HOW ACCURATE IS NETTO?

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SUMMARY

The historical origin and general history of the MacCready vertical current total energy variometer (now termed "netto"), including its optimum airspeed selector ring are reviewed, and some later developments of it are discussed. Polars of three sailplanes of different spans are charted for straight and circling flight, then plotted to reveal their parabolic anomaly and the effect of circling flight sink rate. These effects are further analyzed for their influence on the transient compensation of netto variometers as well as the speed ring. Some other disturbances due to the quality of sailplane preparation and flight dynamics are listed. Conclusions are drawn about the problems to pilots from imperfect netto variometer compensation and its effect on the maximization of ground speed from the speed ring. A modification for improvements to the speed ring and computer is suggested.

DISCUSSION

Ideally a variometer would be "compensated" to eliminate needle deflection resulting from speed changes so as to show only the vertical motion due to vertical air currents surrounding the glider. But the sailplane is an isolated energy system in which changing speed requires an exchange of its potential energy for kinetic energy, causing changes of altitude. Its drag forces also increase generally with airspeed squared, producing a parabolic variation of sink rate with airspeed (ref. 1).

The pure total energy variometers are compensated through the change of dynamic pressure with airspeed which is converted by either a venturi (ref. 2), Braunschweig tube, etc., or an elastic bellows (ref. 3) to cancel the unwanted "stick thermal" coming from the zoom and dive maneuvers necessary to change speed in a glider. But they do not produce a fixed variometer needle with airspeed variations because of the drag force variation. Thus they leave something to be desired.

In 1949, Paul MacCready Jr. had disclosed his invention of the "speed ring" in a paper (ref. 4) read at the IAS-SSA meeting at Elmira while its author was busy winning the National Soaring Championship there. In 1954 MacCready first disclosed at the IAS-SSA meeting in New York his new "vertical current" variometer (ref. 1) today known as "netto" which more effectively than anything else known even today improved the "compensation" of sailplane variometers. At the same time it greatly simplified the use of the speed ring. The theory of the device was to leak a small calibrated flow of air proportional to V^2 outwards through the variometer, causing it to add the sink rate for still air to the variometer indication. The result was to indicate the vertical air current rather than the climb or sink rate of the sailplane. MacCready pointed out that with this arrangement the speed ring now indicated directly the speed to fly, dispensing with "iteration", that is the need to chase the needle while bringing the sailplane speed to a number never quite stabilized on the ring by the variometer needle. Today it seems incomprehensible that the soaring world took twenty years to appreciate the device which twenty five years later remains the best. It is perhaps natural that a meteorologist would be preoccupied with the measurements of vertical currents, but only one who was also a sailplane expert would have combined the need with the tool and come up with such an ultimate solution.

There are several ways of plumbing the laminar leak (refs. 1, 3, and 5) used for the vertical current compensator to various total energy systems so as to produce the specified flow proportional to V^2. MacCready had placed the leak between the pitot and the variometer capacity line since he had used a venturi type total energy compensator (ref. 2) which is connected outboard of the variometer static vent. This produces a pressure differential across the leak of twice the dynamic pressure, which we call 2q, where $q = 1/2\ \rho V^2$, ρ being density. Thus, $P_s + q - (q + P_s) = 2q$, where P_s is the static pressure of the altitude of the sailplane. Because q contains V^2 the pressure across the leak is proportional to V^2 and the flow through a laminar leak is proportional to the pressure across it.

In "Soaring" for 1975 (ref. 5) Don Ott's arrangement of the leak with a total energy venturi was described. He ran the netto leak from the capacity line to static pressure, and showed that cockpit pressure was close enough, so he left the leak simply open to the cockpit. Here the pressure across the leak is:

$$P_s - (-q + P_s) = q$$

still giving the specified V^2 pressure variation of MacCready.

Where a bellows or diaphragm total energy compensator (ref. 3) is used which is driven by the difference of pitot pressure and the capacity (Burton, PZL, Schuemann etc.), the leak parallels the bellows and the pressure differential is:

$$P_s + q - P_s = q$$

and again we have MacCready's V^2 pressure variation.

With the arrangement shown by MacCready, the capillary must be twice as long as with the other systems mentioned here. Reference to the 1975 Soaring article (ref. 5) will yield the formula for calculating the capillary.

In 1954 the Ka-6 sailplane was three years in the future. But many modern sailplanes today incorporate camber changing flaps, broad drag bucket airfoils, and very rigid and smooth wing skins, and realize broad areas of laminar flow in the boundary layer. Still the shape of the polar is much as MacCready had described it: "approximately" and "fairly exactly" and "within a few inches per second" of parabolic, which means of course that the sink rate is nearly proportional to airspeed squared. It is nearly proportional, but not quite, as figures 4 to 6 herein show. Those are generally sharper curved at the low end than the parabola, that is the sink rate in that area is greater. The PIK does not show any droop at the fast end while 1-26 and the AS-W 17 do show it.

SCOPE AND LIMITS OF STUDY

We investigate here specifically a) those netto errors, transient and steady, that come from the parabolic anomalies of some typical real world polars, b) those netto errors that are due to the variations from these straight flight polars that occur in banked circling flight, and c) errors from the netto speed ring. We do not go into some other errors due to

1) Flight off design altitude of variometers.

2) Transient variations in L/D from maneuvers causing accelerations that change the wing loading and from L/D changes caused by uncoordinated skidding or slipping.

3) Changes in L/D from wing loading variations due to weight of crew, equipment, ballast, center-of-gravity effect, etc.

4) L/D variations from flap position, aileron rig, aileron flap couplers, etc.

5) L/D variations coming from air leaks, ventilators, loose fairings and gear doors, etc.

6) Pitot static position and airspeed calibration errors.

7) Total energy probe and vent position errors from wing pressure field and wake, probe yaw and angle of attack errors, and uncoordinated skidding and slipping probe errors.

8) Plumbing hose length and capacity resistance in fittings, and hose pinch, restrictors, filters, electric damping, etc. as they affect variometer indication.

9) Dirty wings and skins, skin stress wrinkles, assymetrical ballast, etc.

Such errors may or may not be transient, will be difficult to predict, detect, and measure, may be cumulative, and may have comparative values that are significant compared to the errors analyzed.

In the light of the foregoing a knowledgeable pilot has a right to wonder about the reliability of his netto for finding better air as well as for the maximization of ground speed from the speed ring or computer. He may ask

1) How important is the effect of the parabolic anomaly of polars versus the true parabolic characteristics of the V^2 driven leak?

2) If the variometer that is read in circling flight, and the speed ring set to it, is compensated according to a polar derived in straight flight (since this indicates too low a climb and sets the ring too low (slow), will this significantly affect the maximization of ground speed?

3) If the speed ring that is derived for circling climb (no progress being made along course while climbing) is set during straightaway climb along course, this sets the ring too low (slow) (refs. 6 and 7). Does this affect the maximization of ground speed?

4) What are the effects of a mismatched leak to accomodate parabolic anomaly (it would be too short, too much flow) or one for the wrong sailplane or incorrect polar? (Capillary somewhat too short or too long.)

5) Is netto well enough compensated both for climb circling or straightaway so that it can be relied upon during small speed changes?

To obtain answers to these questions we have considered polars of the 12-meter 1-26 sailplane, the 15-meter PIK-20 and the 20-meter AS-W 17 (ref. 7). The polars have then been reworked by recalculating the slow ends for 40 and 50 degrees of banked turning (30 degrees has an insignificant effect) by the method of the Appendix (taken from ref. 8). (See figs. 1 to 3.)

The results, including the noncircling polar, have been replotted with the sink rate against airspeed squared. When any parabola is so plotted, it is a straight line passing through the origin. This makes it easy to inspect the parabolic anomalies of the curves. True parabolic characteristics of netto leaks can be compared to polars. If the polar were parabolic and the leak matched it they would plot the same, as one straight line. If the leak is enlarged to compensate for some droop from the parabolism of the polar, the leak plot will be lower, cutting across the tighter curve of the polar (figs. 4 to 6). The leak sink rate in the midspeeds will then be lower and higher at the end portions. The difference, or the extent of the anomaly, can thus be directly measured on the plot along the sink direction under the square of the airspeed of interest, from any straight line that passes through the origin.

The effects on netto speed rings of the parabolic anomalies and of circling sink rates, as well as climbing along course with a ring designed for circling climb, have been computed for climb rates of 200 and 800 ft/min. The classic graphic analysis is used before and after modifying the polar values to reflect the above mentioned deviations. The work was done directly on the preplotted polar analysis sheets from reference 7 and is not reproduced here. Instead, the results are shown in table 1. There they can be seen to have an insignificant effect on the maximization of ground speed by the speed ring.

TRANSIENT ERRORS OF NETTO COMPENSATORS

Even small parabolic anomalies of the polars cause annoying transient netto compensation errors whose trends and speed ranges can be seen in figures 4 to 6, and are discussed below and further detailed in table 2.

The time lags of variometers (they vary widely between models and installations) (ref. 9) will modify these transient errors. In the slow portion of the polars (see figs. 4 to 6), slowing down causes an erroneous indication of worsening air (decreasing rise, increasing sink). Variometer time lag tends to reduce this error. The effect begins as slight at about 55 knots and becomes larger with decreasing speed. This is an important regime of soaring flight where after the pilot has had a signal of better air he may be slowing down in an effort to locate the lift and use it, and possibly to circle and center it. If circling has begun during the slowing, the compensation errors are increased. Here the pilot should stay alert to his sense of vertical acceleration, heed the roll motion of his wing tips, and pay less attention to the netto variometer. As the charts show, the effects become significant with the 1-26 below 50 knots, the PIK -20 below 55 knots, and the AS-W 17 below 55 knots.

In the slow zones of the polars, speeding up will indicate erroneously better air than actual and the errors are increased by variometer time lag. But in this flight regime, the netto and its compensation become less important in the search for lift, because a pilot will probably be accellerating into his speed ring glide towards the next gaggle or cloud.

At the fast zones of the polar, slowing down will erroneously indicate improving air and variometer time lag will worsen the error. This is an important regime of soaring. The effect lessens as the speeds are lowered, vanishing with the 1-26 above 75 knots and with the AS-W 17 at above 85 knots. The PIK-20 is not affected.

In the fast portion of the polars, speeding up shows better air than actual and variometer lag will decrease the error. Searching for lift is less important in this regime, making the error less disruptive. The error increases with speed above the speeds noted in the previous example. Table 2 shows some values for smaller speed changes and steepened banks.

Pilots may check the calibration of their netto by flying in still air at three or preferably five speeds in the slow, medium, and fast portions of the polar. At the steady speed in still air the netto should indicate zero. The non netto total energy variometer should indicate the sink rate for each speed tested taken from reliable polars such as those derived by Bikle and Johnson in various issues of Soaring and those found in reference 7. Individual airspeed calibration errors may be troublesome here. It is convenient to tabulate the speeds and sink rates of interest for use in the cockpit. Indicated airspeeds are used.

Errors of transient compensation of netto can be noted in the slow and faster ends of polars by slowing down and speeding up while noting the behavior of the needle as it deviates from zero. Again the air must be still for this. What the pilot observes here in still air, he can apply to his actual soaring.

ERRORS OF THE NETTO SPEED RING

Calculations of speed rings and related computers (as well as of netto leak size) have usually been based upon the straight flight polars (refs. 1, 4, 9, and 10), but the ring is often set during banked circling climb where the actual vertical sink rate is greater than the netto variometer is indicating. This causes the ring or computer to be set too low (slow). Rings based on the pure MacCready mode (fig. 7) consider that no progress is being made along course while in circling climb (ref. 4). The so called street speed ring (refs. 6 and 7) of figure 8 acknowledges that some course distance is used up during straightaway climb, thus shortening the distance to go to the next lift and so allowing a steeper glide at faster speed. The pure MacCready mode ring would be set too low (slow) while in climb along course. A street speed ring would seem better when set for both circling and along-course climb netto.

CONCLUSIONS

1) A Pilot who flys glued to his variometer may well be confused by the compensation errors of netto in slow straightaway climb and in steeply banked climb if his speed is not steady.

2) In slow speed climbing by netto, holding speed steady or use of a standby non netto total energy variometer may be helpful.

3) While shortening (increasing the flow of) the netto leak may give better steady speed matching to the anomalies of the polar, this will not help transient compensation errors.

4) The time lag of variometers has an effect on the transient compensation of netto. Where this is favorable speeding up, it will be unfavorable slowing down, and vice versa.

5) The netto errors studied have a negligible effect on the maximization of ground speed from the speed ring.

6) The match of the netto speed ring or computer might be very slightly better through use of the street ring construction.

7) The study hints that proponents of steady speeds instead of a miriad of little speed changes may have a point, due, if for no other reason, to the fact that even the best variometer system is plagued with compensation errors. A slow response variometer is favored by some to delude themselves to

thinking the variometer is compensated correctly, while fast repsonse is the goal of certain variometer makers who see better compensation giving more accurate information.

8) One total energy variometer with netto and a total energy variometer without netto might be the best solution for most of us, using the one that fits the soaring situation of the moment.

APPENDIX

Determination of sink rate due to circling flight for figures 4 to 6 is done by the method treated in "The New Soaring Pilot" by Welch and Irving. There it is assumed that the sailplane has the same L/D so long as the circling flight angle of attack is the same as in straight flight. The formulas are

$$V_{\phi} = V_{o} \frac{1}{\sqrt{\cos_{\phi}}} \tag{1}$$

and

$$S_{\phi} = S_{o} \frac{1}{\cos_{\phi} \sqrt{\cos_{\phi}}} \tag{2}$$

where the subscripts

ϕ and o are bank angles, V is airspeed and S is sink rate.

REFERENCES

1. MacCready, Paul B., Jr.: Measurements of Vertical Currents. Soaring, vol. 18, no. 3, May-June 1954, pp. 11, 14, 16, 17, and 25.
2. Dawydoff, Alexis: Total Energy Variometer. Soaring, vol. 7, nos. 1/2, pp. 7, 12.
3. Wolf, Mix: Total Energy Variometer Operated by Pitot Pressure. Soaring, vol. 25, no. 8, Aug. 1961, pp. 16-17.
4. MacCready, Paul B., Jr.: Optimum Airspeed Selector. Soaring, vol. 18, no. 2, Mar.-Apr. 1954, pp. 8-9.
5. Brandes, Tom: Competition Workshop. Soaring, vol. 39, no. 3, Mar. 1975, pp. 37-39.
6. Abzug, Malcolm J.: A Speed Ring for Cloud Street Flying. Technical Soaring, vol. IV, no. 1, [1975], pp. 9-14.
7. Du Pont, S.: New Soaring by the Number. Published by author, 1974, 1977.
8. Welch, Ann; Welch, Lorne; and Irving, Frank: The New Soaring Pilot. John Murray (London), 1960.
9. Schuemann, Wil: Advertisement - Second Annual Report to Soaring From Sage Instruments. Soaring, vol. 40, no. 6, June 1976, pp. 12-13.
10. Ball, Richard: Description of Netto Cruise Control Option. Ball Engineering Co., Boulder, Colorado, undated circa 1977.

TABLE 1

MAXIMIZATION OF GROUND SPEED AS AFFECTED BY PARABOLIC ANOMALY AND CIRCLING SINK RATES WITH NETTO SPEED RING AS COMPARED TO SOLUTION FROM CLASSIC MacCREADY GRAPH.

Glider types	(1) Actual glider climb, fpm	(2) Still air sink best sink speed, bank 40^o	(3) Polar sink deviation from parabolic, fpm bank 40^o	(4) Actual airmass rise, fpm (1)+(2)	(5) MacCready speed to fly, knots	(6) Netto indicated airmass rise at zero bank (1)+(2)+(3)	(7) Netto ring indicated speed to fly, knots	(8) MacCready ground speed, knots	(9) Netto ring ground speed knots
1-26		40^o at 40 knots	40^o at 40 knots						
	200	275	-80	475	53	555	55	22.5	22.5
	800	275	-80	1075	71	1440	73.5	43.5	44
PIK-20		40^o at 51.5	40^o at 51.5						
	200	195	-20	495	70	415	70	32	32
	800	195	-20	995	92	1015	87	59	59
AS-W 17		40^o at 52	40^o at 52						
	200	160	-50	360	64	410	75	38.5	36
	800	160	-50	960	105	1010	97	66	65

TABLE 2

SOME TRANSIENT COMPENSATION ERRORS OF NETTO VARIOMETER FOR THREE SAILPLANES, NOT CONSIDERING VARIOMETER LAG

	Slowing 5 knots, bank angle 50^{o}	Slowing 5 knots, bank angle zero	Slowing 5 knots, bank angle zero
1-26			
ΔIAS	40 to 35	40 to 35	43 to 33
Δsink	- 15 fpm	- 30 fpm	- 50 fpm
at sink	- 350 fpm	- 180 fpm	- 210 fpm
PIK-20			
ΔIAS	60 to 55	40 to 35	55 to 45
Δsink	-30	-10	-20
at sink	-250	-130	-130
AS-W 17			
ΔIAS	60 to 55	50 to 45	55 to 45
Δsink	-25	-20	-20
at sink	-200	-120	-110

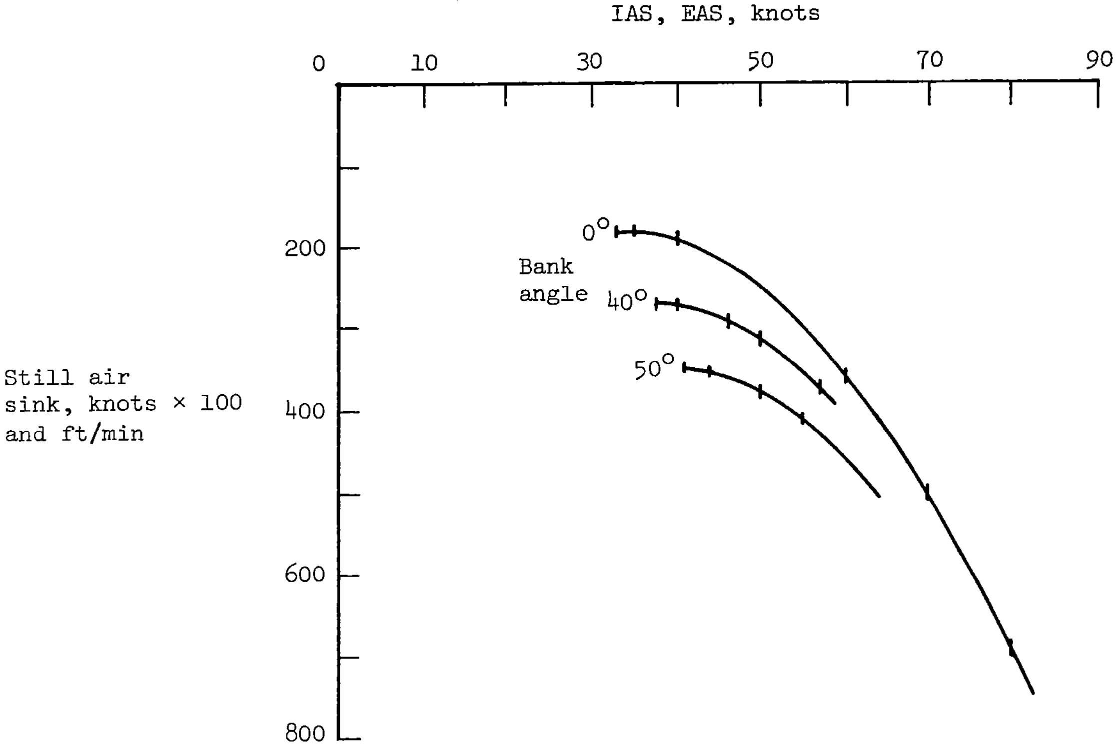


Figure 1. - Performance polars: I-26, 12 meter.

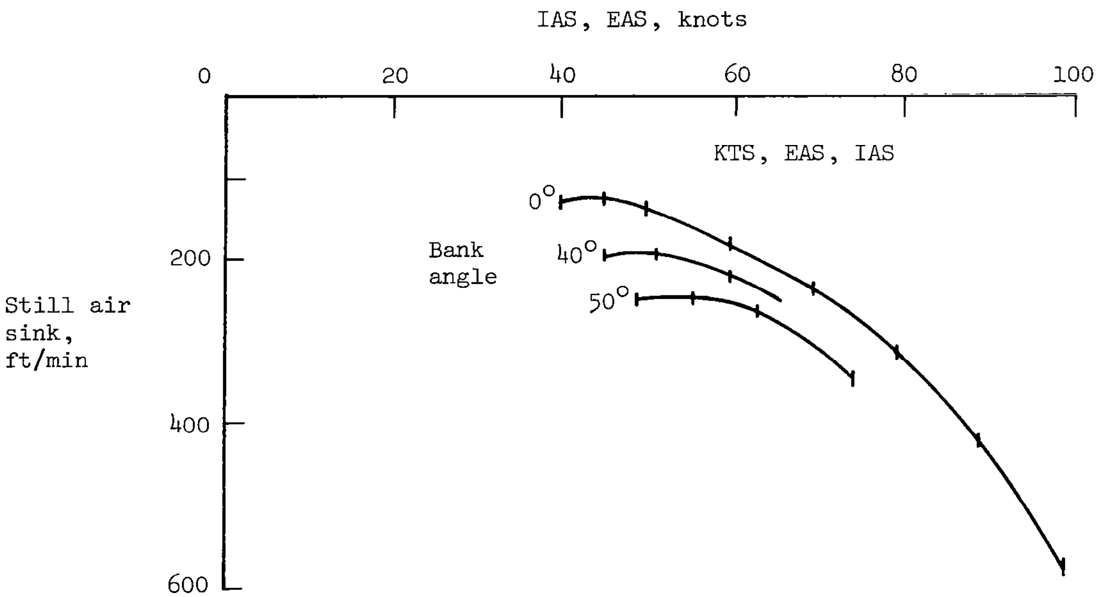


Figure 2. - Performance polars: PIK-20, 15 meter.

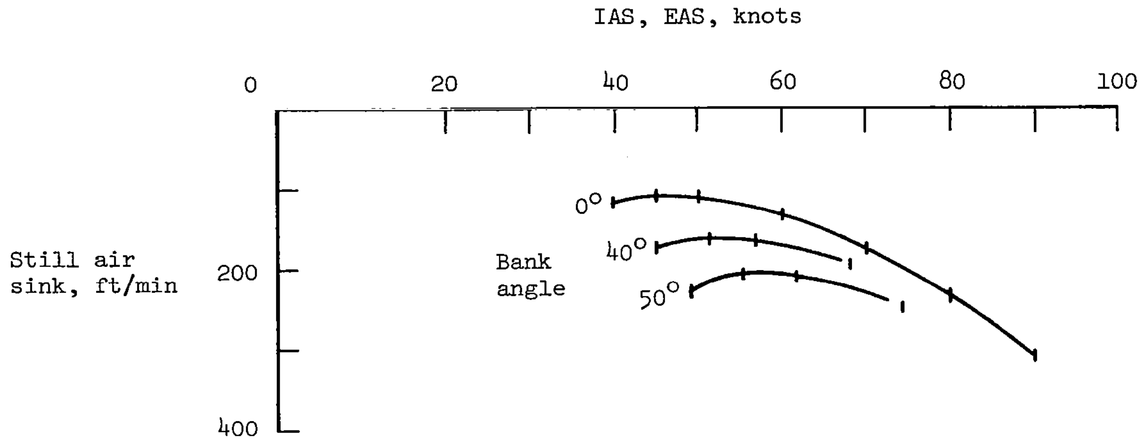


Figure 3. - Performance polars: AS-W 17, 20 meter.

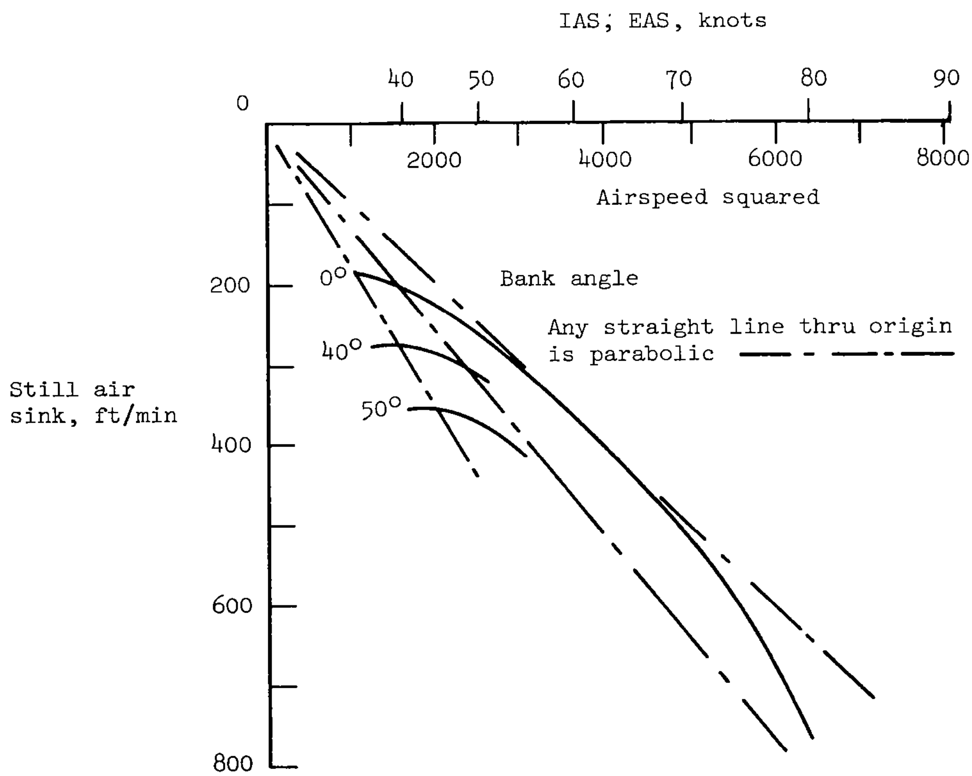


Figure 4. - Sink versus V^2: I-26, 12 meter.

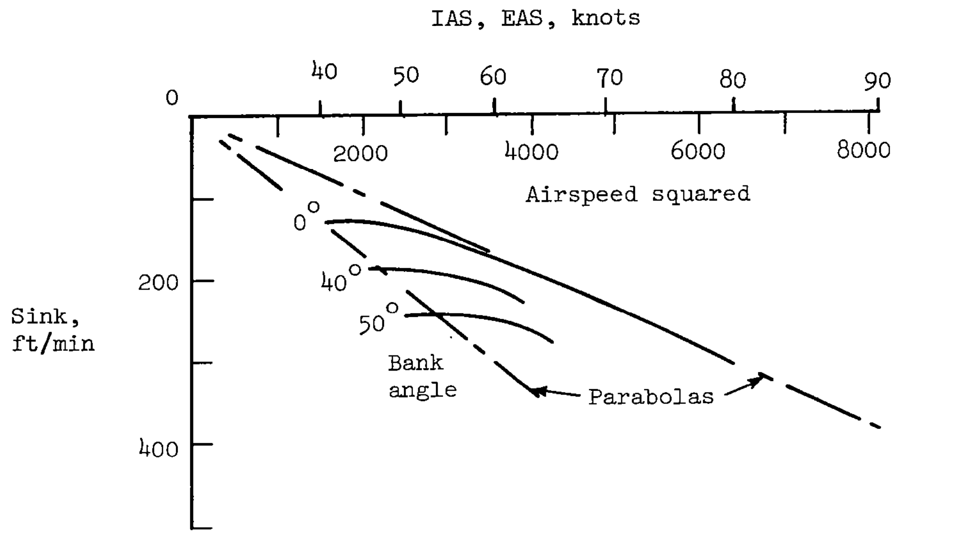


Figure 5. - Sink versus V^2 (see fig. 4): PIK-20, 15 meter.

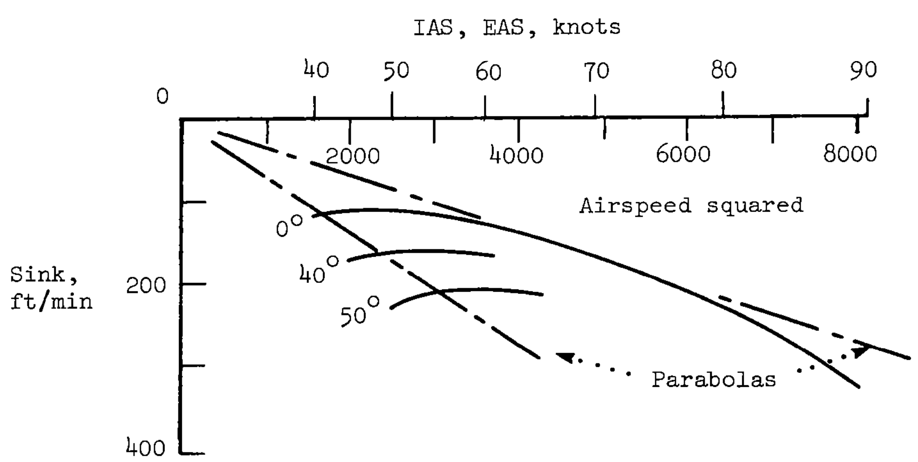
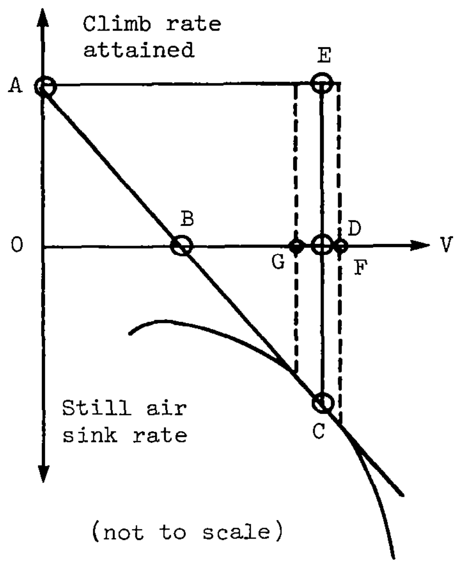
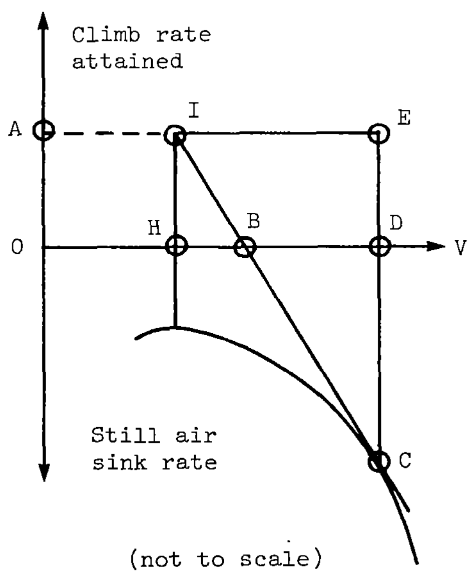


Figure 6. - Sink versus V^2 (see fig. 4): AS-W 17, 20 meter.



A Circling climb at zero speed along course.
B Average groundspeed, for one climb glide cycle, begin and end at same altitude.
C Tangent at polar.
D MacCready optimum airspeed between climb zones.
EC Ring layout arc, ft/min between index and speed to fly.
FG Tolerance of speed to fly for insignificant effect to average ground speed.

Figure 7. - Pure MacCready speed ring derivation, all climbs circling.



A Rate of climb along course at speed H
B Average ground speed for one climb glide cycle, begin and end at same altitude.
C Tangent at polar (see above FG)
D Ring optimum airspeed between climb zones.
EC Ring layout arc, ft/min between index and speed to fly.
H (I) flight speed during climb along course.
I Climb speed

Figure 8. - Street speed ring derivation, climbs are along course.