AN ARTIFICIAL HORIZON AND DIRECTION GYRO SUITABLE FOR SAILPLANES.

By A.H. YATES

THE COLLEGE OF AERONAUTICS, CRANFIELD, ENGLAND.

I. THE ARGUMENT FOR A HORIZON.

Few sailplanes are yet fitted with artificial horizons but many enter clouds. Their pilots rely on the airspeed indicator and turn-and-bank indicator to maintain circles at constant airspeed. With perseverance many pilots become sufficiently skilled in the use of these indirect indications of the glider's motions to fly safely and competently. Many others, however, are discouraged from cloud flying by the difficulties they encounter on their early attempts.

The task inside the cloud is to maintain the airspeed indicator reading as near as possible at a figure chosen from knowledge of the sinking speed, the stall, the roughness of the air and the tightness of the turn. At the same time, the rate of turn must be kept constant except when a slight variation in the path is required to move into a better lift area. The cloud flying novice finds an irresistable tendency to "chase the ASI" and his attempts to keep a constant airspeed usually end in a series of dives and climbs while he circles. If the amplitude of this speed oscillation is not more than $\pm$ 10 miles per hour no serious harm results but the up and down path gives readings to the variometer which have no relation to the strength of the thermal. The novice has then no indication of the direction of the best lift and soon loses it.

A similar tendency to "chase the ASI" is often to be found among learners in powered aircraft (and some in gliders) when flying in visual conditions. In these cases the instructor merely advises them to concentrate on maintaining a constant attitude to the horizon and the difficulty is at once overcome. In a cloud, too, the difficulty vanishes as soon as a horizon (artificial) is visible. The pilot maintains a constant attitude, whether he is circling or flying straight and makes adjustments to it only occasionally when the airspeed appears fast or slow. The rate of turn is set by maintaining a constant angle of bank (depending on the size of the lift area - say, 30°) and keeping the "slip" needle or ball central. The turn needle is not now needed in the turn since a correctly banked 30° turn at a known airspeed correspondends to one rate of turn only - i.e. the turn indicator is redundant 1).

With an almost constant airspeed the variometer reading now means something and the process of centring in the lift can be begun.

II. THE ARGUMENT FOR A DIRECTION GYRO.

The direction gyro gives a continuous indication of the heading of an aircraft. The presentation is usually similar to that of a compass (a card marked 0° - 360° passing behind a window) but the gyro is unaffected by turns. While the glider is circling, the card of the magnetic compass may give a completely erroneous reading, so that the pilot has no idea when to stop his turn to fly out of the cloud on, say, a northerly course. He stops the turn, waits for the card to settle down and then finds, perhaps, that he is flying south. He turns again - by counting seconds since the compass will be no guide - and again stops the turn. This process for coming out of a cloud with the aid of a magnetic compass is wasteful of time, height and distance. The inconvenience is minimised if the compass is well damped but the turning error cannot be eliminated.

The direction gyro suffers from no turning error or damping deficiency. It must be set to read the same as the compass and then uncaged before the glider enters the cloud or, at least, while the glider is flying straight. The pilot can then see at any moment what his heading is and can leave the cloud on any course he wishes without waste of time. Unavoi-

1) The turn needle is still useful for keeping a straight course in cloud - unless a direction gyro is available.

dable friction in the bearings of the gyro causes a "precession", i.e. a slow departure of the gyro bearing from the compass bearing. The direction gyro should therefore be caged and re-set every 15 minutes or so. A slight inaccuracy in the D.G. reading is of no serious consequence since, if the pilot straightens up to fly out of the cloud in a northerly direction by the D.G. but finds his magnetic compass reading 010 after it has settled down, the small correction to his flight path causes no inconvenience. The keeping of a straight course with a direction gyro is as easy as keeping a straight course in visual conditions. With a turn indicator the pilot must maintain the average rate of turn at zero and this must be checked frequently by glances at the compass.

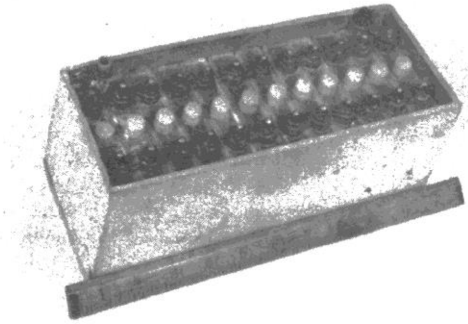
The other great use for the D.G. is in centring in the lift in the cloud. In clear air many sailplane pilots note the direction in which they are flying when the lift strength falls and then, when they have turned through 180°, straighten up for a few seconds before resuming the steady turn (to allow for the lag in the variometer the angle should be reduced to, say, 120°). The direction in which the greater lift lies is then fixed in the pilot's mind and he has some indication of the general direction of the best lift. He may fix his direction by the sun or by landmarks on the ground but he will not have the use of a magnetic compass which will be reading inaccurately in the turn. This technique can be used in cloud if the D.G. is available. Other pilots measure the 120° or 180° by knowing the time for a 360° turn (say, 20 or 25 seconds) and counting 1/3 or 1/2 of this before straightening up. A third technique consists of continuing the steady rate of turn after the lift strength falls and of straightening up for a few seconds when the lift improves again.

My impression is that most pilots use the first technique, using the sun or a neighbouring town as a direction fix, and for those pilots the D.G. should be a help in a cloud.

III. POWER SUPPLIES FOR GYRO INSTRUMENTS.

The power supply to the horizon and direction gyro should be independent of the outside air conditions. Windmill driven generators and venturis for sucking air are not permissible because they may be useless under icing conditions. Electrical storage batteries or compressed air in bottles are the best power sources. The capacity must be enough to run the instruments for about five hours continuously before recharging is necessary, and the important factors are then the weight and bulk of the power supply with this capacity.

The equipment about to be described is powered by twelve Venner 1) accumulator cells, type BB. Each cell gives 1.5 volts and has a nominal capacity of 15 ampere-hours at the 20-hour rate. The cells were removed from their bakelite cases and fitted into a specially built wooden box (Figure 1). Details of power supply are:



Weight:	Wooden box	0.8 lb.	(0.35 kg)
	Cells	7.8 lb.	(3.55 kg)
	Total	8.6 lb.	(3.9 kg)

Size of box: 10.2" x 4" x 4.2" high (26 x 10 x 11 cm)

Capacity: 18 V — 15 A-H nominal (at 20-hour rate)
16 A-H on test (at 5-hour rate)

1) "A new battery for gliders" by A.H. Yates. "Gliding", Spring 1951. The 18-V battery costs £45 in Great Britain.

IV. THE ARTIFICIAL HORIZON.

The horizon described below has been developed from the German (Horn) combined horizon and turn-and-bank indicator by the removal of the turn gyro and fittings and the shortening of the case. The modified instrument is shown in Figure 2 with one of the original instruments. Details of the two instruments are:

	Horn combined H. and T. and B.	Modified Horizon.
Weight:	4.5 lb. (2.0 kg)	2.8 lb. (1.25 kg)
		(i.e. a saving of 38%)
Length:	7.2 ins. (18.5 cm)	6.0 ins. (15.0 cm)
Diameter:	4.1 ins. (10.5 cm)	4.1 ins. (10.5 cm)

The modified horizon has a single gyro driven by 36 V, 500 cycle 3 phase alternating current. The gyro can be caged with its axis vertical by rotating the milled ring surrounding the dial. When uncaged, the movement of the horizontal relative to the glider is shown by the movement of the horizon bar relative to the model aeroplane which is fixed on the dial. The presentation is quite natural and no difficulty is found in entering and leaving turns or in flying straight.

The limits within which the indication is correct are:

Pitch $\pm$ 80°

Roll $\pm$ 100°.

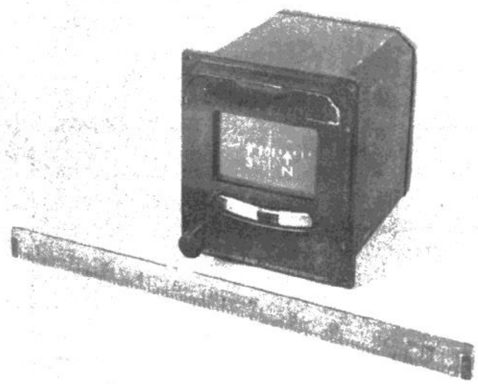
If these limits are exceeded, for example by aerobatics, the gyro topples.

An erecting mechanism will bring the horizon bar slowly to the horizontal if the gyro is toppled or uncaged when the glider is not on an even keel. The time taken is, however, of the order of 20 minutes so that the process of re-setting to zero is best performed by caging the gyro and uncaging when the glider has been brought back to an even keel by means of the other instruments.

The erecting mechanism consists of a small mercury switch and an erecting coil which is energised via the switch when the gyro axis does not coincide with the apparent direction of gravity. In a properly banked turn the apparent direction of gravity is not vertical but in the plane of symmetry of the glider. This will cause the horizon to erect in a sense which reduces the angle of bank shown by the instrument until it eventually indicates zero bank. If this took place the pilot would be steadily increasing his angle of bank while the artificial horizon indicated a constant bank angle. This is not, apparently, a real problem since many hours of flying with the horizon, including continuous circling in one direction for periods of over 15 minutes, have not led to any difficulty. If the erecting system did cause trouble it could, of course, be disconnected.

A slip indicator is fitted at the bottom of the dial. A ball moves in a curved tube filled with liquid. The turn needle of the original instrument has been removed on the modified horizon.

V. THE DIRECTION GYRO.



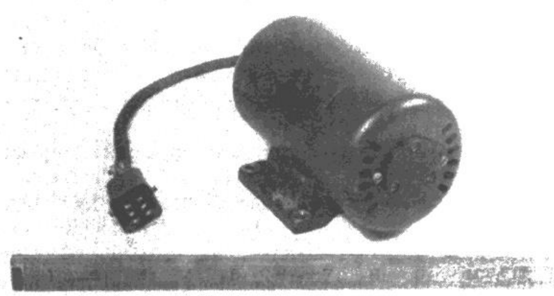
The direction gyro described has been constructed from a German (Siemens) "Kurskreisel". This instrument (Figure 3) consists of a free gyro with axis horizontal which can be caged by a knob on the left and rotated about a vertical axis until the scale indicates the desired reading - i.e. the same reading as that of the compass. The gyro can be uncaged and remains with its axis fixed in space. The scale reading in the window then indicates the course being steered by the glider. This gyro, too, is driven by 36 V, 500 cycle 3 phase alternating current.

The original instrument had a second scale above the first, which was adjustable by a second knob on the right, and a large number of slip-rings from which signals were sent to the automatic pilot. All unnecessary parts were removed and data for the modified direction gyro are:

Weight:	3.5 lb.	(1.6 kg)	
Length:	5.1 ins.	(13.0 cm)	(behind instrument panel)
Width:	4.4 ins.	(11.0 cm)	(behind instrument panel)
Height:	5.0 ins.	(12.5 cm)	(behind instrument panel)

There appears to be no manoeuvre which will topple the gyro. The friction in the gimbal bearings causes a slow precession of the gyro, i.e. the scale very slowly rotates in space at a rate of perhaps one degree in two minutes. It is necessary to adjust the D.G. to read the same as the compass every 15 minutes or so. This is no great hardship, particularly since glider navigation is seldom conducted to accuracies of more than 10°; the whole advantage of the D.G. over the magnetic compass is that, while turning, the pilot knows the direction, at least approximately, at each instant.

VI. ALTERNATING CURRENT SUPPLY.



A standard German inverter 1) (shown in Figure 4) has been used to convert the direct current at 18 V to alternating current. The inverter is designed to operate from 27 V D.C. and to deliver three phase A.C. at 500 cycles and 36 V, but operates successfully from 18 V D.C. The A.C. frequency is reduced with the voltage and it is the frequency which decides the gyro R.P.M. However, no ill effects from precession of the gyros have been observed and it is concluded that 18 V is an adequate D.C. voltage.

1) Inverter = "Umformer" in German.

Details are:

Weight: .... 4.6 lb. (2.0 kg)

Length: .... 6.1 ins. (15.5 cm)

Diameter: .... 3.4 ins. (8.5 cm)

VII. LABORATORY TEST RIG EXPERIMENTS.

Tests on the Venner battery and the instruments described above have been conducted in the laboratory and in an Olympia. The circuit was as shown in Figure 5 and the quantities measured during the run were:

The battery voltage V_B

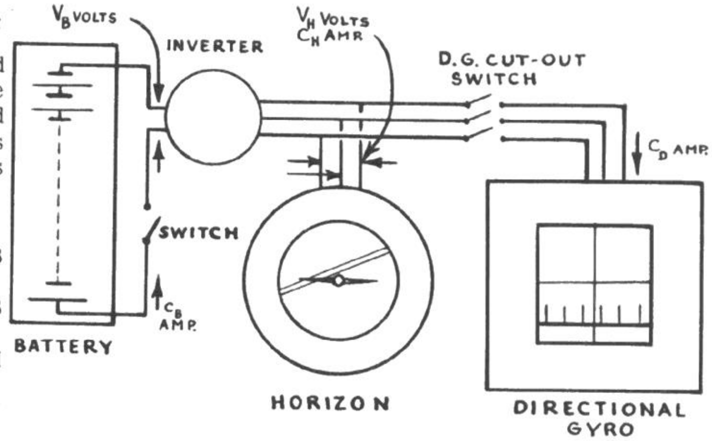
The current from the battery C_B

The A.C. voltage from the inverter V_H

The A.C. current to the horizon C_H

The A.C. current to the D.G. C_D

The A.C. frequency



CIRCUIT OF THE TEST RIG AND OF GYRO INSTRUMENTS IN THE SAILPLANE.

The variations in these quantities with time have been determined during runs with the horizon only and with both horizon and direction gyro. A typical result is plotted in Figure 6 (see page 55). Both the horizon and direction gyro were being driven in this test and both ran satisfactorily for nearly seven hours. It is seen that:

I. V_B, the battery voltage, falls quite quickly to 17.8 volts (1.48 volts per cell) and then remains remarkably constant for nearly five hours. The fall in battery voltage is then fairly rapid and at about 8 volts the gyros topple. A warning blinker on the glider dashboard is set to close at 13 volts, and this gives 15 minutes warning of gyro failure.

II. C_B, the current taken from the battery, is large immediately after the switch is closed, but falls as the inverter gathers speed and remains at about 2.5 amps. until the last 15 minutes of the run when it increases slightly. The battery thus delivers about 17 ampere-hours at the six-hour rate although its nominal rating is only 15 ampere-hours, at a gentler rating.

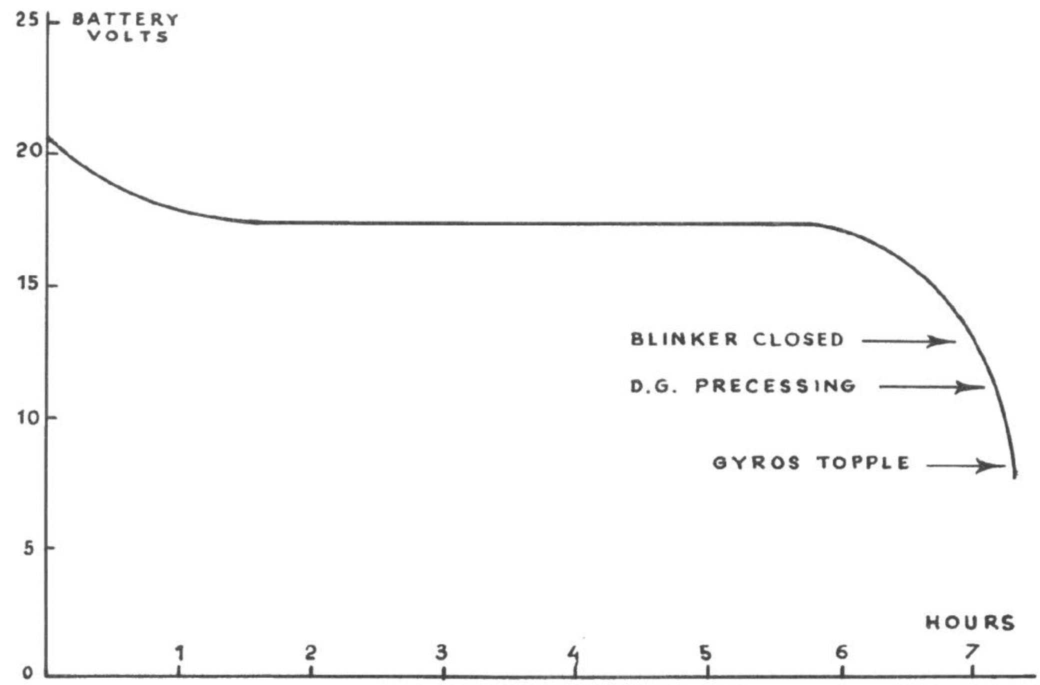
III. V_H, the A.C. voltage from the inverter, is 30 V.

IV. C_H, the A.C. current to the horizon, is 0.21 amps.

V. C_D, the A.C. current to the direction gyro, is 0.36 amps.

VI. The A.C. frequency is 360 cycles per second (380 if the D.G. is disconnected).

BATTERY ENDURANCE. The quantity which decides the endurance of the battery is C_B, the current taken from the battery. The values measured are summarized below:



VENNER BATTERY DISCHARGE CURVE WITH MODIFIED HORIZON AND DIRECTIONAL GYRO.

	C_B	Battery Endurance
(a) Horizon, in original state with turn gyro	2.3	7 hours
(b) Horizon, modified by removal of turn gyro	2.1	
(c) Direction gyro	1.7	
(d) Modified horizon + direction gyro (b) + (c)	2.5	nearly 7 hours.

VIII. FLIGHT TESTS.

When fitted to an Olympia for flight testing the batteries were mounted between the wings, on the top decking of the fuselage; the inverter was mounted under the nose cap replacing the ballast weight stowage normally there. The instrument panel was redesigned to give the horizon the pride of place at the top centre, while the direction gyro was mounted at the very bottom of the panel on a floor pedestal.

Endurance tests confirmed that the Venner 18 V battery will run the original horizon for more than 6 hours continuously (or the modified horizon plus the D.G.).

IX. CONCLUSIONS.

The three instruments described (inverter, horizon and direction gyro) driven by a Venner 18 V 15 A-H battery form a valuable set of blind flying instruments for a sailplane. The weights are:

Battery	8.6 lb.	(3.9 kg)
Inverter	4.6 lb.	(2.1 kg)
Horizon	2.8 lb.	(1.3 kg)
D. G.	3.5 lb.	(1.6 kg)
Total	19.5 lb.	(8.9 kg)

Laboratory and flight tests show that the instruments will run continuously for at least six hours before the battery needs re-charging.

The disadvantages of the instruments described are:

I. The lack, at present, of easily available substitutes for the German instruments used.

II. The very high cost of gyro instruments and of the Venner batteries. The tests have shown, however, the type of instrument and battery needed so that sailplane pilots must rely on the aircraft instrument industry to produce the instruments at a reasonable price or on their own ingenuity to modify existing instruments.

X. SUMMARY.

This note argues that the artificial horizon, together with the direction gyro, form the ideal pair of instruments for the accurate and safe flying of sailplanes in clouds. A description is given of a pair developed from German instruments together with full details of their weight, size and current consumption. It is shown that for a total weight of 20 lb. (9 kg) a sailplane can be fitted with an electrically driven horizon and direction gyro which will run continuously for six hours before the batteries need re-charging. The batteries used were the Venner silver-zinc accumulators.