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ABSTRACT

The current status of the Lincoln Training System (LTS) is reported. This document describes LTS as a computer supported microfiche system which: 1) provides random access to voice quality audio and to graphics; 2) supports student-controlled interactive processes; and 3) functions in a variety of environments. The report offers a detailed description of LTS-3, the current embodiment of the system concept outlined above, discussing its microfiche reader terminal, audio recording, audio reader, logical processor, and lessons. Results of the field test of LTS-3 are given, the most significant of which indicate that a system can be designed which is cost effective, which reduces training time without adversely influencing training quality, and which enhances the performance of low ability students. Further developments growing out of the LTS-3 project are also treated. These hardward modifications are expected to result in LTS-4, a streamlined and significantly less expensive version of the LTS in which each LTS-4 console will be capable of stand-alone operation and self-contained computational power. (LB)

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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THE LINCOLN TRAINING SYSTEM: A SUMMARY REPORT

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TECHNICAL NOTE 1972-26

3 OCTOBER 1972

LEXINGTON MASSACHUSETTS

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ABSTRACT

This report presents the current status of development of the Lincoln Training System. The LTS-3 is described in some detail together with the results of field evaluation and consideration of expected cost-effectiveness.

Accepted for the Air Force
Nicholas A. Orsini, Lt. Col., USAF
Chief, Lincoln Laboratory Project Office

I. INTRODUCTION

The Lincoln Laboratory program in Educational Technology was established with Air Force support in January 1970. A major product of that program has been the development and continuing evolution of the Lincoln Training System (LTS).

The LTS was conceived as a potentially cost effective means to support training in a wide variety of skills and training environments. In order to accomplish this, it seemed clear that there were certain essential requirements that would have to be met. These are listed in Table 1.

TABLE I

System Requirements

Random access to

- voice quality audio
- photographic quality graphics

Interactive support

- student control of access rate
- continuous knowledge of progress

Capable of ex-school operation

The system must be capable of storing and accessing high level graphical material such as engineering drawings, circuit layouts, and photographs in black and white. Medical and other areas may require color photographs. The system should include an audio capability, and both audio and visual material must be available on a random access basis as it will not generally be possible to anticipate the moment-to-moment needs of any particular student or instructor. The student must be able to control the rate at which material is presented. He must be able to speed it up or slow it down. He must be able to scan ahead, to stop, to go back, and to review. (Training films and TV are generally not satisfactory training aids just because they cannot be rate-adjusted in this fashion by the individual viewer.) It is equally important that the student be provided with relatively continuous knowledge of his progress. This not only reinforces and maintains motivation but is necessary if the student is to pace himself effectively.

It is an important general requirement that the system be largely independent of schedules and geography. It must not only support individual self-instruction, but it must carry out this function at times and places that are convenient to the student.

II. THE LINCOLN TRAINING SYSTEM

The Lincoln Training System is a computer supported microfiche system that is being developed to meet the requirements outlined above. (Microfiche is a 4 × 6 inch transparency containing a number of photographic images.) At the recording densities that we are using, microfiche images have extremely high resolution, half-tone and continuous-tone reproduction are very satisfactory, and color is feasible. The use of microfiche for the recording of text and pictures is increasingly common and it is, in fact, the most economic means currently available for publication, distribution, and storage of such material.*

Development work at Lincoln Laboratory has made it possible to include visual i.. ;ges, voice quality audio, and computer control logic on the same fiche. This development makes it possible to design a "distributed" system with all lesson specific information — audio and visual displays and branching logic — located at the

*Teplitz, Arthur. Microfiche for Technical Information Dissemination: A Cost-Benefit Analysis, SDC SP-3223, 1968.

student's terminal. It is thus possible to load terminals with different lessons, and there is no competition for resources (except terminals) among students operating within the system.

It also makes it possible to design the LTS terminal with its own logic processor and control for stand-alone operation. Because there is a natural exchange of "amount of control information on the fiche" for "complexity of processing," fairly elaborate interpretations of student response can be achieved with minimal hardware costs. Response interpretation (program) as well as branching control tables (data) can be read into the processor from any microfiche frame. The file management problem is obviated because there is no off-line bulk storage to be concerned with and because information is directly available on the fiche when it is needed, in conjunction with the appropriate visual and auditory displays.

Audiographic fiche provide the course author with a wide range of presentation techniques, lesson formats and instructional strategies — from conventional text and lecture material to highly interactive, tightly programmed drill, test and remediation. Furthermore, they encourage the kind of modular course construction that individualization requires. Since it is not feasible to develop full length courses to match the idiosyncratic needs of each student, a course must be thought of as a sequence of units selected from a larger set to provide what is needed by a particular student at a particular time. The larger set would include units at different "levels" to match differences in ability and to permit flexibility in the construction of a short, narrow course with very specific educational objectives or a longer, broader course which allows more freedom to the student in the selection of content and the establishment of goals. Microfiche facilitates this sort of course structure in that it enables inexpensive publication and distribution of small units — 10 to 30 minutes of instruction — and encourages the development of lesson material by classroom instructors or specialists who would not normally author an entire course.

Perhaps the most important interaction between the system and lesson development, however, derives from the fact that the lesson logic is included on the fiche as an integral part of the lesson module. This insures that the material is used at least as the author intended it to be and, in this sense, some of the classic functions of the teacher are transferred to the lesson development process. The system delivers instruction, not simply instructional materials, and we would expect that course authors will be experienced teachers or will work closely with teachers.

III. LTS-3

The LTS-3 is the present embodiment of the system concept that we have outlined above. The terminal for LTS-3 (Figure 1) is built around an Image Systems, Inc. microfiche reader. Under computer control, this unit selects an image on any one of up to 750 microfiche stored in its carousel fiche holder. Extensive modifications to the basic equipment have been made to satisfy LTS-3 performance requirements. An audio reader with its associated projection optics, and a film-referenced vernier X-Y position control to provide the precise fiche positioning required for audio reading have been added. The projection optics have been changed to improve fiche illumination. Mechanical changes have been made to provide room for the audio reader. Figure 2 shows the inside of the modified terminal.

LTS-3 uses fiche in the format shown in Figure 3, with each of the 12 visual images having a corresponding audio image. The coded metal spine clamped to the edge is the mechanism for selecting individual fiche.

The audio record is made using a recording optical galvanometer that is

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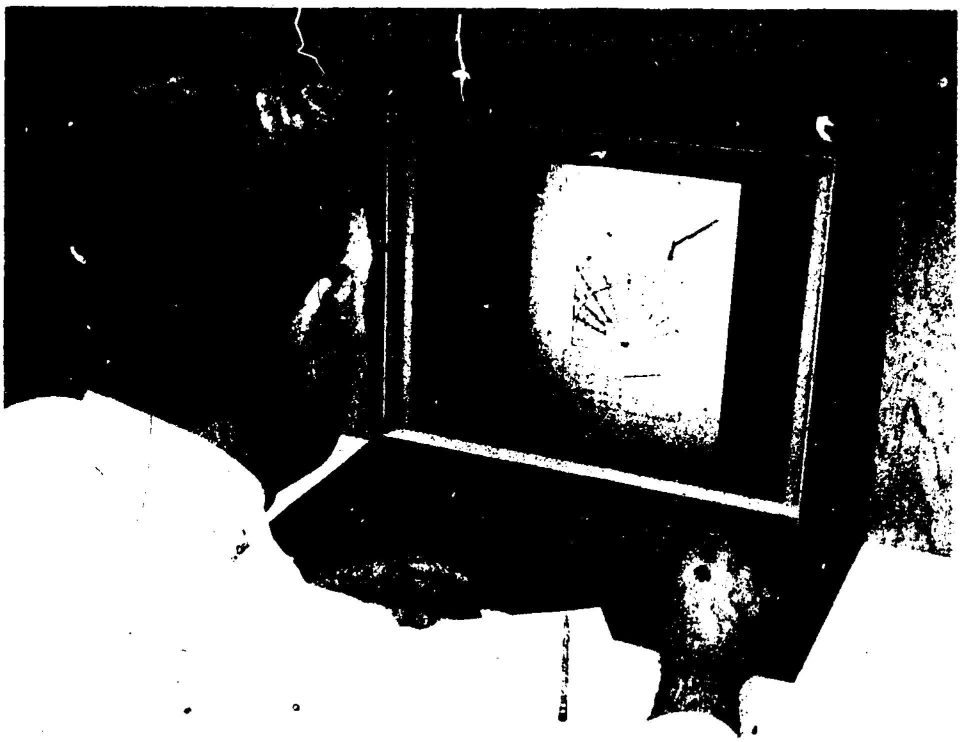

Fig. 1. The LTS terminal.

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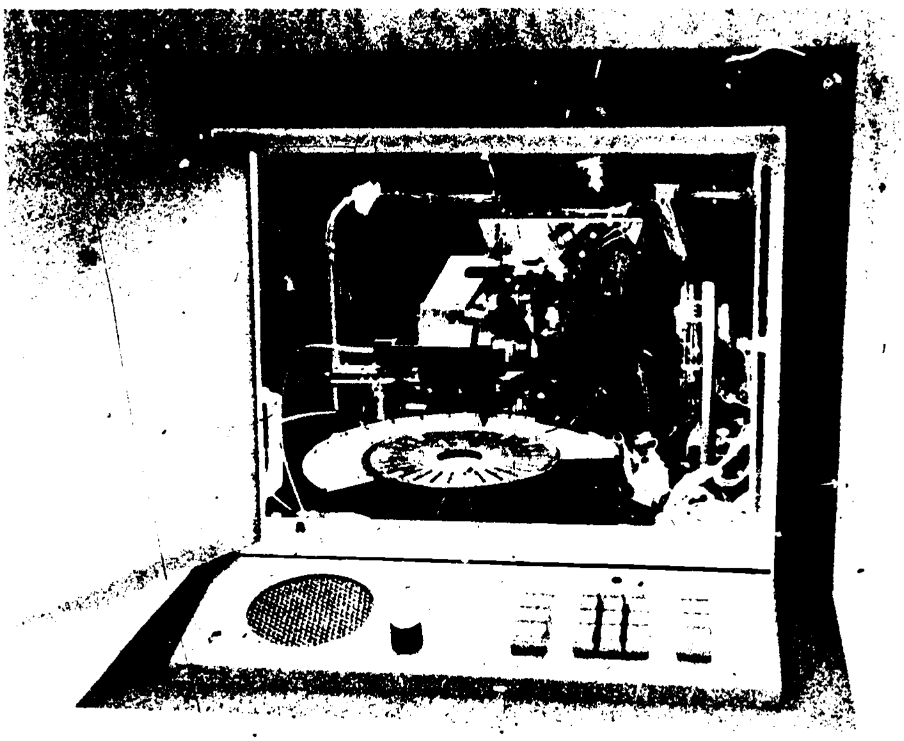


Fig. 2. The LTS fiche and audio read mechanism.

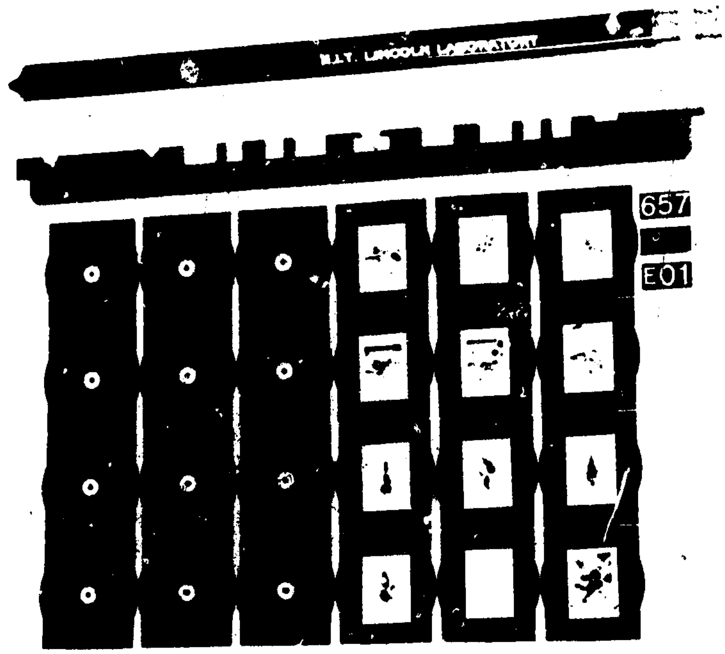


Fig. 3. An LTS fiche.

mechanically driven across a rotating film to produce a spiral record (Figure 4).

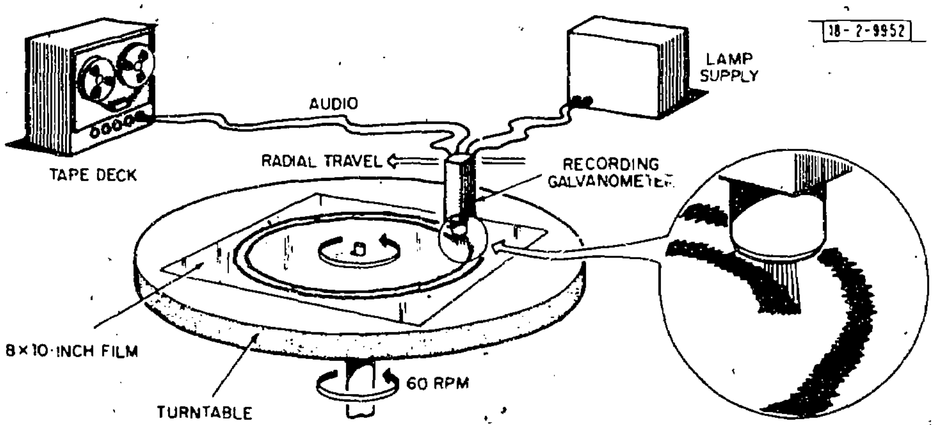


Fig. 4. Area modulation film recorder.

The output light beam is modulated by the audio signal producing an exposed negative image as shown in Figure 5. A master audio frame which may contain

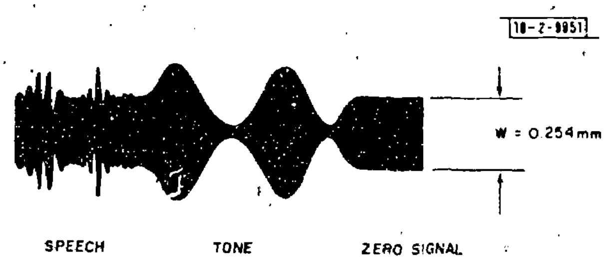
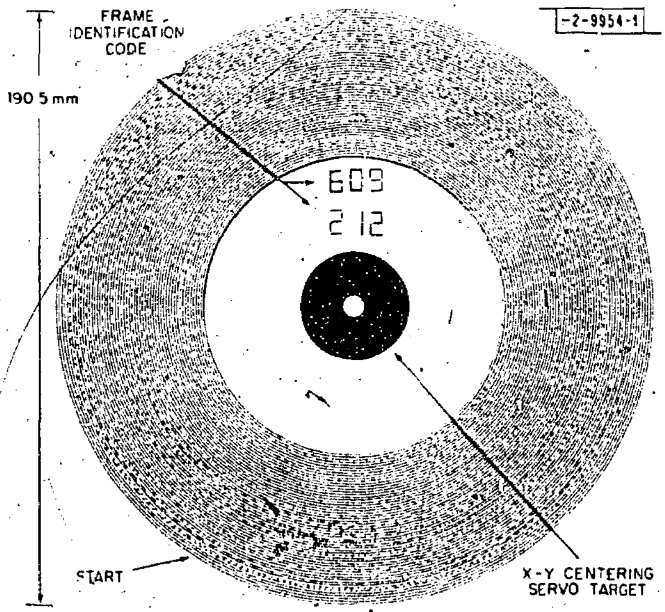


Fig. 5. Recording galvanometer track format.

up to 28 seconds of speech is shown in Figure 6. This image is reduced by 8.7 to 1 on the microfiche master.



OUTSIDE DIAMETER ——— 190.500 mm
INSIDE DIAMETER ——— 91.840 mm
MEAN TRACK HEIGHT ——— 0.254 mm
PEAK-TO-PEAK TRACK HEIGHT ——— 0.508 mm
TRACK SPACING ——— 0.820 mm
TIME PER REVOLUTION ——— 0.5 sec
TIME PER FRAME ——— 28.0 sec

Fig. 6. Original master audio frame.

The audio reader assembly rotates at 120 RPM, driving the signal track diode assembly (Figure 7) along a circular path. An "Audio-on" signal from the computer

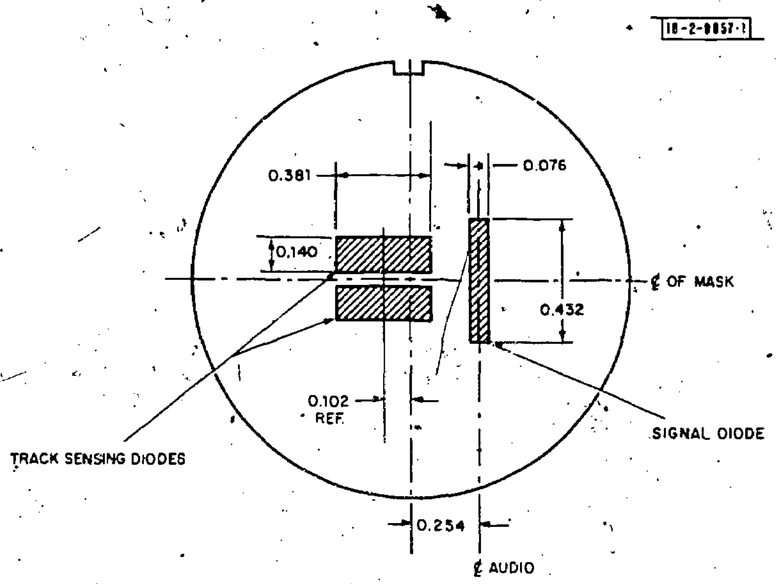


Fig. 7. Track/read head assembly.

activates the track servo system and then the diode assembly is driven along the spiral audio record. Measured acquisition time is less than 0.1 second.

A stationary coherent fibre light pipe is mounted in the center of the rotating reader assembly. The audio frame boresight target is imaged onto this pipe, and the light signal is conducted through the hub of the assembly to a quadrant diode sensor mounted on the rear. The diode develops vernier X-Y error signals for final positioning of the fiche. The rms acquisition error in X and Y are, in general, better than 0.001 inches which limits maximum frequency modulation in the playback to ±1%.

With appropriate pre-emphasis before recording, the overall audio system frequency response is flat to within ± 2 dB from 0.3 to 3.0 KHz.

A logical processor controls the operating sequence in accordance with the student's response and the lesson logic prescribed by the author. In the present configuration, a Digital Equipment Corporation PDP-8/I is used to support five LTS-3 terminals, operating independently, i.e., five students each on different lessons. To expedite field testing, author logic was recorded on magnetic tape rather than on fiche. This had the added advantage of facilitating correction during the debugging phase. Two tape drives are available – one for author logic and another for data recording. Student records and messages to the classroom monitor are printed on a teletype machine.

LTS lessons consist of a set of information frames each of which may communicate instructions, facts, problems, and/or questions via visual and/or auditory messages to which the student responds by selecting among prescribed alternatives. The alternatives include responses that allow the student to conduct his own review of frames previously covered or that access supplementary material, either reference material or expanded instructional material. Students interact with LTS-3 by means of the keyboard shown in Figure 8. It is simple enough to be almost self-explanatory, but has proven to be quite flexible and powerful.

INDEX and SELECT are used for entry into lessons, BACK and FORTH for review.

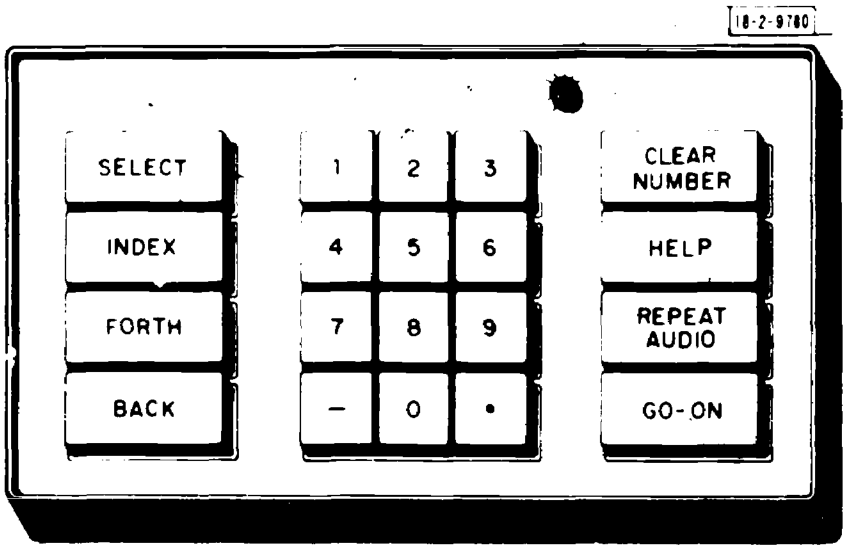


Fig. 8. Keyboard.

When a student is responding to a frame, he uses one of the three keys at the right – HELP, REPEAT AUDIO, or GO-ON. To the student, a press of GO-ON always means "I am ready for more information – more sound or an entire new frame." It will always cause new information to appear. In some cases, the machine has asked for information from the student and expects it in the form of a number (e.g., a multiple choice question or the results of a computation). It will not go on to a new frame unless an acceptable number has been entered.

HELP is a button that may be pressed if there is doubt about how to respond. Pressing HELP may cause a new frame to appear with further instruction. It can be used to signal the instructor.

There are also other ways in which the student may expand on the material presented to him. For instance, technical terms may be subscripted, in which case entering the appropriate number and pressing SELECT will move the student to a descriptive frame or frames. BACK would, under these circumstances, return the student to the main lesson sequence.

The keyboard is completely programmable. As there is control logic associated with each frame of each lesson, the course author has complete freedom in the assignment of functions to keys and in the interpretation of student responses.

The following author programs are currently available:

(a) CHOOSE - The author provides one set of alternatives ranging from 1 through 9, from which the student selects one answer.

(b) ANYORD - The author provides one set of alternatives, from which the student selects a specified subset (up to five) and enters them in any order.

(c) FIXORD - The author provides up to five alternatives from which the student selects a specified subset (up to five) that must be entered in a specific order.

(d) COMPOS - The author provides up to three sets of alternatives, from which the student must select one alternative from each set.

(e) NUMBER - The author specifies several parameters in this program which allow the student to enter a numerical response that he has calculated off line. The student response is analyzed and branch options are determined in the following order:

(1) Selection of unit of measurement error.

(2) Decimal point location error.

(3) Sign or magnitude error.

(4) Correct response.

No knowledge of computer programming is required to write LTS programs.

IV. FIELD TEST

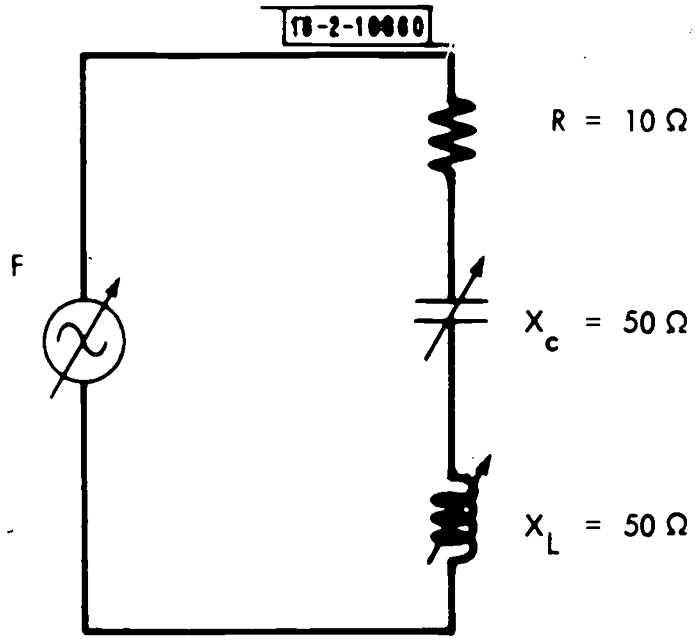
A field test of LTS-3 was conducted by the 3380th Technical School of the Air Force Air Training Command at Keesler Air Force Base in the Spring of 1972. * The course material was developed by a team of regular Air Force classroom instructors and instructional programmers and consisted of one week (30 hours) of material from the ATC Standardized Electronic Principles Course. The subject matter – RCL circuits – is largely conceptual but does require some laboratory work using electronic test equipment. The learning objectives were identical with those of the regular course.

Figure 9 is a sample of one instructional frame. From the audio script, it is apparent that this is part of a remedial loop.

Twelve students were randomly selected each week from among all of the students entering the appropriate week of the Electronic Principles Course. They were then assigned to the experimental (LTS) group or to the Visible Control or Hidden Control groups. A total of 165 students, 55 per group, were involved in the experiment. **

*Keesler Project Report 72-112, 31 July 1972, Keesler TTC, Keesler Air Force Base, Mississippi.

**Students from the Self-Pacing Branch (those with exceptionally high aptitudes or previous electronic experience) were excluded. A sample of 20 students from this group was run on the LTS at a later date.



Solving for Z

$$Z = \sqrt{R^2 + (X_L - X_c)^2}$$

$$Z = \sqrt{(10)^2 + (50 - 50)^2}$$

$$Z = \sqrt{100 + 0}$$

$$Z = \sqrt{100}$$

$$Z = 10\,\Omega$$

You now have another important characteristic of series resonant circuits.

Z equals R

Without changing R, could Z be less than Ω in the above circuit?

1. No
2. Yes

(lower limit of visual frame)

AUDIO

No that's not correct. Remember this is still a series RCL circuit and the formulas for series RCL circuits are still valid. Using the formula to solve for impedance in the resonant circuit you can see that impedance is equal to R.

Fig. 9. Example of lesson frame visual and audio components.

An analysis of background data, aptitude test scores and achievement in the previous instructional blocks of the course revealed no significant differences among the three groups.

Students in the LTS group scored consistently, though not significantly, higher in achievement tests covering the affected subject material in Electronic Principles, from which it was concluded that training on the LTS was equivalent to training in the classroom. The important finding was that there was a 37% savings in average training time using the LTS. The distribution of individual times is shown in Figure 10.

There is indication that students with lower aptitude spent more time in training.* One consequence of this fact is that there were fewer failures; another consequence is that the correlation between General AQE and the End-of-Week Test scores was higher for the Visible Control group (.53) than the LTS group (.22). (Hidden Control did not take the EOW Test.) The evidence seems clear that despite the narrow range of aptitude among students selected for electronics training, the LTS does automatically compensate for slower individuals, and even these students were able to progress more quickly than under conventional training.

The observed savings in time are large, even when compared to results such as those reported for programmed texts, and further savings may be expected after revisions of the course materials, deletion of unnecessary test procedures, etc. The effect of improved classroom management alone is indicated by the fact that average training times dropped from 20 hours for the first half of the study to 16 hours for the second.

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*The correlation between the General AQE score and time spent in training for the LTS group is -.30, a statistically significant result ($p < .05$).

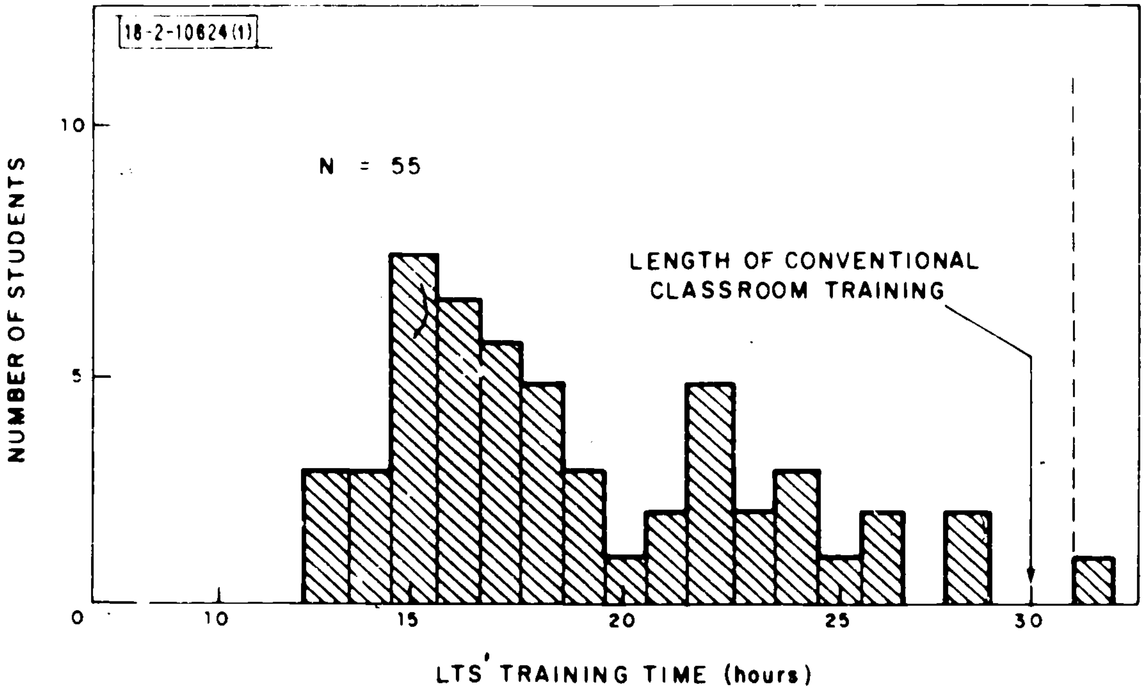

Fig. 10. Distribution of LTS Training Time. (One subject required 59 hours to complete training and is not shown in the above distribution.)

In most situations where savings have been achieved through "programming" there have been major revisions and deletions of learning objectives. Since there was no paring down of the behavioral objectives in the transfer of instruction to LTS, the large saving cannot be accounted for in this way. Nor is it likely that the savings are due to students merely skipping over what they already knew, since few of the students had any prior knowledge of the material. It is most likely that the large savings arise from the individualized, minute-to-minute tutoring provided by the machine — a teaching strategy not open to the instructor in a class of even moderate size.* Also, an attitude survey, as well as unsolicited remarks suggest a high degree of motivation. The students commented that they were "turned-on" by the highly responsive nature of the instruction.

The results of the Keesler tests support the validity of the LTS concept, and show that instructional materials can be developed and the system can be beneficially introduced into an on-going operation without extensive training of course authors or instructors.

V. CURRENT DEVELOPMENTS

At this writing, the LTS hardware must be considered experimental, though only a small fraction of the system (the audio reader) is non-commercial. The optimum configuration of the LTS-3 is a cluster of 5-10 consoles managed by a PDP-8 computer. The LTS-4, now under development at Lincoln Laboratory, is a vastly streamlined and significantly less expensive version of the LTS and each LTS-4 console will be capable of stand alone operation. The computational power required for each console will be self contained, an approach made possible by the rapidly decreasing cost of digital storage and processing equipment. Until the LTS-4 becomes available, field trials of the LTS concept will use LTS-3 equipment.

*This conclusion is further supported by preliminary data that indicate significant savings within the Self-Pacing Branch.

In the LTS-4, fiche will be stored in easily interchangeable cassettes each containing about 30 fiche, instead of in the large carousel used in LTS-3.

VI. COSTS

It is anticipated that each LTS-4 terminal will cost $2000 or less in production quantities. A table can be developed which shows the cost per terminal (student) hour for various initial costs and utilization schedules. It is assumed that the equipment is amortized over a 5 year period and that maintenance costs are 5% of initial cost per year. Curriculum development cost, including fiche production and distribution, is estimated at 15 cents per hour. (This last figure is dependent on the number of students who eventually use the material; we have assumed that the development costs will be distributed over 10,000 students. The lesson development cost is assumed to be $1100 per student hour; the per hour cost for a number of students other than 10,000 can be derived by pro rating this $1100 – or other appropriate cost – over the presumed number.)

Table II was developed using the foregoing assumptions.

TABLE II

LTS Cost per student hour

Hours Utilized	Terminal Cost $2000	$1000	$500
500	1.15	0.65	0.40
1000	0.64	0.40	0.28
1500	0.48	0.32	0.23
2000	0.40	0.28	0.21

It must be noted that these are incremental costs. No technological system that we are aware of proposes to entirely eliminate teachers and supervision (which constitute 75-90% of the present costs of education and training). Any potential economic gain is derived either from expanding the number of students that can be supervised by a single teacher, or by reducing the time required to achieve a desired skill-knowledge level. Our experience indicates that gains are possible in both of these dimensions.

Economic gains are most likely to be achieved when the current cost of supervision (instruction) is high – either because of high salaries, because of small class size, or because the students are being paid. Educational technology has not had, and is not likely to have, an important impact on areas of public education where none of these conditions hold.

Figures 11 and 12 provide a quantitative measure of the changes in cost per student hour that occur when the LTS is introduced.

Figure 11 indicates the change in cost per student hour as a result of an increase (or decrease) of class size resulting from the introduction of an LTS costing $2000 per terminal (LTS 2000). Cost per instructor per class hour is assumed to be $10.00 regardless of class size. If the present class size is 10 and the size with LTS is 20, then the cost per student hour remains constant. If the present class size is 5 without LTS and 9 with LTS, then the cost per student hour decreases by $ .50. The effect of other class size changes is easily determined.

Figure 12 shows how much training time must be saved with LTS if no increase in cost is to be caused by introducing LTS (2000). Each curve shows the break even point. As in Figure 11, supervisory (instructor) cost per classroom hour is assumed to be $10.00 per hour and invariant with class size. Class size is assumed not to change when the LTS is introduced. It is clear that decreased cost through increased efficiency (speed) is difficult to achieve when student wages are not a part of the overall cost of the system. It is equally clear that only modest decreases in training time are required when wages are a part of the cost. For example, if the class size is 7 and the students receive no subsidy (salary), a 25% saving is required to keep the cost of education with LTS equal to that without LTS. If the student is being paid $3.00/hour, as he might be in an industrial training situation, then only a 10% reduction in training time is required to reach the break even point. With student wages of the order of $10.00 per hour (professional training), LTS is required to save only a very small amount of training time over the conventional classroom in order to reduce training costs. It is expected that LTS will find its initial use in industrial, professional, and military training where the cost of maintaining the student is an important factor.

It should be emphasized that in any educational system, there are other than purely economic factors to be considered. Systems such as LTS can improve the quality of education by providing a better match of the instruction to the individual than can be achieved in classroom teaching. Even more important is the possibility of meeting the needs of all those who have left the classroom and are now becoming aware of what they do not know, of what they need, and of what they are unable to get because they have never learned how.

The school system has been ineffective in responding to these demands. We believe it will continue to fail. It is not economically feasible to set up the number and variety of conventional vocational training and adult education classes that would be necessary to overcome geographic and cultural isolation and to meet the tremendous range of individual needs. Competent teachers are seldom available locally, and for adults it is often difficult, if not impossible, to schedule classes around the competing demands of work and family. Individual self-education is the only true solution to this problem, but most people do not have access to the necessary instructional materials nor do they possess the skills that are required for self-instruction using conventional materials and techniques. These are the deficiencies that the LTS is designed to remedy.

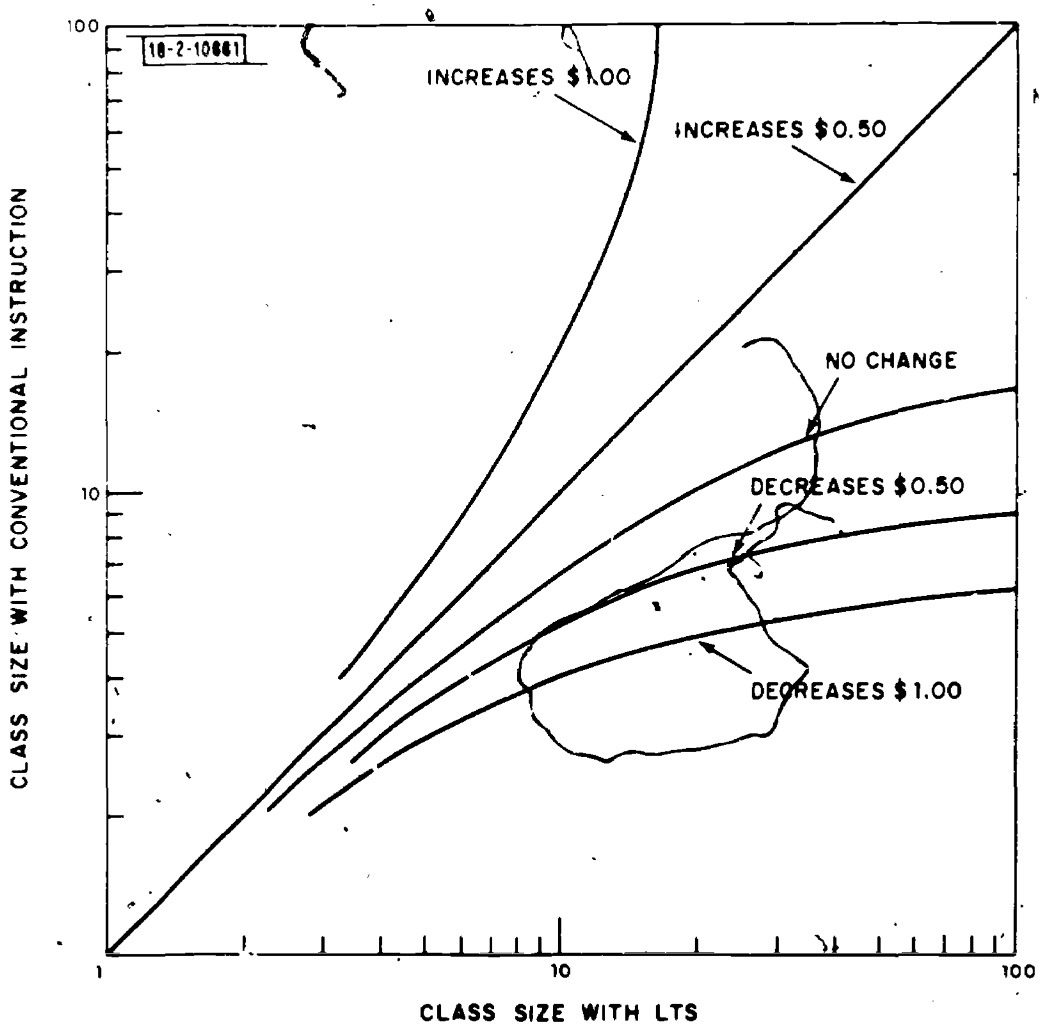

Fig. 11. Effect of change in class size caused by introduction of LTS (2000) on cost per student hour, given that: (1) supervisory (instructor) cost is $10.00/hour/class regardless of class size, (2) no overhead costs are included.

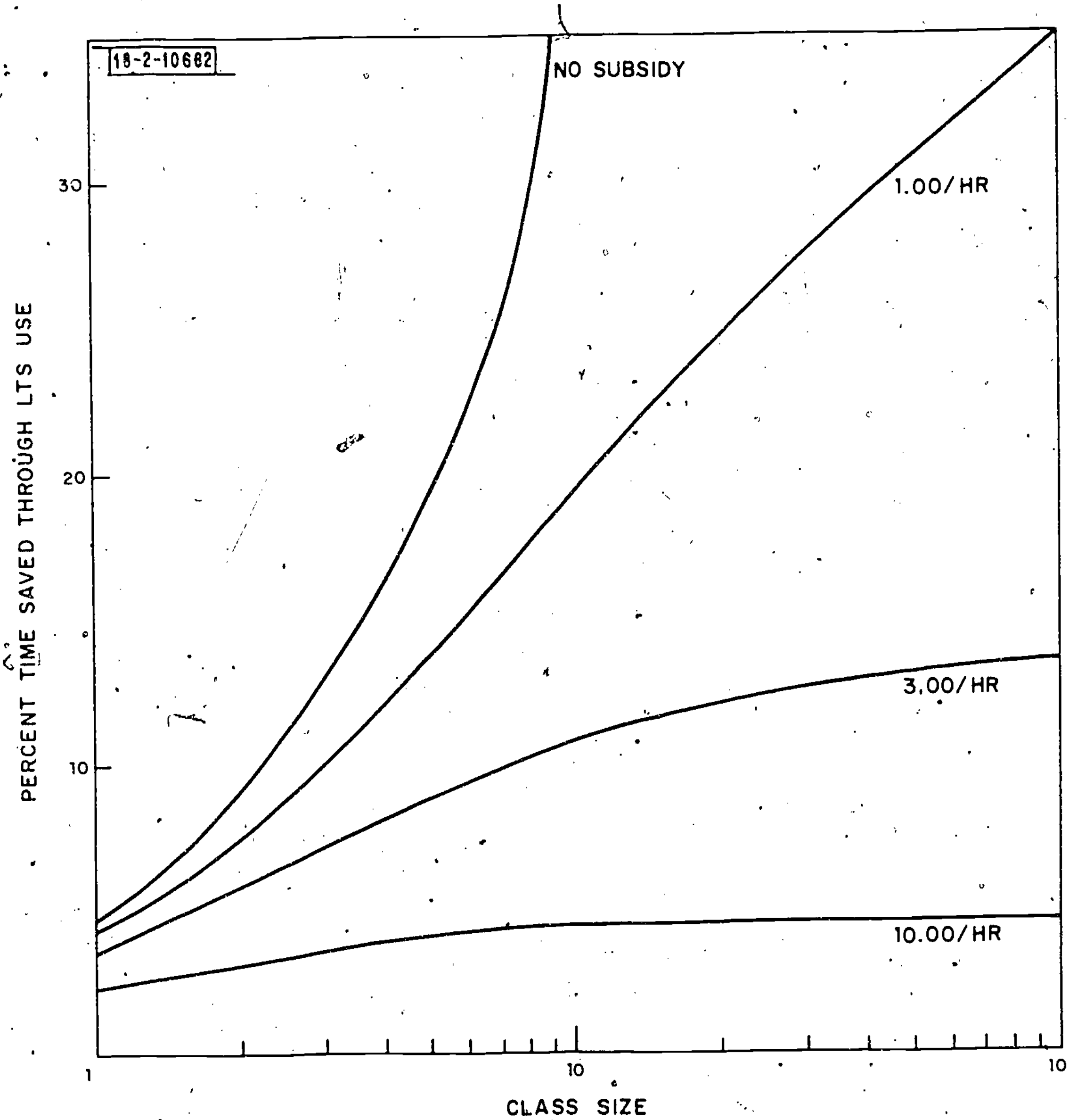

Fig. 12. Effect of student subsidy (wage) on percent time saving required to maintain cost using LTS equal to cost of conventional classroom education, given that: (1) supervisory (instructor) cost is $10.00/hour/class regardless of class size, (2) no overhead costs are included, (3) class size does not change with introduction of LTS.

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13. ABSTRACT

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14. KEY WORDS

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