A Total-Energy Variometer Operated by Pitot Pressure

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Summary. This paper examines the theory of a total energy variometer controlled by the pitot pressure, a scheme suggested by G. Vögeli. It is shown that, strictly, the stiffness of the controlling capsule should be variable with height, but that in practice a constant-stiffness capsule will be satisfactory over an adequate range of height.

Introduction. So far, most total-energy variometers have been controlled by a venturi or other external device supplying a pressure of $\left(p_s - \frac{1}{2}\varrho v^2\right)$ to the "static" side of the instrument (Ref. 1). The application of the total-energy principle to variometers has been found to be of very great utility, and a large proportion of British gliders are fitted with suitable venturis. However, the advantages of this arrangement are offset by the ease with which the venturi ices up in cloud, and a tendency for it to admit water to the variometer when flying in rain. A water-trap and vent to cockpit pressure have somewhat reduced these difficulties, but the only really satisfactory method of excluding water is by fitting a silica-gel dryer between the venturi and the variometer instrument, remembering that the silica-gel must be regenerated from time to time.

However, G. Vögeli (Ref. 2) has suggested a means of obtaining the total-energy effect using only the pitot and static pressures from the airspeed system of the glider. This involves connecting the variometer capacity to one side of a capsule, the other side of which is at pitot pressure, thus effectively giving a variable-volume capacity. Since this mechanism is carried inside the glider, no additional external fittings are involved; if the glider is fitted with a nose-pitot and flush static vents there are no external protuberances whatsoever, with consequent freedom from icing.

Theory. The arrangement proposed by G. Vögeli is shown in fig. 1. Its theoretical equivalent is shown in fig. 2, the function of the diaphragm being to produce changes in the volume of the capacity in accordance with the difference in pressure across it.

When the glider is flying at a speed v at some height h, let the speed change by δv.

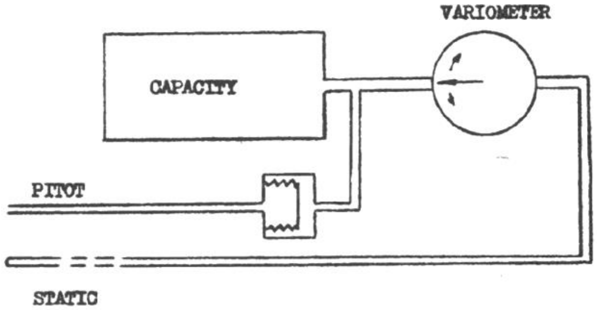

Fig. 1.

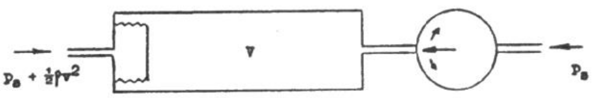

Fig. 2.

Then for constant total energy:

$$\delta h = -\frac{v\delta v}{g} \tag{1}$$

The corresponding change in atmospheric static pressure, p_s, is given by:

$$\delta p_s = -g\varrho\delta h \tag{2}$$

If the volume of the capacity is V, V being variable, and if the mass of air in the capacity remains constant at constant total energy (i. e. there is inflow or outflow through the instrument) then the changes of pressure and volume in the bottle will be governed by an equation of the form:

$$p_s V^n = \text{const.}$$

Hence
$$\frac{\delta V}{V} = -\frac{1}{n}\left(\frac{\delta p_s}{p_s}\right)$$

$$= \frac{1}{n}\frac{g\varrho\delta h}{p_s} \quad \text{from equation (2)}$$

and from (1)
$$= -\frac{1}{n}\frac{\varrho v\delta v}{p_s} \tag{3}$$

It is, of course, assumed that any pressure differences across the variometer instrument are negligibly small, so that the capacity is always at atmospheric static pressure.

Hence the pressure difference across the diaphragm will be

$$q = \frac{1}{2}\varrho v^2$$

and hence
$$\delta q = \varrho v \delta v + \frac{1}{2}v^2\delta\varrho \tag{4}$$

It has been shown in Ref. 1 that the second term of equation (4) is negligible for gliders.

Hence from equations (3) and (4)

$$\frac{\delta V}{V} = -\frac{\delta q}{np_s} \tag{5}$$

Integrating at a given height (p_s constant),

$$\log_e V = -\frac{q}{np_s} + \text{const.} \tag{6}$$

and if $V = V_o$ when $q = 0$, then

$$\log_e\left(\frac{V}{V_o}\right) = -\frac{q}{np_s}$$

or

$$\frac{V}{V_o} = 1 - \frac{q}{n p_s} \quad \text{approx.} \tag{7}$$

since for gliders, $\frac{q}{np_s}$ is small.

This may conveniently be written

$$\frac{V_o - V}{V_o} = \frac{q}{n p_s} \tag{8}$$

We wish now to determine the required "stiffness" of diaphragm in a practical case.

If we define the diaphragm stiffness as the volume change produced by a unit pressure difference across it, it will be seen that this is inversely proportional to the atmospheric pressure.

Examples. At sea level, p_s = 2116 lb./sq.ft. = 407 inches water gauge. If the changes in the capacity are adiabatic,

$$n = 1.4.$$

The usual size of capacity for "Cosim" variometers is

$$1 \text{ pint} = 568 \text{ cu. cm.} = V_o.$$

Hence, if q = 1 inch water gauge:

$$V_o - V = \frac{568}{1.4 \cdot 407} = \underline{1.00 \text{ cu. cm. per } 1'' \text{ water gauge.}}$$

At 5000 ft., p_s = 0.8320 × 2116 lb./sq.ft.

Other things being equal

$$V_o - V = 1.00 \div 0.8320 = \underline{1.20 \text{ cu. cm. per } 1'' \text{ water gauge.}}$$

If one assumes that in the UK, most club glider flying takes place between these heights, a diaphragm stiffness of 1.10 cu. cm. per 1 inch water gauge pressure difference would seen to be reasonable. Near sea-level, the total-energy diaphragm will tend to over-compensate for speed changes, whilst at heights above about 2500 ft., it will be slightly under-compensate. The alternative, in order to obtain accurate compensation, would be to control the diaphragm from a spring via a linkage whose ratio was varied by an altimeter capsule, but this would be excessively complicated and expensive.

The arrangement shown in fig. 1 has been found to work well in practice. It should be remembered that the volume of the capacity must be adjusted to allow for the volume of air around the diaphragm in the total-energy unit.

References:

1. Irving, F. G., "Total Energy Variometer". 5th OSTIV Congress, Buxton, 1954.
2. Vögeli, E., "Totalenergievariometer". "Schweizer Aero-Revue", *3*, p. 91, 1955.

List of Symbols:

h: height
v: true airspeed
g: gravitational acceleration
p_s: atmospheric static pressure
ϱ: atmospheric density
V: volume of variometer capacity
n: index of expansion
q: velocity head