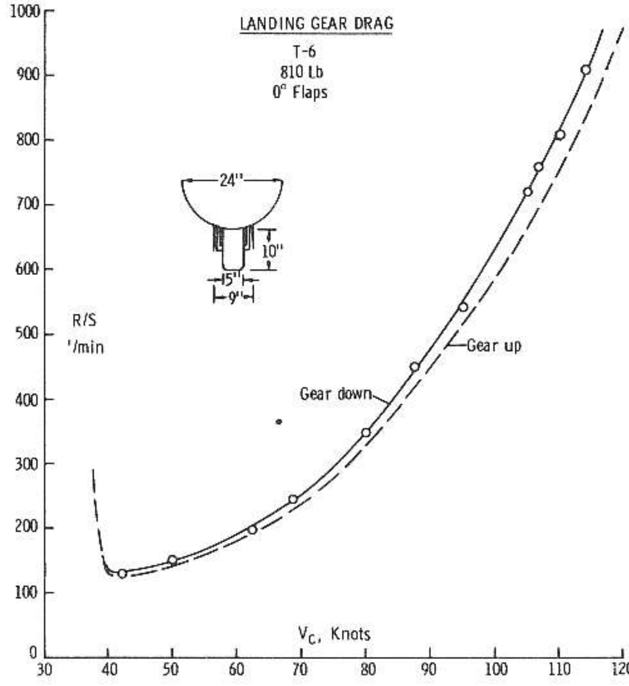


FIGURE 9

use a larger wheel, shock struts, and powerful brakes without an undue drag penalty.

Another factor that may be of some concern in considering the performance of a sailplane is the amount of elevator deflection required to trim the sailplane for various speeds. Elevator angles measured at different speeds are shown in Fig. 10 for the T-6; these reflect a reasonable horizontal stabilizer angle and are well within the range for efficient operation as well as showing an adequate level of longitudinal stability for the flight conditions that prevailed for these tests.

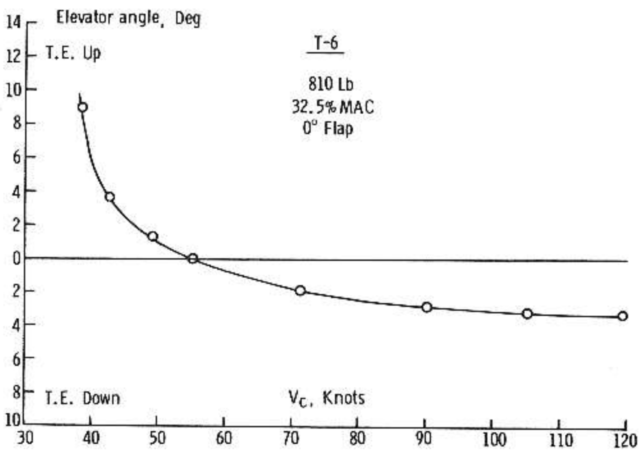


FIGURE 10

The airspeed system consists of two static orifices located on the side of the fuselage nose and a total pressure probe located in the nose duct that furnishes air for ventilating the cockpit (Fig. 11). A great deal of attention has been given to the determination of airspeed system errors to ensure accurate calibrated airspeeds. Figures 12 and 13 show that, for this installation, the errors are small; and, generally, the system performs in a satisfactory manner for a sailplane. Calibration flights were made on eleven occasions. These included two series of tests with airplanes that had been calibrated over a ground speed course; calibration against a test airspeed system consisting of a wing boom-mounted swivel airspeed head 2.3 chord lengths ahead of the wing as shown in Fig. 14; calibration with a trailing static cone as a reference (Figs. 15 and 16); and calibration against a previously calibrated SHK. Check calibrations were also made during the comparison tests. All gave consistent results with a scatter of less than ±1 knot.

Test procedures and data reduction were generally the same as those used by many others over the past 30 or 40 years and very similar to those described in some detail by Dick Johnson in "Sailplane Flight Test Performance Measurement," in the April 1968 Soaring magazine. There was nothing new or exotic about either the instruments or techniques used in the tests. Nor was there any single aspect of the work that was particularly difficult. Yet the overall magnitude of the task in its requirement for extreme care and attention to detail, for integrity and objectivity, for a good understanding of the factors involved, as well as the time and expense and the need for sufficient interest in the results to follow it through to the end, all tend to place the work well beyond the scope of a casual past-time effort. There does seem to be an inordinate amount of work involved and one would hope that there would be an easier way.

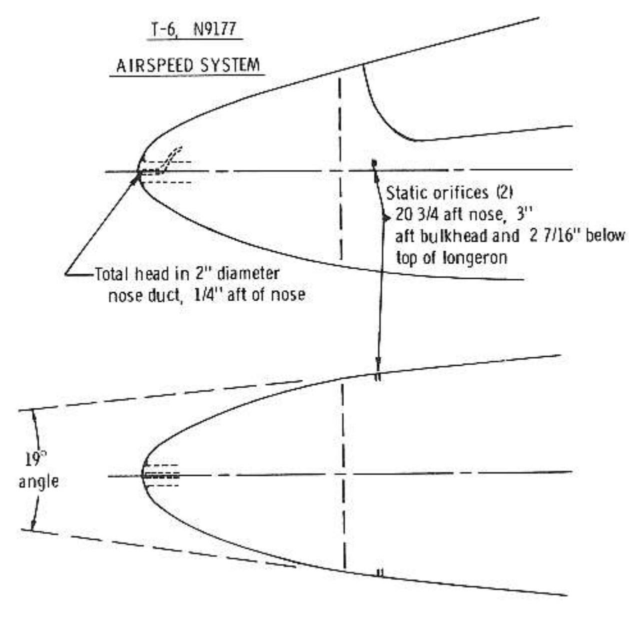


FIGURE 11

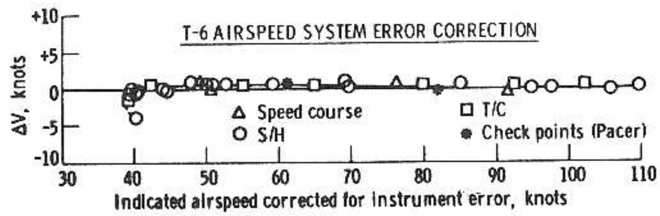


FIGURE 12

T-6 N9177

POSITION ERROR CORRECTION

Flaps

810 Lb, c.g. = 30%

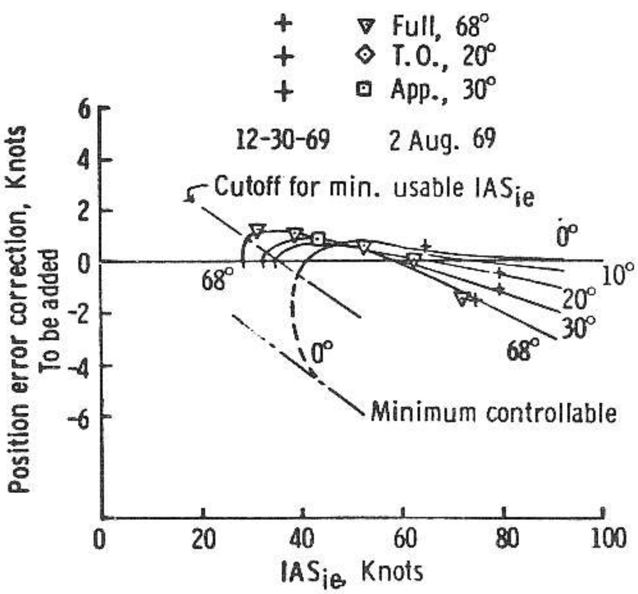


FIGURE 13

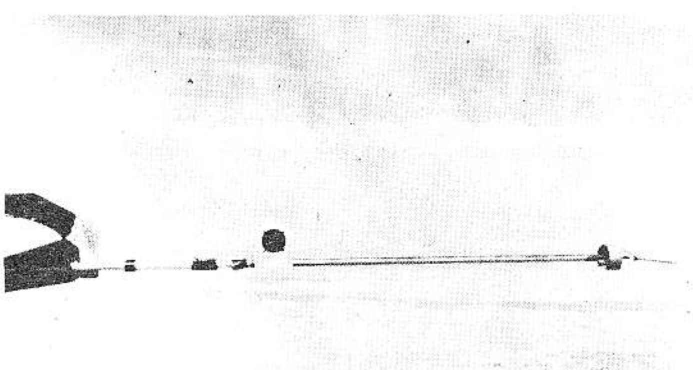


FIGURE 14

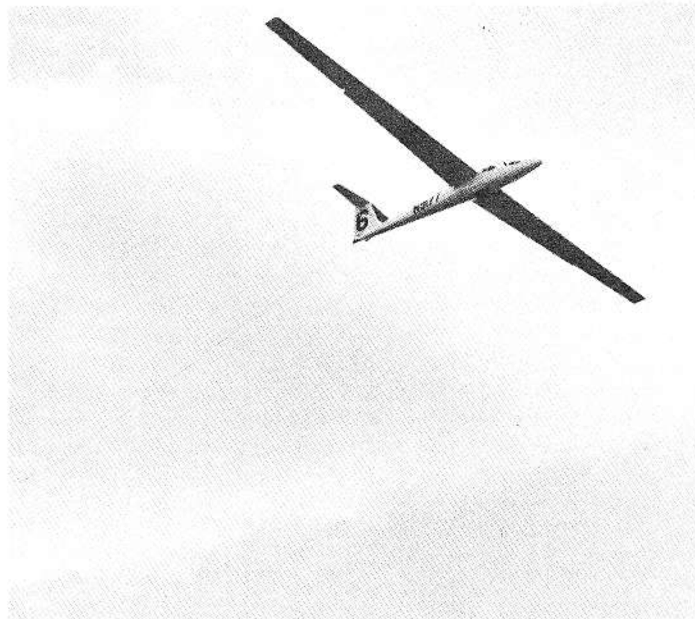


FIGURE 15

FIGURE 16

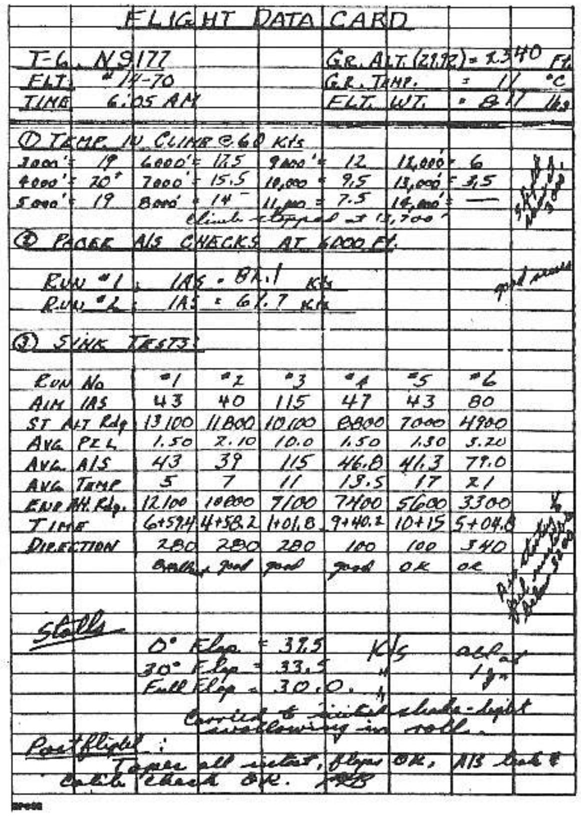
Many other techniques and modifications of this procedure have been suggested and a number used with varying degrees of success. Most involve new instrumentation approaches such as towline force gauges, sensitive accelerometers, or relatively extensive ground tracking systems. These have had a tendency to evolve into instrument development projects or have involved even more work than required by what, at first glance, may appear to be an old-fashioned, brute force approach.

A number of new suggestions appear to be attractive because they may require only one or two short flights to obtain all data necessary for a complete polar. However, it turns out that the greatest source of error in most approaches is the inability to know for certain what the air is doing. The sailplane flies through the air and its performance is relative to the air. About all that we can do is to fly only in air that appears to be stable and to do so enough times to have some assurance that at least, on the average, the air truly represented "still air." Any procedure or tests based on one short series of tests on one or two days is unlikely to solve this aspect of the problem, which inherently requires repeated sampling.

In any event, the general approach used in these tests appears to provide consistent data. Following it through in a step-by-step fashion may be of some interest and will at least provide a basis for judging the adequacy of the performance data presented.

Rate-of-sink tests were all timed runs at constant speed for a minimum of at least five minutes or 1000 ft; some were continued for as long as 15 min., and some for as much as 5000 ft of altitude. All were made on very early morning flights to altitudes in the neighborhood of 12,000 to 13,000 ft on days when the lapse rate was stable and wind velocities and wind shear were at a minimum. Temperatures were measured in flight; the aircraft had been weighed on several occasions during the flights; instruments were calibrated; and the configuration was carefully controlled during the period of the tests.

A typical flight data card is shown in Fig. 17 for the last flight made in the program to ensure that there had been no change in performance. These data were obtained early in the morning; stable air and low winds had been forecast; temperature readings (^{O}C) taken in the climb confirm the stable lapse rate. The climb had been interrupted at 6000 ft to make two level flight pacer airspeed calibration checks with a calibrated airplane. Six stabilized tests were made to



FLIGHT DATA CARD

T-6, N9177 — GR. ALT. (29.92) = 2340 Ft.
FLT. #14-70 — GR. TEMP. = 11 °C
TIME 6:05 AM — FLT. WT. = 811 lbs

① TEMP. IN CLIMB @ 60 Kts

3000' = 19	6000' = 17.5	9000' = 12	12,000' = 6
4000' = 20	7000' = 15.5	10,000 = 9.5	13,000' = 3.5
5000' = 19	8000' = 14	11,000 = 7.5	14,000' = —

climb stopped at 13,700'

② PACER A/S CHECKS AT 6000 FT.

Run #1 : IAS = 82.1 Kts
Run #2 : IAS = 61.7 Kts

③ SINK TESTS:

RUN No	#1	#2	#3	#4	#5	#6
AIM IAS	43	40	115	47	43	80
ST ALT Rdg	13100	11800	10100	8800	7000	4900
AVG PZL	1.50	2.10	10.0	1.50	1.30	5.20
AVG A/S	43	39	115	46.8	41.3	79.0
AVG TEMP	5	7	11	13.5	17	21
END Alt. Rdg.	12100	10800	7100	7400	5600	3300
TIME	6+59.4	4+58.2	1+01.8	9+40.2	10+15	5+04.8
DIRECTION	280	280	280	100	100	340
	[illegible] good	good		good	OK	OK

Stalls

0° Flap = 37.5 K/s
30° Flap = 33.5 "
Full Flap = 30.0 "

Postflight:
Tapes all intact, flaps OK, A/S leak & calib. check OK.

FIGURE 17

measure rate of sink as shown in Part 3 of the card. Indicated airspeed is in knots, altimeter readings in feet, PZL variometer readings in knots, temperature in ^{O}C and time in minutes and seconds. Slight atmospheric instability was noted below 3000 ft and the remaining altitude was used to recheck stall speeds as defined by initial shake and light wallowing in roll. Postflight checks of all seals, as well as airspeed leak checks and spot calibration checks, were also made before securing the sailplane at the end of the flight.

These data must be corrected for instrument errors, corrections made for airspeed system error, and all corrected to a standard atmospheric set of conditions corresponding to flying at sea level in an atmosphere with the characteristics listed in the table in Fig. 18.

The altimeter calibration is shown in Fig. 19. If the instrument had no error, the altitude reading and pressure relationship would be the same as that shown in Fig. 18. Corrections in Fig. 19 show the number of feet to be added to the indica-

TABLE I STANDARD ATMOSPHERE					
Height, ft	Pressure, in. Hg	Temp., °C	Height, ft	Pressure, in. Hg	Temp., °C
S. L.	29.92	15	8,000.	22.22	-1
1000	28.86	13	9,000	21.38	-3
2000	27.82	11	10,000	20.58	-5
3000	26.81	9	11,000	19.79	-7
4000	25.84	7	12,000	19.03	-9
5000	24.89	5	13,000	18.29	-11
6000	23.98	3	14,000	17.57	-13
7000	23.09	1	15,000	16.88	-15

FIGURE 18

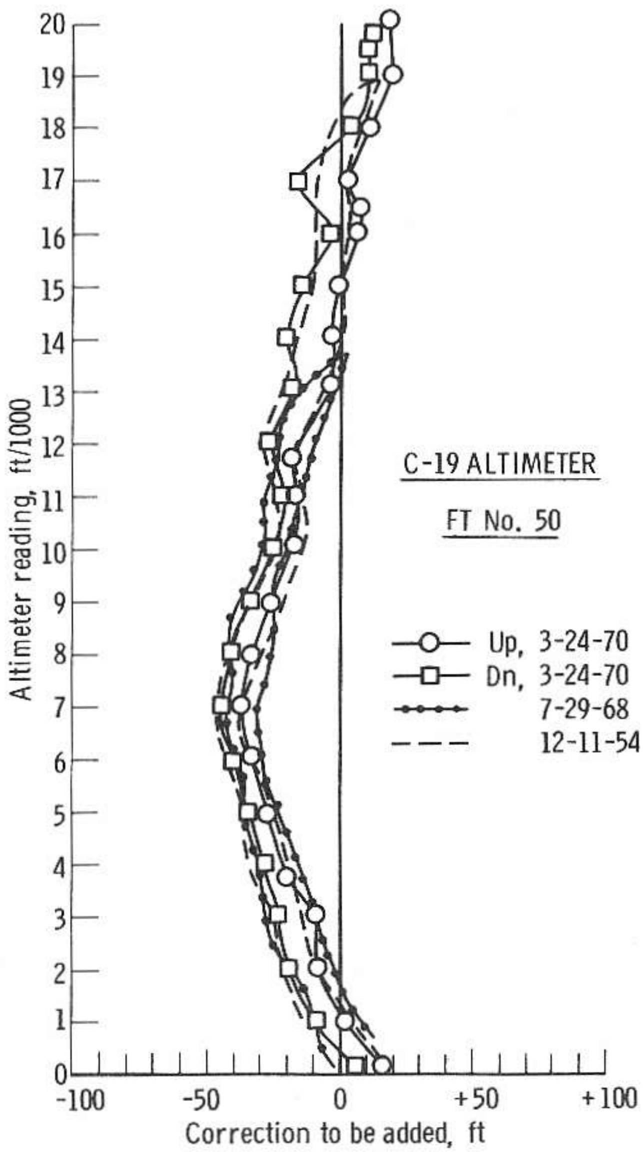


FIGURE 19

ted reading to obtain the correct relationship. All calibrations and all flight readings are made with the altimeter set to the standard sea-level pressure of 29.92 in. Hg. The most recent calibration is plotted with one set of points (represented on the graph by circles) obtained while the pressure was dropping and another set of points (squares) plotted while the pressure was increasing. This particular altimeter has been calibrated at least once a year over the past 17 years. Calibrations made in 1968 and 1954 are also shown in order to show the consistency that may be obtained. Errors amount to as much as 45 ft, but all the data generally fall within a band of about 25 ft and are consistent to within about ±5 ft when upward or downward movement of the indicator is taken into account. The difference between the up and down movement represents sort of a loop, and this characteristic is generally referred to as "hysteresis" in the instrument; it may be easier to just think of it as "slop" between up and down. Note that the calibration was started down at different readings on the several calibrations shown, and that it takes about 400 ft to move fully over to the down curve once the down part of the cycle is started. With some care in setting up the tests in flight, it is possible to take test readings so that they fall well within the down sequence where the error is known to about ±5 ft.

Few altimeters are as consistent as the one in Fig. 19. Most good altimeters will have somewhat greater errors; but, more important, the consistency may be more like ±10 ft. Many altimeters are worse than this and are completely unsuited to test work. Only careful and repeated calibration will tell the story. Whatever the instrument's characteristics, they must be considered in setting up the test points in flight. At best, if we measure the time to change from one reading to another, we have two readings and a total uncertainty of twice that for one reading. Even with the altimeter shown here, the uncertainty in a 100-ft increment could be ±10 percent, and for a 1000-ft increment would be ±1 percent.

By comparison, timing is relatively more accurate. Experience shows that stopwatch accuracy is generally about one second for a complete start-stop cycle, and we can be assured of 1 percent time data by keeping runs longer than 100 sec.

A more important reason for the longer runs is the possible effects of slight changes in speed (+1 knot), in which speed energy may be exchanged for height with a resulting effect on the overall accuracy. We generally like to use a minimum of 1000 ft or 5 min., whichever is greater, for a run. Even with the most careful work, these uncertainties plus others in speed measurement result in a total uncertainty for an individual point approaching 5 to 6 percent, but these uncertainties are random and tend to cancel; many repeated points provide the basis of a curve which is within 1 or 2 percent. Hopefully, repetition of points will also provide for averaging out any residual atmospheric instability, so that the final data may reasonably be expected to fall within this 1 to 2 percent range.

Airspeed indicator calibration data are plotted in Fig. 20. No effort has been made to account for hysteresis because flight tests are made at constant indicated airspeeds, where the actual speeds and pressures may be increasing or decreasing within the band of scatter of the plotted points. An average curve is faired through this scatter, and a good instrument will be consistent to about +5 knots or less. The magnitude of the error, or difference between the indicator reading and the correct value, is not important. Corrections can be made for errors but inconcistency results in uncertainty.

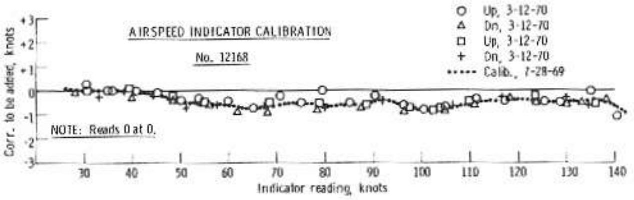


FIGURE 20

Referring again to the test data obtained on the final flight, the test data card shows indicated airpseeds for the T-6 of 82.1 knots and 61.7 knots for the two check points. Corresponding calibrated airspeeds (airspeeds that would have been indicated if there were no instrument errors or errors in the airspeed system) obtained from the pacer airplane were 81.1 knots and 61.8 knots. By correcting the T-6 indicated airspeeds for instrument errors, we find that the T-6 would have shown readings of 82.1 + (-0.6) = 81.5 knots and 61.7 + (-0.6) = 61.1 knots if its airspeed indicator had no errors. The difference between these speeds and the calibrated airspeed is then due to errors in the T-6 airspeed system. In this case, the system error corrections are 81.1 - 81.5 = -0.4 knots at 81.5 knots and 61.8 - 61.1 = 0.7 knots at 61.1 knots. These are plotted as points (asterisks) on Fig. 21 and show sufficient agreement with previously obtained points to permit us to proceed with assurance that there has been no change in the airspeed system calibration.

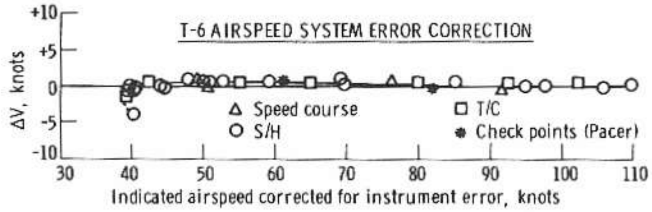


FIGURE 21

We are now ready to proceed with our calculations to find the actual rate of sink and airspeed we measured during the test and to reduce these to what we would have found if we had made the tests at sea level in a standard atmosphere. This relatively simple procedure is spelled out in a step-by-step fashion in the Table in Fig. 22. Lines 1 to 6 identify the test conditions; 7 to 12 are the readings noted on the Test Data Card. Corrections 13 and 14 are read from Fig. 19 and Correction 15 from Fig. 20. Line 18 represents the change in altitude that would have been shown by an altimeter with no error; line 19 is the average altimeter reading that would have been shown by this hypoethetical zero-error altimeter; and line 20 is the corresponding pressure of the air as obtained from Fig. 18 data plotted on a scale to permit reading pressure at 10-ft altitude increments; while line 21 is the corresponding temperature obtained from the Fig. 18 relationships. Lines 22 and 23 change the test temperatures and the standard-day temperatures for the same altitudes to absolute values by adding 273 to each; line 24 is the ratio of these absolute temperatures, which is used to calculate the actual change in height during the test.

TABLE II

	DATA REDUCTION TO S. L. STANDARD CONDITIONS						
1	Flight number	14-70	14-70	14-70	14-70	14-70	14-70
2	Symbol						
3	Run number	1	2	3	4	5	6
4	Gross weight, lb	811	811	811	811	811	811
5	Flaps, deg	0	0	0	0	0	0
6	Gear	Up	Up	Up	Up	Up	Up
7	Start altimeter, ft	13100	11800	10100	8800	7000	4900
8	Airspeed ind., kts	43.0	39.0	115	46.8	41.3	79.0
9	PZL R/S, kts	1.5	2.1	10.0	1.5	1.3	3.2
10	Average temp., °C	+5	+7	+11	+13.5	+17	+21
11	End altimeter, ft	12100	10800	9100	7400	5600	3300
12	Time, min	6.99	4.97	1.030	9.67	10.25	5.08
13	St. alt. error corr., ft	-15	-25	-30	-35	-45	-35
14	End alt. error corr., ft	-25	-20	-35	-45	-35	-25
15	Airspeed ind. corr., kts	-.1	0	-.5	-.2	-.1	-.6
16	Start alt. = (7) + (13), ft	13085	11775	10070	8765	6955	4865
17	End alt. = (8) + (14), ft	12075	10780	9065	7355	5565	3275
18	Δ alt. = (16) - (17), ft	1010	995	1005	1410	1390	1590
19	Avg. alt. = [(16) + (17)]/2, ft	12580	11280	9570	8060	6260	4070
20	Press. (table I) at (19), in. Hg	18.59	19.57	20.92	22.17	23.75	25.77
21	Std. temp. (table I) at (19), °C	-10	-7.5	-4	-1	+2.5	+7
22	Test temp. = 273 + (10), °C abs.	278	280	284	286.5	290	294
23	Std. temp. = 273 + (21), °C abs.	263	265.5	269	272	275.5	280
24	Temp corr. = (22) / (23)	1.058	1.055	1.055	1.055	1.053	1.050
25	Test ΔH = (18) × (24), ft	1069	1050	1060	1488	1464	1670
26	Test R/S = (25) / (12), ft/min	153	211	1030	154	143	329
27	Density ratio = 9.625 × (20) / (22)	.64	.673	.708	.745	.788	.840
28	Sq. root of dens. ratio, (27)	.8	.82	.842	.863	.888	.917
29	S. L. std. R/S = (26) × (28), ft/min	122	173	867	133	127	301
30	IAS = (8) + (15), kts	42.9	39.0	114.5	46.6	41.2	78.4
31	A/S system corr. (fig. 3), kts	+0.3	-0.5	+0.1	+0.5	+0.3	+0.7
32	V_c = (30) + (31), kts	43.2	38.5	114.6	47.1	41.5	78.7
33	R/S = (29) / 101.3, kts	1.205	1.707	8.56	1.313	1.254	2.97
34	L/D = (32) / (33)	35.9	22.6	13.4	35.9	33.1	26.5
35	W/S = (4)/142.5, lb/ft^2	5.69	5.69	5.69	5.69	5.69	5.69
36	C_L = 296 × (35) / (32) × (32)	.885	1.115	.126	.746	.962	.267
37	C_D = (36) / (34)	.0247	.0493	.00942	.0208	.0291	.0101
38	C_L^2 = (36) × (36)	.782	1.24	.0158	.555	.926	.0714

FIGURE 22

Note that the test temperatures were, on the average, about 15°C higher than the standard-day temperatures for the same altitude. An altimeter really only senses changes in pressure, and the actual change in pressure only corresponds to a change in height as shown in Fig. 18 when the air temperatures are those shown in Fig. 18. The pressures at each height, in effect, reflect the weight of a column of air at the point where the pressure is measured, and the difference in pressure at two heights reflects the weight of the portion of the column of air between those two heights. On a warm day, the air expands and it takes a greater difference in height to make the same difference in pressure; the reverse is true on a cold day. This change in height is proportional to absolute temperature and is taken into account on line 25 where we see, on the first run, that a difference in corrected altimeter readings of 1010 ft was really 1.058 x 1010 = 1069 ft in actual geometric height. On line 26 we divide 1069 ft by the time to find the true rate of sink during the test.

From here we need to find out what the rate of sink would have been if we had made the test at sea level in a standard atmosphere at the same indicated airspeed. If we keep the same indicated airspeed, we know that the glide angle and the ratio of rate of sink to true speed will be the same at sea level. We also know that, at this same indicated speed, the true speed at altitude will be reduced to a true speed at sea level by a factor equal to the square root of the ratio of the air density during the test to the standard sea-level air density. This ratio can be expressed in terms of temperature and pressure differences; the calculation is shown as line 27 and the square root as line 28. Since the ratio of rate of sink to true speed remains the same, it is necessary to multiply the actual test rate of sink by line 28 to find the sea-level rate of sink that would be obtained at this same indicated airspeed, as is done in line 29. The steps in this paragraph can be combined but are kept separate here in the hope of better explaining what is actually done. Also, by calculating the actual test rate of sink, line 26, we can compare this with the variometer reading to see if it is reading correctly.

The next step is to find what the indicated speed would have been if we had no instrument or airspeed system errors (at sea level on a standard day, this indicated airspeed would be the true speed). Line 30 is the airspeed reading from the Test Data Card corrected for the instrument error, and line 32 further corrects this for the airspeed system errors to give us what we call calibrated airspeed (V_C), or the indicated airspeed we would have at sea level in a standard atmosphere if there were no errors.

Each of the six test points (a circle with a dot inside) may now be plotted as rate of sink, line 29, vs. calibrated airspeed, line 32, on Fig. 23, which also shows the points obtained previously and the polar curve drawn through them. The agreement is excellent and we can safely conclude that the performance has remained the same throughout the seven months of testing. Finding corresponding L/D ratios, line 34, requires only that we convert the rate of sink, line 29, in feet per minute to rate of sink in knots, line 33, and divide this into the calibrated airspeed, line 32. The last four lines are concerned with the nondimensional aerodynamic coefficients, which are of interest, as well as being of considerable use in interpreting the results of the testing.

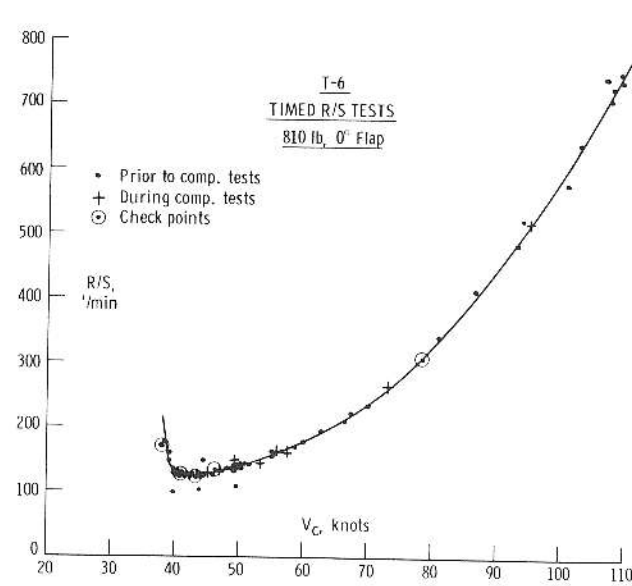


FIGURE 23

Referring again to Fig. 23, most of the points fall quite close to the curve which has been faired through them; almost all are much closer than the 5 to 6 percent uncertainty referred to earlier and this is normal. Yet, several of the points are much further off, and we can only infer that this is a result of undetected vertical motion in the atmosphere at the time of the tests. In particular, the three points showing very low sink rates at about 40, 44, and 50 knots were all obtained on one five-point flight early in the program. The other two points were the low point near 102 knots and a high-speed point, now shown, near 130 knots. Considered by themselves, these five points define a fairly representative looking curve with superior performance and a maximum L/D of about 45. Obviously, serious errors can be made in even the most closely controlled testing unless testing is repeated a number of times on different days.

All of the data obtained have been summarized in Figs. 24 through 29. In Fig. 24, test data at higher speeds for both 0-deg flap and 3.5 deg up flap have been added to the 0-deg flap data already shown in Fig. 23 and this same data plotted as $(C_L)^2$ vs. C_D in Fig. 25. The use of up flap is advantageous for improved performance only at speeds above those of general interest. Performance with flaps down is shown in Figs. 26 and 27 with all

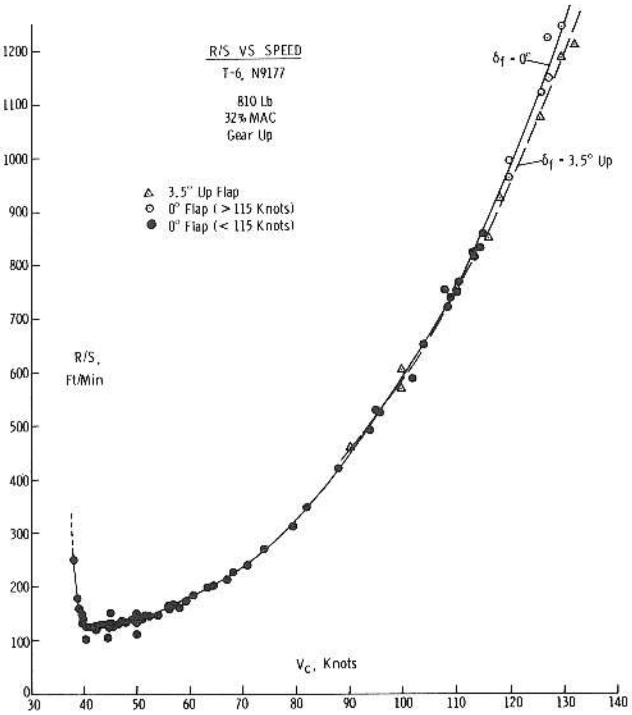


FIGURE 24

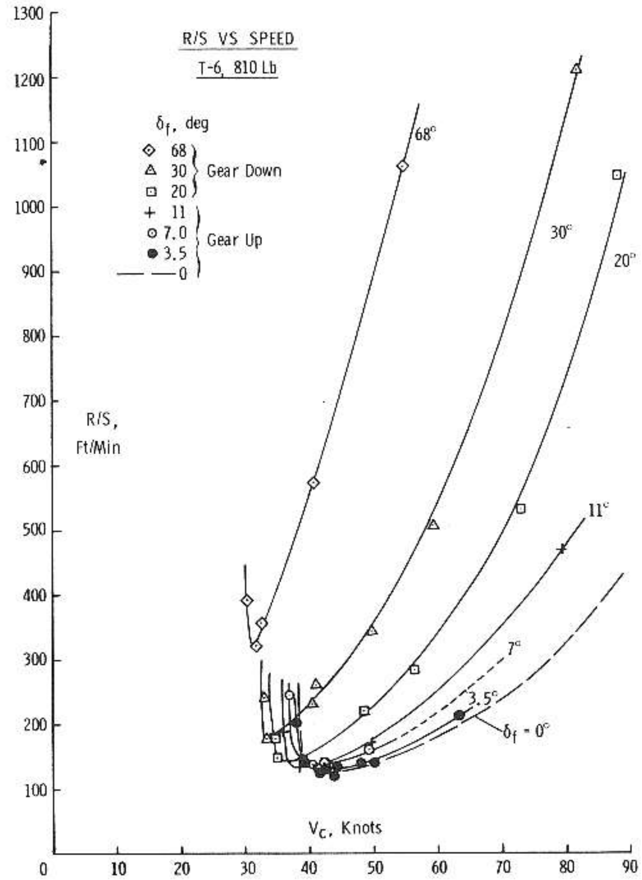


FIGURE 26

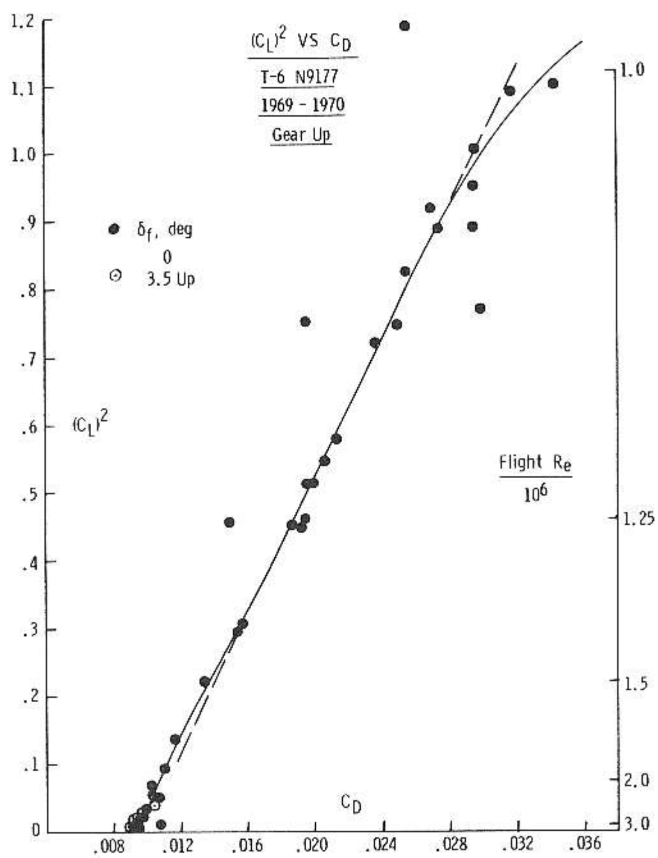


FIGURE 25

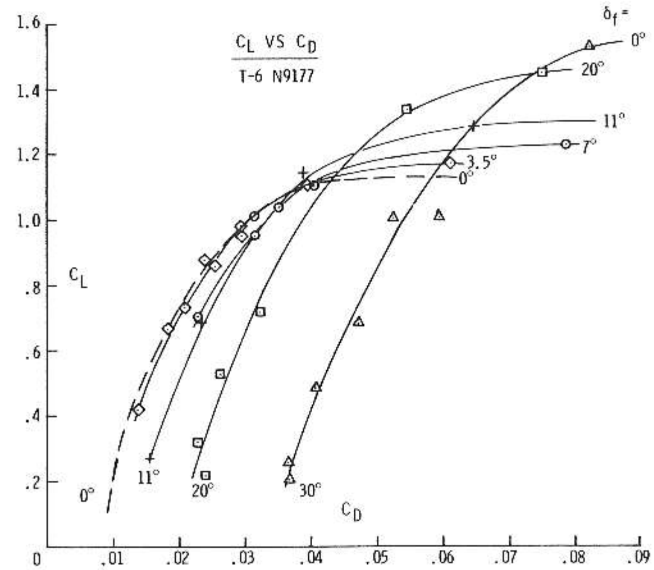


FIGURE 27

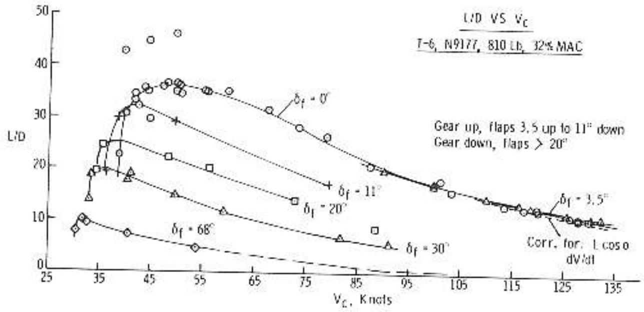


FIGURE 28

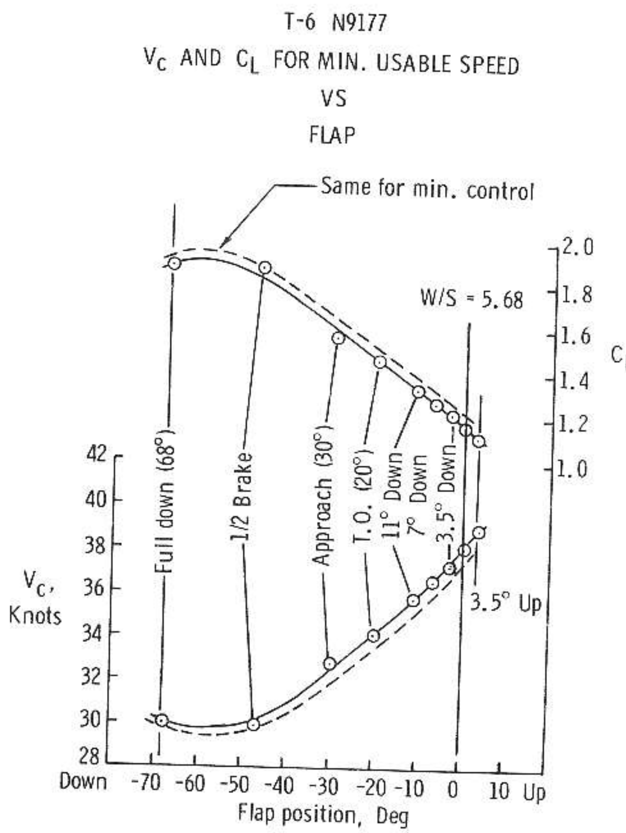


FIGURE 29

of the level flight data shown as L/D vs. speed in Fig. 28. Stall speeds and $C_{L\ max}$ have been shown as a function of flap setting in Fig. 29. In general, use of flaps is not advantageous in reducing sinking speed or for thermalling, except for situations which require flying at speeds below the 0-deg flaps stall speed.

Relationship of these data to angle-of-attack is shown as C_L vs. angle-of-attack in Fig. 30. Angle-of-attack was measured in tests using a piece of yarn mounted so as to be offset from the front of a 2.3 chord-length boom located at about the 40 percent semispan station on the wing (Fig. 31). The angle of the string relative to the chord line was then read directly through a calibrated goid scale marked on the canopy. Corrections were made for measured effects of "g" on the droop of the yarn at different speeds; and, also, corrections were made for the theoretical upwash at the position of the yarn as function of C_L. At the steeper glide or dive angles, angle-of-attack was determined from readings which were obtained from a sensitive inclinometer bubble and then related to the flight-path angle as determined from the performance tests. In these tests, bubble readings were corrected for the deceleration effects inherent in making tests at constant indicated speeds where the true speed is normally decreasing with altitude. Data from the two methods show good agreement and appear to be accurate within about ± 1 deg, which is insufficient for aerodynamic purposes requiring greater precision of measurement.

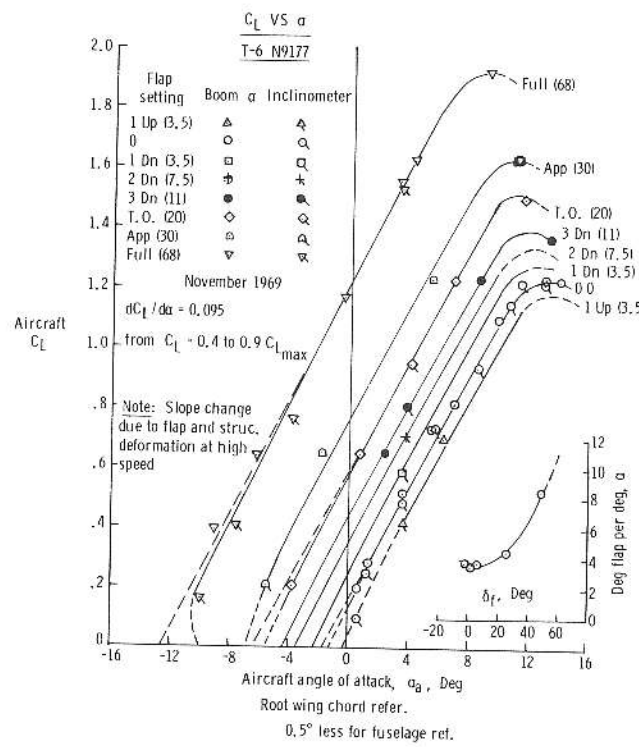


FIGURE 30

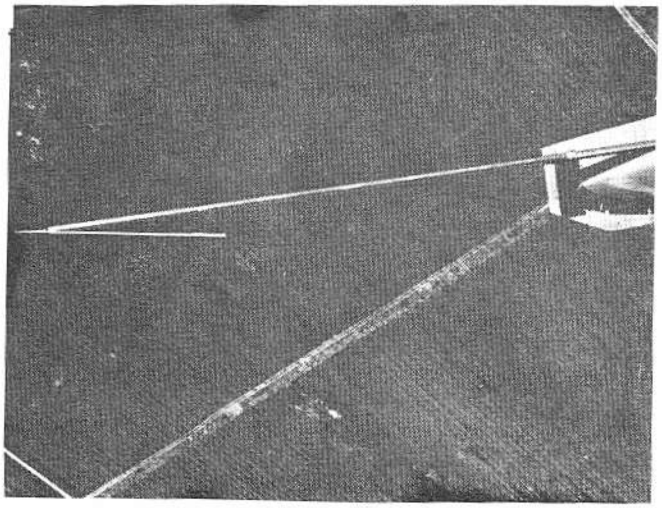


FIGURE 31

Flap loads were also obtained from measurements of the forces required at the flap handle in the cockpit. Handle loads vs. flap setting positions are plotted in Fig. 32. Forces and moments for representative flap settings are shown as a function of speed squared in Fig. 33, and as hinge-moment coefficients in Fig. 34. In general, all flap deflections listed in these tests are flap deflections measured on the ground for specific cockpit flap handle settings with the flaps statically loaded to simulate 1-g flight loads at 50 knots.

During the T-6 tests, a two-week period of relatively stable weather was used to carry out a series of comparative tests with seven other sailplanes: a Kestrel, Cirrus, Phoebus C, 16.5-meter Diamant, Phoebus A, BG-12, and a 1-26. Photographs of all of these sailplanes, except the Phoebus C, are shown in Fig. 35. Each sailplane was weighed, as flown, on calibrated platform scales which were placed in a hangar to avoid any effects of wind. Most weighings were close to the weights on the aircraft weight forms, but all were a few pounds heavier; one was found to be 79 lb heavier than listed. Wing surface waviness measurements were made for the forward 50 percent chord at six chordwise

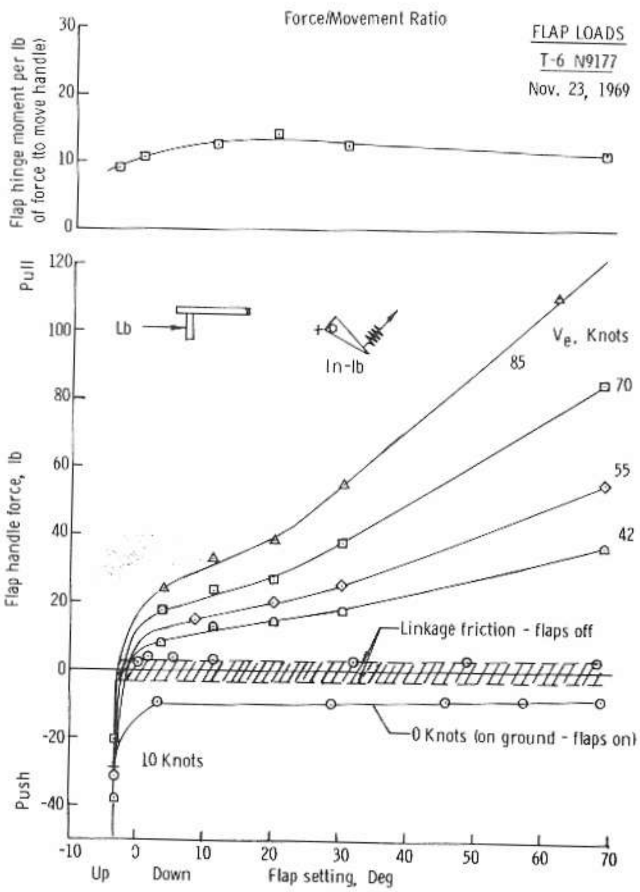


FIGURE 32

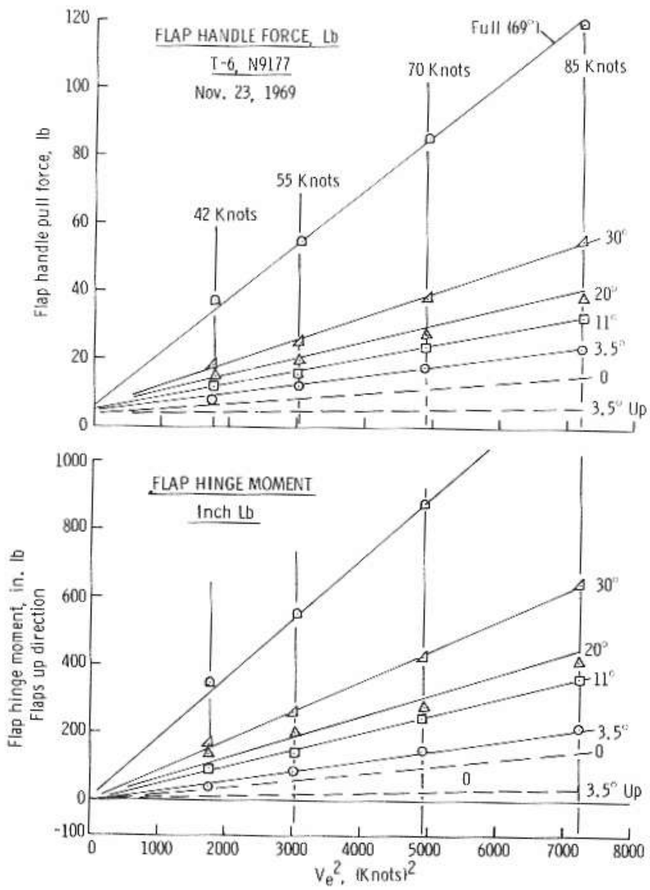


FIGURE 33

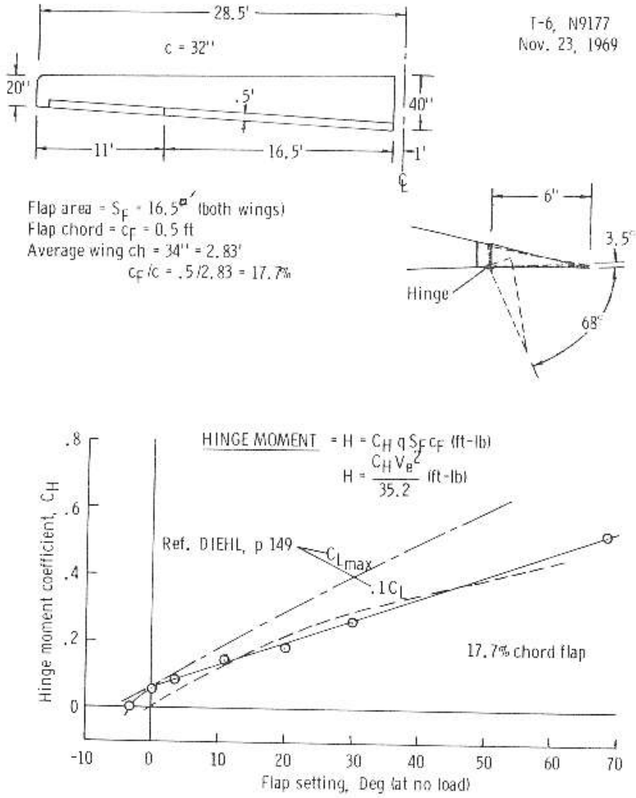


FIGURE 34

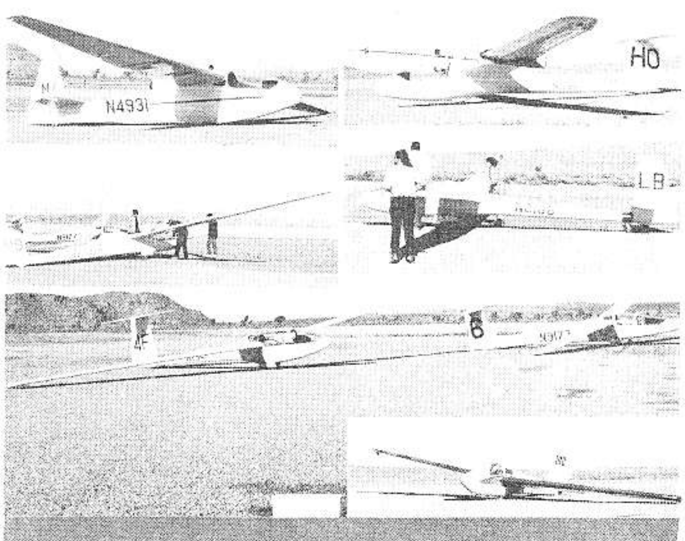


FIGURE 35

stations on the wings of the higher performance sailplanes; these measurements indicated wave heights in thousandths of an inch using a 2-in. gauge spacing. A representative plot showing the data for the Cirrus is included as Fig. 36. Airspeed systems were checked and any leaks were corrected. Airspeed indicators were calibrated against the T-6 indicator and also against a standard indicator borrowed from a local government laboratory. Each sailplane was carefully sealed and checked for the tests.

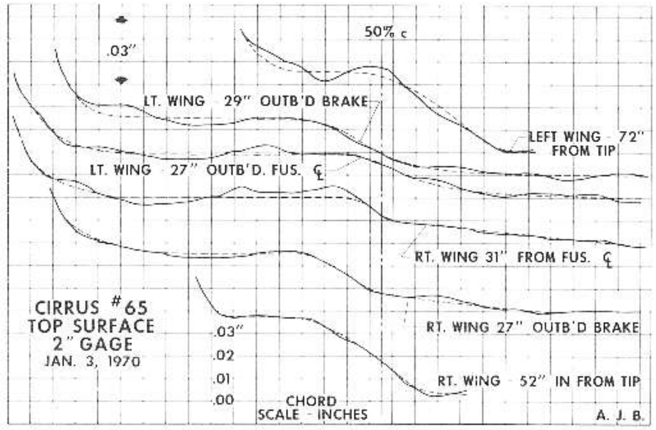


FIGURE 36

No attempt was made to standardize loadings or pilot weights. The five fiberglass sailplanes and the T-6 were all contest sailplanes with normal contest equipment and generally in excellent condition. The condition of the Phoebus C was outstanding; the Phoebus A almost as good. The wing of the Diamant had accumulated a number of small scratches and patches. The Cirrus was nearly new, with no sanding done on the factory wing finish. Condition of the Kestrel was outstanding except for a leaking forward canopy seal which was not discovered until the tests were completed. Except for an inherent waviness in the metal wing surface greater than the fiberglass sailplanes, the T-6 was in first-class condition. The BG-12 was in generally good condition, while the 1-26 was representative of the average club trainer which it was. Obviously, the results of the tests pertain to these eight individual sailplanes as flown and should be applied to other sailplanes of the same type with some degree of caution.

It was fortunate that only one or two sailplanes were available on any given day. The limited number of experienced flight-test people were able to give close attention to each sailplane and every detail of the testing. Pilot experience varied widely from that of Einar Enevoldson, a research pilot for NASA in between his soaring activities, and Ross Briegleb, with more than 6000 hr of glider time, down to the less than 200 hr of 16-yr old Alan Bikle, who flew the 1-26. Testing techniques on the comparison flights were adjusted to suit so that the less experienced pilots had nothing to do but hold their aircraft at a series of steady speeds. In addition to having a chance to fly in the tests, each participant received a copy of the test results on his sailplane including instrument calibrations, weighing, airspeed system errors, and a level flight performance polar.

Testing of individual sailplanes involved one flight with either the swivel-head wing boom or a trailing static cone to obtain a complete airspeed error calibration. A crosscheck on this calibration was also obtained from the T-6 airspeed readings during side-by-side comparative sink tests made on later flights. Airspeed system correction curves and data points are plotted in Fig. 37. Errors for the Kestrel, Diamant, and T-6 were found to be negligible. On the other hand, neglect of these corrections, in the case of the Phoebus C, Phoebus A, and BG-12, would result in serious errors in the high-speed performance measurements. There is a tendency to lose sight of the fact that a polar represents both rate of sink and speed. One knot may not seem like much, but it is equivalent to about 15 or 20 ft per minute in R/C at 100 knots; at 50 knots, one knot is equivalent to 2 percent in L/D or nearly 1 point in L/D on the higher performance sailplanes.

At least two flights, and in some cases three or four flights, were then made on each sailplane for comparison tests with the T-6. All flights in this series were made from tows to the neighborhood of 10,000 ft, with the first flights each day made at about nine in the morning. Temperature data were taken in the climb and tests were discontinued if the lapse rate was not stable. On several of the flights the air was smooth enough for absolute, timed rate-of-sink

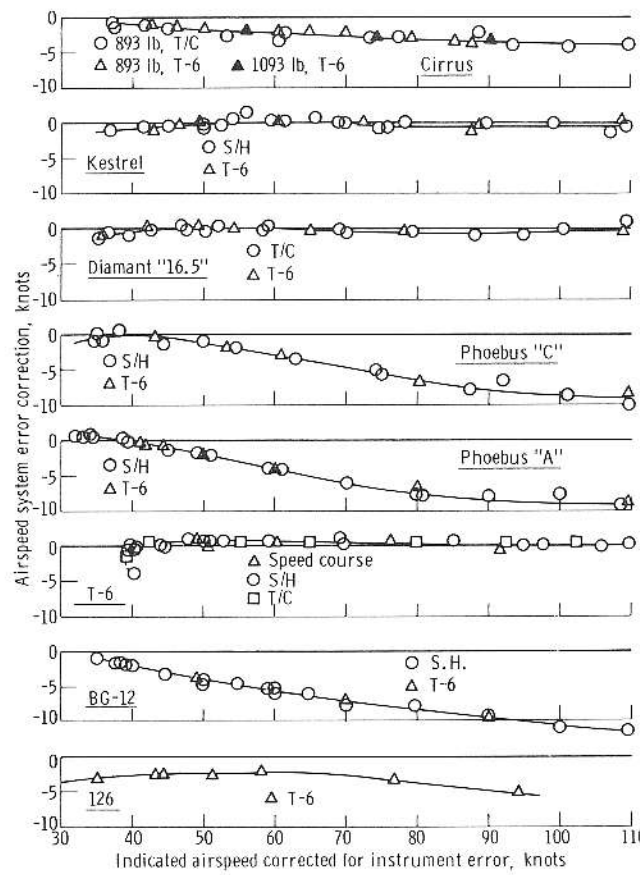


FIGURE 37

measurements, and these were made when the opportunity presented itself. However, the bulk of the data were obtained when the air was not completely smooth and not suitable for absolute measurements. Tests were discontinued at lower altitudes whenever convection was encountered.

Basic comparisons were made in 5-min., side-by-side glides. For each point, the lead sailplane would establish a steady glide at a constant indicated airspeed; the second sailplane would then take a position about 200 to 300 ft out from the wing tip of the lead sailplane. When both pilots were ready, the run would start, both pilots noting the altimeter and airspeed readings and estimating the difference in height between the sailplanes at this point. At the end of five minutes, the pilots took the same readings and the run was terminated. Where the performance of the two sailplanes was about the same, change in the relative heights of the two ships was determined most accurately from the estimates made by the pilots. For height differences in the neighborhood of 50 ft or less, the accuracy appeared to be about ±5 ft; when divided by five minutes, this would give an incremental rate of sink within about ±1 foot per minute.

Greater differences in performance resulted in relative height changes considerably in excess of 50 ft over a period of 5 minutes. In these cases, estimates were augmented with the use of transparent grids which could be used to gauge height differences in fuselage lengths, and the relative altimeter increments were also used as a source of data. For height differences approaching 150 ft, relative height differences were only accurate to about ±15 ft, and this would give an uncertainty of about ±3 ft per minute to measurements of difference in rate of sink. The differences were corrected to sea-level standard condition by the same methods used for reducing absolute rate-of-sink data to sea level. Corrected increments were then added to the standard rate of sink already determined for the T-6 at the specific calibrated airspeed at which the test was flown.

In cases where the difference in sink exceeded 30 ft per minute, comparisons were made by having the second sailplane start behind and to one side of the lead sailplane, maintaining the same rate of sink by keeping the lead sailplane on an appropriate line of sight to the horizon, and noting the difference in calibrated airspeeds. The same technique was also used for points where the speed of the test airplane was outside the speed range of the T-6. This procedure required stable air, clear visibility, and a far-off horizon for reference, as well as a good understanding of the factors which might lead to a slight inclination of the line of sight; generally, any effect of an inclined line of sight was minimized by selecting diverging flight paths so that the relative distance between the sailplanes remains about the same. The technique has been developed to a point where good results were obtained, and a number of points were checked using both techniques. It was then only necessary to read the rate of sink for both sailplanes from the standard-day, sea-level T-6 polar at the T-6 calibrated speed and to plot it at the calibrated speed of the test sailplane during the run.

Test points for the 1-26 and BG-12 are plotted with the summary curves in Fig. 38. Curves for the Cirrus, both with and without 215 lb of water ballast, are shown in Fig. 40 along with the test points for both conditions. The heavyweight points have also been corrected to the lighter weight and plotted on the lightweight curve, showing full agreement with the theoretical effect of weight. Kestrel, Diamant, Phoebus C, and Phoebus A test data are shown in Figs. 41, 42, 43, and 44. The points represented by circles are side-by-side comparisons: points portrayed by squares are from comparisons at the same rate of sink, while crosses indicate timed rate-of-sink measurements made in completely smooth air. Figure 45 is the reference curve for the T-6, with timed rate-of-sink points (crosses) obtained during the comparison tests plotted along with earlier test points (black dots) on which the curve was based. All data have been plotted in nondimensional form as lift coefficient squared vs. sailplane drag coefficient in Fig. 46.

Performance of all eight sailplanes is summarized in Figs. 38 and 39 and in the Table, Fig. 47. Of course, the absolute level of performance for all sailplanes is entirely dependent on the validity of the T-6 reference data.

Wing-profile drag for the T-6 taken from the published wind tunnel data for the FX61-163 airfoil is shown in Fig. 48. This data is given in the form of C_L vs. C_D for several Reynolds Numbers of interest to sailplane designers. Actual inflight Reynolds Numbers for the T-6 wing are listed along the C_L scale. These are for flight at 7500 ft. A C_L vs. C_D curve for these Reynolds Numbers has been crossplotted and shown as a solid-line curve crossing the constant Reynolds Number curves from the wind tunnel. The right side of this plot shows the C_L vs. angle-of-attack, α, curve as published for the two-dimensional data. The dash-line curve shows the computed C_L vs. α relationship anticipated for the T-6 wing with an aspect ratio of 22. Further adjustment of the basic FX61-163 data is required to account for the trailing edge modification to the airfoil on the T-6 because of the effective reduction in camber which shifted both the angle of attack and C_D relative to C_L as shown by the dotted lines on Fig. 48. Finally, the "drag

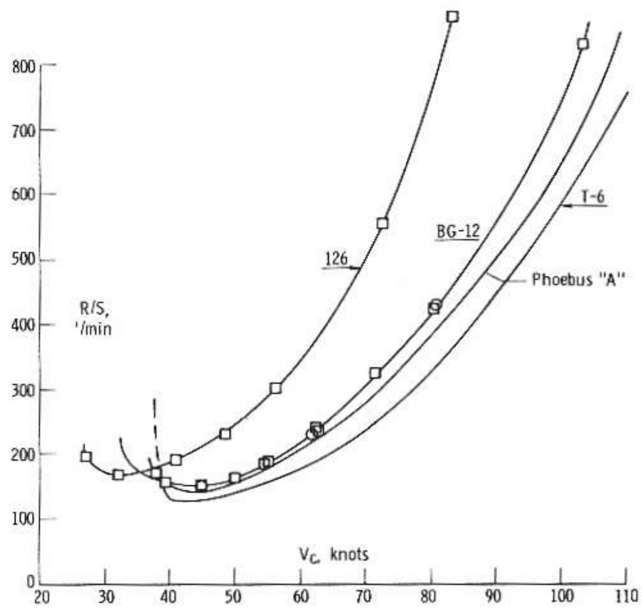


FIGURE 38

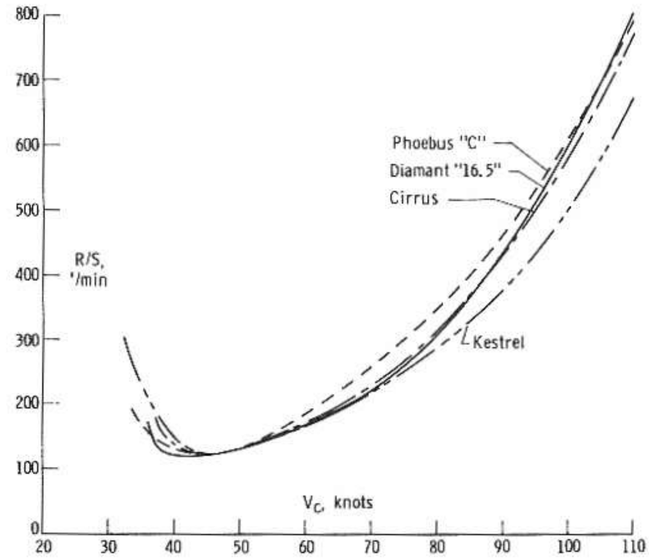


FIGURE 39

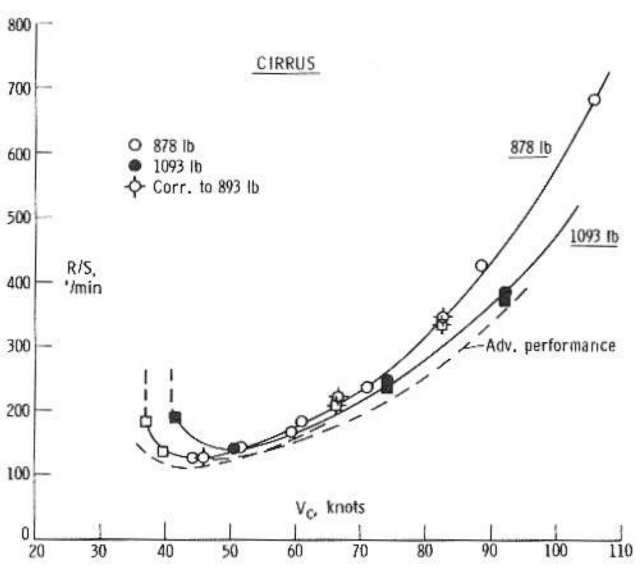


FIGURE 40

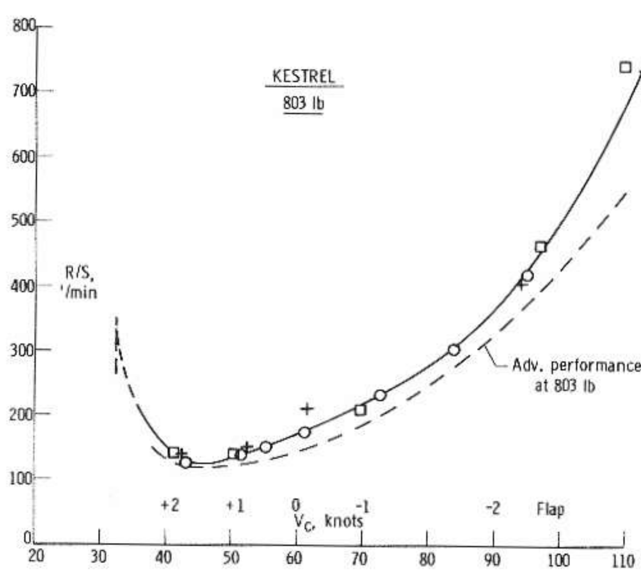


FIGURE 41

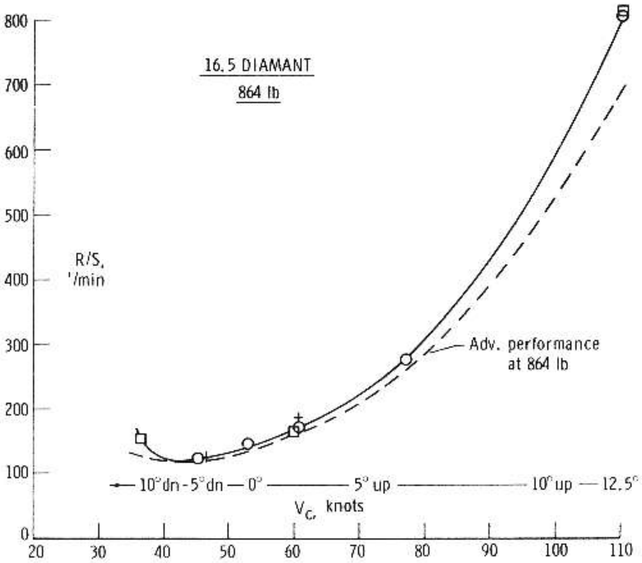


FIGURE 42

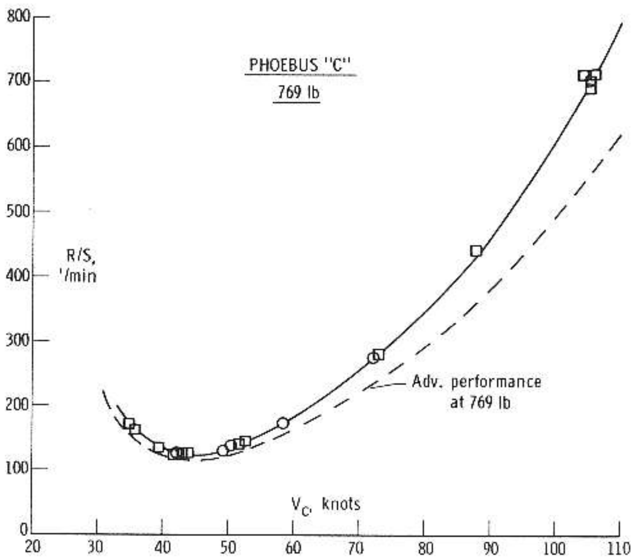


FIGURE 43

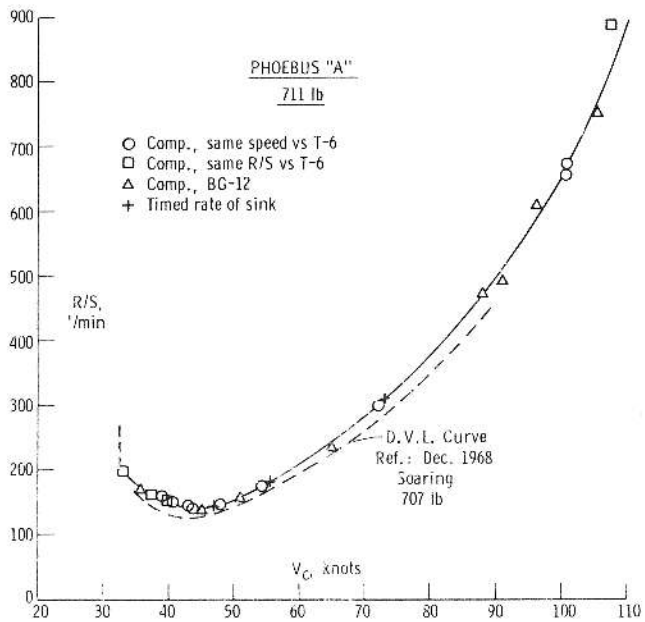


FIGURE 44

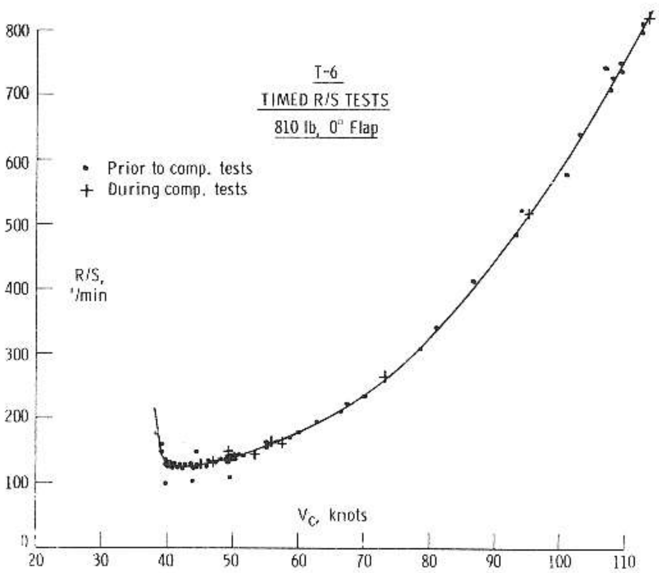
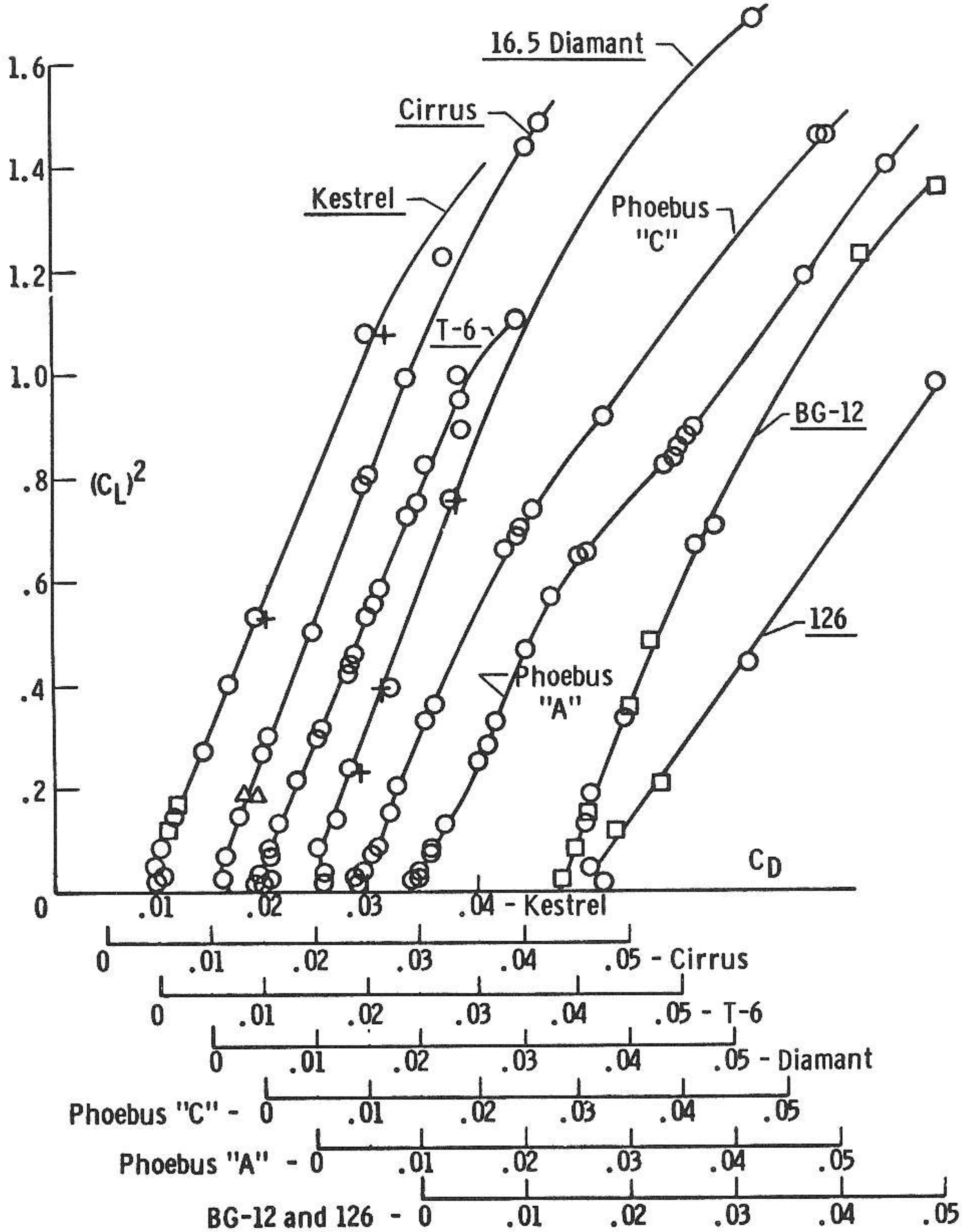


FIGURE 45



16.5 Diamant
Cirrus
Kestrel
Phoebus "C"
T-6
BG-12
126
Phoebus "A"
$(C_L)^2$
C_D
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
.01 .02 .03 .04 - Kestrel
0 .01 .02 .03 .04 .05 - Cirrus
0 .01 .02 .03 .04 .05 - T-6
0 .01 .02 .03 .04 .05 - Diamant
Phoebus "C" - 0 .01 .02 .03 .04 .05
Phoebus "A" - 0 .01 .02 .03 .04 .05
BG-12 and 126 - 0 .01 .02 .03 .04 .05

FIGURE 46

TABLE I

A/C	Kestrel	16.5 Diamant	Phoebus C	Cirrus	Cirrus	T-6	Phoebus A	BG-12	1-26
Factory No.	Apr. '68	042	833	65	Same but with 215 lb of water	6	41	113	100
Span, ft	55.7	54.2	55.8	58.2		57	49.2	50	40
Area, ft^2	123.7	143	151.2	135.6		142.5	139.7	141	160
Aspect ratio	25.1	20.5	20.6	25		22.8	17.3	17.7	10
Flap	As spec.	As spec.	None	None		0°	None	0°	None
Gear	Up	Up	Up	Up		Up	Fixed	Fixed	Fixed
Gross wt., lb	803	864	769	878	1093	810	711	828	593
Pilot wt., lb	165	175	165	218	218	200	200	155	160
W/S, lb/ft^2	6.5	6.04	5.08	6.5	8.06	5.7	5.08	5.9	3.7
Airfoil	-----	-----	E403	-----	-----	Mod-FX 61-163	E403	4415R 4406R	-----
Wave factor*	6	8	3	6	6	10	2.5	10+	Very
Min. V_c, kt	32	36	33	37	41	37.5	32.5	37	27
At R/S, '/min	-----	170	200	180	200	-----	200	190	220
Min. R/S, '/min	124	120	124	127	140	125	139	151	165
At V_c, kt	45	43	43.5	44	49	43	45	43	32.5
Best L/D	38	38.5	37.5	37	37	36.3	34	31	21.5
V_c at best L/D, kt	52	51	49	50	55	48	48	50	42
V_c, 394 '/min, kt	92	87	84	87	93	86	81	78	64
'/min at 35 kt	N/A	N/A	170	N/A	N/A	N/A	177	N/A	171
'/min at 40 kt	148	122	134	138	N/A	130	151	154	186
'/min at 50 kt	132	131	134	136	141	140	152	162	243
'/min at 60 kt	168	168	184	173	168	179	207	217	343
'/min at 70 kt	219	219	257	230	213	236	282	307	500
'/min at 80 kt	287	307	347	319	278	326	380	419	760
'/min at 90 kt	372	435	458	430	362	450	497	562	-----
'/min at 100 kt	495	598	609	577	472	590	655	746	-----
'/min at 110 kt	672	803	790	766	624	758	890	-----	-----

***Wave factor is the maximum wave height in thousandths of an inch measured on the forward 50 percent of the wing surface with a 2 inch gage at six chordwise stations.**

FIGURE 47

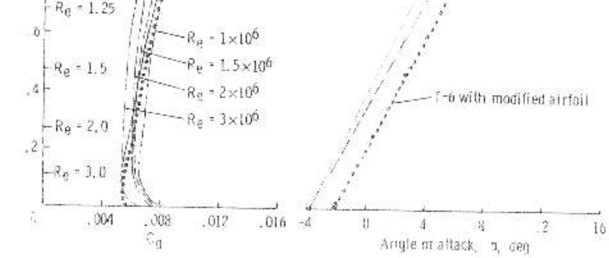


FIGURE 48

due to lift" was calculated, since this is a function of C_L^2, span, and speed, with no bearing on the basic airfoil characteristics. A span efficiency (factor to account for possible nonoptimum span lift distribution), "e", of 0.95 was assumed. Comparison of calculated drag estimates of Ref. 1* with the flight data in Fig. 25 shows relatively little difference which indicates that the sailplane is doing about as well as could be expressed with the modified airfoil using the zero degree flap setting. In earlier times, it was commonly assumed that all drag but the drag due to lift could be expressed with a constant value of C_D over much of the C_L range, and that the slope of the C_L^2 vs. C_D curve would then be a direct measure of "e" or span efficiency. This

*Ref. 1, P. Bikle, "T-6 Performance," Soaring, Vol. 34, #10, October 1970, p. 25.

is certainly not true for the T-6 nor is it the case for other modern high performance sailplanes. For the T-6, the slope of the curve is something like 0.7, but there can be no question that "e" must be close to 0.94 if the estimated drag values of Fig. 25 are considered.

There is always the possibility of some systematic error in procedure which has not been detected or the possibility that the average smooth air in the El Mirage area has some residual subsidence. The fact that the measured data presented here for the T-6 are almost identical to the data obtained by Dick Johnson in the flat lands of Texas with his quite similar H-13 tends to indicate that this is not the case. What about the overall accuracy of the comparison tests? We ran additional tests on the Phoebus A flying with the BG-12; points obtained from comparisons with the BG-12 (represented by triangles) are plotted with the points from the T-6 in Fig. 44 for the Phoebus A, with excellent agreement between the two sets of data. As a further check on the overall consistency of the test results, the BG-12 data of Fig. 38 were compared with data obtained on the original BG-12 in 1956 with quite close agreement. The 1-26 points plotted in Fig. 2 fell so close to the curve for a different 1-26 tested in 1960 that the curve drawn through the points is the same 1960 curve.

Figures 40, 41, 42, and 43 also show dashed curves taken from the manufacturers' advertised curves. It is not too surprising that these range from 5 percent to 15 percent better performance than obtained in the tests. It is interesting to note that the Diamant performance curves almost agree at slow speed. Curves for other sailplanes are displaced about the same amount throughout the speed range, while some others differ more at slow speed than at high speed. Use of such advertised data for comparison purposes between sailplanes may introduce more differences than actually exist between the sailplanes tested. In several instances, it was noted that maximum L/D, for example, was quoted as something like 44 in the tabulated performance, the curve in the same brochure showed 42, and the test results for the airplane tested showed something like 37 or 38. For another sailplane, the published L/D curve was 15 percent better than the rate-of-sink curve published on the same plot, in this case the rate-of-sink data agreeing with that obtained in these tests.

Of greater concern was the difference shown by the dashed curve in Fig. 44 for the Phoebus A. This is the D.V.L. polar for the Phoebus A from the article by Hans Zacher which was reprinted in the December 1968 Soaring. The original data in the D.V.L. report have been checked and certainly appear to be correct. Earlier D.V.L. data obtained on a Ka-6CR were very close to the data obtained on a similar Ka-6CR in this country in 1961. We have been unable to account for this difference in Phoebus A performance except for a possible difference in the sailplanes.

Certainly the relative difference in performance for the eight sailplanes tested is valid within fairly close limits. The extent to which these sailplanes represent other sailplanes of the same type and the extent to which they represent the best of each type is, of course, unknown. It would be reasonable to assume that the performance of the sailplanes tested does indicate the general level of factory-built planes in the hands of the customer. Wing waviness measurements would indicate that the extent of laminar flow might be considerably less than claimed. Comparison of the lift-coefficient squared vs. drag-coefficient plots, Figure 46, with claimed polars, also indicates an incremental drag which could very easily be explained by a difference in the extent of laminar flow. This leaves open a very real question as to what extent laminar flow can be achieved in flight.

Closely examining the performance obtained and comparing it with experience in contests emphasizes a very real but hard to analyze and too often neglected consideration of the low-speed performance in comparing sailplanes. It would certainly appear that a combination of good performance and agility in maneuvering at very low speeds and rapid roll accelerations could combine to make up for a considerable deficiency in high-speed performance under many soaring conditions. At best, level flight polar data of the type reported here are only one piece of the puzzle of what makes a good sailplane.

Results presented here represent a portion of the performance measurement work under way in the United States over the past 15 years. With completion of work now started, it should be possible within the next year to summarize the flight measured performance of 23 sailplanes and, hopefully, to correlate these results with meaningful design parameters of general use in sailplane performance evaluation and prediction.

NOTE

All data for these tests are shown for sea-level conditions except that the Reynolds Numbers correspond to those at the altitude at which the tests were made. Any correlation with wind tunnel or other sea-level derived data should take this into account since the somewhat higher Reynolds Numbers corresponding to flight at sea level could show about two percent lower drag than was obtained in these tests at altitudes that averaged about 7000 ft. Corrections of this kind are somewhat uncertain and, from a practical standpoint, are best neglected since the test altitudes are fairly representative of normal soaring altitudes.