$\log UCL_{95} = \log M_{max_{ct}} + \phi \,(S.\ E._{95})$.

$\log M_{max_{ct}}$ represents the logarithm of $M_{max_{ct}}$ at the 95th percentile,

ϕ represents the confidence level

$\log UCL_{95}$ represents the logarithm of the upper confidence limit of $M_{max_{ct}}$ (95th percentile).

AUTOMATIC ELECTRONIC MEASUREMENT AND EVALUATION AND ITS APPLICATION TO TRAINING SYSTEMS AND DEVICES

RAYMOND C. LOWRY
Northrop-Nortronics

1. Why Automatic Measurement and Evaluation?

It would seem appropriate at the very start of this discussion to ask the question: "Why are we concerned with automatic measurement and evaluation?" The answer is not long in coming to the surface. The rapid pace of developments in scientific technology has resulted in some very real, and critical, growing pains. Far from the least of these pains is man's almost breathless effort to keep up with his machines. The human mind, for example, is simply incapable of comprehending the speed with which a modern digital computer performs its computations, yet this same speed has provided machine capabilities heretofore unknown. Computer techniques are now employed in an almost endless variety of applications from the control of milling machines to the baking of bread; from the making of decisions to supplying vast amounts of information from systems in outer space.

As these capabilities increase and their applications are expanded, their importance in our society continues to grow. In both the civilian and the military, we have arrived at the point where a breakdown in some of our creations can produce havoc, and even disaster. We are faced then with the necessity of directing substantial effort toward, first, minimizing the number of breakdowns, and second, of returning our systems to operational status in the shortest possible time when the inevitable breakdown does occur.

With this great dependence upon the proper functioning of machines, we are left with no alternative but to admit to the fact that the conventional multimeter and handbook easter egg hunt technique is no longer an acceptable maintenance procedure. This fact is recognized, and we are well on our way toward providing the technician with the necessary high speed tools of his trade.

2. What is Automatic Electronic Measurement and Evaluation?

Let's look briefly at what, exactly, automatic electronic measurement and evaluation is.

It could be defined, in short, as simply a program controlled performance, by machine, of the very same activities which are involved when a technician manually troubleshoots a malfunctioning equipment. Just what are these troubleshooting activities? There are variations, of course, but they consist in some form and degree in the performance of these six operations for each measurement made:

THE SIX OPERATIONS OF A TEST MEASUREMENT

1. Reference to Available Data
2. Selection of a Measurement Point
3. Gaining Access to the Measurement Point
4. Making the Measurement
5. Evaluating Result of the Measurement
6. Making a Decision.

For the technician, the available data will always consist in part, of his individual knowledge gained from training and experience. In a few cases, this knowledge along may be all that he will need. Usually, however, he will turn for reference to handbooks, charts, diagrams, etc. From this point he will proceed through some more or less organized plan, depending on his training, experience and judgement, to go through these six steps as many times as necessary.

We indicated that these very same steps are performed in automatic measurement and evaluation. Let's see how. First, most of the effort involved in reference to available data is accomplished a long time prior to the actual need for the series of measurements. Careful engineering studies will have produced a complete test program. The program will be proofed on operating equipment at a test facility. Any additions, corrections, or deletions which may be found necessary will be accomplished. This process will be repeated as many times as required in order to insure a test program as nearly perfect as possible. This program, generally on tape, is then sent into the field for further proofing. When finally approved, the tape program represents the knowledge and experience of capable engineers and technicians, plus the added bonus of many hours of testing and de-bugging. Selection of the measurement points has been made, and the tape contains instructions to the automatic test set for gaining access to these points. The tape also contains instructions for setting the measurement subsystem to the scale and range required for each measurement. Data also stored on the tape will instruct the evaluation subsystem as to what value limits are acceptable. Each measurement is made, evaluated, recorded, and a decision is rendered. How long does all this take? On the average, only a fraction of a second per measurement.

There are, of course, many variations in design, flexibility, and capability in automatic test systems. These variables are dictated by requirements.

The block diagram, Figure 129, depicts in a very fundamental manner the typical functional blocks and information flow in an automatic test system. These blocks will carry different designations in different systems, but the functions will be similar. In some systems, logic circuitry may be included to modify the test program as a result of measurements made. More on that later. Let me emphasize that in this diagram no attempt is made to show actual flow paths. Rather, it is intended to depict the general flow of functional activities and information.

For a moment then, let's examine the diagram. As already stated, our complete program is on tape. It is identified on the slide as "Test Program Information." This information is fed, sequentially, into the "Programmer," where it initiates the generation of various control signals. Typically, such signals are those which are routed to the "Stimuli" block. This block covers a multitude of functions which range from such as simply energizing the "System Under Test" to injecting a signal into an amplifier for a gain measurement to supplying RF energy into a wareguide for a standing wave ratio measurement. A control signal to the "Test Point Selector" directs its function of connecting the desired points within the system under test into the "Measurement Subsystem." Similarly, control signals are routed into the "Evaluation Subsystem" to insert the required high and low limits for each measurement, and into the measurement subsystem to set it to the correct scale and range, and to start the measurement cycle. The value of the measured quantity is then forwarded to the evaluation subsystem, and to the "Display and Recording Subsystem," where it will be displayed and recorded along with the result of the evaluation. Not shown in this block diagram, but integral to all such systems, is the feedback loop. This loop, along with other verification methods, helps to insure the validity of the test results. These checks verify the internal performance of the test set many times for every measurement made. This is Automatic Electronic Measurement and Evaluation.

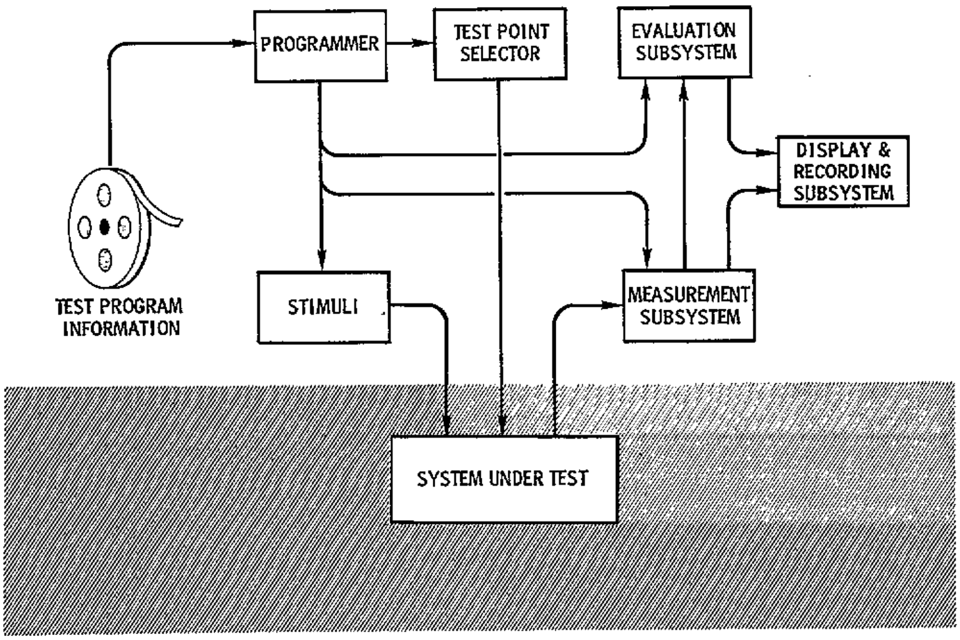

Figure 129. Typical Functional Blocks and Information Flow in an Automatic Test System.

Up to this point we have discussed automatic test systems in their capacity of failure isolation devices. There is another function of at least equal value and importance. It is that of detecting trends, and providing warning of impending failure. By simply programming measurements at specially selected test points, at regular intervals, degradation from normal conditions can be observed. Such automatic measurement sequences can be run in a matter of seconds, at predetermined intervals, and the evaluation subsystem can be instructed to flag small deviations from normal. With the printout of each measured value at hand, the maintenance technician sees the trend. He is able to take corrective action at a time when the system can be taken off the line with a minimum loss of service, and the actual failure is aborted.

3. The Evolution of Automatic Test Systems

Let's look now for a moment at the evolution of automatic testing. It would be difficult to erect a signpost at some specific point in history, and say "Here is where automatic testing started." Certainly the child was not born full grown. It has rather been a natural development resulting from a universal problem; that of keeping our ever-increasingly sophisticated systems on the line. Early efforts in this direction were represented by little more than meters, mounted on the front panels of prime equipments, fed through a multiple position manually operated switch. From that start, we proceeded through a proliferation of semi-automatic, and usually portable, testing devices of limited capability. Continuing effort was rewarded by the introduction of completely automatic test systems. These early test systems had one thing in common. They were designed to exercise their capabilities on one prime system only. Important as this single purpose device was, and still is today, it soon became apparent that automatic test systems were needed which could be readily married to many different prime systems.

Relatively early examples of each of these types of systems evolved during the 1956-1958 period. RCA, for example, produced a special purpose system called DATS, Dynamic Accuracy Test Systems. (Figure 130) DATS was designed specifically to check out the weapon control system on the F-120 interceptor. At about the same time, Nortronics introduced its "universal," or general purpose, system which was labled DATICO; Digital Automatic Tape Intelligence Check Out. Both of these systems proved to be highly effective, and both went into production. Subsequently, we have seen consistent progress in the enhancement of the speed, accuracy, and reliability of automatic test systems.

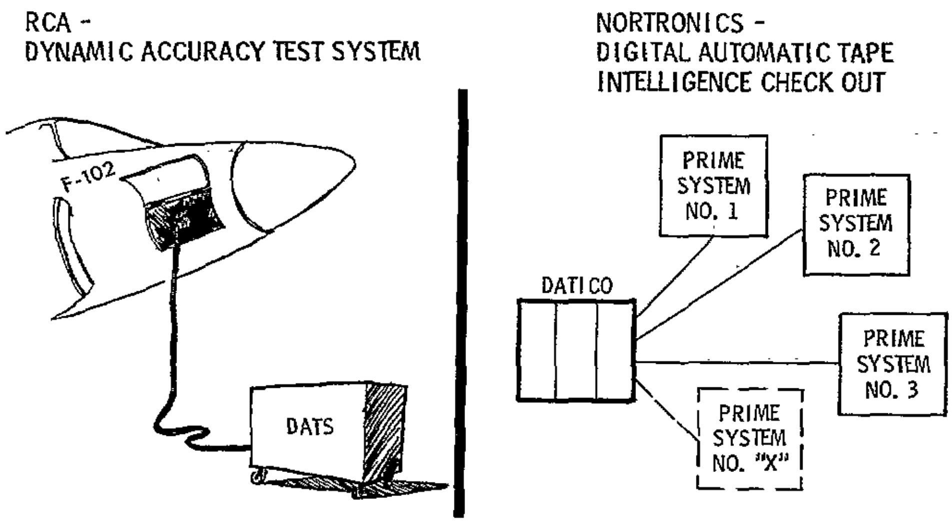

Figure 130. DATS - DATICO

Thus far, we have considered automatic test system classifications in terms of "general purpose" and "special purpose." Functionwise, and sometimes equipmentwise, they may be classified also as "on-line" and "off-line." Although these terms are largely self-explanatory, some expansion may be in order. The off-line function, or system, is generally able to perform tests to a greater depth. That is, a card or module removed from its parent system may be checked to component or immediate circuit level. The requirements for off-line tests are such that they cannot be made while the unit under test is performing its normal function in the system. On-line tests, on the other hand, may be made while the system is in normal operating configuration.

4. Some Applications of Automatic Test Systems

A few examples of past and present applications of automatic testing might be of interest. We have already mentioned the application of DATS to the F-102 weapon control system. The Army Rocket and Guided Missile Agency directed the development of an early automatic test system. It was used to verify the performance of the Nike, La Crosse, Hawk, Sergeant, and Corporal missiles at all levels, from system through piece part. The Air Force has employed automatic test systems to bench test and fault-isolate such systems as the APX-25 Radar Transponder, the ARC27 Transceiver, and the B-6 Multi-Channel Amplifier. Typical tests performed were transmitter power and frequency measurements, receiver bandwidth, DC and AC voltage measurements, and general malfunction isolation. The Polaris/Poseidon missile program employs automatic testing and monitoring from initial missile assembly checkout to preparation and checkout for launch; from depot package testing to underway off-line fault isolation testing.

5. What Does ATS Buy for Dollars Invested?

"Very well," you say, "but what does all this buy for me for the dollars I put into it?"

This is certainly an appropriate question. Let's look for some answers. The first, and probably the most obvious answer, is less down-time on your systems. ATS contributes to this in at least two ways. First, when a casualty occurs, fault isolation is much more easily and swiftly accomplished. Second, the regular surveillance of selected system parameters facilitates the detection of potential failures before they occur.

Another value received is in the area of maintenance personnel. The initial cost of a major electronic system represents a relatively small portion of its total life cycle cost. Far from the smallest factor in this long range cost is that for personnel. ATS, in providing more rapid fault isolation, reduces the total maintenance manpower requirement. In addition, personnel with lesser skill levels may be employed in many maintenance billets. This, in turn, reduces training costs.

What might be looked upon as a "bonus" return is the factor of improved overall prime system performance. It has been demonstrated under operational conditions, that where a system is regularly monitored by a well-engineered automatic program, the performance of that system can be maintained at a consistently higher level than a similar system not so monitored.

6. What is the Manpower Impact of ATS?

A somewhat related question to be considered is that the total manpower impact of ATS. The answer to this question will be, to a large extent, dependent upon the total of the factors in each individual application. The design goal is to realize an overall reduction in maintenance personnel for any specific situation and set of conditions.

7. ATS as a Factor in Maintainability

The factor of maintainability has, over the years, certainly received less than its share of attention in the design and manufacture of just about everything from automobiles to radar systems. Many of us have encountered the maintainability problem when we decided to change the "plugs" in the family car. Sure, it was no problem at all for the factory to install those plugs when the engine was out on the assembly bench. When it was slid down between the radiator and the fire-wall however, with a half inch clearance between each side and the wheel wells, it was something else again. What with the intake and exhaust manifolds already in the way, the power brake actuator, the power steering pump, the smog control pump, the air conditioner compressor, battery, air intake filter, and a multitude of belts and hoses are all carefully laced into place and individually bolted down on top of it all. Now, just try to find the spark plugs. This situation is not at all unlike that which has faced our military maintenance man through the years. While he has tried to snake a test probe through a maze of components and hot wires to make a measurement, some sniper was taking pot-shots at him, or his ship was rolling in heavy seas. This, of course, represents only one of the many facets of the big picture of maintainability. It is gratifying to see that these dark ages, so to speak, are on their way out.

NavShips document number 94324 "Maintainability Design Criteria Handbook for Designers of Shipboard Electronic Equipment" contains this definition:

> MAINTAINABILITY DESIGN IS THAT PART OF ELECTRONIC EQUIPMENT DESIGN THAT PROVIDES FEATURES AND FUNCTIONS THAT CONTRIBUTE TO THE RAPIDITY, ECONOMY, EASE, AND ACCURACY WITH WHICH AN EQUIPMENT CAN BE KEPT IN OR RETURNED TO ITS SPECIFIED OPERATING CONDITION IN THE ENVIRONMENT IN WHICH IT WILL BE USED.

I think that there surely is no other single feature which will contribute more to the factor of system maintainability than automatic electronic measurement and evaluation. Certainly there are many other important considerations, but let's examine ATS just now, and in general terms, see how its contribution is realized. The NavShips definition lists four criteria for evaluation. First is "rapidity." Automatic test systems presently deployed make complete measurement and evaluation cycles at the rate of five per second. Second is "economy." This includes many factors such as equipment availability, performance, etc., which enter into an economy comparison figure. Each anticipated application must be examined on its own merit. Next is "ease." Ease of repair, of course, is a function of the design and manufacture of a system. Ease of fault isolation by automatic versus manual methods, like rapidity, is hardly subject to comparison. Needless to say, automatic test systems are seldom subject to motion sickness. Finally, we look at accuracy. The present degree of ATS measurement equipment accuracy is more than adequate to satisfy operational requirements. In addition, the human error in reading and interpreting is eliminated.

The advantages of all these factors are realized both in the requirement for keeping the equipment in top operating condition, and in the requirement for returning it to its specified operating condition when breakdown does occur.

In order to establish standards of performance and evaluation, certain relationships have been expressed in mathematical formula. Where "A" is equipment availability factor, "MTBF" is mean time between failures, and "MTTR" is mean time to repair;

$$A \text{ is equal to } \frac{MTBF}{MTBF + MTTR}$$

Figure 131 gives a typical example of the effect of decreased MTTR on equipment availability.

You will note that MTBF is the same in both cases. The figures for both MTBF and MTTR could very well be typical in both cases, with case No. 1 representing manual troubleshooting procedures, and No. 2 representing automatic procedures. In the first case, an availability factor

$$A = \frac{MTBF}{MTBF + MTTR}$$

CASE 1
MTBF = 1000 HRS
MTTR = 5 HRS

$$A = \frac{1000}{1000 + 5} = 0.9950 \text{ OR } 99.50 \text{ PERCENT}$$

CASE 2
MTBF = 1000 HRS
MTTR = 0.2 HRS

$$A = \frac{1000}{1000 + 0.2} = 0.998 \text{ OR } 99.98 \text{ PERCENT}$$

Figure 131. Effect of Decreased MTTR on Equipment

TEAMS SYSTEM CAPABILITIES

1. PERFORMANCE MONITORING
2. FAULT ISOLATION AND IDENTIFICATION
3. FIVE COMPLETE MEASUREMENT CYCLES PER SECOND (TWO WITH PRINTOUT)
4. HI - LO - GO - PASS INDICATION
5. UP TO 10,000 TEST POINT CAPACITY
6. PRINT MODE SELECTION (ALL, NO-GO, PASS & NO-GO)
7. PERFORMANCE MONITOR OF THREE RADAR SYSTEMS, WITH TOTAL OF 231 MEASUREMENTS IN LESS THAN ONE MINUTE
8. UP TO 10 SYSTEM CAPABILITY
9. CONTINUOUS VARIFICATION & SYSTEM SELF TEST

Figure 132. TEAMS System Capabilities

FAULT ISOLATION DIAGRAM

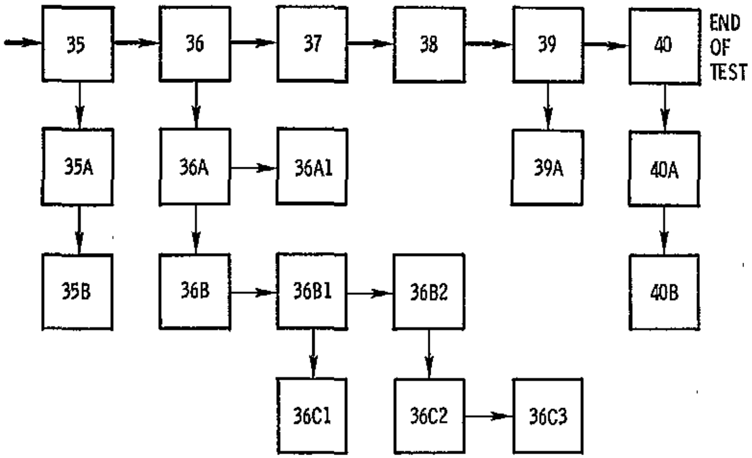

Figure 133. Fault Isolation Diagram (1)

FAULT ISOLATION DIAGRAM

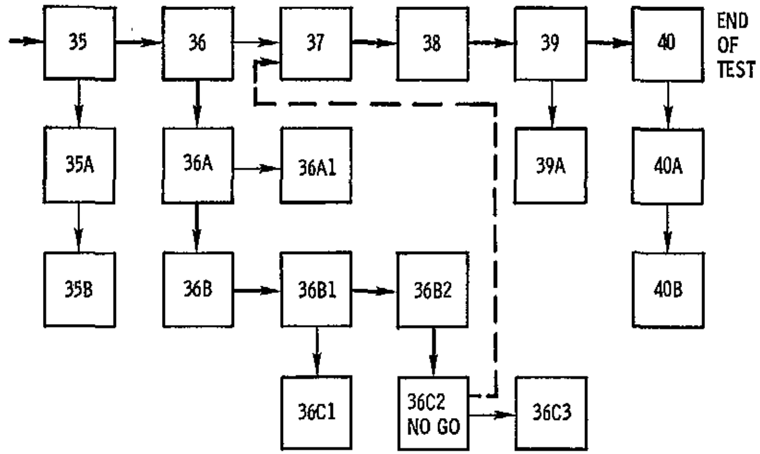

Figure 134. Fault Isolation Diagram (2)

of 0.995 (or 99.5 percent availability) is realized. This figure of 99.5 percent doesn't look bad on the surface, but that particular five hours down time could be very important should it occur at a strategically critical period. In the second case, the availability figure is increased to 99.98 percent when MTTR is reduced to 0.2 hours. MTTR figures of less than 0.2 hours have been demonstrated with automatic test system fault isolation.

8. What is the Present State of the Art?

Several applications of automatic testing and fault isolation have already been noted. We will now take a closer look at a system which is probably representative of the present state of the art.

TEAMS, Test Evaluation and Monitor System, is in current production, and reflects the advances in the art of ATS to the present time. TEAMS is a general purpose system in that it can be adapted to perform effectively in a wide variety of applications. It is classified as an on-line system. Its initial application is to shipboard monitoring, performance evaluation, and fault isolation of certain radar systems. TEAMS is a tape program controlled device, with a capability (mentioned earlier) for program modification as a result of test findings. It provides two modes of operation, automatic and semi-automatic.

Figure 132 lists some of the more vital statistics relating to TEAMS capabilities. The first item "Performance Monitoring" could bear some elaboration. It is this capability that provides the information necessary for the prediction of impending failure. Two classes of measured value limits may be stored for each programmed measurement. Each measurement will produce a decision of GO, PASS, or NO-GO. The tolerance limits to produce a GO are usually quite narrow. The limits specified for a PASS decision range out from either side of the GO limits to points which represent barely acceptable performance. Measurements outside these limits result, of course, in a NO-GO. With a performance measurement cycle occurring at regular intervals of, say every fifteen minutes, a gradual deterioration of any measured parameter may be detected by checking the printed tape record. Next, consider "Fault Isolation and Identification." At this point let's stop and take a look at just how this fault isolation is accomplished.

Figure 133 is an example of a portion of a fault isolation diagram. The top horizontal row of blocks represent first level measurements in major portions of a system or subsystem. Each block in the top row might, for example, represent a key measurement point on a complete chassis. The second row might represent "black boxes" on the various chassis. The third row could represent boards in black boxes, and the fourth, components on boards.

In this example we show the last six, in a series of forty first level measurements. The heavy lines between boxes on the top row indicate the order of measurements, and in this case all measurements were GO, and none of the lower level blocks entered into the test series. The top level blocks are those which are always measured in routine monitoring cycles. Let's look at the test sequence path should a failure occur in block 36C2 (Figure 134).

The test will proceed at top level up to block 36 where a NO-GO condition is found. Test system logic will now divert the next measurement from block 37, on the same level, to block 36A, on the next lower level. 36A indicates a NO-GO, diverting the next measurement to the next lower level, 36B. Block 36B indicates a GO, so the test path is to 36B1, on the same level. This also provides a GO. Still on the same level, 36B2 is measured and results in a NO-GO. This drops the test path one more level, and 36C2 is measured and indicates NO-GO. This block, being in the lowest level of this particular chain, signifies that the trouble which produced a NO-GO in the top level block 36 has been isolated to block 36C2. This might be a single component, such as a tube, or it might be a single stage of an amplifier, for example. Had a "GO" resulted from the measurement at 36C2, then the next measurement would have been at 36C3, which is also a part of major subassembly 36.

In this example, however, the NO-GO at 36C2 will be printed out, along with the measured value, and the block identification. The normal test sequence will now resume at block 37, indicated by the heavy dashed line, and continue through to the end of test.

Returning now to Figure 132, we will review briefly the remaining items:

3. This system can make five complete measurements per second with no printout. With the result of all measurements printed, the speed is reduced to two per second.
4. Each measurement is evaluated as either GO, HIGH PASS, LOW PASS, HIGH NO-GO. or LOW NO-GO.
5. The maximum test point capacity of a single system, as presently produced, is 10,000.
6. The operator of the system may select certain options as to the data he wants printed. He may elect to have all measurement results printed, or just those which result in a NO-GO decision, or all PASS and NO-GO decisions.
7. TEAMS currently operational, are interfaced with three radar systems with a total of 231 possible measurements. These 231 measurements can be made in less than one minute.
8. As presently configured, up to ten prime systems may be interfaced with a single TEAMS.
9. Finally, in order to insure the greatest possible degree of reliability and confidence, TEAMS and other such systems are equipped with the capability of continuous self-vertification. In addition, a portion of the tape is programmed to provide a complete system self-test, including fault isolation.

9. The Next Generation of ATS . . . . What is in Sight?

It is difficult to envision all that is in sight. Were we able to list everyting today, tomorrow there would be something new to add. It can just about be said, "What do you need? It will be ready for you soon." Listed below are a few of the items which are in the mill.

1. Computerized Automatic Performance Degradation Trend Prediction - The maintenance force will be warned in advance that a specific circuit can be expected to fail within x number of hours.
2. Automatic Spare Parts Inventory and Ordering Control - When a defective component or subassembly is isolated by the test system, a punched card will be generated which will order a replacement for the item drawn from stock.
3. Centralized Maintenance Control - A central maintenance control room, or van, will coordinate and direct all maintenance effort within a specific complex. Centralized monitoring, failure prediction, and fault isolation equipment will maintain surveillance over many types and numbers of systems and machines.
4. Computerized Failure Analysis - This capability already exists and is currently employed. Significant advances can be expected however.
5. Higher Speed Systems with Greater Reliability and Accuracy - This is a general goal, of course, but of no less urgency and ultimate value.

10. Application of Automatic Test, Evaluation, and Monitoring to Training Systems and Devices. Why? Where? How? When?

I shall try to answer these four questions by briefly summarizing that which has been said. First, Why? . . . . Because the basic problems encountered in the maintenance of complex training systems and devices are essentially the same problems faced by electronics maintenance personnel in any other situation and lend themselves to similar solutions. Because ATS will keep your systems on the line a greater percent of the time, by both helping to avoid unexpected failures, and by greatly reducing the time required to locate the cause of failures that do occur. Because your maintenance technician can perform more effectively on more equipments by virtue of his reduced need for extensive and intimate knowledge of the theory and circuitry of the systems he maintains. Because the maximum utilization of your training devices is crucial to effective training, and effective training is crucial to effective performance by man with his machines.

Where? . . . . Anywhere that the size and complexity of a training device, or of a group of training devices presents significant and important problems of maintenance. Automatic test systems come in a variety of sizes, capabilities, and prices.

How? . . . . The technology is here. The wheel is already invented. The application of ATS to training systems and devices is accomplished by employing the same proven techniques that are used in tactical hardware applications. Engineering studies are made of each device or system which is a potential candidate for ATS. Its peculiar needs are determined, interfaces defined, specific hardware requirements established, and test programs prepared.

When? . . . . Were it to any avail, I should answer by saying "Years ago." The best I can say, however, is "Now." The hardware is here, the techniques are developed, and the concept is proven. Whether your maintenance problem is a building full of radar training systems, all different, or a computer controlled flight simulator, a major portion of the solution is to be found in automatic failure prediction, detection, and isolation.

The theme of this conference is "Innovations in Training Device Technology." Automatic electronic measurement and evaluation has long since ceased to qualify as a contemporary innovation. Its application to training devices, however, might well qualify as an innovation.

AUTOMATIC TESTING THROUGH INTROSPECTION

H. C. OKRASKI
Head, Maintenance Engineering Division
Naval Training Device Center

The message that I wish to convey to you today is quite simple and because it is so elementary, I trust that you do not consider it to be no message at all. It deals with the need for the automatic, on-line testing of training devices and specifically, automatic testing through "introspection."

It is my opinion that training device technology is taking the maintenance community for a ride; a high-speed ride that, if allowed to continue on it's present course, will end in training device "system ineffectiveness." Training devices have evolved from simple analog equipments to complex digital and hybrid analog/digital systems, often including the latest state-of-the art techniques. In the early generations of training devices, the approach to maintenance was to train the maintenance technician in the entire system so that he could maintain the equipment with general and standard test equipment, utilizing recommended troubleshooting techniques.