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MINISTRY OF AVIATION

**AEROPLANE AND ARMAMENT
EXPERIMENTAL ESTABLISHMENT**

BOSCOMBE DOWN

EVALUATION OF SPERRY GM7 COMPASS SYSTEM IN THE DIRECTIONAL
GYROSCOPE MODE. [C]

BY

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-5 OCT 1965

AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT
BOSCOMBE DOWN

② Evaluation of Sperry GM7 Compass System in the Directional
Gyroscope Mode LC 7, 8

by

⑩
Sqn. Ldr. D. A. Stonehouse,
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Summary

↙
The Sperry GM7 compass system incorporates the CL11 directional gyroscope and is roll stabilised by an external horizon reference. Trials of a GM7 operated as an unslaved directional gyroscope were conducted at Boscombe Down.

The trials showed that the long term heading stability of the system was better than 0.3°/hr., that the short term stability was better than 0.6°/hr., and that normal aircraft manoeuvres had little effect on the system's performance. They also revealed that certain precautions were necessary to obtain optimum results from the system.

* *disputed*

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1. Introduction

As a part of the Phase 3 modification of Shackleton aircraft the G4B compass was replaced by a dual Sperry GM7 installation. Because these compasses include high precision directional gyroscopes, the possibility arose of conducting operations with the gyroscopes unslaved and operating in the directional gyroscope (DG) mode. An evaluation of the system's performance in the DG mode was authorised by Nav.1(b) (Headquarters letter AS/568/08 dated 23rd February 1965 refers.) The aims of the trial were:-

- (a) To determine the gyroscope's drift rate when operating in the DG mode,
- (b) to determine the accuracy of the gyroscope's performance in turns and manoeuvres, and
- (c) to assess the performance of the gyroscope's bank out-out mechanism.

The equipment was installed in Comet 4C XS 235 in time for a first flight on 15th March 1965. The early stages of the trial were carried out in conjunction with other equipment trials, and it was not until 5th April, 1965 that a flight was executed solely for the GM7 trial. Seven sorties were then necessary to complete the data acquisition phase of the trial, with the final flight taking place on 4th May, 1965. The equipment was removed from the aircraft on 25th May, 1965.

2. Description of Sperry GM7 Compass System (DG Components)

The DG portion of the Sperry GM7 compass system consists of a CL11 directional gyroscope, a Horizon Gyro Unit Mk. 3 (H.G.U.), a compass master unit, a latitude controller, power supply units, amplifiers and synchro repeaters.

The CL11 is a precision gyroscope which is mounted in a roll ring with a nominal roll freedom of $\pm 82^\circ$. The outer roll ring is stabilised in this installation by an external horizon reference, the H.G.U. The inner gymbal is maintained horizontal by a motor controlled by a liquid levelling switch. Directional torque motors are incorporated on the gyro unit for the application of earth rate corrections. If the system is operated in the slaved (H.G.) mode, the slaving signals are cut out by a micro-switch whenever the bank angle exceeds 6° .

The H.G.U. is maintained vertical by a pair of liquid levelling switches, one fore and aft and the other athwartships. The fore and aft switch is slightly offset to compensate for pendulosity effect caused by the aircraft's tendency to 'toe-in' during turns. In turns where the bank angle exceeds 10° the erection mechanism is disconnected and the H.G.U. is free running.

The compass master unit receives heading information from the CL11 gyroscope by means of a synchro receiver equipped with a rotatable stator. Rotation of this stator is accomplished by means of a knob labelled O-X on the face of the instrument. This allows the compass to be synchronised when operating in the slaved mode, or allows any desired heading to be set when operating in the DG mode.

The latitude controller applies power to the electro-magnets of the torque motors in the CL11 to counteract the apparent drift caused by earth rotation. The amount of precession is controlled by a potentiometer in the unit which is calibrated in degrees of latitude from 90°S to 90°N . Compensation is thus provided for drift rates varying between $\pm 15.0^\circ/\text{hour}$. Also incorporated in the latitude controller is a switching facility for selection of the magnetically slaved mode when this is included in the installation.

The CL11 gyro is maintained horizontal in the roll plane by signals derived from the H.G.U. These signals are obtained from a comparison of the output of the roll potentiometer incorporated in the H.G.U. with that of a second potentiometer geared to the roll ring of the CL11 gyro. This signal

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excites a servo-motor which drives the gyro package back to the horizontal. However, should a failure in the system allow a difference of greater than 5° to exist for more than $\frac{1}{8}$ th of a second, a relay functions which disengages the roll stabilisation mechanism and locks the roll ring gear in the central position.

In DG operation the heading information from the CL11 gyro is transmitted to the receiving synchro in the master unit and there modified by any off-set in the stators plus any variation set on the V.S.C. It is then transmitted by more synchros to equipments which require aircraft heading. The heading transmitted to all ancillary equipment will therefore agree with the master indicator reading but will differ from the gyro output by a combination of the two off-sets plus any transmission error.

3. Trials Method

To achieve the aims of the trial, measurements were required of:-

- (a) The gyroscope's drift rate on the ground both with and without latitude compensation.
- (b) The gyroscope's drift rate in unmanoeuvred flight with the correct value of latitude compensation.
- (c) The gyroscope's loss of datum in normal aircraft manoeuvres.
- (d) The gyroscope's loss of datum in a typical tactical manoeuvre.
- (e) The angle at which the bank cut-out mechanism actually functions.
- (f) The amount of time during which the bank cut-out operates while the aircraft is not manoeuvring.
- (g) The deterioration of heading information between the gyroscope and a typical repeater unit.

3.1. Ground Drift Measurements

When correctly set up, the gyro's apparent drift rate is a combination of the actual gyro drift and errors in earth rate compensation. The gyro's basic rate is directly measurable with the latitude control set to 0° , but because of random variations in gyro drift, the latitude compensation errors are less readily determined. However, assuming the latitude compensator errors are repeatable, a very close approximation to their magnitude could be obtained by first determining the average drift rate of the gyro and then comparing this rate with drift rates measured when various values of latitude compensation are inserted. By repeating this exercise on different days and subtracting the average drift rates and the known value of earth rate at the trials location from the results obtained, the performance of the latitude compensator was determined. A calibration curve showing the performance of the latitude compensator compared to earth rate for the controller and gyro combination was made and is at Figure 1.

For this portion of the trial the only instrumentation required was a compass repeater capable of being read to 0.01° . Such a repeater, the Smith's Navigator's Compass Repeater Type B (MCR), was used in the installation.

3.2. Airborne Drift Measurements

In flight measurement of gyro drift rates required a heading datum with an accuracy of the order of 0.1° . No simple method of achieving this on a 'one-shot' basis was available. However, the trials aircraft possessed a modified AN/LVF1 astro-tracker whose average accuracy was of that order. By making a series of simultaneous recordings of both the gyro reading and the astro-tracker heading over a period of about two minutes an accuracy of this order was obtained by averaging the differences. For optimum astro-tracker performance the sun's altitude should have been below 30° , but in order to allow sorties of a more representative length, higher altitudes were accepted /and partially...

and partially compensated for, by using more readings.

3.3. Datum Loss in Normal Manoeuvres

Measurements of the datum loss in manoeuvres were accomplished in the same manner as for airborne drift measurements, but it was not possible to separate, by direct measurement, datum losses occasioned by the manoeuvre from those occasioned by normal short term gyro drift between observations. To provide some measure of likely error in turns approximately 40 observations (20 each port and starboard) of datum loss in 90°, 180°, and 360° turns were made, and compared statistically with the likely value of short term gyro drift. In addition a limited number of measurements of datum loss were obtained after turns of long duration (720°) when the precession of the free-running H.G.U. would have allowed a false vertical to be established.

3.4. Datum Loss in Tactical Manoeuvres

As a representation of the datum loss likely to be encountered on a typical tactical manoeuvre, measurements were made of the error occurring after a fifteen minute manoeuvre (Figure 2). This manoeuvre consisted of a 90° turn, a straight and level run of approximately 25 miles, a 360° turn at rate one and a 270° turn at rate two and finally a straight and level run of approximately five miles. Because the trials aircraft operates at approximately twice the speed of the Shackleton, rate one turns were simulated by turns at 90°/min. and rate two turns by turns at 180°/min. in order to approximate the 'g' loading occasioned on the compass by the slower aircraft. As a result the trials aircraft was involved in turning for a longer period than would be the case with the Shackleton and the loss of datum would be expected to be slightly greater.

3.5. Bank Angle Measurements

To measure the angle of bank at which the bank cut-out mechanism actually functioned, a simultaneous record of bank angle and the operation of the cut-out switch was required. This record was provided by instrumenting the H.G.U. potentiometer to give a single output of the entire range of bank angle. This was obtained with only minimal effects on the potentiometer voltage, whereas the provision of an additional output to show the first 10° to a higher order of precision degraded the roll stabilisation function, and was therefore removed. The bank angle record, together with a record of the operation of the bank cut-out micro-switch were presented side by side on a C.I.D. trace.

3.6. Bank Cut-out Time Measurements

An indication of the proportion of time during which the bank cut-out switch was operating during nominally straight and level flight was available on the trace recordings described in para. 3.5.

3.7. Transmission Errors

To obtain a value for the heading transmission errors of the system, a simultaneous record of the gyro's heading and the heading presented by a typical repeater was made. Any change in the difference between these readings with heading was a measure of the transmission system errors. Because the gyro heading could not be determined to a greater accuracy than 0.1° without considerable alteration to the system, the gyro heading was recorded at the same frequency as the astro-tracker data and at least 10 readings were averaged on every heading to obtain a more accurate representation of transmission errors.

3.8. Trials Plan

The complete trials plan, thus, consisted of four phases:-

- (a) Approximately 25 hours of ground running to calibrate the latitude compensator and to determine the gyro's drift rate under static conditions.

/(b)...

- (b) Approximately 15 hours of straight and level flight to determine the gyro's airborne drift rate.
- (c) Approximately 20 hours flying to determine the likely loss of heading datum in turns of various magnitudes, and
- (d) Approximately 10 hours flying to determine the likely loss of heading datum in a typical tactical manoeuvre.

4. Instrumentation and Installation

Because the regular aircraft auto-observer positions were not available at the time of the trial, it was necessary to mount the entire GM7 installation on a palette fixed to the seat rails at the rear of the aircraft. This palette also contained facilities for two photographic auto-observers, one for the W.C.R. and one for the CL11 itself, and for the C.I.D. trace recorder. All three recording devices were connected with the aircraft's recording control unit which provided timing pulses synchronised with those of the astro-tracker and thus enabled simultaneous observations of true and gyro headings to be made. Because of the difficulties with the C.I.D. recorder described in para. 3.5., this equipment was unavailable until the last six flights, but, since these flights were the only ones for which bank recordings were particularly required, no significant loss of data resulted. The complete installation on the rear palette thus consisted of:-

- (a) A roll stabilised CL11 gyro.
- (b) An Horizon Gyro Unit Mk. 3.
- (c) A compass master indicator.
- (d) A Navigator's Compass Repeater, type B.
- (e) A latitude controller.
- (f) A power supply unit.
- (g) A servo-amplifier.
- (h) Two camera auto-observers.
- (j) A C.I.D. trace recorder, and
- (k) Switches and controls.

5. Trials Experience

All the equipment except the C.I.D. recorder was installed in Comet 4C XS 235 on the 15th March, 1965 and preliminary ground runs and airborne functional checks commenced immediately. During ground running the basic drift rate of the gyro was established, and a calibration graph (Figure 1) prepared for the latitude controller. The aircraft was fully committed to other trials during the month of March, but advantage was taken of a number of sorties flown for these trials to collect data on airborne drift rates. After the completion of the other trials, seven sorties totalling 33 hours 20 minutes were required to complete the data acquisition phase of the GM7 trial. The last sortie was flown on 4th May, 1965, and after analysis of the data collected on this flight had shown that no further sorties were required, the equipment was withdrawn from the aircraft on 25th May, 1965. Flight experience is summarised in Table 1.

/Table 1...

Date	Time	Flying Time	Data Acquired
15 Mar	1120	4:05	No data, - System check-out
19 Mar	1240	4:00	Drift measurements
24 Mar	1010	5:35	Drifts and 180° turns
26 Mar	1300	3:50	Drifts and 180° turns
29 Mar	1520	1:50	Drift measurements
30 Mar	1450	2:45	Drifts and 180° turns
31 Mar	1430	3:40	Drifts and 180° turns
Total flying in conjunction with other trials		25:45	Equivalent of 3 sorties
5 Apr	1505	4:15	Drift measurements
7 Apr	1330	4:30	90° turns
12 Apr	1145	5:10	180° turns
13 Apr	1130	4:40	360° turns
28 Apr	1245	4:45	360° and 720° turns
30 Apr	1125	5:15	Tactical manoeuvres
4 May	1215	4:45	Tactical manoeuvres
Total flying solely for GM7		33:20	7 sorties
Grand Total		59:05	Represents total flying experience

Table 1 - Flight History of GM7 Trial

6. Unserviceabilities

No unserviceabilities were experienced with the GM7 components during the trials, but a failure of the trials aircraft's power supply which had a severe effect on the system's performance occurred on the 13th April flight, and was subsequently repeated on the ground prior to the 28th April flight. During flight the symptoms of this power failure were a large precession (80°) of the CL11 and a toppling of the H.G.U. during a 360° turn. The cause of the occurrence was traced to greasy dirt on the fuse guarding one phase of the installation's three phase power supply. This allowed the voltage on this phase to drop sharply and so reduced the rigidity of the H.G.U. that a large bank error was allowed to accumulate once 10° of bank was exceeded and the H.G.U. was operating as a free gyro. The result was that the CL11 was not horizontal during the turn, and a large coupling error was introduced. The effect of this failure on the trials' results was negligible since the test data for this manoeuvre was only one of a large number of samples. However, there is nothing to prevent a similar occurrence with an operational aircraft's power supply and such a large datum loss could be very disturbing under operational conditions.

7. Results and Analysis

The results of the trial are considered under four main headings:-

- (a) Ground measurements, - covering long and short term gyroscope precession rates, and the calibration of the Latitude Controller.
- (b) Airborne Drift Rates, - covering long and short term gyroscope precession rates in flight.
- (c) Performance in Turns, - covering the behaviour of the GM7 in turns of various magnitudes, and

/(d)...

(d) Performance in manoeuvres, - covering the performance of the GH7 in a simulate tactical manoeuvre.

7.1. Ground Measurements

A total of 26 hours of ground running time was devoted to determination of the gyroscope's precession rate, to calibration of the latitude controller, and to confirming that calibration. The gyro's precession rate was determined for both short term periods of 20 mins. and for long term periods of an hour or more. To eliminate latitude controller errors, these measurements were taken with the latitude controller set to 0° and the known value of earth rate was subtracted from the measured drift. The results of these measurements are tabulated in Table 2 and show a 1σ value of long and short term drift of 0.13°/hr. and 0.24°/hr. respectively.

Date	Drift	Dr ²	n = Running Time	$\frac{Dr^2}{n}$	Σ Short Term Rates ²	No. of Obs (N)
19 Mar	0.30	0.09	1.17	0.077	0.445	6
24 Mar	0.12	0.014	1.25	0.011	0.111	6
26 Mar	0.10	0.010	1.25	0.008	0.553	6
29 Mar	0.13	0.017	1.25	0.014	0.290	6
30 Mar	0.08	0.006	1.25	0.005	0.484	6
31 Mar	0.03	0.001	1.33	0.001	0.288	7
5 Apr	0.11	0.012	1.25	0.010	0.174	6
Totals			7.75	0.126	2.345	43
$1 \sigma \text{ Long Term Drift} = \sqrt{\frac{\sum \left(\frac{Dr}{n}\right)^2 n}{\sum n - 1}} = \sqrt{\frac{\sum \frac{Dr^2}{n}}{\sum n - 1}} = \sqrt{\frac{0.126}{7.75}} = 0.13^\circ/\text{hr.}$						
$1 \sigma \text{ Short Term Drift} = \sqrt{\frac{\sum (STD r)^2}{N - 1}} = \sqrt{\frac{2.345}{42}} = 0.24^\circ/\text{hr.}$						

Table 2. GH7 Drift Rates with No Latitude Compensation

Results of the latitude controller calibration indicated that 46°N was the correct controller setting for Boscombe Down (51°10'N) and to confirm this finding, a number of drift runs were carried out with this value set on the latitude controller. These runs are tabulated in Table 3 and show a 1σ value of long and short term gyro drift of 0.19°/hr. and 0.40°/hr. respectively. This result confirmed the repeatability of the latitude compensation and, contrasted to the average drift of 1.24°/hr. obtained with 51° set on the controller, confirmed both the accuracy of, and necessity for latitude controller calibration. Other results of the latitude controller calibration are plotted in Figure 1 and tabulated in Table 4.

/Table 3...

Date	Drift	Dr ²	n = Running Time	$\frac{Dr^2}{n}$	Σ Short Term Rates ²	No. of Obs = N
17 Mar	0.16	0.026	2.00	0.013	1.613	11
19 Mar	0.22	0.048	1.50	0.032	0.762	8
7 Apr	0.07	0.005	0.83	0.006	0.351	4
12 Apr	0	0	0.83	0	0.682	4
28 Apr	0.13	0.017	1.17	0.015	0.270	6
30 Apr	0.38	0.144	1.17	0.123	1.464	6
4 May	0.75	0.273	2.17	0.126	2.768	12
Totals			9.67	0.315	7.910	51
$1 \sigma \text{ Long Term Drift} = \sqrt{\frac{0.315}{9.67}} = 0.19^\circ/\text{hr.}$						
$1 \sigma \text{ Short Term Drift} = \sqrt{\frac{7.910}{50}} = 0.40^\circ/\text{hr.}$						

Table 3. GM7 Drift Rates With 46°N on Latitude Controller

N.Lat.	Earth Rate °/hr.	Latitude Con. Rate °/hr.	Error °/hr.
0°	0	0	0
10°	2.61	2.71	+0.10
20°	5.14	5.59	+0.45
30°	7.52	8.33	+0.81
40°	9.67	10.59	+0.92
50°	11.52	12.55	+1.03
60°	13.02	13.81	+0.79
70°	14.14	14.77	+0.63
80°	14.85	15.10	+0.25
90°	15.04	15.11	+0.07

Table 4. Latitude Controller Compensation

7.2. Airborne Drift Rates

Airborne Drift Rates were computed for all sorties, up to and including that of 12 Apr., a total 28 hours flying time. These include the sorties flown for 90° and 180° turns as well as those flown expressly for drift measurements. The sortie of 13 Apr. is not included because of the malfunction already mentioned, and those for subsequent flights show measurable losses of datum in the more demanding manoeuvres. The sorties in which regular series of 90° and 180° turns were performed are included for comparison purposes and as an indication of any performance deterioration likely in a long series of normal aircraft manoeuvres. As with the ground measurements, two drift rates were computed, a long term rate based on the total drift per sortie and weighted in proportion to the sortie length, and a short term rate based on drift measurements over periods averaging 20 minutes in length. The results of these computations are tabulated in Table 5 and show a 1σ value of long and short term drift of 0.24°/hr. and 0.52°/hr. respectively.

/In the...

In the 14.85 hours devoted exclusively to drift measurements, the corresponding values of long and short term drift are $0.21^\circ/\text{hr.}$ and $0.51^\circ/\text{hr.}$ When allowance is made for the likely error of the airborne test datum, these figures are in close agreement with the values of $0.19^\circ/\text{hr.}$ long term and $0.40^\circ/\text{hr.}$ short term found in the ground measurements, and indicate that ground and air drift rates are not significantly different.

For the flights in which a series of turns were performed, the corresponding values of long and short term drift are $0.28^\circ/\text{hr.}$ and $0.54^\circ/\text{hr.}$ While these figures seem to reveal a slight deterioration of performance in a series of turns, statistical significance tests applied to these results show that the differences between these values are well within the likely chance variation of small samples. It is thus unlikely that any real difference in performance exists, and therefore, the two sets of results can be grouped together to yield the overall estimates of gyro drift, $0.24^\circ/\text{hr.}$ long term, and $0.52^\circ/\text{hr.}$ short term quoted above.

Date	Drift	Dr^2	n = Running Time	$\frac{\text{Dr}^2}{n}$	Σ Short Term Rates	No. of Obs = N
19 Mar	0.9	0.81	3.28	0.246	2.80	10
24 Mar	0.3	0.09	4.12	0.022	2.99	9
26 Mar	0.3	0.09	3.15	0.029	0.75	7
29 Mar	0.4	0.16	0.98	0.163	0.53	3
5 Apr	0.7	0.49	3.32	0.147	2.36	8
Sub-totals			14.85	0.607	9.43	37
30 Mar	0.7	0.49	2.05	0.239	0.96	5
31 Mar	0.1	0.01	2.98	0.003	1.90	7
7 Apr	1.5	2.25	4.02	0.561	4.39	11
12 Apr	0.8	0.64	4.07	0.157	1.99	9
Sub-totals			13.12	0.960	9.24	32
Totals			27.97	1.567	18.67	69
$1 \sigma \text{ long term rates - drift flights} = \sqrt{\frac{0.607}{13.86}} = 0.21^\circ/\text{hr.}$						
$\text{ - turn flights} = \sqrt{\frac{0.960}{12.12}} = 0.28^\circ/\text{hr.}$						
$\text{ - overall} = \sqrt{\frac{1.567}{26.97}} = 0.24^\circ/\text{hr.}$						
$1 \sigma \text{ short term rates - drift flights} = \sqrt{\frac{9.43}{36}} = 0.51^\circ/\text{hr.}$						
$\text{ - turn flights} = \sqrt{\frac{9.24}{31}} = 0.54^\circ/\text{hr.}$						
$\text{ - overall} = \sqrt{\frac{18.67}{68}} = 0.52^\circ/\text{hr.}$						

Table 5. Airborne Drift Rates

7.3. Performance in Turns

The behaviour of the GM7 in turns was investigated during turns of 90° , 180° , 360° , and 720° . Statistical samples were taken of the datum loss /experienced...

experienced on the three smaller turns, and a limited sample, (six observations) was taken of the loss on the 720° turns (eight minutes of continuous turn). Results of these observations are tabulated in Table 6 and show for 90° turns a 1σ value of datum loss of 0.15°/port, 0.14°/starboard, and 0.15° overall; for 180° turns, 0.17°/port, 0.15°/starboard, and 0.16° overall; for 360° turns, 0.17°/port, 0.18°/starboard, and 0.18° overall; and for the limited number of 720° turns 0.45° overall. These results show no significant variation with either direction or magnitude for the three smaller turns and, indeed, when corrected for the likely value of short term drift between observations, show a complete compatibility with the assumption that no datum loss whatsoever occurred during the turns and that the 1σ value of the error in the test datums was 0.1°. This assumption is in agreement with the results of paragraph 7.2. and when considered in conjunction with the chance variation of small samples, could fully account for the difference observed between ground and air drift measurements. In the turns of 720°, however, a significant increase in datum loss did occur. This was to be expected since the H.G.U. gyro runs unmonitored when bank angle exceeds 10°. As a result, the levelling signals to the directional gyro are in error by the amount of free drift which accumulates on the H.G.U. during turns. When the turns are of less than four minutes duration, AP 1275 specifies that this drift shall be less than 4°; for turns of greater duration, however, the amount of error present can increase proportionately and result in measurable amounts of cross coupling between gyro axes.

Turn°	Σ Datum Loss ²	No. of Obs.	σ°	Prob. Drift°	σ° Corr. for DR.
90P	0.45	20	0.15	.05	0.14
90S	0.38	20	0.14	.05	0.13
All 90°	0.83	40	0.15	.05	0.14
180P	0.82	28	0.17	.07	0.15
180S	0.62	28	0.15	.07	0.13
All 180°	1.44	56	0.16	.07	0.14
360P	0.57	19	0.17	.09	0.14
360S	0.59	19	0.18	.09	0.15
All 360°	1.16	38	0.18	.09	0.15
All 720°	1.02	6	0.45	.12	0.43

Table 6. Performance in Turns

7.4. Performance in Manoeuvres

Observations of the datum loss in the manoeuvre described in para. 3.4. and sketched in Figure 2 are tabulated in Table 7. These show a 1σ value of datum loss of 0.61° when the main turns were made to starboard, 0.52° when the main turns were made to port, and 0.56° overall. Significance tests on the difference between the port and starboard readings reveal that a difference between these values of 0.14° could well arise by chance, and that there is no reason to suppose that the G-7 behaves differently in port or starboard manoeuvres. If the findings of paras. 7.1. and 7.2., a 1σ short term drift of 0.52°/hr., and no loss of datum in 90° turns, are accepted, the datum loss during the 360° turn at rate one followed by the 270° turn at rate

two exhibits a 1σ value of $\sqrt{.31-.02} = 0.54°$. This value is not statistically

inconsistent with the value found for the 720° rate one turns in para. 7.3. and tends to confirm the deterioration of G-7 performance in turns lasting more than four minutes.

/Date...

<u>Date</u>	<u>Datum Loss</u> ²	<u>No. of Obs.</u>	<u>σ^0</u>
30 Apr	5.18	15	0.61
4 May	3.56	14	0.52
Overall	8.74	29	0.56

Table 7. Performance in Manoeuvres.

7.5. Other Trials Results

Three other trials parameters remain to be considered; the bank angle at which the slaving cut-out switch operates, the amount of time during which this cut-out is in operation in straight and level flight, and the transmission error of the system.

(a) Bank Angle

Because of difficulties with the instrumentation discussed in para. 3.5., it proved impossible to measure this parameter exactly. However, a rough measure of the operation of this switch in approximately 150 turns and manoeuvres was made. Each trace recording of a turn or manoeuvre was examined and no instance of the switch operating at an angle measurably different from 6° was detected. There is, therefore, no reason to suppose that this switch functions otherwise than as intended.

(b) Cut-out Operation Other Than During Manoeuvres

During 27 hours of flying, 42 instances totalling 217 seconds of the bank cut-out switch operating during straight and level flight were detected. These include instances arising from turbulence, and instances caused by the pilot making minor alterations to the flight controls. The occurrences ranged in duration from 2 to 17 seconds with an average value of 5.2 seconds. The operation of this switch would, therefore, have a negligible effect on the GM7's performance in the magnetic mode unless conditions of severe and continuous turbulence were encountered, when the system would behave as if DG had been selected. It is stressed, however, that these observations were obtained in a Comet flying at high level, and rather more time in DG mode can be expected in Shackleton flying.

(c) Transmission Errors

Transmission errors, determined as described in para. 3.7., were measured for various combinations of GL11 heading and repeater reading. These revealed a 1σ deterioration of heading of 0.15 between the gyro and the NCR output. The investigation revealed that, within the precision of the measurements, the error was approximately repeatable for any one heading provided that no adjustment was made to the rotatable stators in the gyro master unit, but that when any such adjustment was made, a new set of errors was introduced. Since manipulation of these stators is required every time the compass is synchronised in the magnetic mode, or reset in the DG mode, calibration of transmission errors is not practical in the GM7 system. For trials purposes, it was possible to remove these errors when computing drift rates and datum losses by the use of different corrections for every flight, but in squadron service, heading errors of this magnitude caused by the transmission system must be expected. Because this type of error is independent of time it will have almost no effect on long term drifts, but will tend to increase the short term drifts when turns are involved. Though a reduction of this error by the use of multi-speed synchros in the transmission system is possible, the operational advantage to be gained from the small increase in accuracy would not appear to justify the resultant increase in system complexity.

8. Conclusions

The results of the trial show that the GM7 is a high performance compass system, capable of great precision in the DG mode. They also reveal the necessity for calibration of the Latitude Controller in order to obtain full advantage from the performance available. If this is done, the GM7's long term drift should be less than $0.3^{\circ}/\text{hr.}$, and its short term drift should not exceed $0.6^{\circ}/\text{hr.}$ (1σ). Neither the long term drift nor the short term drift are affected to any appreciable extent by normal flight or by turns of under 4 minutes duration. Not only do such turns produce no detectable loss of heading datum, but, in addition, long series of such turns have no significant effect on the gyro's long term drift rate.

The only major weakness of the system detected during the trials was its susceptibility to cross coupling errors whenever the horizon inputs from the H.G.U. were seriously in error. Errors from this source would not occur in normal flight, but only during periods of prolonged bank in excess of 10° , or in the event of a power failure such as that described in para. 6. In the former case, the amount of error introduced is small but increases with the duration of the turn. Trials experience has shown that an error of about 0.5° will be accumulated in a continuous turn of 8 minutes duration. Any interruption of the turn would, of course, reduce the error because of the re-erection function of the electrolytic levels in the H.G.U., and, as a result, large errors from this source are unlikely to arise in operational conditions. The effect of partial power failures can, however, be much more serious. Such failures can reduce the rigidity of the vertical gyro to such an extent that the bank angle input to the GL11 is grossly in error. After a turn involving this type of failure, heading errors of tens of degrees can be experienced. A total power failure to the H.G.U. on the other hand is less likely to cause large errors since, in this case, the comparator circuit described in para. 2 would immediately disengage the roll stabilisation mechanism. A further problem with the partial failure case is the difficulty in detecting such a malfunction during a turn, since the pilot would not expect the H.G.U. to be level in any event, and the fact that it was indicating a larger or smaller degree of bank than was actually in use would not be easily noticed. In a completely twinned system with separate H.G.U.'s, driven by independent power supplies, controlling the roll rings of separate GL11's any cross coupling errors would immediately become apparent. However, in an installation like the Shackleton's the only immediate solution to the problem is to operate only one system in the DG mode at a time and to retain the other in the slaved mode as an assurance against gross errors.

9. Recommendations

Recommendations as to the most effective operation of the GM7 system and as to possible improvements are considered under four headings:-

- (a) Operation of present system,
- (b) The latitude controller,
- (c) The horizon gyro unit, and
- (d) The transmission system.

9.1. Operation of Present System

From the trials results it is apparent that the precision available from the present GM7 system in the DG mode is of a high quality and that the accuracy obtainable by operating in this mode compares more than favourably with that of most magnetic systems. Three precautions are, however, necessary to obtain optimum performance from the system:-

- (a) A calibration graph must be prepared for the latitude controller and used in all DG operations;

/(b)...

(b) Where two systems are available, one should be left in the slaved mode at all times to ensure against gross errors resulting from faulty H.G.U. operation; and

(c) Continuous turns involving bank angles in excess of 10° for periods in excess of 4 minutes should be avoided unless some deterioration of performance is acceptable.

9.2. Latitude Controller

Although, when properly calibrated, the present latitude controller can effectively eliminate earth rate drifts, its maximum compensation rate of 15.04/hr. restricts DG operations to the use of grid heading in many situations. Because true heading operation is more suitable for many purposes, it would be desirable if the GM7 could be operated in DG mode using a true heading reference over a much larger portion of the earth. The difficulty with the presnet installation is that, to fly to a true reference using a directional gyro, a correction for transport wander as well as earth rate is required which can be beyond the range of the controller. An aircraft flying east at 200 knots at $70^\circ N$ would, for example, require a combined earth rate and transport wander compensation rate of over 24/hr. to maintain a true heading in DG operation. Whether a particular user unit would require this facility or not would depend on its operational role, but it is certain that the operational flexibility of users of the GM7 would be increased if an alternate latitude controller providing for about 30/hr. of drift compensation were available. If such a controller were provided with a dual scale, calibrated in both degrees latitude and degrees per hour of compensation, the navigator would be able to set transport rates directly without reference to tables or graphs, and would have more time to attend to his more important duties.

9.3. Horizon Gyro Unit

The H.G.U. can introduce errors into the system under two distinct sets of circumstances, either during turns of long duration when its own free drift produces errors or by losing rigidity through a faulty power supply. Errors from the first cause are not large and, if datum losses of the order of 0.5 in 8 minutes continuous turning are acceptable then the present installation is quite adequate. If, however, turning errors of this magnitude are unacceptable, the only simple solution that does not introduce other errors of even greater magnitude is to replace the present vertical gyro by one of considerably less free drift. The other and more serious problem of preventing large heading errors during periods of faulty power supply is one of more complexity. The recommendation of para. 9.1.(b) provides a method of detecting these errors where two systems are installed, but does nothing towards rectifying the situation. It may be that the rarity of such occurrences renders them operationally acceptable, but if not, remedial action can take one of two forms; - either redesigning the power supply to ensure that such failures do not occur, or arranging for automatic reversion to a secondary mode when they do. Engineering investigation would probably reveal a number of ways in which either of these goals could be met, such as duplicated power supplies or automatic cut outs that function when the angular velocity of the H.G.U. rotor falls below a pre-determined value, but without considerable experience on the frequency of such occurrences it is impossible to estimate the urgency of such a modification.

9.4. Transmission System

The performance of the system could be improved by the use of multi-speed synchros to reduce transmission errors. Such a modification would add little to the accuracy of the system in general navigation or in manoeuvres carried out on a large scale, but would serve to reduce errors occurring in 'close-in' tactical manoeuvres. It would not be required for all outputs, but would be limited to the transmission train between the CL11 itself, the compass master unit, and the aircraft's ground position computer. The synchros presently installed seem quite adequate for other purposes.

/9.5. ...

9.5. Summary of Recommendations

The following is a summary of recommendations regarding the GM7 arising from its trials in the DG mode at A. & A.E.N.

<u>Recommendation</u>	<u>Urgency</u>
(i) Calibration of latitude controller	Essential for accurate DG operation.
(ii) Retaining one system in magnetic mode at all times	Highly desirable - Guards against large undetected errors in event of H.G.U. malfunction.
(iii) Avoiding continuous turns of more than about 4 minutes duration.	Desirable - Errors of about 0.5° can occur in turns of 8 mins. duration.
(iv) Substituting a new latitude controller with provision for more than $15.04^{\circ}/\text{hr.}$ drift compensation.	Advantageous - Improves flexibility of operation in high latitudes.
(v) Modification of system to avoid large errors caused by faulty H.G.U. operation.	Depends on frequency of occurrence in operational aircraft.
(vi) Substituting a higher performance vertical gyro for that in the H.G.U.	Depends on aircraft role, very advantageous for aircraft whose role involves extensive manoeuvring.
(vii) Provision of multi-speed synchros in heading drive to position computers.	Advantageous, particularly for 'close-in' manoeuvring.

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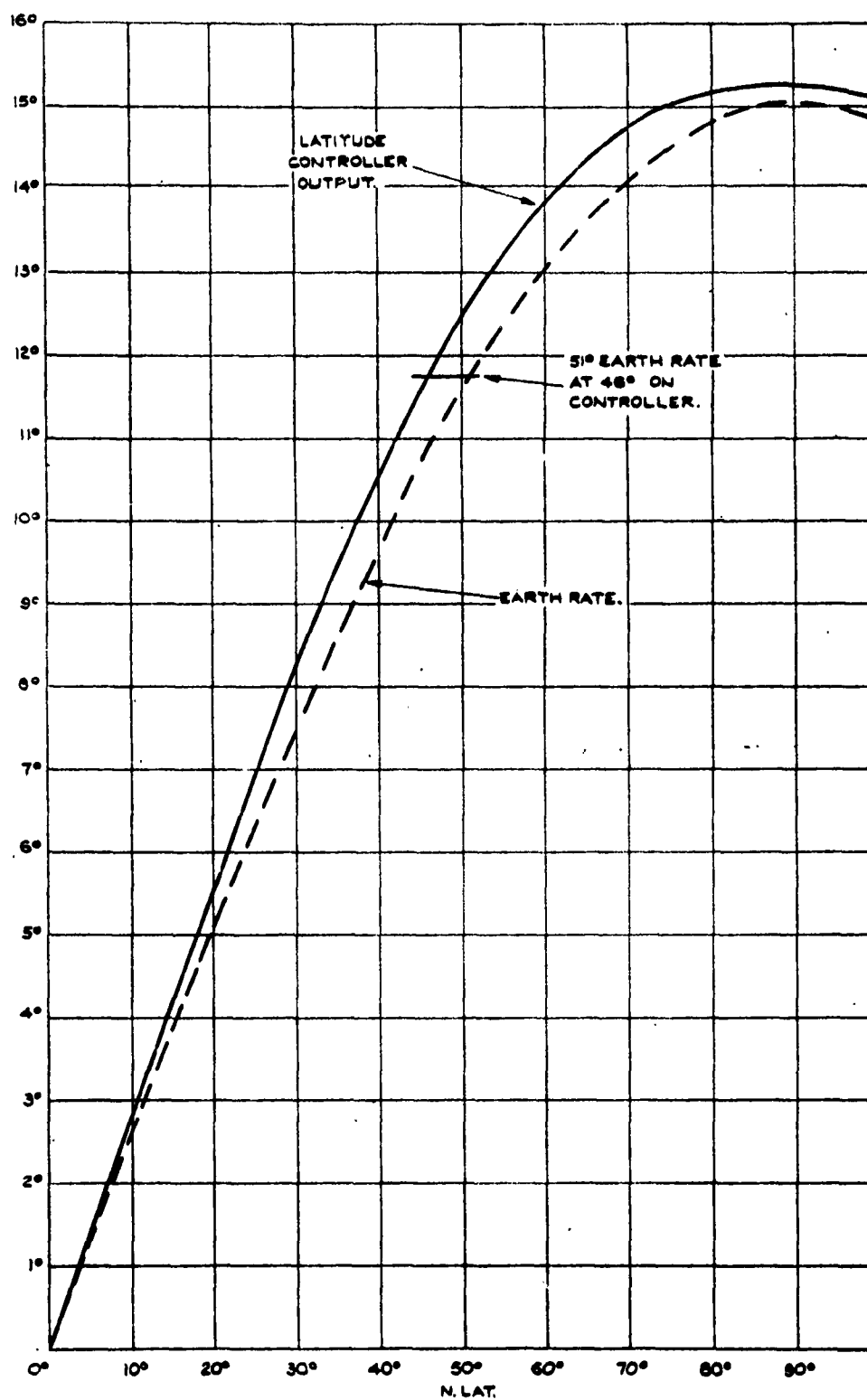
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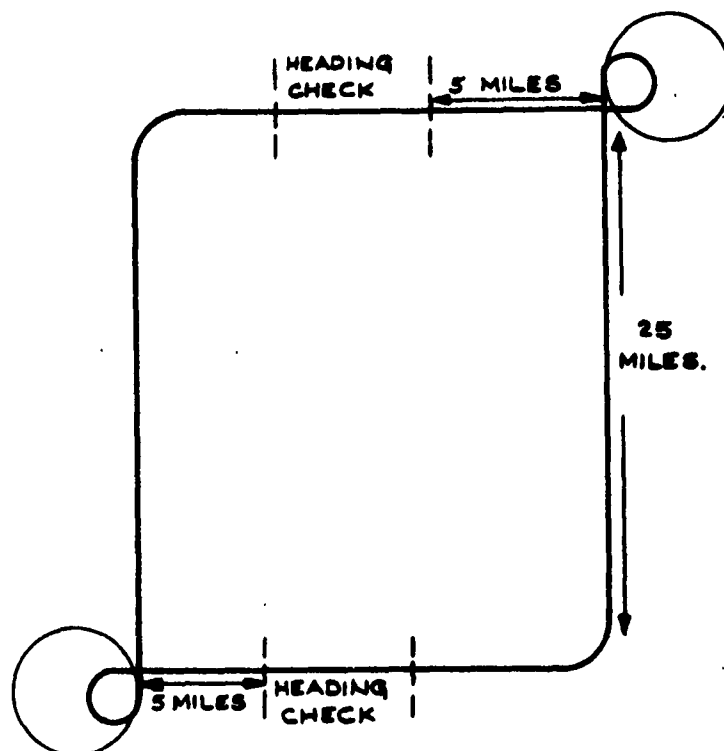
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FIG. 1.



LATITUDE CONTROLLER COMPENSATION.

FIG. 2.



PATTERN FLOWN TO SIMULATE A TYPICAL TACTICAL MANOEUVRE
(TWO MANOEUVRES SHOWN).

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