Sailplane Performance Measured in Flight

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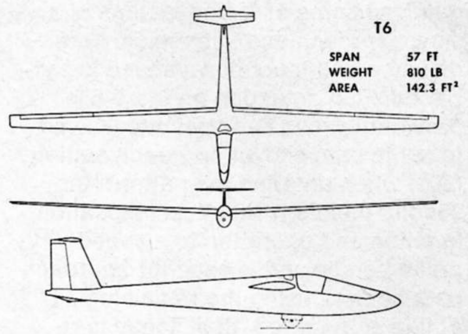

Fig. 1

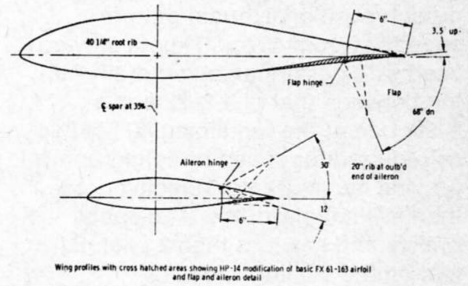

Fig. 2

Wing	
Span	57' 0"
Area	142.5 ft^2
Root chord	40.6"
Tip chord	19.4"
MAC	30.0"
Aspect ratio	22.8
Incidence	0.5°
Dihedral (static)	2.1°
Sweep (35 percent)	0°
Twist	0°
Taper ratio	2.09
Thickness (percent)	16.5
Airfoil	Mod. FX61-163
Flap	
Span (each)	16' 6"
Chord	6"
Area (each)	8.25 ft^2
Avg. percent chord	17.7 percent
Degrees up	3.5°
Degrees down	68°
Actuation	Manual

Tab. I

Introduction

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-hour 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, and the test techniques, and then briefly covers the comparison tests and results obtained for the other seven sailplanes.

The T-6

External aerodynamic design of the T-6 is essentially the same as the HP-14T except for an additional 15-inch tip on each wing, which makes the span an even 57 feet. 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.
Side, top and front views are shown in figure 1, and more detailed information is listed in table I. Profiles in figure 2 show the extent of the modification to the basic FX 61-163 airfoil and also the use of a constant 6-inch 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. Filling in the cusp has removed an effective part of the camber or curvature from the back of the wing so that it 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 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° 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° of down flap is used. However, the performance of the sailplane is deficient at the slower speeds and use of even the 4° setting only increases the drag at all useable flying speeds down to 1 or 2 knots above the stall.
This is not too surprising considering that the flaps extend over only part of the wing span. 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 speed, but the wing loading is kept low to obtain acceptable slow-speed performance and the high-speed performance then suffers because of this. 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.
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; one is used to set the flaps to an approach setting (30°) 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° of flap as required. Stall speed is reduced from 38 knots (0° 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° 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.

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 figure 3. The incremental drag very nearly approaches 10 percent of the zero lift drag of the sailplane.

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 figure 3. 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 use a larger wheel, shock struts and powerful brakes without an undue drag penalty.

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. Figures 4 and 5 show that, for this installation, the system errors are small and, generally, the system performs in a satisfactory manner for a sailplane. Calibration flights included 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, calibration with a trailing static cone and calibration against a previously calibrated SHK. All gave consistent results with a scatter of less than ± 1 knot.

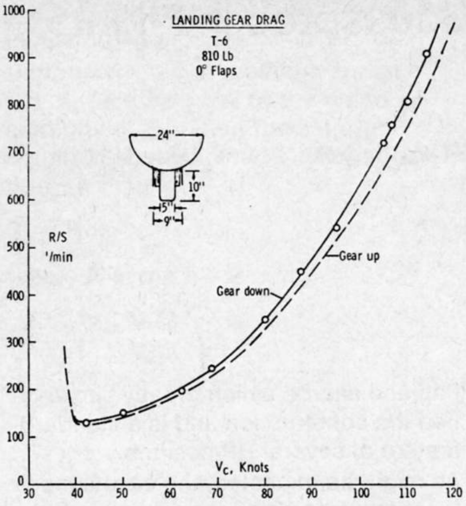

Fig. 3

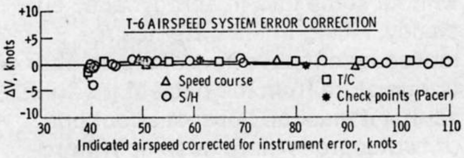

Fig. 4

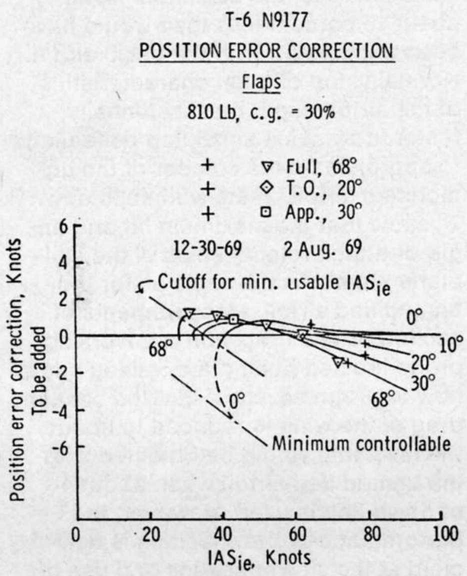

Fig. 5

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 [1]. There was nothing new or exotic about the instruments or techniques used, nor was any single aspect 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 pastime effort. There does seem to be an inordinate amount of work involved and one would hope that there would be an easier way. Many techniques have been suggested. Most involve new instrumentation approaches and have a tendency to evolve into instrument development projects or involve even more work than the apparently old-fashion, 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 is the inability to know what the air is doing. 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 repeating sampling.

Rate-of-sink tests were all timed runs at constant speed for a minimum of at least five minutes or 1,000 feet; some were continued for as long as 15 minutes, and some for as much as 5,000 feet of altitude. All were made on very early morning flights to altitudes in the neighbourhood of 12,000 to 13,000 feet on days when the lapse rate was stable and wind velocities and wind shear was 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.

The data were corrected for instrument errors and airspeed system error, and then to standard atmosphere at sea level. The Reynolds Numbers, however, correspond to the test attitudes, averaging 1,700 ft. This is representative of normal soaring altitudes. Drags would be about two percent lower at sea level due to scale effect. An 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. Even with the most careful work, the uncertainty for an individual point approaches 5 to 6 percent, but the 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. The data obtained have been summarized in figures 6 through 11. At the higher speeds data for 0° flap and

3.5° up flap are given and the same data are plotted as $(C_L)^2$ vs. C_D in figure 7. The use of performance up flap is advantageous for improved only at speeds above those of general interest. Performance with flaps down is shown in figures 8 and 9 with all of the level flight data shown as L/D vs speed in figure 10. Stall speeds and C_{Lmax} have been shown as a function of flap setting in figure 11. 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° flaps stall speed.

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 figure 12. Hinge-moment coefficients are given in figure 13. 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.

Seven Other Sailplanes

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. 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 and one was found to be 79 pounds heavier than listed. 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.

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 in generally 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

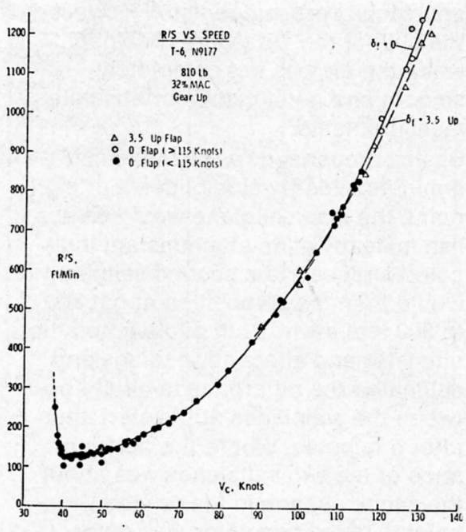

Fig. 6

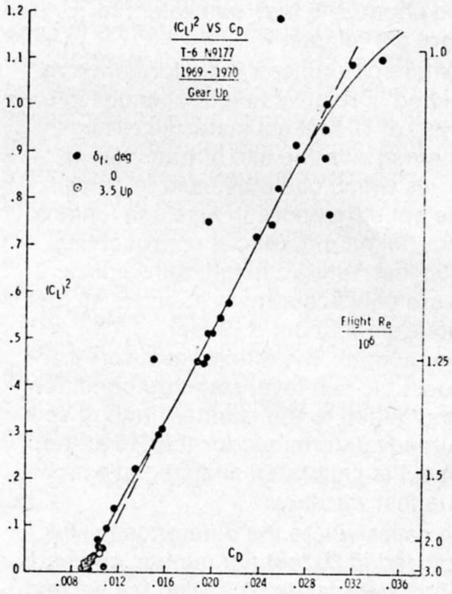

Fig. 7

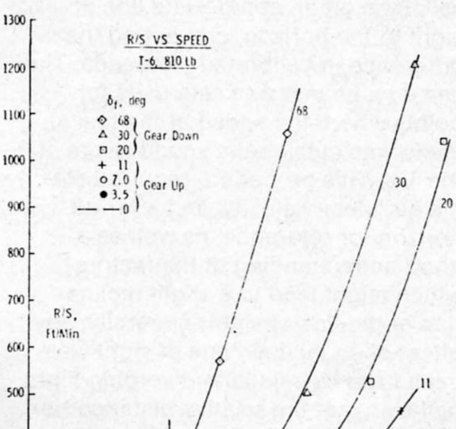

Fig. 8

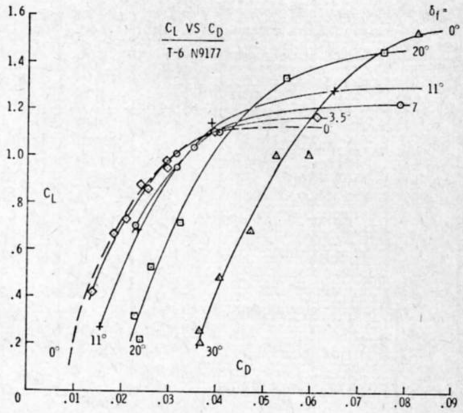

Fig. 9

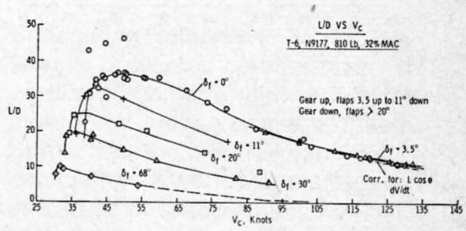

Fig. 10

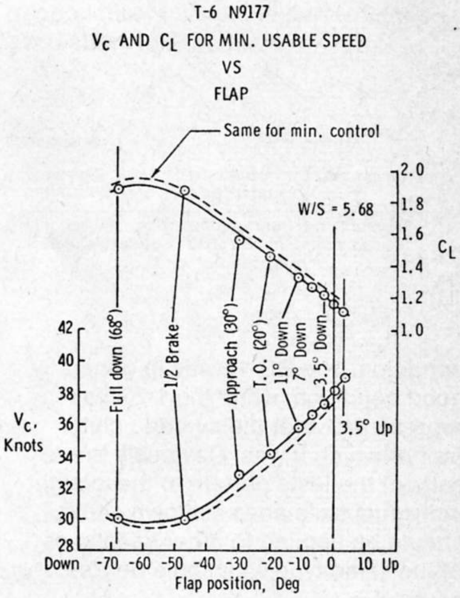

Fig. 11

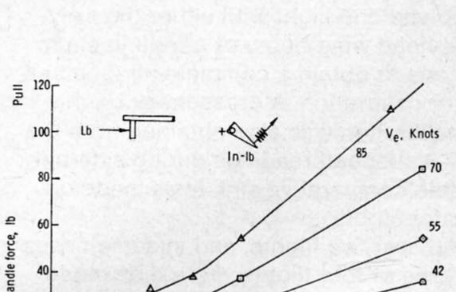

Fig. 12

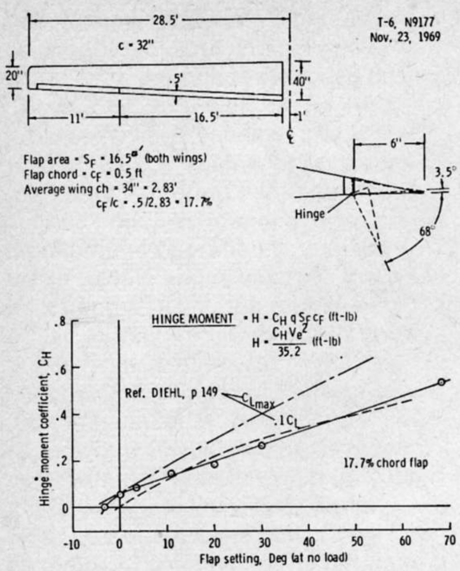

Fig. 13

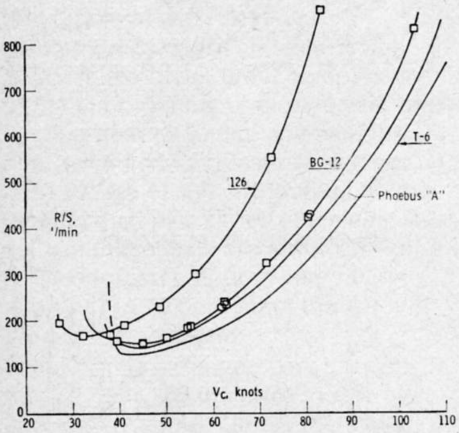

Fig. 14

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.

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.

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 were made from tows to the neighbourhood of 10,000 feet, with the first flights each day made at about nine in the morning. Temperature data was taken in the climb and tests were discontinued if the lapse rate was not stable. Timed rate-of-sink measurements 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.

Basic comparisons were made in 5-minute, 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 feet away. Both pilots noted the altimeter and airspeed readings and estimated the difference in height between the sailplanes at the start and after 5 minutes. 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 neighbourhood of 50 feet or less, the accuracy appeared to be about ± 5 feet, equivalent to ± 1 foot per minute.

Where differences in performance resulted in relative height changes in excess of 50 feet estimates were augmented with the use of transparent grids which could be used to gage height differences in fuselage lengths. For height differences approaching 150 feet, relative height differences were only accurate to about ± 15 feet, equivalent about ± 3 feet per minute. The differences were corrected to sea-level standard condition and 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 feet 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

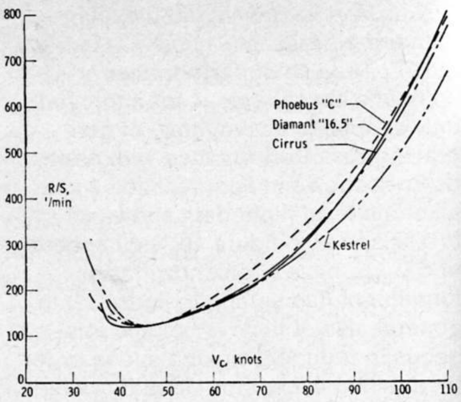

Fig. 15

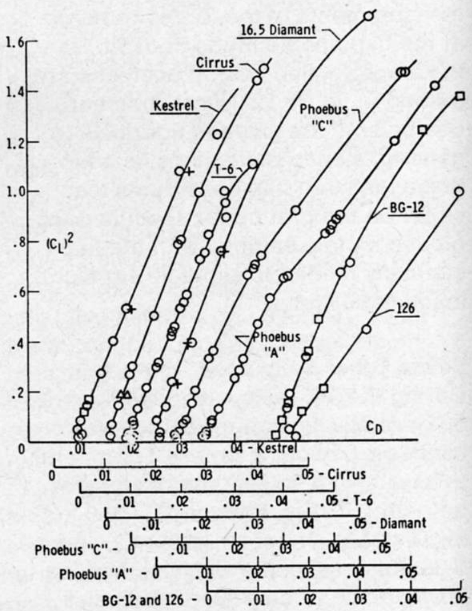

Fig. 16

it at the calibrated speed of the test sailplane during the run.

Performance of all eight sailplanes is summarized in figures 14 and 15 and in table II and in non-dimensional coefficients in figure 16. Of course, the absolute level of performance for all sailplanes is entirely dependent on the validity of the T-6 reference data.

What about the overall accuracy of the comparison tests? We ran additional tests on the Phoebus A flying with the BG-12 and obtained 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 figure 14 were compared with data obtained on the original BG-12 in 1956, with quite close agreement. The 1-26 points plotted in figure 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.

The manufacturers' advertised curves, it is not too surprising to find, range from 5 percent to 15 percent better performance than obtained in the tests. Use of such advertised data for

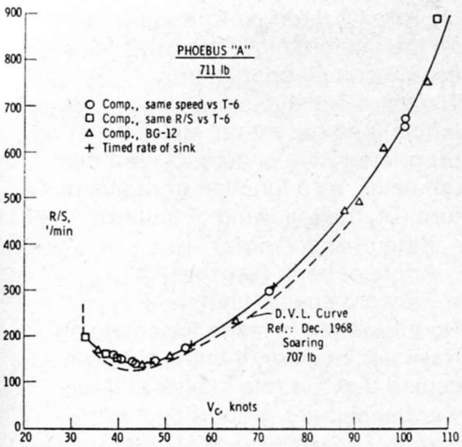

Fig. 17

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

Tab. II

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. Of greater concern was the difference, shown in figure 17, between the Phoebus A result and the DVL polar measured by Hans Zacher [2]. The original data in the DVL report have been checked and certainly appear to be correct. Earlier DVL data obtained on a Ka-6CR were very close to those 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. 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 difficiency in high-speed performance under many soaring conditions. At best, level flight polar data of the type reported here is only one piece of the puzzle of what makes a good sailplane.

Concluding Remarks

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.

References

1 Johnson, R. H.: Sailplane flight test performance measurement. Soaring (April 1968).

2 Zacher, Hans: Flugmessungen mit Standard-Segelflugzeugen. OSTIV-Publication IX.