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AUTHOR	Frick, Frederick C.; Karp, David
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ABSTRACT

An investigation was carried out to determine the feasibility and relative cost of developing pictorial procedures that could be used in conjunction with the Lincoln Training System (LTS) for task simulation in the support of performance laboratory instruction. Results showed that the technique was economical and effective. The storage and data processing capabilities of the LTS made it possible to monitor and assess the student's performance. It was also possible to record and monitor system performance in the same fashion, and a scheme for "system performance assurance" was developed which capitalized on this capability. (Author/PB)

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Use of the Lincoln Training System (LTS) for Task Simulation in the Support of Performance Laboratory Instruction

F. C. Frick

D. Karp

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

LEXINGTON, MASSACHUSETTS

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LINCOLN LABORATORY

USE OF THE LINCOLN TRAINING SYSTEM (LTS) FOR TASK SIMULATION IN THE SUPPORT OF PERFORMANCE LABORATORY INSTRUCTION

F. C. FRICK

Division 2

D. KARP

Group 25

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ABSTRACT

An investigation was carried out to determine the feasibility and relative cost of developing pictorial procedures that could be used in conjunction with the Lincoln Training System for task simulation in the support of performance laboratory instruction. The technique appears to be economical and effective. The storage and data processing capabilities of the LTS make it possible to monitor and assess the student's performance. It would also be possible to record and monitor system performance in the same fashion, and a scheme for "system performance assurance" is developed which capitalizes on this capability.

Accepted for the Air Force
Joseph J. Whelan, USAF
Acting Chief, Lincoln Laboratory Liaison Office

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USE OF THE LINCOLN TRAINING SYSTEM (LTS) FOR TASK SIMULATION IN THE SUPPORT OF PERFORMANCE LABORATORY INSTRUCTION

I. SUMMARY

Current Air Force technical training begins with the determination of job performance requirements and is ultimately evaluated by how effectively it qualifies personnel for successful performance on the job (AFM 50-2).[1] With this focus, the "performance laboratory" becomes a particularly important component of the instructional process. Unfortunately, it is also a particularly expensive form of instruction that often requires the duplication of expensive equipment, the development of special trainers or simulators and, characteristically, a very low student/instructor ratio.

It appeared that the Lincoln Training System (LTS) might be cost-effective for task simulation in support of at least some aspects of performance training. In order to investigate this possibility, a sequence of instruction on the calibration of a Tektronix 545A oscilloscope was developed with the dual aim of (a) establishing the feasibility and relative cost of developing pictorial procedures for student guidance and drill, and (b) providing a means for evaluating particular features of the LTS in this application.

It was determined that pictorial procedures could be developed relatively easily by photographing an expert in the performance of the task and that such material could be used effectively to support performance laboratory instruction. This technique appears to be economical in comparison with other means of developing and publishing performance aids.

The symmetry between task trainers and proceduralized job performance aids was noted, and a major result of the investigation has been development of the concept of System Performance Assurance (SPA), to be achieved through the use of pictorial procedures and an automated maintenance and performance monitoring system. In this context, it appears that a modified LTS could insure improved system performance and also support meaningful on-the-job training for operations and maintenance personnel.

II. BACKGROUND

The systems approach to instructional system development adopted by the Air Force in 1970[1] represents an orderly process of gathering and analyzing job performance requirements, translating these requirements into behaviorally stated learning objectives, and integrating instructional techniques and procedures to assure achievement of these objectives. The emphasis is on the job and job performance. Knowledge of principles, the acquisition of a specialized vocabulary, and the ability to "verbalize" the job are regarded as secondary and are included in formal instruction only to the extent that it is believed that they may improve job performance.

With this approach to instruction, it is apparent that the performance laboratory takes on a very central role. The reference here is to training on the specific tasks that the student will be expected to perform in the field. Basic skills training – soldering, welding, the use of hand tools and simple instruments -- are elements in the performance laboratory, but our focus here is on more complex jobs such as the tuning, calibration, trouble shooting, and repair of equipment or exercises in operational procedures using mock-ups, simulators, or actual field systems. In most such cases, the emphasis is on learning a <u>sequence</u> of behavior, it being assumed that the individual actions – meter reading, knob turning, cover removal, probe insertion, etc. – are already in the student's repertoire.

These procedural sequences will generally not be fixed, and present actions will be dependent on previous actions and the outcome of prior tests or measurements. The most difficult aspect of this sort of learning is the establishment and remembering of the discriminative clues that determine the specific sequence of actions that must be carried out under various circumstances. In maintenance and repair tasks, the appropriate procedures will often have to be derived from a Technical Order and the student's knowledge of the principles of operation of the system at hand. Technical Orders emphasize system structure and operation; usually, they do not lay out procedures for fault location, part replacement, or repair, and they are not written for apprentice repairmen. It is therefore necessary for the instructor in a performance laboratory to demonstrate procedures and then to guide and correct the individual student as he attempts to carry them out on his own. This is essentially a tutorial situation. Student/instructor ratios tend to be very low and the associated cost correspondingly high.*

It seemed apparent that the Lincoln Training System (LTS),[2] which is an interactive system that has been developed to support tutorial-like training, could be used in this context for the following reasons.

(a) It has the capability of guiding the student through any step-by-step operation at the student's own pace, a procedure of known effectiveness.[3,4]

(b) The audio capability should alleviate the reading proficiency requirement that has been a problem with some proceduralized performance aids.

(c) Audio instruction should facilitate performance where the student is engaged in a difficult manipulative task.

(d) The LTS is designed around a pictorial display that should minimize errors of instruction arising from ambiguity in textual descriptions of procedures.

(e) The branching capability of the system could be used for quick reference to part numbers, circuit diagrams, etc., or for entry to explanatory or theoretical material, either automatically or under student control.

In this context, the system would be used in lieu of an instructor who might otherwise be guiding the student through the task at hand. As we have noted, programmed instruction of this sort has been shown to be effective, but the generation of instructional material appropriate to this kind of application has proved to be difficult and expensive.[5] Using the LTS it would, however, be possible and perhaps economical to use pictorial procedures generated by simply photographing the instructor, or expert, as he carries out the job. A pictorial aid of this sort would in effect put the student in direct contact with the instructor and should eliminate errors and ambiguities introduced by attempts to translate actions into words.

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* The present Metrology (precision measuring equipment) course at Lowry AFB is a good illustration. This is a 1290-hour (43-week) course with approximately 50% of the time devoted to performance laboratories. Students are taught to calibrate and repair a wide variety of equipment, most of which is expensive and fragile and therefore not duplicated in the laboratory. As a result, each student, or pair of students, may be working with different equipment and require separate supervision or instruction; 2:1 student/instructor ratios are common under these conditions.

Accordingly, it was decided to develop a brief sequence of instruction with the dual aim of (a) providing a means for evaluating particular features of the LTS in the context of a performance laboratory, and (b) establishing the feasibility and relative cost of developing pictorial procedures for this purpose.

III. PROCEDURE

A subset of the calibration procedures for a Tektronix 545A oscilloscope was chosen as a vehicle for demonstrating the feasibility of this approach to performance training and the generation of proceduralized instructional material. The task chosen represents 30 to 60 minutes of activity on the part of a highly trained technician, the length of time depending on how much adjustment is required.

We began by observing an individual performing the task; whenever a change in operational setup was required, a requirement for a photograph was established. When test points or controls were difficult to see, a requirement for a close-up photograph was indicated. Approximately 60 discrete photographs were thus identified (1-2 per minute of actual activity).

A flow chart of the calibration procedure and photographic requirements was established in this fashion, and the complete procedure was then performed by the instructor in stop-action. Photographs (identified from the flow chart) were taken first as Polaroid samples, and then final exposures were made. A voice recording was made of the instructor's comments and explanations as he performed calibration tasks.

The final calibration procedure flow chart was then assembled using the Polaroid prints for each frame, the text messages required for trainee response options were added, and frames of specific audio messages were prepared. The size of each final glossy continuous tone print was then specified, the intent being to use as much of the $8\frac{1}{2}$- × 11-inch display area as possible for viewing ease. Frame notes were developed indicating arrows or other special additional marks which would be required to complete the visual displays. Audio frames were recorded, using the instructor's audio tape for guidance, and LTS procedures were used for assembling the frame branching logic.

Four standard LTS microfiche cards, containing a total of 41 audio-graphic frames, were produced and used for procedure debugging purposes. Approximately 10% of the graphics, text, audio, and logic content was found to be in error and revised microfiche were produced. The material was also produced in booklet form (available on request) in order to determine the ease with which this material could be translated between these two methods of presentation. Only minor modifications in the audio text, which is printed on the page facing the pictorial material in the booklet, were required. In addition, frame branching (page location) options were added to the text.

Four laboratory technicians served as trainees to determine whether they could calibrate the Tektronix 545A oscilloscope supported solely by pictorial procedures. The technicians had no prior experience with oscilloscope calibration procedures and had not used the required test equipment prior to this test. Three technicians satisfactorily calibrated the oscilloscope in 1.75 to 2.0 hours, using the LTS, and one technician completed the task in 2.5 hours, using the booklet. The time required (first trial) by the trainees was 2 to 4 times that required by a highly experienced instructor, and we did not attempt repeated trials to determine the rate at which these times might improve.* The important point is that our technicians were able to perform the calibration successfully the first time, without requiring the instructor to be present.

As would be expected, users were able to point out a number of minor problems in the content of the procedure. In general, these problems related to graphic displays without adequate pointers and audio frames with too much content, which made them difficult to remember or required that they be repeated several times. A final revision would require changes in approximately 20% of the frames to be responsive to these complaints.

This observation is of interest because revision after initial trials must be anticipated in the development of any training or performance aid, and the ease and cost of such revision must be factored into any cost estimates or cost comparisons among different forms of publication. This is explicitly taken into account in the cost estimates for pictorial procedure development that are given in Appendix I.

IV. DISCUSSION

The work described above demonstrates that it is relatively easy and economical to develop pictorial procedures that can be used to guide people through quite complex tasks with which they have had no previous experience. However, if these procedures are to serve as training aids it is necessary also that some provision be made to monitor and assess the student's performance. In particular, it might be desirable for the system, rather than the student, to determine the need for remediation and to control branching to additional exercises, further explanation, etc.

In order to accomplish this, it will be necessary for the student to input appropriate information to enable the system to make such decisions. To illustrate how this might be done, consider the procedure for a step-by-step check of the oscilloscope low-voltage power supplies. The general strategy employed is for the student to make a voltage reading, compare this with a nominal value that is presented to him, and select the next frame on the basis of the difference between the observed and nominal values. With the LTS it would be possible, however, to have the student enter the observed voltage through the keyboard and have branching to an adjustment sequence or to the next measurement programmed within the machine, contingent on the value entered.

If the procedure is considered purely as a performance guide, there is probably little to choose between student or system initiated branching. On the other hand, if the student is not

* It is our opinion that the observed initial difference in time required by the student using the booklet and those using the LTS would hold up if the size of the sample were increased. This is supported by the observation volunteered by the LTS users that the audio supported a feeling of confidence that the actions they took, or were about to take, were correct and safe. The one technician using the booklet reported a lack of confidence and a concern that pre-conditions for his current actions were possibly not complete. This was reflected in considerable backtracking, checking, and rechecking of prior frames.

It is interesting to compare this reaction to the audio with similar comments from Air Force trainees using the LTS at Keesler AFB. In designing the LTS, a requirement was established for audio as a means for minimizing the need for reading proficiency. It is increasingly apparent, however, that the audio has an important affective as well as informational content. This is reinforced by the unexpected observation noted here.

There is, of course, no reason to believe that repetition would not increase student confidence without the audio, and we would not expect significant differences in the ultimate performance of this type of task by students trained with booklets or the LTS.

given nominal values, he is forced to carry out the necessary measurements and he is precluded from successfully guessing his way through a procedure.* Furthermore, such information would make it possible to take advantage of the memory and logical processing capacity of the computer to condition branching decisions on the student's cumulative performance as well as his current response. In the simplest case, the student could be transferred to a different sequence of frames when a cumulative index of responses made in one of several areas exceeds some established criterion.

The conditional branch feature has now been implemented in LTS software and has made it possible to simulate a wide range of problems in diagnosis and trouble shooting. The general approach is to present the student with the gross performance (or symptoms) of the system being simulated. The student then selects any one, or several, diagnostic tests which he inputs to the LTS. He is then informed of the results of these tests and on this basis chooses a tentative diagnosis and runs more tests, or makes a final diagnosis. He is then told whether or not his diagnosis is correct and, in either case, he receives further feedback which tells him if he has performed all of the pertinent tests. Treatment, or repair, is handled in a similar fashion, and the software permits constraints to be put on the order in which tests or treatments are carried out if that is important.†

Cumulative evaluation should also permit the development of more efficient pre- and post-tests of skill and knowledge. For instance, the student might be required to answer a series of questions, receiving immediate feedback for each answer, but with the length of the test conditioned by the error rate or error type. The system would thus allow for tests which are individualized in both content and extent.

When the student keys into the LTS the results of his tests and observations, it is not only possible to monitor his performance but alternatively to obtain a record of the performance of the system that is being studied. This capability suggests an application of the LTS that goes well beyond its function as a task trainer, and we now consider the problem of maintaining system performance rather than the more limited though related problems of training and providing performance aids to operations and maintenance personnel.

V. SYSTEM PERFORMANCE ASSURANCE

Procurement policies that have been in effect for over a decade have introduced into the Air Force high technology systems that are designed to be stable, reliable, and maintainable. To achieve this, the Air Force has paid substantial premiums on built-in instrumentation for performance monitoring, for marginal checking systems, modular design, and "throw-away" maintenance, and these measures have not generally been sufficient to assure continued effective operation. At the time of acceptance from the vendors, these systems meet or exceed specified criteria; after a time in the field, maintenance costs are found to be greater than anticipated, MTBF is shorter than expected, and system performance is substantially below specification.

* This would not, of course, be true in carrying out as simple and well specified task as the voltage checks in the present example.

† With this addition to the LTS software, it was possible to transfer to the LTS a simulation program, developed by the University of Kentucky Dental School for the IBM 1500 system, involving the diagnosis and treatment of endodontic disease. This material was selected because it had already been used extensively and successfully to develop skills comparable to those required in trouble shooting and repair of complex systems.

As an example, an intensive study (Project SCOPE CREEK) of the Air Force world-wide communications system indicated that performance of that system – individual links as well as over-all – had decreased about 3 dB from "like new" operation by the end of the first year of operation and had decreased by 17 dB at the end of 20 months.[6] There is reason to suspect comparable degradation in other Air Force systems.

The usually suggested remedy for problems of this sort is to provide increasing numbers and/or more extensively trained operations and maintenance personnel. (This has been the approach taken by AFCS to alleviate the deficiencies noted above.) However, this is an expensive and not generally applicable solution because

(a) It is difficult to obtain and train appropriate personnel.

(b) It is difficult to insure that field maintenance and operational personnel adhere to approved maintenance procedures.[7]

(c) Operational and maintenance procedures should be continually updated in response to the accumulation of operations data and field or factory equipment modifications. It has proved to be extremely difficult to track this information and to insert it into the training-field operation cycle in a timely fashion.

On the other hand, as mentioned above, sophisticated engineering design has actually simplified the operation and maintenance of contemporary systems. Expert knowledge is not required to make measurements, to record them, to adjust voltage levels, to check monitoring instruments, and to replace defective equipment modules. What would seem to be required is a set of precise, up-to-date job guides or FPJPA's (fully proceduralized job performance aids), and a monitoring system that will (a) insure that the procedures are properly carried out, and (b) provide a continuous record of subsystem and system performance.

To be effective, the monitoring system must be automated and centralized to whatever extent is necessary to enable merging and tracking of performance data from individual units or subsystems in a timely fashion. (Data for large systems will generally be acquired at different times and from different locations.) Such records would make possible a variety of actions beyond the simple accumulation of failure data for logistic support. These would include revision of operational procedures, decrease or increase in maintenance rates, and revision of measurement schemes to uncover sources of inadequate performance. The data would serve as a base for the initiation of ECP's to remedy persistent failures.

There will always be need for high-level technical expertise and judgment to maintain the performance of a complex system. However, if there exists an accessible, cumulative and continually updated record of system and subsystem performance (as well as operations and maintenance performance), then it is possible to exercise expert supervision without an expert at each site or operational location. Advantage can be taken of modern communications. Problems can be diagnosed and repairs effected over a telephone, and engineers can be flown in if necessary.

This is essentially the mode of operation, for example, of large oil refineries. In this case, it is made possible by the existence of highly reliable, automated monitoring equipment with a central display of refinery operation. AF systems – radar, communication, command/control, avionic – almost always require human intervention for control, performance measurement, and maintenance. As a consequence, data are not generally gathered in machine readable form; they are not always reliable, and the aggregation of data for diagnostic purposes is more often a crisis operation than a routine procedure.

It is suggested that these deficiencies can be remedied by using the LTS for system performance assurance.* The LTS-4, which is currently under development, will be a completely self-contained and portable system suitable for use at remote field sites. It offers

(a) An economical means for distributing, storing, and presenting job performance aids and guides for system checkout. In particular, it can take advantage of pictorial procedures to insure accuracy and ease in the interpretation of instructions.

(b) Automatic control and monitoring of maintenance procedures. The LTS incorporates sophisticated decision processing, i.e., it can process stored data and current information to select at each juncture the best succeeding procedure. By monitoring each step of the procedure, the system can eliminate typical human failures such as forgetting relevant data, omitting steps, or making erroneous decisions.

(c) A point of operation, data entry device. By attaching a simple digital recorder† to the LTS-4, it would be possible to record in machine readable form (1) the sequence and timing of each operation performed by O/M personnel, (2) remedial actions taken, and (3) measurements and system performance data. This information can be processed for use by the site manager or by technical experts to evaluate system performance, to anticipate (and avoid) system failure, and to evaluate the adequacy of maintenance procedures.

Lastly, the system offers a significant capability for supporting on-the-job training. For instance, it would be possible under technician or system control to branch to specific training (as opposed to performance aid) material. Exactly the same instruction could be available on-site as at the training school; it would, however, be available in a job connected context with visible relevance and the expectation of an enhanced motivation to learn.

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* An illustrative example is given in Appendix II.

† Alternatively, LTS-4 terminals can be directly connected to a central computer which would perform the necessary data reduction, storage, and display.

APPENDIX I

COST ESTIMATES FOR PRODUCING PROCEDURALIZED AIDS

Personnel costs represent the major factor in developing any form of proceduralized aid (PA). Table I presents time records of the personnel who developed the PA on calibration of a Tektronix 545A oscilloscope.

TABLE I

PERSONNEL CHARGES

	Hours
Instructor (laboratory technician)	14
Producer (staff assistant)	30
Instructional specialist	20
Instructional programmer	4
Photographer* (laboratory technician)	12

* Includes photography (4 hours), photo development, and art work.

This was a first attempt at the development of a pictorialized procedure and therefore represents only an approximation to times that might be required under commercial production conditions. In particular, a substantial fraction of the time spent by the producer and instructional specialist was invested in learning, and this added substantially to the time required of the instructor/demonstrator. On the other hand, the material being developed was relatively simple in terms of content and the instructional strategy that was adopted. The total time involved – 80 man-hours for 30 minutes to 1 hour of material – is not out of line with that reported for the development of other forms of programmed instruction.

The instructor and photographer are technicians, for which we will estimate $5 per hour; the producer and instructional programmer are staff assistants at $6.50 per hour; the instructional specialist is a professional staff member estimated at $12 per hour. To estimate the cost of commercial development, we add overhead (105%), G and A (10%) and profit (10%) to these figures to develop Table II. Cost of materials is low and assumed to be covered by overhead.

TABLE II

DEVELOPMENT COSTS

Instructor	14 hours @ $12.40	$ 173.60
Producer	30 hours @ $16.13	483.90
Instructional specialist	20 hours @ $29.77	595.40
Instructional programmer	4 hours @ $16.30	64.52
Photographer	12 hours @ $12.40	148.80
		$1466.22

The PA material is in the form of $8\frac{1}{2}$- × 11-inch typed text and continuous tone glossy prints. The audio messages are stored on magnetic tape and are converted to LTS formatted spiral records on $8\frac{1}{2}$- × 11-inch film, using a special-purpose recording optical galvanometer. The approximate costs, for time and materials, to process this material for microfiche distribution are shown in Table III.

TABLE III

MICROFICHE PRODUCTION COSTS

41 audio plates @ $1.25	$ 51.25
41 video plates @ $1.25	51.25
4 microfiche masters @ $4.50	18.00
Duplicates @ $0.11 per card (4000 cards)	440.00
Total cost 1000 copies	$560.50
Distribution cost, labor and postage	$140.00
Cost to distribute 1000 copies	$700.50
Cost per copy (four fiche)	$ 0.70

Xerox copies of this material were made for the booklet used in the experiment, but we have developed approximate costs (Table IV) to produce suitably bound copies with good halftone quality photographs. The same master PA material is furnished as input to this process.

TABLE IV

BOOKLET PRODUCTION COSTS

35 halftone plates @ $6.00	$ 210.00
47 photo-direct plates @ $1.00	47.00
Paper @ $4/1000 pages	164.00
Printing @ $3/1000 impressions	246.00
Binding	
Labor (collation, punching, binding)	400.00
Bindings (1000 @ $0.10 ea)	100.00
Total estimated cost	$1167.00

We discussed production of the booklet with several commercial printing shops, and obtained informal telephone quotations which average $1250 for 1000 bound booklets. This is to be compared with our estimate of $1167 for time and materials costs. Using the higher figure, the total estimated cost for 1000 booklets is $1250.

Distribution, labor and postage (3rd class bulk rate)	$ 200.00
Total cost	$1450.00
Cost per booklet	$ 1.45

While the above cost estimates are only approximate, we believe that the general conclusion is accurate – audio-graphic microfiche (12 frames per card) can be produced and distributed at substantially less cost than conventional printing and publishing of the same material.

This conclusion holds even if we were to use line drawings, rather than photographs (cf. JPA-UH-IH-2TS-17). In this case, the time required of the instructor/demonstrator and photographer would be reduced by about two-thirds and halftone plates would not be required in production. In the present example, this might represent a savings of $400 or about 14%. However, this is outweighed by the cost of producing the drawings.

If we assume that the ratio of separate drawings to instructional frames is only 1:3, we would still require 11 drawings, which we estimate at approximately $64 each (4 hours × $16 per hour for artist-illustrator) for a total cost, exclusive of assembly and layout, of approximately $700.

A final consideration in comparing costs between conventional publication and microfiche involves the cost of revision. As pointed out in the body of the report, we can anticipate a need for the revision of any training or performance aid material after initial tryouts with trainees. In the present case, we have estimated that approximately 20% of the material would be helped by revision. This would be increased to 50% if we wished to take advantage of the memory and recording capability of the LTS as suggested in Section IV. (This would not be a consideration for the booklet.)

Development charges for revision are independent of the publication medium. Production charges for revised microfiche would run approximately $68 (for 50% revision). This is derived from Table III as follows:

8-20 frames revised	$2.50	= $20-$50
4 microfiche masters		= $18

There would be essentially no extra charge for duplication and distribution. Microfiche are duplicated and distributed "on demand," with no significant savings from large runs. In this situation, we would make only a few prints, try them out, and revise. Prints of the final revised procedures would be made only to meet the actual demand.

Small runs are not economical in conventional publication, and it would not be worthwhile to print a few booklets for test, evaluation, and revision prior to full production unless full production was a very large number. In the present case, major revision of the material, 20% or more, would very nearly duplicate the costs presented in Table IV.

APPENDIX II
SYSTEM PERFORMANCE ASSURANCE: AN ILLUSTRATION

A simple example may give a better understanding of how the system suggested here might work in practice.

The System Performance Assurance (SPA) concept involves the development of a set of pictorial procedures for use with a (perhaps modified) LTS-4. These procedures will, in most cases, closely resemble acceptance test procedures and might be developed by the same engineering group. In any event, the intent would be to guide a technician through system setup, appropriate performance measurement and normalization, or component replacement where required. Most of the actions to be performed will use mode-switch options and observations of built-in instrumentation; readings for these instruments will be recorded through the LTS keyboard. They will be used to determine the O/M procedure sequence, to monitor O/M personnel performance, and to update system performance records.

Typically, these procedures will involve a number of conditional branch points such as the following where the O/M man must make a power measurement and enter the result. Suppose:

greater than +3 dBm	→	high gain fault
+1 – +3 dBm	→	marginal
–1 – +1 dBm	→	normal
–3 – –1 dBm	→	marginal
less than –3 dBm	→	low gain fault

The design engineer will have programmed the LTS for subsequent action at this point. If he considers the observed value to represent a system fault, he will arrange a branch to a fault search or fault clear procedure. When this procedure is completed – a module is replaced or an adjustment is made which clears the fault – the system displays an initialization frame for resetting the proper mode of operation, and the procedure continues to the next main-line frame (which is also the "normal" branch). If a high normal or low normal response was entered, a weighted number is stored for use in calculating a "system quality" factor. Based on the cumulative total of high or low normal measurements, the operator may be branched to a tune-up or recalibration procedure, or he may be continued in the normal checkout mode.

A recording would be made of all the performance measures entered and the times and the sequence of actions taken (branches). Relatively simple automatic data processing would then provide continuously updated information on the maintenance history as well as module, subsystem, and system performance. These records, interpreted by a trained system engineer, could provide the basis for preventive maintenance and the generation of ECP's in addition to the usual development of logistical support needs.

In order to evaluate these general concepts, we have examined them against the ALTAIR radar system. The ALTAIR radar is a modern high technology system; it is highly modular; it has considerable designed-in test equipment; and it provides for monitoring of subsystem performance while the system is on-line and operating. The specifications for procurement of this radar system were generated in 1963-1964 (almost a decade ago), and we believe that it is representative of much of the present-day military radar and communications systems, in-place and operating globally. Aside from the high power transmitting TWT's, klystron and vacuum tubes, the system is entirely solid state. It is compartmentalized into a set of major systems, each operated and monitored from its own test console.

The Calibration and Monitoring subsystem (C/M) is the on-line equipment which is used to perform power, gain, phase, and noise figure measurements on portions of the receiver, exciter, and transmitter subgroups. When the ALTAIR system is in a mission, the C/M is used for monitoring purposes only. Receiver, exciter, and transmitter power monitor functions are controlled by the System Data Distribution and Timing subgroup (DDT) via the C/M control unit. When the ALTAIR system is not in a mission, then the C/M may be used for either calibration or monitoring purposes. Under this condition, either the DDT, the C/M, or a combination of both will control the functions of the subgroups.

All the above-mentioned measurements may be performed in the receiver by using the exciter, a noise generator contained within the receiver rack, or the actual received signal as a test signal. The RF level to the receiver is adjusted and passed to the appropriate receiver front end. When the noise generator is used as the signal source, noise is injected directly into the receiver front end. In any case, the desired IF receiver output is selected by the distribution system and sent to the C/M for measurement. The output of the C/M then appears on either a power meter or on an oscilloscope located on the C/M front panel. The exciter RF output may be monitored on the power meter or displayed as detected video on the oscilloscope. In this mode of operation, the selected exciter output is passed directly to the C/M display device and not to the receiver.

The personnel responsible for this subsystem, as well as the systems which it monitors, use this facility for

(a) Daily tests for gross characteristics such as gain, S/N, frequency, sidelobe level, etc.,

(b) On-line (operational) monitoring of the system on a non-interference basis, to detect and act on fault alarms,

(c) When radar system test has isolated a fault in this system, and it is required that it be found and cleared,

(d) Periodic (but infrequent) system test verifying that the system meets design performance specifications.

A section of Receiver Calibration Procedures is included (Appendix III) to show the format of the textual material which is provided to support maintenance personnel in performing these functions. It should be noted that while the ALTAIR manual has been highly proceduralized, the procedures are "success oriented" in that there is no provision for other than nominal operation, and highly skilled maintenance personnel must be immediately available to trouble shoot when faults occur. The many references to tables and the need to perform frequent calculations add significantly to operator error and unnecessary adjustment and replacement of equipment modules. A computerized maintenance support system, such as we are proposing, would eliminate this source of system performance variability.

However, the most important contribution to system performance assurance derives from the capability of the LTS to monitor the performance of O/M personnel (just as it monitors the performance of students in a training situation). Not only is it able to control and record the sequence of checks and operations performed, but it is able to store the results and modify procedures on the basis of prior tests and measures.

For instance, there may be as many as twenty modules consisting of RF amplifiers, digitally controlled attenuators, IF amplifiers, cables, coaxial mode switches, etc., in the chain over which it is desired to measure system gain.

In a typical procedure, the operator will enter a CW power measurement at a number of node points (see Fig. 1):

(a) Output of front-end amplifier,

(b) Output of mixer-preamplifier plus cable run to console,

(c) Output of front IF amplifier,

(d) Output of second IF amplifier following mode switches and hybrid power dividers, attenuators, etc.

At any point, an abnormal gain or loss will cause a branch to a fault location and clear procedure for the module under test. The nominal power is reset at each node by adjusting the level of the input test signal, and the new level is entered via the keyboard. A cumulative too low/too high gain condition would be detected in this way. It is also possible to measure nominal over-all path gain while intermediate modules are operating at abnormal gain. There might be too low front-end amplifier gain which is compensated by too high IF amplifier gain. By eliciting responses from the operator in a logical sequence, it is possible to detect abnormal conditions and instruct the operator in restoring the module(s) to nominal operation. The operator might continue through most of the modules in this path without encountering a fault, but the "quality factor" (number of modules with acceptable but marginal performance) may exceed a clip level (too many marginal modules), and the operator would be branched to the start of the sequence. At this point, he would be required to restore each module to nominal performance.

Using this approach, the author of the SPA maintains control of the operating characteristics of the system. Modules are allowed to drift within designer specified limits without continual trimming. Rates of drift are determined and an optimum required rate of O/M can be established. Defective modules (based on failure rate, drift rate, magnitude of drift, etc.) are identified, and replacement or ECP's can be initiated.

Decisions relative to nominal values and acceptable margins are thus made by the system expert, not by O/M personnel. The SPA system remembers modes, calibration constraints, logical routes to task completion, etc., and keeps records in a format that permits automatic data processing for performance accountability of both the system and the operator.

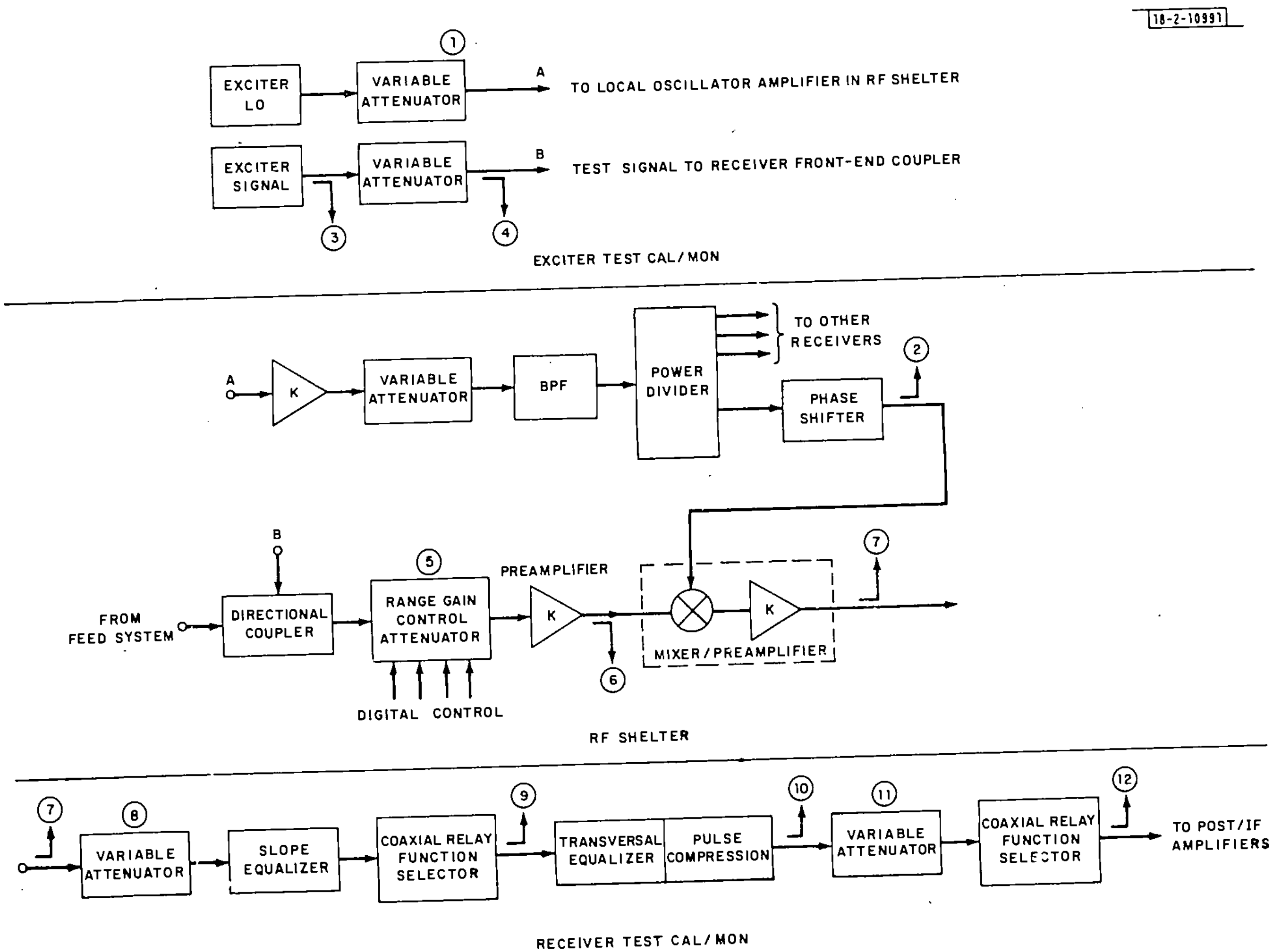

Fig. 1. Typical receiver gain test setup.

APPENDIX III

RECEIVER CALIBRATION PROCEDURES

A section of the general procedure for performing gain measurements has been taken from the ALTAIR Radar System Calibration and Monitoring System (CAL/MON) Operation and Maintenance (O/M) Manual to illustrate the state-of-the-art approach in supporting field O/M personnel. A typical set of log sheets from the CAL/MON O/M Manual is included to illustrate the number of node point measurements involved in receiver gain checkout.

4.3.2.1 General Procedure

The general procedure for making the above measurements is as follows:

1. Establish the proper input test signal levels for the selected Receiver channel.
2. Establish the Receiver IF output levels which are to be monitored and measured.
3. Select the monitoring device.
4. Make the desired measurements.

The positions for significant Control Panel controls for each type of measurement are given in Table 4-2. The following procedures presume that these controls have been properly positioned prior to performing the calibration measurements.

4.3.2.2 Gain Measurements

In this subsection, two different procedures for making gain measurements are given:

Signal	Method of Measurement
CW	Power Meter
Pulse	Scope/Power Meter

To make gain measurements in the CW mode, the power meter is used to set up both the Receiver input and output levels.

CW Gain Measurement – Power Meter – The procedure for making CW gain measurements is given in Table 4-4.

TABLE 4-4
PROCEDURE FOR CW GAIN MEASUREMENT

Step	Procedure
1	Position the C/M switches for Mode 2 as shown in Table 4-2.
2	Rotate the CHANNEL SELECT switch to the desired UHF or VHF channel.
3	Rotate the OUTPUT SELECT switch to the desired Receiver output.
4	Select the desired waveform (VCW or UCW) with the WAVEFORM SELECT switch.

TABLE 4-4 (Continued)

PROCEDURE FOR CW GAIN MEASUREMENT

Step	Procedure
5	Place the DISPLAY SELECT switch in the desired POWER METER position (VHF IN or UHF IN).
6	With the precision step attenuator set at 0 db, monitor the exciter output on the power meter and record the reading.
7	From Table 4-5 obtain the calculated loss factor between the C/M and the Receiver front-end for the selected channel.
8	From Table 4-6 obtain the suggested Receiver input level for the selected Receiver channel. This is Power_{in}.
9	Calculate the input attenuation from the following formula: ATT = 0 db power (Step 6) – Losses (Step 7) – Signal Level (Step 8)
10	Set the precision step attenuator to the value obtained in Step 9. NOTE With the precision step attenuator in the required position for the selected channel, the input level to the Receiver is 10 db below saturation.
	To establish the proper IF output level for the selected Receiver channel, continue below.
11	From Table 4-7, obtain the IF attenuator setting for the selected Receiver channel.
12	On the IF attenuator panel, depress the CONTINUOUS/STEP switch-indicator so that it reads STEP.
13	Set the IF step attenuator to the value obtained in Step 11.
14	Place the DISPLAY SELECT switch in the IF OUT position.
15	Observe the power meter reading and record.
16	From Step 8 obtain the input power, and from Step 15 obtain the output power. Calculate the Receiver gain from the following formula: Gain = $\text{Power}_{out} - \text{Power}_{in}$.

TABLE 4-5
RF INSERTION LOSS

Channel	Frequency(MHz)	Loss(db)
VHF ΣR	153	13.75
VHF ΣL	153	13.75
VHF ΔAZ	153	13.85
VHF ΔEL	153	13.90
VHF ΣR	157.5	13.85
VHF ΣL	157.5	13.85
VHF ΔAZ	157.5	13.95
VHF ΔEL	157.5	14.00
VHF ΣR	162	13.90
VHF ΣL	162	$\boxed{14.00}$
VHF ΔAZ	162	14.10
VHF ΔEL	162	14.10
UHF ΣR	415	14.15
UHF ΣL	415	14.10
UHF ΣR	427	14.35
UHF ΣL	427	14.35
UHF ΣR	440	14.50
UHF ΣL	440	14.45

TABLE 4-6

RECEIVER INPUT LEVELS

	Suggested Input Level* Waveform		
	CW	S	L
UHF HIGH GAIN (1)	−79 dbm	−93 dbm	−100 dbm
UHF MED GAIN (2)	−55 dbm	−69 dbm	−76 dbm
UHF LOW GAIN (3)	−31 dbm	−45 dbm	−52 dbm
VHF HIGH GAIN (1)	−84 dbm	−97 dbm	$\boxed{-104 \text{ dbm}}$
VHF MED GAIN (2)	−60 dbm	−73 dbm	−80 dbm
VHF LOW GAIN (3)	−36 dbm	−49 dbm	−56 dbm

*All input levels are 12 db below saturation.

TABLE 4-7

IF ATTENUATOR SETTINGS

Channel	Attenuation
VΣR1	31.20
VΣR2	31.40
VΣR3	31.50
VΣL1	$\boxed{31.35}$
VΣL2	31.35
VΣL3	31.45
VΣL TRK	27.25
VΣL RGC	27.50
VΔAZ1	31.60
VΔAZ2	31.40
VΔAZ3	31.45
VΔAZ TRK	27.40
VΔEL1	31.45
VΔEL2	31.55
VΔEL3	31.40
VΔL TRK	27.25
UΣR1	31.45
UΣR2	31.35
UΣR3	31.10
UΣL1	31.55
UΣL2	31.50
UΣL3	31.80
UΣL TRK	29.40
UΣL RGC	28.10

APPENDIX A

VHF RECEIVER GAIN CALIBRATION

Date______________

Time______________

A-1. RECEIVER GAIN

1. EXCITER __________ dbm with 0 db RF ATTENUATOR

2. C/M __________ dbm with 30.27 db in CONT ATTENUATOR (adjust for +9.0 dbm)

   48.8 db IF STEP ATTENUATOR

3. RF DISTRIBUTION LOSSES at 162 MC: R = 13.90 AZ = 14.10
   L = 14.00 EL = 14.10

4. INPUT −36 dbm (RF ATT. 22.0 db + ITEM 1 = ____ ____ ____)

	CHANNEL	IF ATT.	OUTPUT LEVEL	EXPECTED LEVEL +0.25 db
TGC = 63 db	ΣR TRK (RGC)	27.65	______ dbm	+ 8.0
	ΣL TRK	27.20	______ dbm	+10.0
	AZ TRK	27.45*	______ dbm	+10.0
	EL TRK	27.40*	______ dbm	+10.0
	ΣR 3 (Recorder)	32.45**	______ dbm	− 2.0
	ΣL 3 (Recorder)	32.50	______ dbm	− 2.0
	AZ 3 (Recorder)	32.55*	______ dbm	− 2.0
	EL 3 (Recorder)	32.70*	______ dbm	− 2.0

5. INPUT −60 dbm (RF ATT. ITEM 4 + 24 db = ____ ____ ____)

TGC = 39 db	ΣL TRK	27.20	______ dbm	+10.0
	AZ TRK	27.45*	______ dbm	+10.0
	EL TRK	27.40*	______ dbm	+10.0

6. INPUT −84 dbm (RF ATT. ITEM 5 + 24 db = ____ ____ ____)

TGC = 15 db	ΣL TRK	27.20	______ dbm	+10.0
	AZ TRK	27.45*	______ dbm	+10.0
	EL TRK	27.40*	______ dbm	+10.0

7. RECHECK EXCITER: ________ ______dbm, and C/M: ______________dbm

8. COMPARE EXCITER VCW to CW (ref): ____________ = Δ1

* 0.1 db added to correct for RF distribution error.

** 0.1 db substracted to correct for RF distribution error.

COMPARE EXCITER VL to VCW (ref): ____________ = Δ2

COMPARE EXCITER VS to VCW (ref): ____________ = Δ3

9. RECEIVER PULSE GAIN (compare VL & VS to VCW) (MAX ALLOWABLE ERROR ± 0.5 db)

VCW input −36 dbm (RF ATT. = same as ITEM 4 = ______ ______ ______)

VL input −56 (RF ATT. = ITEM 4 + 20 db + Δ2 = ______ ______ ______)

VS input −49 dbm (RF ATT. ITEM 4 + 13 db + 3 = ______ ______ ______)

	ΣR	ΣL	AZ	EL
VL	________ db	________ db	________ db	________ db
VS	________ db	________ db	________ db	________ db

A-2. RECEIVER PHASE

1. C/M ____________ (Cont. IF ATT. = 34.0 db)

				ΣL	AZ	EL	ATT. CHECK
CW	2.	Input ≈ −36 dbm (RF ATT. = 20-3-3.1) TGC = 60 db	RECORDER (3)	_____	_____	_____	(6.5) ________
			TRK	_____	_____	_____	(17) ________
	3.	Input ≈ −60 dbm (RF ATT. = 40-7-3.1) TGC = 36 db	TRK	_____	_____	_____	(17) ________
	4.	Input ≈ −84 dbm (RF ATT. = 70-1-3.1) TGC = 12 db	TRK	_____	_____	_____	(17) ________
VCW	5.	Input ≈ −36 dbm (RF ATT. = 20-3-3.1) TGC = 60	RECORDER (3)	_____	_____	_____	(6.5) ________
			TRK	_____	_____	_____	(17) ________
VL	6.	Input ≈ −56 dbm (RF ATT. = 40-3-3.1) TGC = 60	RECORDER (3)	_____	_____	_____	(6.5) ________
			TRK	_____	_____	_____	(17) ________
VS	7.	Input ≈ −49 dbm (RF ATT. = 30-6-3.1) TGC = 60	RECORDER (3)	_____	_____	_____	(6.5) ________
			TRK	_____	_____	_____	(17) ________

Max. Allowable Difference between ΣL and AZ or EL is ± 5 degrees.

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13. ABSTRACT

An investigation was carried out to determine the feasibility and relative cost of developing pictorial procedures that could be used in conjunction with the Lincoln Training System for task simulation in the support of performance laboratory instruction. The technique appears to be economical and effective. The storage and data processing capabilities of the LTS make it possible to monitor and assess the student's performance. It would also be possible to record and monitor system performance in the same fashion, and a scheme for "system performance assurance" is developed which capitalizes on this capability.

14. KEY WORDS

educational technology
Lincoln Training System (LTS)
microfiche production
computer-aided instruction (CAI)
job performance aids

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