US ARMY TEST & EVALUATION COMMAND

FINAL
REPORT OF
MILITARY POTENTIAL TEST OF A
DOPPLER NAVIGATOR IN A FIXED-WING AIRCRAFT

DA PROJECT NO. 1G641203D526

USATECOM PROJECT NO. 4-4-4305-01

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US ARMY
AVIATION TEST BOARD
FORT RUCKER, ALABAMA

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UNITED STATES ARMY AVIATION TEST BOARD
Fort Rucker, Alabama 36362

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Raymond E Johnson
for A. J. RANKIN
Colonel, Armor
President

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ABSTRACT

The Military Potential Test of a Doppler Navigator in a Fixed-Wing Aircraft was conducted by USAAVNTBD personnel in the vicinity of Fort Rucker, Alabama, and Tampa, Florida, during the period 22 February - 12 June 1964. The test item's weight, power requirements, accuracy, repeatability, and reliability did not meet the requirements of the MC's and SCL 5953. The test item was not suitable for tactical use and was marginally acceptable from a human factors standpoint. It was concluded that the test item is not suitable for Army use and recommended that the test item be given no further consideration for Army use.

To P. 3

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UNITED STATES ARMY AVIATION TEST BOARD
Fort Rucker, Alabama 36362

FINAL

REPORT OF

MILITARY POTENTIAL TEST OF A DOPPLER NAVIGATOR IN A FIXED-WING AIRCRAFT

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SECTION 1 - GENERAL

1.1. REFERENCES.

1. Military Characteristics for Lightweight, Self-Contained Navigator, as recorded at SCTC Meeting, No. 599CS, Item 4731, 31 August 1959.

2. US Department of Commerce Coast and Geodetic Survey Bearing and Distance Tables VOR/TACAN, 2nd Edition, October 1959, as changed.

3. US Army Electronic Research and Development Laboratories Technical Requirements SCL 5953, subject: "Light Weight Airborne Doppler Navigator," 10 May 1963 (Classified).

4. Combat Developments Objectives Guide, paragraphs 533c(5) and 533c(6), revised 16 July 1963.

5. Report of Test, USATECOM Project No. 4-3-3600-01-G, "Military Potential Test (Comparative Evaluation) of Doppler Navigation Systems," US Army Aviation Test Board, 2 October 1963.

6. Letter, AMSTE-BG, Headquarters, US Army Test and Evaluation Command, 26 October 1963, subject: "Directive for Military Potential Test of LFE Doppler Navigator, USATECOM Project No. 4-4-4305-01-A."

7. Letter, AMSTE-BG, Headquarters, US Army Test and Evaluation Command, 19 December 1963, subject: "Directive for Participation in Military Potential Test of LFE Doppler Navigator, USATECOM Project No. 4-4-4305."

8. Letter, STEBG-TPD, US Army Aviation Test Board, 13 December 1963, subject: 'Military Potential Test of LFE Doppler Navigaotr, USATECOM Project No. 4-4-4305-01-A," with 1st Indorsement, SMOSM-ECCV-2, US Army Aviation and Surface Materiel Command, 31 December 1963.

9. Report of Test, USATECOM Project No. 4-4-3600-( )-G, "Military Potential Test (Comparative Evaluation) of Doppler Navigation Systems," US Army Aviation Test Board, 6 January 1964.

10. Letter, AMSTE-BG, Headquarters, US Army Test and Evaluation Command, 29 January 1964, subject: "Military Potential Test of LFE Doppler Navigator, USATECOM Project No. 4-4-4305."

1.2. AUTHORITY.

1.2.1. Directive.

Letter, AMSTE-BG, Headquarters, US Army Test and Evaluation Command, 26 October 1963, subject: "Directive for Military Potential Test of LFE Doppler Navigator, USATECOM Project No. 4-4-4305-01-A."

1.2.2. Purpose.

To determine the suitability of the Test Doppler Navigator:

a. In fixed-wing aircraft.

b. For possible use in Southeast Asia.

1.3. OBJECTIVES.

To determine the:

a. Physical characteristics.

b. Installation requirements.

c. Operational characteristics.

d. Reliability during the test period.

e. Tactical suitability.

f. Personnel requirements.

g. Maintenance requirements.

h. Human engineering characteristics.

1.4. RESPONSIBILITIES.

The US Army Aviation Test Board (USAAVNTBD) had sole responsibility for conducting and reporting on the Military Potential Test.

1.5. DESCRIPTION OF MATERIEL.

1.5.1. The test Doppler navigator is a three-beam, interrupted-CW system operating at 13,325 megacycles. It provides point-to-point navigation from a known base to any number of destinations without use of ground-based navigation aids or visual reference to the ground.

1.5.2. The system consists of a receiver-transmitter unit with attached antenna, a frequency-converter tracker, a high-voltage power supply, and a navigation computer with necessary controls and read-out instruments. (See figure 1.)

1.6. BACKGROUND.

1.6.1. The USAAVNTBD evaluated the test Doppler (less the MINAC-6 computers) in a CH-21 Helicopter for Advance Research Projects Agency (ARPA), Department of Defense, under USATECOM Project No. 4-3-3600-01-G. The results of this evaluation were submitted in a report dated 2 October 1963 (reference 5).

1.6.2. After a review of the test results obtained during the rotary-wing evaluation, ARPA determined that further evaluation of the system should be conducted in a fixed-wing aircraft, preferably a CV-2 (Caribou). In addition, ARPA requested that this evaluation be oriented to determine suitability for use in Southeast Asia, as was the rotary-wing evaluation. Upon receipt of the directive to conduct an evaluation of the same equipment in a fixed-wing aircraft, the USAAVNTBD requested and received authority from the US Army Test and Evaluation Command (USATECOM) to include a navigation computer in the evaluation. The navigation computer was subsequently furnished by the manufacturer.

1.6.3. Prior Doppler reports of test (references 5 and 9) have been researched and the following pertinent information considered: system accuracies, weight, power requirements, and human factors.

1.6.4. The equipment was received for test on 22 January 1964.

1.7. FINDINGS.

1.7.1. The weight and power requirements exceeded limitations contained in the Military Characteristics and SCL 5953 (references 1 and 3).

1.7.2. Test item installation presented no unusual problems.

1.7.3. The accuracy and repeatability of the test system did not meet the criteria specified in the Military Characteristics and SCL 5953.

1.7.4. The test item did not meet reliability criteria set forth in SCL 5953.

1.7.5. The system, as tested, was not suitable for Army tactical use.

1.7.6. Operator personnel required 12 hours of training to enable them to operate the system. At present, no maintenance personnel are trained to maintain the test item.

1.7.7. Maintenance support for the test item is not presently available in the Army supply system.

1.7.8. The test item was marginally acceptable from a human factors standpoint.

1.8. CONCLUSION.

The test item is not suitable for Army use.

1.9. RECOMMENDATION.

It is recommended that the test item be given no further consideration for Army use.

SECTION 2 - DETAILS AND RESULTS OF SUB-TESTS

2.0. INTRODUCTION.

The Military Potential Test of a Doppler Navigator in a Fixed-Wing Aircraft was conducted by US Army Aviation Test Board personnel in the vicinity of Fort Rucker, Alabama, and Tampa, Florida, during the period 22 February - 12 June 1964. The test consisted of 47 flights and approximately 35 hours of test item operation. The test item was installed in a CV-2 (Caribou) Airplane, Serial No. 57-3803, and was flown over pre-selected courses. The values for the computer inputs were calculated using data obtained from the Coast and Geodetic Survey Manual (reference 2). Courses were flown repeatedly in both directions at altitudes ranging from the nap of the earth to 10,000 feet. Position readings from the computer control panel were recorded at the various check points and compared with the computed data in order to determine the system accuracy.

2.1. PHYSICAL CHARACTERISTICS.

2.1.1. Objective.

To determine size, weight, and power requirements of the system.

2.1.2. Method.

Each component was weighed and measured. The a.c. and d.c. power requirements were measured and recorded.

2.1.3. Results.

2.1.3.1. Size and weight of the test system components are as follows:

Component	Size (Inches)	Weight
Computer, Navigational	5 7/16 x 7 11/16 x 13 1/2	25 lb. 3 oz.
Plotting Board, Pictorial Display	10 3/16 x 9 1/2 x 3 11/16	10 lb.
Control, Indicator, Computer	5 3/16 x 5 3/4 x 7 11/16	9 lb. 12 1/2 oz.
Converter, Signal Data	6 1/16 x 10 1/8 x 12 7/8	13 lb.

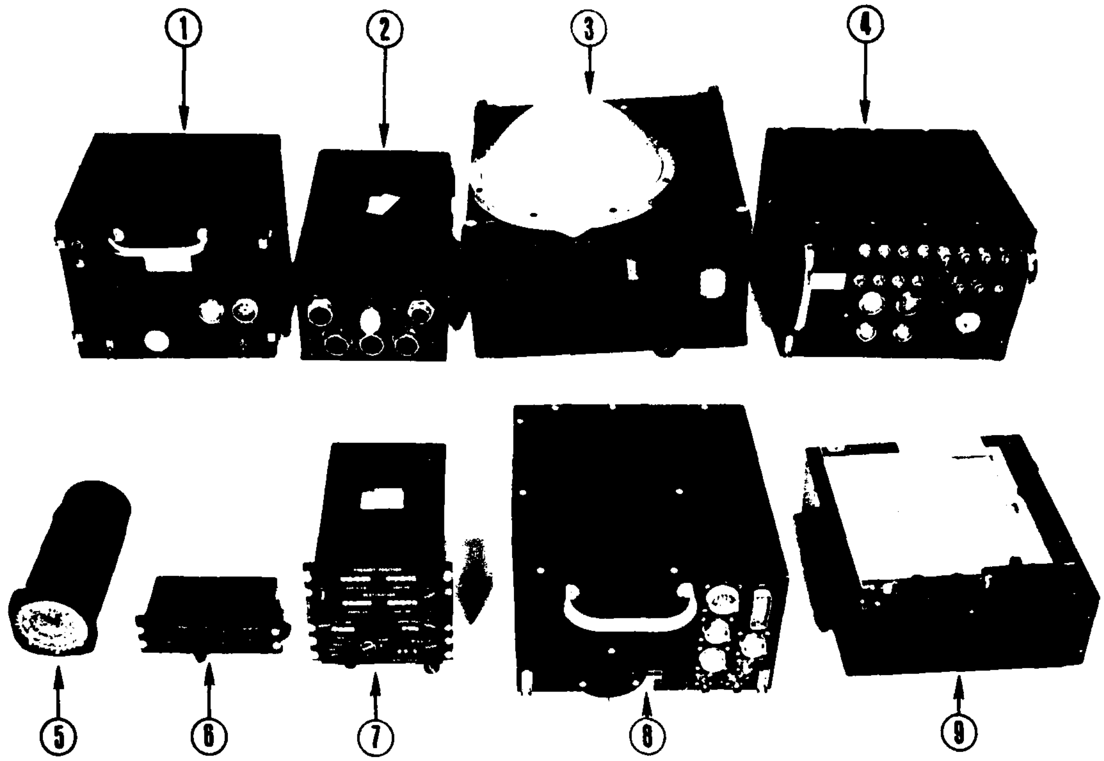

Figure 1. Test Doppler Navigator
Arrow 1: High Voltage Power Supply
Arrow 2: Navigational Computer
Arrow 3: Receiver-Transmitter with Antenna
Arrow 4: Frequency Converter-Tracker
Arrow 5: Bearing Distance Heading Indicator (BDHI)
Arrow 6: Radar Set Control
Arrow 7: Computer Indicator and Control
Arrow 8: Signal Data Converter
Arrow 9: Pictorial Display and Plotting Board

Component	Size (inches)	Weight
Control, Radar Set	1 13/16 x 5 13/16 x 2 9/16	9 1/2 oz.
Bearing, Distance, Heading Indicator	3 15/16 diameter 7 5/16 depth	3 lb. 1 1/2 oz.
Frequency Converter Tracker	7 3/4 x 12 1/16 x 13 1/2	19 lb.
Power Supply, High Voltage	8 x 10 1/8 x 12	20 lb. 1 oz.
Receiver-Transmitter w/Antenna	7 1/4 x 15 1/8 x 14 1/4 4 1/8 (antenna radome)	25 lb. 4 oz.
TOTAL WEIGHT		125 lb. 15 1/2 oz.

2.1.3.2. Power requirements were 1053 volt-amperes at 115 volts, 400-cycle a.c. and 1.5 amperes at 28 volts d.c.

2.1.4. Analysis.

The weight (125 pounds, 15 1/2 ounces) and the power requirements (1053 volt-amperes at 115 volt, 400-cycle a.c. and 1.5 amperes at 28 volts d.c.) of the test item were greater than the other Doppler systems previously tested (references 5 and 9) and exceeded the limitations specified in the Military Characteristics (reference 1) and SCL 5953 (reference 3).

2.2. INSTALLATION REQUIREMENTS.

2.2.1. Objective.

To determine installation time, personnel requirements, and any unusual installation characteristics.

2.2.2. Method.

The test item was installed by USAAVNTBD personnel with technical assistance from the manufacturer and installation time was recorded. One Aviation Electronic Equipment Mechanic, MOS 284.1, and one sheet-metal repairman (civilian) were used. This installation was made solely

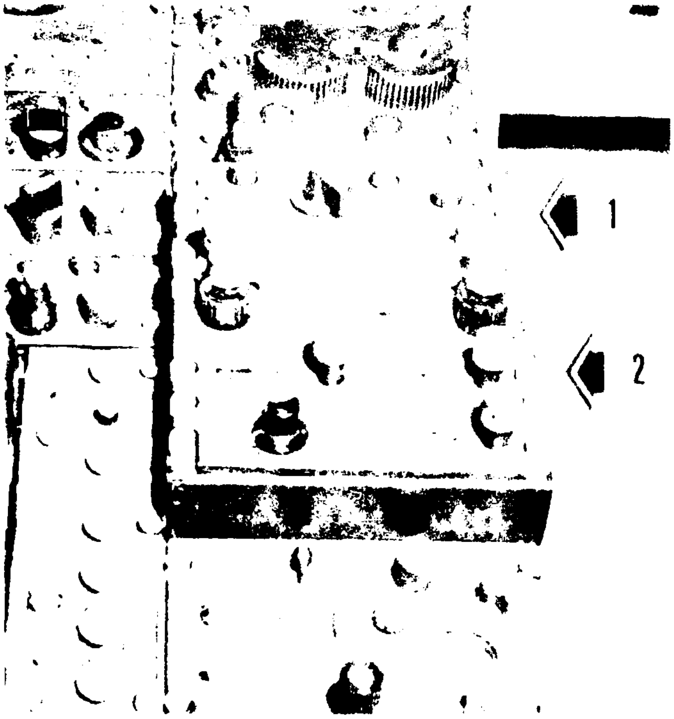

Figure 2. Installation of radar set control (arrow 1) and computer indicator and control (arrow 2).

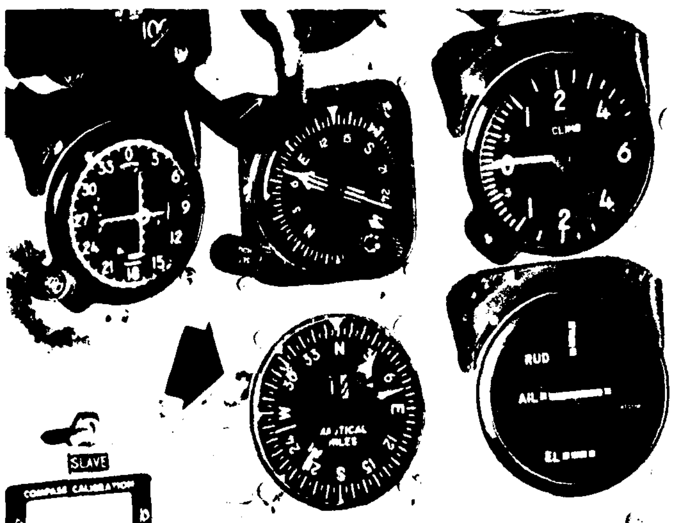

Figure 3. Installation of Bearing Distance Heading Indicator (BDHI).

to facilitate testing of this Doppler system (figures 2 through 6). No detail drawings were made for MWO purposes.

2.2.3. Results.

A total of 679 man-hours was required to complete the installation: 305.5 hours for sheetmetal work and maintenance support; and 373.5 hours for avionics including planning, installation, operational checks, and compass swing (appendix I, part A). No unusual problems were encountered.

2.2.4. Analysis.

Installation time of 679 man-hours and personnel requirements of one Aviation Electronic Equipment Mechanic, MOS 284.1, and one sheet metal repairman were comparable to other electronic installations of this type. No unusual installation characteristics were noted.

2.3. ACCURACY.

2.3.1. Objective.

To determine overall system accuracy.

2.3.2. Method.

Position readout over each computed ground reference point was recorded on 47 flights and compared with the computed data.

2.3.3. Results.

Errors recorded ranged from .05 percent to 4.84 percent and the average error was determined to be 1.69 percent of the distance traveled. (See appendix I, part B.)

2.3.4. Analysis.

The system accuracy of 1.69 percent of the distance traveled (mean error of all flights) failed to meet the accuracy standards established in the Military Characteristics (reference 1) and SCL 5953 (reference 3).

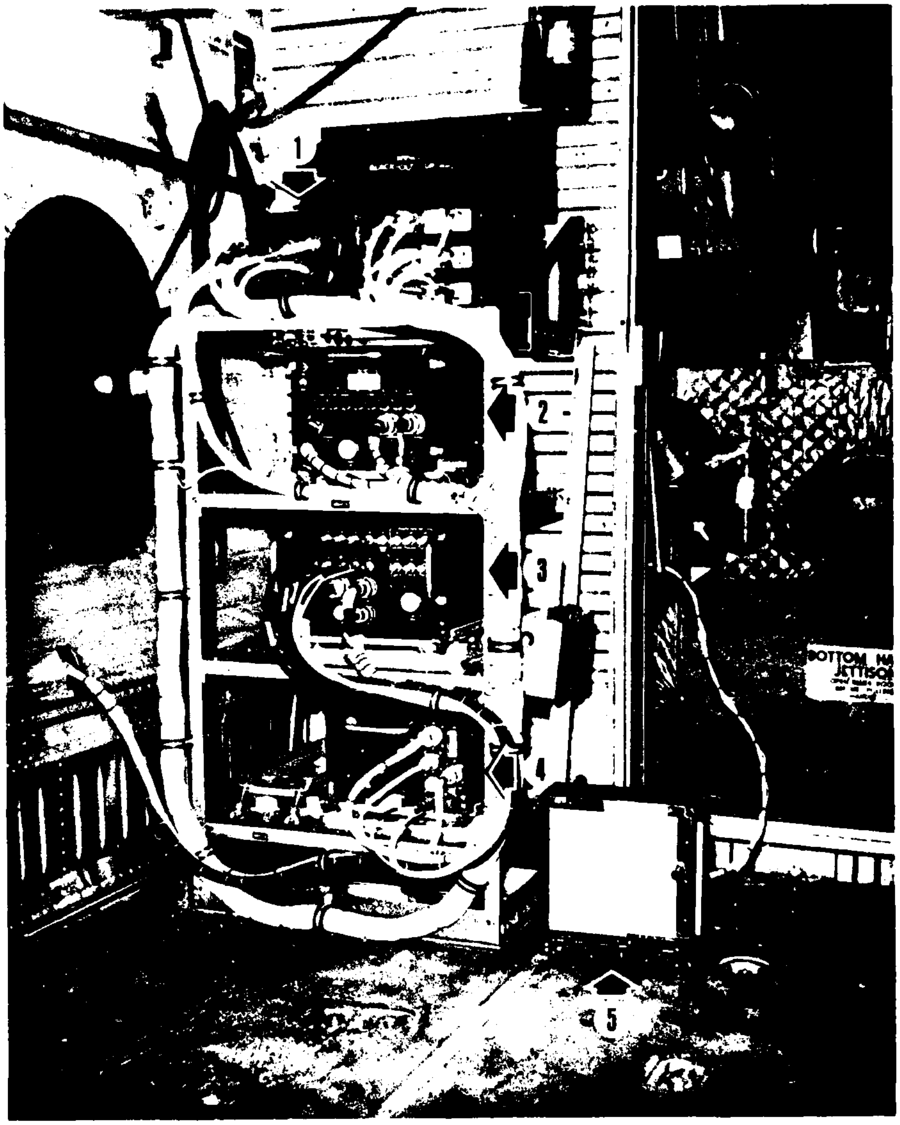

Figure 4. Installation of navigational computer (arrow 1), high voltage power supply (arrow 2), frequency converter-tracker (arrow 3), signal data converter (arrow 4), and pictorial display and plotting board (arrow 5).

Figure 5. Pictorial display and plotting board, mounted behind pilot's seat.

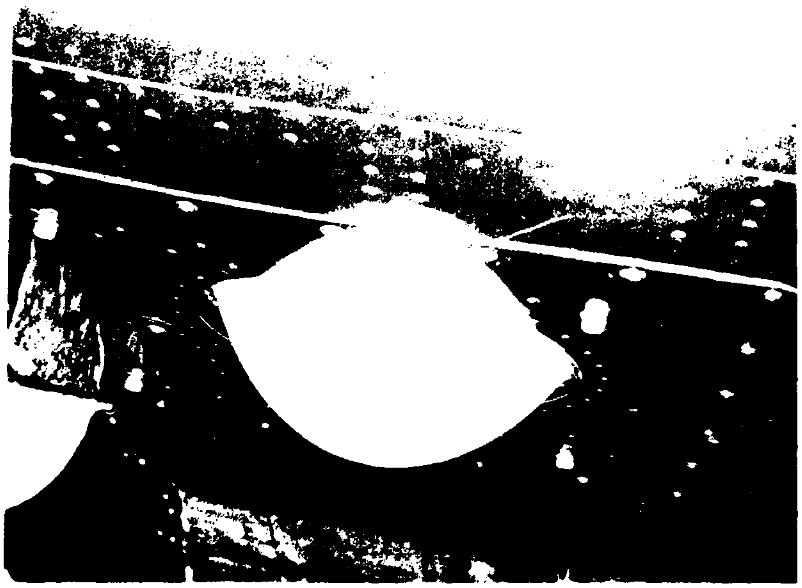

Figure 6. Installation of antenna radome on underside of fuselage.

2.4. OVERWATER AND WIND-MEMORY OPERATION.

2.4.1. Objective.

To determine system accuracy during overwater flights and during wind-memory operation.

2.4.2. Method.

The test system was flown over water with a sea state of Beaufort 2 for a distance of approximately 100 kilometers during a flight of 191.3 kilometers and the data recorded.

2.4.3. Results.

2.4.3.1. The distance-traveled error for the overwater flight was 1.57 percent. (See appendix I, part B.)

2.4.3.2. Wind-memory operation could not be tested because the true-airspeed transducer was not compatible with the MINAC-6 computer due to conflicting scale factors.

2.4.4. Analysis.

System accuracy of 1.57 percent for the overwater flight was comparable to the overall system accuracy of 1.69 percent, both of which failed to meet accuracy criteria established in the Military Characteristics (reference 1) and SCL 5953 (reference 3).

2.5. REPEATABILITY.

2.5.1. Objective.

To determine the test system's ability to repeat identical readouts over the same courses.

2.5.2. Method.

The test system was flown over pre-selected courses and position errors were recorded. The flights varied from 78.5 kilometers to 148.5 kilometers at altitudes from nap-of-the-earth to 10,000 feet. These flights were graphed and analyzed (figures 7 through 16). In addition, all flights were reduced to a common base of 100 kilometers and graphed (figure 18). Distance errors were reduced and positioned proportionately.

2.5.3. Results.

The test system's ability to repeat identical readouts over the same courses varied extensively as shown in appendix I, part B.

2.5.4. Analysis.

Repeatability of the system was unacceptable because of the wide dispersion of the flights as shown in figures 7 through 16 and position errors that ranged from .05 percent to 4.85 percent.

2.6. COMPATIBILITY.

2.6.1. Objective.

To determine the test system's compatibility with other installed avionics equipment.

2.6.2. Method.

The test system was operated simultaneously with other installed avionics equipment.

2.6.3. Results.

No interference or adverse effects were noted between the test item and the other installed avionics equipment.

2.6.4. Analysis.

Not applicable.

2.7. RELIABILITY.

2.7.1. Objective.

To determine reliability of the test item during the test period.

2.7.2. Method.

Operation time, number of failures, and repair time of the test item during the test period were recorded and analyzed.

2.7.3. Results.

2.7.3.1. The system was operated a total of 148 hours, including calibration, check flights, and bench time.

2.7.3.2. Following is a list of failures, corrective actions taken, and man-hours required for repair.

Date	Failure	Corrective Action	Man-hours
17 Mar 64	Magnetic variation counter failed to drive.	Replaced counter.	1:00
27 Mar 64	Bearing distance heading indicator-relative bearing indicator inoperative.	Replaced servo amplifier in computer course angle and distance module.	1:00
13 Apr 64	Wind speed and direction readout unreliable.	True airspeed transducer scale factor found to be incompatible with MINAC-6 computer. Wind synchro transmitter placed in locked position at 137 knots (average cruise speed).	1:30
16 Apr 64	Computer inoperative, no integration.	Repaired cold solder joint on "A" integrator circuit.	1:30
20 Apr 64	Bearing distance and heading indicator No. 2 needle inoperative.	Repaired broken wire in aircraft interconnecting wiring.	1:00
30 Apr 64	Doppler radar inoperative.	Replaced preamplifier.	1:00
2 Jun 64	Doppler errors excessively large at higher aircraft altitudes.	Replaced 51 megacycle driver board in antenna unit.	1:15

Date	Failure	Corrective Action	Man-hours
8 Jun 64	East-West present position counter inoperative.	Replaced East-West counter in computer control indicator.	0:30
9 Jun 64	Doppler inoperative, no integration.	Replaced input amplifier in signal data converter unit.	0:30

2.7.4. Analysis.

The test item failed to meet maintenance reliability criteria established in the MC's and SCL 5953 because of the ratio of operating time to maintenance time and component failures.

2.8. TACTICAL SUITABILITY.

2.8.1. Objective.

To determine tactical suitability.

2.8.2. Method.

Simulated tactical missions were planned and flown at altitudes from the nap of the earth to 10,000 feet over computed courses and the following data recorded:

a. Mission planning time using crews with varying degrees of experience and operating with various types of maps and charts.

b. Doppler warm-up time.

c. Total system reaction time.

d. Accuracy during the simulated tactical missions.

2.8.3. Results.

Mission planning time varied from one to three hours depending upon type of maps used, method of programming the computer, and degree of training of aircraft crew. Doppler warm-up time was approximately one minute. Total reaction time varied from 2 to 10 minuted depending upon the amount of data inserted into the computer. Position errors ranged from .05 percent to 4.85 percent. (See appendix I, part B.)

2.8.4. Analysis.

Planning time, equipment warm-up time, and total reaction time were acceptable. Position errors ranging from .05 percent to 4.85 percent were unacceptable when considering point-to-point navigation required for tactical missions such as personnel drops and resupply of isolated units during night and all-weather operations.

2.9. TRAINING.

2.9.1. Objective.

To determine training requirements for operator and maintenance personnel.

2.9.2. Method.

Manufacturer's operating and maintenance instructions were reviewed to determine training requirements.

2.9.3. Results.

2.9.3.1. It was determined that a minimum of 12 hours was necessary to train operators in the use of the test item. This training included familiarization with equipment, dead-reckoning navigation, determination of geographical coordinates from maps or charts, and determination of trigonometric functions, using a slide rule or published tables. (See appendix I, part C.)

2.9.3.2. It was determined that an Aviation Electronic Equipment Mechanic, MOS 284.1, would require a minimum of 16 hours of classroom instruction and 24 hours of on-the-job training in order to perform organizational maintenance. Extensive formal training would be required to train an Aviation Electronic Equipment Repairman, MOS 284.2, to perform third echelon or higher maintenance.

2.9.4. Analysis.

Training requirements for operator and maintenance personnel was compared with those previously established in other Doppler tests (references 5 and 9) and found to be essentially the same.

2.10. MAINTENANCE REQUIREMENTS.

2.10.1. Objective.

To determine how well the test item conformed to the present Army maintenance and support system.

2.10.2. Method.

Maintenance and repair of the test item was performed by the manufacturer's representatives. Each maintenance operation was observed, recorded, and evaluated by avionics maintenance personnel using AR 750-6 as a guide.

2.10.3. Results.

2.10.3.1. Maintenance package. No maintenance package was furnished. The manufacturer performed all maintenance during the test period.

2.10.3.2. Standardization of parts. The major components and subassemblies were not in the Army supply system. They were peculiar to the test item which was not standardized Army equipment.

2.10.3.3. Ease of maintenance. Modular construction and the availability of test points facilitated troubleshooting and maintenance.

2.10.3.4. Adequacy of tools available. The TK-87/U and TK-88/U Tool Equipment Sets commonly found at second, third, and fourth echelon levels were adequate when supplemented by a printed circuit repair kit.

2.10.3.5. Test equipment. Standard organizational test equipment was adequate for organizational maintenance. Special test and support equipment not available in Army supply channels would be required to maintain the Doppler navigation system. The following test equipment would be required for field and depot maintenance:

a. Bench test kit, for interconnecting Doppler navigation components.

b. Doppler simulator, for simulating aircraft flight characteristics.

c. Spectrum analyzer, for testing Doppler transmitters.

2.10.4. Analysis.

Although maintenance parts are not presently in the Army supply system, the concept of using sub-assemblies and modular replacements conforms with current Army maintenance doctrine.

2.11. HUMAN ENGINEERING CHARACTERISTICS.

2.11.1. Objective.

To determine the extent to which the test item conformed with accepted human engineering standards.

2.11.2. Method.

Comments from pilots and operators during the test period were collected and evaluated. In addition, two other Doppler evaluation reports (references 5 and 9) were researched for human engineering characteristics.

2.11.3. Results.

The following comments were considered significant:

2.11.3.1. Bearing Distance Heading Indicator (BDHI) lighting was inadequate.

2.11.3.2. Computer was difficult to program. The slewing knobs were difficult to operate because of high friction levels. The counters were difficult to position accurately because they continued to turn after the knob was returned to the neutral or stop position.

2.11.3.3. Destination counters creeped during flight. This could be serious if pilot lost or forgot the data he had inserted.

2.11.3.4. The present position and destination markings indicate only north and east. This was confusing to some pilots when south and west coordinates were inserted into the computer.

2.11.4. Analysis.

The above discrepancies are of a type that, compared with a properly human engineered system for Army aviation use, will require more time from the operator, will have a higher probability of error associated with their use, and will require greater mental effort on the part of the operator. These discrepancies were substantially the same as reported in the previous Doppler test report (reference 9). The test item showed no improvement over previously tested systems; therefore, this system was considered only marginally acceptable from the human engineering standpoint.

SECTION 3

APPENDICES

APPENDIX I

TEST DATA

PART A

COMPASS SWING

The ground calibration of the J-2 Compass System (with 1D998 Indicator) in YCV-2 57-3083 was completed on 19 February 1964. This swing was made using the MC-1 compass calibration unit. It is agreed that this calibration (data provided below) provides the most accurate heading reference system possible with the means available.

HEADING	WITHOUT POWER 1ST READING DEVIATIONS	WITH ENGINES RUNNING AND ALL EQUIPMENT ON 2ND READING DEVIATIONS	3RD READING DEVIATIONS	4TH READING DEVIATIONS
00°	+16'	+03'		
15°	-04'		-20'	-17'
30°	-20'	-05'		
45°	-10'		-17'	-02'
60°	-02'	+-2'		
75°	+15'		+12'	+15'
90°	+25'	+21'	+18'	+22'
105°	+34'		+10'	
120°	+37'	+15'		
135°	+33'		+17'***	+30'
150°	+28'	+10'		
165°	+20'		-02'	
180°	+15'	-13'	-10'****	-10'
195°	00			-10'
210°	-01°	-25'		-17'
225°	+05'			-05'
240°	+08'	-10'*		
255°	+15'			+07'
270°	+20'	+18'		+17'
285°	+25'			+15'
300°	+32'	+25'		+20'
315°	+24'			+20'
330°	+35'	+22'**		
345°	+27'			+02'
360°		-07'		-07'

* Engine RPM reduced from 1500 to 1200

** Power unit battery boiled over, changed power unit

*** Power voltage adjustment made on MC-1 console

**** Power unit fuel ran out. Third set of reading repeated in Column #4

/s/Raymond Bedard	/s/Claud Short
/t/RAYMOND BEDARD	/t/CLAUD SHORT
Field Engineer	Civilian, GS-11
LFE	Project Officer

PART B

FLIGHT DATA

Cairns AAF to Crestview VOR — Distance: 103.2 Kilometers

Flight #1

Computed Coordinates	49.1 S		90.1 W
Recorded Coordinates	49.1 S		91.6 W
Actual Error	00.0		1.5 W
Percentage-of-Distance-Traveled Error		1.45%	

Flight #2

Computed Coordinates	49.1 S		90.1 W
Recorded Coordinates	49.5 S		91.2 W
Actual Error	.4 S		1.1 W
Percentage-of-Distance-Traveled Error		1.16%	

Flight #3

Computed Coordinates	49.1 S		90.1 W
Recorded Coordinates	53.1 S		89.5 W
Actual Error	4.0 S		.6 E
Percentage-of-Distance-Traveled Error		3.92%	

Flight #4

Computed Coordinates	49.1 S		90.1 W
Recorded Coordinates	49.6 S		89.4 W
Actual Error	.5 S		.7 E
Percentage-of-Distance-Traveled Error		.85%	

Flight #5

Computed Coordinates	49.1 S		90.1 W
Recorded Coordinates	50.5 S		90.1 W
Actual Error	1.4 S		00.0
Percentage-of-Distance-Traveled Error		1.35%	

Flight #6

Computed Coordinates	49.1 S		90.1 W
Recorded Coordinates	50.1 S		90.8 W
Actual Error	1.0 S		.7 W
Percentage-of-Distance-Traveled Error		1.16%	

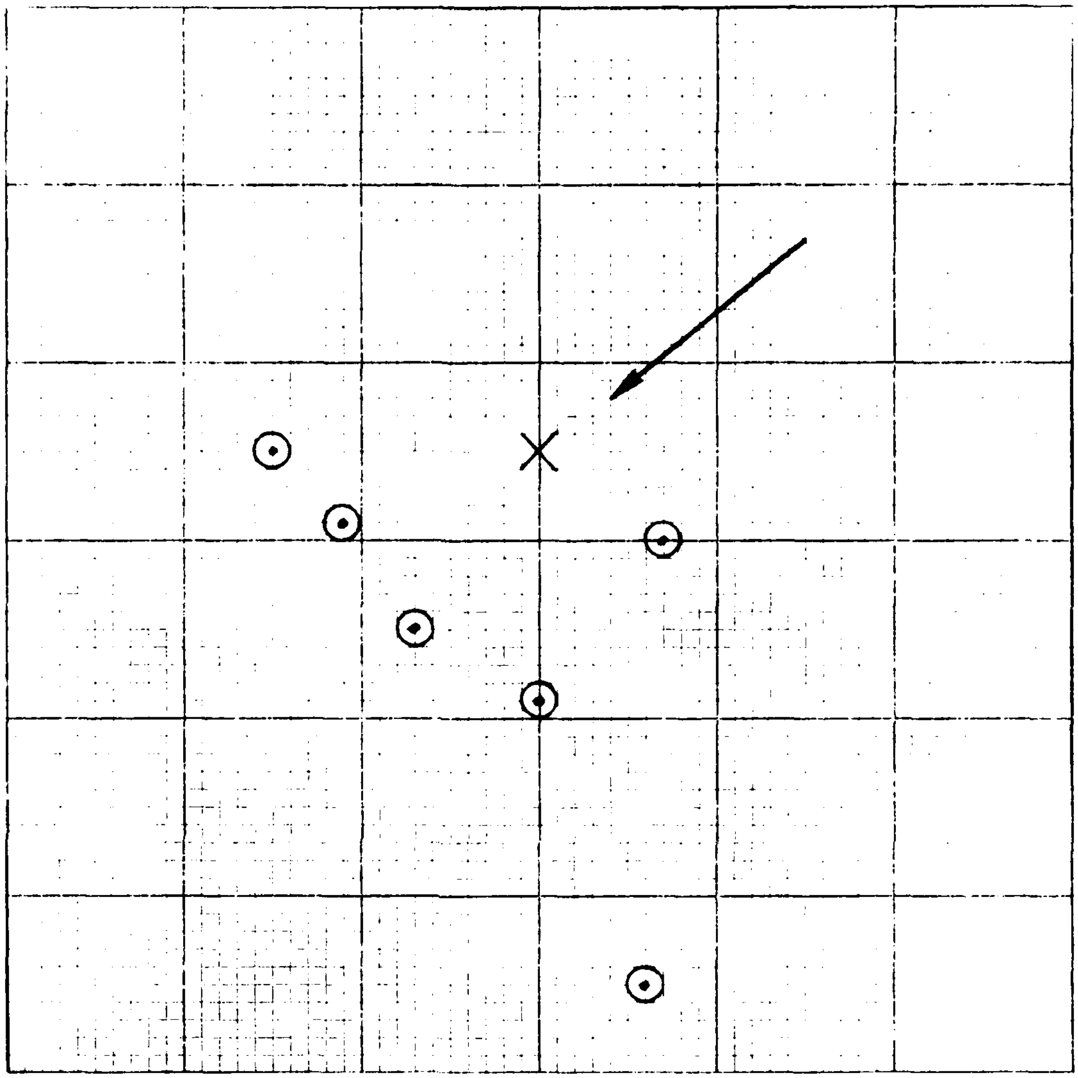

Figure 7. Cairns AAF to Crestview VOR
Distance: 103.2 Kilometers
Magnetic Bearing: 242 Degrees
Scale: 1 Inch = 1 Kilometer

Crestview VOR to Marianna VOR — Distance: 148.5 Kilometers

Flight #1

Computed Coordinates	4.5 S		148.58 E
Recorded Coordinates	4.1 S		149.14 E
Actual Error	.4 N		.56 E
Percentage-of-Distance-Traveled Error		.47%	

Flight #2

Computed Coordinates	4.5 S		148.58 E
Recorded Coordinates	5.2 S		148.14 E
Actual Error	.7 S		.44 W
Percentage-of-Distance-Traveled Error		.54%	

Flight #3

Computed Coordinates	4.5 S		148.58 E
Recorded Coordinates	7.0 S		149.94 E
Actual Error	2.5 S		1.36 E
Percentage-of-Distance-Traveled Error		1.91%	

Flight #4

Computed Coordinates	4.5 S		148.58 E
Recorded Coordinates	6.8 S		148.74 E
Actual Error	2.3 S		.16 E
Percentage-of-Distance-Traveled Error		1.55%	

Flight #5

Computed Coordinates	4.5 S		148.58 E
Recorded Coordinates	8.7 S		149.54 E
Actual Error	4.2 S		.96 E
Percentage-of-Distance-Traveled Error		2.89%	

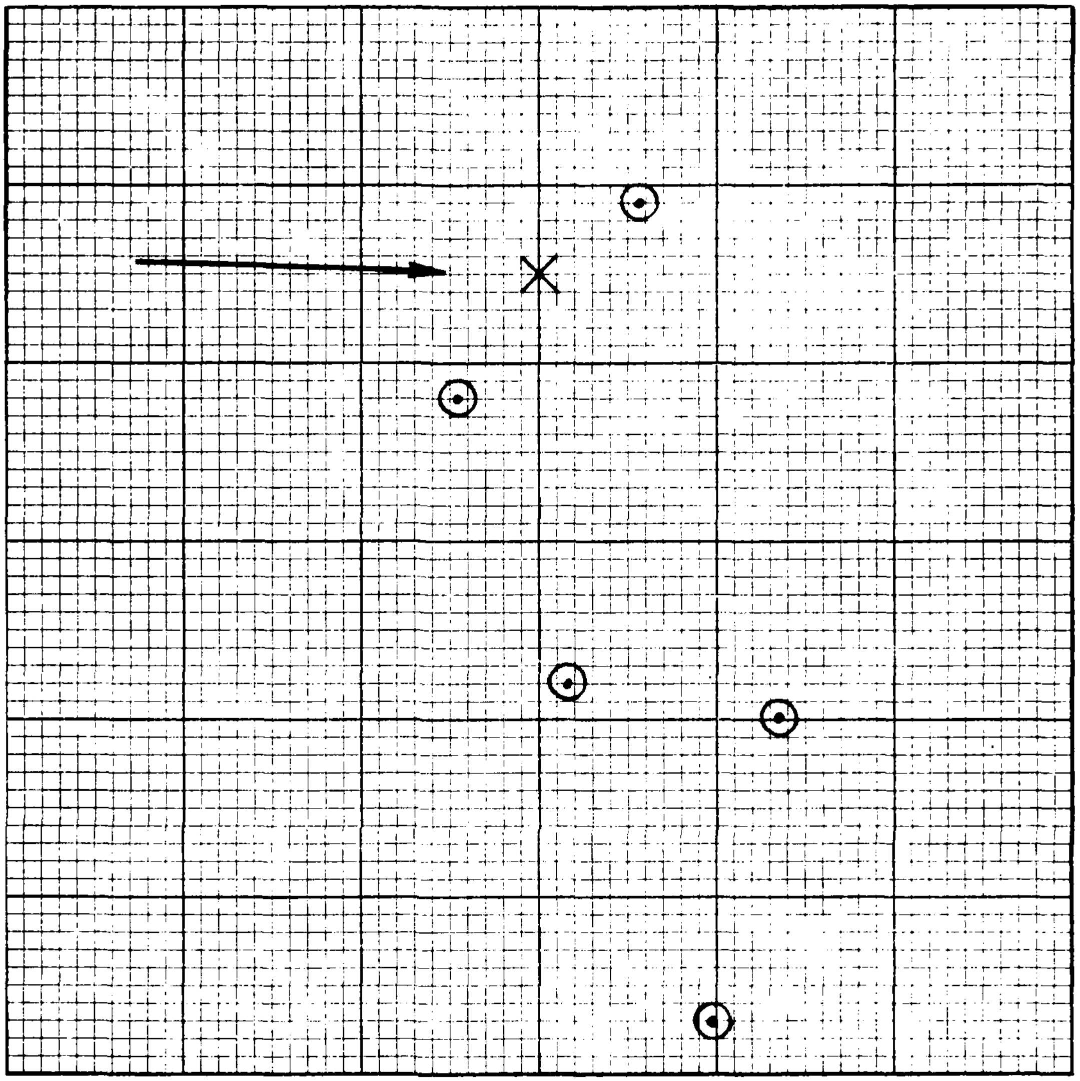

Figure 8. Crestview VOR to Marianna VOR
Distance: 148.5 Kilometers
Magnetic Bearing: 91 Degrees
Scale: 1 Inch = 1 Kilometer

Marianna VOR to Cairns AAF — Distance: 78.5 Kilometers

Flight #1

Computed Coordinates	00.0		00.36 E
Recorded Coordinates	0.5 N		0.40 E
Actual Error	.5 N		.04 E
Percentage-of-Distance-Traveled Error		.64%	

Flight #2

Computed Coordinates	00.0		00.36 E
Recorded Coordinates	.4 N		.10 W
Actual Error	.4 N		.46 W
Percentage-of-Distance-Traveled Error		.76%	

Flight #3

Computed Coordinates	00.0		00.36 E
Recorded Coordinates	3.2 S		2.50 E
Actual Error	3.2 S		2.14 E
Percentage-of-Distance-Traveled Error		4.84%	

Flight #4

Computed Coordinates	00.0		00.36 E
Recorded Coordinates	2.7 S		.80 E
Actual Error	2.7 S		.44 E
Percentage-of-Distance-Traveled Error		3.43%	

Flight #5

Computed Coordinates	00.0		00.36 E
Recorded Coordinates	1.9 S		.60 E
Actual Error	1.9 S		.24 E
Percentage-of-Distance-Traveled Error		2.41%	

Flight #6

Computed Coordinates	00.0		00.36 E
Recorded Coordinates	1.7 N		00.00
Actual Error	1.7 N		.36 W
Percentage-of-Distance-Traveled Error		2.22%	

Flight #7

Computed Coordinates	00.0		00.36 E
Recorded Coordinates	.7 N		.40 W
Actual Error	.7 N		.76 W
Percentage-of-Distance-Traveled Error		1.27%	

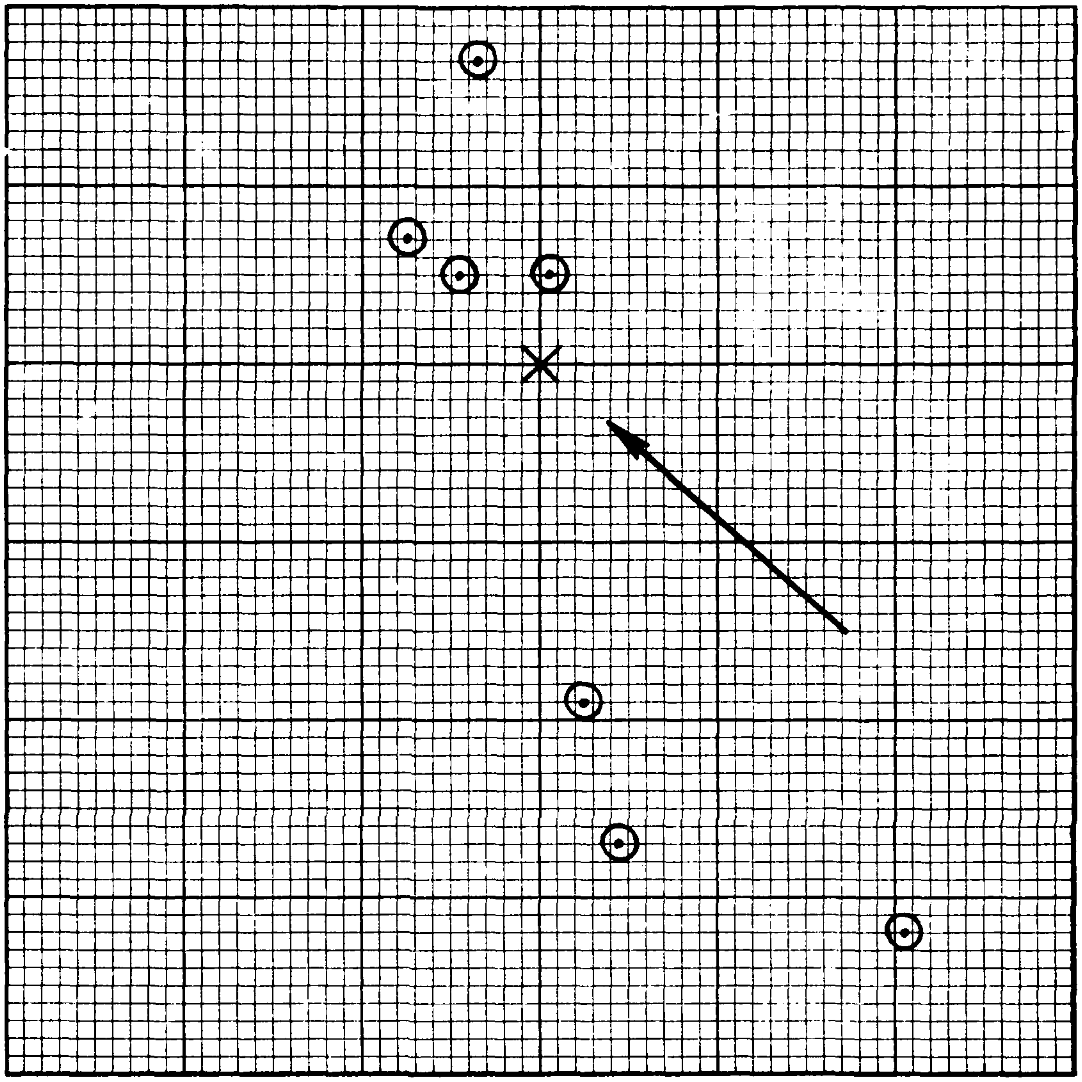

Figure 9. Marianna VOR to Cairns AAF
Distance: 78.5 Kilometers
Magnetic Bearing: 313 Degrees
Scale: 1 Inch = 1 Kilometer

Cairns AAF to Marianna VOR — Distance: 78.5 Kilometers

Flight #1

Computed Coordinates	53.59 S		57.38 E
Recorded Coordinates	56.80 S		57.50 E
Actual Error	3.21 S		.12 E
Percentage-of-Distance-Traveled Error		4.07%	

Flight #2

Computed Coordinates	53.59 S		57.38 E
Recorded Coordinates	55.70 S		57.70 E
Actual Error	2.11 S		.32 E
Percentage-of-Distance-Traveled Error		2.67%	

Flight #3

Computed Coordinates	53.59 S		57.38 E
Recorded Coordinates	54.00 S		57.80 E
Actual Error	.41 S		.42 E
Percentage-of-Distance-Traveled Error		0.76%	

Flight #4

Computed Coordinates	53.59 S		57.38 E
Recorded Coordinates	55.60 S		57.50 E
Actual Error	2.01 S		.12 E
Percentage-of-Distance-Traveled Error		2.55%	

Flight #5

Computed Coordinates	53.59 S		57.38 E
Recorded Coordinates	55.00 S		57.10 E
Actual Error	1.41 S		.28 W
Percentage-of-Distance-Traveled Error		1.78%	

Flight #6

Computed Coordinates	53.59 S		57.38 E
Recorded Coordinates	53.60 S		56.80 E
Actual Error	.01 S		.58 W
Percentage-of-Distance-Traveled Error		0.70%	

Flight #7

Computed Coordinates	53.59 S		57.38 E
Recorded Coordinates	54.60 S		57.00 E
Actual Error	1.01 S		.62 W
Percentage-of-Distance-Traveled Error		1.52%	

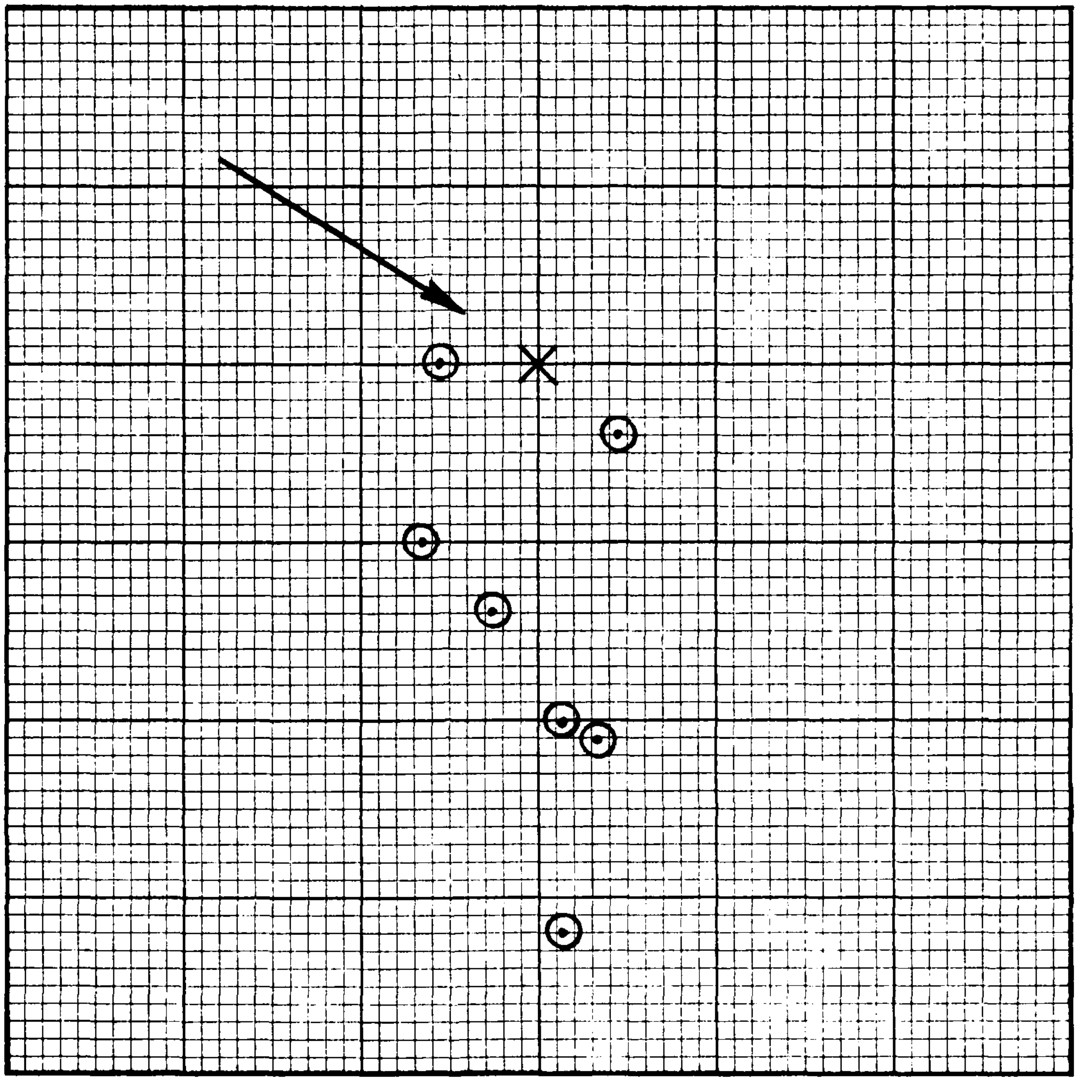

Figure 10. Cairns AAF to Marianna VOR
Distance: 78.5 Kilometers
Magnetic Bearing: 133 Degrees
Scale: 1 Inch = 1 Kilometer

Marianna VOR to Crestview VOR   Distance: 148.5 Kilometers

Flight #1

Computed Coordinates	04.43 N	148.48 W
Recorded Coordinates	3.80 N	148.20 W
Actual Error	.63 S	.28 E
Percentage-of-Distance-Traveled Error	.47%	

Flight #2

Computed Coordinates	04.43 N	148.48 W
Recorded Coordinates	3.10 N	150.30 W
Actual Error	1.33 S	1.82 W
Percentage-of-Distance-Traveled Error	1.55%	

Flight #3

Computed Coordinates	04.43 N	148.48 W
Recorded Coordinates	5.80 N	149.00 W
Actual Error	1.37 N	.52 W
Percentage-of-Distance-Traveled Error	1.00%	

Flight #4

Computed Coordinates	04.43 N	148.48 W
Recorded Coordinates	3.80 N	154.70 W
Actual Error	.63 S	6.32 W
Percentage-of-Distance-Traveled Error	4.24%	

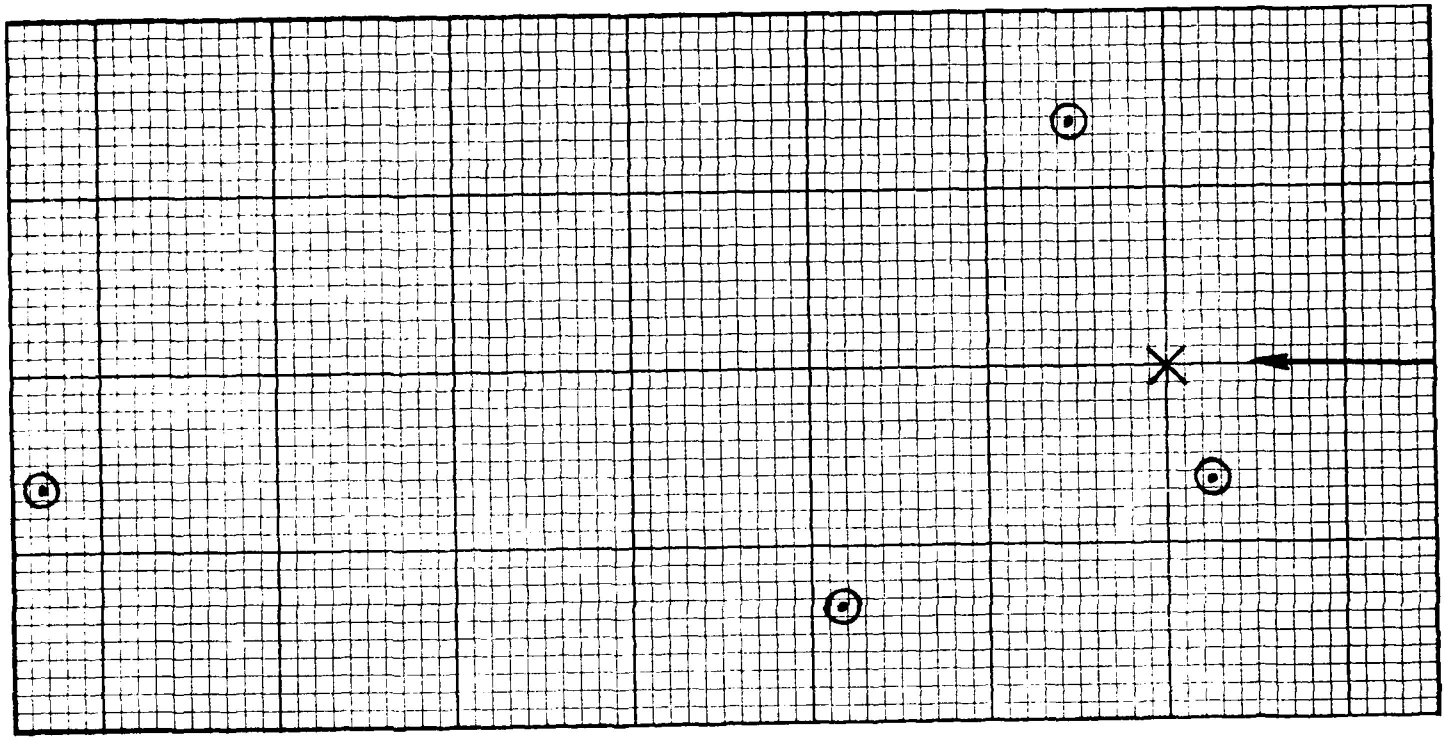

Figure 11. Marianna VOR to Crestview VOR
Distance: 148.5 Kilometers
Magnetic Bearing: 271 Degrees
Scale: 1 Inch = 1 Kilometer

Crestview VOR to Cairns AAF Distance: 103.2 Kilometers

Flight #1

Computed Coordinates	00.0	00.36 W
Recorded Coordinates	0.4 S	3.80 W
Actual Error	0.4 S	3.54 W
Percentage-of-Distance-Traveled Error	3.43%	

Flight #2

Computed Coordinates	00.0	00.36 W
Recorded Coordinates	0.4 S	0.70 W
Actual Error	0.4 S	.34 W
Percentage-of-Distance-Traveled Error	.50 %	

Flight #3

Computed Coordinates	00.0	00.36 W
Recorded Coordinates	0.2 N	0.80 W
Actual Error	0.2 N	.44 W
Percentage-of-Distance-Traveled Error	.50%	

Flight #4

Computed Coordinates	00.0	00.36 W
Recorded Coordinates	0.4 N	.05 W
Actual Error	0.4 N	.31 W
Percentage-of-Distance-Traveled Error	.05%	

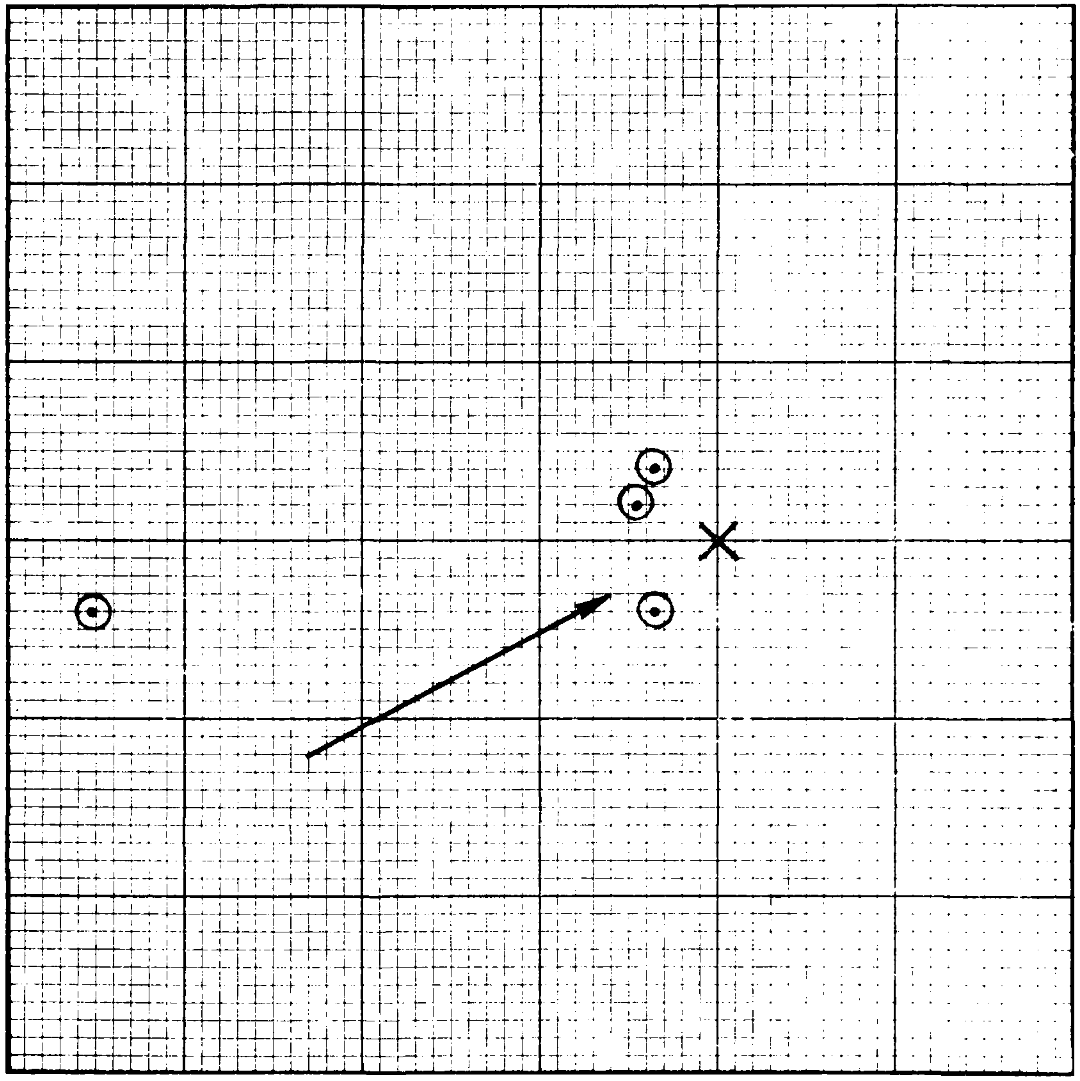

Figure 12. Crestview VOR to Cairns AAF
Distance: 103.2 kilometers
Magnetic Bearing: 62 degrees
Scale: 1 inch = 1 kilometer

Cairns AAF to Eufaula VOR	Distance: 94.5 Kilometers	

Flight #1

Computed Coordinates	75.84 N	56.45 E
Recorded Coordinates	78.50 N	57.30 E
Actual Error	2.66 N	.85 E
Percentage-of-Distance-Traveled Error	2.96%	

Flight #2

Computed Coordinates	75.84 N	56.45 E
Recorded Coordinates	76.40 N	56.40 E
Actual Error	.56 N	.05 E
Percentage-of-Distance-Traveled Error	.59%	

Flight #3

Computed Coordinates	75.84 N	56.45 E
Recorded Coordinates	77.00 N	55.30 E
Actual Error	1.16 N	1.15 W
Percentage-of-Distance-Traveled Error	1.74%	

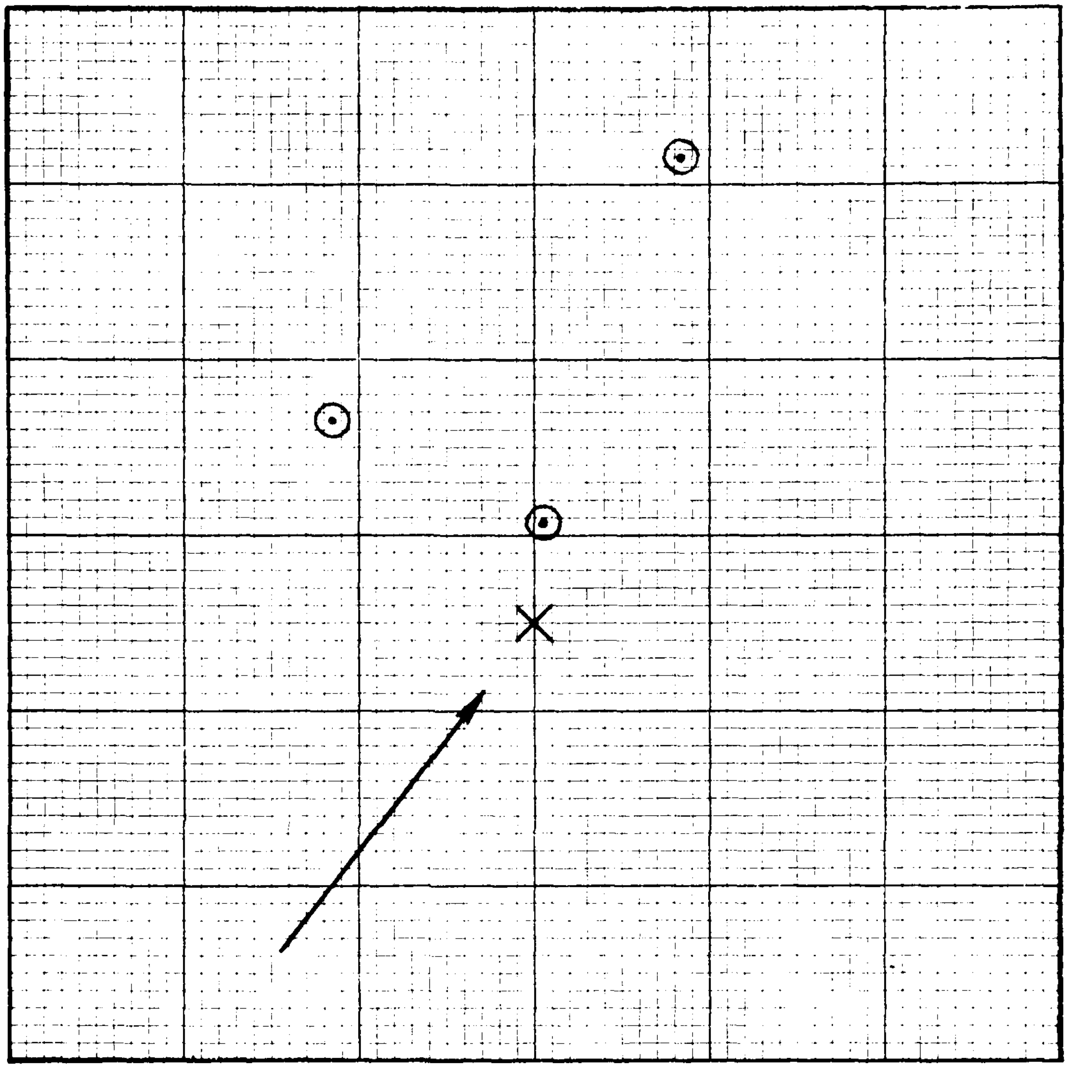

Figure 13. Cairns AAF to Eufaula VOR
Distance: 94.5 kilometers
Magnetic Bearing: 37 degrees
Scale: 1 inch = 1 kilometer

Eufaula VOR to Marianna VOR Distance: 129.4 Kilometers

Flight #1

Computed Coordinates	129.44 S	00.85 E
Recorded Coordinates	124.84 S	2.65 W
Actual Error	4.60 N	3.50 W
Percentage-of-Distance-Traveled Error	4.48%	

Flight #2

Computed Coordinates	129.44 S	00.85 E
Recorded Coordinates	129.74 S	1.95 E
Actual Error	.30 S	1.10 E
Percentage-of-Distance-Traveled Error	.89%	

Flight #3

Computed Coordinates	129.44 S	00.85 E
Recorded Coordinates	129.24 S	1.25 E
Actual Error	.20 N	.40 E
Percentage-of-Distance-Traveled Error	.37%	

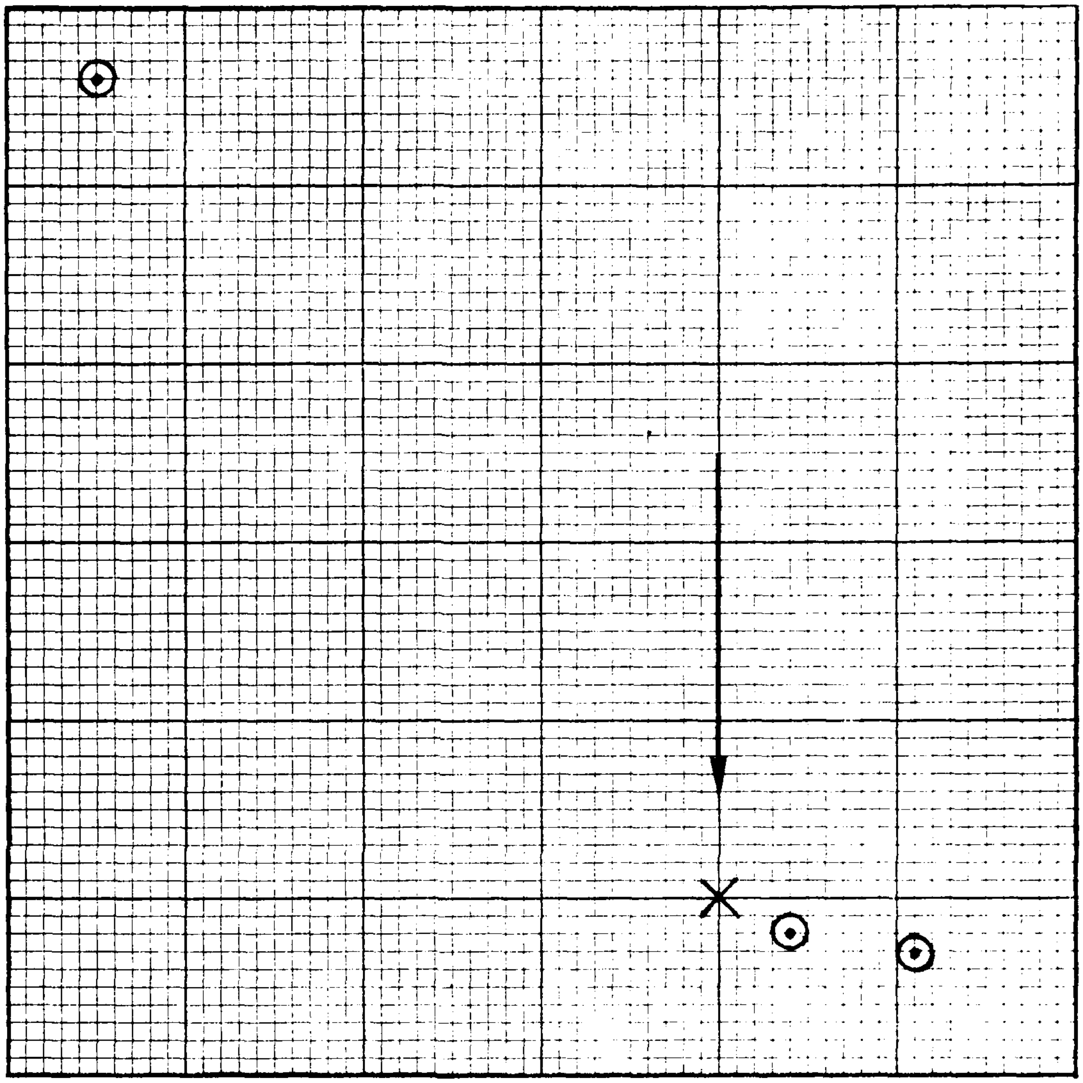

Figure 14. Eufaula VOR to Marianna VOR
Distance: 129.4 kilometers
Magnetic Bearing: 180 degrees
Scale: 1 inch = 1 kilometer

Marianna VOR to Eufaula VOR   Distance: 129.4 Kilometers

Flight #1

Computed Coordinates	129.44 N	00.58 W
Recorded Coordinates	128.99 S	.88 W
Actual Error	.45 S	.30 W
Percentage-of-Distance-Traveled Error	.39%	

Flight #2

Computed Coordinates	129.44 N	00.58 W
Recorded Coordinates	129.49 N	1.08 W
Actual Error	.05 N	.50 W
Percentage-of-Distance-Traveled Error	.39%	

Flight #3

Computed Coordinates	129.44 N	00.58 W
Recorded Coordinates	129.79 N	00.32 E
Actual Error	1.65 S	.70 E
Percentage-of-Distance-Traveled Error	.39%	

Flight #4

Computed Coordinates	129.44 N	00.58 W
Recorded Coordinates	129.28 N	.10 W
Actual Error	.16 S	.48 E
Percentage-of-Distance-Traveled Error	1.39%	

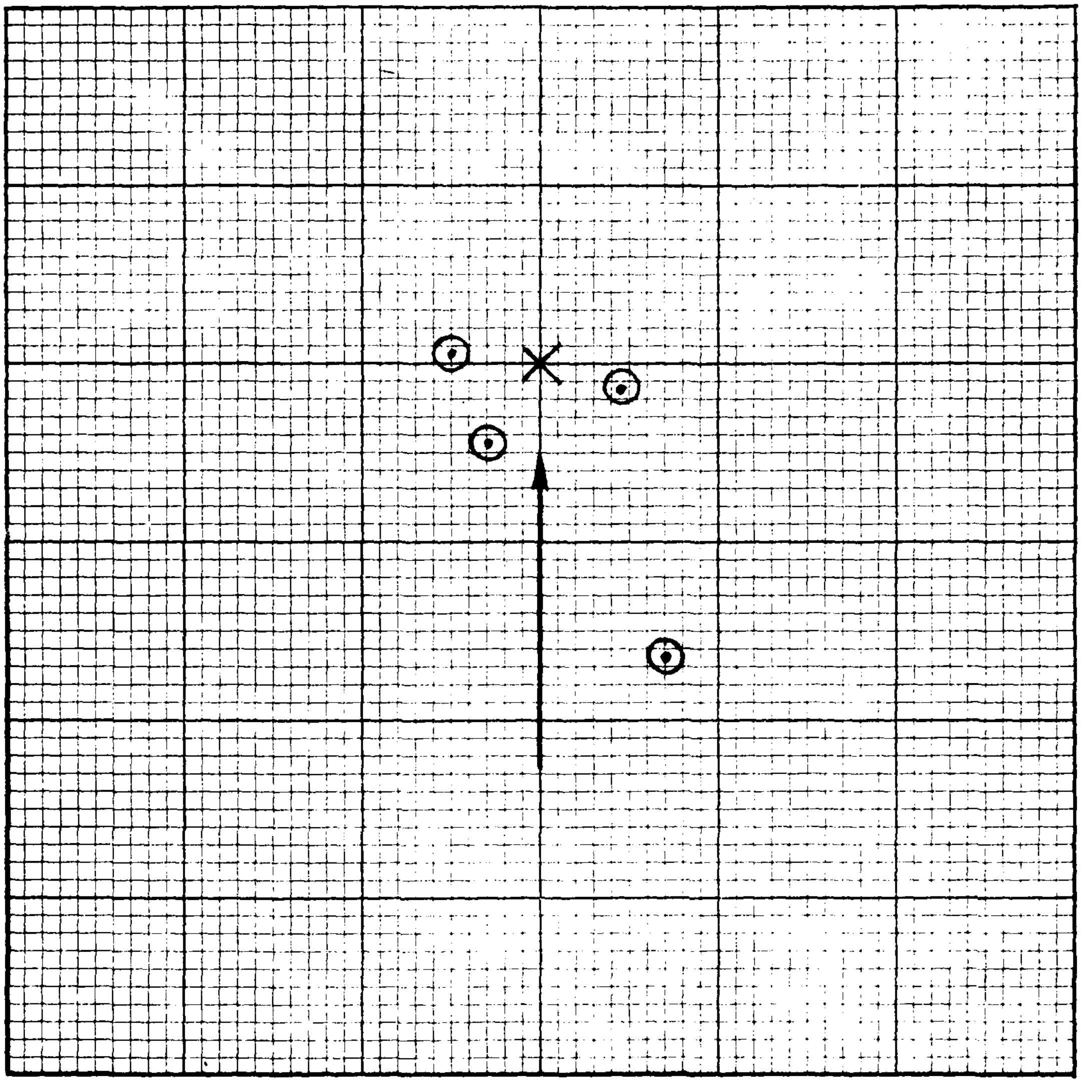

Figure 15. Marianna VOR to Eufaula VOR
Distance: 129.4 Kilometers
Magnetic Bearing: 360 Degrees
Scale: 1 Inch = 1 Kilometer

Eufaula VOR to Cairns AAF Distance: 94.5 Kilometers

Flight #1

Computed Coordinates	000.0		00.35 E
Recorded Coordinates	.1 N		1.20 W
Actual Error	.1 N		1.55 W
Percentage-of-Distance-Traveled Error		1.69%	

Flight #2

Computed Coordinates	000.0		00.35 E
Recorded Coordinates	000.0		00.30 E
Actual Error	000.0		.05 E
Percentage-of-Distance-Traveled Error		.05%	

Flight #3

Computed Coordinates	000.0		00.35 E
Recorded Coordinates	2.6 S		1.90 E
Actual Error	2.6 S		1.55 E
Percentage-of-Distance-Traveled Error		3.18%	

Flight #4

Computed Coordinates	000.0		00.35 E
Recorded Coordinates	2.8 S		1.90 W
Actual Error	2.8 S		2.25 W
Percentage-of-Distance-Traveled Error		3.82%	

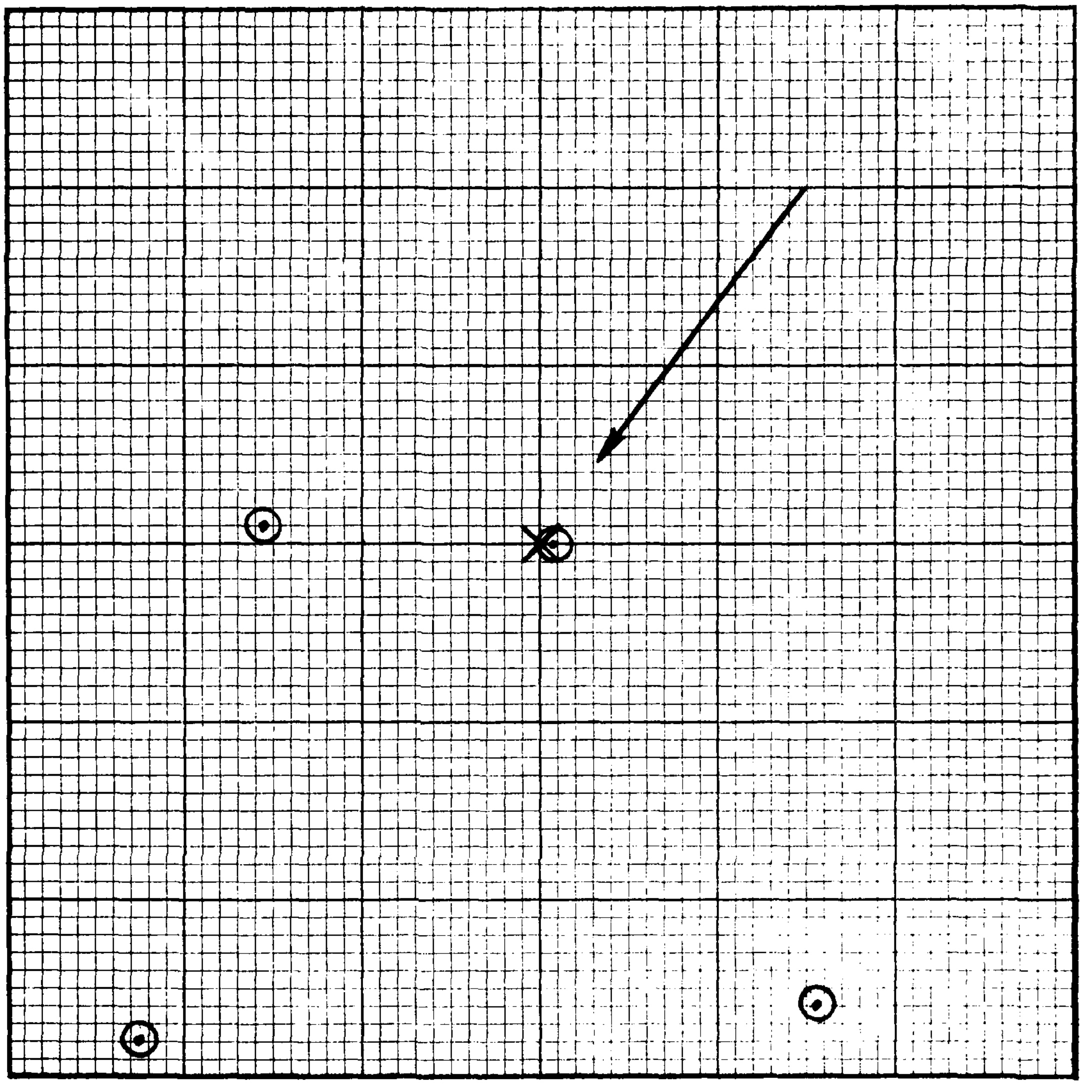

Figure 16. Eufaula VOR to Cairns AAF
Distance: 94.5 Kilometers
Magnetic Bearing: 217 Degrees
Scale: 1 Inch = 1 Kilometer

Tampa VOR to Cross City VOR Distance: 191.3 Kilometers

OVERWATER FLIGHT

Computed Coordinates	188.14 N	35.54 W
Recorded Coordinates	189.00 N	38.40 W
Actual Error	.86 N	2.86 W
Percentage-of-Distance-Traveled Error	1.57%	

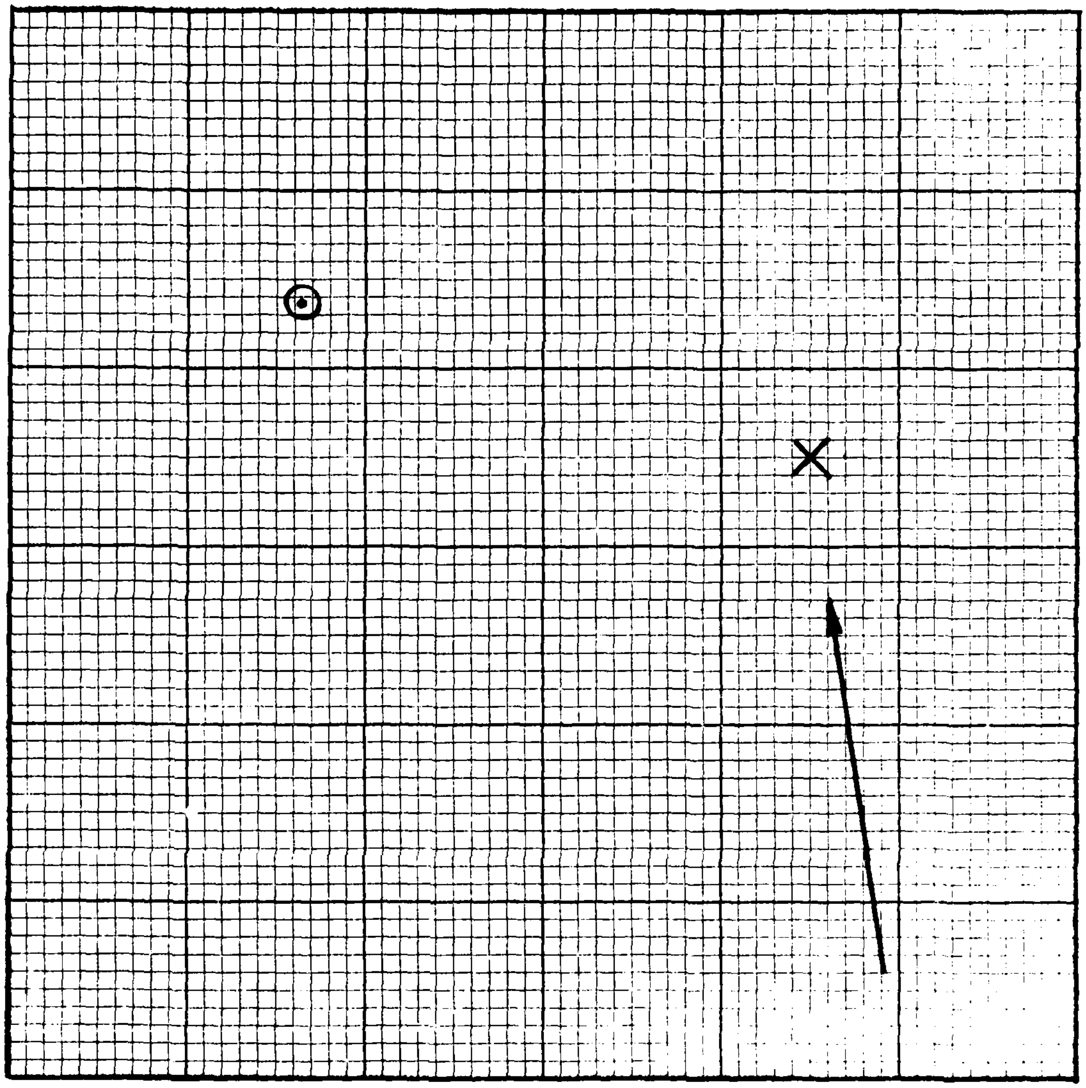

Figure 17. Tampa VOR to Cross City VOR
(Overwater Flight)
Distance: 191.3 Kilometers
Magnetic Bearing: 349 Degrees
Scale: 1 Inch = 1 Kilometer

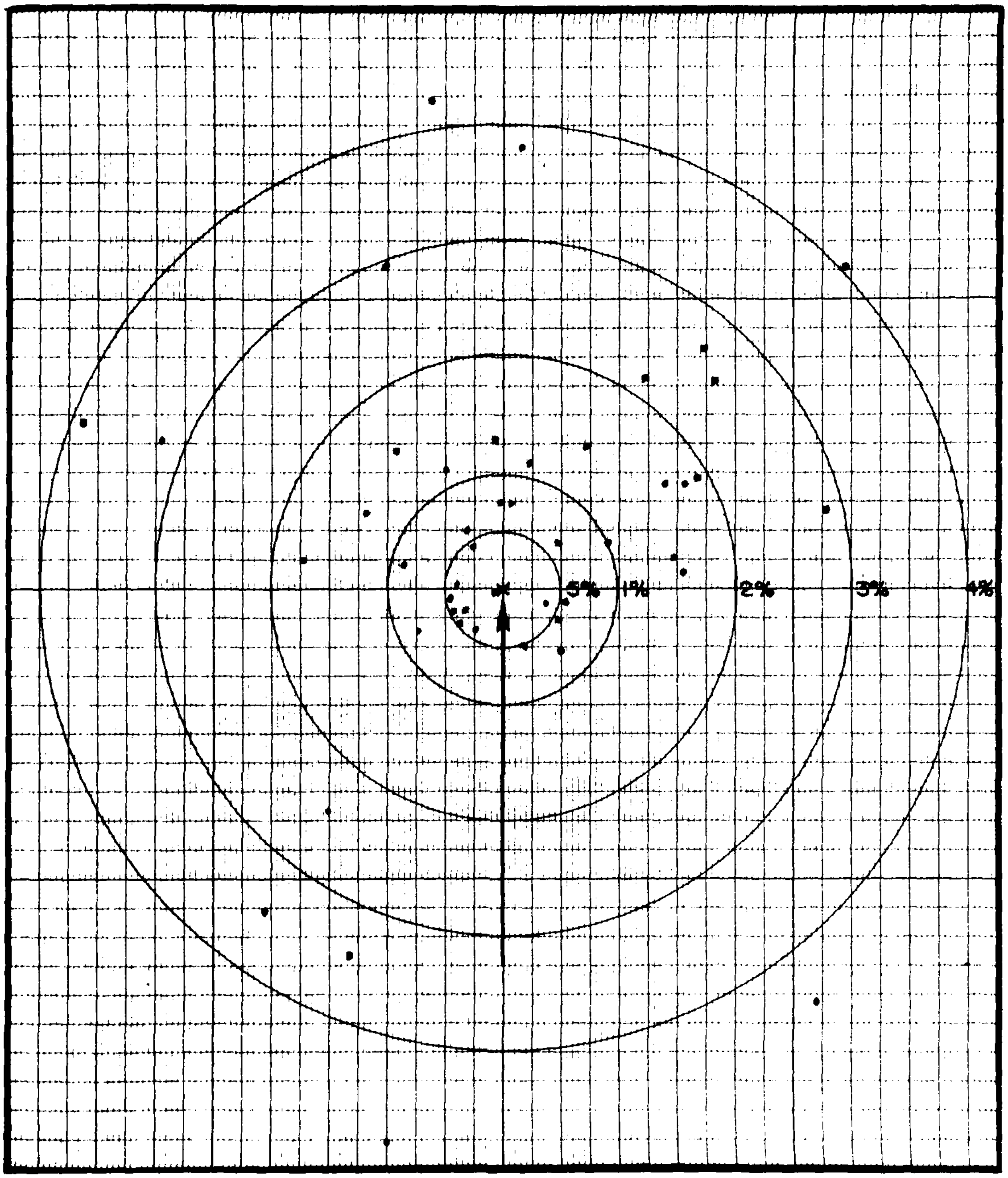

Figure 18. Overall performance. (All flights were reduced to a common base of 100 kilometers. Distance errors were reduced and positioned accordingly.)

PART C

DETERMINATION OF DATA FOR

PROGRAMMING DOPPLER COMPUTERS

1. Map Data.

a. North-south and east-west values required for programming the Doppler Navigation Computer may be determined from a map by the following procedures (reference figure 35):

(1) Locate the terminal points of the flight path.

(2) Draw a true north-south line through one point and a true east-west line through the second point so that they intersect.

(3) Measure the north-south and east-west distance from base (point 1) to destination (point 2) along these lines.

b. Accuracy of the values obtained by this method are dependent upon the scale and quality of the map used and on the care taken in making the measurements.

2. Computed Data from Latitude and Longitude. North-south and east-west data can also be determined from latitude and longitude information by the following process:

a. From a source such as US Coast and Geodetic Survey publications or other reliable publications, determine the latitude and longitude of the base (point 1) and destination (point 2).

Example: Base - Cairns AAF 31° 16' 05" N
85° 43' 36" W

Destination - Crestview VOR 30° 49' 33.4" N
86° 40' 45" W

b. To determine the north-south distance from base to destination, subtract latitudes and convert directly to nautical miles or kilometers.

NOTE: One minute of latitude equals 1 nautical mile.

31°	16'	05.0"
30°	49'	33.4"
	26'	41.6"

26' 31.6" = 26.5 nautical miles = 49.16 kilometers.

c. To determine the east-west distance from base to destination, subtract longitudes.

86°	40'	45"	57' 09" = 57.15 n.m. at equator
85°	43'	36"	
	57'	09"	

Since the lines of longitude converge at the poles, this is not the true east-west distance and must be corrected by multiplying by the cosine of the mid-latitude.

d. Determine the mid-latitude cosine.

(1)

31°	16'	05.0"
30°	49'	33.4"
	26'	31.6"

(2)

```
   13'  15.8"
2/26'  31.6"
  2
   6
   6
     3
     2
     11
     10
      16
      16
```

(3)

30°	49'	33.4"
	13'	15.8"
31°	02'	49.2"

(4) From trigonometric tables - Cosine 31° 02' 49.2" = .856749.

e. East-west distance is therefore 57.15 x .856749 = 48.96 n.m. = 90.74 kilometers.

f. Since Crestview is southwest of Cairns, the values 26.5 n.m. south (49.16 kilometers) and 48.96 n.m. west (90.74 kilometers) would be inserted in the navigation computer as the desired destination.

3. Determination of Variation. Variation for insertion into the navigation computer is determined directly from the available maps. For short flights over areas of little variation change, an average variation can be determined by inspection of the map. For longer flights or for flights over areas of erratic variation change, the flight should be broken into shorter legs and the variation determined for each leg. These values are then inserted into the computer as the flight progresses. If an approach or any significant flying is to be done at the terminal area, the variation of the terminal area should be inserted at the destination in order to prevent the introduction of unnecessary errors.

APPENDIX II

COORDINATION

This report has been coordinated with the following agencies:

US Army Aviation School

US Army Combat Developments Command Aviation Agency

APPENDIX III

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United States Army Aviation Test Board, Fort Rucker, Alabama
Report of USATECOM Project No. 4-4-4305-01, Military Potential Test of a Doppler Navigator in a Fixed-Wing Aircraft, 28 September 1964. DA Project No. 1G641203D526. 64 pp., 18 illus.
The Military Potential Test of a Doppler Navigator in a Fixed-Wing Aircraft was conducted by USAAVNTBD personnel in the vicinity of Fort Rucker, Alabama, and Tampa, Florida, during the period 22 February - 12 June 1964. The test item's weight, power requirements, accuracy, repeatability, and reliability did not meet the requirements of the MC's and SCL 5953. The test item was not suitable for tactical use and was marginally acceptable from a human factors standpoint. It was concluded that the test item is not suitable for Army use and recommended that the test item be given no further consideration for Army use.

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