THE BERKSHIRE ELECTRIC VARIO

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For the weekend soaring pilot who cannot select the best day of the week (or month) for his recreational soaring, an ultra-sensitive electric variometer is a great aid for sustaining in weak or marginal lift conditions. A really nimble vario that responds in a fraction of a second to any change in lift and can show lift or sink down to 0.2 ft/sec permits utilization of the largely neglected region just above zero sink. To facilitate rapid centering in a small New England-type thermal, to promptly indicate when ridge lift is fading and the figure eight turn started, or even to milk the last foot of altitude from a dying wave, this vario is a tremendous aid. Here in the Berkshire Hills of western Massachusetts, the members of the Berkshire Soaring Society have been enjoying "home-made" varios with the above virtues for nearly two years now.

This development grew out of the author's long interest in audio and hi-fi and his experience in building capacitor microphones and electrostatic loudspeakers extending back over fifteen years. This interest coupled with recent addiction to soaring has spawned the Berkshire Vario. What could be more natural than adapting the art of sensitive microphone construction to the related problem of sensing delicate pressure changes (at subsonic frequencies) involved in measuring rate of climb of a sailplane.

We borrowed the existing concept of the slow leak of air from a reservoir through a small diameter constriction or capillary tube and used a capacitor microphone of the balanced type to sense the pressure difference at either end of the capillary tube. Our microphone does not transform acoustic energy or sound to electrical energy; it does transform a miniscule change of pressure to a proportional change in voltage. Thus, it should properly be termed a capacitance-type differential pressure transducer. We shall hereafter refer to the device as the "transducer."

Figures 1 and 2 show external views of the complete assembly of flask, transducer, electronics and meter without the battery. An angle plate adapter used in mounting the instrument on the bottom of the panel of the club's 2-22 is also shown in the figures. This adapter is omitted in the version used in the 1-26.

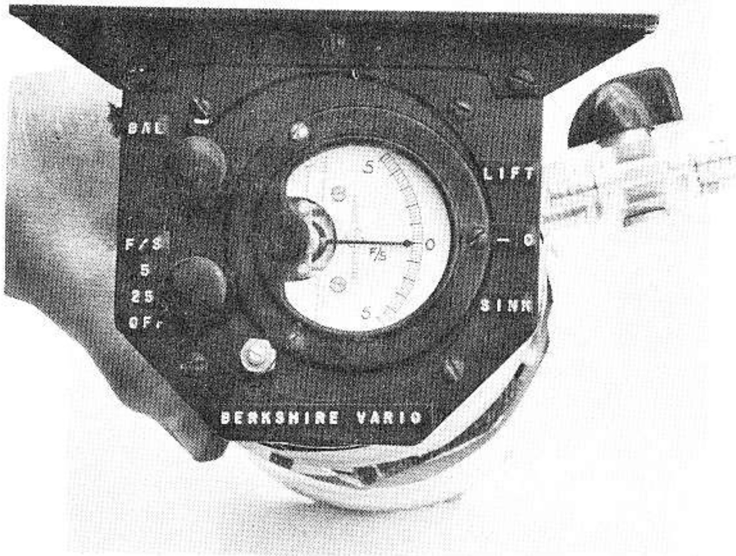


FIGURE 1

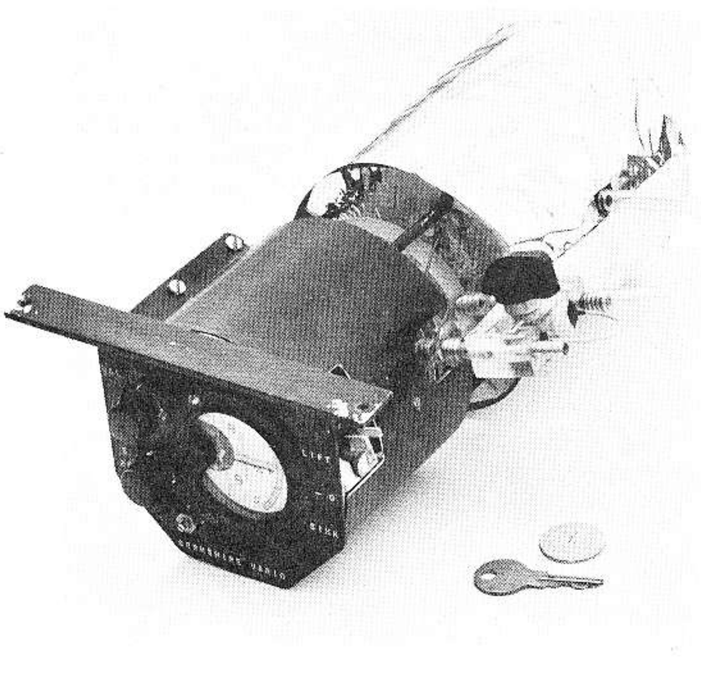


FIGURE 2

In both versions, a dual range display on the meter of 5 or 25 ft/sec is used. The full-scale range is selected by a three-position switch which includes the battery on-off switch. The switch knob is located at the lower left of the meter face. Above the switch is the knob of a zero adjustment potentiometer. The least reading division on the 5 scale is 0.2 ft/sec, with major divisions at integral feet per second for both lift and sink. When operated on the 25 ft/sec range, all the above divisions are multiplied by five so that the least reading divisions are integral feet per second and the major divisions are 5 ft/sec units.

On either scale the "time constant" which is defined as the time for the meter needle to reach 63 percent of its ultimate value on being subjected to a sudden pressure (or rate of climb) change is from 4 to 6 tenths of a second. Since a time duration of five time constants is necessary for the completion of 99 percent of the needle motion, we can say that final needle setting is attained in from 2 to 3 sec.

The meter, controls, and electronics circuits are mounted on a 4.12-in. diameter plate with the meter and controls clustered to fit within a standard 3.12-in. panel opening. The transducer is mounted on four posts behind the front plate and it, in turn, supports the insulated flask on another four posts behind it.

We should like to encourage others to try their hands at building this instrument. Our model was built from lathe-machined parts for the transducer, front plate, and posts. Some experience with electronic kit building and access to a high-impedance voltmeter and oscilloscope is also very helpful. However, much simpler approaches can be devised and the latitude of tolerance on components used in the circuitry is so broad that it is difficult to fail completely.

Depending upon the resourcefulness of the builder and the contents of his shop junk-box, the cost will range from $50 downward for materials and components. The most expensive component is the 50-0-50 microammeter listed in Allied Industrial Electronics Catalog for 1971 at approximately $22. All the other electronics components will run less than $15 depending on brand and quality. In our design no attempt was made to dress it up, and simple bread-board techniques were used to facilitate development changes, even in the flying configurations.

Figure 3 is a simplified schematic diagram of the pneumatic and electronic circuitry. In addition to the classic insulated flask and capillary restriction, we show the transducer with a small cavity behind each side of a flexible, electrically-conductive diaphragm, connected to either end of the capillary. Also shown is a shunting or by-pass valve around the capillary tube whose purpose will be explained later.

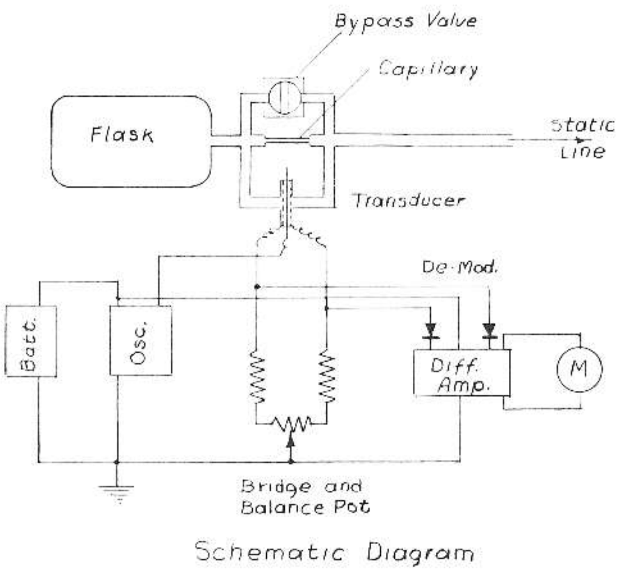


FIGURE 3

The transducer is simply a thin plastic film membrane, metalized on one side to make it electrically conductive, stretched between two perforated metal discs or plates to form a three-plate capacitor. Aluminized Mylar approximately 0.003-in. thickness is used in our unit. It is spaced away from the plates a few thousandths of an inch by the slightly raised annular ring surrounding the cavity in the plastic blocks holding the fixed plates. Figure 4 shows a detailed cross-sectioned drawing of the transducer. This drawing is to scale except for the 0.004 to 0.006-in. spacing (diaphragm to plate) used in our unit, and the exaggerated

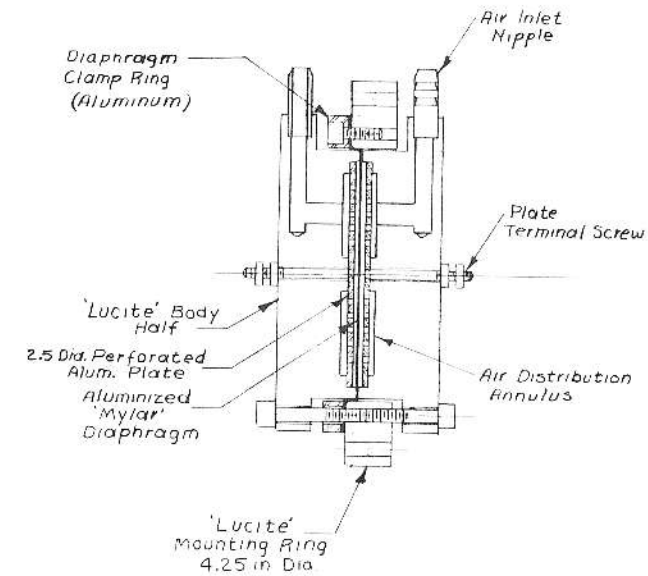


FIGURE 4

thickness of the diaphragm for purposes of illustration. This model of the transducer features a clamped diaphragm with provision for adjusting its tightness by forcing one plastic body half into the central ring by means of the external circle of clamping screws. Simpler models have been used with the diaphragm externally stretched in concentric rings, as in the old-fashioned embroidery hoops, then cemented to the raised annular ring on one of the body halves.

In any event, the diaphragm should be stretched only tightly enough to insure a wrinkle-free, stable, and repeatable center or zero position when the pressure on each side is the same.

Up until now, the description of the transducer sounds very similar to the highly regarded Ball Engineering Company vario which also employs a thin Mylar diaphragm. The distinction lies in the method of sensing changes in position of the diaphragm due to differential pressure.

In our unit, the least unbalance of pressure will deflect the diaphragm toward the lower pressure and upset the balance of electrical capacitance between the metalized film and the fixed plates on either side. In the Ball vario, the diaphragm displacement is sensed by a balanced inductive coil on either side of the membrane, measuring the motion of a thin magnetic steel tape or chip attached to the membrane. The metalized Mylar diaphragm used in our transducer is coated with a film of aluminum a few millionths of an inch thick, and the entire active portion weighs in the order of 0.002 oz, so that inertia effects are minimized.

The transducer is energized by AC voltage derived from an oscillator drawing power from a 12- to 14-volt battery. The transducer is used in an AC bridge circuit so that diaphragm displacement changes the capacitive reactance of either leg of the bridge and consequently the AC voltage balance at the two fixed plates. The two AC voltages are then rectified and fed to a differential DC amplifier, which essentially compares the level of the two DC voltages, and display the difference on a sensitive zero-center microammeter. The battery voltage was selected principally because our aircraft radios operate at this voltage. The total battery drain in this voltage range is from 10 to 12 ma. Actually the circuit will function very well with reduced sensitivity at 5 volts.

In discussing the options available to the designer of the pneumatic (or is it fluidic) elements, we may recall that the rate of flow of air out of the flask on attaining a constant rate of climb depends essentially only on the volume of the flask and the climb rate. This comes about because any parcel of air initially at the earth's surface expands as it is lifted. The corresponding increase in volume of a given weight of air as it is lifted is accompanied by escape of air through the capillary. The rate of expansion is nearly (but not exactly) constant for any increment of altitude increase. This non-linearity will be discussed later when we come to calibrate the instrument.

The pressure difference existing across the capillary as a consequence of the flow through it depends directly on the volume rate of flow, the length of the capillary, the viscosity of the air, and inversely as the fourth power of the capillary inside diameter. Viscosity of air changes slightly with temperature, but this is another source of non-linearity which we will treat later.

The sensitivity of the diaphragm to motion depends directly on the pressure difference and its free area and inversely with tautness or degree of stretched tension. The kind of material and its properties appear to be unimportant as long as the material is stretched enough to induce tensile stresses appreciably larger than the pressure-induced stresses. Another condition to insure the diaphragm's acting like a membrane is to be sure it is <u>thin</u> enough and <u>limp</u> enough so that it <u>will not</u> support <u>itself</u> in bending. We selected a very thin metalized plastic film rather than aluminum foil as better at meeting the above conditions. Perhaps a more practical reason for recommending the plastic is that it is far more forgiving in its ability to be stretched and still return without rupturing.

All plastic materials will absorb moisture to some extent, but Mylar is outstanding in having the lowest absorbtivity of the commonly available films. Moisture has the effect of reducing the tautness and increasing the deflection for a given pressure difference.

The most readily controlled parameter of the diaphragm is the degree of tautness. A very tight diaphragm will deflect less than a relatively slack one. A slack diaphragm will experience a larger displacement for a given pressure difference and hence show higher sensitivity, but one runs the risk of ambiguity in zero position due to wrinkles or possible shorting to one of the fixed plates.

The most important factors affecting the time constant or rapidity of response of the instrument are the volume of the flask, the length, and diameter to the fourth power of the capillary. Other factors are restrictions to flow of air into and out of the transducer due to the very close spacing of the diaphragm to the plates; hence the well-ventilated plates and annular air distribution chambers on both sides of the diaphragm.

Lesser sources of time delay are the propagation time of pressure waves from outside the aircraft (at the speed of sound and therefore negligible for the few feet involved). It is possible that a meter movement may have excessive damping built in; but of several makes we have tried, this does not appear to be limiting.

The flask volume and the capillary diameter are the major determinants of the system time constants, and the calibration procedure detailed later will show how we measured this.

Figure 5 is a detailed schematic of the electronic circuit. The oscillator for exciting the capacitance bridge is a modification of a standard Colpitts circuit shown in Ref. 1. The modification consists of raising the resonant frequency to approximately 30 kHz by changing the tank circuit inductance to 1.0 mh and stepping up the output voltage by substituting a subminiature-driver-type audio transformer for the emitter resistance shown in the manual. The bridge resistors R_4 and R_5 should be selected so that the total resistance in each leg (including one-half the balancing potentiometer R_6) equals the capacitive reactance of each of the transducer halves at the exciting frequency. This arrangement simply divides the bridge exciting voltage by a scalar two at the bridge output. After rectification, the DC voltage at the base of Q_2 and Q_3 should also be approximately one-half the collector (or battery) voltage. Since it may be difficult to attain the specified 200 pf capacitance within ±20 percent, the exciting voltage may be raised or lowered by changing R_1 to make the DC voltage come out right. The balancing potentiometer should be large enough in resistance value to encompass all system imbalances and yet small enough to provide a comfortable degree of shaft rotation for the desired resistance change.

The demodulating diodes D_1 and D_2 can be any of numerous signal level silicon diodes with a peak inverse voltage rating of at least 30 volts. The filter capacitors at the input to the diff-amp act to hold the rectified voltage at near the peak value of the AC voltage. The RC time constant of this filter is negligibly small compared with the time constant of the flask and capillary, and permits detecting very fast envelope changes in the bridge output.

The diff-amp in the common collector or emitter follower configuration does not provide any voltage gain but acts as a buffer amplifier or impedance changing device between the relatively high-impedance bridge circuit and the very low impedance meter. Any of numerous audio type NPN silicon transistors having a current gain (h_{fe}) of from 80 to 120, but preferably matched to within 10 percent may be used. A more expensive approach is to use the integrally-packaged pair specifically designed for this type of diff-amp service. The advantage is lower drift in absolute and relative gain with temperature excursion. Silicon diodes and transistors are used because they have smaller changes in characteristics with temperature change.

The sensitivity changing switch is a 3-pole, 3-position rotary which includes the battery on-off switching. The two resistors R_9 and R_{10} should be calculated from the known or measured meter resistance in order to present a constant impedance load for the diff-amp output in the two active switch positions. In the off position, the meter is shorted to provide heavy electromagnetic damping to prevent needle motion. Our meter has a resistance of 1000 ohms, but other meter movements can be accommodated by changing R_9 and R_{10} in proportion to the meter resistance.

Because all DC amplifiers drift somewhat with temperature changes, we have provided a fool-proof method of checking the zero-sink or zero-center position of the meter while in flight. This is accomplished by opening the by-pass valve around the capillary tube. This in effect removes the restriction of the capillary and provides a much larger diameter passage for air around the diaphragm thus equalizing the pressure on both sides. With the valve open, the balancing potentiometer can be adjusted if necessary to bring the meter to zero position. Simply closing the valve restores normal operation.

While this trick does not insure constancy of calibration, it does provide assurance of unequivical distinction between lift and sink, which we consider an important feature of this design.

The valve is built into a plastic block which also supports and terminates the capillary tubing. The valve is connected with Tygon tubing to the transducer, flask, and static line. The valve handle is accessible at a position just behind and below the instrument panel. The valve block assembly is shown projecting to the right in Figs. 1 and 2. Figure 6 shows a scale drawing and some dimensions of the design. Nothing is critical in this assembly, except a reasonably good fit be-

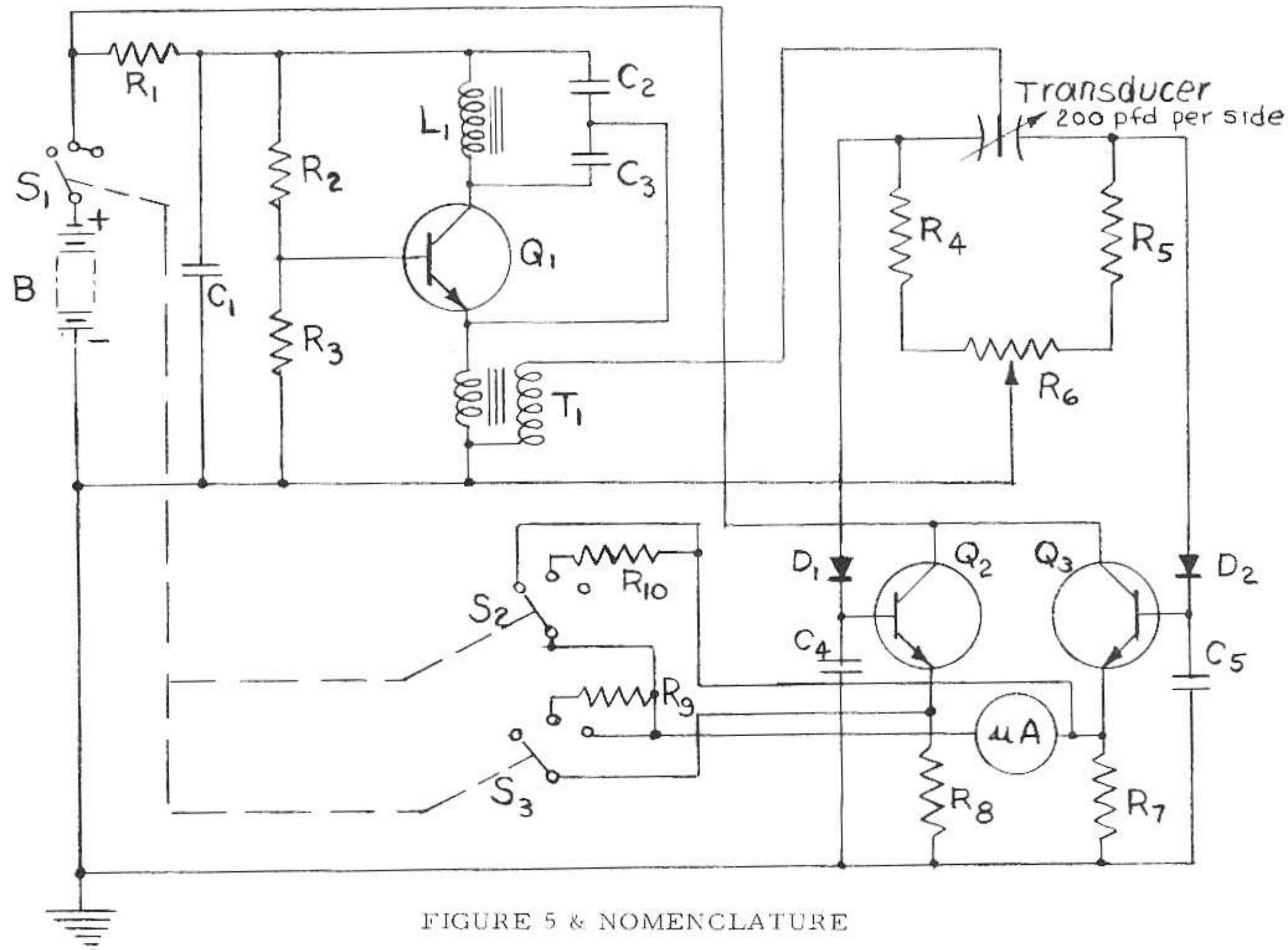
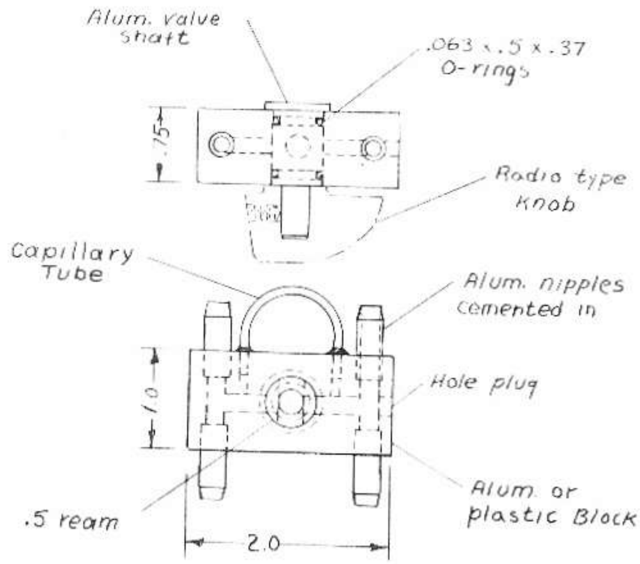


FIGURE 5 & NOMENCLATURE

A	= 50-0-50 Microampere Meter, 2.5 in. dia. nominal size
B	= 14 volt battery of 11 Ni-Cad rechargeable cells, Eveready No. B225 (or equal)
C_1	= 10 fd. 25 volt electrolytic
C_2	= 0.1 fd. paper or Mylar
C_3	= 0.047 fd. paper or Mylar
C_4, C_5	= 0.01 fd. paper or Mylar
D_1, D_2	= Diode 1N457
L_1	= 1 Mh Inductance, J.W. Millter Type 70F103A1 (or equal)
Q_1, Q_2, Q_3	= Transistor 2N3569
R_1	680 ohms, 0.5 watt
R_2	= 12,000 ohms, 0.5 watt
R_3	= 8,200 ohms, 0.5 watt
R_4, R_5	= 22,000 ohms 5% tolerance, 0.5 watt
R_6	= 10,000 ohm, 2 watt potentiometer Ohmite CU1031 (or equal)
R_7, R_8	= 27,000 ohm, 5% tolerance, 0.5 watt
R_9	= 820 ohm, 0.5 watt
R_{10}	= 270 ohm, 0.5 watt
$S_{1\,2\,3}$	= 3-pole, 3-position rotary switch Calectro Cat. No. 2-165 (or equal)
T_1	= Subminiature Audio Driver Transformer 2k: 10k Impedance, Calectro Cat. D1-711 (or equal)



Capillary and Bypass Valve

FIGURE 6

tween the valve rotor and body bore and the seating of the O-rings to prevent leaks. The O-rings and rotor are lubricated with a silicone grease which does not stiffen at low temperatures and does provide a sufficiently viscous sealing medium to prevent leaks even at high temperatures.

CALIBRATION

Now we must introduce some elementary formulas to enable the interested instrument builder to calculate performance and to better illustrate the effects of changing some of the design parameters as they bear on sensitivity, responsiveness, calibration, etc.

The first problem we address is to arrive at a relation between rate of climb and volume rate of flow of air from the flask. We used a table of properties of the standard atmosphere as defined by NACA (now NASA) in Ref. 2. In this table the temperature, density, and viscosity, among other properties, is shown for each thousand feet of altitude above sea level up to 50,000 ft. The ratio of any two adjacent densities is a measure of how much the air is expanded in rising 1000 ft. We checked the expansion ratio between several heights: sea level and 1000 ft; 10,000 and 11,000 ft; 20,000 and 21,000 ft; 30,000 and 31,000 ft; 40,000 and 41,000 ft, to see how the relation behaves. It turns out to be non-linear as one might expect, in that it expands more as the altitude increases, for the same increment of 1000 ft change. We will return to this non-linearity a bit later. For now, we will calculate the volume expansion ratio for the first 1000 ft from sea level. From the table, we find the density of air at sea level $\rho = 0.002378$ slugs/cf and at 1000 ft it is 0.002310 slugs/cf. Never mind what the units mean since we are going to divide the larger by the smaller or 0.002378/0.002310 = 1.02943. This is a dimensionless number which expresses the ratio of two densities. Since density here is a mass per unit volume and the inverse or reciprocal relation is a volume per unit mass, we have arranged our density ratio to actually show how much the volume per unit mass or specific volume has increased in being lifted from sea level to 1000 ft altitude. The 1.02943 ratio means that any volume of air will expand 0.02943 or 2.943 percent in being lifted this height. Now it can be seen why the volume rate of air flow out of the flask is proportional to the size of the flask and the rate of climb. If the flask holds 100 cu in. at sea level, 100 x 0.02943 or 2.943 cu in. will have leaked out at 1000-ft altitude. If 1000 ft was attained in 1 min, then 2.943 cu in./min is the average volume rate of flow. Naturally a smaller flask, say 10 cu in., will experience only 1/10 the volume rate of flow for the same climb rate.

By some early experimenting, we had determined that a 1-pint flask gave us adequate sensitivity, so our calibration went as follows: A pint contains very nearly 29 cu in. In being lifted 1000 ft, it would leak 29 times 0.02943 = 0.856 cu in. If this altitude were attained in 1 min or 60 sec, the climb rate would be 1000/60 = 16.67 ft/sec and the volume flow would be 0.856 cu in./60 sec = 0.0143 cu in./sec. Since we wished to have our full scale reading in the most sensitive position, i.e., 5 ft/sec, we reduce the flow proportionately as follows:

$5/16.67 \times 0.0143 = 0.0043$ cu in./sec

Thus, we have arrived at an air flow rate to represent climbing at 5 ft/sec which is a flow through the capillary tube of 0.0043 cu in./sec.

Our calibration scheme involves simply pushing 0.0043 cu in./sec of air through the capillary tube. The transducer which responds only to a difference of pressure on its two sides caused by air flow through the capillary does not know or care whether it is actually climbing or not. We arranged a flat pan of water with relatively large surface area as a reservoir to supply a controlled and timed flow of water to a small diameter glass capillary tube. The rate of flow is controlled by the fixed head or elevation of the pan above the horizontal capillary and the adjustment of a sensitive needle valve. A convenient length of glass capillary is 12 in. We used a strip of a broken flexible steel tape fastened to the glass tube with adhesive tape. The scheme is shown in Fig. 7. A

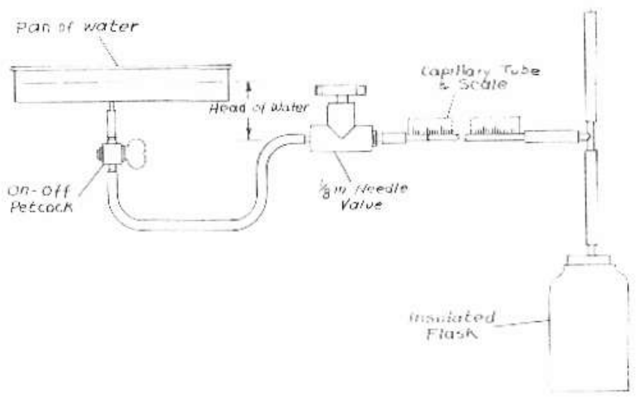


FIGURE 7

timed flow of water through a known area of tubing yields a measured flow rate of displaced air. We used a glass tube with an inside diameter of 0.139 in. or 0.0152 sq in. inside area. Since volume is equal to area times length, we have a capillary volume of 0.0152 cu in. per in. of tube length. Thus, the time for the water flow to displace 0.0152 cu in. is:

$$\frac{0.0152 \text{ cu in./in.}}{0.0043 \text{ cu in./sec}} = 3.54 \text{ sec/in.}$$

To make this a more comfortable time to measure, and to enhance the accuracy of measurement of time with a stop watch, we allow the flow to continue for a precise 10 in. We adjust the flow with the needle valve so that the column of water moves 10 in. in 35.4 sec. Actually this is somewhat difficult and tedious to do, so that any stop-watch reading from 34 to 37 sec for a 10-in. flow will be good enough for our purposes with at most a 3-percent error. To maintain a constant flow over a 35-sec period, the head of water must not fall appreciably; hence, the use of a large surface area of reservoir is advised. The meter will clearly show the reduction in flow as the head falls, and an average reading over the time interval may be estimated.

Once the correct volume flow is established the transducer capillary tube is selected by a cut-and-try process to show a full scale or 5 ft/sec reading on the meter. Taking advantage of a suggestion made by Steve DuPont for the use of electrical "spaghetti" tubing for capillaries, we used the plastic insulation stripped from hook-up wire as our capillary tube. As mentioned before, the resistance to air flow through a capillary is directly proportional to the length of the tube and inversely as the fourth power of the internal diameter. The formula, credited to 19th century scientists Hagen and Poiseuille, describing laminar (nonturbulent) flow through very small tubes for any gas or fluid is as follows:

$$\Delta p = \frac{128\mu lQ}{\pi d^4} \quad \text{or} \quad \Delta p = \frac{40.8\mu lQ}{d^4}$$

Where Δp = pressure difference, lb/sq in.
l = length of capillary, in.
Q = volume flow rate, cu in./sec.
μ = viscosity, absolute, Reyns. lb-sec/sq in.
d = inside diameter capillary, in.

Table 1 shows wire diameters, or inside diameters of capillaries, made from stripped wire insulation. The fourth power of the inside diameter is also given. Thus it is seen that a 4:1 change in diameter from AWG No. 18 to AWG No. 30 will effect a 256:1 change in Δp, with the smaller tube providing the greater pressure drop.

TABLE I

AWG No.	Diameter (in.) d	d^4
18	0.040	256×10^{-8}
20	0.032	105×10^{-8}
22	0.025	39×10^{-8}
24	0.020	16×10^{-8}
26	0.016	6.55×10^{-8}

We found that AWG 24 wire required capillary lengths of fractional inches; AWG No. 20 wire in the order of 2-to-3 in., which was much easier to trim to length. The question of reduction of diameter with temperature drop was investigated and found to be nearly negligible. At 30,000-ft altitude the approximately 100°F drop in temperature will decrease the d^4 factor by some 3 percent for the 0.032-in. diameter tube.

While the formula relating pressure drop to volume flow is not essential in calibrating the instrument, it is instructive to calculate the actual pressure difference we are sensing. We need only to find a value for absolute viscosity of air in Reyns. or lb-sec/sq in. units at surface temperature, and assume some capillary dimensions to plug into the formula. A relation between air viscosity and temperature is found in Ref. 3, p. 362.

$$\mu = 2.39 \times 10^{-9} + 3.62 \times 10^{-12}\ ^\circ F, \text{ Reyns.}$$

For a surface temperature of 70°F, this works out to:

$$\mu = 2.64 \times 10^{-9} \text{ lb-sec/sq in.}$$

Assuming our 5 ft/sec climb; an air flow rate of 0.0043 cu in./sec; and a 0.032-in. diameter capillary, 3-in. long, we find:

$$\Delta p = \frac{(40.8)(2.64 \times 10^{-9})(3)(4.3 \times 10^{-3})}{105 \times 10^{-8}}$$

$$= 13.9 \times 10^{-4} \text{ or } 0.00139 \text{ lb/cu in. or } 0.096 \text{ millibars or } 0.072 \text{ mm Hg}$$

The instrument meter will readily show climb rates and pressure differences of 1/25 of this figure.

It is very enlightening to evaluate the result of small but sudden changes of temperature of the air in the flask. Assuming the transducer and electronics are in good working order, substitute an uninsulated 1-pint tin can for the regular flask. The mere touching of a finger to the can will cause the meter needle to swing almost immediately off scale due to heat expansion of the air in the can. This experiment points out the importance of sufficient insulation so that changes in volume due to extraneous temperature changes are slow compared to changes in pressure caused by altitude changes. One can also draw the inference that very rapid climb rates will cause errors due to heat stored in the walls of the flask. We have neglected this error, as do all variometers and flask systems that we know of. The assumption is made that modest climb and descent rates permit the flask to assume the temperature of the air flowing in and out.

The time constant can be checked with the set-up shown in Fig. 7. The flask should have the same volume as the one to be used in the aircraft. With any constant flow established which will cause a relatively large meter-needle swing, say half or more full scale, the flow is suddenly shut off at the petcock, with simultaneous starting of a split-second stop watch. The needle will immediately start to drop back toward zero. When it has apparently reached zero and all needle motion has entirely stopped, the stop watch is simultaneously stopped. The reading on the stop watch, which in our case was of the order of 3 sec, represents at least five "time constant" periods and should be divided by five to arrive at the overall time constant for the vario-flask system. Actually, a 0.6-sec time constant may be uncomfortably short for many pilots since the meter needle may dance wildly in rough air. A quick fix for this is to insert a small wad of fiber-glass wool in one or both of the nipples leading to the transducer. This will slow the flow of air to the chambers on either side of the diaphragm. Adjust the response time up to 1 sec or whatever is personally comfortable.

Incidentally, we had difficulty performing this test on windy days (even indoors) because small pressure changes outdoors caused very perceptible needle swings; we were never certain when the needle reached zero.

Other climb rates can be simulated and checked on the meter by changing the water-flow rate and, of course, the time to traverse the 10-in. capillary. All climb rates should be strictly proportional to the water-flow rates up to the maximum 25 ft/sec within reading limits and accuracy of the scale-changing resistors in the meter circuit.

Of course it should be appreciated that this calibration represents only a single condition of temperature, humidity, and pressure. The real-world conditions with other ambient ranges will change the apparent calibration of this rather simple-minded vario. A rigorous treatment or mathematical analysis of all the nonlinearities in the atmospheric structure, and response of pneumatic and electronic components is quite beyond the scope of this project (and author), but we will point out some of the factors and causes for the vario straying from the truth.

A principal error source is the nonlinear behavior of the expansion of the air with altitude. At 20,000 ft the expansion rate is 16 percent higher than at sea level; at 40,000 ft it climbs to 49 percent higher than at sea level. This effect is partially countered by the reduction of air viscosity with falling temperature. At 20,000 ft the viscosity has dropped 12 percent and at 40,000 ft it is 20 percent lower than the surface value. There is no change in viscosity from near 36,000 ft to 100,000 ft because in the NASA Standard Atmosphere the temperature is constant in this region.

Another effect that counters the increased expansion rate is the falling sensitivity due to reduction of transistor gain with falling temperature. It is quite possible that sophisticated electronics additions could be made (at higher cost) to inherently balance amplifier gain with increased expansion ratio with altitude. However, if this were done on the basis of temperature drop alone, the vario would be badly fooled on a cold day at the surface.

Since we believe that the exact calibration at extreme heights is of somewhat secondary importance, and that our vario can probably be trusted to within ± 10 percent up to 20,000 ft, we earnestly hope that others will build models and develop their own variants of this concept. While this project up to now has dealt principally with the development of a novel method of measurement of climb rate, we are now actively pursuing methods of supplementing the basic device with audio aids and total energy compensation. We will keep you posted.

ACKNOWLEDGEMENT

We should like to acknowledge the assistance and encouragement of many members of the Berkshire Soaring Society in the development of this vario. To Ted Gordon and Dick Scace for suggestions about performance and construction; to Chuck Wales for inspiration and detailed contributions on the by-pass valve and the simple water flow scheme for calibration, our sincere thanks. In addition, the aid of Bill Lubitz and Milt Musbach of the General Electric Company's Ordnance Systems, Circuit Design Engineering Staff, is gratefully acknowledged for fine points of transistor circuit design.

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