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Report No. AEE/tech/222/1'w.

MINISTRY OF AVIATION

**AEROPLANE AND ARMAMENT
EXPERIMENTAL ESTABLISHMENT**

BOSCOMBE DOWN

AN ASSESSMENT OF THE MILITARY FLIGHT SYSTEM
COMBAT INSTALLATION IN THE TYPICAL B. W. 2

[U]

PRESENTED BY

FLY. LT. E. C. WILLIAMS R.A.F.
NAVIGATION SECTION

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Report No. A.A.E.E./Tech/222/Nav.

AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT
BOSCOMBE DOWN

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An Assessment of the Military Flight System
Compass Installation in the Vulcan B. Mk. 2

Presented by

Flt.Lt. E. C. Williams R.A.F.
Navigation Section

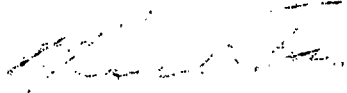
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Summary

The Military Flight System Compass installation in the Vulcan B. Mk. 2 provides a satisfactory gyro-magnetic compass system for navigational use. The Track Control Unit provides a useful and accurate navigation aid. The large amplitude Northerly phugoid instability, and the loss of gyro datum in turns, reduces the usefulness of the system and could degrade weapons system accuracy. Modifications to overcome these deficiencies are recommended.

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1. Introduction

During Navigation Assessment trials carried out at this Establishment on Vulcan B. Mk. 2 ZH.536, the opportunity was taken to investigate the performance of the Military Flight System (M.F.S.) compass installation. This report summarises the results of that investigation.

The trial included assessment of the following aspects:-

- (a) A magnetic survey of the aircraft.
- (b) A ground calibration of the M.F.S. compasses.
- (c) An air calibration of the M.F.S. compasses.
- (d) An assessment of Auto-Pilot/Compass stability.
- (e) An assessment of the performance of the Azimuth gyro used in the 'free' mode.
- (f) An assessment of the performance of the Track Control Unit.

Much of the information obtained during these trials has been progressively reported in letter reports from this Establishment.

2. Magnetic Survey

The following coefficients were obtained from a Fourier analysis of the measured deviations obtained from a twelve point swing of the aircraft with the compass detectors replaced by direct reading survey compasses. These results are within the limits specified by Av.P.970.

TABLE 1 - MAGNETIC SURVEY RESULTS

Compass Detector Position	Coefficients				50% Errors	
					Deviation	B - E
Port detector position	B +.39	C +.02	D -.04	E -.04	±.12	±.049
Starboard detector position	+.08	+.17	0	-.06	±.07	±.029

No significant effect was noted at the detector positions from running the aircraft engines or the operation of controls and electrical services, either singly or in combination. It is concluded that the M.F.S. compass detector positions satisfy the requirements of Av.P.970, Chapter 717 and are acceptable for use in the Vulcan B. Mk. 2.

3. Ground Calibration of the Compass Systems

During the initial ground calibration of the compass systems it was found that significant errors were introduced by the application of deviation corrections at the compass resolver units. Subsequent investigation at this Establishment showed that this effect was due to the large 2,400 cycle ripple content of the aircraft D.C. supply to the deviation corrector circuits. Capacitive coupling between the corrector circuits and the detector output leads produced a false signal at the compass resolvers which was manifested as

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an incorrect heading. A modification was subsequently introduced to overcome this deficiency by screening the detector output leads between the compass detectors and the resolver units (Vulcar mod. 1072). Nine compass calibrations were carried out on YH.536 after the incorporation of this modification and the quality was found to be good, the mean 50' deviation error being $\pm 0.08^\circ$.

An accurate calibration of the B and C deviation corrector after Mod. 1072 was incorporated, still showed some departure from linearity and it was concluded that this was produced by a small amount of inductive coupling between the deviation corrector coils and the earth inductor coils within the detector units. The compass manufacturers proposed a modification to overcome this effect by introducing some extra circuitry in the compass amplifiers to smooth and stabilise the D.C. supply to the deviation corrector circuits. A prototype modification was examined at this Establishment and was found to be completely effective in eliminating all residual cross coupling effects between the deviation corrector circuits and the rest of the compass system. It was recommended that this modification should be applied to all M.F.S. compass amplifiers (A.M.R. C.6 dated 13th June, 1961 refers). It is hoped that action is now in hand to implement this recommendation.

4. Air Calibration of the Compass System

A calibration of the compass system was carried out in the air in order to assess the mean change of deviation during flight. Twelve thirty-minute legs were flown on equally spaced headings and on each leg 30 simultaneous photographic observations were made of the Sun's relative bearing and the compass resolver dials. From these observations mean flight leg deviations were calculated and subjected to Fourier analysis. The results of this calibration are shown in graphical form at Appendix 'A' and compared with the previous and the subsequent ground calibrations. No abnormal results were revealed by the air calibration and it is concluded that, from the magnetic aspect, the M.F.S. compass system in the Vulcar B. Mk. 2 is acceptable.

5. Auto-Pilot/Compass Stability

The stability of the aircraft while under auto-pilot control was assessed by reference to accelerometer trace recordings of relevant aircraft manoeuvre and attitude performance, and compass information. Table 2 gives a summary of the results in the form of peak to peak amplitudes of the oscillations of the aircraft for the various conditions of the trial.

TABLE 2 - AUTO-PILOT/COMPASS HEADING STABILITY

Direction	Height	Speed	Compass Mode	Hdg. Stability
North	40,000'	.35MH	(Magnetic Compass Steering)	$\pm 2\frac{3}{4}^\circ$
"	50,000'	"	" " "	$\pm 3\frac{1}{4}^\circ$
"	54,000'	"	" " "	$\pm 4\frac{1}{2}^\circ$
South	40,000'	"	" " "	$\pm 3^\circ$
"	50,000'	"	" " "	$\pm 1^\circ$
East	40,000'	"	" " "	$\pm 1^\circ$
West	50,000'	"	" " "	$\pm 1^\circ$
South	50,000'	"	(Magnetic (Track) Steering)	$\pm 1^\circ$
"	40,000'	"	(Gyro Compass Steering)	$\pm 1^\circ$
"	50,000'	"	" " "	$\pm 1^\circ$

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This Table clearly illustrates the magnitude of the phugoid instability experienced on a heading of Magnetic North, and it also indicates that this oscillation increases in amplitude with increase of altitude. This effect is attributed to slackening of the aerodynamic response to control, with reduction of indicated airspeed, as altitude is increased. The period of this oscillation is approximately 4 minutes at 40,000 ft. increasing to 5 minutes at 54,000 ft.

To illustrate the compass error due to Northerly instability Appendix 'B' shows the oscillation of compass deviation obtained by comparing the oscillation of M.F.S. heading with that of a high grade free gyro. This graph indicates the probable accuracy of instantaneous compass heading during this condition of instability. It is concluded from these results that the Auto-Pilot/M.F.S. compass combination provides an unstable platform response on a heading of Magnetic North. This instability will seriously degrade the accuracy of astro sighting and of radar bombing, particularly when long range offsets are being employed. It is recommended as an interim measure that, for astro sight taking or bombing, the free gyro mode of the M.F.S. compass system is employed on headings within 45° of Magnetic North.

In an attempt to overcome the problem of instability on Northerly headings, the compass manufacturer has produced a prototype partial-integrating amplifier, the function of which is to effectively increase the compass monitoring time constant on susceptible headings. This prototype amplifier is currently undergoing assessment at this Establishment and a separate report on the results will be issued in the near future. Preliminary results indicate that this amplifier produces a marked improvement in compass performance on headings about North. If this finding is confirmed in detailed analysis a recommendation will be made to introduce the modified amplifier for use in Vulcan and Victor aircraft.

6. Performance of the Azimuth Gyro in the Free Mode

Two sorties were flown to assess the drift of the unmonitored compass gyro on a straight flight leg of three hours duration. The results were obtained by comparing simultaneous photographic records of the relative bearing of the Sun and the compass resolver dials, with the compass selected to free gyro mode. The results are shown at Appendix 'C' as the resultant drift rate after correction has been made for transport rate and the difference of Earth rate from the latitude of mass balance compensation (57°N). The results indicate that the compensated free gyro drift rate did not exceed 5° per hour and this supports other evidence which suggests that the mean free gyro drift rate is approximately 4° per hour at the one sigma level. The drift rates shown at Appendix 'C' were measured over twenty minute intervals as the condition of the trial did not allow the rates over a shorter period to be assessed. Thus it is possible that there may be short period drift rates considerably exceeding $5^{\circ}/\text{hr}$. but no evidence was found to support this suggestion when the aircraft was flying a constant heading.

This gyro performance is adequate for use in a compass system utilising magnetic monitoring, but would be inadequate in conditions where magnetic monitoring was not available and frequent astro heading checks unobtainable. The maximum observed gyro wander rate could produce a hang-off error in a monitored compass system of 0.12° .

The trial also included an assessment of free gyro performance during and after turns. In these cases gyro heading before and after the manoeuvre was compared with true heading obtained from astronomical observations. The accuracy of this method is assessed at 0.2° (S.D.). In all cases the turn was carried out at 25° bank at an altitude of 38,000 ft. and an indicated Mach Number of 0.85. The results are shown in Table 3 which demonstrates a marked tendency for the gyro to lose datum during a turn.

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TABLE 3 - EFFECT OF TURNS ON FREE M.F.S. GYRO DATUM

Direction and Amount of Turn	Shift of Datum		Diff of Datum shift
	Port Gyro	Starboard Gyro	
180°S	6.0°S	7.5°S	3.5°
345°P	7.4°P	6.6°P	.8°
105°P	.9°P	1.3°P	.4°
340°S	7.5°S	6.4°S	1.1°
160°P	2.8°P	3.8°P	1.0°
90°S	0	1.8°S	1.8°
180°S	4.4°S	1.5°S	2.9°
270°P	7.7°P	5.3°P	2.4°
100°S	1.6°S	2.6°S	1.0°
370°P	7.0°P	6.7°P	.3°
175°S	3.2°S	2.5°S	.9°
390°P	8.7°P	7.1°P	.4°
360°S	6.8°S	6.5°S	.3°

This table shows that the M.F.S. gyro tends to lose datum in the direction of a turn by an amount which varies with the amount of turn. This result is clearly demonstrated by Appendix 'D' which presents these results in graphical form by plotting the amount and direction of datum shift, against the amount and direction of turn. An analysis of the data from which these results were compiled indicates that there is no tendency for the gyro to precess back to its pre-turn datum when the turn is completed. Further experiments have shown that the datum shift appears to be related only to the amount of turn and is not affected by altitude, speed, or rate of turn.

No explanation can be offered for the systematic nature of these errors. Nutation drift, caused by vibration when the gymbal axes are not orthogonal, does not appear to satisfy the obvious symmetry of the findings. It is understood that the compass manufacturer is currently investigating this effect in an attempt to provide a physical explanation and to determine what remedial action might be possible. The loss of gyro datum during turns is a serious limitation of the M.F.S. compass system and is likely to degrade weapons system accuracy, particularly when offset bombing techniques are employed. It is recommended that this effect should be fully investigated, and appropriate modification action taken to eliminate this source of error.

7. Assessment of the Track Control Unit (T.C.U.)

The Track Control Unit provides an output of true track to the M.F.S. Beam Compass, when 'REMOTE' is selected at the pilot's M.F.S. selector, and thus controls the auto-pilot when this is engaged. True heading is also provided both to M.B.S. and to the Ground Position Indicator. Current values of drift and variation may be set in either manually or automatically, from Green Satin in the case of drift, and from a cam in the Navigation Panel Mk. 1A (N.P.1.A.) in the case of variation. A direct measurement of true heading accuracy is difficult to make as no suitable means of presenting the information is normally available, but the error in this quantity must be the sum of the error in the basic compass loop, the error in the application of variation and residual deviation, and the accumulated transmission errors between the compass resolver and the output. Taking the known values of these quantities it can

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be shown that the instantaneous true heading accuracy over the U.K., or an area where variation is known to a similar accuracy, is $\pm 1.5^\circ$ at the one sigma level. This figure is supported by measurements made during this trial which also indicated that the mean true heading accuracy over a period of approximately three minutes was about $\pm 1^\circ$ at the same level of probability.

Due to the extreme accuracy of the drift output of Green Satin the true track output of the T.C.U. has a probable error approximately equal to that of the true heading output. A smoothing time constant is introduced in the application of drift at the T.C.U. which provides a stable output of track, allowing accurate and simple track steering. This track steering facility was assessed on two long flight legs between Boscombe Down and Idris. On both occasions variation was set to 'AUTO' but the current value checked against charted values, and reset if necessary, at 30 minute intervals. Drift was selected to 'AUTO' except for two short periods when Green Satin unlocked. On each flight two small alterations of heading were made, based on monitoring fixes, and the maximum measured deviation from the preplanned track was 3 N.M. The track steering facility of the M.F.S. was found to be a most useful and convenient aid to routine navigation and appreciably reduced the work load on the Navigator/Plotter.

The variation setting control of the T.C.U. can be used to apply corrections for residual compass deviation, but accurate checking is made difficult by the oscillation produced in the auto-variation system. At this Establishment's suggestion the manufacturers have produced a prototype modified T.C.U. which includes a large scale deviation trimmer permitting accurate setting of corrections up to $\pm 3^\circ$. This was found to be a most useful modification providing means for applying deviation corrections and also F.M.A. corrections derived from the measured cross track error in the aircraft D.R. position. It is recommended that the modified T.C.U. is introduced for service in all Vulcan and Victor aircraft.

8. Conclusions

The Military Flight System compass installation in the Vulcan B. Mk. 2 provides a satisfactory magnetic compass system for navigation use. The track steering facility of the Track Control Unit provides a useful and accurate means of navigating the aircraft and reduces the work load on the Navigator/Plotter. The basic compass system was found to meet the requirements of Av.P.970 Chapter 747 and the accuracy of the true heading and true track outputs was found to be approximately $\pm 1.5^\circ$ (S.D.) instantaneous or $\pm 1^\circ$ (S.D.) averaged over about 3 minutes. The aircraft/compass combination was found to suffer from severe phugoid instability on Northerly headings with a maximum measured amplitude of $\pm 4.5^\circ$ at 54,000 ft. at 0.95 I.M.F.

The performance of the azimuth gyro was found to be adequate for use in a magnetically monitored system on constant headings, but would be of little use in a 'free' mode unless frequent Astro heading checks were available. The gyros were found to exhibit a disturbing loss of datum in turns, the magnitude of which appears to have a linear relationship with the amount of turn. This effect is likely to degrade the weapons system accuracy when offset bombing techniques are employed. No explanation can be offered for this error.

9. Recommendations

The following recommendations are made as a result of this trial:-

- (i) Magnetically, the M.F.S. compass system is satisfactory for use in the Vulcan B. Mk. 2.

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- (ii) A modification should be applied to all M.F.S. compass amplifiers to improve the smoothing and stability of the D.C. supply to the deviation corrector circuits.
- (iii) Action should be taken to eliminate the instability of the Auto-Pilot/Compass combinations on headings about Magnetic North.
- (iv) The loss of azimuth gyro datum in turns should be fully investigated and action taken to eliminate this source of error.
- (v) A modified Track Control Unit incorporating a large scale deviation trimmer should be introduced for service in all Vulcan and Victor aircraft.

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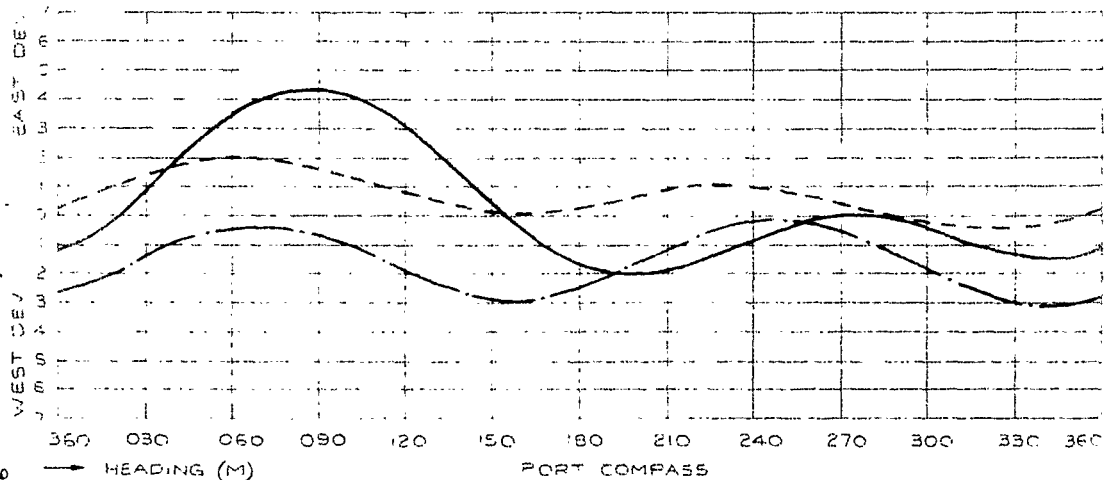
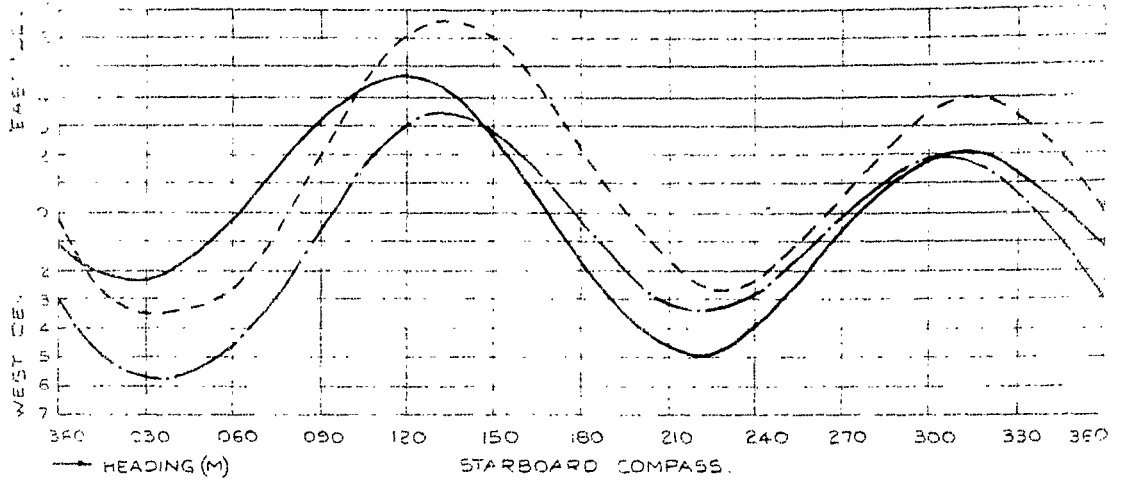
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APP. A.

LEGEND -

- AIR CALIBRATION.
- - - - - PREVIOUS GROUND CALIBRATION
- SUBSEQUENT GROUND CALIBRATION.



NOTES -

- 1 THE ABOVE GRAPHS ARE A PLOT OF CALCULATED DEVIATION OBTAINED BY FOURIER ANALYSIS OF OBSERVED DEVIATION
- 2 THE ANALYSIS SHOWED THE FOLLOWING 50% DEVIATION ERRORS

TYPE OF SWING & DATES	50% DEVIATION ERRORS	
	PORT COMPASS	STBD COMPASS
GROUND 7 TH SEPT 1960	.05°	.05°
AIR 9,10,15+16 TH SEPT 1960	.14°	.19°
GROUND 26 TH SEPT 1960.	.10°	.06°

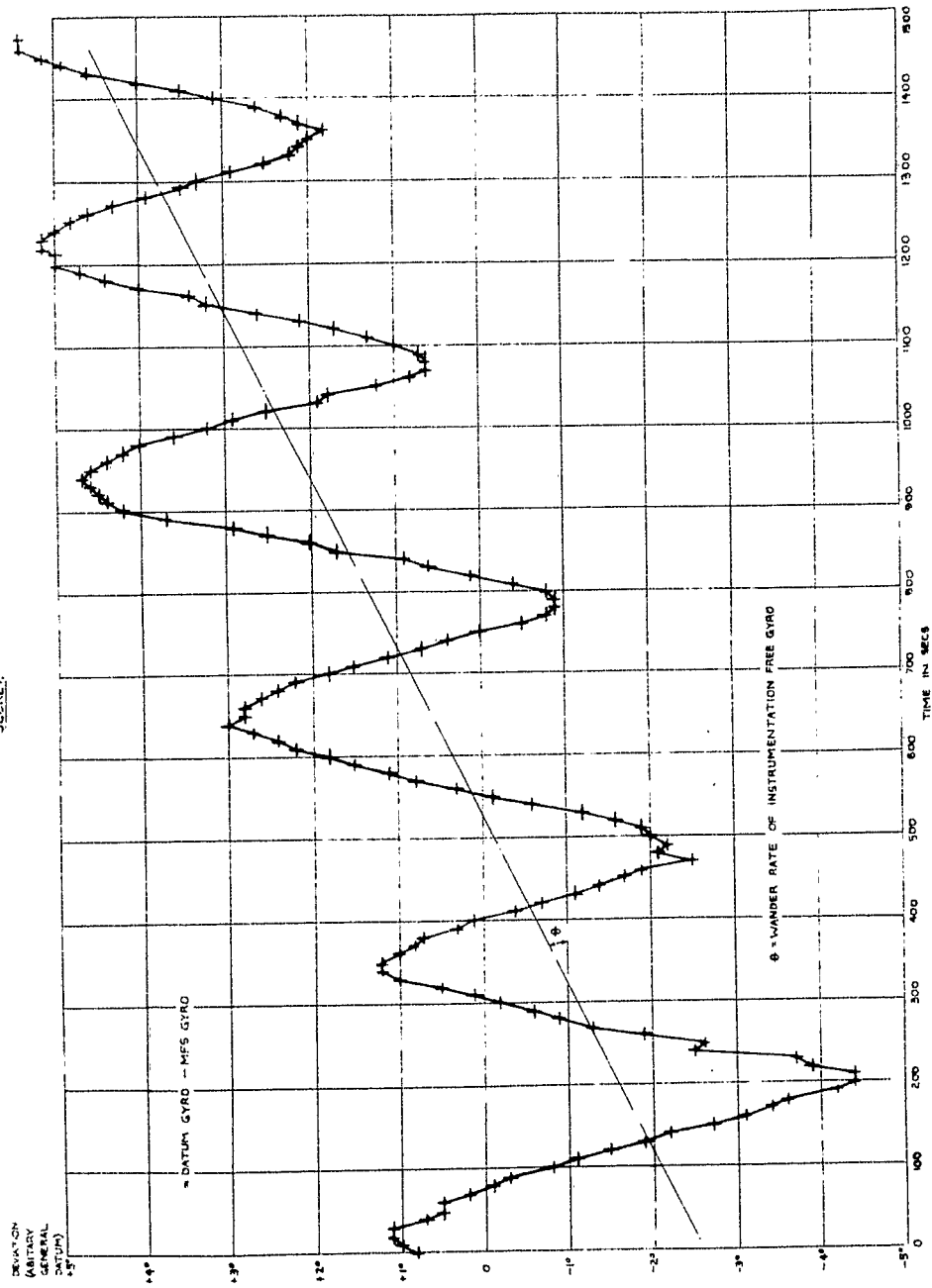
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AIR CALIBRATION OF THE COMPASSES.(VULCAN MK.2)

SR NO 1494: TECH/222/NAV VULCAN MK 2 XHS36

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APP. B.

OSCILLATION OF COMPASS DEVIATION DUE TO NORTHERLY INSTABILITY NORTH COMPASS RUN A 50,000 FT.

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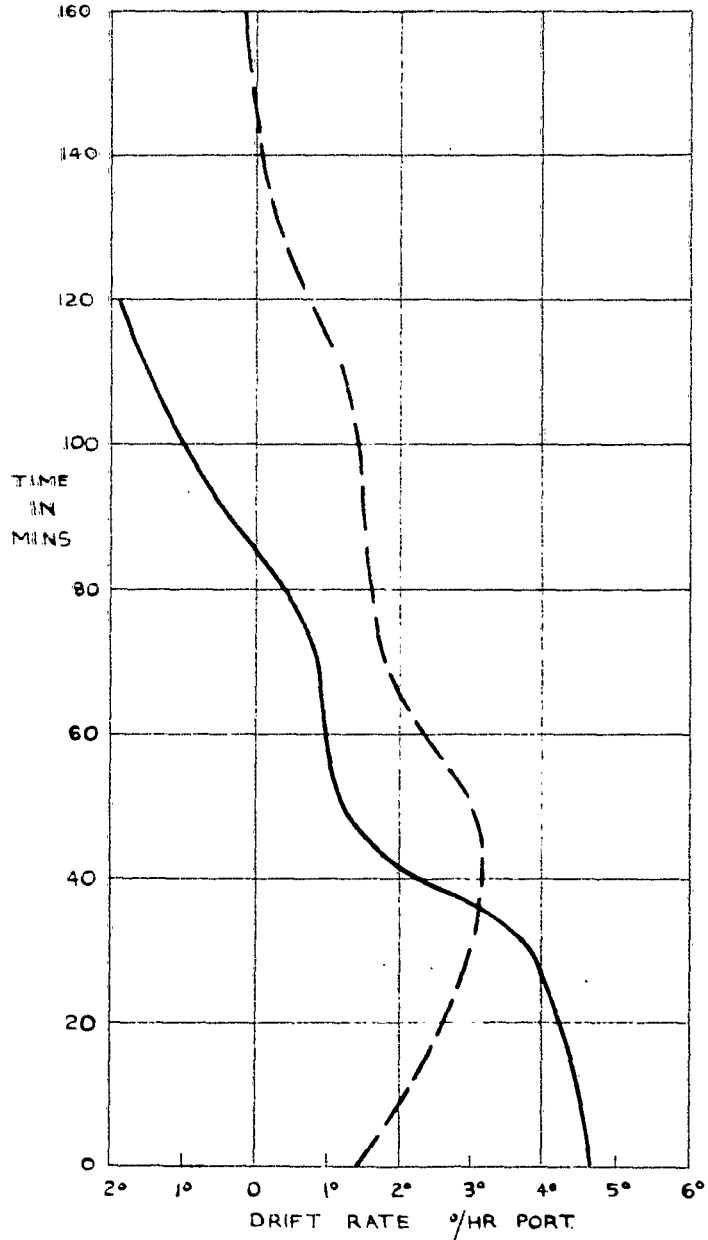
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APP. C.

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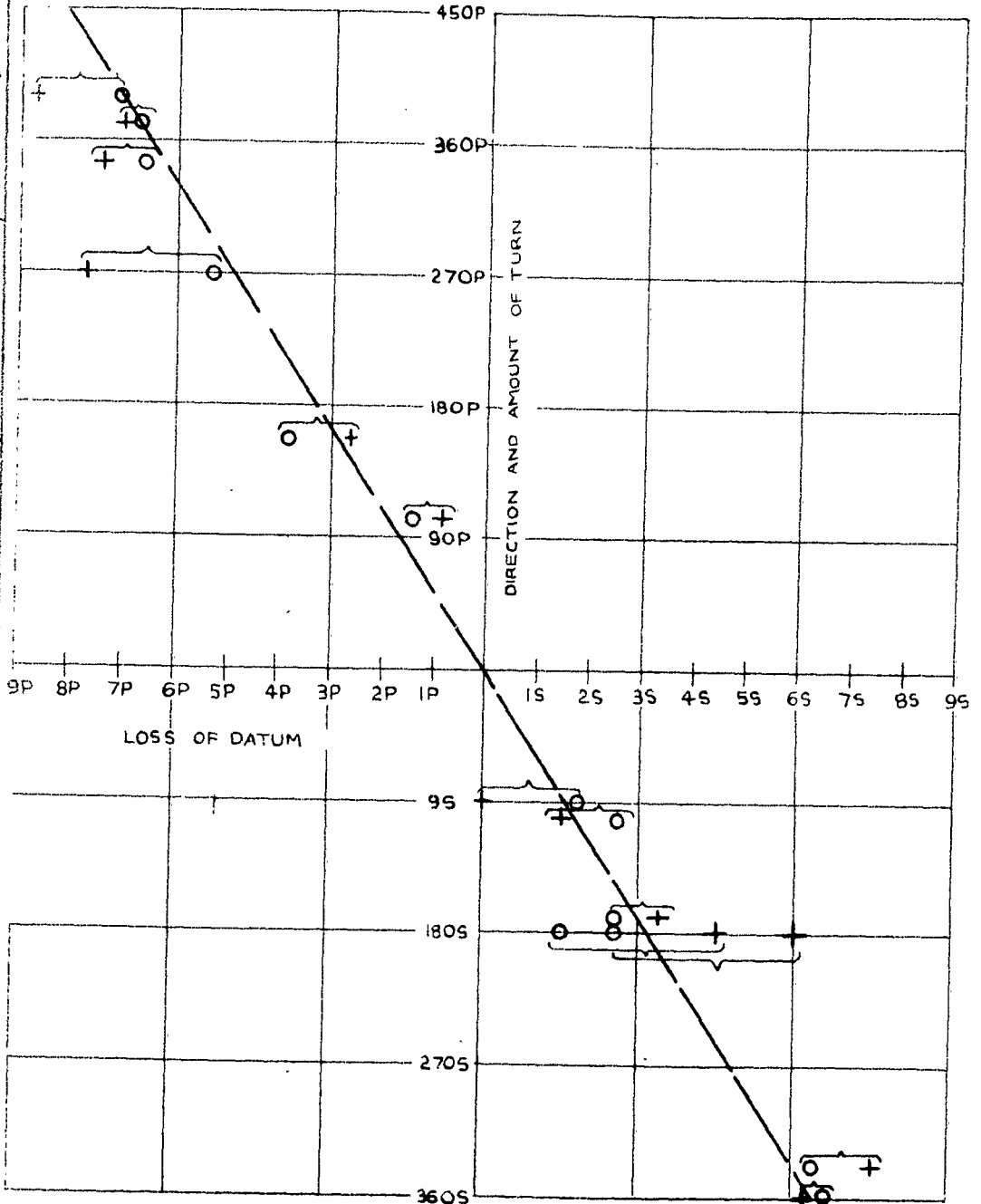
M.F.S. AZIMUTH GYRO DRIFT RATES

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APP. D.

LEGEND

- ◆ PORT GYRO
- STARBORD GYRO



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EFFECTS OF TURN ON M.F.S. GYRO

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