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Report No. AAEE/Tech/318/Nav.

MINISTRY OF AVIATION

**AEROPLANE AND ARMAMENT
EXPERIMENTAL ESTABLISHMENT**

BOSCOMBE DOWN

ELLIOTT MCS 920 DIGITAL COMPUTER TRIAL

[c]

BY

FLIGHT LIEUTENANT I. K. St.C. BARTLEY, R.A.F.
NAVIGATION AND RADIO DIVISION

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AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT
BOSCOMBE DOWN

(11) 8 NOV 1965

(7) Elliott MCS 920 Digital Computer Test [C-111A], (12) 42p-

(10) Flight Lieutenant I. K. St. C. Bartley,
Navigation and Radio Equipment

A. & A.E.E. Ref: ANR/45/09
Period of Trial: 15th March 1965 to 23rd July 1965

Summary

Results are given of flight trials to demonstrate the navigational capability of the MCS 920 computer, and of an investigation into the programming and compatibility problems involved in using the computer for flight testing navigation and radio equipment.

It is concluded that the computer can perform navigational tasks rapidly, reliably and accurately; it is reasonably easy to program and is compatible with existing A. & A.E.E. services. The MCS 920 would be a valuable addition to the flight trials resources of A. & A.E.E.

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JR. Bird

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1. Introduction

Under the sponsorship of D.A. Nav., Navigation and Radio Division, A. & A.E.E. were tasked to carry out a trial of the Elliott MCS 920 digital computer in both airborne and ground environments. Authority for the trial was issued in Nav. 1(c) letter AS/492/07 dated 14th January, 1965.

This report covers the work undertaken during the MCS 920 trial. Following two months of equipment and navigation program preparation, the airborne part of the trial was phased in with other trials of navigation equipments installed in Comet XS 235, over the period 15th March, 1965 to 6th April, 1965. A preliminary report on the flying part of the trial was submitted to Nav. 1(c) under cover of A. & A.E.E. letter ANR/45/09 dated 21st April, 1965 (Reference No. 1). The ground part of the trial, which was concerned with studying the use of the computer as a ground processing device, followed the airborne part and was terminated on 23rd July, 1965.

2. Aims of the Trial

The aims of the trial were to:-

- (a) Demonstrate that the basic logic of the MCS 920 computer was capable of performing navigation tasks effectively in "real time".

(Note.- For this purpose performing in "real time" is defined as: "the processing of data in synchronism with a physical process in such a manner that the data processing results are useful to the physical operation".)

- (b) Investigate the ease of programming the computer.
- (c) Establish the feasibility of using the MCS 920 as an airborne computer for A. & A.E.E. trials.
- (d) Study the problem of compatibility between the MCS 920 computer and other data recording and processing facilities at A. & A.E.E.

3. Trials Aircraft

The aircraft used for the trial was Comet 4C, XS 235. This aircraft was fitted with a number of non-standard items of navigation and recording equipments over the trials period. Advantage was taken of this fit to devise a representative series of navigational, programming and data recording/processing exercises for the MCS 920.

4. Trials Equipment

The trials equipments used are shown in the block schematic diagram at Figure 1.

4.1 Major Navigation Components

The following three major components were connected to provide a representative navigation sub-system:-

(a) MCS 920

The units comprising the computer system were mounted on pallets and included:-

MCS 920 computer
Input/Output Unit(I.O.U./Interface Unit)
Power Unit
Engineer's Control Panel
Tape Winder
Tape Reader
Tape Punch
Flexowriter

/(b) ...

(b) Inertial Reference System(I.R.S.)

An inertial reference system pallet was used, which comprised:-

Stable Platform
Platform Power Unit
Standby Gyro Unit

(c) Doppler Radar

The doppler radar used consisted of:-

An Aerial Assembly (roll stabilised from the I.R.S.
or Standby gyro)
Transmitter/Receiver Unit
Tracker Unit
Waveguide Run

4.2 Ancillary Datum, Recording and Control Equipments

Ancillary equipments available in the aircraft were used to provide datum, recording and control facilities as follows:-

(a) Decca Mk. 8

The Decca Mk. 8 system was used as the main datum aid against which to compare sub-system performance and performance of peripheral navigation equipments under controlled conditions. Digitised Decometer outputs were fed to the MCS 920 and to the GEC Highway recording system (sub-para. (c) below refers).

(b) G4B/Twin Gyro Platform

Outputs from a hybrid G4B/TGP compass system were fed to the I.R.S. to provide initial azimuth alignment. A further output was fed to the MCS 920 for use in reversionary modes.

(c) GEC Highway Recording System

A GEC Highway recording system was used to record Decca Mk. 8 information. The data obtained was processed on a Ferranti Pegasus computer after flight to obtain datum latitude and longitude where necessary. This information was, in the main, required for other trials purposes but was also used to check the integrity of corresponding MCS 920 recordings of the Decca Mk. 8.

(d) Trace Recorder Pallet

A number of trace recorders were mounted on another pallet in the aircraft for use during concurrent trials on the aircraft. These recorders provided useful information for the MCS 920 trial as follows:-

Cambridge Recorder Console - to record I.R.S. Data.
Two Rustrak Recorders - to record Doppler Inertial
Mixing Signals.
Colbrook Instruments Ltd. Recorder - to record I.R.S. and standby gyro pitch and roll outputs.

(e) Control Units

Three control units were mounted in the trials observers compartment: these provided remote control of the doppler, I.R.S. and MCS 920 equipments.

5. Brief Description of MCS 920 Computer

The MCS 920 series of computer includes:-

(a) MCS 920

The MCS 920 is a small, parallel mode, general purpose computer with special facilities for real time processing. The computer has been field tested and used in the Army "Fire Brigade" fire control system, and was the computer used for the A. & A.E.E. trials. The MCS 920 has an 8192 word memory, an 18 bit word length and requires 500 w. of power. A short summary of the specification characteristics is attached at Appendix I; Figure 2 shows the internal elements of the computer, Figure 3 shows the trials equipment pallet prior to installation and Figure 4 shows the pallet installed in Comet XS 235.

(b) 920B

The 920B is a development of the MCS 920. This computer uses similar register structures, instruction codes, memory and programs but incorporates NAND circuits instead of AND/OR circuits in its logic. The system may be built up in blocks to incorporate the power supply and computing features required. In particular, the basic memory can be either 4096 or 8192 words and may be increased if necessary in blocks of 4096 words. Power supply requirements are reduced to 120 watts, and protective "power dump" facilities are available.

(c) 920M

The 920M is a further advance which is still under development. This computer will use similar logic and programs to the other 920 computers, but will incorporate integrated micro-miniature logic circuitry to reduce the size and weight of the computer considerably.

6. Trials Methods

6.1 Demonstration of Navigation Capability

To demonstrate the navigation capability of the MCS 920, Elliott Bros. undertook to build an interface unit which would function as the link between the computer and the doppler and I.R.S. sense elements. A special program (designated MC-01) was called for to control the sensory equipments and compute navigation (and, if time permitted, steering) equations. Acceptance of Decca position information was required for use as a datum navigation reference at selected fix points to allow updating of present position and periodic "fix monitored azimuth (F.M.A.)" correction to I.R.S. azimuth. Every minute the computer was required to punch out selected navigational parameters in machine code on 8 hole tape; after each flight the data tape was to be processed in situ on the aircraft, using the MCS 920 together with a specially written Translation program (designated MC-03). This second tape output was to be in teleprinter code to allow a printed record of the flight to be obtained in a standard format via a flexowriter or line printer. Wherever possible data processing was to begin in-flight, during the aircraft's return and descent into Boscombe Down. Descriptions of the special programs written for the MCS 920 trial are attached at Appendix II.

6.2 Programming

Investigations to determine the ease of programming the MCS 920 were to be carried out as follows:-

- (a) At some stage during the trial the Firm was to be requested to write modifications to the basic MC-01 program; these modifications were to be realistic examples of program changes called up as a consequence of trials flying results, the time taken for the required modifications to be written being considered indicative of a qualified programmer's task using MCS 920 machine code.

/(b) ...

(b) If time permitted, selected members of the A. & A.E.E. staff were to be given a short general programming course, an instruction booklet on programming the MCS 920 and access to a qualified programmer for advice. Using this knowledge the subjects were to be tasked with writing small programs, covering mathematical problems, for use with the 920 machine. The time taken to write these programs was to be recorded together with comments on the difficulties experienced.

(c) The possibility, time-scale and cost of using a major computer (such as the Elliott 503 system at A. & A.E.E.) to convert simple programs written in Algolrithmic (Algol) code to 920 machine code was to be investigated. The feasibility of providing this facility also affected the degree of compatibility obtainable between the Elliott 503 and the MCS 920.

6.3 Trials Use

The major assessment of the suitability of the computer as a piece of general purpose, airborne and ground, trials equipment was to be made on the basis of the results achieved using the programs and equipment specifically designed for the trial. However, to increase the scope of the trial, and in particular to establish realistic cost/effectiveness figures relating to usage as a trials device, Navigation Division in conjunction with I.E.E. Department, R.A.E. Farnborough undertook to present the Firm with typical trials requirement specifications. Elliott Bros. agreed to study these requirements and submit estimates of cost, time-scales, technical and programming effort required to undertake the tasks using the MCS 920. Details of this "paper-study", which includes the Firm's answers to the questions asked, are attached at Appendix III. It will be seen that the first requirement was for a simple task and the second simulated a complex equipment trial requiring from 40 - 50 flying hours and a considerable quantity of data recording and processing to complete.

6.4 Compatibility

In determining the degree of compatibility existing, or capable of development, between the MCS 920 and other equipments it was considered necessary to investigate:-

(a) Methods by which the computer could be made compatible with other equipments, possibly under test, in the aircraft. The development of an interface unit, to couple the sensory doppler and I.R.S. systems to the computer, was to be used as a practical test example.

(b) Methods by which the output of the MCS 920 could be processed by existing ground computers at A. & A.E.E. For this purpose, compatibility between MCS 920 output and Elliott 503 input required special consideration.

(c) Methods by which the MCS 920 could be used as a small back-up ground computer to the Elliott 503 during periods when the MCS 920 was not being used in the air. It is now common practice to use an automatic language for most scientific computer programs: at A. & A.E.E. the language used is the Algol 1960 Algorithmic language. Consequently, one aim of this part of the trial was to determine the feasibility of either using Algol with the MCS 920 or obtaining a 503 output in MCS 920 machine code from an Algol input.

7. Pre-flight Preparation

Pre-flight preparation, involving MCS 920 installation, engineering acceptance and MC-01 program testing, was completed, in conjunction with aircraft periodic servicing over the period 12th February 1965 to 12th March 1965. Because of conflicting servicing and MCS 920 requirements the aircraft was available for MCS 920 work on approximately twelve days in this period. The following paragraphs outline the progress made during pre-flight preparation.

7.1 Engineering

One major computer fault was found; this was a broken wire, in the magnetic core store of the computer, which made the first 64 store locations unusable. Replacement of the core store cleared the fault. During investigation into this failure, the computer was removed from its mounting and the ducting of the cooling air supply was disturbed. The computer became highly temperature conscious in this condition and a number of failures occurred.

7.2 Program Testing

The MC-01 navigation program had been written by Elliott Bros. prior to the arrival of the equipment at A. & A.E.E.; program testing, however, was carried out for the first time in conjunction with the engineering acceptance. No major difficulties were met and it was possible to conduct a successful simulated flight prior to airborne trials. This test included functioning of the computer in Doppler/Inertial mixed, Doppler plus Platform Heading and Doppler plus Compass Heading navigation modes using simulated velocity inputs.

8. Flying Schedule

The aircraft became available for airtest on 15th March, 1965. At this time it was envisaged that an extension of T.S.R.2 Navigation trials was to begin in the Comet on 6th April, 1965. Consequently the flying schedule for the MCS 920 trial had to be confined to this three week interval. Ten sorties, totalling 36 flying hours were completed. Details of the flying schedule, showing a sortie by sortie activity break-down, is attached at Appendix IV; it will be seen from this Appendix that, although difficulties of varying nature and degree were present on the first five sorties, the last five sorties were flown in quick succession, using the range of MCS 920 programs built up in the trial, with complete success.

9. Flight Trials Results

9.1 Computer Programming

Details of the MC-01 navigation program and the special modified program, MC-01A and MC-01D, used during flight trials are attached at Appendix II. Trials results, relevant to the use of these programs, are summarised in the following paragraphs:-

9.1.1 MC-01 Navigation Program

This program was completed in the two months preceding flight trials and was successfully ground tested in the aircraft prior to the first flight. Navigation facilities provided by the program were used on all flights and routine (one minute and fix point) recordings of navigation parameters was available on seven flights. On the remaining three flights the recording facilities of the program were concentrated on the special high speed recording routines of MC-01A and MC-01D. Comments on the performance of the MC-01 program are as follows:-

/(a) ...

- (a) No recording difficulties were met.
- (b) No major functional faults in the navigation facility were met.
- (c) On the first flight the Random Fixing routine did not work. The reason for this was not definitely established and the routine worked satisfactorily on all other flights. Since the computer failed on take-off on the first sortie (sub-para. 9.2(b) and (c) refer) it is possible that this part of the MC-01 program became corrupt at the time of computer failure.
- (d) During the trial the Y-integrator FMA circuitry of the I.R.S. was found to be incorrectly scaled. Compensation for the scaling error was easily introduced into the MC-01 program (and mods. MC-01A and D) to maintain a high standard of navigation.
- (e) The MC-01 program occupied less than half the 8192 word capacity of the MCS 920 store. If sufficient time had been available it would have been possible to extend the program to include steering and probably bombing functions, without loss of the recording facility.

9.1.2 MC-01A, I.R.S. Performance Testing Program

In accordance with the trials plan (para. 6.2(a) refers), a modification to the MC-01 program was called for to allow comparisons to be made between I.R.S. velocities (recorded at 1/5th sec. intervals by MCS 920) and aircraft velocities (recorded at the same time interval by FPS 16 radar at Aberporth Range) during manoeuvre. This modification, designated MC-01A was completed by the Elliott Bros. programmer in six working days. Details of the program are contained in Appendix II. Comments on the airborne performance of the program are as follows:-

- (a) The first attempt to use the program (Sortie No. 4) was unsuccessful because of an engineering fault (para. 9.2.6 refers).
- (b) The second attempt to use the program (Sortie No. 5) was also unsuccessful. In writing the MC-01A modification the programmer had decided to remove an FMA instruction routine; this routine was left open-ended and, as a result, the I.R.S. was presented with an effective "floating" voltage in the FMA input channel. Alignment of the I.R.S. was, therefore, seriously disturbed. The program was modified by setting the FMA term to zero and this cleared the fault.
- (c) Two more flights using MC-01A were then completed successfully (Sorties 6 and 7).
- (d) An additional facility in this program allowed recordings to be made (at 1 sec. intervals over two minute periods) of I.R.S. azimuth and β angle prior to each major I.R.S. velocity recording. This facility was used in post-flight analysis to relate Astro-Tracker "Datum" True Heading (GEC Highway system recordings) to I.R.S. True Heading.

/9.1.3 ...

9.1.3 MC-OLD. Doppler Velocity Noise Program

A second special requirement, to test the versatility of the MCS 920, called for high speed (1/10 sec. interval) recording of Doppler and I.R.S. velocities in addition to basic MC-01 navigation. This program was designated MC-OLD and was designed to show the variations of Doppler velocities from the smoother I.R.S. velocities over selected short periods of time (2 to 3 minutes). Details of the program are at Appendix II. The program modification was completed within four working days and was successfully used in flight on the fifth working day (Sortie No. 8).

9.1.4 "Quick-Look" Facility

A particularly useful feature, which was written into all the trials programs, was a "quick look" facility which enabled the computer to produce a limited sample of key quantities on 8-hole paper tape within 10 to 12 minutes of the end of recording. This tape could be run directly through a flexowriter after landing to provide printed samples of flight data. On all sorties where the facility was used these samples were available within one hour of landing. On sortie No. 9 the flexowriter was carried in the aircraft; the trial was completed at 2,000 feet overhead Boscombe Down and the printed sample was made available before the aircraft had completed the circuit and landing procedure. (The total time from last recorded data to sample print-out was under 7 minutes). The immediate advantage of this facility was that a high frequency of flight trials sorties could be maintained in the last half of the trial with complete confidence that flight trials time was not being wasted. Examples of quick-look data are attached at Figure 5.

9.2 Engineering

Apart from the magnetic core store failure (para. 7.1 refers) no MCS 920 engineering faults were noted. However, on the first four flights difficulties of varying degree were met with on the peripheral equipment provided for the trial. Since the trial had been instigated at fairly short notice and since some of this equipment (particularly the interface unit) was in prototype form this was not unexpected. On the last six flights, when these initial problems had been overcome, it was possible to undertake medium and low level navigation, I.R.S. performance and Doppler testing flights, on consecutive working days without a single failure in the system. Difficulties in the early flights included:-

(a) Interface unit faults which caused spurious pulses to be generated between the Doppler velocity output and computer input. These effectively produced intermittent noise on the Doppler/Inertial mix signals and periods of mis-reading of Doppler groundspeed (computer groundspeed 20% below Doppler groundspeed). The faults were cleared by introducing increased slugging to reduce the trailing edge noise on an encoder interrogate signal and by the re-building of a suspect staticiser.

(b) An incorrectly set -10 volt trip circuit within the interface unit was prone to break the computer power supplies when sudden load changes occurred. For sortie No. 4, the first I.R.S. performance test flight, two extra circuit boards were fitted to the interface unit; this extra power requirement caused the computer supplies to be cut off with small changes in load (e.g. connection of I.R.S. to MCS 920). Examination of the interface unit circuitry then revealed that the -10 volt trip circuit had been marginally set throughout the earlier part of the trial. Once this circuit had been re-set to the optimum level no further supply cut-offs were experienced. On two previous flights (sortie Nos. 1 and 3) computer stoppages had occurred on take-off and/or landing. It would appear that the marginally set trip circuit may have been the underlying cause of these stoppages but no direct evidence to substantiate this was available; investigations into this aspect of trials performance are being continued by Elliott Bros.

/(c) ...

(c) The MCS 920 (Model No. 7) provided for this trial had not been fully modified to current standards. One of the modifications not embodied provided for protection from electrical interference between the computer and its Engineer's Control Panel. In consequence, it could not be established whether the stoppages which occurred at take-off or landing were caused by interference break-through or by the incorrectly set -10 volt trip circuit. A number of actions had to be taken during the first half of the trial to reduce the interference, but from the fifth flight onward no further problems were apparent; the actions taken included:-

- (1) Removal of a faulty tape winder which, in presenting a heavy inductive load when switched, caused large voltage transients to break through to the computer circuits.
- (2) The fitment of a filter in the computer 50 c.p.s. supply.
- (3) Re-soldering of a suspected loose connection on the tape punch.

(d) On the second flight the computer failed twenty minutes after take-off; this was caused by overheating which occurred as a result of a dirty filter restricting the cooling air supply. This incident, coupled with the problem encountered during engineering acceptance (para. 7.1. refers), shows that it is important to maintain an adequate supply of cooling air to the MCS 920 at all times and in all environments.

9.3 Airborne Data Handling and processing

The standards of data handling and processing which could be achieved with the MCS 920 were impressive. The computer, being a parallel mode device, is very much faster than the A. & A.E.E. Pegasus computer (a serial mode device) and its capacity is approximately four times as large as the Verdan computer. This combination of speed and capacity makes it a useful and flexible airborne instrumentation tool; the computer also has a capacity to work in four levels of priority which allows for different functions (e.g. navigation, simulation of inputs to other equipments, recording and processing) to be undertaken at any suitable time-interval sequence over the same overall period of time. During the A. & A.E.E. trials processed data from a flight was invariably available, in 8-hole paper tape form, before the aircraft had landed. Final print-out of the recorded data, via the flexowriter, was much slower, taking about two hours for a four-hour period of recording at one minute intervals. The quick look facility (para. 9.1.4 refers), however, obviated the need for printing out all the recorded data between flights. Details of the use made of data recorded during the I.R.S. performance and Doppler velocity noise testing flights are included in the ground trials results (para. 11.3.1 and Appendix V refer). Subsequent to flight trials an Elliott 503 and Lineprinter combination became available at A. & A.E.E. Advantage was taken of this facility to feed one of the airborne paper-tape records through the lineprinter; by using this facility it was possible to obtain a complete print-out of the airborne record within ten minutes which shows a considerable advantage over the flexowriter.

9.4 Navigation

It was apparent from the start of flight trials that the MCS 920, given a satisfactory program such as MC-01, was capable of performing navigation tasks. The computer's "real-time" capability was clearly evident from the speed at which present position and β angle changes were effected following fixing and FMA correction; in both cases the corrections appeared to have been completed before the operator had released his "fix" button. Sub-system performance data was complicated in the early flights by the difficulties with the peripheral equipment (para. 9.2 refers), and, because of the limited time available, no navigation analysis was made for these flights. Analysis of the navigation sorties completed in the last part of the trial, namely one medium altitude and one low altitude flight, has however been completed and the results obtained are recorded in the following paragraphs.

/9.4.1 ...

9.4.1 Medium Altitude Flight Profile

The medium altitude flying was carried out at quadrantal heights about 34,000 feet. The aircraft was positioned on the purple bisector of the English Decca Chain 5 and a series of transits between the Southampton and Grimsby ends of the bisector were made. Navigation assessment was made against selected Decca fix points along the bisector, the positions of the fix points being fed to the MCS 920 before flight as Check Point Data. Although the navigation assessment was confined to this area, MCS 920 navigation was in fact started before the aircraft left the Boscombe Down dispersal and continued until the aircraft was overhead Boscombe Down at the end of the flight. The check points used were:-

C.P. 00	-	Boscombe Down	
C.P. 01	-	5049 ¹ / ₂ N 0331W	
C.P. 02	-	5059N 0115 ¹ / ₂ W	} Datum Fix Points
C.P. 03	-	5147N 0050W	
C.P. 04	-	5233N 0024W	
C.P. 05	-	5321N 0004E	

9.4.2 Medium Altitude Navigation Results

Analysis of data obtained from the medium altitude flight, with the system operating in its primary D/I mix mode, showed a systematic distance gone scaling error of +0.52% over eleven samples of leg lengths between 50 N.M. and 100 N.M. Subsequent to flight trials it was found that an incorrect formula for aerial temperature correction had been used in the MC-01 program. Residual system error after compensating for this amounted to +0.02% in distance gone. After removal of aerial temperature scaling error and the initial I.R.S. azimuth error, prior to the first FMA correction (22.5 arc mins.) the overall navigation error, both along and across track, was bounded by bands of less than 1,000 feet for the first 140 minutes of the flight. During the remainder of the flight error velocities of up to 4 ft./sec. were experienced in the X and Y channels; deterioration in the quality of available Decca datum position information in the latter stages of the flight prevented any satisfactory conclusion being reached on the source of these velocity errors.

9.4.3 Fixing Accuracy

The accuracy with which present position was updated by the MCS 920 was determined by comparing the recorded corrected position after fixing with the known co-ordinates of the fix points used.

R.M.S. values, calculated for a total of 17 fixes, were as follows:-

R.M.S. Latitude Fixing Error: = 0.026 arc. mins.
R.M.S. Longitude Fixing Error: = 0.015 arc. mins.

9.4.4 Accuracy of FMA Correction Calculations

Fixing errors in the trials system were calculated in the MCS 920 by comparing the recorded present position to the fix position at the time of fixing. These errors were then resolved into an across track error which, together with the leg length, was used to calculate the amount of azimuth error in the system. This calculated angle was then used to modify the system transport angle; the fix point data print-out contained a record of the angle used by the MCS 920.

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A similar calculation was manually computed for the FMA fixes obtained against which the accuracy of the MCS 920 computation was assessed. The results obtained are listed in Table 1 below.

Leg No.	Mean True Track	Leg Length NM	Cross Track Error (NM)	Theoretical Az. Error	MCS 920 Az. Error	Difference
1	018° 42'	98.97	-0.644	-22.5'	-22.5'	-0-
2	199° 03'	100.03	-0.122	-4.2'	-4.1'	+0.1'
3	018° 42'	98.97	-0.078	-2.7'	-2.9'	-0.2'
4	199° 03'	100.03	-0.292	-10.0'	-9.9'	+0.1'
5	018° 42'	98.97	+0.413	+14.6'	+14.5'	-0.1'
6	199° 03'	100.03	+0.100	+3.4'	+3.5'	+0.1'

Table 1

Accuracy of FMA Correction Calculations

9.4.5 Air Alignment of I.R.S.

On four occasions during flight trials the procedure for airborne alignment of the I.R.S. was carried out. Because of a minor fault in the I.R.S. circuits the final relay closure to put the I.R.S. into the "Flight" mode could not be made. However, on each occasion the MCS 920 computer performed the necessary alignment sequences satisfactorily.

9.4.6 Reversionary Mode Navigation

On a number of flights, other than the ones used for assessment purposes in the D/I mixed mode, the system was functioned in reversionary modes. Periods of navigation using Doppler or TAS velocity and either I.R.S. or Compass Heading were successfully completed. No detailed analysis of navigational accuracies in these modes was made but in-flight observation indicated that the equipment performance compared favourably with other systems tested at A. & A.E.E.

9.4.7 Low Altitude Flight Profile

On the low altitude flight the aircraft was flown on straight, 100 nautical mile, legs between Boscombe Down and Hartland Point at heights between 1,000 feet and 300 feet. Four 100 NM legs were flown, each either starting or finishing overhead the end of Boscombe Down runway 24. This "visual fix" point was the only check point used and updating of present position, as computed by the MCS 920, was completed on each transit of the fix point. No FMA corrections were applied but an attempt was made to align the I.R.S. in azimuth to a surveyed datum prior to take-off. Calibrated Decca Chain 1 data was used as a position datum against which to assess the performance of the MCS 920 trials sub-system.

9.4.8 Low Altitude Navigation Results

A graph of the recorded differences, along and across track, between the Decca datum positions and the MCS 920 computed positions is attached at Figure 6. It can be seen from the graph that two systematic errors were present in the system; a distance gone scaling error showed that the procedure used for initial insertion of datum heading to the I.R.S. had been unsatisfactory. Table 2 summarises the results achieved.

/Table 2 ...

Leg No.	Leg Length	Height	Percentage Distance Gone Scaling Error	I.R.S. Azimuth Error (arc mins.)
1	100 Nm	1000 ft.	+0.29	-25
2	100 Nm	500 ft.	+0.26	-22
3	100 Nm	300 ft.	+0.29	-32
4	100 Nm	300 ft.	+0.31	-26

Mean Distance Gone Scaling Error = 0.285%
Mean Azimuth Error = 26.3 arc mins.

Table 2
Low-level Distance Gone and Azimuth Errors

10. Ground Trials

On completion of flight trials a ground phase was started and continued over the period from 7th April, 1965 to 23rd July, 1965. The aims of this phase were to gain further knowledge of MCS 920 programming, to study, so far as was practicable, the compatibility problems between the MCS 920 and existing computing and recording services at A. & A.E.E. and to extend investigations into possible uses of the MCS 920 for A. & A.E.E. trials instrumentation tasks.

11. Ground Trials Results

The following paragraphs describe the results obtained during the ground phase of the trial.

11.1 Programming

MCS 920 programming was investigated in three ways:-

(a) Because of staff shortages only one member of the Navigation and Radio Division staff could be allocated for direct MCS 920 programming duties, and this was on a part-time basis. The work undertaken was therefore very restricted. The subject concerned had already written small Pegasus and Elliott 503 programs to calculate the correlation coefficient between two given lists of data. Although he had no previous knowledge of MCS 920 machine code he was requested to re-write his program in this form and comment on the problems encountered. The assistance and guidance of a qualified MCS 920 programmer was provided on request. This MCS 920 program was written and working within about 19 working days. Once the standard input routines had been mastered, the subject found the work easier to do in MCS 920 machine code than in Pegasus machine code; this was, in the main, due to the limited number (fifteen) of instructions that can be used with the MCS 920. On the other hand the subject found that Algol programming for the Elliott 503 was much easier than MCS 920 machine code programming. The trial indicated that, using machine code, Navigation and Radio Division staff could learn to use the MCS 920 for simple tasks without much difficulty.

/(b) ...

(b) To make full use of the data recorded during flight trials the Elliott programmer was asked to extend his trials program library as far as possible, within the time available, and thereby provide facilities for ground analysis of the airborne data. The following programs, details of which are attached at Appendix II, were written:-

(i) Processing Program for MC-01A (I.R.S. Flight Testing Program).

(ii) Processing Program for MC-01D (Doppler Test Program).

(c) Although the trial had shown that an experienced programmer could program the MCS 920 with ease, and that less experienced staff could handle more simple tasks, it was considered uneconomic to make A. & A.E.E. staff learn yet another machine code. In conjunction with Mathematical Services Section enquiries were therefore made into the possibility of using the Elliott 503 to convert programs written in Algol to MCS 920 machine code. It was found that, provided the initial Algol program was written within a restricted instruction set, production of an Algol/MCS 920 machine code program for the Elliott 503 was feasible but was beyond the current capability of the A. & A.E.E. programming staff. The work would have to be contracted out, possibly to University or experienced industrial programmers; about three to six months would be required to complete the task at an approximate cost of £1,000 (estimated). In the course of this enquiry it became known that Elliott Bros. are in process of writing an Algol compiler program for the MCS 920 itself (para. 11.2.3 refers). Although details of the proposed MCS 920 Algol compiler are not yet available, it is probable that it will be directly compatible with the 503 Algol compiler though, possibly, limited in the number of instructions to be used. For this reason production of a special Elliott 503 program is not recommended.

11.2 Compatibility

The use made of the interface unit for the airborne trials phase showed that the MCS 920 could be made compatible with equipments under test in the aircraft. Extension of the trial to determine the degree of compatibility that could be established between the MCS 920 and existing trials instrumentation and data processing facilities at A. & A.E.E. was a formidable task which could only be cursorily examined in the time available. The following paragraphs record the work undertaken and the conclusions reached during the trial.

11.2.1 MCS 920/GEC Highway Compatibility

To demonstrate that the MCS 920 could be used to process data recorded by the Comet GEC Highway recording system a small input routine was written which allowed the current 5 hole paper tape Highway output to be accepted and read by the MCS 920. A simple binary output was produced from the MCS 920 store which showed that the computer had accurately interpreted the Highway data tape. The experiment showed that the MCS 920 could be used to process Highway data in a similar manner to current practice on Pegasus or the Elliott 503; it also indicates that, if the GEC Highway (or any other digital recording equipment) were connected electronically to the MCS 920 in an aircraft, an integrated and self-contained recording and processing network would be available. Such a system would have many advantages. It would be independent of access to ground computers and would therefore provide very useful overseas trials facilities; the combination could be used to record and process data from different sources, on a time sharing basis using the four levels of priority which are available (Appendices I and II refer) and thereby handle simultaneous equipment trials on the same aircraft. Where a double processing requirement exists (e.g. the two Pegasus routine required to

/complete

complete conversion of Decca co-ordinates to Latitude and Longitude and then to distance gone) initial processing can be completed in the air, leaving the final processing stage to the ground computer. (It can be shown that considerable time saving will be achieved by this type of system; for example current Highway/Pegasus processing of Decca co-ordinates to distance gone in nautical miles takes up to 7 hours ground processing per 5 hour sortie. Using the Elliott 503 (without backing store) this time may be reduced to about 3 hours whereas using an MCS 920/Elliott 503 combination the same results could be obtained in about 10 to 15 minutes after landing. Assuming that a "quick look" facility was available it could be argued that full ground processing could continue on the ground based computers at a convenient pace, whilst the MCS 920 provided a guarantee of reliability, via the "quick look" system, in high intensity flight trials.

11.2.2 MCS 920/Elliott 503 Compatibility

Although no direct evidence was obtained from the trial to show compatibility between the MCS 920 and the Elliott 503 there is little doubt that, given a simple input routine, the 8-hole paper tape output from the MCS 920 could have been fed into and processed by the Elliott 503. It is also possible that a magnetic tape output could be obtained from MCS 920 for direct feed to Elliott 503.

11.2.3 MCS 920 as an Additional Ground Facility

Work undertaken to carry out an analysis, on the ground, of the data recorded in flight (para. 11.3.1 refers) demonstrated that the MCS 920 was capable of meeting a high proportion of the ground processing tasks of Navigation and Radio Division, A. & A.E.E. At the present time, with the facilities of the Elliott 503 available, it would be uneconomic to set up another ground computing facility in its own right. Furthermore, until the MCS 920 Algol compiler program is available, a requirement to produce separate programs for these computers would be undesirable. However, since the Elliott 503 will be "off-line" at regular intervals for routine servicing considerable advantage could be gained from using an MCS 920 as a combined airborne/ground computer when the MCS 920 Algol compiler program becomes available. The ground use of the computer could be subordinated to the airborne task and would consist primarily of filling in the gaps when the Elliott 503 was being serviced or when pressure of work became unusually high. The advantage of an "air transportable" digital computer are most apparent when considering the promotion of overseas trials. Data processing and analysis could be progressed in step with the airborne trial at the overseas base; the quick appreciation of faults in trials equipment, instrumentation or records which such a facility could provide would be most useful in ensuring that flight time was not wasted and would considerably reduce the overall time-scale of the trial.

11.2.4 Conclusions on MCS 920 Compatibility

The MCS 920 can be integrated into the existing A. & A.E.E. trials facilities with little difficulty. The mobility and flexibility of the computer suggests that it is best suited for combined airborne/ground use; the computer can be set up to work in parallel with both airborne recording and ground computing facilities at A. & A.E.E. The provision of an MCS 920 would increase the scope of airborne trials that could be undertaken by A. & A.E.E., would provide a self-contained overseas trials recording and processing system and would provide a useful back-up to the Elliott 503 for ground data analysis.

11.3 Further Investigations into MCS 920 Suitability for Trials Support

Further investigations to determine the suitability of the MCS 920 as a trials support equipment were made, in two parts, during the ground phase of the trial. The results of this investigation are recorded in the following paragraphs.

11.3.1 Practical Demonstration

By using the analysis programs listed in para. 11.1(b) a complete analysis was made of the airborne data produced in the trial. Apart from the reduction of Decca co-ordinates to Latitude and Longitude or Distance Gone, all data processing and analysis was handled on the MCS 920. The processed data was passed to the trials officers directly interested in Doppler and I.R.S. performance and, as a result, Tech. Memorandum NR 2/65 (a copy of which is attached at Appendix V) was issued. The Memorandum details the conclusions reached on sensory equipment performance. Bearing in mind that the flying phase of the trial was severely limited it can be seen from this Memorandum that the end product of the I.R.S. and Doppler flights has proved most useful. Indeed, in both instances, the data produced by the MCS 920 could not have been obtained so easily by any other system currently available at A. & A.E.E.; both techniques employed were completely new trials methods based on the simultaneous provision of Doppler/Inertial mixed navigation, I.R.S. control, Doppler aerial stabilisation, high-speed recording of Doppler and I.R.S. parameters and subsequent post-flight analysis by the MCS 920 computer.

11.3.2 Paper Study

To establish some realistic cost/effectiveness estimates for the use of the MCS 920 as a trials instrumentation device Elliott Bros. were given two examples of typical trials requirements (para. 6.3 and Appendix III refer). The Firm studied these requirements and their estimates of cost, time-scales, technical and programming effort required to undertake the tasks using the MCS 920 are included in question and answer form at Appendix III.

12. Conclusions

The following conclusions were drawn from the trial:-

- (a) The MCS 920 computer has successfully demonstrated that it is capable of performing navigation tasks reliably, accurately and in "real time".
- (b) The speed at which the computer programs and sub-routines were written for the trial and the integrity of performance provided by these programs indicate that the MCS 920 is reasonably easy to program in machine code. The addition of an Algol compiler facility, currently being developed by Elliott Bros., will be of further advantage in this respect.
- (c) The data obtained from the MCS 920 during the I.R.S. performance and Doppler noise test flights could not have been obtained so easily by any other method currently available at A. & A.E.E.; these trials indicate that the MCS 920 would be a most valuable trials instrumentation equipment in larger aircraft, such as the Comet. Successful development of the MCS 920M, a micro-miniaturised version of the MCS 920, could well lead to the use of a digital computer in smaller aircraft, such as the Canberra, Lightning or Hunter.

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(d) The MCS 920 can be integrated into the existing A. & A.E.E. trials facilities with little difficulty. The demonstrable mobility and flexibility of the computer suggests that it is best suited to combined airborne and ground use. Working in parallel with both airborne recording and ground computing facilities at A. & A.E.E. the MCS 920 would increase the scope of airborne trials that could be undertaken, would provide a self-contained overseas trials recording and processing system and would be a useful back-up to the Elliott 503 for ground data analysis.

13. Recommendations

(a) Because of the promise shown by this initial trial of the MCS 920, it is recommended that consideration be given to the use of the computer as a standard, airborne and ground, trials instrumentation equipment at A. & A.E.E.

(b) If the MCS 920 is to be used as an airborne computer in future Service aircraft, it is recommended that work should begin at the earliest possible stage to determine what functions the computer should handle. By this means it should be possible to exploit the flexibility of the computer to the full.

(c) To take full advantage of the increasing use of digital computers in an airborne environment it is recommended that a readily available library of standard navigation and weapon system programs, in clearly expressed mathematical (Algorithmic) as opposed to machine code form, should be established at some specified central information depot.

REFERENCES

<u>Ref No.</u>	<u>Title, etc.</u>
1	Preliminary Report on MCS 920 Computer Trial in Comet XS 235. A. & A.E.E. Letter Ref. ANR 45/09 dated 21st April, 1965.
2	The Elliott MCS 920 Computer. Elliott Bros. Brochure MCD/8/2/63.

Circulation List

D.A. Nav.	1 Copy
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SHORT SUMMARY OF MCS 920 SPECIFICATION

The following paragraphs provide a short summary of the MCS 920 specification as quoted in Elliott Bros. Brochure MCD/B/2/63 - The Elliott MCS 920 Computer (Reference 2).

1. TYPE. A parallel general purpose computer with special facilities for real time processing. Numbers are represented in the two's complement notation.

2. WORD LENGTH - 18 bits.

3. INSTRUCTION CODE - 16 functions.

4. PRIORITY LEVELS - 4.

5. MEMORY CAPACITY - 8192 words.

<u>INSTRUCTION FORMAT</u>	B	F	N
	1 bit	4 bits	13 bits
	Modifier	Function	Address

7. TYPICAL COMMAND AND INSTRUCTION TIMES

<u>FUNCTION</u>	<u>TIME</u>
Add	8 (27) μ s.
Collate	14 (31) μ s.
Multiply	167 (186) μ s.
Input/Output (Minimum)	(26) μ s.
Priority Interrupt	-8-

NOTE:- Times are those to execute the instruction. Times shown in brackets include executing the instruction, incrementing the Sequence Control Register and accessing the store.

8. INPUT/OUTPUT. The input and output system allows a wide range of peripheral equipment to be connected to the computer. Though the input is digital, analogue devices may be used with the addition of converters. The computer can take in paper tape through a tape reader, and output it from a tape punch. Electrical inputs and outputs are made to separate 18 digit channels and an array of devices can be connected to these channels. In addition there is a control connection consisting of 11 wires to switch the appropriate input or output device onto the input or output channel, and four input and output select and reply lines to control the timing of events. Apart from these connections there are three extra wires to indicate priority demands.

9. ENVIRONMENT. Ambient operating temperature -32°C to +52°C.
 Sub-zero ambients need a warm-up period.
 Storage temperature -40°C to +70°C.
 Operating Relative Humidity 10-90% (without condensation) or 0-100% in special housing.
 Vibration 1-100 c.p.s. at amplitudes less than 0.06 ins. (0.15 cms) and 4g maximum acceleration.
 Meets Military Spec. DEF 133(L2) or DEF 133(L3) in special housing.

10. POWER SUPPLIES. AIRBORNE APPLICATION: Voltage : 208 volts $\pm$ 6%
 Frequency : 400 $\pm$ 20 c.p.s.
 Consumption: 500 VA

11. PHYSICAL CHARACTERISTICS

	Length	Width	Height	Weight
Computer (Military Pack)	3 ft.	1 ft.	1 ft. 2 ins.	170 lbs.
Computer (Civil Pack)	2 ft. 10 ins.	10 ins.	2 ft. 11 ins.	80 lbs.
Power Supply (400 c.p.s.)	1 ft. 8 ins.	10 ins.	7 ins.	50 lbs.

MCS 920 Trial Programs

MC-01

This basic flight program occupied 3000 words of program and workspace. It used two of the four available program levels: level one at 5 m.s. timed interrupt and level three at 320 m.s. period. Level one was used for servicing inputs and outputs at program controlled intervals of 5, 10 and 40 m.s. Level three program contained all the organisation and calculation. The following functions were performed:

- 1) Calculation and display of present position from inertial velocity in x, y axes: also calculation and display of azimuth convergence angle, β . In reversionary modes position was calculated from Doppler or TAS velocity, using either platform or compass heading.
- 2) Calculation and output of Doppler/Inertial errors; also Earth's rate, Z-component and gravity correction.
- 3) Facility for repeated air alignments of the platform.
- 4) Planned and Random visual fixing including optional FMA correction to the platform. Input and display of random fix data.
- 5) Calculation and output of groundspeed and drift angle.
- 6) Punch out of 24 words of data at one-minute intervals and at fixes.

MC-03

This program consisted of 3 basic sections:

- 1) An input routine to read in the binary data tape produced by MC-01. The quantities on this tape were as follows:

<u>1 minute data</u>	<u>Fix Data</u>
1. Mode Markers	Mode Markers
2. Time (minutes)	Time (320 m.s. cycles)
3. VIX	Time (10 m.s. cycles)
4. VIY	FMA angle
5. VDX	Lat. error
6. VDY	Long. error
7. Red Decca	As 1 minute data
8. Green Decca	"
9. Purple Decca	"
10. D/I error X	"
11. D/I error Y	"
12.)	"
) Lat.	"
13.)	"
) Long.	"
14.)	"
15.)	"

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1 minute dataFix Data

16. Drift angle	As 1 minute data
17. β angle	"
18. Platform Heading	"
19. Compass Heading	"
20. Across track error x	"
21. Along track distance y	"
22. $\dot{x}$	"
23. $\dot{y}$	"
24. Calculated Track angle ψ_T	"

- 2) In addition, MC-03 calculated the following quantities:

Doppler groundspeed: $(V_{DX}^2 + V_{DY}^2)^{\frac{1}{2}}$

Total D/I error: " $-(V_{IX}^2 + V_{IY}^2)^{\frac{1}{2}}$

Inertial track: $\tan^{-1} V_{IX}/V_{IY}$

Doppler track: $\tan^{-1} V_{DX}/V_{DY}$

Heading error: Platform heading + Drift - $\tan^{-1} V_{DX}/V_{DY}$

- 3) MC-03 then rescaled all these quantities and used standard output subroutines to produce a teleprinter coded tape for print-out on a Flexowriter or lineprinter.

MC-03B

A version of MC-03 to search through the binary flight data tape and only print out fix data, to allow a quick estimate to be made of the success of a sortie.

Another similar version of MC-03 was written to print out specified parts of the total data over a chosen period.

MC-01A

This program was an extensive modification of the basic MC-01 to allow a specific test to be made of the inertial platform during manoeuvres. On receipt of a signal, which also started the ground range recording, the program stored the current values of $\dot{x}$, $\dot{y}$ and $\dot{z}$ from the inertial platform at 1/5 second intervals. When the starting signal was received for the second time, the program ceased recording and punched out all the accumulated data in binary code. Sufficient store space was available for up to 5 minutes recording. As a confidence check on the program working, and the start signal input functioning correctly, the program was arranged to drive up an unused counter display whenever the start signal was triggered with the "Normal" button on the control panel depressed. An additional program facility was available to record and punch out platform heading and β angle at 2 second intervals, controlled by another switch input. In order to

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allow a high degree of accuracy and synchronisation with ground recording the top priority program was re-written to allow the use of a 10 m.s. interrupt signal instead of the usual 5 m.s. which was slightly inaccurate. All facilities of the MC-01 program were retained with the following exceptions:

- 1) One minute and fix punch-outs were suppressed.
- 2) FMA correction at fixes was removed.
- 3) D/I errors were held at zero during runs.

Processing Program for MC-01A

A translation input program was written to enable information on 5-hole, Ferranti-coded teleprinter tape from the Aberporth range, to be used by the 920. The velocities recorded by the range were passed through an axis change, and Earth's velocity was added to make possible direct comparison with the inertial velocities recorded by the 920. Velocity errors in each axis were meaned over 5 samples, i.e. one second, and formed the output for printing on a Flexowriter.

MC-01D

This program was essentially MC-01 with the 10 m.s. interrupt top level program. In addition a facility was provided to record Doppler velocity and drift angle at 1/10 sec. intervals, platform x and y velocities and heading at 1/5 sec. intervals. This recording was initiated by a control panel switch, and was automatically continued by the program for 2 minutes. At the end of this period the stored data was punched out on tape. All MC-01 facilities were retained.

Processing Program for MC-01D

This program calculated the difference between doppler velocity and calculated groundspeed, and between doppler drift angle and calculated drift, for each 1/10 sec. interval. These differences were accumulated and used to produce mean errors, root mean squares and standard deviations. The necessary position data for each run was extracted from the one minute print out of the flight and was fed in as a separate data tape.

"Quick Look" Programs

These programs were written to read in the binary tapes produced by MC-1A and D, and output samples of the recorded data at intervals of a few seconds. This enabled a quick assessment to be made of the success of a sortie.

Appendix III

Estimates of Cost, Time-scales, Technical and Programming Effort Required to Undertake Typical Trials Tasks Using the MCS 920 Computer

1. To further investigations into the possible use of the MCS 920 for trials instrumentation, Elliott Bros. (London) Ltd. were asked to make a study of two typical trials requirement specifications. The study was to include estimates of cost, time-scales, technical and programming effort required to undertake these tasks.
2. Annexure A contains details of a relatively simple task related to a proposed flight to Miami, for an I.A.T.A. conference, where the computer would be required to demonstrate its suitability as an in-flight data processing device.
3. Annexure B contains details of a typical major equipment trial requirement: in this case the trial of an Inertial Reference System.
4. The study was conducted by means of question and answer; Elliott Bros. answers to the questions posed by A. & A.E.E. are recorded in the following paragraphs:-

a. Question

How long would it take to write the programs for each of the trials?

Answer

The time necessary for the preparation of programs for the paper exercises is shown below:-

<u>Exercise</u>	<u>Writing</u>	<u>Testing</u>	<u>Total</u>
(i) MIAMI (Data Processing)	4½ Man/wks	1½ Man/wks	6 Man/wks
(ii) F.M.P. (Flight)	13 Man/wks	6 Man/wks	19 Man/wks
(iii) F.M.P. (Data Processing)	6 Man/wks	2 Man/wks	8 Man/wks

NOTE: There is no reason why these three exercises should not be worked on simultaneously by three programmers. Further, by using more than one programmer on the F.M.P. flight program the actual time taken for the program writing could be telescoped by about 4 and to about 9 weeks. It would not be possible, however, to shorten the testing time so that the minimum time that this program would take would be 15 weeks.

b. Question

How long would it take to build any necessary interface units?

Answer

The time required to build the necessary interface by normal production processes would be approximately 4 months. By laboratory methods this could be reduced to a minimum of 10 weeks. It may, however, be possible to use an existing interface unit, suitably modified, which would show a considerable saving in time (i.e., subject to materials being available, in 4-5 weeks).

c. Question

What would be the likely cost of the programs?

/Answer

- 2 -

Answer

The cost of preparing and testing the programs would be:-

MIAMI D.P. £530
 F.M.P.
 (Flight & D.P.) £2,380

It should be noted that the time and cost figures quoted are budgetary. The figures in practice are not likely to exceed and will probably be less than those quoted.

d. Question

What would be the costs of:-

- (i) Hire of computer per month of flight trials?
- (ii) Hire of engineer to operate computer?
- (iii) Cost or hire of the necessary interface units?
- (iv) Use of existing GEC Highway System as an interface unit?
- (v) Magnetic tape output in addition to, or in lieu of, paper tape? (Compatible with A. & A.E.E. 503 decks).

Answer

The hire costs for equipment, manning, etc., are as follows:-

- (i) Computer and interface unit complete with tape reader and punch.
- (iii)
 - Short term limited period
approximately £1,500 per calendar month.
 - 1 year minimum hire
approximately £1,000 per calendar month.
 - 3 or 5 years leaseings can be arranged at lower costs if thought desirable (prices on application), but these would only be economical if a continuous program of work beyond the exercises under examination was envisaged.
- (ii) Engineers to operate the computing system on site are available at £80 per man per week.
- (iv) The cost of using the G.E.C. Highway system as an interface unit is a little difficult to arrive at as no direct knowledge concerning the cost of this unit is available. However, assuming that a Highway system is available there would be no extra cost involved for the Miami D.P. exercise as it has already been demonstrated that the punched tape output from Highway is compatible with the 920 computing system. For the F.M.P. exercise a direct Highway-MCS 920 feed might be employed and this would entail a special

/digital

digital buffer unit. This might show some saving but a firm statement to this effect could only follow a detailed investigation into the optimum methods of use for the two systems. It should be noted that limited use of Highway with the 920 system has already been made during the current flight trials.

- (v) The cost of providing a magnetic tape output in addition to or in lieu of paper tape is another area difficult to define. It can be stated, however, that it would not be an economical proposition for the paper exercises currently under consideration. In the event of more complex and higher speed tasks being undertaken Elliott's would be happy to investigate and quote accordingly. The cost would be dependent upon the number of parameters to be recorded, the frequency of scan and the overall recording time required.

e. Question

What would be the relative costs of:-

- (i) The firm's acceptance of the complete task on a hire basis to produce the required answers?
- (ii) Hire of computer only?
- (iii) Hire of computer and writing of programs?
- (iv) Hire of computer, writing programs and providing engineering support?
- (v) Purchase of computer and associated equipments?

Answer

- (i) The costs of Elliott's undertaking the entire task can only to be given in terms of costs per month of trial as the firm
- (iv) has no control over the availability of the aircraft or crew or over the British weather.

Over and above the basic programming cost given in (c) above, the cost can be obtained by adding to the cost of computer and interface equipment hire (given in (d) (i) above) the charges for three personnel on site and one rear link support. This support will cost £1,387 per calendar month or £1,280 per four week period. Additionally, maintenance of the system may be required (for details see (k) below).

- (v) The cost of purchase of computer and interface equipment would be

One MCS 920A computer	£26,500 less 15%
One Interface unit	£7,000 nett.

NOTE: A used machine in good condition might be available at a considerably reduced figure.

/f.

f. Question

How long would it take to train A. & A.E.E. personnel to operate the computer in the air and on the ground? What would it cost to train them?

Answer

It would only take two days to train A. & A.E.E. personnel to operate the computer in the air and on the ground. This training would be free of charge.

g. Question

How long would it take to train A. & A.E.E. personnel to write programs for the MCS 920? When will a 920/Algol compiler be available?

Answer

Assuming some previous programming experience, it would be possible to train available A. & A.E.E. personnel to write programs for the 920 on a two week course. If a machine is purchased at list price, three places are provided on Elliott courses free of charge - otherwise the cost is £50 per man per course. The Algol/920 compiler is expected to become available before the middle of 1966.

h. Question

To what extent could an Elliott 503 computer be used to prepare programs for the MCS 920? Can 503 Algol programs be converted by the 503 into 920 machine code? If so, what would it cost A. & A.E.E. in time and money?

Answer

- (i) The 503 computer can be used to prepare programs for the 920 computer if a 920 compiler program is first written.
- (ii) A 503 Algol program can be converted by the 503 to 920 machine code provided suitable translation programs are written.

The procedure would be:

- (a) Feed 503 with Algol translator (available) - no output.
- (b) Feed 503 with ultimate program in 503/Algol - output binary tape (A).
- (c) Clear 503.
- (d) Feed 503 with binary/machine code program (available) - no output.
- (e) Feed 503 with binary tape (A) - output 503 machine code tape (B).
- (f) Clear 503.

/(g)

- 5 -

- (g) Feed 503 with 503 machine/920 machine translator (not written) - no output.
- (h) Feed 503 with 503 machine code tape (B) - output 920 machine code tape.

Whilst there is no doubt that this can be done, the storage capacity might be the limiting factor.

- (iii) Probably a better way of achieving the same result would be to produce a 503 program to convert a program written in 503 Algol direct to 920 machine code. There may be some difficulty with this method until the Boscombe 503 has some supplementary tape storage installed.
- (iv) A further alternative would be to write programs in a restricted Algol suitable for the 920 which could then be run in either the 920 or the 503 (once the 920 Algol compiler was available).

j. Question

How much of the programming tasks would Elliott Bros. be able to undertake without sub-contract?

Answer

Elliott Brothers can undertake all the programming tasks covered by the paper exercises without resort to sub-contract. Other tasks would have to be examined in the light of current work load, required delivery and complexity of the future tasks involved. The Firm will be happy to advise and quote against any prepared specification.

k. In addition to the above questions the firm were asked to comment on what would be necessary to maintain and support an MCS 920 computer in use at A. & A.E.E., and in fact any other information considered relevant. The reply received was as follows:-

"If A. & A.E.E. were to hire a 920 computing system on a short term basis, an "on-call" contract can be arranged with Elliott's Computer Maintenance Division. The cost of this would be approximately £25 per day when called, inclusive of all travel and incidental expenses, but exclusive of material.

If, however, A. & A.E.E. were to purchase a computer or obtain one on a long term hire or lease, then a different arrangement would be available which would include regular visits for routine and preventative maintenance. The cost of this type of contract would be approximately £850 per annum covering computer, tape reader, tape punch and interface unit. Without the interface unit, this figure would be reduced to £600 per annum. Both figures include all routine preventative maintenance and an emergency call service on a single shift bases, i.e., 9 a.m. to 5 p.m., Monday to Friday, public holidays excepted. The figure also includes all spare components."

Proposal for Use of Elliott MCS 920 on Miami Exercise

1. To meet a suggestion that the A. & A.E.E. Comet be positioned at Miami, during an I.A.T.A. conference, as a static display of a well equipped trials aircraft, proposals for the use of the MCS 920 were drawn up. The following paragraphs outline these proposals, which are aimed at the use of the MCS 920 without undue expense to A. & A.E.E. and without asking Elliott Bros. to provide a complex computer program.

2. Outline Proposal

It is suggested that the GEC Highway recording system, already in the aircraft, is used for the recording of all information and that the Elliott MCS 920 is used solely for data processing. The advantages of this idea, which appears from initial investigation to be practical are:-

- (a) It divorces processing from recordings.
- (b) Both functions can be carried out independently.
- (c) 920 programming and preparation would be simplified.
- (d) Highway recording provides a permanent record of flight, it can then be processed in flight, or on-ground.
- (e) The installation has good demonstration potential.
- (f) A minimum of wiring and interface equipments is required.

3. Highway Quantities

Highway will be used to record the following quantities on 5 hole paper tape. The sampling speed will be once per two minutes throughout. It will be desirable to ident Highway for random fixes.

- (i) F.M.P. d. lat. d. long X and Y velocities (from "Navigate")
- (ii) Decca Red. Green. Purple and Chain: Reliability
- (iii) T.G.P. Fine and Coarse Hdg.
- (iv) Doppler Drift and dist. gone.
- (v) Time.
- (vi) Heading F.M.P. if available.

4. 920 Processing

Input to the 920 will be by paper tape. 920 will require a data processing program to be written by Elliotts. This program will require finance from A. & A.E.E. as decided between ourselves and Elliotts. The output of the 920 in telecode will be fed into a Flexowriter and printed out in the air, possibly using rolls of Highway Tape at half hourly intervals.

5. Elliott Program Requirements

The requirements of the program (agreed with R.A.E.) to be written by Elliotts is outlined below:-

/(a)

- 2--

(a) Essential Items

Time	Soemblem clock
Time	From IN to "Navigate"
Decca	Red-Green, Purple, Chain, Reliability
T.G.P./Doppler	Posn. Lat. Long.
T.G.P.	Corrected True Hdg.
Green Satin	Drift
Green Satin	Distance Gone
F.M.P.	Posn. Lat. Long.

(b) Highway Desirable

F.M.P.	X and Y velocities
Difference	F.M.P. X and Y Velocities with Resolved Doppler Vel., Drift and F.M.P. Hdg.

(c) Desirable

Difference	N. Miles	F.M.P./Doppler Positions
F.M.P.	Heading	

(d) Additional Requirements from Random Fixes

(To be fed in by 920 Engineer on Flight)	
F.M.P.	Error in N. Miles
T.G.P./Doppler	" " "

Computer Programme Requirements for a Comet Trial
of an Inertial Reference System

1. In-Flight Calculations

(a) Navigation

- (i) From platform azimuth, doppler drift and velocity calculate present position in latitude/longitude ϕ_D, λ_D .
- (ii) From increments of latitude/longitude from platform Navigation Computer produce present position in latitude/longitude ϕ_P, λ_P .
- (iii) From inertial velocities (whole number, North/East axes) calculate present position in latitude/longitude ϕ_I, λ_I .
Allowance for changes in Earth's surface velocity must be made in this calculation.

(b) Fixing

- (i) Fix positions will be at prescribed Decca intersections or manually inserted positions.
- (ii) At Decca fixes the actual fix position is to be obtained by reading the Decca co-ordinates on pressing the 'fix' button and interpolating from the co-ordinates of the aimed point.
- (iii) Fixes may be initiated either by a manual 'fix' button or automatically at a designated across track Decca reading.
- (iv) FMA corrections are to be calculated at designated fixes and included in the calculations of 1(a)(i).

(c) Steering

- (i) Along and across track steering information to steer to the next fix point is required.

(d) Recording

- (i) The following information is required at one minute intervals:-
Platform azimuth angle; doppler drift angle; FMA correction angle; ϕ_D ; ϕ_P ; ϕ_I ; λ_D ; λ_P ; λ_I ; Decca RED; Decca GREEN; Decca PURPLE; Mean doppler velocity East over last minute; Mean inertial velocity East (corrected for Earth's velocity) over last minute; mean doppler velocity North over last minute; mean inertial velocity North over last minute; track angle computed from inertial velocities; along track distance to go; across track distance; time.
- (ii) The following information is required at fixes:-
 ϕ_D ; Decca interpolated latitude ϕ_C ; λ_D ; Decca interpolated longitude λ_C ; Decca RED; Decca GREEN; Decca PURPLE; Fix mode; Time.

/(e) ...

(e) Displays

The following displays are desirable:-

- (i) Present position from doppler. ϕ_D ; λ_D .
- (ii) Along track and across track distances.
- (iii) Along and across track steering signals (d.c. voltages)
- (iv) Topographical display. This requires increments of distance North and East derived from the platform latitude/longitude increments, and increments of track angle derived from inertial velocities.

2. Data Reduction

- (a) Print-out of basic one minute information.
- (b) Print-out of fix information.
- (c) Quick-lock velocity print-out:
Time; (Mean inertial velocity - mean doppler velocity) East;
(Mean inertial velocity - mean doppler velocity) North.
- (d) Position data print-out:-
Time; Decca position (Decca co-ordinates converted to latitude/longitude); (Platform-Decca) position East/North; (Doppler - Decca) position East/North; (Platform - doppler) position East/North; True track (Platform azimuth + FMA correction + doppler drift); Track computed from inertial velocities; track error; (Platform - Decca) position along/across true track; (Doppler - Decca) position along/across true track; (Platform - doppler) position along/across true track.

FMP-A Interface

Outputs from the IRS system are:-

- (a) Azimuth as a 13 bit V-brush encoder (external logic).
- (b) Latitude/Longitude increments by a two-phase switch encoder.
Scaling is 40 switch cycles per arc minute.
- (c) Velocities as d.c. voltages scaled at 12.5 mV per ft./sec. An analogue to digital converter (Astrodata type 3000) is available for conversion of the velocities to 14 bit + sign accuracy, but the two way switch to time share the converter must be controlled by the computer and is not yet designed.

Topographical Display Interface

M transmission is used for all three channels. For distances East and North the scale is selected to suit the map scale: 24 revs per nautical mile at 1/4 million, 12 revs per n.m. at 1/2 million, 6 revs per n.m. at 1 million. The map scale in use is indicated by a selector switch. One rev has six steps if a +/- system is used and 12 steps if a +/0/- system is used.

Track angle is transmitted at one rev per six degrees.

MCS 920 TRIAL - FLYING SCHEDULE

DATE	SORTIE NO	FLYING TIME	COMPUTER PROGRAM	AIM OF SORTIE	
15 Mar 65	1	4 hrs 5 mins	MC-01 Navigation	Airtest - MC-01 Function Test	a. Navigation function tests successful b. Computer failed on take-off and landed c. Intermittent large fluctuations of 20% error in groundspeed d. 30 mins. after take-off fault developed 20% of true value.
19 Mar 65	2	4 hrs	MC-01 Navigation	Initial Navigation Flight (Medium Altitude)	a. Temperature "Power Dump" occurred b. Function test of Random Fix successful c. Intermittent large fluctuations of 20% error in groundspeed d. Presence of 20% error in groundspeed e. Electronic interference from Tape
24 Mar 65	3	5 hrs 36 mins	MC-01 Navigation	Navigation Flight (Medium Altitude)	a. Computer failed on take-off. Rejected b. Navigation performance during first 30 mins. good c. Fault producing 20% groundspeed error
26 Mar 65	4	3 hrs 50 mins	Initially MC-01A, I.R.S. Program. Subsequently MC-01 Navigation Program.	I.R.S. Performance test using Aberporth Range	a. Unsuccessful. Computer failures b. Part of flight used to investigate incorrectly set interface unit - 1 c. Periods of Doppler/Compass navigation d. I.R.S. air alignments attempted; air alignment mode.
29 Mar 65	5	1 hr 50 mins	MC-01A, I.R.S. Program	I.R.S. Performance test using Aberporth Range	Unsuccessful. Error in MC-01A program FMA correction signal; the I.R.S. aligned the FMA input to zero, cleared the fault
30 Mar 65	6	2 hrs 45 mins	as above	as above	a. Successful. I.R.S. velocities re Navigation during trial good. b. "Quick-look" results available with 10 mins.
31 Mar 65	7	3 hrs 45 mins	Initially MC-01A, I.R.S. Program; subsequently MC-01 navigation program	a. I.R.S. Performance Test. b. Air Alignment of I.R.S.	a. Successful repeat of Sortie 6; "Quick-look" results good. b. Partly successful air alignment as unserviceable in air alignment mode
1 Apr 65	8	3 hrs 10 mins	MC-01D, Doppler Noise Program	To obtain records of Doppler velocity performance	a. Successful; records of 12 runs obtained. b. "Quick-look" results available with 10 mins. c. Navigation during trial good.
2 Apr 65	9	4 hrs 10 mins	MC-01 Navigation	Navigation / assessment (35,000 feet)	a. Successful. MCS 920 records available b. "Quick-look" results produced before 10 mins.
6 Apr 65	10	2 hrs 50 mins	MC-01 Navigation	Navigation Assessment (low level - 300/1,000 ft.)	a. Successful. MCS 920 records available b. "Quick-look" results available with 10 mins.

MCS 920 TRIAL - FLIGHT SCHEDULE

	AIM OF SORTIE	SUMMARY OF RESULTS
	Airtest - MC-OL Function Test	a. Navigation function tests successful, apart from Random Fix. b. Computer failed on take-off and landing. Restart action successful, but probably corrupted Random Fix sequence. c. Intermittent large fluctuations of D/I mix signals. d. 30 mins. after take-off fault developed in interface unit causing MCS 920 computed groundspeed to under-read by 20% of true value.
	Initial Navigation Flight (Medium Altitude)	a. Temperature "Power Dump" occurred 20 mins. after take-off; caused by dirty filter in cooling air supply. b. Function test of Random Fix successful. c. Intermittent large fluctuations of D/I mix signals still present. d. Presence of 20% error in groundspeed noted. e. Electronic interference from Tape Winder created difficulties.
	Navigation Flight (Medium Altitude)	a. Computer failed on take-off. Restart action successful; did not corrupt program. b. Navigation performance during first three hours observed to be of high standard. c. Fault producing 20% groundspeed error developed at end of three hours.
I.R.S.	I.R.S. Performance test using Aberporth Range	a. Unsuccessful. Computer failures occurring frequently when MC-OLA Program used. b. Part of flight used to investigate fault; MC-OL program interchanged with MC-OLA program eventually revealed incorrectly set interface unit - 10V supply trip circuit. c. Periods of Doppler/Compass navigation completed successfully. Quality of navigation good. d. I.R.S. air alignments attempted; unsuccessful due to I.R.S. fault but MCS 920 inputs to I.R.S. satisfactory in air alignment mode.
	I.R.S. Performance test using Aberporth Range	Unsuccessful. Error in MC-OLA program effectively presented the I.R.S. with an open-ended, floating voltage, FMA correction signal; the I.R.S. alignment was consequently disturbed. Modification to MC-OLA program, biasing the FMA input to zero, cleared the fault.
	as above	a. Successful. I.R.S. velocities recorded in turns of 15°, 30° and 45° Bank Angles and in 10° "pop-up" manoeuvre. Navigation during trial good. b. "Quick-look" results available within 1 hour of landing.
I.R.S. only program	a. I.R.S. Performance Test. b. Air Alignment of I.R.S.	a. Successful repeat of Sortie 6; "quick-look" results available within 1 hour of landing. Navigation during trial good. b. Partly successful air alignment sequences carried out. MCS 920 inputs satisfactory but I.R.S. still unserviceable in air alignment mode.
	To obtain records of Doppler velocity performance	a. Successful; records of 12 runs at heights between 300 and 40,000 feet, in straight and level and turning flight, obtained. b. "Quick-look" results available within 1 hour of landing. c. Navigation during trial good.
	Navigation / assessment (35,000 feet)	a. Successful. MCS 920 records available for analysis. Quality of navigation good. b. "Quick-look" results produced before landing. (Flexewriter carried in aircraft).
	Navigation Assessment (low level - 300/1,000 ft.)	a. Successful. MCS 920 records available for analysis. Quality of navigation good. b. "Quick-look" results available within 30 mins. of landing.

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AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT
BOSCOMBE DOWN

Navigation and Radio Division Technical Memorandum NR 2/65

Further flight trials of Tony Doppler (A.R.I.23133) and Inertial
Reference System (I.R.S.) Type 200 in conjunction with an
Elliott 920 Digital Computer - Comet XS 235

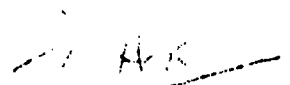
by

Flight Lieutenant G.C. Dyer R.A.F.

Summary

Trials aircraft Comet XS 235 of Boscombe Down was recently engaged in an airborne evaluation of an Elliott 920 Digital Computer. Opportunity was taken during this computer evaluation to obtain further data on Tony Doppler and Inertial Reference System (I.R.S.) type 200 performance. This technical Memorandum details the results obtained during the flight trials of these primary navigation sensors.

This Memorandum is issued with the authority of


Superintendent of Navigation & Radio
Division.

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1. Introduction

During the period 15th March - 6th April 1965, trials aircraft Comet XS 235 at Boscombe Down was engaged in an airborne evaluation of an Elliott 920 Digital Computer. Certain primary navigation sensors were already fitted in the Comet aircraft and it was decided to operate these equipments in conjunction with the 920 computer. This arrangement fulfilled a triple purpose:-

- (a) It would provide an assessment of the computer's ability to 'navigate' with high accuracy sensor inputs.
- (b) It would enable the flexibility of the 920 computer as a trials data recording and processing device to be examined.
- (c) It would provide further in-flight data on Tony Doppler and I.R.S. Type 200 performance.

The performance of the Elliott 920 computer is the subject of a formal Navigation and Radio Division, A. & A.E.E. report. This Tech. Memo details the results obtained with these further flight trials of Tony Doppler and I.R.S. type 200.

Tony Doppler (A.R.I.23133) Trials

2. Aims of the Trial

The aims of the trial as far as the Tony Doppler was concerned were:-

- (a) To check signal/noise ratios at various altitudes and bank angles.
- (b) To measure the fluctuation or 'noise' on ground speed and drift outputs.
- (c) To carry out a further check of the distance gone accuracy at low level.

3. Summary of Flying

The Tony Doppler was operated in the air for a total of 36 hours on the 10 sorties flown. Of these ten sorties two only were devoted to specific tests on the Tony Doppler. On one of these, twelve recorded runs were carried out to measure signal/noise ratios and groundspeed/drift noise at altitudes between 250 feet and 40,000 feet in straight and level flight and with bank angles up to 30 degrees. The other sortie was carried out at low level i.e. at 250 feet - 500 feet A.G.L. to obtain a distance gone accuracy assessment.

4. Doppler Serviceability

The B11. model equipment was used for 35½ hours of the 36 hours flown. The remaining ½ hour was used to confirm the serviceability of the B.7 model equipment. Both equipments were modified to 'nuvistor' standard, had error trip levels set at 2% and had 820 ohm drift time constant resistors fitted. The Doppler performance throughout the trial was good and no failures were recorded.

/5. Instrumentation

5. Instrumentation

5.1. Airborne Instrumentation

In accordance with the aim of the parent trial, the evaluation of the 920 computer, the primary recording of data was carried out in the 920 computer. However, in addition, a Ferrograph Tape Recorder was used to record a spoken commentary and one output from the Doppler.

5.1.1. 920 Computer

As well as carrying out navigation calculations the 920 computer was used to record and store the following parameters which were punched out on paper tape immediately after each 2 minute run.

Doppler drift angle (δ_D)	- every 1/10th second
Doppler groundspeed (V_D)	- every 1/10th second (Doppler Velocity Counter reading)
I.R.S. heading (ψ_p)	- every 1/5th second
I.R.S. horizontal velocities (V_{IX}, V_{IY})	- every 1/5th second
Latitude (λ)	- every 1 minute from the normal navigation print-out
I.R.S. transport angle (β)	

5.1.2. Ferrograph Recorder

The model used was a twin track machine, type 4C/FN, with a frequency response up to 15 Kc/s.

Track 1

On track 1 a spoken commentary was made detailing aircraft height, roll angle and remarks on qualitative performance e.g. whether tracking or on memory and approximate groundspeed and drift readings.

Track 2

This track was connected to the output of the audio amplifier in the Doppler tracker unit and recorded the received doppler signal used by the frequency tracker to derive groundspeed and drift.

5.2. Ground Processing

5.2.1. 920 Data Tapes

The Elliott trials team at Boscombe Down wrote a special 920 computer program to analyse the computer flight data tapes. For each run the program produced the following quantities:-

Mean groundspeed difference ($\bar{V}$)
Mean drift angle difference ($\bar{\delta}$)
Doppler groundspeed noise (η_V)
Drift noise (η_D)

The equations used in the program to derive these quantities are given and described in Appendix 'A'.

/5.2.2. Ferrograph

5.2.2. Ferrograph Tape

The Ferrograph tape recording was analysed by the Decca Radar Company engineers using an R.R.E. spectrum analyser (Type E.901). The mean receiver signal to noise ratio for each run was obtained by relating the peak spectrum amplitude to peak noise level.

6. Trials Results

The results of the signal/noise ratio and groundspeed/drift noise measurements are given in Appendix 'B'. The results for the low level distance gone accuracy assessment are given in Appendix 'C'. The following sub paragraphs summarise the results obtained.

6.1. Signal/noise Ratios

In straight and level flight over land the received signal/noise ratios were satisfactory, being 28 dB over the trip level at 250 feet and 16 dB over the trip level at 40,000 feet. Over sea at 40,000 feet the margin was 12 dB. (R.R.E. have stated that these figures are approximately 6 dB less than theoretical design values).

With 11 degrees of bank at 40,000 feet over land the signal to noise ratio was 3.5 dB over the trip level. Thus over a fairly calm sea in similar conditions of flight it is probable that the signal to noise trip would be actuated.

6.2. Groundspeed Noise

The mean groundspeed differences found were satisfactorily small, being in each straight and level case very close to the least significant bit size of the datum inertial velocity i.e. 1.6 ft./sec. or .95 kts.

The 'percentage noise' values on groundspeed were between 1.39% at 250 feet decreasing to 0.34% at 40,000 feet. The increased noise at low level is consistent with theory and is due to the increased effect of 'scanning noise'.

6.3. Drift Noise

The drift noise values show that with the servo feedback resistor decreased from its original design value of 6.8 K ohms there is still some oscillation of the aerial in drift. This is not considered to be important if the doppler is used in conjunction with an analogue computer or a digital computer with a sampling rate of several times per second.

Previous trials at A. & A.E.E. have shown that if the doppler drift servo is further slugged there is a danger that the tracker will not be able to follow real fluctuations rapidly enough and the error trip circuit will be actuated.

6.4. Distance Gone Accuracy

The distance gone accuracy assessment was carried out in the same way as on previous trials with the Tony Doppler, with the exception that the navigation equations in this case were solved in the 920 computer. The instrumentation was the same as on these previous trials, in that Highway, the permanent digital recording system in Comet XS 235, was used to record doppler distance gone increments and Decca fixes.

/The assessment ...

The assessment was made by accumulating distance increments measured between Decca fixes taken at intervals of 20 seconds, and comparing the total with accumulated Doppler distance gone. A full description of this technique is given in A. & A.E.E. Report No. Tech./268/Nav. Part V. The route chosen was the 100 n.m. leg between Boscombe Down and Hartland Point; this route having been previously 'Decca calibrated'. Corrections were applied to the datum to reduce systematic Decca error and the resultant data was smoothed to reduce random Decca noise. Based on Decca noise at the time it is estimated that the residual error in the technique was 200 feet i.e. .03% in 100 n.m.'s.

Three assessment runs were carried out, the results obtained being shown in Appendix 'C'. A mean error of +.17% was found.

Note: Combining these results with similar samples from previous trials, namely +.06% and +.17%, an overall mean error of +.15% is obtained.

Inertial Reference System (I.R.S.) Type 200 Trials

7. Aim of the Trial on the I.R.S.

Two sorties were flown to assess the accuracy of the inertial velocity outputs from the inertial reference system during various turning and climbing manoeuvres. The manoeuvres were carried out in the area of highest accuracy cover of Aberporth Range FPS 16 radar. The FPS 16 radar provided datum velocities for the platform x, y and z channels.

8. Trials Equipment

The equipment used for the trial was the existing installation comprising the I.R.S. itself, Tony Doppler, and the Elliott 920 Computer, with the addition of a Transponder beacon. The transponder beacon enabled the FPS 16 radar to track the aircraft with improved accuracy. The only other modification to the overall Comet installation was to the wiring of the Tone circuit. This enabled the 920 computer to start recording when the tone button was pressed.

9. Trials Procedures

9.1. Manoeuvres Tested

Four manoeuvres were carried out on each sortie:-

- 180° level turn with 45° bank, at 16,500 ft.
- 180° level turn with 30° bank, at 16,500 ft.
- 180° level turn with 15° bank, at 16,500 ft.
- Max. rate climb for 1 minute, from 16,500 feet.

The sortie profile is shown at Figure 1 to this memorandum.

9.2. Platform Levelling

To ensure that the platform was correctly levelled prior to the commencement of a manoeuvre the aircraft approached the range area on a straight run in of 50 n.m.'s. during which time full D/I mixing was taking place.

9.3. Platform Alignment

A secondary aim of the flight was to assess azimuth gyro drift rate by allowing the I.R.S. to 'run-free' throughout the flight. As unknown misalignment of the accelerometer axes at the time of manoeuvre

/would introduce ...

would introduce errors into the assessment the following precautions were taken:-

(a) Pre-flight alignment was carried out in the magnetic mode, the platform being slaved to an accurately surveyed heading set into the Comet G4B/T.G.P. installation. (It was found both on these two sorties and other sorties in the 920 Computer trial, where a magnetic alignment sequence was used, that at completion of the alignment sequence the azimuth binary readout on the platform was 0.3° high on the T.G.P. reading. To get platform heading to agree with surveyed heading the T.G.P. had to be set 0.3° low. The compressed time scale of the 920 computer trial made it impossible to carry out bench tests to prove the accuracy of the platform azimuth binary readout, as this would have involved removal of the platform and delay. Tests were not carried out at completion of the trial as development work on the platform was cancelled.)

(b) Heading checks, using AVN 1 Astro Tracker information recorded on Highway, were taken on each 50 nm leg inbound and outbound the range. Instantaneous checks every 2 secs. were meaned over a 2 minute period. Simultaneous recording of platform heading and beta angle allowed the misalignment between range axes and aircraft axes to be determined at the time of manoeuvre.

10. Instrumentation

10.1. Airborne Recording

The parameters detailed below were recorded by the 920 computer in-flight:-

10.1.1. On each 50 n.m. leg inbound and outbound the range,

Platform Heading
Beta Angle

every 2 secs. for a selected 2 min. period (i.e. coincident with recording of Astro tracker heading on Highway).

10.1.2. During manoeuvres,

Platform x, y, z inertial velocities
Beta Angle

every 1/5th sec.

10.2. Ground recording - Aberporth Range

The Aberporth F.P.S. 16 radar provided datum velocities during manoeuvres also at every 1/5th sec. As these velocities were related to a grid North line drawn through the F.P.S. 16 radar base, knowledge of the misalignment between range axes and aircraft axes (see para. 9.3. (b)), was necessary to make an axes rotation correction in data analysis.

Aberporth estimated that with the smoothing period they adopted on the range information i.e. 4 secs, the radar velocity noise was limited to about 1 ft/sec. in each channel. The data analysis carried out however suggested that 2.5 ft./sec. was more representative.

/10.3. Synchronisation

10.3. Synchronisation

Synchronisation of air and ground recording was achieved by a tone signal generated from the aircraft just prior to the start of the manoeuvre. The initiation of the tone started the 920 Computer recording and also provided a zero time datum for the ground recording. Both air and ground recording ceased on a second tone transmission at the end of each manoeuvre.

10.4. Ground Computing Facilities

The platform inertial velocities and F.P.S. 16 radar velocities were subsequently compared in the 920 Computer by the Elliotts trials team. The major steps in the specially written program were as follows:-

- (a) Aberporth information in 5 hole, Ferranti coded teleprinter tape was input into the 920 using a special translation program.
- (b) The velocities recorded by the range were passed through an axes change and Earth's velocity added to allow direct comparison with recorded inertial data.
- (c) Velocity errors in each channel were meaned over 5 samples (i.e. one second), and were output for printing on a flexowriter.

11. I.R.S. Faults

The I.R.S. performance was generally satisfactory during the 36 hours of airborne operation time. The following faults however were noted:-

- (a) A fuse blew several times in the boost heat circuit during initial platform gyrocompassing. Due to the compressed time scale of the trial, the fault was not fully investigated and the fault area was bypassed by using a magnetic alignment technique.
- (b) An intermittent fault in the roll cut-out circuit occasionally allowed the Tony Doppler to remain locked on even though 10° bank was being exceeded.
- (c) The scaling of the Y integrator F.M.A. (Fix monitored azimuth) correction within the I.R.S. was found to be in error. This was due to a slight change in the value of a resistor within the I.R.S. The fault was bypassed by a computer program modification.

12. Trials Results

The results obtained are discussed in the paras. below and are given in tabular form in Appendices D and E. The analysis proved to be far more tedious than had been visualised. The major problem in comparison of air and ground velocity plots is to ensure the velocities are measured with respect to the same axes. Hence the precautions taken to assess platform misalignment at the time of manoeuvre. Initial analysis suggested that there was a discrepancy between the datum used for platform heading and the alignment of the accelerometer axes, and further analysis was hence necessary. Difficulties were encountered with noise on the Aberporth recording estimated at 2.5 ft./sec.

12.1. Scaling and Azimuth Errors - D/I Mix Phase

12.1.1. The high rate of recording allowed a reasonable number of samples of D/I Mix system velocities to be compared with range

/velocities in ...

velocities in the period from manoeuvre start to doppler cut-out (i.e. 10° bank or pitch as appropriate). Such comparisons provided a measure of the scaling and azimuth errors in the D/I Mix loop (i.e. the system errors). Results are given in Appendix D.

12.1.2. The results show there was a track error in the navigation system which was considerably bigger than the error in the platform heading output indicated by the astro check. The mean value of the discrepancy was 31 mins. of arc. This tends to support the evidence of an error in platform heading read out (para. 9.3.(a)) but this cannot be verified. In any case this would not account for all the error.

12.2. Scaling and Azimuth Errors - Pure Inertial Phase

12.2.1. Initial Analysis

The astro heading checks indicated that platform misalignment at the time of manoeuvre was small. A rotational correction equal to the I.R.S. transport angle (β) was applied to the range velocities, and a first comparison with inertial velocities made. The form of the X and Y channel error plots pointed to either desynchronisation between ground and air recordings or an uncorrected accelerometer axes misalignment. Desynchronisation was rejected as comparison of Z channel velocities was satisfactory.

12.2.2. Further Analysis

Further analysis was undertaken by the Elliott trials team to confirm the evidence of accelerometer axes misalignment. Comparisons of velocities were made in the computer with various values of axis rotation and assumed scale factor errors until the residual error plot was reduced to zero.

Appendix E details the apparent axes misalignment, i.e. the rotation (additional to β), and the scale factor that was required to reduce the error plot to zero. The misalignments found were consistent for a particular sortie, but not for the two sorties (-25, +25 mins. arc). The discrepancy found in the D/I Mix phase was -31 mins. arc.

The X and Y scale factor errors were found to be 2.1% and 0.8%. Due to the smaller velocity range experienced in the Z channel, coupled with 'noise' in the datum information it was more difficult to measure its scale factor. Where possible the performance of the Z channel has been presented in the form of velocity 'drift' (ft./sec.²), from the datum velocity. The 'drifts' measured varied between maximums of ± 0.05 ft./sec.².

The analysis took 3 months to complete but other factors which influenced the time scale were a 50% cut in the Elliott trials team, and errors found in the Aberporth data tapes. The range reproduced two additional sets of data tape before satisfactory analysis could proceed. At Aberporth, the basic FPS 16 radar information is produced on Hollerith cards; although the range was able to transfer the data to teleprinter tape form (for 920 compatibility) they possess no 'play-back' facilities to check the accuracy of the copy tape.

13. Conclusions

13.1. Tony Doppler

(a) In general, Tony Doppler performance was very satisfactory, the 820 ohm value for the drift time constant resistor being proved suitable for the Comet environment.

/(b) In straight ...

(b) In straight and level flight over land and received signal to noise ratios were satisfactory, but 6dB down on theoretical design values. With 11° of bank at 40,000 ft. over land the signal to noise ratio was 3.5 dB over the trip level. Over a fairly calm sea in similar conditions of flight it is probable that the doppler signal to noise trip would be actuated.

(c) There was a good margin of signal in hand at 250 ft. and it can be concluded that the equipment would have tracked satisfactorily at lower altitudes.

(d) The accuracy of Tony Doppler distance gone at low level, assessed over 5 legs of 100 n.m's. was +.15%.

13.2. Inertial Reference System

(a) The trial revealed some disconcerting azimuth anomalies within the I.R.S. type 200. There was an inconsistent difference between the apparent alignment of the accelerometer axes and the datum used for platform heading.

(b) The X and Y channel velocity errors, i.e. 2.1% and 0.6% respectively, were outside specification. Difficulties were experienced in assessing the Z channel due to noise in the range data. There was however no significant scale factor error, i.e. > 2% in that channel.

13.3. General

The ability of the 920 Digital Computer to cope with the variety of tasks undertaken, showed its value as an airborne data recording and analysis aid.

14. Recommendations

The following recommendations are made from the results of these flight trials:-

Tony Doppler

Further flight trials are required to check the performance of Tony Doppler in those areas which have not yet been investigated, e.g. performance and accuracy checks over sea.

Inertial Reference System

No direct recommendation is made with respect to the I.R.S. type 200 as development work on this inertial system has been cancelled. However, the azimuth errors found emphasise the need for all internal components of an inertial system to be aligned with the greatest care to a common datum.

Equations used in '920' Doppler Analysis Program

1. Mean Groundspeed Difference ($\bar{V}$)

This represents the mean difference between doppler and inertial groundspeed. It should ideally be zero, or at least very small when measured over a period of time. This was calculated from:-

$$\bar{V} = \frac{1}{N} \sum \left[V_D - (V_x^2 + V_y^2)^{\frac{1}{2}} \right] \text{ft./sec.}$$

$$\text{where } V_x = V_{Ix} - RW \cos \lambda \cos \beta$$

$$V_y = V_{Iy} - RW \cos \lambda \sin \beta$$

$$N = \text{No. of } 1/10\text{th second samples}$$

$$R = \text{Effective radius of the Earth}$$

$$W = \text{Angular velocity of the Earth}$$

2. Mean Drift Angle Difference ($\bar{\delta}$)

This represents the mean difference between doppler and inertial measurements of drift angle. As with groundspeed, the mean difference over a period should be small and is calculated from:-

$$\bar{\delta} = \frac{1}{N} \sum \left[\delta_D - (\psi_p - \tan^{-1} \frac{V_x}{V_y}) \right] \text{degrees}$$

$$\text{where } \delta_D = \text{Doppler drift}$$

$$\psi_p = \text{Platform heading}$$

The calculation does not provide an absolute measure of doppler drift error as platform misalignment is included in the term

$$(\psi_p - \tan^{-1} \frac{V_x}{V_y})$$

3. Doppler Groundspeed Noise (η_v)

Measurement of groundspeed noise or fluctuation in groundspeed output provides one figure of reference for use in the optimisation of a doppler/inertial mixed navigation system.

This fluctuation is conveniently expressed by the standard deviation of the instantaneous groundspeed about the mean i.e.

$$(\eta_v)^2 = \frac{\sum}{N} \left[\bar{V}_D - V_D \right]^2$$

The results table at Appendix 'B' shows this fluctuation expressed as a percentage of groundspeed.

4. Drift Noise (η_p)

During development and testing of the Tony Doppler by R.R.T. and A. & A.E.E. the rate feed back resistor in the drift servo has been subject to change in value in an attempt to optimise drift oscillation of the aerial. For the purposes of this trial, however, the resistor was fixed at the now accepted 820 ohm value throughout.

/The following ...

Appendix 'A' (Cont'd)

The following calculation was performed to provide a measure of drift oscillation:-

$$\eta_D^2 = \frac{\Sigma}{N} \left[\frac{\delta_D}{\Delta_1} - \Delta_1 \right]^2$$

where $\Delta_1 = \delta_D - \left(\psi_p - \tan^{-1} \frac{V_x}{V_y} \right)$

The standard deviation of the drift noise (η_D) has been calculated above from the deviations in the doppler drift angle from the drift angle defined by the inertial velocities. The value of η_D provides a good estimate of the accuracy in an instantaneous reading of doppler drift, as platform misalignment does not affect the calculation.

Appendix B to
Tech. Memo. 2/65

Table of Results - Tony Doppler Performance

Run No.	Height (feet)	Junk Angle (Degrees)	Signal Noise Ratio (dB)	Mean Groundspeed Doppler-Inertial (Kts)	Mean Drift Angle Diff. Doppler-Inertial (Degrees)	Groundspeed Noise			S.D. Drift Noise (Degrees)	Remarks
						S.D. Noise (Kts)	Ground-speed	% Noise		
1	250	0	34	+68	+0.549	2.32	167	1.39	0.545	
2	800	0	36	+71	+0.757	2.00	189	1.06	0.408	
3	15,000	0	31	-1.04	+0.250	1.86	316	0.59	0.246	
4	15,000	0	28	+0.63	+0.418	1.92	320	0.60	0.283	
5	15,000	16	12	-8.50	+0.198	1.74	328	0.53	0.436	Roll Limit Switch Bypassed
6	30,000	0	26	+0.09	+0.321	1.58	431	0.37	0.191	
7	30,000	0	26	+1.22	+0.443	1.68	401	0.42	0.178	
8	40,000	0	18	-0.23	+0.319	1.48	381	0.39	0.217	Over-sea. Beaufort Wind Force 4. 5-6 ft. waves
9	40,000	0	22	+0.37	+0.263	1.44	428	0.34	0.184	
10	40,000	11	9.5	-1.00	+0.098	1.60	395	0.40	0.344	Roll Limit Switch and sig/noise trip bypassed
11	40,000	20	Not Measurable	+0.71	+0.788	1.70	390	0.44	0.490	"
12	40,000	30	No signal Detectable	-5.50	-0.123	1.74	388	0.45	5.211	"

Tony Doppler Distance Gone Accuracy

1. The table below shows the results obtained on the flight used to assess Tony Doppler distance gone accuracy.

Run No.	Date	Route Direction	Mean Ht AGL (feet)	Dist. Gone % Error
1	6th April 1965	Boscombe - Hartland Pt.	500	+.15
2	"	Hartland Pt. - Boscombe	500	+.18
3	"	Boscombe - Hartland Pt.	250	+.23

from which $\bar{\epsilon} = +.17\%$

Aberporth Sorties Analysis

Scaling and Azimuth Errors of D/I Mix Loop

1. The table below shows the scaling and azimuth errors found in the D/I mix loop, as estimated from initial velocity errors w.r.t. range.

		(1)	(2)	(3)	
Date	Run No.	D/I Mix Scaling Error %	D/I Mix Azimuth Error (Mins)	Platform Heading Error (Mins)	Discrepancy between Platform Heading Error and D/I AZ error (Mins)
30.3.65.	1	+.32	-31	+6	-37
"	2	+.68	-43	+1	-44
"	3	+.55	-44	-1	-43
"	4	+.50	-47	+3	-50
31.3.65.	1	+.85	-28	-10	-18
"	2	+.86	-41	-19	-22
"	3	+.49	-48	-18	-30
"	4	+1.07	-55	-13	-42

Notes:-

(1) A positive scaling error implies that the velocities in the nav. system were greater than the reference.

(2) A negative value for the azimuth error implies that the doppler velocity was resolved about a track angle less than the reference.

(3) A positive platform heading error indicates that the heading output of the navigation system was greater than the astro heading. The quoted results were found from the mean of two astro runs made immediately before and after the range, on reciprocal headings.

Aberporth Sorties Analysis

Scaling and Azimuth Errors - Pure Inertial Phase

1. Horizontal Channels

The table below shows the misalignment of the accelerometer axes, and X and Y channel scale factor errors deduced from the pattern of inertial - range errors over the period of pure inertial navigation on the range:-

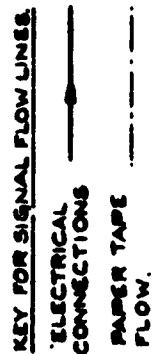
Date	Run No.	Manoeuvre	X Channel Error %	Y Channel Error %	Accelerometer Axes Misalignment (Mins)	Platform Heading Errors (Mins)	Discrepancy between Accel. Axes and Platform Heading
30.3.65.	1	45° Turn	-2.9	-1.3	-23	+6	-29
"	2	30° Turn	-2.0	-0.7	-23	+1	-24
"	3	15° Turn	-2.1	-0.7	-23	-1	-22
31.3.65.	1	45° Turn	-2.1	-0.6	+9	-10	+19
"	2	30° Turn	-2.1	-	+9	-19	+28
"	3	15° Turn	-2.1	-0.6	+9	-18	+27

2. Vertical Channel

The table below shows the performance of the vertical channel in terms of its 'drift' from the datum range velocity. Where no result is quoted the range data was too noisy for an assessment to be made.

Date	Run No.	Manoeuvre	Drift (ft/sec ²)	Date	Run No.	Manoeuvre	Drift (ft/sec ²)
30.3.65.	1	45° Turn	-	31.3.65.	1	45° Turn	+0.03
"	2	30° Turn	+0.05	"	2	30° Turn	+0.03
"	3	15° Turn	-0.01	"	3	15° Turn	0
"	4	Max Rate Climb	-0.05	"	4	Max Rate Climb	-

MCS 920 TRIAL - SCHEMATIC OF TRIALS INSTALLATION.



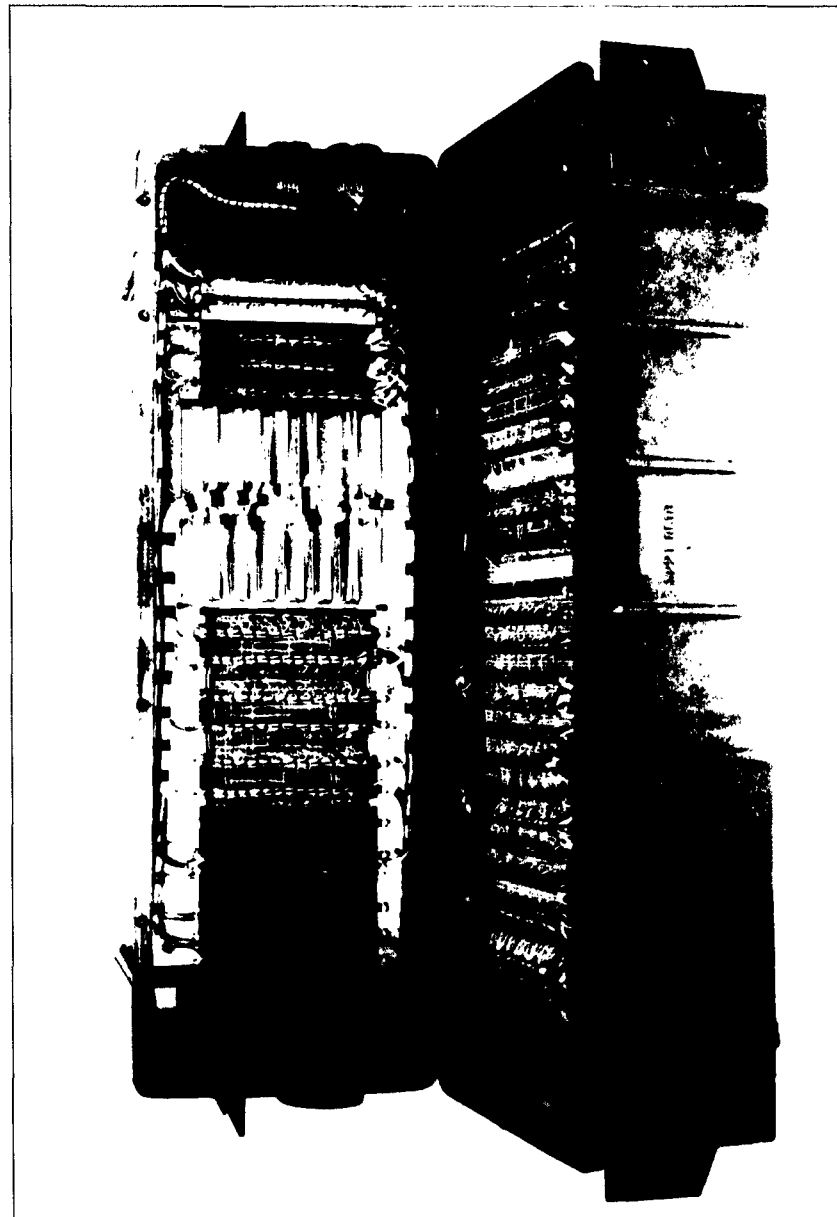


FIG. 2. M.C.S. 920 - INTERNAL ELEMENTS.

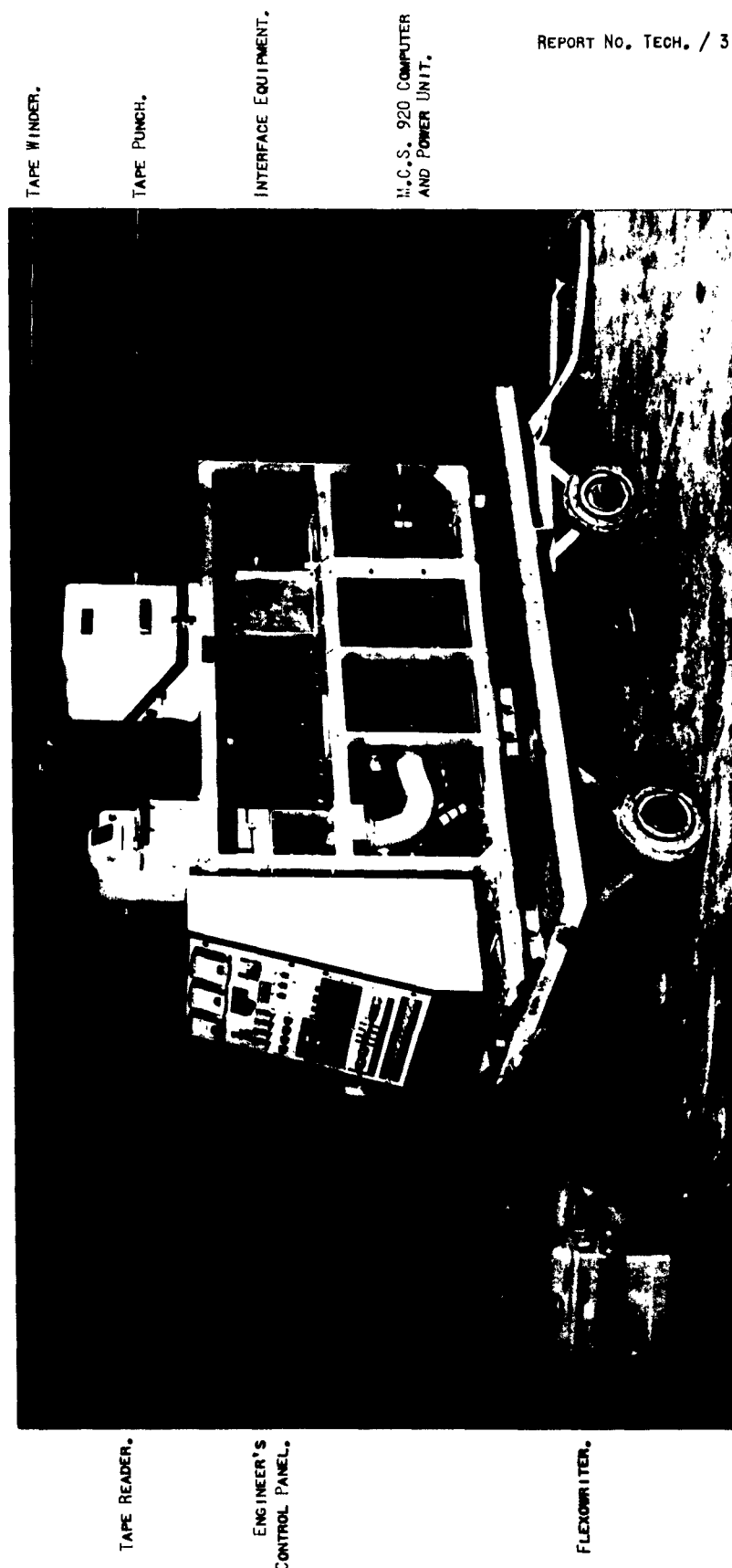


FIG. 3. M.C.S. 920 EQUIPMENT PRIOR TO INSTALLATION.

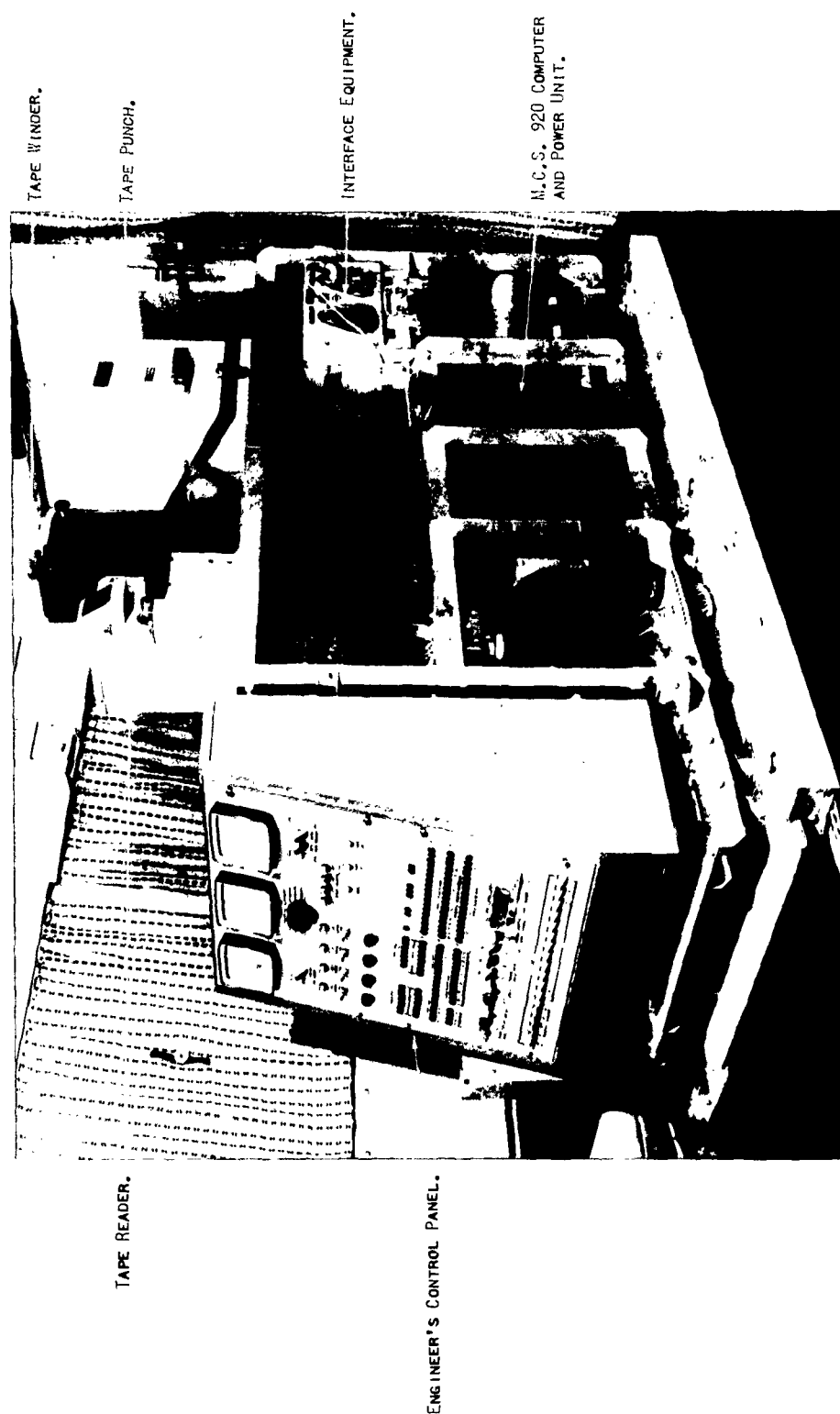


FIG. 4. M.C.S. 920 INSTALLED IN COMET AIRCRAFT.

FIG. 5

Date 30 Mar 65

Run No. 1

ABERPORTH QUICK-LOOKA/C LANDED:- 1734Z
PRINT OUT :- 1815Z

	Time	Vex	Vey	Vez
+0				
+	510.4 +		275.2 +	819.2
+5				
+	540.8 +		312.0 +	822.4
+10				
+	534.4 +		310.4 +	836.8
+15				
+	481.6 +		240.0 +	841.6
+20				
+	425.6 +		124.8 +	824.0

DOPPLER TEST QUICK-LOOK

1 Apr 65

A/C LANDED:- 1610Z
PRINT OUT :- 1705Z

	RUN 1; $\dot{x}_p$ (includes Earth Rate)	LOW LEVEL; S & L $\dot{y}_p$	1306 30 $\dot{\psi}_p$	V_D	Drift
+0					
+	1243.2 +	120.0 +	68.751 +	307.4 -	1.812
+5					
+	1249.6 +	123.2 +	69.102 +	316.0 -	1.637
+10					
+	1257.6 +	121.6 +	69.608 +	323.2 -	1.307
+15					
+	1256.0 +	120.0 +	69.651 +	313.2 -	1.549
+20					
+	1249.6 +	116.8 +	69.124 +	313.2 -	0.362

FIX PRINT-OUTDATE: 6/4/65 FLIGHT NO.
920/10A/C LANDED:- 1530Z
PRINT OUT :- 1555Z

Mode

C.P. No.	Time	F.M.A.	Lat. Error	Long. Error
Red	Green	Purple	D/I Error X	D/I Error Y

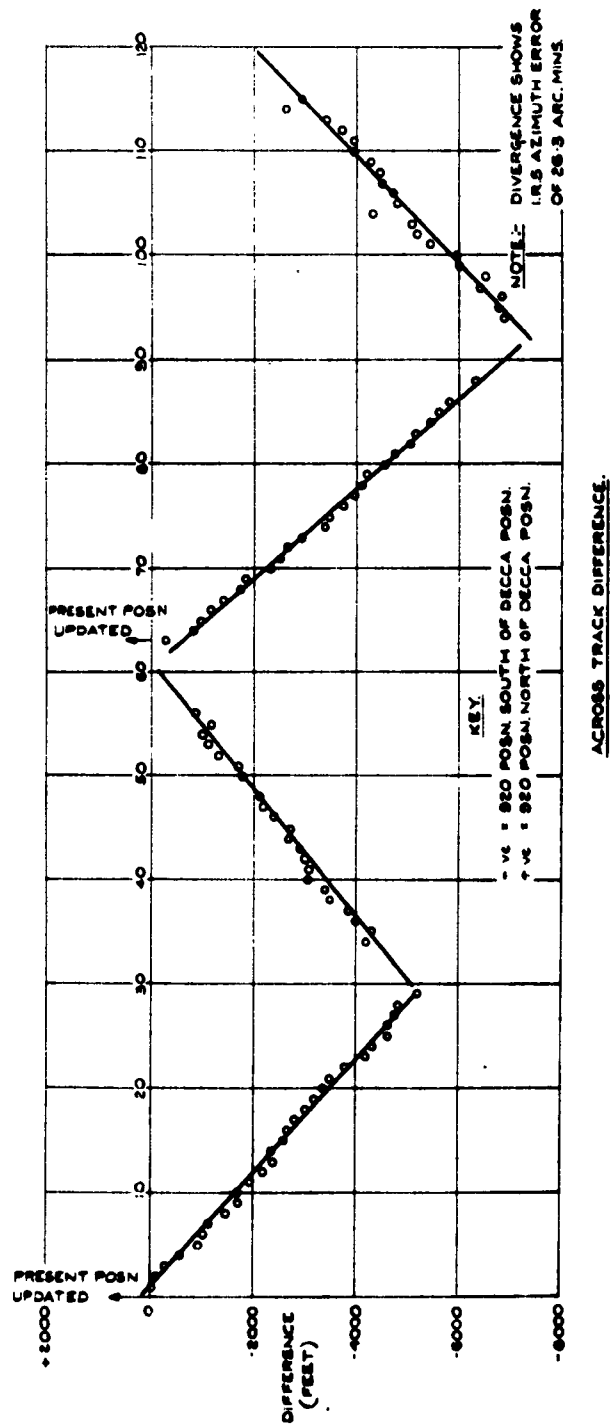
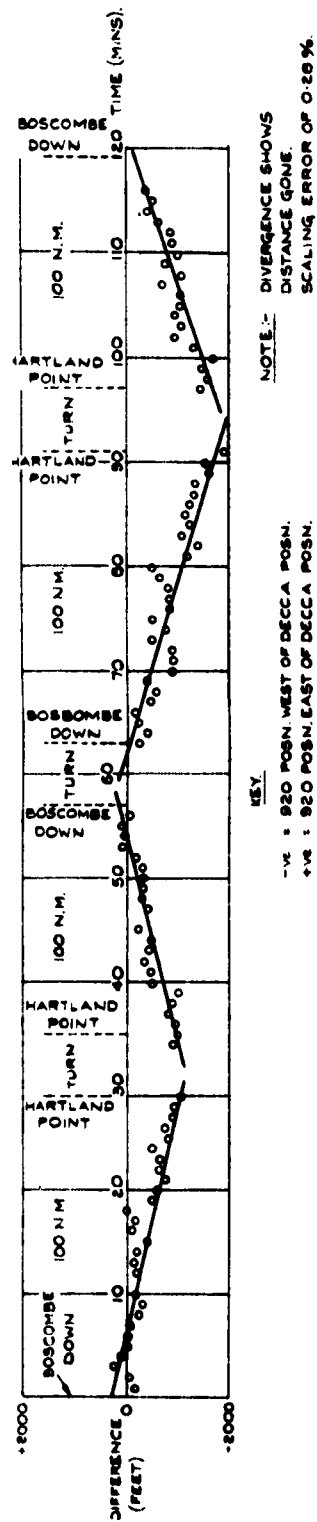
Latitude

Longitude

Drift	B	Plat. Hdg.	Standby Hdg.	
x	y	dx/dt	dy/dt	Track

-484
+0 +31 + 0 0.0 +1046 +105
+0.000 +17.965 +23.437 -0.562 -3.398
+ 51 9.781
- 1 44.042
+ 0 36.3 - 0 0.1 + 49 21.7 + 48 39.9
+0.000 +0.000 +0 +0 +49 30.9

FIGURE 5. EXAMPLES OF QUICK-LOOK DATA



**DIFFERENCES BETWEEN DECCA DATUM POSN. AND
MCS 920 COMPUTED POSN.-LOW LEVEL NAVIGATION.**

FIG. 6.

DETACHABLE ABSTRACT CARDS

These abstract cards are inserted in Reports for the convenience of Librarians and others who need to maintain an Information Index.

RESTRICTED Report No. AAE/Tech/318/Nav. AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT Flt. Lt. I. K. St.C. Bartley, R.A.F. ELLIOTT MCS 920 DIGITAL COMPUTER TRIAL Results are given of flight trials to demonstrate the navigational capability of the MCS 920 computer, and of an investigation into the programming and compatibility problems involved in using the computer for flight testing navigation and radio equipment. It is concluded that the computer can perform navigational tasks rapidly, reliably and accurately; it is reasonably easy to program and is compatible with existing A. & A.E.E. services. The MCS 920 would be a valuable addition to the flight trials resources of A. & A.E.E.	RESTRICTED Report No. AAE/Tech/318/Nav. AEROPLANE AND ARMAMENT EXPERIMENTAL ESTABLISHMENT Flt. Lt. I. K. St.C. Bartley, R.A.F. ELLIOTT MCS 920 DIGITAL COMPUTER TRIAL Results are given of flight trials to demonstrate the navigational capability of the MCS 920 computer, and of an investigation into the programming and compatibility problems involved in using the computer for flight testing navigation and radio equipment. It is concluded that the computer can perform navigational tasks rapidly, reliably and accurately; it is reasonably easy to program and is compatible with existing A. & A.E.E. services. The MCS 920 would be a valuable addition to the flight trials resources of A. & A.E.E.
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[dstl] Porton Down,
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Tel: 01980 613753
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8725 John J. Kingman Road, Suit 0944
Fort Belvoir, VA 22060-6218
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