

**THE EFFECT OF ELECTRONIC APTITUDE ON
PERFORMANCE OF PROCEDURALIZED
TROUBLESHOOTING TASKS**

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FOREWORD

This study was initiated by the Behavioral Sciences Laboratory of the Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio. It represents a portion of the exploratory development program conducted under Task 171004, "Techniques for Training, Aiding, and Evaluating the performance of Technical Tasks" of Project 1710, "Human Factors in the Design of Training Systems." Dr. Gordon A. Eckstrand was project scientist. Dr. Ross L. Morgan was task scientist. This research was begun in April 1966 and was completed in November 1966.

This report covers part of the research conducted under Contract AF 33(615)-3966 by Applied Science Associates, Inc.; Dr. John D. Folley, Jr., was principal investigator. Dr. John P. Foley, Jr. of the Technical Training Branch, Behavioral Sciences Laboratory, monitored the contract for the Aerospace Medical Research Laboratories.

This technical report has been reviewed and is approved.

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ABSTRACT

After twelve hours training, twenty subjects with no prior training in electronics solved complete electronic equipment maintenance problems on a realistic equipment simulator, the MTS-2. Subjects selected were from two electronic aptitude groups (AQE-E1 45-60 and 80-95 percentiles). The problems were composed of equipment checkout, malfunctioning "black box" isolation (within-stage troubleshooting), piecepart isolation (within-stage troubleshooting), and repair tasks. In lieu of expensive conventional electronic training, subjects were aided in the performance of the above tasks by troubleshooting guides which, given the result of previous checks, told subjects where to check next. Results of the study showed that aptitude had no effect on performance time, or errors in repair. A small but significant difference was noted in the ability of the two groups to isolate defective "black boxes" and piece-parts; high-aptitude subjects performed somewhat better on this dimension.

TABLE OF CONTENTS

Section No.	Page No.
I. INTRODUCTION	1
II. METHOD	2
Subjects and Design	2
Apparatus	2
MTS-2	2
Subjects' Tasks	3
Performance Aids	7
Between-Stage Troubleshooting Guide	7
Within-Stage Troubleshooting Guide	10
Training	13
Data Collection	15
Scoring	16
Checks	16
III. RESULTS AND DISCUSSION	19
Between-Stage Troubleshooting	19
Within-Stage Troubleshooting	22
IV. SUMMARY AND CONCLUSION	26
APPENDIX I	
Subject Aptitude	28
APPENDIX II	
MTS-2 Check Procedure	29
APPENDIX III	
Criterion Tests 1 and 2	34
APPENDIX IV	
Summary of Method Used in Development of Within-Stage Troubleshooting Test Sequences	43
REFERENCES	45

LIST OF TABLES

Table No.		Page No.
I	Between-Stage Troubleshooting: Problem Means and Group Mean Differences on Problems 1-13	20
II	Between-Stage Troubleshooting: Total Group Errors on Problems 1-13	20
III	Within-Stage Troubleshooting: Problem Means and Group Mean Differences on Problems 1-13	23
IV	Within-Stage Troubleshooting: Total Group Errors on Problems 1-13	23

LIST OF FIGURES

Figure No.		Page No.
1	L., The MTS-2 Front Panel and R., The MTS-2 Module Chassis	4
2	Typical MTS-2 Modules	4
3	MTS-2 Modules with Backs Removed to Show Circuit Boards	5
4	Typical Module Circuit Boards	5
5	The Module Test Jig	6
6	The Within-Stage Troubleshooting Work Area	6
7	Example Parts Location Diagram	8
8	A Typical Card From the Between-Stage Troubleshooting Guide	9
9	Example Parts List	13

Contrails

SECTION I

INTRODUCTION

Over the past decade the armed services have spent hundreds of millions of dollars annually to train and support electronic maintenance personnel. Over that same period of time much research effort has gone into the search for techniques which might reduce this tremendous cost. One of the techniques which has for some years shown promise, is that of proceduralized troubleshooting. Numerous studies (references 1, 2, 3, 4, 7, 8) have shown that proceduralized troubleshooting can produce good or superior proficiency while significantly reducing training requirements. Research results also suggest that proceduralized troubleshooting offers the hope of reduced requirements in the aptitude of electronics maintenance personnel. And finally, it has been shown that proceduralized troubleshooting produces more predictable performance of the electronics maintenance task.

The advantages suggested above accrue from a simplification of the task which obviates the need for technicians to decide where in the system to check. These decisions are made by a performance aid which, given the result of a previous check, tells the technician where to check next.

All of the studies employing proceduralized troubleshooting have, to date, concerned themselves almost entirely with the problem of between-stage or between "black box" malfunction isolation. Yet, perhaps the greatest portion of most technicians' training is devoted to acquisition of knowledge which is intended to support their ability to troubleshoot within-stage. Thus, if the gains of proceduralized troubleshooting at the between "black box" level could be realized for within-stage troubleshooting, great savings in the cost of maintenance might be realized. Furthermore, it is probably primarily at the within-stage level of troubleshooting that the need for high-aptitude subjects is felt most critically.

This study has two objectives. The first is to attempt to develop workable within-stage troubleshooting procedures for a realistically complex piece of electronic equipment and to discover and solve some of the problems associated with that development.

The second is to try these procedures in an equipment maintenance context with subjects of two aptitude levels; those typically selected at present for electronics maintenance training, and those of lower aptitude who are presently unavailable due to the intellectual requirements of the maintenance training.

SECTION II

METHOD

Subjects and Design

Twenty high school senior boys were selected on the basis of willingness to participate and on the basis of electronic aptitude as estimated by the electronic index of the Airmen Qualifying Examination. Ten subjects were placed according to their aptitude scores in a high-aptitude group and ten in a medium-aptitude group. Scores of the high-aptitude group ranged from 80 to 95, with a mean of 90.50. Scores of the medium-aptitude subjects ranged from 50 to 65, with a mean of 56.00. Aptitude scores of individuals are tabled in Appendix I.

Apparatus

The apparatus used by the subjects consisted of:

1. Test equipment - A tektronix 545A oscilloscope
A triplet model 630-PLK volt ohmmeter
A gain and leakage transistor tester
2. The MTS-2 described below.
3. A soldering iron and common hand tools.
4. Common electronic pieceparts: resistors, capacitors, transistors, etc.
5. A jig used to hold components for test purposes.

MTS-2

The Maintenance Task Simulator-2 (MTS-2) is a recently developed device designed for use as a research tool in a study of tasks associated with electronic maintenance. A detailed description of an earlier version of the device will be found in Reference 5 and of a more recent version in Reference 6. Physically, the MTS-2 is composed of five relay racks and an operator's control panel which together contain or support all component equipment. The front panel is supported by three racks (Figure 1), the other two racks contain twelve module chassis, each containing eight modules in two parallel rows (Figure 1).

The modules are outwardly identical, 3 by 4 by 5-inch black boxes, each having two telephone-type test jacks side by side below a nomenclature plate which denotes the module type (Figure 2). Each module type contains one of twenty-three different circuits mounted on from one to three terminal strips affixed to the module back

plate (Figure 3). In all cases, the cable between the circuit boards mounted on the back panel is of a length which permits sufficient separation of the module on the back panel to permit easy access for maintenance to all sides of the circuit boards. Removal of the screws at either side of the circuit board permits their separation from each other and from the module back panel for replacement of components on the lower boards. Figure 4 shows two circuit boards thus separated.

All equipment data flow signals and some power supply voltages originate within the MTS-2 modules. Virtually an infinite number of waveshapes can be generated, either directly or by a combination of waveshapes. Modules contain an average of twenty piecparts and from one to five stages. Reference 6, Vol. I contains a list of the module types with a description of circuit functions performed and typical waveforms.

Subjects' Tasks

The task of the subjects was to solve a series of complete system troubleshooting and repair problems. A problem began as the subject energized the system and started a system-check procedure. At some point in the procedure, he detected an out-of-tolerance system output and, at that point, entered a troubleshooting guide. The guide told the subject what additional checks to perform, both on the front panel and inside the equipment. The guide also provided expected readings and tolerances, the location of testpoints, the state of switches and other controls in the system (system state) required to produce the expected readings, and the sequence in which checks were to be performed. The sequence of checks was dependent upon the result of previous checks; that is, the result of each check determined which of two alternative checks was next to be made. Ultimately, the subject reached a check, the result of which was an instruction to replace a particular module. At this point, the module was replaced and proper system operation verified. The defective module was taken to a test bench in the same room and installed on the module test jig (Figure 5). The function of the jig was to provide supply voltages to the modules, and also to hold both the module and the circuit board so that both the subject's hands were free for tool and test equipment manipulation.

Here again, the subject's actions were controlled by a troubleshooting guide which told the subject what checks to perform, expected readings and tolerances, and in conjunction with a parts location diagram, system geography information. When the guide indicated that a component should be replaced, the subject selected the appropriate part number from the parts list and selected the required part from stock on the basis of this number. He then installed the new



Figure 1. L., The MTS-2 Front Panel and
R., The MTS-2 Module Chassis

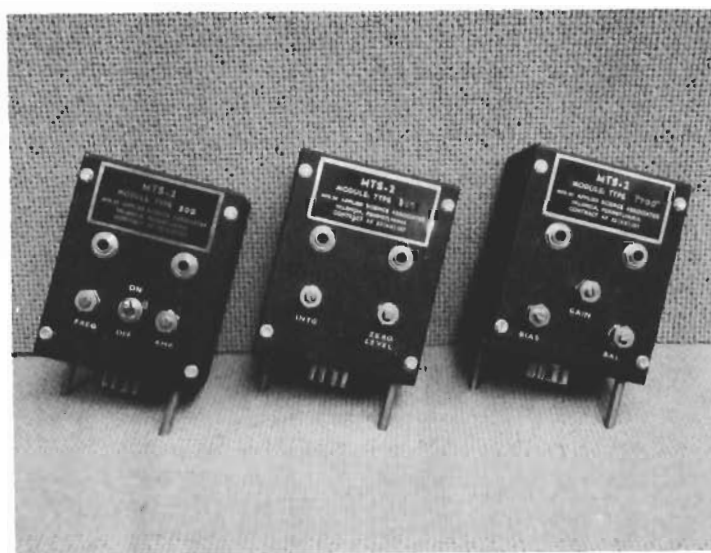


Figure 2. Typical MTS-2 Modules

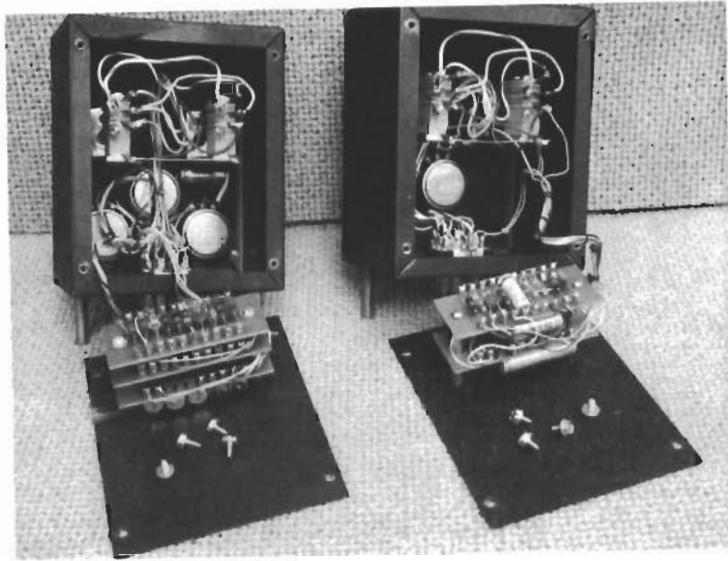


Figure 3. MTS-2 Modules with Backs Removed to Show Circuit Boards

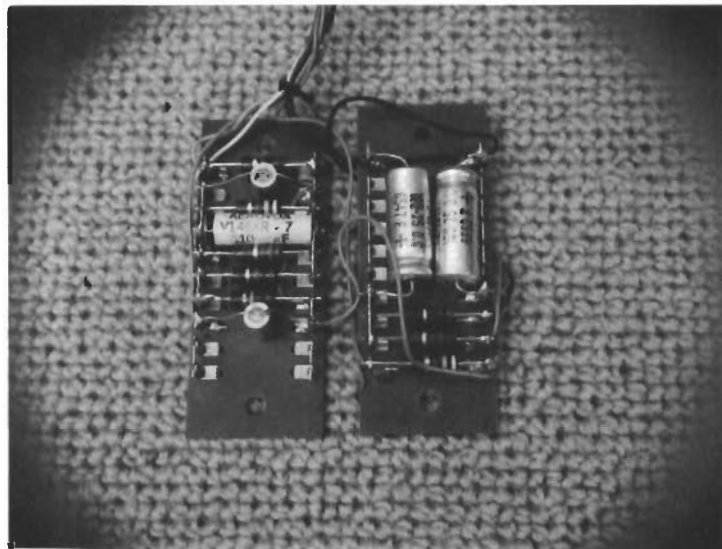


Figure 4. Typical Module Circuit Boards

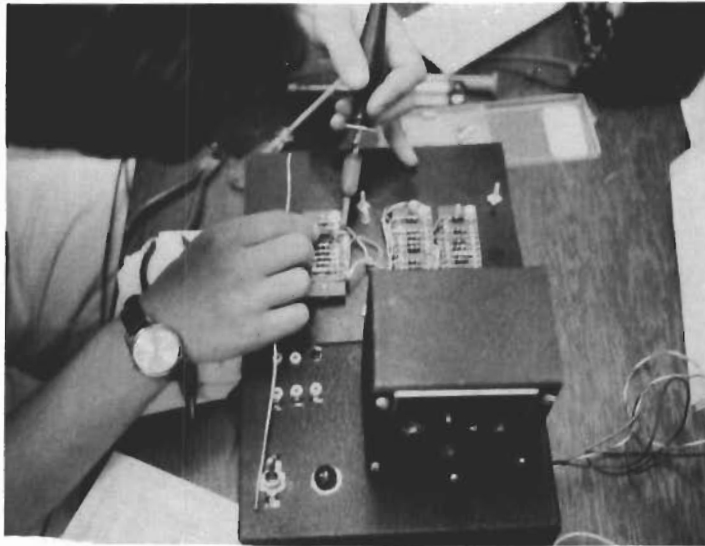


Figure 5. The Module Test Jig



Figure 6. The Within Stage Troubleshooting Work Area

component, reassembled the module, and returned it to the MTS-2 verifying on the front panel that the correct repair had been made.

Problems - A total of twenty problems in ten modules were available. A problem consisted of a single defective component within one of the modules. About half of the problems consisted of open, short, or leaking transistors. About forty percent more were resistors which either had changed in value or opened. In addition, there were two problems involving visibly broken components and one involving an open capacitor.

No effort was made to control the salience or subtlety of the symptoms produced by the malfunctions either on the front panel or within-stage. As a result, some symptoms, primarily those on the front panel, required careful discrimination for detection. However, many of the check results were completely unequivocal. In a number of cases, the signal to be expected was totally absent. Likewise, within-stage, most bad transistors tested completely dead, but many resistance measurements were either just inside or just outside of tolerance.

From two to twelve checks were required to identify malfunctioning components within-stage, and from one to six checks to identify a defective module (in addition to front panel checks).

Performance Aids

The system of performance aids used by the subjects was composed of a system check procedure, a between-stage troubleshooting guide used to identify the defective module, a within-stage troubleshooting guide, and a part and terminal location diagram (Figure 7) used for identifying the defective component within the module, a parts list containing module part numbers and stock numbers, an oscilloscope control-preset checklist, and a list of expected readings and tolerances for transistors by type, used in conjunction with the transistor tester.

The performance aid system was designed before the problems to be used in the study were selected, with the intent that it would solve all possible system problems, both between modules and within modules. It was manifestly impossible, however, to test the information system against all possible problems. It was tested, therefore, only against those problems selected for use by subjects either in practice prior to testing or in testing.

Between-Stage Troubleshooting Guide

The between-stage guide was composed of approximately 200 cards in the format shown in Figure 8. An index number in the upper

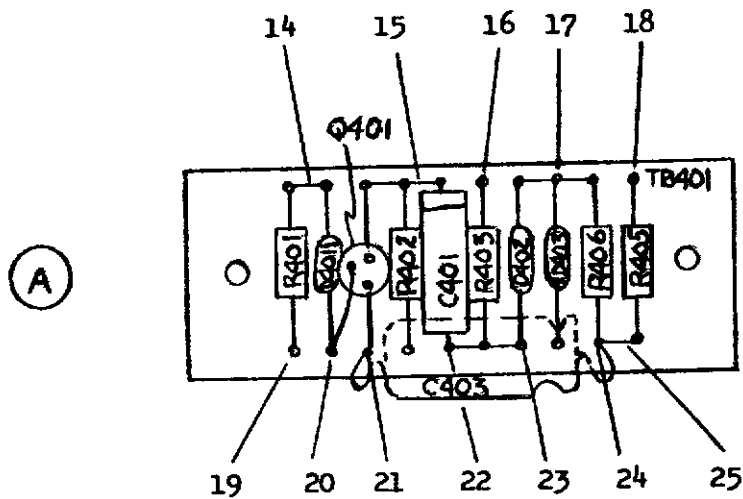
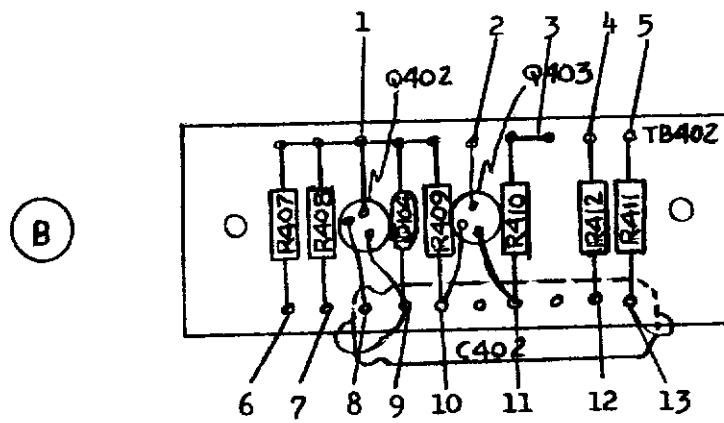


Figure 7. Example Parts Location Diagram

lefthand corner of each card identified the card. A testpoint number (in the example, the input of the third module on module chassis 2) was found in the upper center of the card with the normal indication immediately below it. The normal indication was virtually always a photograph of the scope graticule with the expected waveform displayed. At the left of the normal indication, the system state required to obtain that indication was listed. At the right of the normal indication were listed the settings of controls on the oscilloscope required (in addition to presets) to obtain the expected display. At the bottom of the card were located instructions which told the subject what to do if the outcome of the check indicated by the card was good and what to do if the outcome was bad. Usually, the instructions consisted of the number of another card. Some instructions, however, indicated repair operations to be performed, usually the replacement of a module.

BTSG 3966-I

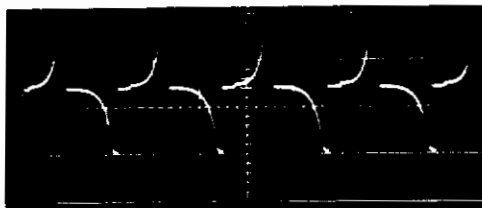
TEST POINT: I 2-3

B 021

NORMAL INDICATION

SYSTEM STATE

Radiate
ANS Heater on
BNS PWR on
T.C. Sweep off
Sweep Delay off
PRI PWR off



SCOPE CONTROLS

Volts/CM 0.1V/CM
Trigger Slope int.
Time/CM 0.5 m sec.
Other:

Good R 2-3

Bad B C022

Figure 8. A Typical Card from the Between-Stage Troubleshooting Guide.

The between-stage troubleshooting guide was developed in the following manner:

First, using the system data flow, optimal troubleshooting strategies were developed for the detection of a malfunctioning component upstream of each output. Thus, there was a troubleshooting tree associated with each front panel output. Each tree was coded with a letter corresponding to the front panel output, and a number preceded by that letter was assigned to each checkpoint in the tree.

After the troubleshooting trees were converted to cards (a card for each checkpoint) containing the testpoint, index number, system state, and good and bad alternatives. Each input and output test point was measured with the oscilloscope, the graticle photographed, and the setting of scope controls (other than presets) recorded for that trace. The normal indications and the required scope controls were then added to the troubleshooting guidecards, testpoint by testpoint.

The 5 by 8 cards were then bound, in alphanumeric order, into a two volume three-ring notebook, and slotted for easy removal in conjunction with the data collection process.

The first card in each tree was used to verify the system state in order to reduce the possibility that a troubleshooting tree would be entered as a result of error in the check procedure. Thus, if a subject made a mistake in setting a control during the running of a check procedure, when he entered the troubleshooting tree and verified all the control positions required to obtain the normal front panel indication, and he found one or more control positions in error and corrected the error, the troubleshooting tree would cause him to branch back into the check procedure rather than into the troubleshooting sequence.

Within-Stage Troubleshooting Guide

The within-stage troubleshooting guide for each type of module consisted of a set of from ten to sixty cards containing the instructions for troubleshooting the module. The sets were filed by module in a card file so that when the subject began troubleshooting a particular module he selected the set of cards appropriate to that module. Within each set, cards were placed in order by their index numbers.

All cards in the sets were in one of the five formats shown below.

Format I

Index No.

When the module is properly installed on the test jig, carefully inspect each component, wire, and connection for visible signs of damage.

If none is found go to index no. .

If a wire or connection is broken, repair it and ask E to inspect your work.

Contrails

If a component is damaged, remove it and exchange it for a good one from stock. Install the good one, and ask E to inspect your work.

Format II

Index No.

One at a time, remove and check all transistors.

If a bad one is found, replace the transistors removed thus far except the bad one. Exchange the bad one for a good one from stock. Install the good one, and ask E to inspect your work.

If all transistors check good, do not reinstall them on the board. Go to index no._____.

Format III

Index No.

Lift D 402 17
Lift R 416 16
Lift C 401 12

Meter: 10K

⑫
17

Read: 1.3 - 1.6

Good: Index no._____

Bad: Index no._____

Format IV

Index No.

Lift D 107 12

Meter: 10K

Lifted end D 107
15

Read 1.1 - 1.3

Good: Index no._____

Bad: Index no._____

Format V

Index No.

Remove C 104 and replace it with a good one from stock. The end of C 104 with the black stripe should be connected to 14 and the other end to 12. Replace all the transistors which were removed from the board, and solder down the ends of components which were lifted. When you are finished ask the experimenter to check your work.

Formats I and II were found in that order at the beginning of each deck, followed by formats III and IV. Each troubleshooting sequence was terminated by a card in format V.

Formats III and IV required reference to the part and terminal location diagram in order to locate testpoints within the module; thus, on format III, lift D 402 19 means the terminal 19 end of D 402 should be lifted from the terminal board. Likewise, meter: 10K 12 17 means that the meter selector switch should be placed in the 10K position, the red lead to the meter placed on terminal 12, and the black lead to the meter placed on terminal 17. In the actual cards used, the number 12 would have been written in red. It is circled here to avoid the necessity for color reproduction.

The expected readings and tolerances on the cards were in scale values rather than ohms or volts, since as the task was structured, the concepts of ohms and volts were not necessary. A reading between the stated scale values was considered good and a reading outside the indicated scale values was considered bad.

Format V cards required reference both to the part and terminal location diagram, and to the parts list (Figure 9) found on the reverse side of the diagram. The parts list conveyed the information that C 104 was a .01 microfarad capacitor at 100 working volts, the required information for selecting the replacement part from stock.

The method used for developing the troubleshooting procedures is briefly outlined in Appendix V. It is covered in somewhat greater detail in a separate report soon to be published.

<u>Component</u>	<u>Stock No.</u>	<u>Component</u>	<u>Stock No.</u>
C 401	0.1MFD, 150V	R 401	1K, 1/2W
402	200MFD, 15V	402	1.2K, 1/2W
403	100MFD, 25V	403	1.5K, 1/2W
404	100MFD, 25V	404	5K, 2W
		405	33K, 1/2W
D 401	1N191	406	82K, 1/2W
402	1N191	407	3.9K, 1/2W
403	1N191	408	2.2K, 1/2W
404	1N191	409	1K, 1/2W
		410	3.9K, 1/2W
Q 403	2N2614	411	390 ohm, 1/2W
		412	270 ohm, 1/2W

Figure 9. Example Parts List

Training

Subjects were trained individually in three 4-hour sessions. Sessions occurred on alternate days for each subject and sessions were broken for 10 minutes at the end of each hour. The first two sessions took place in a room remote from the MTS-2 and dealt primarily with the use of test equipment, within-stage troubleshooting, soldering, and the stock system. This phase of training was followed by a criterion test (Appendix III) prior to entering the final four hours of training. The last training session took place in the room with the MTS-2 and was devoted primarily to between-stage troubleshooting, the MTS-2 check procedure, and a second criterion test on both between and within-stage troubleshooting. An outline of the training content follows:

Session 1 - 4 hours

1. Introduction to personnel, equipment, and materials and a description of the task to be performed by the subjects at the end of training.

2. Operation of the 545A Oscilloscope.
 - a. Presets.
 - b. Troubleshooting guide instructions.
3. Soldering demonstration and practice, installing and removing components from circuit boards.
4. Meter operation and reading.
5. Module assembly and disassembly and use of the module test jig.
6. Parts and terminal location diagrams and their use.
7. Following the within-stage troubleshooting guide, using the meter, and installing and removing components.
8. Selecting components from stock.
9. Integrated practice using the stock system and the parts and terminal location diagram, selecting components from stock, and installing components on circuit boards according to the diagram.

Session 2 - 4 hours

1. Review. Review was tailored to the needs of the subject as indicated by his performance in the first session.
2. Identification of good and bad waveforms on the 545A oscilloscope.
3. Use of transistor test set and measurement of unknown transistors.
4. Review.
5. Criterion test (Appendix III).
6. Module assembly and disassembly. All components were removed from all circuit boards in one module and re-installed using the parts location diagram.

Session 3 - 4 hours

1. Location of testpoints within the MTS-2.
2. Check procedure practice, and identification of out-of-tolerance indications.

3. Use of the between-stage troubleshooting guide.
4. Explanation of instructions for testing.
5. Criterion test, composed of a complete between and within-stage troubleshooting problem under test conditions except that subject was assisted where help was needed. The criterion test will be found in Appendix III.

All subjects consumed the full 12 hours of training, though in some cases it was necessary to fill the time at the end of sessions with review. This was done in order to equalize training time. The purpose of the criterion tests given at the end of sessions 2 and 3 was to identify the need for remedial training and the type of remedial training needed, however, no subject was judged to require additional training. As a result, training times are substantially equal for all subjects. It should be noted that subjects who completed the required training exercises sooner received somewhat more training in that they had additional opportunity to review and practice.

Data Collection

All subjects solved the same problems in the same order. Testing sessions were 4 hours in length and occurred for each subject on alternate days. Subjects solved as many problems as they could in the three sessions available for testing.

The data collection procedure was as follows:

When the subject entered the room, a malfunction was already in the equipment. He began by energizing the equipment in order to run the system check procedure. The time at which the subject operated the first front panel control in energizing the equipment (part of the check procedure) was recorded. Time was recorded again when the subject inserted a probe in a testpoint as part of a between-stage troubleshooting procedure and again when he identified a defective module or connection.

As the subject worked through the troubleshooting guide, he removed from the guide each card he used and placed it in a tray. When he completed the module replacement operation, he took the module replaced and the cards used during between-stage troubleshooting, to the experimenter. The experimenter then recorded the card sequence and the number and location of the module replaced. If the correct module had been identified, S was so informed by E and was given a good module to put in place of the defective one. The system was then checked to verify repair. If S detected the wrong module, he

was informed by E that he had made an error and was told the location of the faulty module, then given the correct module and instructed to install it in the appropriate location. Finally, the system was checked and the repair verified.

After verification of repair, the module containing the malfunction was given to S for within-stage troubleshooting and the time was recorded. When S identified a faulty component inside the module, he informed E, who recorded the time, the sequence of within-stage troubleshooting guide cards used, and the component identified. S then selected an appropriate component from stock, replaced the defective component, and notified E that the repair was complete. E then recorded the time and inspected the subject's work.

On visual inspection, if the repair appeared correct, E told S to close the module and put it in the system for check. However, if the repair was incorrect, if the wrong component was installed or a component was installed incorrectly or if the module was damaged in some way, E pointed out the error to S, but S was not permitted to correct the error. If a malfunction still existed, the module was set aside for later repair by a technician. The repair action taken by the technician was incorporated into the data for that subject and that problem.

Scoring

Between-Stage Troubleshooting Time Scores

1. Initial check time. The time in minutes from the beginning of the MTS-2 check procedure, the first control actuation in the MTS-2 check procedure, until the insertion of the scope probe in a module checkpoint as part of the interstage isolation routine.
2. Module isolation time. The time from the first isolation check, beginning with the insertion of the probe into a testpoint, until the time at which a module replacement operation is identified.
3. Total time. The sum of 1 and 2 above. Note that total time does not include the time required to replace the defective module nor the time required to check the system to verify that the correct module has been replaced.

Checks

The number of checks required to identify the defective module. This number will always be equal to the number of between-stage troubleshooting guide cards used in between-stage isolation. Variation in this score will be due primarily to the location of the malfunction in the data flow. For a single problem, however, variations between subjects can be expected to be related to errors in so far as error

sequences are longer or shorter than correct sequences. The major purpose of this score is to indicate the number of checks required to solve the problems and thus an estimate of difficulty useful in comparing these results to other results on the same or similar equipment.

Between-Stage Troubleshooting Errors

1. Correct module isolation.
2. On-card errors. In an on-card error, the subject selects the wrong alternative of the two on the card. This type of error results from a number of causes discussed in the next section of the report.
3. Off-card errors. The subject selects a card which is not one of the alternatives listed on the previous card. This type of error results from an accident in selection of the card from the guide.
4. Checkout errors. This category includes failure to detect the symptom of malfunction in running a check procedure as well as errors in control setting which caused the subject to enter the troubleshooting guide at the wrong point.

Within-Stage Troubleshooting Time Scores

1. Component isolation time. The time from the moment the subject is given the defective module and told to begin until he informs the experimenter that he has isolated the defective component.
2. Module repair time. The time from the end of component isolation time until the experimenter is called to check the completed repair.
3. Total isolation repair time. The sum of the above two times.

Checks

The number of checks (cards) required to identify the defective piecepart.

Within-Stage Troubleshooting Errors

1. Correct component isolation regardless of repair.
2. Correct repair after correct component isolation.

3. Correct isolation and repair.
4. Off-card errors.
5. On-card errors.
6. Repair errors. Those resulting in failure of module to function properly after a correct component isolation. Repair errors were observed to fall into five categories which were scored separately: (1) physical damage, (2) component orientation, (for example, a diode in backwards or transistor leads reversed or electrolytic capacitor installed with wrong polarity), (3) component location, (4) selecting the wrong part from stock, and (5) cold solder joints.

SECTION III

RESULTS AND DISCUSSION

In the 12 hours allotted for testing, subjects completed a variable number of problems. To insure comparability of treatment group means, all comparisons are based on the first 13 problems. These problems were completed by all subjects. Due to occasional unscheduled equipment malfunctions, it was necessary to discard the scores for various performance dimensions for some subjects on particular problems. Since this occurred very rarely, (only 18 times of a possible 520) missing scores were supplied by substituting the average score of the subjects in the appropriate aptitude group for the missing score.

Between-Stage Troubleshooting

There was no statistically significant difference on any time dimension between the performance of high- and medium-aptitude subjects. Nor was there any statistically significant difference in the number of checks required for between-stage isolation for the two groups. However, a significant difference between the two groups was observed in the percentage of correct module isolations. Table I summarizes the results on the above dimensions. The significance of the mean differences was evaluated with a conventional t test for all dimensions, except correct module isolation which was evaluated by Chi square. The means tabled in Table I are group problem means, that is, the group's mean score on the mean problem.

Table II compares the error performance of the two aptitude groups in terms of the three possible types of between-stage troubleshooting errors. Tabled are the total group score on all of the 13 problems attempted by the subjects in the group. The rarity of errors prevented statistical analysis. Note, however, that low aptitude subjects made nearly twice as many total errors as high aptitude subjects, and that the major part of this difference is on the dimension of on-card errors. The reason that most of the difference is found here is that most of the opportunity for error is contained in this source.

Any off-card, on-card, or checkout error precludes successful completion of the problem (except for a statistically impossible compensating error). Only one error (the first error) is scored for each problem failed. There was an opportunity for checkout errors of one per problem. Once the checkout was successfully completed, there was an opportunity for off or on-card errors of one for each card in the problem. Thus, off and on-card errors, and checkout errors

TABLE I
BETWEEN-STAGE TROUBLESHOOTING:
ON PROBLEMS 1-13

Performance Dimension	Aptitude Groups		Difference	p
	80-95	50-65		
Initial check time (minutes)	7.73	7.89	.16	>.1
Module isolation time (minutes)	4.57	4.15	-.42	>.1
Total time	12.30	12.04	-.26	>.1
Checks	4.43	4.31	-.12	>.1
Correct module isolation (%)	79.00	64.00	-15.00	<.01*

*Significant

TABLE II
BETWEEN-STAGE TROUBLESHOOTING:
TOTAL GROUP ERRORS ON PROBLEMS 1-13

Performance Dimension	Aptitude Groups		Difference
	80-95	50-65	
Off-card errors	3	7	4
On-card errors	19	30	11
Checkout errors	4	6	2
Grand total errors	26	43	17
Opportunity for errors	710	710	0

are mutually exclusive; a subject cannot make more than one type of error in the same problem.

Off-card errors are produced by a slip of the mind or the finger in selecting a card from the troubleshooting guide. On-card errors, however, may be caused by a number of other actions, each of which is probably more likely to occur than the single cause for an off-card error. On-card errors can be the result of inserting the test probe in the wrong module or in the wrong testpoint on the indicated module. They also can be produced by incorrect setting of the test equipment, by failure to detect an out-of-tolerance test indication, or by erroneously accepting as good an out-of-tolerance test result. An on-card error may be caused also by an accident in selecting the correct alternative on the card.

There is nothing in the data to suggest a reason for the medium-aptnitude subjects increased incidence of errors. The small and insignificant differences between the two groups in terms of performance time and in number of checks required for problem solution might suggest that the medium-aptnitude subjects simply were more careless. It would be difficult to attribute the differences to motivation, since all subjects in both groups seemed well motivated, interested in what they were doing, and plainly enjoyed it. The somewhat more practice prior to testing that the quicker subjects received as a result of completing training earlier may in part account for the results, but another reason seems more likely.

In a study done in 1965 in the same laboratory, 18 high school boys were selected in the same manner as those used in the present study and were divided into two aptitude groups (aptitudes 40 to 60 and 70 to 95). The subjects solved similar between-stage troubleshooting problems on the MTS-2, using a similar between-stage troubleshooting guide. Results of that study showed aptitude to have no effect on either speed or accuracy with which the subjects solved the problems. There were some notable differences between the problems used in the two studies, however, and therein may lie the reason for the conflicting results.

The major differences between the two studies were as follows:

1. In the previous study every effort was made to assure that the question of signal condition, i.e., whether a signal was good or bad, both on the front panel and in internal equipment checks, was as unequivocal as possible. The report states

Contrails

that "stated tolerances were plus and minus ten percent; and when an indication was out of tolerance, it was out by at least twenty percent. This was done to reduce the variance contributed by the subject's ability to interpret test equipment, a source of variance not under test and not otherwise controlled."

In the present study, no effort was made to control signal condition equivocality. And stated tolerances were $\pm 2\%$ of full scale.

2. In the previous study, opportunities for errors in use of the oscilloscope were much reduced. The oscilloscope had few controls, and those not absolutely necessary for the tests required were blacked out. The present study employed an unaltered Tektronix 545A.
3. The waveshapes used in the previous study were less numerous and less complex, and in general could be out of tolerance only in amplitude or shape. In the present study, waveshapes could be out of tolerance in frequency and level as well.

The above points suggest that with respect to the use of the oscilloscope the discrimination and responses required of the subjects in the second study (this study) were more numerous and more difficult than those required of the subjects in the first (earlier) study. It may be, therefore, that the aptitude effect was revealed in the present study by the greater difficulty of the tasks. It should be pointed out, however, that the magnitude of the difference is small (though significant) in light of the brief training involved in both cases. And, even though more training time was spent on use of the oscilloscope in the present study than in the earlier one, additional training might well have obliterated the differences both between the two studies and between the two aptitude groups in the present study.

Within Stage Troubleshooting

As in between-stage troubleshooting, aptitude showed no statistically significant differences in the time or the number of checks required by subjects in the two aptitude groups (Table III). Time differences though small were, however, consistently in favor of the high-aptitude group.

Table III also shows a significant difference in the accuracy with which high- and medium-aptitude subjects correctly identified malfunctioning piecparts within the module, high-aptitude subjects making 93% correct identifications and medium-aptitude subjects, 82%. The frequency with which a correct repair action after a correct isolation was made was not significantly different for the two groups though the difference was 89% versus 87% in favor of the high aptitude group.

TABLE III

WITHIN STAGE TROUBLESHOOTING:

PROBLEM MEANS AND GROUP MEAN DIFFERENCES ON PROBLEMS 1-13

Performance Dimension	Aptitude Groups		Difference	p
	80-95	50-65		
Component Isolation time (minutes)	14.84	15.37	.53	>.10
Module repair time (minutes)	13.00	13.65	.65	>.10
Total isolation and repair time (minutes)	27.84	29.02	1.18	--
Checks	5.33	4.84	-.49	--
Correct component isolation (%)	93.00	82.00	-11.00	<.01*
Correct repair after correct isolation (%)	89.00	87.00	-2.00	>.10
Correct isolation and repair (%)	83.00	71.00	12.00	<.01*

*Significant

TABLE IV

WITHIN STAGE TROUBLESHOOTING:

TOTAL GROUP ERRORS ON PROBLEMS 1-13

Performance Dimension	Aptitude Groups		Difference
	80-95	50-65	
Off-card errors	2	1	-1
On-card errors	5	19	14
Repair Errors			
Physical damage	2	3	1
Component orientation	10	7	-3
Component location	1	1	0
Wrong part from stock	1	1	0
Cold solder joint	0	2	2
Total repair errors	14	14	0
Total errors	21	34	13

Again, on-card errors accounted for the bulk of the difference between the two groups in terms of performance accuracy (Table IV). As was the case in between-stage troubleshooting, the opportunities for off-card error producing actions are considerably more numerous than those for on-card errors. Three pieces of test equipment are involved in within-stage troubleshooting, the scope, the meter, and the transistor checker, any of which can be misset or misread. The proximity of test points on the circuit boards and the similarity in appearance of adjacent circuit boards on the test jig make scope or meter probe placement relatively error likely. And signal condition (in or out of tolerance) was often fairly equivocal as a result of the obtained reading's proximity to tolerance limits.

Note that both the high- and medium-aptitude group made the same absolute number of repair errors. (The percentage of errors was slightly different, due to differential opportunity resulting from high-aptitude subjects correctly identifying malfunctioning components somewhat more frequently than did medium-aptitude subjects.) Most of the repair errors in both groups were of the component orientation type, and a close examination of the data shows that the bulk of these errors resulted from installing diodes in reverse polarity. This condition was traced to some ambiguity in the training situation regarding this aspect of repair. Correction of this defect would have eliminated more than half of the component orientation errors.

Though the percentage of correct between- and within-stage isolation and repair operations (final row in Table III) was not as high in either the high- or medium-aptitude groups as perhaps would be expected of technicians in the real world work situation, three points should be mentioned:

1. There is no evidence to indicate that present technical performance in the Air Force is significantly better than this. This is not to say that it is not better, merely that its condition is unknown. Thus, it is possible that the performance noted herein is better than that now obtained in the field.
2. The scores presented in Tables I and III represent a single attempt at a problem solution. In the field, a technician is usually permitted to work on a problem until he solves it or determines that he cannot solve it, for a variety of possible reasons, e.g., lack of test equipment, lack of needed parts, etc. Further, it is his job to "get the equipment on the air", and the pressures on him to do so might be greater than those on the experimental subjects.

3. The measures in the present study were recorded at the end of an extremely brief training period relative to that normally experienced by Air Force technicians. If the training of the present subjects had been increased by a factor of 10, their performance would doubtless have improved. Yet, the time invested in their training would then be three weeks as opposed to the 20 to 40 weeks training now common in the Air Force.

It is also true that the performance of these subjects was measured immediately after training. Yet, it is commonly accepted that the proficiency of the conventional technician improves steadily for a period of several months after training. The point is that it is probably more reasonable to compare the performance of these subjects to that of three-skill-level technicians immediately after tech school, rather than to that of five- and seven-skill-level technicians with some years of experience in the field.

Clearly the foregoing is of little significance if the job performed by the subjects in this study is not comparable to that performed by Air Force technicians. In terms of the number of electronic pieceparts, about 2,000, the MTS-2 is comparable to many small systems. The MTS-2 has about a hundred "black boxes". This makes it comparable to many medium-sized fire control systems in that respect. It should be pointed out that many Air Force AFSC's maintain equipment only to the "black box" level.

Once a small "black box" is removed from a system and maintenance is to be performed on that box only, the task is then a function of the size complexity, number of components, etc. in that "black box". Rationally, the problem must be approached with the objective of delimiting the malfunction in the box to a stage, or small number of components, and then troubleshooting within that small group of components to find the defective piecepart. This is exactly what the subjects did in this study.

In terms of the size and complexity of the equipment and the extent of the task (maintenance level), the job done by the subjects in this study is comparable to the jobs done by a majority of Air Force electronic technicians. If we may make a distinction between job and task, however, the task performed by the subjects was very different from that performed by Air Force technicians. This difference resulted from the present subjects' training and performance aids which operated together to structure and support the tasks involved in doing the job. An integrated training and performance aid system of the sort used by these subjects exists nowhere in the Air Force.

SECTION IV

SUMMARY AND CONCLUSION

Twenty high school junior boys were used as subjects in a study of the effect of subject aptitude on performance of procedural between and within-stage troubleshooting, and repair tasks on a real piece of electronic equipment, the MTS-2. Two aptitude groups (AQE Electronic index 50 to 65 and 80 to 95 percentiles) were used. Subjects detected malfunction symptoms in the course of checkout procedures, collected information at test points located on black boxes inside the equipment using an oscilloscope, installed and removed black boxes, isolated and repaired electronic malfunctions in circuitry inside the black boxes using a scope, volt ohmmeter, and transistor checker.

Each subject had a total of 12 hours of training and practice in operation of test equipment, the operation of the MTS-2, and in the use of troubleshooting guides, parts locations diagrams, and parts lists in connection with malfunction isolation activities. The troubleshooting guides controlled the sequence of checks performed in between-and within-stage isolation on the basis of results of checks having binary outcomes. Immediately after training each subject solved a minimum of 13 corrective maintenance and repair problems on the MTS-2.

The study had two major objectives:

- I. To develop and try out within-stage troubleshooting routines which could be used after very brief training by subjects with no previous training or experience in electronics. This effort was successful to the extent that 87.5% of problems attempted by all subjects were solved correctly in a single attempt.
- II. To test the effect of electronic aptitude, as traditionally measured, on performance of such tasks. Here there were three important findings:
 1. Aptitude had no effect on the time required for between-or within-stage isolation.
 2. Aptitude had no effect on errors made in repair of defective modules.
 3. A statistically significant difference attributable to aptitude was demonstrated in the ability of subjects to correctly isolate defective modules within the system and defective components within the modules.

The above findings suggest that the use of proceduralized troubleshooting could reduce the cost of training Air Force electronic maintenance technicians. They also suggest (the performance difference between high-and medium-aptitude subjects notwithstanding) that the use of proceduralized troubleshooting could effectively enlarge the manpower pool from which trainees must come. These potential benefits are of little significance, however, if they can be realized only by sacrificing the quality of maintenance.

If the sort of training-performance aids system used in the present study is as effective as conventional Air Force training and performance aids, an excellent demonstration would consist of a comparison of the performance of the present subjects to that of skilled Air Force technicians using Air Force tech orders in solving the same problems used in the present study. Such a study, involving the within-stage portions of the problems only, is presently in the planning stages and will be executed in 1967.

APPENDIX I

SUBJECT APTITUDE

	Medium Aptitude	High Aptitude
AQE - EL Score	65	90
	50	85
	50	95
	55	85
	50	90
	55	95
	55	95
	60	80
	60	95
	60	95

APPENDIX II

MTS-2 SYSTEM CHECK PROCEDURE

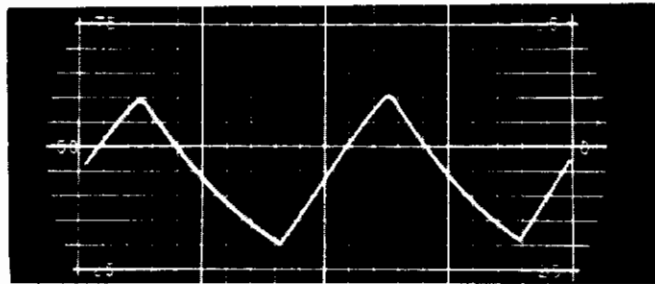
- | | | |
|--------|--|---------------------|
| | 1. System CB's | on |
| | 2. Standby | on |
| | 3. Standby Light | lights |
| | 4. Meter Selector | 300 B |
| (S004) | 5. Test Meter | 155 |
| | 6. Meter Selector | 120 |
| | 7. Test Meter | 45 - 50 |
| | 8. Meter Selector | mix XTL 1 |
| | 9. Test Meter | 165 |
| | 10. Meter Selector | mix XTL 2 |
| | 11. Test Meter | 55 |
| | 12. Ready Light | lights |
| | 13. Frequency Tune | up |
| (Q004) | 14. | motor sound |
| | High Limit Light | lights |
| | | motor sound stops |
| | 15. RF | off |
| | 16. Frequency Tune | Down |
| | 17. Frequency Meter | RF carrier power 10 |
| | If this cannot be done
go on to 18. | |
| | 18. RF | 1 |
| | 19. Frequency Meter | RF carrier power 20 |

Contrails

If this reading is not
obtained continue to
step 20.

- | | | |
|-----|--|---------|
| 20. | Frequency Tune | down |
| 21. | Lo Limit Light | lights |
| | Motor Stops | |
| 22. | Radiate | on |
| 23. | Radiate Light | lights |
| | Standby Light | off |
| | Ready Light | off |
| 24. | ARI Power | on |
| 25. | ARI Scope Graticle | on |
| 26. | ARI Sweep | on |
| 27. | TC Input | off |
| | Range | 1 |
| | ARI Sweep Speed | 1 |
| | Allow scope to warm for
about 2 minutes. | |
| 28. | Center the trace on the
scope X & Y and adjust
trace length for 20
divisions. | |
| 29. | ARI Sweep Speed | 2 |
| | Range | 5 |
| | Sweep Delay | on |
| | Computer | on |
| | BNS Power | off |
| | TC Sweep | off |
| | Primary Power | off |
| | Sweep Vernier | full CW |

(A001) 30. Scope



31. TC Input

5

32. Range

7

Primary Power

on

BNS Power

on

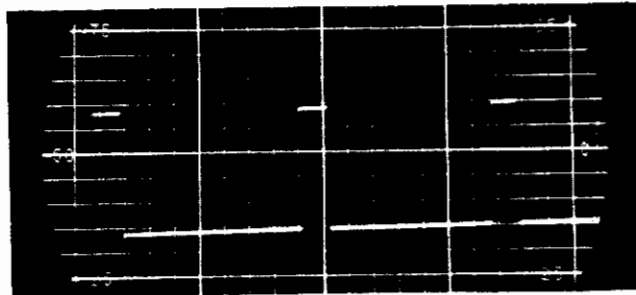
BNS Heater

on

ARI Y Atten.

CW

(B001) 33. Scope



34. RF

off

(C001) 35. Frequency Meter

40 - 50% modulation

36. ARI Y Atten.

CW

BNS Heater

off

TC Input

2

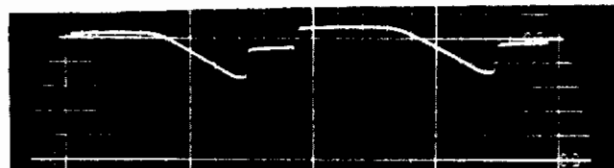
Range

6

Primary Power

off

(E001) 37. Scope

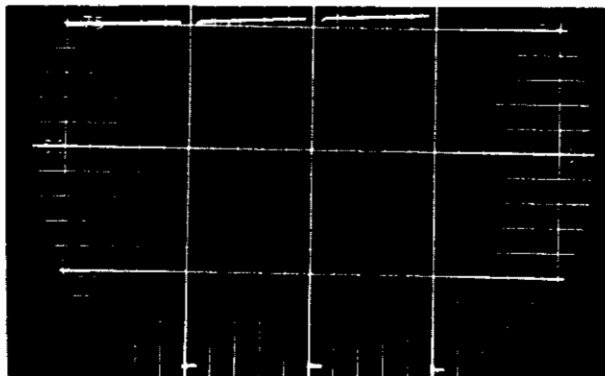


Contrails

	TC Sweep	on
38.	RF	1
39.	BNS Power	off
(F001) 40.	Frequency Meter	10 - 20% modulation
	ARI Y Attenuator	off
	Primary Power	on
	Sweep Vernier	1
	TC Input	3
	BNS Heater	on
	Sweep Delay	off
	TC Sweep	off

Adjust X position & X Amplitude
to obtain desired display

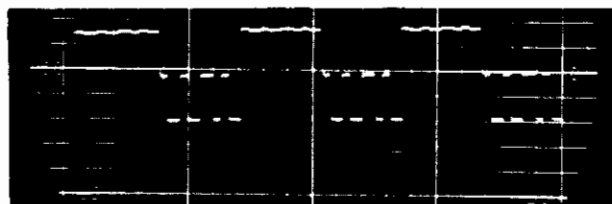
(G001) 41. Scope



42. TC input

1

(H001) 43. Scope



44. Expand portion of sweep marked
above to 20 Div.

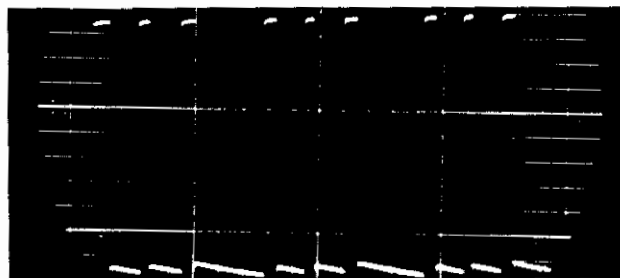


45. Readjust full trace to 20 Div.

46. TC Input

4

(K001) 47. Scope

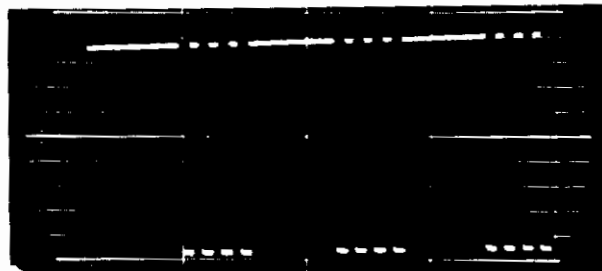


48. TC Input

off

(J001) 49. TC Scope

A slight adjustment of
sweep vernier may be
necessary at position 1



APPENDIX III CRITERION TESTS 1 and 2

Criterion Test - 1

3966-1

Module 600 - R 603 bad

Subject_____ No._____ Group_____ Date_____ Session_____

- | | | |
|--------------------------|---|--------------------------|
| <input type="checkbox"/> | 1. Install module on test jig | |
| <input type="checkbox"/> | 2. Select correct page in layout book | Soldering Assists |
| <input type="checkbox"/> | 3. Take back plate off (use care in handling boards) | <input type="checkbox"/> |
| <input type="checkbox"/> | 4. Unstack erie boards according to book (in this case only one exists) | <input type="checkbox"/> |
| <input type="checkbox"/> | 5. Visual inspection - Card 601 | <input type="checkbox"/> |
| <input type="checkbox"/> | 6. Card 602 | <input type="checkbox"/> |
| <input type="checkbox"/> | Remove transistors properly (heat sink) | <input type="checkbox"/> |
| <input type="checkbox"/> | Clip transistors with numbered clips | <input type="checkbox"/> |
| <input type="checkbox"/> | Check Q 602 properly | <input type="checkbox"/> |
| <input type="checkbox"/> | Correct reading - good | |
| <input type="checkbox"/> | 7. Card 603 | |
| <input type="checkbox"/> | List R 606 from 5 properly | |
| <input type="checkbox"/> | Select correct meter scale (1k) | |
| <input type="checkbox"/> | Zero the meter | |
| <input type="checkbox"/> | Proper probe placement (5 and 4) | |
| <input type="checkbox"/> | Correct reading - good | |
| <input type="checkbox"/> | 8. Card 604 | |
| <input type="checkbox"/> | Select correct meter scale (1k) | |

Contrails

- ☐ Zero the meter
- ☐ Proper probe placement (12 and Free R 606)
- ☐ Correct reading - good

9. Card 609

- ☐ Select correct scale (1k)
- ☐ Zero the meter

Soldering
Assists

- ☐ Proper probe placement (8 and 2)
- ☐ Correct reading - good

☐
☐

10. Card 611

- ☐ Select correct scale (X10)
- ☐ Zero the meter

☐
☐

- ☐ Proper probe placement (3 and 9)
- ☐ Correct reading - bad

11. Card 612

- ☐ Remove R 603 properly
- ☐ Get correct placement from stock
- ☐ Install replacement properly

12. Reinstall transistors properly (heat sink)

13. Close up module properly

Score

Criterion NMT: 1 assist on Scale Selection

1 assist on card selection

2 assist on probe placement

2 assist on meter zero

3 assist on soldering

Contrails

2 assist on rough handling _____

1 assist in any other category _____

Note:

Final Criterion Test

Subject Name _____ No. _____ Group _____

Date _____ Session _____

Bug - Remove wire from patchboard IV D-1

System check procedure

Time _____

- | | | |
|---------------------------------|---|---------------------|
| <input type="checkbox"/> | 1. System CB's | on |
| <input type="checkbox"/> | 2. Standby | on |
| <input type="checkbox"/> | 3. Standby Light | lights |
| <input type="checkbox"/> (S002) | 4. Meter Selector | 300 B |
| <input type="checkbox"/> | 5. Test Meter | 155 |
| <input type="checkbox"/> | 6. Meter Selector | 120 |
| <input type="checkbox"/> | 7. Test Meter | 45 - 50 |
| <input type="checkbox"/> | 8. Meter Selector | mix XTL 1 |
| <input type="checkbox"/> | 9. Test Meter | 165 |
| <input type="checkbox"/> | 10. Meter Selector | mix XTL 2 |
| <input type="checkbox"/> | 11. Test Meter | 55 |
| <input type="checkbox"/> | 12. Ready Light | lights |
| <input type="checkbox"/> (Q002) | 13. Frequency Tune | up |
| <input type="checkbox"/> | 14. | motor sound |
| <input type="checkbox"/> | 15. High Limit Light | lights |
| <input type="checkbox"/> | 16. | motor sound stops |
| <input type="checkbox"/> | 17. RF | off |
| <input type="checkbox"/> | 18. Freq. Tune | down |
| <input type="checkbox"/> | 19. Freq. Meter | RF carrier power 10 |
| <input type="checkbox"/> | 20. If this cannot be done go to next step. | |

Contrails

- | | | |
|--------------------------|---|---------------------|
| <input type="checkbox"/> | 21. RF | 1 |
| <input type="checkbox"/> | 22. Freq. Meter | RF carrier power 20 |
| <input type="checkbox"/> | 23. If this cannot be done go on to next step. | |
| <input type="checkbox"/> | 24. Freq. Tune | down |
| <input type="checkbox"/> | 25. Lo Limit Light | lights |
| <input type="checkbox"/> | 26. Motor Stops | |
| <input type="checkbox"/> | 27. Radiate | on |
| <input type="checkbox"/> | 28. Radiate Light | lights |
| <input type="checkbox"/> | Standby Light | off |
| <input type="checkbox"/> | Ready Light | off |
| <input type="checkbox"/> | 29. ARI Power | on |
| <input type="checkbox"/> | 30. ARI Scope Graticle | on |
| <input type="checkbox"/> | 31. ARI Sweep | on |
| <input type="checkbox"/> | 32. TC Input | off |
| <input type="checkbox"/> | 33. Range | 1 |
| <input type="checkbox"/> | 34. ARI Sweep Speed | 1 |
| <input type="checkbox"/> | 35. Allow scope to warm up for about 2 minutes. | |
| <input type="checkbox"/> | 36. Center the trace on the scope x and y and adjust trace length for 20 divisions. | |
| <input type="checkbox"/> | 37. ARI Sweep Speed | 2 |
| <input type="checkbox"/> | 38. Range | 5 |
| <input type="checkbox"/> | 39. Sweep Delay | on |
| <input type="checkbox"/> | 40. Computer | on |
| <input type="checkbox"/> | 41. BNS Power | off |
| <input type="checkbox"/> | 42. TC Sweep | off |

Contrails

<input type="checkbox"/>		43. Primary Power	off
<input type="checkbox"/>		44. Sweep Vernier	full CW
<input type="checkbox"/>	(A001)	45. Scope	
<input type="checkbox"/>		46. TC Input	5
<input type="checkbox"/>		47. Range	7
<input type="checkbox"/>		48. Primary Power	on
<input type="checkbox"/>		49. BNS Power	on
<input type="checkbox"/>		50. BNS Heater	on
<input type="checkbox"/>		51. ARI Y Atten.	CW
<input type="checkbox"/>	(B001)	52. Scope	
<input type="checkbox"/>		53. RF	off
<input type="checkbox"/>	(C001)	54. Freq. Meter	40 - 50% modulation
<input type="checkbox"/>		55. ARI Y Atten.	off
<input type="checkbox"/>		56. Antenna	on
<input type="checkbox"/>		57. TC Input	2
<input type="checkbox"/>		58. Range	6
<input type="checkbox"/>		59. Primary Power	off
<input type="checkbox"/>	(E001)	60. Scope	
<input type="checkbox"/>		61. TC Sweep	on
<input type="checkbox"/>		62. RF	1
<input type="checkbox"/>		63. BNS Power	off
<input type="checkbox"/>	(F001)	64. Freq. Meter	10% modulation
<input type="checkbox"/>		65. ARI Y Atten.	off
<input type="checkbox"/>		66. Primary Power	on
<input type="checkbox"/>		67. Sweep Vernier	1

Contrails

- ☐ 68. TC Input 3
- ☐ 69. Sweep Delay off
- ☐ 70. Adjust X position and X amplitude to obtain desired display.
- ☐ (G001) 71. Scope
- ☐ 72. TC Input 1
- ☐ (H001) 73. Scope
- ☐ (H001) 74. Expand portion of sweep marked to 20 divisions.
- ☐ 75. Readjust full trace to 20 divisions.
- ☐ 76. TC Input 4
- ☐ (K001) 77. Scope
- ☐ 78. TC Input off
- ☐ (J001) 79. TC Scope (malfunction)
A slight adjustment of sweep vernier may be necessary at position 1.
- ☐ 80. Card J001
- ☐ 81. Proper switch positions set
- ☐ 82. Card J002
- ☐ 83. Proper system state, proper scope set up, proper module, proper testpoint
- ☐ 84. Conclude Bad Conn IV D-1 II C-14
- ☐ Module 200 (Bug - R 203 10 meg)
- ☐ 1. Position module properly on test jig, select proper parts layout, and TSG deck.
- ☐ 2. Remove back plate properly.

Contrails

- ☐ 3. Remove erie boards properly
and position them on test
jig according to the diagram
(A-top, B-middle, C-bottom)
- ☐ 4. Fasten erie boards to test jig.
- ☐ 5. Card 201
(Switch must not be on reset)
Visual inspection
- ☐ 6. Card 202

Remove transistors properly (heat sink)

Test transistors properly

Correct reading - all good
- ☐ 7. Card 204

Lift D 203 from 42

Lift R 203 from 10
- ☐ 8. Card 205

Set VOM correctly (1k)

Zero the meter

Proper probe placement

red - free end D 203;
black - 19

Correct reading - good
- ☐ 9. Card 206

Set VOM correctly (1k)

Zero the meter

Proper probe placement

black - 19
red - Free end R 203

Correct reading - bad

Contrails

- ☐ 10. Card 208
- ☐ Remove R 203 correctly
- ☐ Get proper component from stock (8.2 k 1/2 watt)
- ☐ Replace R 203 with proper component
- ☐ 11. Replace transistors correctly (heat sink)
- ☐ 12. Ask E to make a visual inspection
- ☐ 13. Replace erie boards on back plate
- ☐ 14. Button up module properly
- ☐ 15. Check in MTS-2

APPENDIX IV

SUMMARY OF METHOD USED IN DEVELOPMENT OF WITHIN-STAGE

TROUBLESHOOTING TEST SEQUENCES

Step I: Visual Inspection

This rather low cost check can be made without complete disassembly and has a high probability of identifying any mechanically damaged components, wires, terminals, etc.

Step II: Fragment the Circuit

This step is performed in two phases. The first phase, with power on, fragments the circuit conceptually. It consists of an attempt to find a point in the circuit upstream of which the signal is good and downstream of which the signal is bad, using an oscilloscope or volt meter. Frequently the attempt is successful resulting in a considerable reduction in the search field and, thus, in the time (and opportunity for error) required to resolve the remaining uncertainty.

In phase two, with power off, all transistors in the group of components to which the malfunction has been localized are removed and checked one at a time. If none is found to be bad, all are left out of the circuit. This fragments the circuit physically. It leaves the group of components known to contain the malfunction in a state of unconnected strings of one to a half dozen resistors, capacitors, and diodes.

Step III: Specify the Test Sequence

This is done by first rank ordering the fragments to be tested in decreasing order of probability of containing the malfunction. Other things being equal, the fragment most likely to contain the malfunction is the fragment which contains the most components.

Then for each fragment a single test is specified which, if it is passed, eliminates the fragment from possibility of containing the malfunction. Further fragmentation by lifting one lead of a component may be necessary in some cases to eliminate the possibility of equivocal test results. Tests of each fragment in order are specified until all fragments are exhausted.

A test sequence must, similarly, be specified for the identification of each component within each fragment. In practice, (using the test sequence to identify a defective component) each fragment

is tested until an out-of-tolerance result is obtained; then tests are made within the fragment on which the bad test result is obtained, half splitting series connecting components wherever possible until the defective component is identified.

Step IV: Define and Check the Procedure for Efficiency

Step V: Determine Normal Readings and Tolerances

In practice, these two steps involve fragmenting the circuit and making the measurements on the fragments, as required by the tests specified in the test sequence. Theoretically, these measurements could be calculated but actually making them serves as an additional check on the steps which have gone before and is likely to bring about some procedural improvement.

The setting of tolerances is highly judgmental, particularly when the tolerances are on check results involving a string of five components whose tolerances are nominally ten per cent.

Step VI: Format and Validate the Procedure

Once the procedure is formatted, it remains to test it against the hardware. This requires putting "bugs" in the equipment to see if the procedure will find them. In a surprisingly short time the procedure can (and should) be tested against at least one malfunction in every system component.

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Contrails

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13. ABSTRACT <p>After twelve hours training, twenty subjects with no prior training in electronics solved complete electronic equipment maintenance problems on a realistic equipment simulator, the MTS-2. Subjects selected were from two electronic aptitude groups (AQE-E1 45-60 and 80-95 percentiles). The problems were composed of equipment checkout, malfunctioning "black box" isolation (within-stage troubleshooting), piecepart isolation (within-stage troubleshooting), and repair tasks. In lieu of expensive conventional electronic training, subjects were aided in the performance of the above tasks by troubleshooting guides which, given the result of previous checks, told subjects where to check next. Results of the study showed that aptitude had no effect on performance time, or errors in repair. A small but significant difference was noted in the ability of the two groups to isolate defective "black boxes" and pieceparts; high-aptitude subjects performed somewhat better on this dimension.</p>			

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