AREA DISPLAY OF OBSTACLE LOCATION FOR USE WITH A GUIDANCE DEVICE FOR THE BLIND

by

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Department of Electrical Engineering, Sept. 1, 1950

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Thesis Supervisor

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Chairman, Departmental Committee on Graduate Students

E.E.
Thesis
1950

PREFACE

The author wishes to thank the following: Dr. O. H. Straus of the Research Laboratory of Electronics for his many helpful suggestions and criticisms; the R. L. E. Machine Shop and the R. L. E. Wiring Shop for constructing the equipment; the R. L. E. Photographic Laboratory and the R. L. E. Drafting Section for the illustrations included in this report; the Perkins Institution and Massachusetts School for the Blind, for providing subjects and facilities for the experimental work; and Miss S. Strong, Miss Z. Kaufman, Mr. E. J. Waterhouse, and Mr. and Mrs. F. L. Skinner for their help during the experiments.

CONTENTS

I - INTRODUCTION

The Problem

The problems of the blind lie in several major fields.

Psychological and social workers are helping the blind to adjust to their handicap and to take their place as an active group in the community in spite of the physical limitations imposed by blindness.

Facilitating daily routines in a completely familiar environment (at home or in a specific job) is another phase of the problem, and can be handled by adapting the environment to the limitation. Braille, special household implements adjusted for touch rather than for sight, and machines and measuring devices with touch indicators all come under this heading.

Another problem is that of finding some way to replace sight so that the person can adapt himself to the environment in a situation where the environment cannot readily be adapted to him. Travelling beyond the confines of a familiar environment is an important part of normal life; at present this is almost impossible for the great majority of the blind without dependence on sighted companions.

Some blind people can travel unaided remarkably well; however, they are the exception rather than the rule. Those able to use guide dogs often find them highly satisfactory, but it is estimated that only about five per cent of the blind could use them, and only about one-half per cent actually have such dogs at present.

What then of the others? Can they have a "guidance device" which replaces their eyes well enough to enable them to travel alone?

The problem can be analyzed in terms of a "motor system-environment-sensory system-brain" feedback loop. Motion of the subject, by means of his motor system, causes the environment's relation to him to change. His sensory system perceives the change and transmits the information to the brain, which evaluates the information and initiates corrections of the motor system action to achieve the desired performance.

A sighted person relies mainly on his vision for this feedback from the environment; a blind person is forced to depend on his other senses, primarily the auditory. The performance of the blind in travel shows that the remainder of the environment-to-brain link in the feedback loop is barely adequate for the needs.* The problem, then, centers about the augmentation of this link by the addition of an artificial sensory receptor to receive information from the environment and present this information, in a coded form, as additional stimuli of one or more of the remaining senses.** These sensory channels, in turn, will transmit the coded signals to the brain, which must then decode the signals before being able to use the information contained therein.

The magnitude of the problem of even a partial replacement of vision is indicated by an estimate of visual capacity of 100,000 separate parallel channels, each capable of 10-16 inputs per second.[8]

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* The system is almost "open-loop";—reference is made hereafter, to "closure" of the loop.

** Suggestions have occasionally been made to replace the malfunctioning part of the visual system with a new one, or failing this, to connect the information-receiving device directly into the nervous system. These suggestions are far beyond present surgical technique, expect in the case of corneal replacement, which is effective for only a very small percentage of the blind.

[8] Superscripts refer to numbered items in the bibliography.

Previous Work

Most of the work on guidance devices for the blind was done under the committee on Sensory Devices of the wartime Office of Scientific Research and Development (later transferred to The National Research Council).[3-6] The Brush Development Company, The Stromberg Carlson Company, and The Hoover Company developed portable ultrasonic obstacle detectors, which were tested by blind subjects in obstacle courses at The Haskins Laboratories in New York, as was an optical detecting device developed by The U. S. Army Signal Corps.

At the beginning of the program, thought was in terms of a hand-held probe which would indicate, by means of an audible signal through earphones, the range to the object at which the device was pointed. The device was to be scanned manually over the environment, point-by-point, like a flashlight, azimuth and elevation being perceived by the hand holding the probe. Decoding of the auditory signal and integration of the point-by-point range, azimuth, and elevation data into a usable concept of the environment was to be performed by the user of the device. It was hoped that such a device might successfully replace vision to the extent of enabling the user to know where objects were, and what they were, while travelling through the environment.

It soon became apparent that the combination of memory and auditory and kinaesthetic perception was incapable of readily organizing and integrating point-by-point information to form the necessary mental picture of the environment. (The problem might be somewhat similar to that of reconstructing a television scene by listening to the video signal through a pair of earphones.)

These results forced a revision of research philosophy. It became clear that the quantity of information presented must be greatly restricted and/or presented to the remaining senses in a "patterned" form, -- i.e. with organization and integration performed by the device rather than requiring it of the user. This corresponds to transference to the device of some of the cortical function of the brain, time integration in the device taking the place of memory, for example. (Chapter VI of Wiener's Cybernetics[2] is particularly applicable in this connection.)

The choice was made of restricting the amount of information to be presented, because this course appeared to offer more useful results in the time available.* A guidance device was thus no longer conceived as capable of replacing vision to the extent of gathering and presenting information in such detail as to enable recognition within a fifty-foot range of objects encountered. It was redefined as a short-range (approximately ten feet) obstacle detector and locator which would enble a blind man to find his way safely through an environment of familiar type. It was not expected to enable recognition of objects or avoidance of vehicular traffic.

The testing programs on indoor obstacle courses showed that the information available from this simplified type of device was so much less than from the theoretically desirable devices previously considered, that it was questionable whether this information was useful enough to make up for that lost by interference with normal hearing.** This realization led to the trial of tactile stimulators vibrating against the finger-tips, and later, electrical stimulation of the skin (slight electric shock) as possible means of presenting information while leaving the ears free to function normally. At this point there was only a short time left before expiration

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* Near the end of the program, smme preliminary work was begun on a "pattern optical device" giving patterned auditory presentation. This work is described in Appendix T of the final report of the Haskins Laboratories.

** The natural obstacle-detection ability of the blind is primarily auditory.

of the contract, and little likelihood that the work would be resumed soon; efforts were therefore bent towards concluding the project in some sort of orderly fashion. Although the devices were not yet reliable enough in operation to warrant field tests under ordinary circumstances, it was felt that some testing of the devices should be done under conditions of actual use before the project was terminated. Analysis of the results was difficult because of the limited amount of field trial possible, and also because of malfunctioning of the devices, but the final report of the Haskins Laboratories stated that two to five years of continued research might produce a generally useful short-range obstacle locator.

In summary, the obstacle-course testing at the Haskins Laboratories showed that the information received by the device was not being presented to the user in an easily usable form; i.e. the device was not "well-matched" to the human. This constituted the bottleneck in the production of a really useful device.

Purpose of This Thesis

It would appear that a better system would be one in which only essential information were presented, in a form not requiring extensive decoding and integration; i.e. where these processes are performed by the device, rather than requiring them of the user.

Most of the objections to the previous methods of presenting information could be overcome by presenting range and azimuth information in the form of a relief map which could be read with the fingertips, similar to the reading of Braille text.

Such a method of presentation would:

1.) leave the ears free for normal use.

2.) present a restricted amount of information by eliminating elevation data, which is generally considered unessential.[7]

3.) present the information in an already integrated and what should be a more easily decodable form. The environment would be brought directly into the grasp of the observer, which is just how he is used to obtaining physical concepts of objects. (Stated differently, this presentation would require no transformation of coordinates for decoding, but merely linear magnification. Simultaneous presentation of the complete field would allow observation of all parts together in their correct relation to each other. The environment would be "seen" area-by-area with the fingers, rather than point-by-point with the ears.)

The fact that the blind read Braille at a rate of the order of 1,000 characters per minute indicates that the tactile channel is capable of transmitting considerable information.

The purpose of this thesis is to test experimentally the foregoing ideas by having blind subjects try to navigate obstacle courses on the basis of information presented as described above.

II - DESCRIPTION OF EQUIPMENT

The map is generated by an array of pegs, each of which can either project through a hole in a board, or lie flush with the surface. The "pegboard" is carried by the blind subject in obstacle avoidance tests;* the subject attempts to reach a goal indicated by a loudspeaker which emits an interrupted 600 c.p.s. tone. Any one of eight loudspeakers located around the room can be connected to the amplifier supplying the audio signal.

It is desirable to test the effectiveness of the pegboard in presenting information without having first to accomplish the engineering development of a satisfactory obstacle detector. This is done by having a human operator set up the continually-changing patterns of raised pegs by means of a control unit, simulating, as accurately as he can, the operation of the scanning obstacle detector of a complete device. This insertion of the operator's feedback loop in place of the sensory unit of the subject's feedback loop introduces into the latter an inherent error and delay. The problem, however, is not a very serious one; usually the operator can track the subject to within less than a foot, and when the operator does make a slight error in transmitting information, a second or two suffices to correct the matter. The subject's performance is rated on the basis of his reaction to the information on the pegboard; he is not penalized for collisions he might make because of a slight error on the part of the operator.

The control unit and the operator are located on a six-foot-high observation platform, the control unit and the pegboard being connected by a 100-foot-long electrical cable suspended from the rafters of the testing room.

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* Conducted in Dwight Hall, Perkins Institution and Massachusetts School for the Blind, Watertown, Massachusetts.

Figs. II-1, II-2, and II-3 show the general layout of the testing room and the equipment.

Pegboard

Experience during the Committee on Sensory Devices program[3-6] indicated that a guidance device should detect obstacles to a range of about twelve feet, within an azimuth angle of about 45 degrees.[7] This, accordingly, was the area chosen to be shown on the map. It was felt that the resolution should be adequate to give certain indication of two-foot-wide passages. The map is thus built up from one-foot-square blocks, each peg being located in the center of its block.

The following factors were considered in determining the peg spacing:

1.) the maximum size of the map is limited by the subject's scanning ability, estimated at 5 sq. in. per sec.

2.) the minimum spacing of the pegs is limited by the spatial discrimination between adjacent pegs by the fingers, the two-point discrimination threshold being between 2 and 3 mm. (0.079" and 0.118").[1]

3.) Standard Braille dots are 0.039" high, 0.059" diameter, and spaced 0.118" apart.[1]

Mockup pegboards were made with peg spacings of 0.100" and 0.200", and peg diameters of one-half the spacings. Peg projections of 0.013" and 0.025" were provided on the 0.100"-spaced board and 0.025" and 0.050" on the 0.200"-spaced pegboard.

The mockups were shown to 21 blind students (ages 17 to 21) at Perkins Institution, and their opinions were requested. The results indicated that the smaller map would probably be easier to scan quickly, but might take longer to learn to read. It was therefore decided to use an intermediate spacing of 0.156". Peg projections of 0.025" to 0.050" appeared to be satisfactory; 0.035" projection was chosen. Fig. II-4 is a photograph of the pegboard with a peg projecting.

Each peg is operated by a solenoid actuator* (hereafter called "solenoid" for convenience) by means of a push-wire which slides in a flexible cable.** The solenoid is held in spring fingers on a mounting panel (Fig. II-5b) screwed to the frame of the unit. A backplate (Fig. II-5c) screwed onto the back of the panel limits the outward motion of the plunger. The assembly of the panel and backplate on the frame is shown in Fig. II-6.

The cable is 0.033" diameter. One end is jam-screwed two or three turns into a 3-48 threaded hole in the end of the solenoid (shown in Fig. II-7); the other end of the cable is tinned and wedged into a 0.089" square-bottomed hole in a cable receiver plate (Fig. II-6) which is mounted below the pegboard. The push-wire passes through a 0.031" hole in the plate, and fits into a long axial hole drilled in the peg (Fig. II-8). A setscrew in the bottom end of the plunger adjusts the effective length of the push-wire.

A spring which rests between the bottom of the pegboard and a flange on the peg (Fig. II-8) returns the peg to its "down" position when the solenoid is de-energized, and in addition, puts a continual compressional load on the push-wire to eleminiate backlash in the cable. A light helical plunger return/spring supplied with the solenoid is used to take part of the "return" load.

Fig. II-9 is a schematic drawing of the peg-operating mechanism.

The seventy solenoid leads are wired to two 47-pin AN connectors on panels (Fig. II-5a) screwed to the frame of the unit. The remaining 24 pins are connected to the frame as a ground return.

Fig. II-10 shows the internal construction of the completed pegboard unit. Fig. II-11 shows the method of carrying the unit.

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* Kalart camera shutter-release solenoid, with rewound coil and minor mechanical modifications.

** Supplied by the Gwilliam Co., Brooklyn, New York

Fig. II-1. Testing room.

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If this picture is re-ordered use registration number shown below.

Registered Under (Group or Project)	**Copy No.**
RLE	1470-E
Where Taken	**Date**
Perkins	Aug. 15, 1950

Description

Peg Board Equip. Operation
View of Course

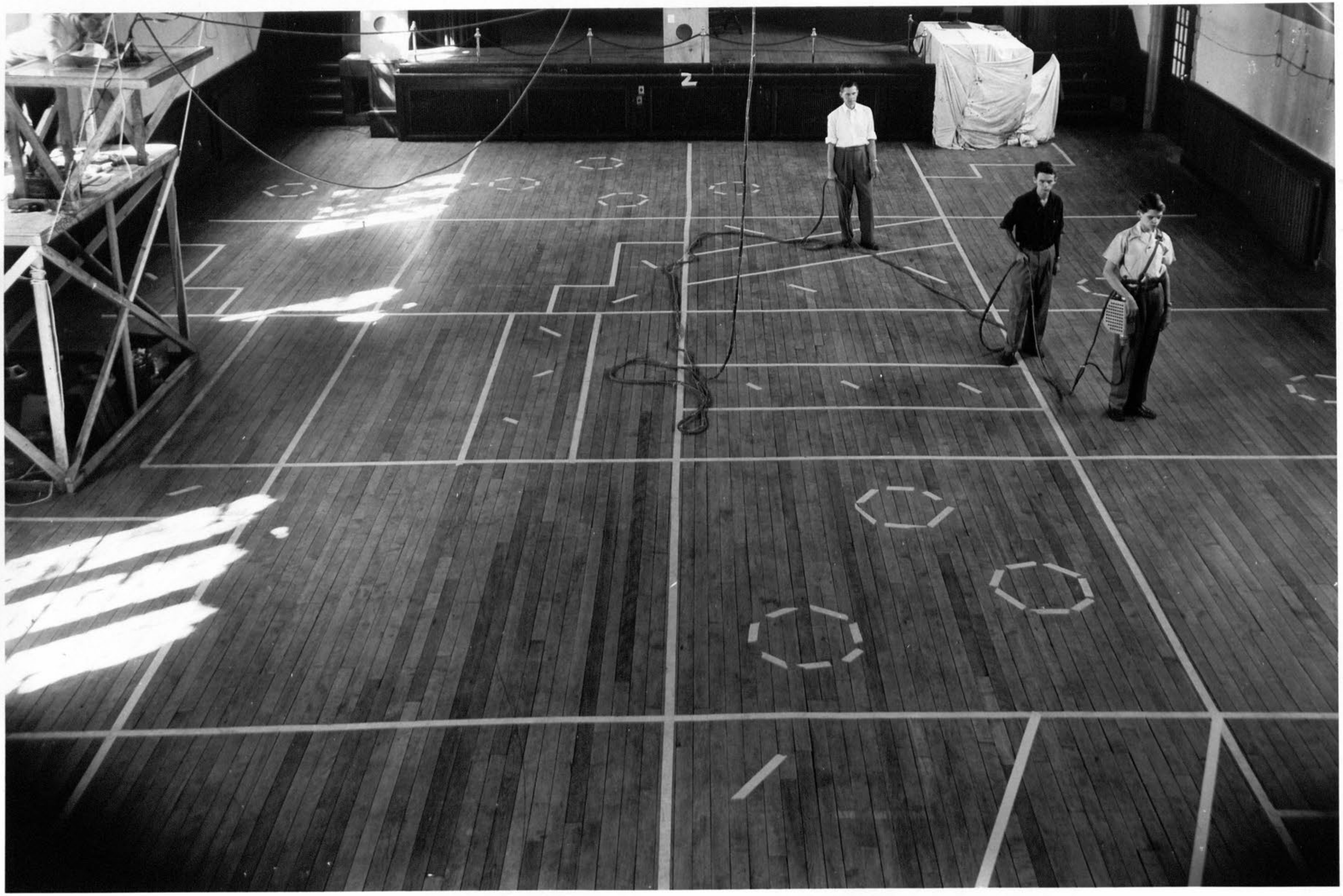

Fig. II-2. Testing room.

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Registered Under (Group or Project): RLE

Copy No. 1470-C

Where Taken: Perkins Institute

Date: Aug. 15, 1950

Description: Peg Board Equip. Operation Course and Subject

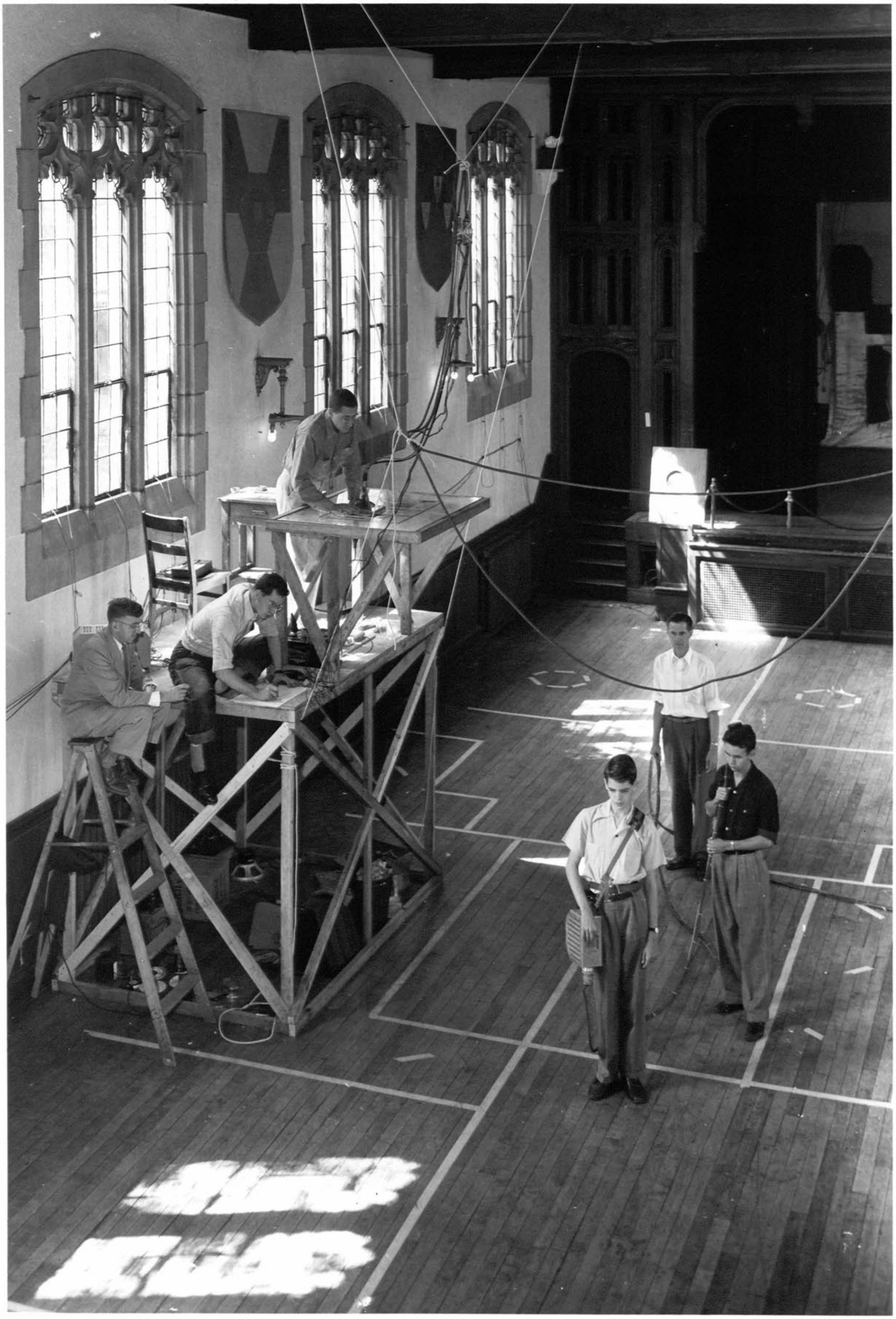

Fig. II-3. Testing set-up.

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Mass. Inst. of Technology

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shown below.

Registered Under (Group or Project)	Copy No.
RLE	1470-A
Where Taken	Date
Perkins	Aug. 15, 1950

Description

Operation of Peg Board Equip.

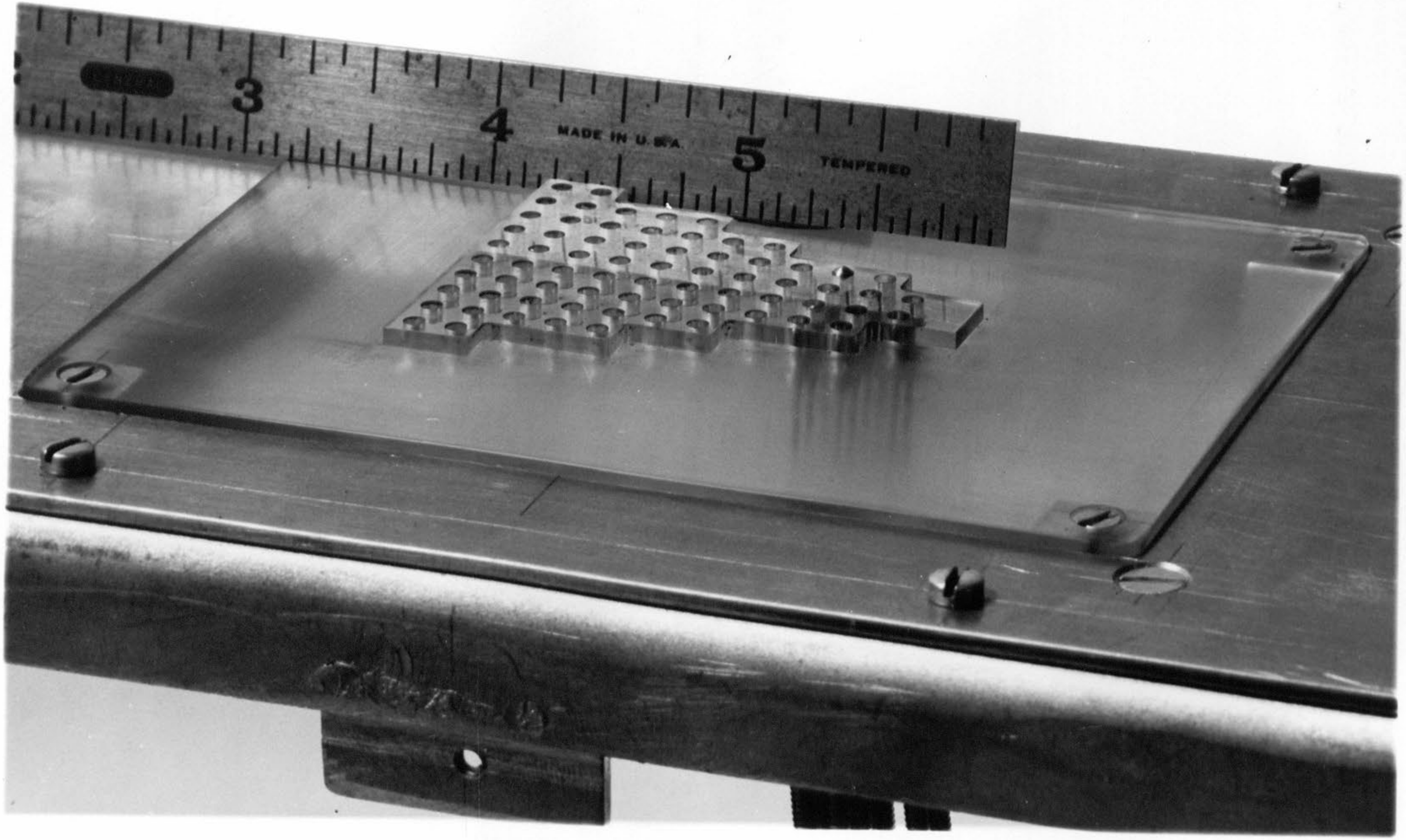
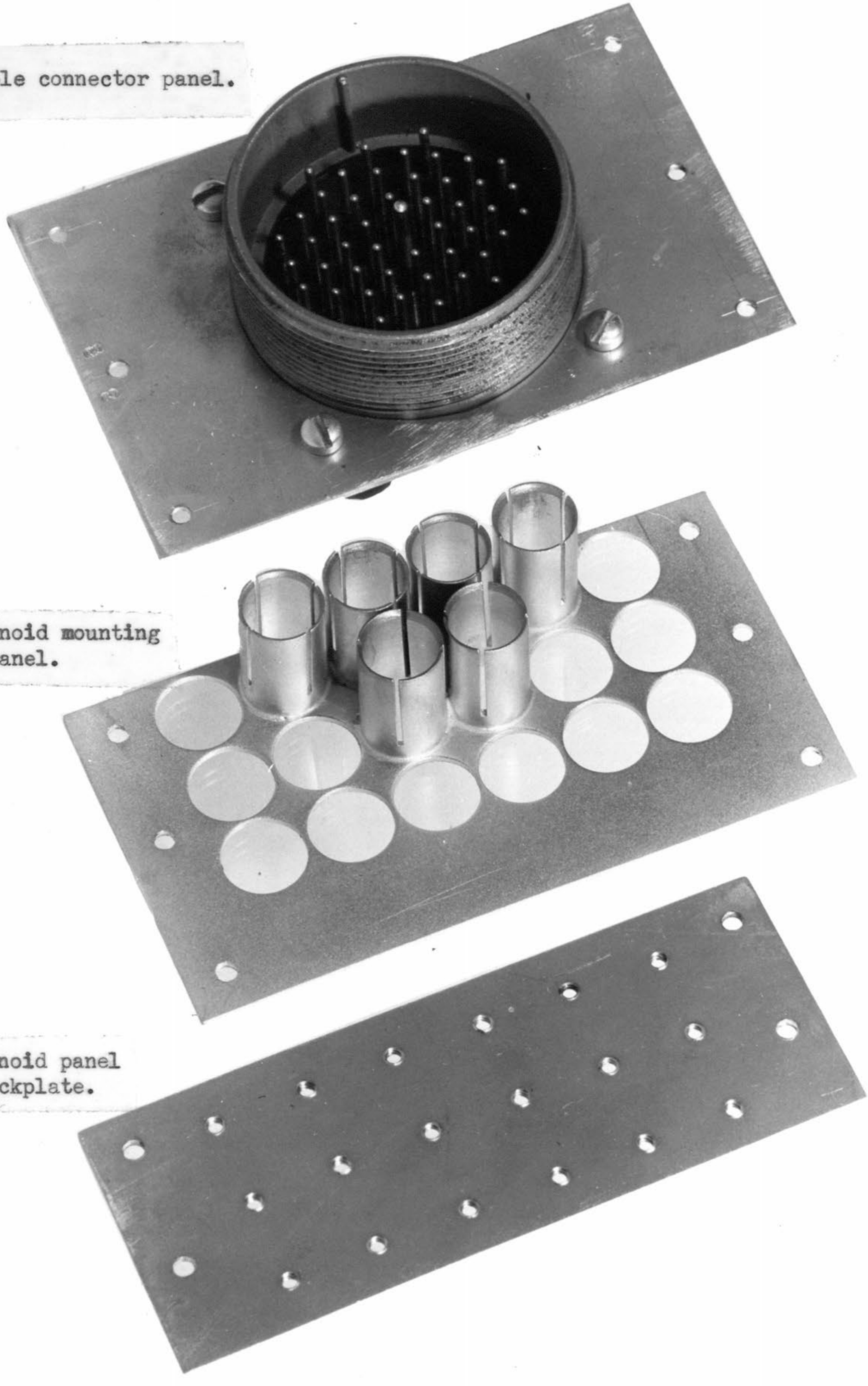


Fig. II-4. Pegboard, one peg projecting.

1459 D



a . Cable connector panel.

b. Solenoid mounting panel.

c. Solenoid panel backplate.

Fig. II-5. Panels for pegboard unit.

F
1459

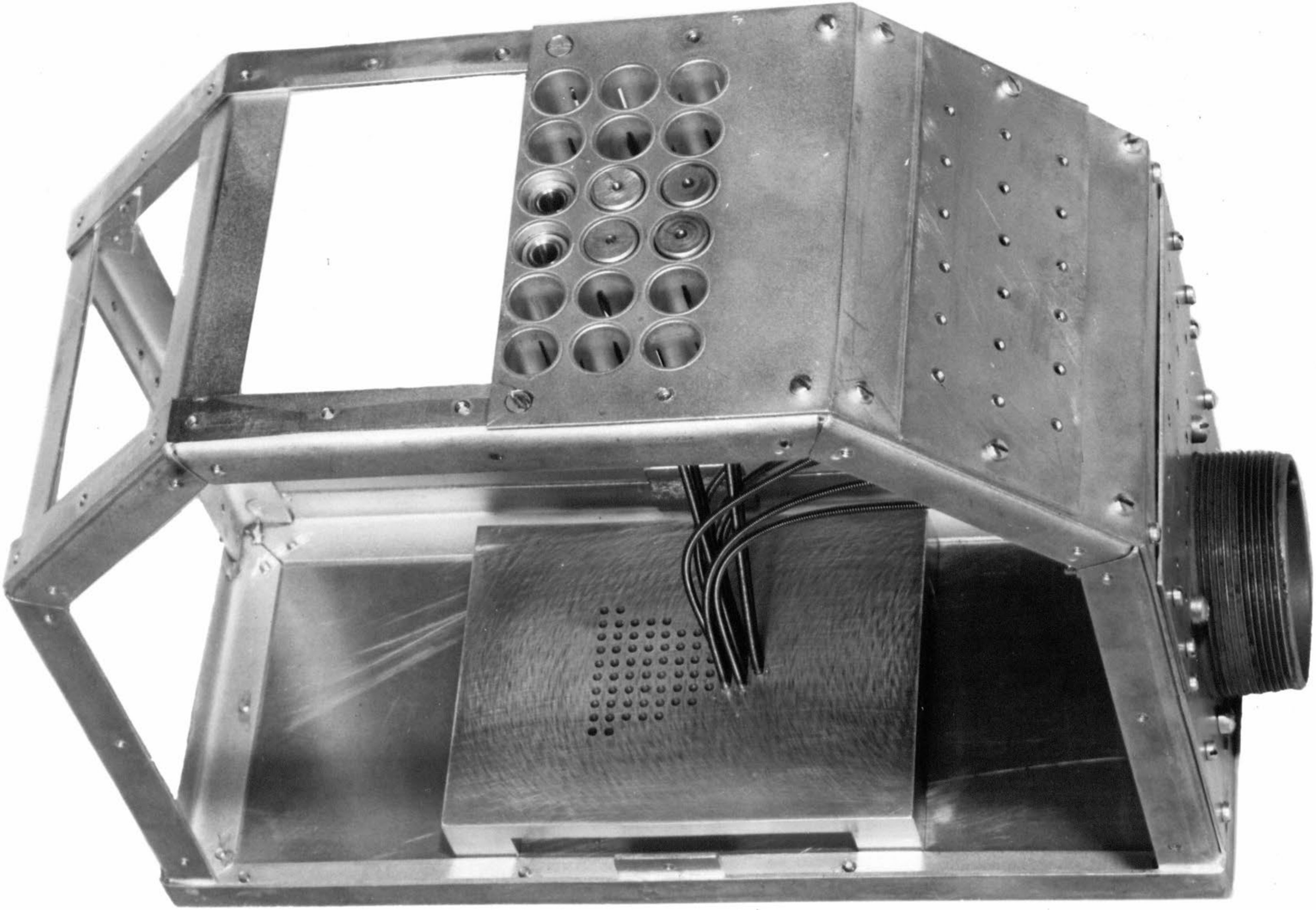


Fig. II-6. Pegboard unit: Frame, panels, cable receiver plate.

Peg-board unit)

showing panel-and-frame construction

and cable receiver plate

1459 B

II-6

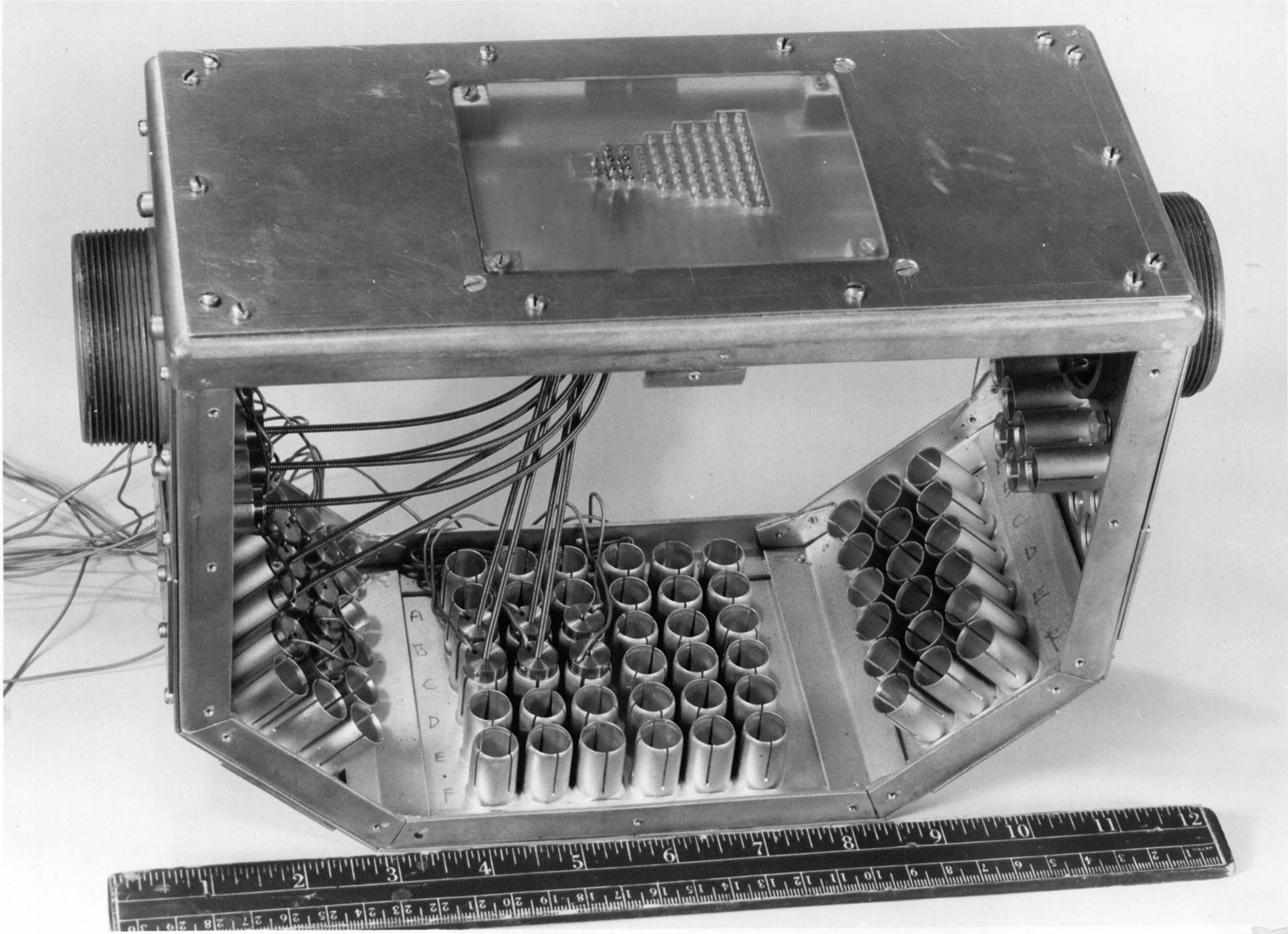


Fig. II-7. Pegboard unit.

Peg-board unit
showing solenoids and cables

14597

II-7

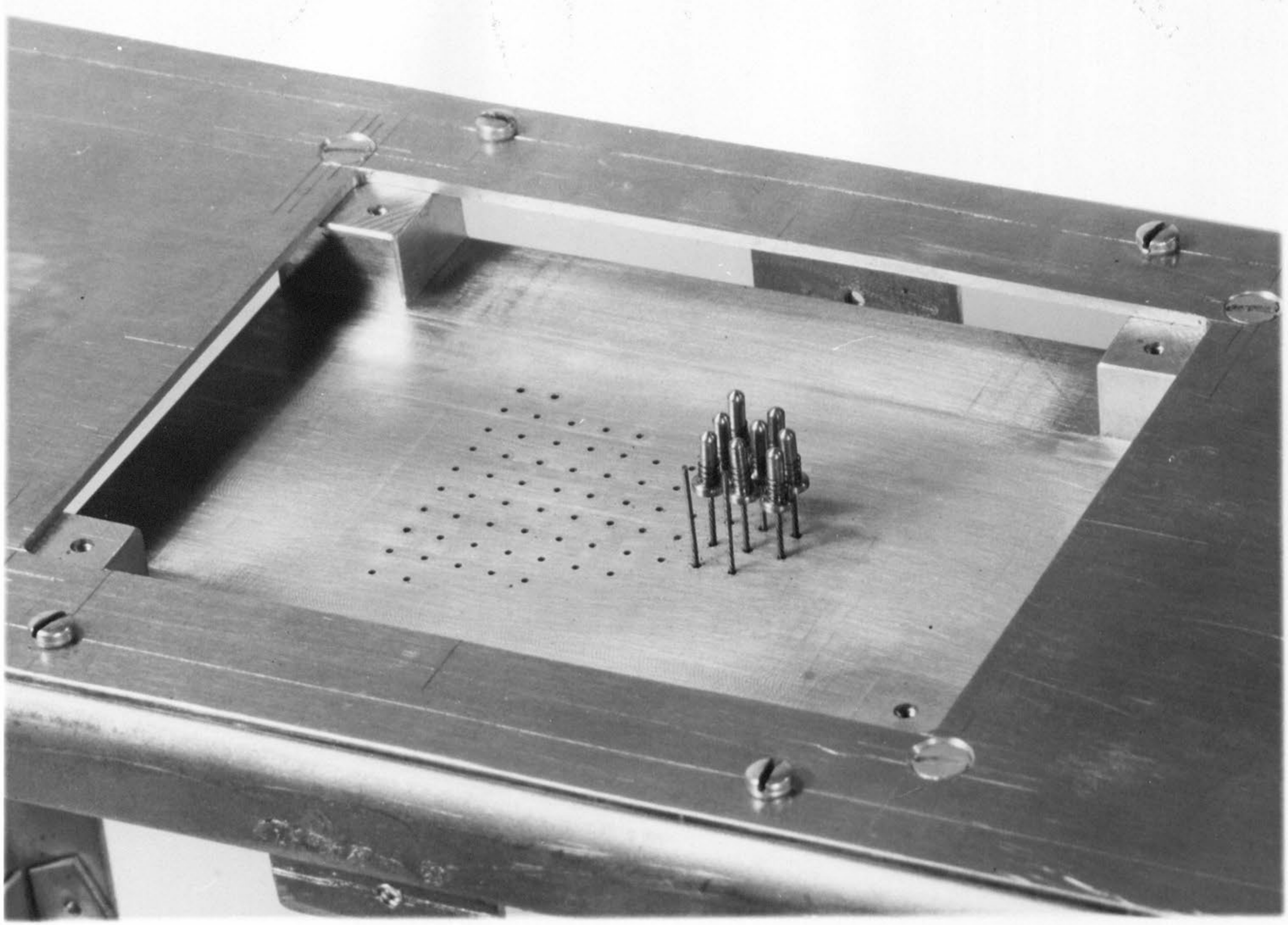
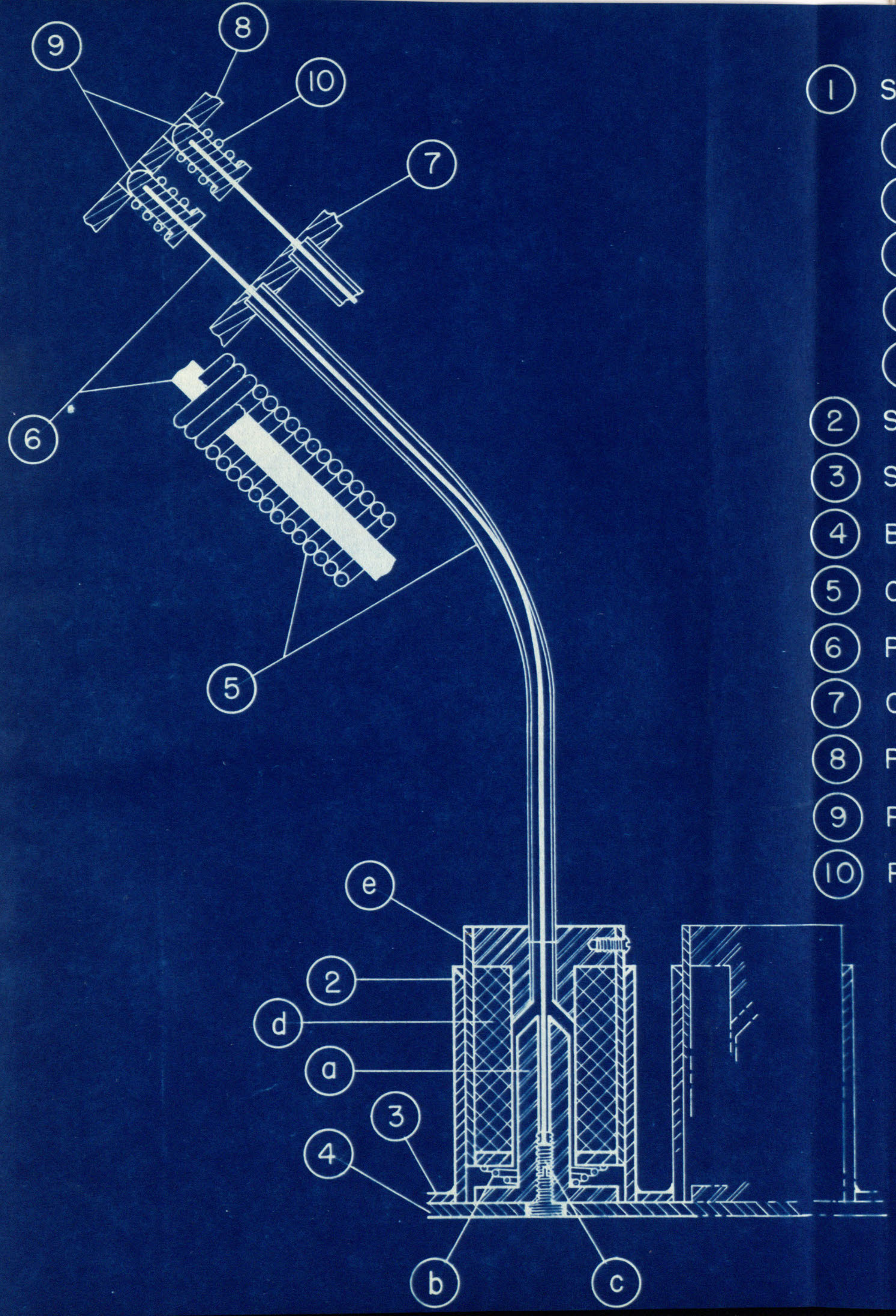


Fig. II-8. Pegs, springs, and pushwires.



① SOLENOID
  - ⓐ PLUNGER
  - ⓑ PLUNGER RETURN SPRING
  - ⓒ PLUNGER SETSCREW
  - ⓓ COIL
  - ⓔ SOLENOID SLEEVE

② SPRING FINGERS
③ SOLENOID MOUNTING PANEL
④ BACKPLATE
⑤ CABLE SHEATH
⑥ PUSHWIRE
⑦ CABLE RECEIVER PLATE
⑧ PEGBOARD
⑨ PEG
⑩ PEG RETURN SPRING

FIG. PEG - OPERATING MECHANISM

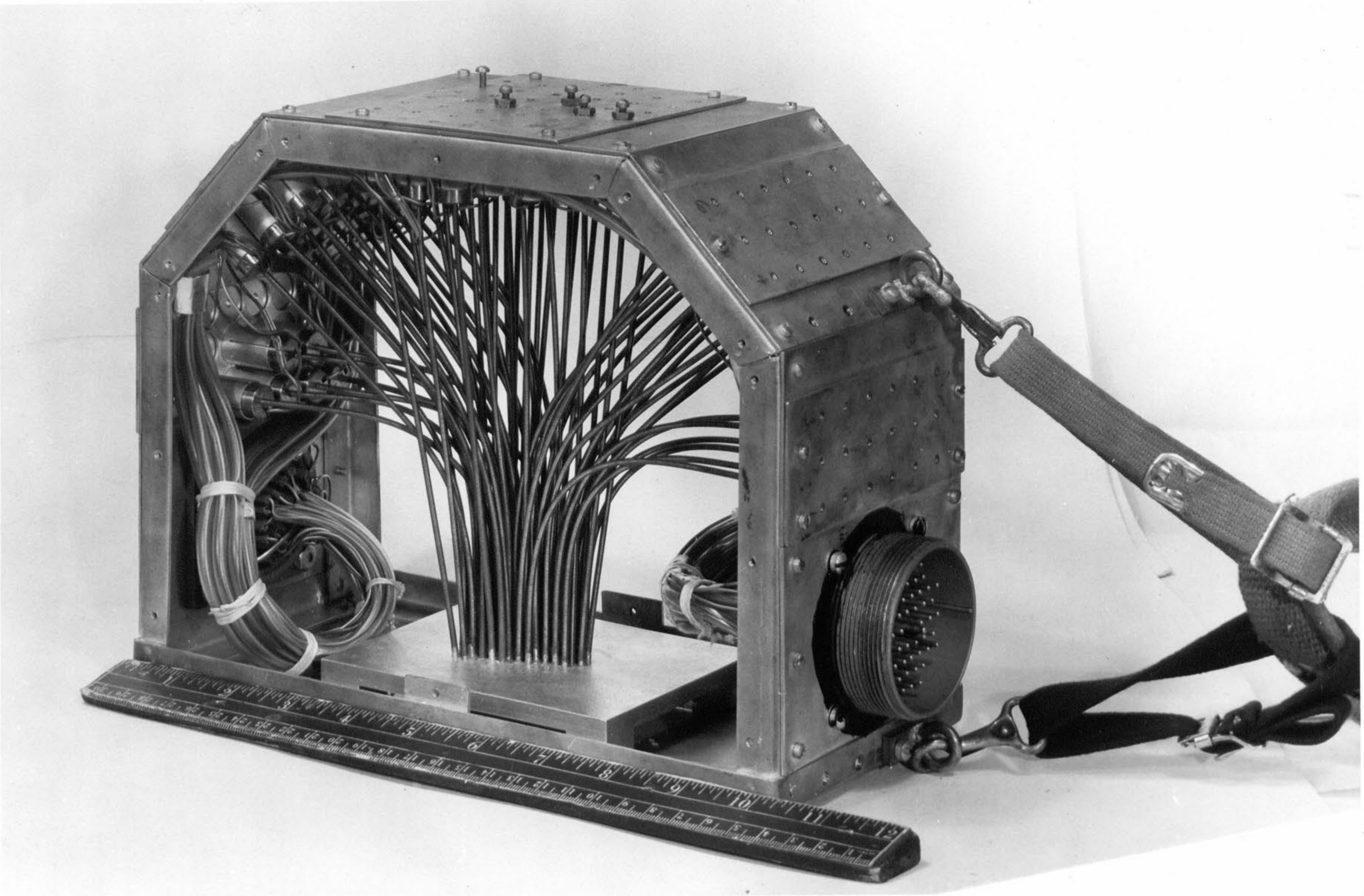


Fig. II-10. Completed pegboard unit.

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Description

Peg Board — Covers Removed

Fig. II-11. Pegboard unit harnessed to author

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RLE

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1477-A

Where Taken
Perkins

Date
Aug. 28, 1950

Description
Key Board + Harness

Control Unit

The solenoids in the presentation unit are connected by the 100-foot cable to an array of contactors arranged in the same pattern as the pegs. This "turtle" (Fig. II-17, II-18) is slid by the operator over a "plotting table", (Figs. II-13, II-14, and II-3) which is a model of the obstacle course with pieces of brass, representing the obstacles, connected to the storage battery power source. The operator maneuvers the turtle so that its position on the plotting table corresponds continually to the subject's position on the obstacle course.

Each contactor is soldered to the end of a square brass tube(Fig. II-15b). The tubes fit in a matrix formed "egg-crate" fashion from interlocking notched strips of Plexiglass (Figs. II-16, II-17, II-19b). Spring loading of the tubes assures good contact between the turtle contactors and the brass "obstacles" in the plotting table.

Three ball rollers (Figs. II-15a, II-17, II-18, II-19a) support the turtle 1/16 inch above the plotting table, allowing room for vertical motion of the contactors in sliding over the "obstacles" which project slightly above the plotting table.

The wires connected to the contactors form a cable which is held in a clamp fastened to the top of the turtle (Fig. II-13).

The plotting table (Figs. II-3, II-13, II-20) is made of Plexiglass to avoid blocking the operator's view of the subject and the obstacle course.

The course is built from six types of 5 inch (10 foot) square Plexiglass blocks screwed onto the plotting table. The course is 6 blocks long and four blocks wide (40x60 feet), surrounded by a 1/2"-wide brass frame which represents the walls of the testing room.

Circular obstacles are made by forcing brass plugs into holes drilled through the blocks; other obstacles are strips of brass set into milled-out areas in both top and bottom faces of the blocks, the strips in opposite faces being electrically connected by screws. The bottom strips touch feeder wires connected through the brass frame to a storage battery; the top strips are exposed to the contactors. The brass pieces project 0.005" above the surface of the blocks to insure good contact.

Fig. II-13. Plotting table and turtle.

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Registered Under (Group or Project)
RLE

Copy No.
1471-A

Where Taken
Perkins

Date
Aug. 15, 1950

Description
"Turtle" Operation

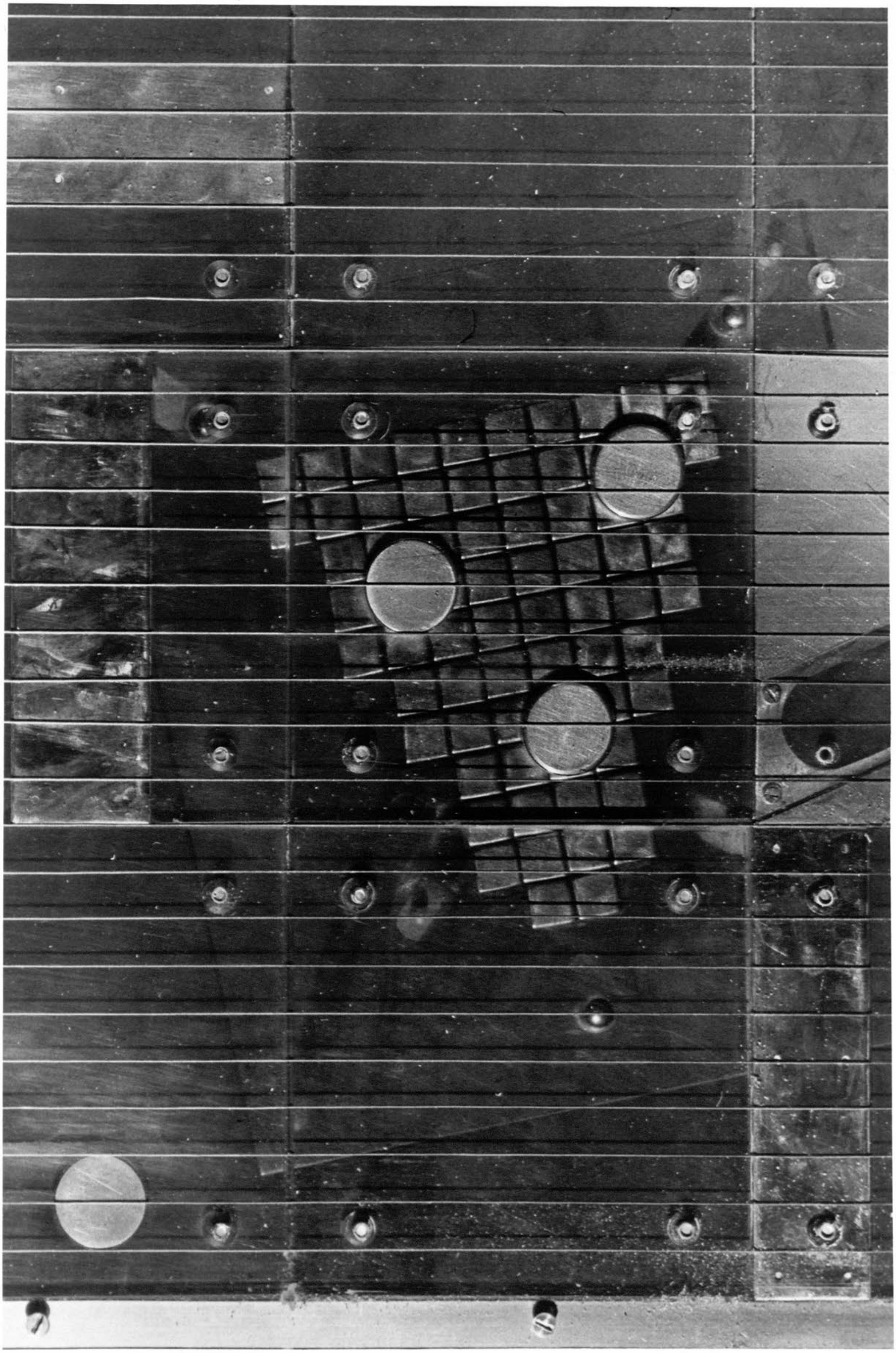

Fig. II-14. Turtle on plotting table, viewed from underneath.

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Research Laboratory of Electronics
Mass. Inst. of Technology

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Registered Under (Group or Project): RLE

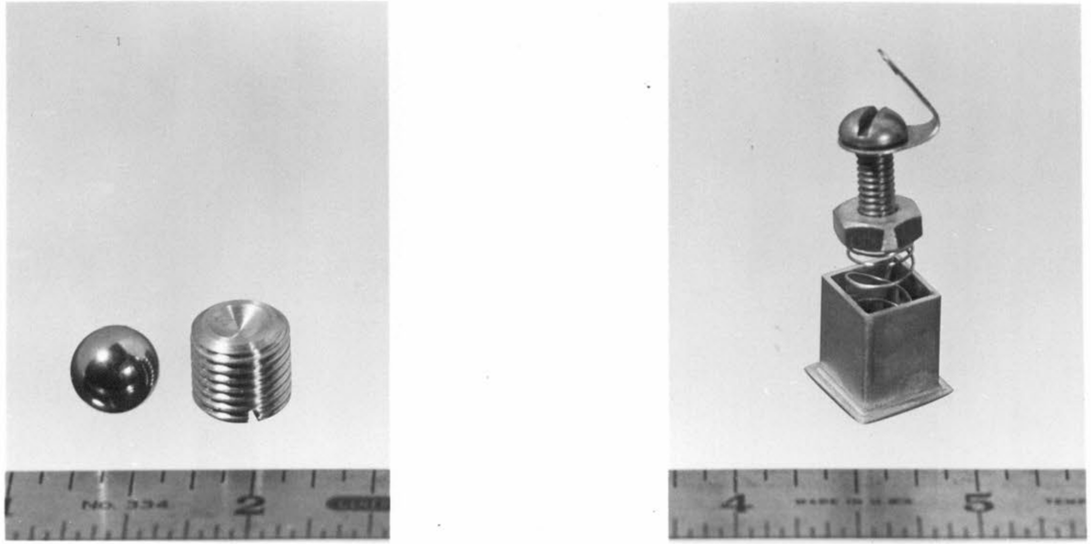
Copy No.: 14170-F

Where Taken: Perkins

Date: Aug. 15, 1950

Description

Peg Board Operation
Pattern Under Turtle



a. Ball roller.

b. Contactor.

Fig. II-15. Turtle parts.

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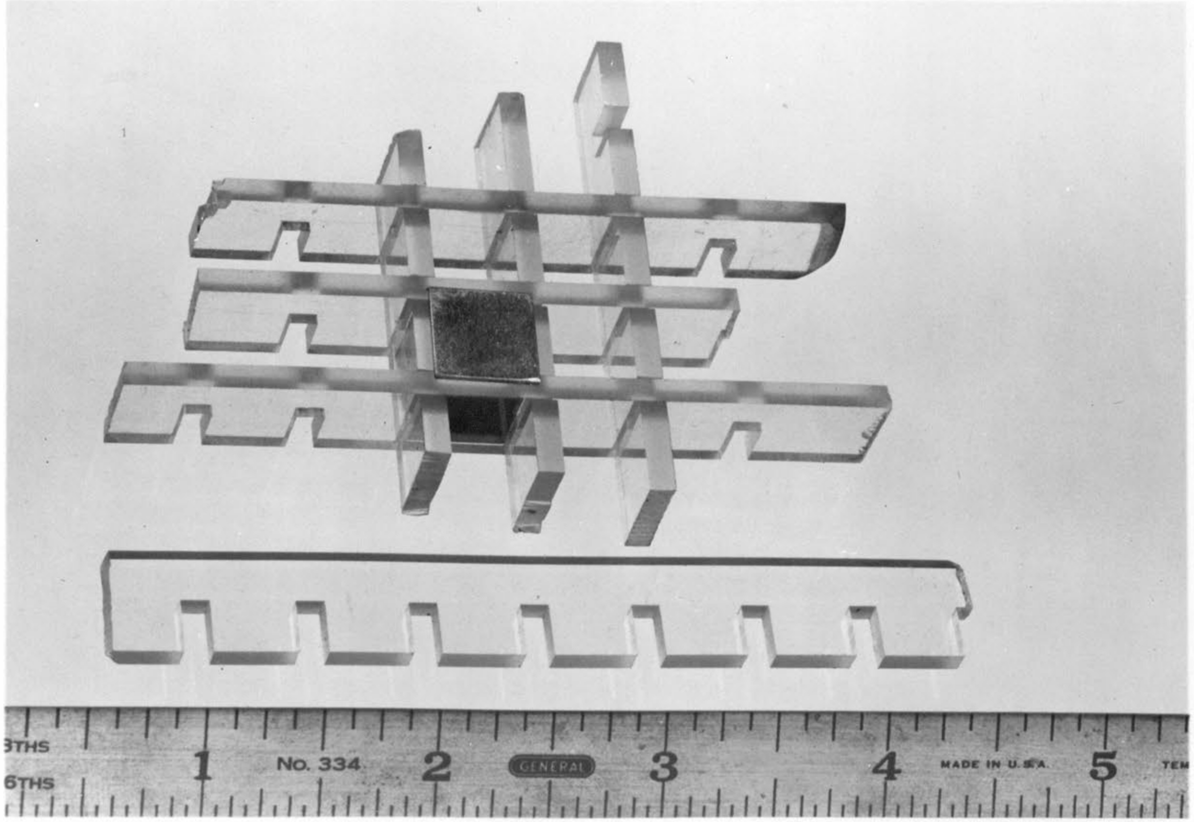

Fig. II-16. Turtle matrix construction.

construction of contactor array

matrix construction of turtle, with one contactor inserted

II-16

1459/C

Fig. II-17. Turtle, bottom view.

contactor array
Turtle, bottom view

II-17

1459 H

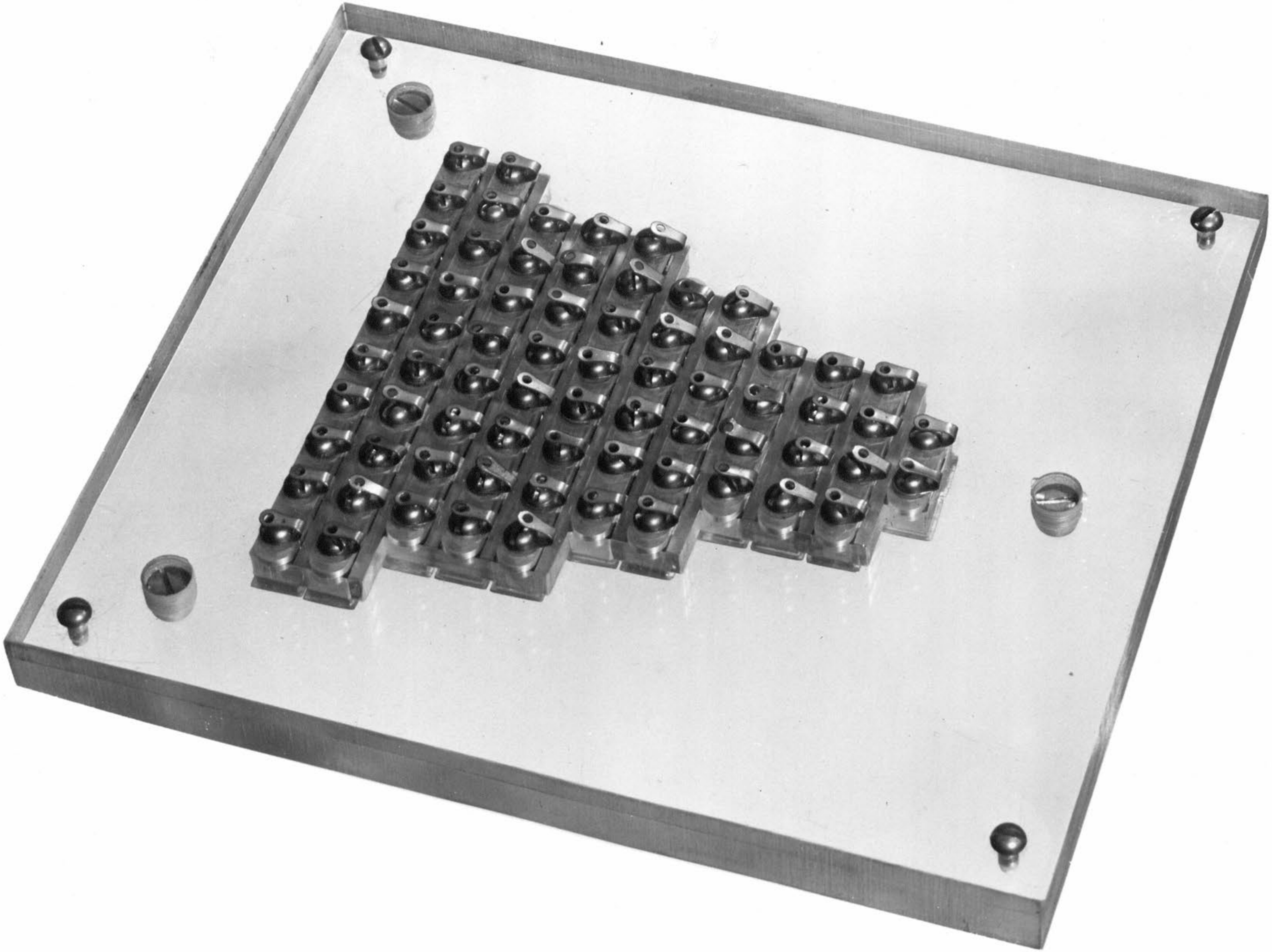

Fig. II-18. Turtle, top view.

G

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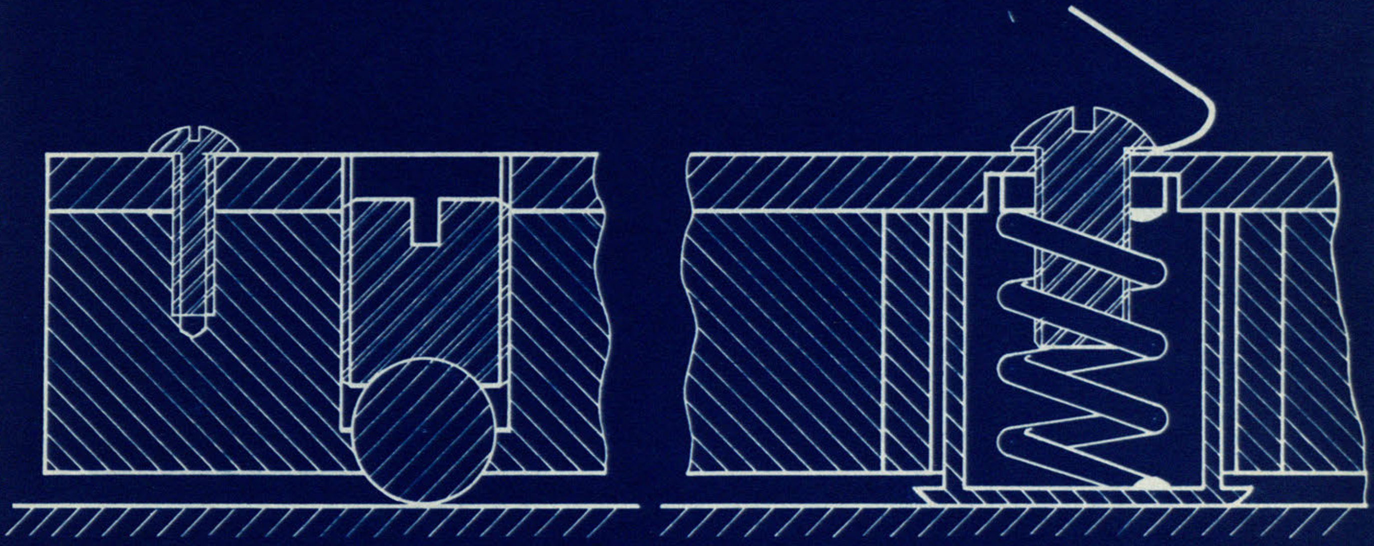

BALL ROLLER

CONTACTOR

FIG. II-19 TURTLE

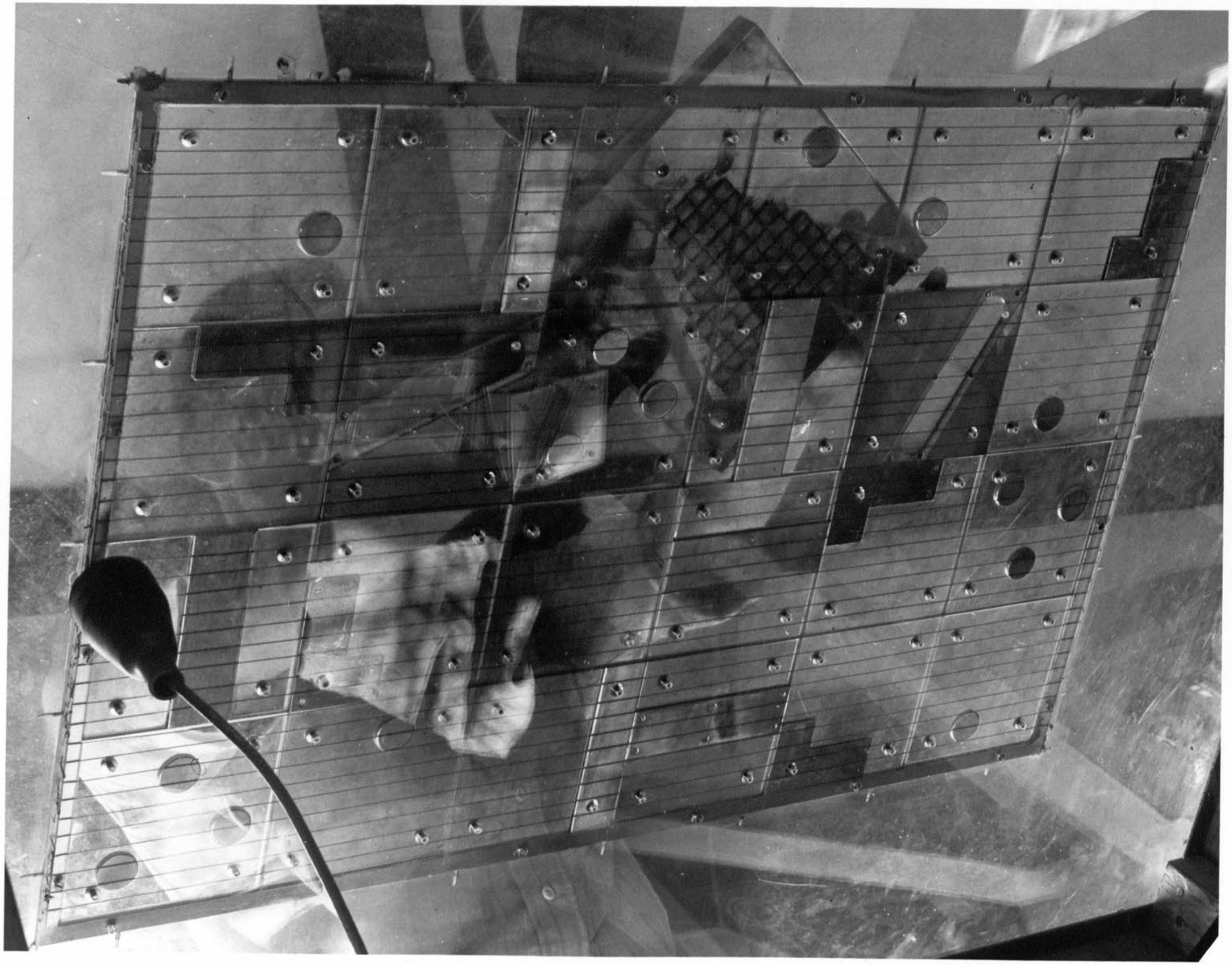

Fig. II-20. Plotting table and turtle, viewed from underneath.

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Copy No.: 1471-B

Where Taken: Deakins

Date: Aug. 15, 1950

Description

Plan of Board

III - EXPERIMENTAL PROGRAM

Introductory sessions were held with nineteen blind subjects obtained with the help of the Perkins Institution and Massachusetts School for the Blind. The purpose and scope of the project were explained briefly, followed by an explanation of the map and the relationships between the map, the environment, and the subject. About twenty minutes of trial walking with the device followed, with demonstrations of the relationships previously explained.

During these sessions, three of the subjects showed little or no aptitude with the device, fourteen showed a fair to good understanding and use of the map and two turned in really excellent performances.

The factors which seem to be involved in understanding and using the map are:

1.) Intelligence: in general, subjects with higher intelligence seemed to do better, although two subjects of low-average intelligence turned in better-than-average and superior performances, respectively.

2.) Spatial concept: those with better spatial concepts usually understood the map more easily, and learned its use more quickly. They had a better idea of the maneuvers required to bring the environment into the desired relation to them. As might be expected, those who had previously been sighted, or those with partial vision, usually had better spatial concepts, although those without such concepts showed appreciable learning during the introductory session.

3.) Various factors which affect the results of any psychological tests: temperament, physical condition, etc., were factors operating in these experiments. Not enough data is available to permit a significant evaluation of the effect of these factors on the individual performances. A similar remark applies in connection with previous experience in tactile reception of information. All the subjects had had training in Braille reading.

Dr. O. H. Straus of M. I. T., who was operating the turtle, commented that the better subjects moved in a smooth, purposeful, and predictable manner, while the poorer ones made erratic and unpredictable motions. This is an indication that the better subjects were obtaining a clear concept of the environment and acting upon it in a logical and confident manner, while the poorer ones did not have such a well-organized concept.

Six of the subjects who learned most quickly and showed most aptitude were selected for further tests. Two of them had five more sessions, and four had four more, each person taking about twenty-five minutes per session. Because of the limited amount of testing possible, all results and opinions expressed must be considered tentative.

Procedure

The subject was led to the starting position, the loudspeaker goal was turned on, and the subject attempted to make his way to the goal, taking as direct a route as possible, avoiding obstacles en route. When the goal was reached, another loudspeaker was turned on, and another run was made, etc. A total of eight runs was made per testing session, except in the case of the first session with the two subjects who had a total of five sessions—their first consisted of six runs. A record was kept of the subject's path and searching operations, times en route at 10-second intervals, and collisions with obstacles. The layout of the obstacle course was changed twice during the testing, when the subjects seemed to be learning parts of the course. Real obstacles were not placed on the course because the subjects seemed sufficiently motivated without them.

Results

It would have been desirable to compare performance with the present device to performances with:

1.) a probe device,* having replaced the imaginary obstacles with real ones.

2.) auditory obstacle perception, again with real obstacles in place of the imaginary ones.

3.) the "ideal" device; i.e. visual navigation of the course. The field of view could be restricted to about the same area as shown on the map by using a suitably masked flashlight on a dark night.

Lack of time prevented such comparative tests; as an index of performance, the subject's average speed during a run is compared to his normal walking speed in a clear environment. The normal walking speed was chosen only to give a base-line for the performance. It is of course understood that even sighted persons would not walk as fast among obstacles as in a clear space; this applies all the more to the blind subjects.

The average speed is computed as distance travelled along the path taken, divided by total time for the run; thus time taken for searching is included in travel time. A collision with an obstacle is an indication that the subject has not assimilated close-range information, while retracing part of his path indicates that he has not planned ahead sufficiently on the basis of far-range information.

A typical obstacle course layout is shown in Figs. II-1 and II-2; the course is intentionally made very cluttered to permit testing in the small space available.

The ratio of average speed to normal speed, the average distance travelled per run, and the average number of collisions and retraces per run made by each subject are given in Table III-1 below; the averages are over the total testing of four or five sessions.

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* Such as the improved model of the Signal Corps device, which is at present being field-tested by Prof. Thomas A. Benham of Haverford College, Haverford, Pennsylvania.

Subject	Number of Sessions	Total Number of Runs	Average Speed Normal Speed	Average Collisions per Run	Average Retraces per Run	Average Distance Travelled per Run (feet)
J.K.	5	38	0.29	0.32	0.26	72
R.R.	5	38	0.36	0.32	0.21	79
A.A.	4	32	0.27	0.13	0.03	63
L.S.	4	32	0.23	0.50	0.22	69
B.S.	4	32	0.26	0.59	0.41	73
G.F.	4	32	0.24	0.62	0.25	74

Table III - 1

Each subject's individual run performances during a testing session were reasonably consistent, most runs being within about 40% of the session average. The subject's session averages are similarly within about 20% of his total average shown in Table III-1, no consistent significant variations being noted.

Subject A.A.'s performance was exceptionally good. He made very few errors and retraces, and consistently took the most direct route to his goal. His performance was characterized by careful scanning of the map, occasional pauses in travel to study the path ahead, careful, precise changes of direction to bring the immediate goal directly in front of him, and very careful and systematic searching for passages when confronted with a block. The subject has high I. Q., and probably the best spatial concept of the group.*

The other subjects exhibited A. A.'s characteristics to a lesser degree. They did not search as systematically and carefully as he did,

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* He has enough sight to be able to see in a cone of vision of a few degrees in daylight or bright artificial light; this is probably the reason for his excellent spatial concept. He was blindfolded during the tests.

and consequently sometimes took more devious routes as a result of not noticing direct passages. They tended to walk somewhat faster than they could assimilate information from the complete map, and consequently tended to concentrate either on the close range, or on the far range.* This occasionally led them, respectively, into traps and blocks they could have bypassed, or into collisions with obstacles they could have avoided, had they assimilated all the information on the map. The time saved by their faster pace was usually lost in searching for the way out of the traps or blocks.

These characteristics, however, are mainly matters of technique, and could probably be largely eliminated by careful training. Improvement in these respects was noted in the five other subjects during the testing program.

The consistency of the session averages indicates that most of the learning was done during the introductory session, when the subjects were learning the rotational and translational relationships between the environment, the map and themselves. Further learning during the testing sessions was confined to matters of technique like scanning the map and searching the environment for passages. Or in other terms, most of the learning was in interpreting the information transmitted by the new link in the motor system-environment-sensory system-brain feedback loop.

The effect of this loop closure was demonstrated most dramatically by a subject who had no memory of any visual experience. After several explanations of the map and its relation to him, he was still wandering

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* Reducing the size of the map by about 50% would probably make scanning considerably easier without making the individual indications difficult to observe.

over the obstacle course with no apparent concept of what was ahead of him. As part of the training, he was instructed to walk toward one of the walls of the room, observing its approach on the map, and correlating this with his auditory sensations of the wall's approach. When he reached the wall, he was instructed to back away from it, observing its recession, correlated with his auditory and kinaesthetic cues. A repetition of this exercise and he suddenly exclaimed, "Now I understand!" and improved rapidly from then on, finishing the session by navigating straight down the middle of a 12-foot long, 2 1/2-foot wide corridor. In a later explanation he said that all his life, all he knew about the world was what he could reach with his arms, and it was the most wonderful thrill he had ever had to realize that he was knowing about things further than his reach.

Several fairly common characteristics of performance were noted among the nineteen subjects:

1.) The subjects walked "crabwise", at a slight angle to the direction they were facing.

2.) They did not walk straight lines.

3.) When turning in place to search for passages, or when changing course to avoid obstacles or to go straight down passageways, the subjects turned much too far, making overcorrections of the order of 100 to 200%.

4.) Many of the subjects stepped into an obstacle as they turned to avoid it, or side-stepped into one obstacle while avoiding another.

The first three characteristics are indications of a lack of proper feedback from the environment to the subject; improvement in the second and third was noted during the introductory and first few testing sessions; i.e. as familiarity was gained with its use, the device became an effective closure of the motor system-environment-sensory system-brain feedback loop. The fourth characteristic was more or less a matter of habit, and reminders during the tests, along with conscious control by the subjects, reduced the frequency of such errors.

IV - CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

Conclusions

The tests have shown that blind people who already have good spatial concepts can learn within about a half hour to assimilate information from a relief map sufficiently well to navigate complex obstacle courses confidently, quickly, and accurately.

Those with poorer spatial concepts showed improvement in performance during the introductory session, and it seems almost sure that with more training, they could achieve results similar to those made by the group tested. In fact, the device could probably be used in its present form as an aid in teaching spatial concepts to the blind.

A comparison of map presentation with the point-by-point presentations of probe devices would not yet be valid, because of the greatly different levels of development of the two types of device. The preliminary results of Prof. Benham's field tests with the improved Signal Corps device indicate that probes may be better than was recently thought.

It is felt that the results of the present investigation, using a simulated device in an artificial obstacle course, justify the development of a research model of a complete device, to be tested under conditions of actual use, and to be compared, as far as possible, with the general class of probe devices.

Suggestions for Future Work

If a complete device is to be built, the following work will be necessary:

1.) A scanning obstacle detector must be developed. Possibly the Signal Corps probe detector could be modified to suit the needs.

2.) A step-down detector will be needed.

3.) A method must be developed to distribute information from the scanner to the separate indicators on the map.

The map might be modified in the following ways:

1.) A small ridge down the centerline of the map might make location of objects easier, and would probably be an aid in learning to use the map.

2.) A scale of 0.100" to the foot would reduce the size of the map and make scanning easier; it would probably still be easy to distinguish individual pegs.

3.) If further reduction in map size is found desirable, the maximum range might be reduced to perhaps ten feet.

4.) To reduce the number of elements composing the map, the area near the side edges could be shown with less definition than the area near the centerline.

5.) A large opaque object such as a wall will block from the scanner's view any objects beyond it. A small or partially transparent object, such as a wastebasket or a wire fence will allow the scanner to "see" beyond it. Thus an ambiguity is present if the map indicates no objects behind one already shown. It might be desirable to eliminate this ambiguity by making all the pegs come up behind the first obstacle, or it might be sufficient for the subject merely to assume that his view is blocked beyond the first obstacle if no others are shown. Elimination of the ambiguity by the first method would discard some information which might be useful to the subject.

APPENDIX - MATHEMATICAL ANALYSIS

Information Gathered by the Detector

Consider a detector which explores the environment in unit cubes, giving "yes-no" answers regarding the presence of an object in each cube. The amount of information gathered by the device in exploring a portion of the environment composed of V cubes is $\sum_{k=1}^{V} p_k \log 1/p_k$* bits, where the probability p_k that an object is in the k-th cube depends upon the statistical character of the environment and how the subject travels through it.

If the device removes elevation data by integrating the cubes into vertical columns, the information gathered in a portion of the environment of A columns is $\sum_{j=1}^{A} p_j \log 1/p_j$ bits, where the probability p_j that an object will be in the j-th column is derived from the same statistical distributions as is p_k. The amount of information will be less after removal of elevation data; the reduction factor depends on the statistical distributions and the heights of the columns.

Actually, the subject is interested not so much in the information carried by each peg (i.e. is each peg up or down?) but in finding the <u>boundaries</u> of <u>groups</u> of "up" pegs to define the area he must avoid. Thus the information content of the map should not be interpreted too literally.

New Information with Motion

As the subject and pegboard translate** through the environment with velocity v, new information comes onto the forward end of the pegboard,

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* Logarithms in this appendix are to the base two.

** Rotation is used for searching; it is not ordinarily used in forward travel. The amount of new information on the board is a function of the angle turned through; the rate of appearance on the board is not so important.

and the pattern moves toward the subject, leaving the board at the sides and rear end. If the board displays an area W wide at the widest part, new information comes onto the board at an average rate of vW new indications per second.

A given portion of the environment remains on the board for a time Y/v, where Y is the extent of the map in the forward direction, at the sidewise co-ordinate in question.

Once in motion, the map presents no more new information than would a single row of pegs displaying a W-wide by unit-deep strip. The usefulness of the map lies in its retention of information, so that far and near can be observed together in their correct relation to each other. The map is a continuous presentation of new information along with just-previously-gathered information. Thus new portions of the environment are observed in relation to the already-known. The retention of information is also a storage function, so that the information can be reviewed, if needed.

<u>Reading the Pegboard</u>

Assume pegs spaced n units apart on the map (not below the discrimination threshold). (i.e. map scale n:1). Assume the reading surface to be two or three adjacent fingers across the map scanning in the forward-and-back direction. A reading surface of extent l in the forward direction and w in the sidewise direction can be postulated. Then wl/n^2 pegs are observed simultaneously, and if the reading surface moves with velocity a, new information reaches the surface, remains under it for a time, and then passes out from under, with geometry similar to that of information entering and leaving the board.*

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* The process can be looked at as two scanning functions occurring

The average rate of reading is aw/n new pegs per second; pegs are under observation for an average of 1/a seconds. (On the forward sweep of the fingers, the relative velocity of the fingers to the pattern is a+vn; on the backward sweep it is a-vn).

Sample Calculations

In the equipment used in the tests, the unit distance was one foot; the calculations are made on this basis.

Assuming $p_j = 1/3$ (roughly the obstacle density in the testing), and neglecting conditional probabilities, the amount of information on the pegboard is $70(1/3 \log 3) = 37$ bits. Conditional probabilities would make the information content less than that given.

At a velocity of 3 ft./sec., with a field 10 feet wide, new information comes onto the pegboard at a rate $vW = 30$ new indications/sec. With $p_j = 1/3$, and neglecting conditional probabilities, this represents $30(1/3 \log 3) = 15.9$ bits/sec. of new information.

With a mean forward extent of 7 ft. shown on the map, information remains on the map a mean of $Y/v = 7/3 = 2.3$ sec. Information on the center line remains for $11/3 = 3.7$ sec. Extreme sidewise information remains for $2/3 = 0.67$ sec.

The map is 1.87" long; at $a = 3$ inches/sec., it takes 0.62 sec. to scan end to end. The width w of a 3-finger reading surface is about 2 inches, enough to cover the full width of the map. The pattern moves at a rate $vn = 3(0.156) = 0.47$"/sec, or about 1/6 as fast as the reading surface. There should be little trouble with missing information during scanning, except perhaps at the extreme azimuth at the 12-foot range, where information

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*(con't.) simultaneously. The detector scans the environment, and the output of the detector is scanned by the subject. The subject sees the environment through two superimposed scanning functions.

remains for only 0.67 sec. The information gets from one to six scans (depending on its sidewise position) before it goes off the board.

The fingers can cover an area of $wl/n^2 = 2(\frac{1}{2})/(0.156)^2 = 41$ pegs, or 41 sq. ft. simultaneously, although on the narrow part of the map, full utilization is not made of the width w.

A given peg is under the reading surface for an average of $1/a = \frac{1}{2}/3 = 1/6$ sec. during a scan.

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Peg-board unit
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