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WALTER GRUNWALD

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AN INVESTIGATION OF THE EFFECTIVENESS OF TRAINING DEVICES WITH VARYING DEGREES OF FIDELITY

APPROVED BY

W R Fulton

Robert E. Olson

Henry Angelino

Herbert R. Hengst

DISSERTATION COMMITTEE

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The opinions and conclusions expressed herein are those of the author and should not be considered to reflect the official views of the Department of the Air Force.

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CHAPTER I

STATEMENT OF THE PROBLEM

Training devices constitute important elements in instructional systems in which the acquisition of skill is among the principal learning objectives. In the typical industrial training environment, such devices often demand considerable investment in terms of money, materials, manpower for maintenance, and space. For the user of such devices, the question of training devices with reduced fidelity therefore assumes considerable prominence, since a reduction of fidelity is almost always synonymous with reduced cost. If one pursues this question, the main problem then centers on the determination of a minimum degree of fidelity that will allow the attainment of desired learning objectives. With this in mind, this study aims to explore the relative effectiveness of five selected training devices with differing degrees of fidelity in the learning of a specific psychomotor task in which manipulative skill is not of primary consideration, and suggests ways in which such training devices may be evaluated with a minimum of bias.

Underlying Assumption and Definitions of Terms

This study is based on the assumption that--contrary to traditional thought--an increase in training device fidelity, whether in appearance, function, or both, may not necessarily result in a corresponding increase in training effectiveness of the device; rather, other factors, such as the potential ability of the device to involve the learner in the total learning situation, may have a far greater influence on the final effectiveness of the device than mere resemblance to the actual equipment.

It should be noted, however, that this assumption is made only with respect to the kind of task under observation, that is a procedural task in which motor functions are subordinate to cognitive functions.

Definitions of Terms

Control. A means by which the operator of a machine or similar device may effect changes in the mode of operation of that device and thus may "control" its functions. Controls may be in the form of switches (rotary or linear), levers, pushbuttons, cranks, pedals, and similar contrivances.

Display. A device that furnishes the operator of a machine or of some other type of equipment with information concerning its operating state which is of importance to the operator in controlling the machine. Such information may be presented through visual or auditory displays in the form of indicator lights, gauges, auditory alarms, and similar devices. Typically, displays provide the feedback from the machine to the man in a man-machine system.

Fidelity. The degree of exactness or faithfulness with which actions or properties are being reproduced.

Flight engineer. A member of the crew in a multi-engine aircraft, responsible for the operation of various aircraft systems, such as electrical, hydraulic, fuel, or pneumatic systems.

Instrument panel. A surface on which are mounted controls and displays necessary for the operation of a machine, whether mechanical, electrical, or of a combination of these or other properties. It is often simply referred to as a "panel."

Man-machine system. A system in which men and machines interact in performing a function.

Procedural task. A task in which all actions take place in a specified sequence, either with the aid of check-lists or by memory, and in which initiation and successful completion of such actions often depends on information supplied by various displays.

Simulator. A training device that closely duplicates the functions of real equipment. A flight simulator, as described in this study, has the appearance and functional properties of a real aircraft cockpit, allowing aircrew trainees to perform all operations as required in the actual aircraft, with correct displays being furnished in response to operator and machine actions by means of a computer.

Training aid. Any object or device used to facilitate the presentation and teaching of informational knowledge.

Training device. An apparatus used in training individuals, especially in the acquisition of specific skills.

Background of the Study

As stated above, training devices form essential elements of instructional systems designed around the central purpose of training individuals in the operation of equipment that demands application of manipulative skills of varying difficulty, usually in conjunction with the exercise of perceptual discrimination, judgment, and response initiation based on the understanding of underlying principles and modes of operation. One of the dilemmas facing the designer of such devices is that of making a choice as to the type of training device best suited to the task at hand. In this case, "best suited" means a device which--at minimum cost--provides the learner with the opportunity to translate abstract concepts into observable behavioral terms in such a manner that transfer to the real task will be at an optimum value.

Unfortunately, the guiding principles in this choice often are based neither on the findings of psychological research, nor on the pursuit of specific learning theories, but rather evolve through adherence to precedent, sheer conjecture, or emulation of other designs based on similar presuppositions. This difficulty is compounded by the absence of any comprehensive guide concerning the functions and applications of training devices; in fact, the definition of what constitutes a training device may in itself prove to be an elusive one. For example, the United States Air Force, being one of the prime users of training devices, publishes a number of manuals and pamphlets pertaining to the use of such devices; but while many of these publications proclaim to provide the user with clear concepts and definitions, these are typically submerged in the practical aspects of utilization of existing devices, and therefore fail to crystallize into a nucleus of basic information that might point the way to a critical assessment of the devices under consideration or to the development of new devices.[1]

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[1]It should be pointed out, however, that the main purpose of such publications is to provide indoctrination for instructor personnel and technicians, and not to provide a taxonomy of training devices for evaluators and researchers. With respect to their stated objectives, such publications fulfill an important requirement. See, for example, Employment of Aircrew Training Devices, Air Force Manual 50-16 (Washington, D.C.: Department of the Air Force, 1953), 131 pp.

One of the most useful definitions is offered by Gagné, who recognizes the difficulty of agreeing on common terminology which has its roots in psychology as well as in engineering jargon:

> As usually understood, training device refers to any piece of apparatus which is used for training individuals. A somewhat more precise and useful meaning, also common, is that a training device is used for the training of skills. Such a definition serves to distinguish the class training devices from the class training aids, which are objects and devices used to facilitate the presentation and teaching of informational knowledge. In this more restrictive sense, training devices are characterized by the possession of a display which presents information necessary to the correct operation of controls, which the student must learn to operate, in most cases during periods of practice on the device.[2]

Thus, the possession of display and control functions may be seen as an essential property of a training device; however, although training aids normally do not possess such properties, this should not preclude the use of many training devices as training aids. In fact, employment of such devices is quite common in the classroom, where their superior ability to show cause-effect relationships serves to emphasize important concepts within some type of instructional setting involving groups of students. In this case, although a student may not be able to interact directly with the device in order to acquire a "skill," he nevertheless becomes a vicarious participant in a learning environment that fosters involvement and that uses a training device as a focal point among other instructional techniques.[3]

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[2]Robert M. Gagné, "Training Devices and Simulators: Some Research Issues," The American Psychologist, 9:96, 1954.

[3]These may include teaching machines, which in essence contain many of the characteristics of training devices.

It is interesting to note that when training devices are used in this context, the amount of displayed information as compared with the capability to provide control inputs often increases sharply. The fact that more displays are utilized in training devices that do not involve the student intimately supports McLuhan's basic premises concerning "cool" and "hot" media: the "cool" medium of the individual training device on which a student may become directly involved apparently does not have to provide as much information as the "hot" medium in form of a device which is being used to disseminate information to a group of students who do not directly participate in the process portrayed by the device.[4]

A somewhat analogous situation may be seen in programed instruction, where bits of information are deliberately withheld in order to elicit from the student responses to specific cues. While there is considerable debate about the efficacy of overt responses as contrasted with covert responses, it is generally agreed that the ensuing involvement of the learner, reinforced by immediate feedback, can lead to more effective learning.[5]

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[4]For a discussion of "hot" and "cool" media, see the chapter of this title in Marshall McLuhan, Understanding Media: The Extensions of Man (New York: McGraw-Hill Book Company, 1965), pp. 22-32.

[5]This is further discussed in Chapter III under the considerations entering the choice of a programed text for this study.

Considerations such as these led to the formulation of one of the main questions underlying the present study, namely: "What is the effect on the learning of a given task if the display capability of a training device--designed to facilitate the learning of the task--is significantly reduced?" If, for example, the observation is correct that training devices used in a setting where student interaction with the device is minimized require additional displays in order to be effective in transmitting essential information, the opposite thesis should also apply, namely that the display capability of a training device may be reduced if the student is able to interact positively with the device. In a sense, reduction of display capability demands more active involvement of the student, who is forced to supply some of the feedback that is not being provided by the device. Such increased activity on the part of the student may lead directly to an increase in learning effectiveness. If one chooses to apply to this situation the tenets of Gestalt psychology, the missing display can be seen as a tension-producing factor that sets up a quasi-need for successful completion of the task element, demonstrating the striving toward "good closure" or the achievement of a "good Gestalt."

For the designer and user of training devices, the answer to the question of fidelity requirements may have far-reaching implications. Traditionally, design of such devices has been based on the assumption that "the greater the similarity, physically and psychologically, in overall pattern as well as item by item, the greater the amount of positive transfer that is likely to occur."[6] As will be shown, this time-honored dictum is placed in jeopardy by the results of this study, which lend considerable support to the basic assumption stated at the beginning.

Outline of the Study

The study was designed to compare the effectiveness of five training devices of differing degrees of fidelity in the learning of a procedural task of moderate difficulty. Listed in the order of decreasing fidelity, the following five devices were used:

1. The actual equipment, fully operational in all aspects of control and display capability.

2. A high-fidelity simulator device, closely duplicating all functions of the actual equipment.

3. A three-dimensional, actual-size mock-up, having movable controls but no display capability.

4. A two-dimensional, actual-size photographic reproduction, mounted in proper position, but having neither control nor display capability.

5. A reduced-size photographic reproduction, normally a part of a programed text used in the instructional procedure.

Five groups of students, homogeneous in prerequisite knowledge--as determined by scores on a subject-matter test--and

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[6] Employment of Aircrew Training Devices, op. cit., p. 27.

naivety with respect to operation of this or similar equipment, were selected at random from a student population that already was highly homogeneous with respect to educational level, aptitude scores, technical background, and exposure to a course of instruction in the principles of the system under consideration.

A certain procedural task was selected as criterion task, with each of the five groups of students subjected to identical training in performing this task, but with each group using a different training device. Instruction was by means of a programed text and a tape recording, so that equal information input and practice was assured for each student of each group; thus, the only variable in the procedure consisted of the specific training device used.

The criterion measure consisted of verbal and performance tests designed to measure understanding of underlying principles, ability to perform the task under routine conditions, and ability to detect and to analyze deviations from normal states.

Following a review of pertinent literature in Chapter II, a detailed description of the procedures, including selection of groups, description of the task, development of instructional instruments, and evaluation procedures is furnished in Chapter III. Chapter IV presents the results and statistical analysis, followed by conclusions and recommendations in Chapter V.

CHAPTER II

REVIEW OF THE LITERATURE

Although the use of training devices has increased greatly with the rise of technological applications that make direct operational training either impossible or uneconomical, research in this area has been relatively meager. Several reasons for this may be tentatively stated: (1) The design of training devices in industrial settings, where most of these devices are used, is commonly delegated to an engineer, frequently to the same person responsible for the design of the original equipment; in this case, the device often turns out to be a replica of the original equipment, with special provisions that are thought to facilitate the learning of specific tasks, for example additional displays, performance measuring devices, and so forth. (2) Where equipment is supplied to a user by a manufacturer under contractual agreement that includes furnishing of appropriate training devices, the manufacturer may find it convenient to utilize existing components in the construction of the training devices, with the result that these are built with a degree of sophistication not justified by their relative effectiveness, which may be accepted without question. (3) In cases where psychologists are consulted--either in the design stage or during the actual employment of training devices--user preferences often have an overriding effect on the final decisions concerning design and use of the devices. Many of the training programs in industrial institutions present typical examples of the dichotomy between research findings and practical application. (4) The study of training devices does not lend itself to "pure" research, which would most likely attract the psychologist in the university laboratory or in a similar research environment. Although training devices deal with very fundamental questions concerning learning, perception, transfer, effects of practice, and other facets of human behavior, they are typically much too involved and present combinations of these behavior aspects in such profusion that the psychologist tends to abandon any attempt at evaluation or principle formulation in favor of work with simpler devices that lend themselves to precise observations and measurements. It would appear that media specialists, with their broader orientation in learning theory as well as in principles of perception and in general aspects of information transmittal, would be ideally suited to perform the roles of design consultants or effectiveness evaluators of training devices, which are--in essence--special types of media; in practice, however, media specialists have not played any significant part in such functions.

When looking at existing literature, it soon becomes evident that there is seldom any consideration allotted to the prospective use of a given training device. Yet, it must be quite clear that a device used for the learning of a new, unfamiliar task may differ fundamentally from a device used for improvement of skill, or from one used in the evaluation or measurement of skill performance. Some notable exceptions illustrate the urgency of this problem. For example, Lindahl[1] investigated training methods used for operators of disc-cutting machines. Training new operators on the disc-cutting machine itself, although representing "perfect fidelity" of the training situation, did not seem to him very effective. After studying the foot movements involved in operating the foot pedal of the machine, he constructed a device that would allow trainees to practice the foot movement in response to a simulated visual presentation. As a result, employees trained by the new method achieved a performance level equal to those trained by the old method in less than half the time.

In a sense, such an approach closely resembles that taken by the systems analyst, who--in building a model of the system under consideration--must make an effort to extract from reality those elements that are crucial to the functioning of the system and who must then show these elements

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[1] Lawrence G. Lindahl, "Movement Analysis as an Industrial Training Method," Journal of Applied Psychology, 29:420-436, 1945.

in proper interrelationship. Thus, his system does not become a "high-fidelity" model of reality, which in fact would serve to submerge essential elements in a multitude of irrelevancies, but a "low-fidelity" model that allows concentration on essentials. In designing a training device, which may be viewed as a model of the real equipment, similar considerations would seem to be in order, especially in the case of initial learning of a new task, where concentration on important aspects of the task--without distraction by non-contributary factors--may be of essence. This is quite in contrast to the situation where performance improvement or performance evaluation is the primary purpose of the device; in this case, close simulation of reality may be the only way in which such functions may be carried out with any degree of validity. Preliminary activities in training device design must therefore include not only a rigid task analysis, but also a search of applicable learning principles that will lead to effective translation of inherent device capability into demonstrable behavior.

Questions of fidelity requirements become particularly pressing when fidelity can be achieved only at considerable cost. Therefore, many of the existing studies in this area have been carried out with regard to aircraft or space flight simulators, where the cost of the training device may approach or even exceed the cost of the original equipment. Of course, the high cost of the training device in this instance is justified by considerations of safety, and--in case of space flight vehicles--by the inability to learn or practice a task on the actual equipment, since the first time the task is performed on the actual equipment it must of necessity be a success.

The question of fidelity requirements in flight simulators was approached by Williams and Adelson,[2] who equipped a standard jet aircraft flight simulator with variable flight control characteristics that would allow simulator control response to be either normal, or to be 25 per cent, 75 per cent, 200 per cent, or 300 per cent of the normal value. Students would be trained first in the simulator (under various states of simulation fidelity), then in the actual aircraft. Their performance in the aircraft would then be compared with that of a control group, trained only in the aircraft, and the difference in learning time, errors, or trials subjected to statistical analysis. Although the results of this study were not conclusive, there were several interesting findings that should be of value in future studies of this type. For example, the number of sub-tasks in a typical segment of training may be so large as to make precise determination of the amount of transfer to the real task impossible, so that it becomes important to limit the number of states to be investigated in some manner. However, while there is a

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[2]A. C. Williams, Jr., and Marvin Adelson, _Some Considerations in Deciding About the Complexity of Flight Simulators_, Research Bulletin AFPTRC-TR-54-106 (San Antonio, Texas: Air Force Personnel and Training Research Center, 1954), 29 pp.

realization that some characteristics are more important to transfer of training than others, there is no initial way to determine what these are in any given situation. In general, it might be said that each task requires one special simulator that would produce optimum transfer for that task; this means that task-simulators or part trainers used separately for the learning of each task would be more efficient than a single, multi-task simulator. In practice, however, this is often found to be neither practical nor economical; for instance, one would not seriously consider a simulator to teach a pilot how to climb, another one to teach him how to make turns, and so forth. On the other hand, such considerations should counteract the tendency to combine all of the tasks encountered in a real task situation within one single training device, regardless of the effect that such an arrangement might have on the learning of individual sub-tasks.

More conclusive findings concerning fidelity reduction in simulators are presented in a similar study by Wilkerson _et al._, who varied the fidelity of a jet aircraft simulator by increasing program cycle time and supplying simplified equations to the digital computer of the device. Neither of these actions had any effect on the performance of the pilots undergoing training. Furthermore, pilots trained under these "unrealistic" conditions showed no significant decrement of performance when transferring to "realistic" simulator conditions.[3]

Briggs and Johnston[4] investigated the effects of varying training task fidelity during team training experiments in a naval combat information center environment. The transfer task required two team members to coordinate their radar-controlled air intercepts. Lowered fidelity of the output features of the task environment affected the ability to coordinate at transfer; however, this deficit was rapidly overcome. Individual skill components were acquired equally well under all conditions of task fidelity variation, which included variation of the input and output features of the task environment, as well as variation of task definition.

Other studies in this field support an opposite point of view, indicating that fidelity of training devices often is a prerequisite for effective training, at least under some conditions. Silver *et al.*[5] attempted to identify radar characteristics and degree of simulation required for training purposes. They found that highly skilled radar observers could be trained in the specific task by presenting the

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[3]Lowell E. Wilkerson, *et al.*, *Pilot Performance, Transfer of Training, and Degree of Simulation: I. Variations in Program Cycle Time and Aerodynamic Equations* (Fort Worth, Texas: Life Sciences Inc., 1965), 64 pp.

[4]George E. Briggs and William A. Johnston, *Team Training Research*, Final Technical Report Feb. 64 - Feb. 65 (Columbus, Ohio: Ohio State University, 1965), 27 pp.

[5]Carl A. Silver, James M. Jones, and Daniel Landis, *Analysis of Radar Training Requirements* (Philadelphia, Pennsylvania: Franklin Institute Research Laboratories, 1965), 37 pp.

information by simple paper-and-pencil means; however, less proficient observers required that the same information be supplied through close simulation.

In a comparison of the effectiveness of animated versus static transparencies, Silverman[6] used three training devices differing in the number of moving parts. It was hypothesized that animation would be most effective when the training device contained many moving parts, and that this effectiveness would be best measured by a non-verbal performance test. Groups of college students were assigned to training on each of the devices, either in an animated or a static training condition. Effects of training were then measured by verbal, written tests and by individual performance tests. While paper-and-pencil tests showed no difference in effectiveness between animated and static devices, performance tests showed significant improvement for the groups utilizing animated devices.

The effect of motion as one factor of fidelity in flight simulators was studied by Ruocco _et al._[7] Two groups of pilots were trained in a landing maneuver; one group used a flight simulator with kinetic cockpit motion, the

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[6] Robert E. Silverman, _The Comparative Effectiveness of Animated and Static Transparencies_, Technical Report (New York: New York University, 1958), 26 pp.

[7] Joseph N. Ruocco, Patrick A. Vitale, and Robert C. Benfari, _Kinetic Cuing in Simulated Carrier Approaches_ (Bethpage, New York: Grumman Aircraft Engineering Corporation, Research Department, 1965), 107 pp.

other group used the same simulator but without the motion system. The investigators found that kinetic cuing improved performance of pilots in terms of percentage of successful landings, altitude error, time outside the flight path, and variability of pilot inputs, while the statically trained pilots showed a decrement in performance. Although the results of this study appear to support the case in favor of motion systems in flight simulators, one should note the fact that the criterion measure was a flight in the simulator with the motion system in operation; it therefore remains open to speculation whether the results would have been as decisive if the criterion task had been performed in the actual aircraft. This is perhaps typical of the problems confronting the researcher in the area of training device fidelity, since it demonstrates the problem of finding a criterion measure that is both valid with respect to transfer of training and amenable to measurement. Obviously, in the case of the motion study, the real equipment did not lend itself to ready measurement of task performance; but in substituting the simulator for the measurement of the criterion task, there is an unwarranted assumption that the motion system produced kinetic cues that corresponded to those encountered in the real situation In the writer's experience with similar systems, this is not necessarily the case; in fact, the very opposite assumption might be made, namely that simulator motion systems cannot adequately reproduce kinetic cues encountered in actual flight, so that any learning resulting from such cues would lead to negative transfer. For example, it is usually not possible to reproduce forces resulting from gravitational pull during a banked turn; however, the simulator motion system "duplicates" the attitude of the aircraft in the turn by banking the simulator, thus producing a sensation of skidding rather than one of coordinated turning. In other words, while we admonish the pilot not to fly the aircraft "by the seat of his pants" but to rely on display of instruments, we then proceed to provide him with an artificial "seat of the pants" and--to further confuse the issue--endow this artificial sense input with the wrong stimuli. Thus it might well be argued that it is a safer practice to forego the realistic atmosphere in a training situation when attempts at providing such realism may incur faulty learning cues.

Since fidelity achievement is synonymous with high cost, both in terms of initial expense and in terms of manpower and maintenance requirements throughout the life of the device, one question of importance concerns the degree of minimum fidelity which is required to allow the device to function in its intended role. To the surprise of many investigators, reduction of fidelity often results not only in maintenance of device effectiveness, but actually may lead to an increase of such effectiveness. This is true particularly in cases where reduction of fidelity in less essential task aspects serves to heighten the display of more essential functions.

Gabriel et al.[8] compared the effectiveness of a relatively simple flight simulator, equipped with a visual (exterior) display facility, with that of a highly specific simulator with a comparable display. The results of their study showed that pilots trained in the simple device acquired improved ability to detect simulated mid-air collision hazards, while attaining performance levels in other flight tasks equal to that of pilots trained in the more sophisticated device.

In a similar study, Pomarolli[9] investigated the effectiveness of a basic instrument trainer used in teaching basic and radio instrument navigation procedures to student pilots. His conclusion was that the simple instrument trainer was as effective as a more elaborate simulator and that the expenditure for such a simulator would therefore not be justified.

That deliberate reduction of fidelity can result in significant learning improvement with respect to some training objectives was shown by Swanson et al.[10] who investigated the relative effectiveness of two training devices used

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[8]Richard F. Gabriel, Alan A. Burrows, and Paul E. Abbott, Using a Generalized Contact Flight Simulator to Improve Visual Time-Sharing (Long Beach, California: Douglas Aircraft Company, 1964), 83 pp.

[9]Richard S. Pomarolli, The Effectiveness of the Naval Air Basic Instrument Trainer (Pensacola, Florida: Naval Aerospace Medical Institute, 1965), 47 pp.

[10]Robert A. Swanson, Arthur Lumsdaine, and Lewis E. Aukes, Two Studies in Evaluation of Maintenance Training Devices (Chanute AFB, Illinois: Training Aids Research Laboratory, 1956), 14 pp.

to teach inexperienced airmen the identification of components and functions of tubing in an aircraft rudder control system. One device consisted of a mock-up of the actual aircraft components and tubing, while the other device depicted components symbolically by simple geometric shapes and color-coded lines. Three groups of students were selected for the experiment: two groups, designated experimental groups, were trained by means of a tape-recorded lecture in conjunction with either the actual mock-up or the simplified symbolic diagram, while the third (control) group was only given the tape-recorded lecture. Test results showed that the group trained on the real-parts mock-up could--as expected--identify components better than the other groups; however, the group trained by means of the symbolic device scored significantly higher on a test concerned with functions of components. Since the ability to discern functions of system components is of greater value to the individual concerned with operation and troubleshooting of such systems than mere ability to identify components, the simplified training device appears to be preferable to the high-fidelity device for training purposes.

The importance of learner involvement was pointed out by Mirabella and Lamb[11] in a study of the effects of adaptive versus non-adaptive training on performance of a visual target detection task. In this case, increasing display complexity

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[11]Angelo Mirabella and Jerry C. Lamb, Computer Based Adaptive Training Applied to Symbolic Displays (Groton, Connecticut: General Dynamics Corporation, 1966), 62 pp.

during training was more effective than maintaining a constant level of complexity when subjects were required to respond actively to the displays, rather than viewing them passively.

Unfortunately, learner participation was not considered a pertinent variable to be controlled in other studies that might--under such conditions--have yielded quite different results. For example, Denenberg compared the effectiveness of three training methods employed in the teaching of certain operational tasks in an army tank.[12] One group of trainees was taught by the conventional method, which included training in the actual tank, with each trainee given the chance to perform the procedure on the actual equipment; a second group was trained by means of a "hull trainer" (which means a full-scale reproduction of the actual tank hull with facsimile controls and instruments), with only some of the trainees being afforded the chance to perform the task, while the rest of the students watched; a third group was trained by means of an inexpensive mock-up of the tank's instrument panel, with none of the trainees going through the steps themselves, but merely watching their instructor demonstrating the correct procedure. A conference period, consisting of a lecture and discussion of the subject, preceded each of the three practice lessons and was the same

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[12]Victor H. Denenberg, The Training Effectiveness of a Tank Hull Trainer, Technical Report, Human Resources Research Office (Alexandria, Va.: George Washington University, 1954), 28 pp.

for each of the three groups tested. A performance-type test on the actual equipment was used to determine each trainee's ability to perform the task, while a paper-and-pencil test was used to determine knowledge of operation of the equipment. The results showed that the actual equipment was superior with respect to task performance, with the inexpensive mock-up next and the fairly expensive hull trainer last. With respect to operating knowledge, there was no difference between the actual equipment and the mock-up, with the hull trainer being less effective. In both cases, the differences were slight and would probably not justify the use of a more expensive type of training device over a cheaper one. In addition, use of the least expensive device resulted in savings of time and space that could not be realized with either of the other two devices.

The following study, performed by Cox et al.,[13] resembles the present study in design and approach; however, there are important differences in procedure that may explain the difference in findings between Cox's study and this study. As in the latter, the central problem of Cox's study was to determine the effectiveness of training devices with varying degrees of fidelity. The investigators compared twelve training devices with fidelity ranging from close

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[13]John A. Cox, et al., Functional and Appearance Fidelity of Training Devices for Fixed-Procedures Tasks, Technical Report 65-4, Human Resources Research Office (Alexandria, Va.: George Washington University, 1965), 44pp.

simulation of the actual equipment to a small black-and-white line drawing of the equipment. The selected task was a procedural task which formed part of the training program of army personnel in the operation of a missile launching site. The experiment consisted of five studies in which research personnel of the Human Resources Research Office acted as instructors, and one field study in which regular army instructors performed this function. Groups of selected students were trained on each of the devices; each student was given a demonstration by the instructor and then was given two opportunities to perform the task on the device with the aid of the instructor. The instructor would reinforce correct responses verbally, would use cues whenever the student hesitated to perform a required action, and would supply verbal information concerning the panel displays on the low-fidelity devices that had no functional display capability. After completing their training, the subjects were required to complete a proficiency test, consisting of demonstration of the entire procedure on a high-fidelity training device that had been determined to be equivalent to the real equipment, being fully functional. The observed task was scored with respect to errors committed and time needed to complete the task.

Results of the five initial studies and of the field study showed that various reductions of functional and appearance fidelity of the training devices had no significant effect on proficiency scores or training times. It must be emphasized, however, that the task selected was a very simple procedural task in which all actions took place in an invariable sequence, did not require decision making, and demanded only moderate psychomotor activities. Furthermore, as stated by the authors, some variations occurred when verbal signals replaced visual and auditory signals; although these variations did not affect performance in these studies, changes in training environment in which the device is used might produce differences in effectiveness between devices of varying fidelity.

What seems to this writer a question of much more importance concerns the influence of instructor behavior on student learning. In addition to the variations that occurred during the verbal feedback process, it remains open to speculation what effects cuing and reinforcement had on trainee behavior. As has been the experience of this writer, instructor-induced motivation can overcome serious drawbacks in the instructional situation, such as lack of training aids, poorly designed training devices, and other deficiencies. The opposite occurrence is, of course, also possible, so that a deterioration of the learning situation may result from rejection by the instructor of a device, program, method, and so forth. One of the essential prerequisites of any evaluation procedure in which the entity to be evaluated forms only one element in a larger instructional system would therefore be an arrangement to insure constancy--or at least control--of all other elements in such a system.

In summary, it may be seen that literature dealing with the question of training device fidelity falls primarily into three categories: (1) literature supporting the traditional view of direct relationship between fidelity and effectiveness, (2) literature supporting an opposite view, at least for special applications, and (3) literature minimizing the effects of varying degrees of fidelity. It was hoped that the results of the present study might allow the formulation of some conclusions that would serve as a basis for a future theory, presenting a synthesis of significant elements common to existing--and apparently contradictory--research findings.

CHAPTER III

DESIGN OF THE STUDY

It was recognized that any attempt at comparison of training device effectiveness would yield valid conclusions only if all factors other than device fidelity itself could be controlled so as to remain constant. Of these factors, the training process itself--consisting of instruction, practice, and means for providing knowledge of results--was seen as posing the principal difficulty with respect to controllability.

As a result, it was decided to divide the study into two separate phases: a preliminary study, concerned primarily with the development and validation of instructional procedures that would insure constancy of information input for the learning of a task involving a typical training device, and--in case the results of such a study were favorable--the application of such procedures to a series of experiments forming the second phase, or principal study, concerned with the investigation of comparative effectiveness of training devices with differing degrees of fidelity.

The preliminary study was designed to contain all essential elements applicable to the principal study, so that the latter might be performed with a degree of expertise that would allow optimum concentration on measurement of pertinent variables without distractions caused by inefficient instruments or procedures.

In essence, the preliminary study was designed to accomplish the following objectives:

1. Selection of a suitable task, requiring the use of a training device.

2. Based on an analysis of the task, development of instructional instruments that could be used repeatedly without variation of information input. It was decided to select programed texts and tape-recorded instructions, these being least expensive among such materials.

3. Development of evaluation instruments with a high degree of validity and reliability to measure three areas of learning: knowledge and understanding of principles, routine task performance, and analytical ability.

4. Comparison of the effectiveness of the instructional materials with that of conventional instruction methods, using appropriately selected groups of subjects and identical training devices and evaluation procedures.

A detailed description of these procedures is given on pages 30 through 50. Based on demonstrated suitability of such training and evaluation instruments, the principal study was then to be organized as follows:

1. Construction of training devices of progressively lowered fidelity, as described below.

   a. A three-dimensional mock-up of actual size, having movable controls, but without display capability.

   b. A two-dimensional photographic reproduction of the device in actual size, but without either controls or displays.

   c. A small (5x7 inches) photographic reproduction of the device, forming a part of the programed text and normally referred to by the student during its use.

2. Using training instruments developed during the preliminary study, administration of training to groups of subjects selected from a homogeneous population of students, each group utilizing a different type of training device, resulting in a total of five groups as follows:

Group I. Optimum fidelity (training task performed on actual equipment).

Group II. High fidelity (training task performed on simulator device which closely duplicates actual equipment appearance and functions).

Group III. Medium fidelity (task performed on mock-up with movable controls but without display capability.

Group IV. Low fidelity (task performed on two-dimensional reproduction without control or display capability).

Group V. Minimum fidelity (task performed vicariously with the aid of a small illustration).

3. Using standardized evaluation procedures developed during the preliminary study, determination of training effectiveness under each of the above conditions.

4. Statistical analysis of results and formulation of conclusions.

Preliminary Study

Location of the study. The study was carried out at an Air Force training center primarily concerned with training pilots and flight engineers in the operation of two types of modern multi-engine transport aircraft. For the type of aircraft under consideration, the curriculum of this school is divided into an academic phase, consisting of approximately 106 hours of classroom instruction, and a flying phase, consisting of 32 hours of flight-simulator instruction and 42 hours of flight training in the actual aircraft. An additional 15 hours is scheduled for ground training which comprises instruction in component location, preflight procedures, and similar items. Successful completion of the course is predicated on passing written, multiple-choice-type examinations at the completion of each of the major subject-matter sections of the academic phase, a comprehensive examination at the completion of the academic phase, and demonstration of proficiency through performance in the actual aircraft and the passing of an oral examination at the completion of the flying phase.

The study was prompted by a desire to explore the use of fairly inexpensive training devices for some training functions traditionally performed on more costly and sophisticated devices, such as flight simulators, which represent large initial investments of funds and require continuous expenditures of resources and manpower for proper maintenance. Any tasks that could be relegated to simpler devices would therefore free the use of the more expensive devices for more important training activities.

Selection of groups. Experimental and control groups were selected at random from the total student population which already represented a highly homogeneous group, based on the following factors:

1. All members of the total population held the same Air Force Specialty Code (Flight Engineer Technician).

2. Award of this Specialty Code is predicated on successful completion of a basic course for Flight Engineers.

3. Entry to the basic course is on a highly selective basis; selection criteria include a high passing score on the Air Force Qualifying Test, completion of high school including courses in physics and mathematics, and passing of a rigid physical examination for flying duty.

In addition, the following criteria were applied to subjects selected for the experimental and control groups:

1. No prior experience on the type of equipment under consideration, nor on any similar type of equipment.

2. Completion of the environmental systems course during the academic phase of the training program.

3. Achievement of a test score of 90 percent or better on the final test of the environmental systems course.

For the preliminary study, an experimental group of sixteen subjects was selected on the basis of the above criteria; this group was to receive instruction by means of a programed text and tape recording. A control group of sixteen subjects was selected in similar manner; this group was to receive instruction by conventional methods.

Both groups had received identical instruction in the fundamentals of the aircraft system from which the task for this study was selected, but without emphasis on the operational aspects of the system. Thus, although the students had demonstrated through a written test that they had acquired some knowledge of the purpose, location, and function of the system components, they had not actually operated any of the system controls and were naive with respect to the procedure under observation.

Selection of the task. The task selected concerned a portion of the flight engineer's preflight check procedure. The preflight check consists of visual and operational checks of the aircraft and of the aircraft systems, such as electrical, hydraulic, and flight control systems. The entire check requires approximately one hour and serves to determine the operational readiness of the aircraft for safe flight. The task under observation concerned the operational check of the aircraft's environmental system, which furnishes the pneumatic requirements for pressurization, air conditioning, anti-icing, and similar aircraft systems.

The task normally is performed by the flight engineer, using controls and displays contained on a special section of his instrument panel. The controls on this panel allow the engineer to select various functions of the individual system components in accordance with operating requirements; feedback from the components is supplied by displays in the form of indicator lights and gauges. The task under observation, designated environmental system check procedure, requires only about five minutes.

Development of instructional instruments. One of the reasons for the completion of a preliminary study was to develop instructional materials to teach the task described above. Since it was recognized that--in order to minimize the bias introduced into the evaluation procedure through factors unrelated to training device effectiveness--it would be necessary to devise a procedure that would assure constant informational input into the training situation, the feasibility of substituting a programed text for the conventional instructor-based lecture-demonstration method was investigated. A review of the literature pertaining to this problem revealed that there was little evidence on which to base programed-text effectiveness in a learning situation that required not only acquisition of facts, but also ability to interrelate such facts in meaningful fashion and to act in specific response to visual displays that formed cues in a problem task that required such knowledge, thus involving some degree of psychomotor activity as well.

It was decided that the programed text should provide more than mere directions for the performance of a fixed-procedure task; it should enable the student to make appropriate decisions when display information deviated from the expected norm, so that understanding of underlying system principles and functions would have to be insured by enclosing of pertinent information in the program.

It was also recognized that the programed text should be constructed so as to furnish the student with responses corresponding to display indications that would be absent in the non-functional training devices, as provided by the verbal instructor cues during Cox's study. Moreover, since psychomotor tasks were involved in the procedure, the program should also furnish appropriate commands for such movements, so that student involvement would be at a maximum. In essence, the goal was to construct a programed text that would serve to teach a trainee without prior experience in the particular subject how to perform a typical check procedure involving manipulation of controls, observation and interpretation of displays, following a sequence, and ability to identify sources of malfunctions as indicated by non-standard displays, while utilizing a training device with greatly reduced fidelity.

Existing literature on such an endeavor was divided between traditionalists--who would deny the capability of self-teaching devices to instill "thinking" behavior--and modern practicians, who see in teaching machines and similar devices the salvation to the ever-increasing problem of dissemination of knowledge in ways that allow the learner to make meaningful (or "thoughtful") use of such knowledge. As an example of the former, Hilton is of the opinion that teaching machines should be called "training" machines, or drill apparata, since the process they engender cannot be called learning, but is, at best, training and drill:

> By this definition, training devices have been developed by the armed services and by industry for several years . . . Essentially, all training devices provide the trainee with statements of facts he is to remember or demonstrations of activities to perform . . . Such training devices are very useful, if they are properly employed to drill the trainee in remembering facts . . . My major objection to such devices and their future usefulness is that they train for automatic response at a time when we must make every effort to educate students to become thinking human beings rather than automata that

are not nearly as efficient as electronic computing machines.[1]

Such statements, obviously, represent extremes of opinion and are not shared by many instructional technologists who recognize that--while self-teaching devices may emphasize supply of facts--there are few areas in which intelligent activity may take place without a basic fact structure. The position of the instructional technologist is exemplified by Briggs,[2] who--in investigating the nature of material to be learned by a typical military technician in the electronics field--identified the following requirements for the programing and construction of teaching machines:

> The technician has to learn to find and to recognize hundreds of parts and objects in the equipment. Some of this learning is done by memory, and some by learning how to use indexes and charts as guides. He does have to follow many fixed sequences of actions; some of the brief ones he performs by memory; the more lengthy ones are performed with the aid of checklists. He has to learn many concepts and rules which are used to decide when and how to perform acts which are not or cannot be specified in manuals for each occasion they may be needed. Related to learning of concepts and rules is the need to understand the fundamental principles of the functioning of the electronic circuits. And somewhere between such general principles of circuit function on the one hand, and fixed procedures of maintenance on the other, there appears a need for understanding of the general objectives of the specific equipment in terms of "what it is trying to do."

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[1]Alice M. Hilton, Logic, Computing Machines, and Automation (Washington, D.C.: Spartan Books, 1963), pp. 395, 396.

[2]Leslie J. Briggs, "Teaching Machines for the Training of Military Personnel in Maintenance of Electronic Equipment," Automatic Teaching: The State of the Art, ed. by Eugene Galanter (New York: John Wiley and Sons, 1959), pp. 131-133.

> . . . Additional requirements also probably exist . . . to make complex judgments, to use general rules to guide the deductive thinking required in troubleshooting, to transpose readily from symbols to words to actual physical appearance of hundreds of objects, _et cetera_.

That it is feasible to devise programed texts with objectives as outlined by Briggs has been demonstrated in many industrial and military training programs,[3] but it was not clear whether this would hold true for the kind of tasks that would be involved in interaction with a training device.

Choice of programed text. In choosing a programed text for the study, the suggestions made by the contributors to _Automatic Teaching_[4] were generally followed. The articles by Gagné and Bolles on factors in learning efficiency and by Beck on methods of programing were especially helpful. The decision to employ a linear text with occasional wash-back was made on the basis of Larkin and Leith's study on the effects of linear and branching methods on learning and retention; the authors found the linear method superior in these respects.[5]

With respect to the question of overt versus covert responses, a survey of the literature yielded conflicting

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[3] I. K. Davies, "Programmed Learning in the U.S. Air Force," _Programmed Learning_, 1:113-124, 1964.

[4] See footnote on preceding page.

[5] T. C. Larkin and G.O.M. Leith, "The Effects of Linear and Branching Methods of Programmed Instruction on Learning and Retention of a Topic in Elementary Science," _Programmed Learning_, 1:12-16, 1964.

information. Pressey and Skinner, as pioneers in programed instruction, emphasized the importance of active overt responses in learning, whether programed or not; since--in their opinion--active student participation in the learning process led to more efficient learning, they considered the activity that a teaching machine demanded from the learner as one of its main benefits. For Skinner and his disciples, overt activity is, of course, the only measurable--and therefore the only "real"--dimension of human behavior. Holland, one of Skinner's collaborators, confirmed this thesis by an experiment in which he showed that students who made overt responses while operating a teaching machine made significantly fewer errors than students who simply read the statements and responses.[6]

As Holland states this principle: "Behavior is learned only when it is emitted and reinforced."[7] Based on similar assumptions, active responses were also found superior by Hovland, Lumsdaine, and Sheffield, who compared two forms of a training film, one of which included passive review sequences, while the other one demanded active audience participation. The authors found that students who participated actively learned the subject matter significantly faster than those

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[6]Edward B. Fry, Teaching Machines and Programmed Instruction: An Introduction (New York: McGraw-Hill Book Co., 1963), pp. 147, 149.

[7]James G. Holland, "Teaching Machines: An Application of Principles from the Laboratory," in Teaching Machines and Programmed Learning, ed. by A. A. Lumsdaine and Robert Glaser (Washington, D. C.: National Education Association, 1960), p. 219.

who viewed the film passively.[8]

In essence, such findings echo the conclusions reached by Gates in his classical (1917) study in which he demonstrated the positive effect of recitation on memorization.[9] Since then, his statements have been challenged by a number of investigators. For example, Evans, Glaser, and Homme used a program in music fundamentals with two groups of students, one group making written responses while no such responses were made by the other group. The group that was not required to make written responses completed the program in less time and achieved a higher mean score on a final test.[10] A similar conclusion was reached by Evans in a study comparing different modes of responding in a program in symbolic logic.[11]

In addition to the two positions exemplified above, either asserting or rejecting the superiority of overt responses, there is a third position that goes beyond simple

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[8]C. I. Hovland, A. A. Lumsdaine, and F. D. Sheffield, Experiments on Mass Communication (Princeton, N. J.: Princeton University Press, 1949), Chapter 9.

[9]John A. Barlow, "Programed Instruction in Perspective: Yesterday, Today, and Tomorrow," in Prospectives in Programing, ed. by Robert T. Filep (New York: The Macmillan Company, 1963), p. 9.

[10]J. L. Evans, Robert Glaser, and Lloyd E. Homme, "A Preliminary Investigation of Variation in the Properties of Verbal Learning Sequences of the 'Teaching Machine' Type," in Teaching Machines and Programmed Learning, pp. 446-451.

[11]Fry, op. cit., p. 149.

rejection of overt responses on the grounds of needless effort; this position asserts that overt activity interferes with the establishment of proper stimulus-response connections and impedes the learning of the responses.[12]

In the light of such contradictory findings, it appears difficult to make a decision concerning the choice of responses to be included in a program; however, if one makes the assumption that all of the different findings were valid within their appropriate settings, the conclusion must be reached that neither overt nor covert responses have any inherent advantage over each other, but that either type may have its preferred place according to the material to be learned, the intellectual and motivational state of the learner, and the situation in which the program is administered.
This sentiment is shared by Fry, who states that "We may well expect to find that sometimes overt responses will be better and sometimes covert responses will be better, depending upon various factors involved in the particular learning situation,"[13] and by McNeil, who writes:

> It cannot be said that an overt response is unnecessary because of the failure to show that selecting a multiple-choice item by pressing a button results in more learning than the "passive" behavior involved in viewing stimuli and keeping responses, if any, to oneself. It is likely that an overt response is advantageous in those situations where the response itself is the behavior to

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[12]J. O. Cook and M. E. Spitzer, "Supplementary Report: Prompting versus Confirmation in Paired Associate Learning," <u>Journal of Experimental Psychology</u>, 59:275-276, 1960.

[13]Fry, <u>op</u>. <u>cit</u>., p. 151.

be taught or where there is a close connection between the overt response and the learning desired.[14]

McNeil was able to support this assumption by an experiment in which he demonstrated that beginners in reading who were taught skills of recognition by a method which required oral responses to stimulus words learned to recall, identify, and comprehend more printed words and sentences than those who had to respond to the stimulus words without saying them aloud.[15]

On this basis, it was decided to construct the programed text for the present study in such a manner that overt responses would not be required by the student for those frames that dealt with verbal knowledge only, but would be required for all "action" frames that involved movement or checking of controls, whether actually performed or simulated. Thus, time would be saved for the completion of verbal responses by having the student merely think of the correct responses before checking their veracity, while ensuring maximum physical interaction with the training device by asking the student to respond actively to the various task stimuli.

The programed text was printed in down-the-page fashion, with a simple paper mask being used to cover responses printed on the right-hand side of the page, and horizontal dividing lines between frames to indicate to the student that

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[14] John D. McNeil, "Programed Instruction and the Elementary School Curriculum," in Prospectives in Programing, pp. 74-75.

[15] Ibid., pp. 75-79.

a frame had ended and that he was to slide the mask down to the next dividing line after having made the appropriate response. A few simple diagrams were included in the text to clarify important relationships between components to which the text referred. A photographic reproduction of the instrument panel used in the task under study was enclosed, together with a transparent overlay sheet that had numbers printed on it in such a manner that ready reference could be made to any control or display mentioned in the text.[16]

Tape-recorded instructional sequences. Since the procedure for the programed text required the student to use one hand to slide the paper mask down one side of the page and to turn the pages of the text, the student was forced to rely on his other hand for the manipulation of the various controls on the panel, as requested by the instructions in the text. While this was quite acceptable during the initial orientation to control functions, the performance of the actual procedure required the use of both hands. Therefore, supplementary instructions were provided by a tape recording to assist the student during the final stages of practice.

The tape recording contained two instructional sequences. The first one provided explicit instructions for the movement of each control and gave an explanation of the reactions that were to be expected and of the meaning of the

[16]See Appendix I for copy of programed text.

various displays corresponding to each control movement; the second sequence provided cues and brief commands for the execution of a check procedure at a normal rate of speed.[17]

<u>Development of evaluation instruments</u>. The evaluation procedures were designed to measure degree of learning in three areas of desired student behavior:

1. Knowledge of principles and understanding of basic system functions in an operational sense.

2. Ability to perform a fixed-procedure task.

3. Ability to detect and to analyze deviations from normal fixed-procedure states.

In devising a scoring system, it was decided to use a different system for each of these evaluation procedures and to treat them statistically as separate and distinct parameters. The test instruments to provide a measure of these parameters were designed as follows:[18]

1. A written test consisting of 10 multiple-choice questions concerning system principles and functions. Care was taken to word questions in operational terms and to provide answer choices free of ambiguity and free of clues as to correct choice.

2. A performance test consisting of completion of the entire procedural task under routine conditions, with a tally of errors being accomplished by the observer, one point being detracted from the perfect score for either an omission, incorrect sequence, or inability to continue with the next step without assistance.

3. A second performance test consisting of completion of the task when certain pre-selected system malfunctions were introduced by the experimenter. Emphasis in observation was directed toward the student's ability to detect,

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[17]See Appendix II for the text of the tape recording.

[18]See Appendix III for copies of the test instruments.

correctly analyze, and rectify the malfunction through appropriate action. Score was based on tally of incorrect responses deducted from the perfect score.

The written examination preceded the performance tests, with a review of the examination immediately following its completion. The performance evaluations were accomplished on the actual aircraft equipment, thus providing a true measure of skill transfer. The system malfunctions during the second performance test were introduced by positioning certain circuit breakers and switches (not located on the environmental panel) without the knowledge of the student. Although task completion time was considered as a performance factor during the preliminary study, it became obvious that time was a variable depending on many factors not related to student performance, such as differences in equipment response times and delays due to sluggish component operation. Therefore, no attempt was made to include time as a performance measure in the final comparative analysis.

Validation of Materials and Tests. Validation of the programed text and tape recording was based on seven steps inherent in the development of these materials: (1) a task analysis, with determination of essential knowledge items for each task element, (2) organization of such items into a logical structure, (3) development of a linear program on the basis of the structure, (4) review of the program by randomly selected instructor personnel, (5) revision of text and tape recording as a result of the review, (6) trial of actual use by randomly selected student personnel, not part of the preliminary test population, (7) revision of text and tape recording on the basis of student comments and observed difficulties. The final result of this procedure was a program that effectively achieved its desired objective, as shown by the subsequent comparison of students trained with the aid of these materials only versus students trained by the conventional "live" instruction, summarized by the data in Table 1.

Validation of the test instruments also rested on the initial task analysis, followed by determination of crucial knowledge and performance items likely to discriminate between good and poor students. Again, opinion of instructor personnel was obtained concerning individual items selected in this manner. In addition, the following procedures were applied in the construction of the test instruments.

For the written test, twenty-five questions were originally selected on the basis outlined above; these were of the multiple-choice type, with four choices for each item. This test was administered to thirty randomly selected students, not part of the final test population, and ten instructors. An item analysis was performed for each of the twenty-five test questions which allowed an assessment to be made of the discrimination value of each item.[19] The criteria for

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[19]The procedure for the item analysis followed that outlined by C. C. Ross and Julian C. Stanley, Measurement in Today's Schools (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1956), pp. 436-453.

selection of a test question into the final test form were (1) high discrimination value and (2) freedom from ambiguity as shown by error-free performance by the instructor group. Reliability of the final ten-question test was determined by a split-half procedure in which the ten items were matched on the basis of difficulty as follows:

1 - 10

2 - 3

4 - 5

6 - 9

7 - 8

A simple form of the Spearman-Brown "step-up" formula[20] was then used to compute the reliability of the test, which was found to be r = 0.98. This high reliability was later confirmed by the actual test results of the preliminary and principal studies. (See Appendix III for format of final test).

For the routine performance test, a list of ninety action items was compiled on the basis of the task analysis. However, initial trial tests showed that it would be impossible to observe all of these actions with any degree of reliability; therefore, a check list of thirty action items was compiled on the basis of significance of each item and of the ease with which it could be observed and identified with

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[20]Ibid., pp. 123, 124. The formula was $r_W = \frac{2r_{\frac{1}{2}}}{1 + r_{\frac{1}{2}}}$ in which $r_{\frac{1}{2}}$ is the correlation coefficient between the half-test scores.

respect to correctness. Students were asked to cooperate in the task of evaluation by pointing to the components on the panel as they were being checked and to state aloud the indications of the displays they were observing. Reliability of the check list was indicated by observation of task performance by two observers; comparison of the scores recorded independently by the observers showed agreement without exception. A total of six observations were made in this manner; since circumstances prevented obtaining a larger number of observations, no statistical analysis of this test's reliability was made, although the findings from the six observations suggested very high reliability. A copy of the check sheet, listing expected student behavior for each action item, is reproduced in Appendix III.

The analytical performance test was developed along the same lines as the routine performance test. Only four critical "malfunction" items were selected; any greater number would have reduced the surprise value of each deviation from the norm and would have duplicated one of the four basic malfunctions. The four problems were selected so that they represented items of increasing difficulty, requiring attention, ability to recognize an abnormal state, and ability to analyze and to solve the problem in approximately identical proportions; this means that Problem 1, which was easiest to detect, also was easiest to solve, while Problem 4 was most difficult to detect and required both critical ability and knowledge of the system for solution.

The problems were spaced evenly during the second check procedure which the student was asked to perform, after having completed the first check under routine conditions. The problems were introduced by the experimenter by positioning switches or circuit breakers for certain controls without the knowledge of the student. Failure to detect a problem or to find a solution was rated as an error, to be subtracted from the perfect score. Details concerning the specific problems are furnished in Appendix III.

In summary, all instructional materials and testing procedures were derived from an analysis of the task under study, with desired objectives stated in operational terms that allowed a measurement of achievement of such objectives through observation of behavioral responses in the areas of (1) knowledge and understanding, (2) skill and competency, and (3) problem solving.[21]

Procedure. Both groups of the preliminary study used one of three flight simulators available within the training center as the specific training device to be used in conjunction with the programed text and tape recording. It was assumed that the flight simulators, with their capability of duplicating very closely all functions of the actual equipment

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[21]These represent three of the four types of behavioral change used by Kearney in the classification of educational objectives, as cited in Arden N. Frandsen, Educational Psychology: The Principles of Learning and Teaching (New York: McGraw-Hill Book Company, 1961), pp. 8, 9.

on the aircraft, would provide a degree of fidelity very close to the optimum while ensuring an environment that could be adequately controlled with respect to lighting, temperature, noise level, and other extraneous variables.

Both groups of students received training in the specific task as part of their normal training program and were not told of the experiment in order to limit the occurrence of "Hawthorne effects." The experimental group received instruction only by means of the programed text and the tape recording. Since time for simulator use was at a premium, students were asked to read the first one hundred frames of the programed text--concerned mainly with system description and component functions--prior to entering the flight simulator, using the photograph of the environmental system control panel with the transparent number sheet for orientation. Approximately one hour was allocated to the study of the text in this fashion; the remainder of the programed text was then completed in the flight simulator, with the student actually performing all steps as required. When a student had completed the entire text, the experimenter would then start the tape recorder for the practice sessions, consisting of two complete check procedures as outlined above. After completion of the practice sessions, the student was required to answer the ten questions on the written test. The evaluation of the student's ability to perform the task under routine and under abnormal conditions was performed on the actual aircraft equipment on the day following the simulator practice sessions.

The control group received instruction through conventional instructor-student dialogue and demonstration-performance type of instruction in the flight simulator. Several instructors of the school were randomly chosen to administer this training, with the request to limit the amount of instruction and practice to that required by the self-taught group. The same written test was then administered by the instructor. As with the experimental group, the performance evaluation was administered by the experimenter on the actual aircraft equipment after a time lapse comparable to that of the experimental group.

Neither group was aware of the nature of the experiment. The programed text and tape recording were introduced as new methods of instruction, and all activities were perceived by the students as part of their normal training program.

Results of Preliminary Study and Analysis of Data

The main purpose of the preliminary study was to develop instructional materials, test instruments, and general procedures, and to validate these through statistical analysis. Where necessary, methods were modified so as to make them readily applicable to the principal study, in which the primary concern was the determination of effectiveness of five different training devices.

Two groups of sixteen subjects were selected on the basis of similar background and achievement on a test in the same subject area. One group was administered conventional training in the task under observation, while the other group received this training by means of a programed text and tape recording. The training device in both instances was a high-fidelity simulator device that closely duplicated the functions and appearance of the real equipment. Both groups were subjected to the same criterion tests, consisting of a written test and two different performance tests.

Test scores obtained by the two groups are presented in Table 1. A two-tailed t-test was performed for each pair of test-score columns between related tests of the control and experimental groups. Results showed that there was no significant difference between any of these pairs of scores. Thus, it could be assumed that the method of instruction with the programed text and tape recording was equally effective as the traditional method. In addition, correlation coefficients were computed for each pair of test-score columns of the experimental group. Results showed a correlation between the written test and the routine performance test of $r=0.31$, correlation between the written test and the analytical performance test of $r=0.39$, and a correlation between the routine performance and analytical performance tests of $r=0.33$. In view of the fact that each of the tests was designed to measure one special parameter of knowledge or

TABLE 1

RESULTS OF PRELIMINARY STUDY: COMPARISON OF TEST SCORES OF STUDENTS TRAINED BY SELF-TEACHING METHOD WITH TEST SCORES OF STUDENTS TRAINED BY TRADITIONAL METHOD

	GROUP I (SELF-TEACHING)			GROUP II (TRADITIONAL)		
N	(X) Written	(Y) Performance	(Z) Analytical	(x) Written	(y) Performance	(z) Analytical
1	8	22	3	7	25	3
2	6	24	2	7	25	2
3	6	27	2	6	27	3
4	9	24	1	8	25	3
5	8	26	3	7	25	4
6	9	27	4	7	26	3
7	9	26	3	4	24	1
8	8	25	2	5	21	1
9	5	22	1	8	27	4
10	6	27	2	8	25	2
11	8	29	2	10	28	4
12	4	20	2	9	28	4
13	7	24	4	7	26	3
14	10	28	4	7	27	2
15	9	26	3	7	27	1
16	7	24	3	6	26	3
Sum	119	401	41	113	412	43
	$\bar{X}=7.44$	$\bar{Y}=25.06$	$\bar{Z}=2.56$	$\bar{x}=7.06$	$\bar{y}=25.75$	$\bar{z}=2.69$
	$s^2=4.67$	$s^2=5.80$	$s^2=0.93$	$s^2=2.06$	$s^2=3.00$	$s^2=1.16$

Null hypothesis: There is no difference between the means.
Assuming alpha=.05, two-tailed test: Reject H_o if $t \leq -2.04$ or if $t \geq +2.04$
For $\bar{X}-\bar{x}$, $t=0.58$; thus, do not reject H_o (there is no significant difference).
For $\bar{Y}-\bar{y}$, $t=-0.93$; thus, do not reject H_o (there is no significant difference).
For $\bar{Z}-\bar{z}$, $t=-0.18$; thus, do not reject H_o (there is no significant difference).

performance, the correlation appeared sufficiently high to allow consideration of the triple-test package as a valid indicator of student achievement in the selected task area.

In summary, the conclusions from the preliminary study were that (1) the instructional instruments were well suited to the teaching of the theoretical and practical aspects of the subject matter, (2) the test instruments were reliable in indicating student achievement, and (3) the procedures of observing, scoring, and analyzing student behavior were sufficiently simple to assure consistent results free from observer error.

Consequently, it was decided to apply these same procedures and instruments to the principal study, in which any variations in results could then be charged to differences in effectiveness of the particular training devices that were to be used.

Principal Study

Based on the demonstrated effectiveness of instructional materials, test instruments, and general design of experimental procedures, the principal study was directed toward the determination of relative effectiveness of five training devices with degrees of fidelity ranging from the optimum possible--in the case where the actual equipment was used for training--to an arbitrarily defined minimum, consisting of a small illustration of the equipment.

Description of training devices. Five different devices were used for comparative study; of these, two were already in existence and were normally used for the administration of training (these two being the actual aircraft equipment and the flight simulators), while the remaining three devices were specially constructed. Specifically, the five devices may be described as follows:

1. Optimum-fidelity device. This was the actual equipment, located in the flight station (cockpit) of a large transport aircraft and consisting of a portion of the flight engineer's instrument panel, designated Environmental Control Panel. The panel is mounted in a vertical plane in front of the operator, who--by means of an adjustable seat--may assume a position within easy reach of the controls on the panel. In addition to the controls in the form of rotary and toggle switches, the panel contains displays in the form of gauges and indicator lights that illuminate printed legends. This panel occupies approximately one-fifth of the total area of the flight engineer's instrument panel. All controls and displays were fully functional during the training sessions and during the evaluation procedures.

2. High-fidelity device. This was the same equipment as described above, but located in one of three flight simulators that were identical to each other with respect to appearance and function of the equipment under study. All controls and displays were fully functional, with proper responses assured through electronic circuits controlled by

digital computers. The appearance of the simulator panel was identical to that of the actual equipment; however, there were slight functional differences, primarily in the rate of some responses and in the audible effects of certain actions.

3. Medium-fidelity device. This was an actual-size, three-dimensional mock-up constructed of plywood fastened to a metal frame. Photographic reproductions of all sections that make up the entire flight engineer's instrument panel were mounted in the proper locations, and the remaining areas were painted to resemble the actual equipment. All controls were real components, installed in their proper place and operable in normal manner. All displays, however, were non-functioning; gauges were depicted by photographs, with their pointers indicating a "normal" reading, while indicator lights were shown illuminated by means of transparent strips of plastic in the appropriate color that allowed reading of the legends beneath. A transparent sheet of plexiglass was supplied that could be fastened to the face of the instrument panel. Numbers were printed on this sheet in such a manner that they would be superimposed over the controls or displays identified by like numbers in the programed text. The sheet could be easily removed by the student after he had learned to identify the various components. The entire device was mounted on a platform, with a seat that permitted the operator to assume a position relative to the instrument panel comparable to that in the actual

aircraft.

4. Low-fidelity device. This was a full-sized, photographic reproduction of the equipment, mounted on a board that allowed the student to position it on a table in front of him. There were no controls installed on this panel, and the color of the indicator lights was not duplicated. Students were instructed to place the device in a position that corresponded approximately to that of the actual equipment. They were also asked to reach for the depicted controls and to simulate their movement as required by the instructions of the programed text and tape recording.

5. Minimum-fidelity device. This was a small photographic reproduction (5x7 inches) of the actual equipment, provided with a numbered transparent overlay that served the same function as the transparent sheet supplied for the mock-up.[22] The device was furnished as an integral part of the programed text; thus, if used by itself it would constitute the minimum-fidelity training device, or, if used in conjuction with one of the other devices, it would serve as an aid during initial orientation. In fact, most students preferred to use it in this manner when training on one of the other devices, rather than bother with the installation of the large transparent number-sheet. When used as the only training device, the small photograph did

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[22]See sample attached to programed text in Appendix I.

not allow the simulation of control movements, so that the student had to perform all actions vicariously.

Selection of groups. Five groups, each comprising twenty-five subjects, were randomly selected from the total student population on the basis of naivety with respect to the task under study, lack of prior experience in the type of system involved, and completion of a standard course of instruction in basic subject-matter theory with a final test score of 90 per cent or better. The reasons for the imposition of this last criterion were as follows:

1. As observed on previous occasions, high test scores on written tests correlate positively with reading ability. Since the instruction for the task to be performed on the training device was primarily by means of a printed programed text, it was felt that the learning of the task should not be hampered by reading difficulties, which might lead to deficiencies in performance incorrectly ascribed to idiosyncrasies of the particular training device.

2. Since the study was conducted under field conditions, it was thought prudent to limit the training administered under experimental conditions to students who--in all probability--would not be penalized by the absence of intensive, personal instruction in this specific task.

3. The test scores further enhanced the homogeneity of the test population.

4. The test scores were readily available, obviating the necessity for additional testing; furthermore, they guaranteed the existence of a common level of basic knowledge of system principles relevant to the task under observation.

As pointed out in the discussion of selection criteria during the preliminary study, the above criteria were in addition to those governing the composition of the total population from which the groups were selected, thus ensuring highly homogeneous sample populations for the five groups.

Each of the five groups were assigned to training on one specific training device as follows:

Group I ....Optimum-fidelity device (aircraft)

Group II ....High-fidelity device (simulator)

Group III ......Medium-fidelity device (mock-up)

Group IV ....Low-fidelity device (full-size panel)

Group V ....Minimum-fidelity device (illustration)

Assignment of individual subjects to a particular group was completely at random.

Procedure. The procedure for the principal study followed that outlined for the preliminary study, with the exception of the number of groups being compared and of the nature of the comparisons; while in the preliminary study identical training devices were used with different teaching methods, the principal study aimed to keep instructional methods and materials constant except for the criterion variable in the form of the training device, which would differ for each of the five groups.

The instructional materials were the same as those used during the preliminary study, namely a programed text followed by a tape recording. Since the preliminary study had shown that time limitations would not make it possible for students to complete the entire programed text while in the flight simulator and, therefore, the decision had been made to require students to complete the first one hundred frames of the text before entering the simulator, this scheme was adopted for all five groups of the principal study. Although representing a compromise between original intentions and exigencies of the actual situation, it was the only way to assure equal use of instructional materials for all five groups. Since the first one hundred frames of the text dealt primarily with system and component description, while subsequent frames dealt with the specific actions of the task to be learned, interaction between student and training device remained at a high level during the portion of the program devoted to the task under study. Although students were told that it would not be necessary to write in the responses indicated by blank spaces in the program frames, they were urged to perform all necessary motions (or, if this was not possible, to simulate such motions) required to position controls on the panel and to visualize the results. The practice sessions, aided by the instructions supplied by the tape recording, followed completion of the programed text, as during the preliminary study.

The evaluation procedures were the same as those established during the preliminary study. After having completed the written test, students were not told of plans for a performance test, which was then administered unannounced on the following day. All performance tests were carried out on the actual equipment, with the experimenter acting as observer, aided by check sheets that had been developed to facilitate the observation and recording of significant student actions.

Results of the evaluations were recorded on a score sheet that allowed tabulation of scores under a heading corresponding to the particular training device used.[23] Table 2 represents a comprehensive overview of the collected scores, forming the data for the comparative analysis.

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[23]See sample score sheet in Appendix III.

TABLE 2

COMPARISON OF TEST SCORES BETWEEN FIVE GROUPS OF STUDENTS TRAINED ON FIVE TRAINING DEVICES OF PROGRESSIVELY LOWERED FIDELITY

N	Group I Actual Equipment			Group II Flight Simulator			Group III Mock-Up			Group IV Full-Size Panel			Group V Illustration		
	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
1	7	26	3	8	22	3	9	25	3	10	28	3	5	21	2
2	7	25	3	6	24	2	10	27	3	10	24	2	8	22	3
3	4	21	1	6	27	2	7	25	1	8	24	3	7	21	2
4	8	25	4	9	24	1	10	28	4	8	24	2	6	19	3
5	9	26	4	8	26	3	8	26	2	4	21	1	10	25	2
6	6	22	1	9	27	4	9	25	2	9	22	3	8	21	4
7	7	20	2	9	26	3	9	26	4	7	21	1	7	23	1
8	8	24	3	8	25	2	9	27	3	6	23	1	5	23	1
9	10	28	4	5	22	1	8	27	2	10	25	4	7	23	2
10	10	25	4	6	27	2	7	21	2	5	19	1	6	24	1
11	5	23	2	8	29	2	10	26	3	9	25	3	9	22	2
12	10	27	3	4	20	2	6	25	1	8	26	3	9	24	4
13	8	26	4	7	24	4	5	23	0	5	19	1	5	18	2
14	5	25	1	10	28	4	6	22	1	6	24	3	9	26	2
15	7	23	3	9	26	3	9	27	2	6	23	2	6	24	2
16	9	26	2	7	24	3	7	24	1	9	27	2	7	21	1
17	8	24	1	10	28	3	7	25	2	8	26	4	4	17	0
18	8	24	3	7	23	1	9	28	3	7	22	2	9	19	2
19	5	23	1	9	23	2	7	24	4	7	25	3	6	21	1
20	9	24	0	9	21	1	9	28	4	10	30	4	6	18	1
21	6	22	2	7	22	2	10	25	2	8	22	2	8	27	4
22	7	23	1	9	23	3	7	27	3	5	18	0	5	21	3
23	9	29	3	8	20	4	6	24	2	7	23	1	10	26	4
24	9	27	2	10	25	4	10	28	4	9	26	4	9	24	2
25	6	26	2	6	19	1	8	29	4	7	26	3	5	22	3
SX	187	614	59	194	605	62	202	642	62	188	593	58	175	552	54
SX^2	1469	15192	173	1598	14819	180	1691	16582	186	1488	14263	167	1314	12354	146
$\bar{X}$	7.44	24.56	2.36	7.76	24.20	2.48	8.08	25.68	2.48	7.52	23.72	2.32	7.00	22.08	2.16
s^2	2.93	4.68	1.41	3.87	7.41	1.09	2.45	4.00	1.34	3.09	8.21	1.35	3.71	6.91	1.23

Note: a - written test scores; b - performance test scores; c - analytical test scores.

CHAPTER IV

RESULTS OF THE STUDY AND ANALYSIS OF DATA

The results of the evaluation procedures in terms of test scores were subjected to an analysis of variance for the five groups under study. The scores for each of the three types of tests--written, performance, and analytical--were treated as separate parameters, since it was felt that the criterion variable (in the form of a training device of certain fidelity) might have a different effect on the learning behavior evinced by each type of test, as indeed corroborated by the subsequent statistical analysis. For the same reason, it was not deemed necessary to convert the raw test scores into standard scores, or to combine the three test scores of each student into one comprehensive total score.

Analysis of Variance

The treatment of data for the analysis of variance followed the procedure outlined by Lindquist.[1] The analysis of variance technique was selected as the statistical tool

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[1]E. F. Lindquist, Design and Analysis of Experiments in Psychology and Education (Boston: Houghton Mifflin Company, 1956), Chapter 3.

most appropriate to the design of the study, which was based on the examination of differences among five groups of subjects in terms of test scores. The method of analysis of variance is superior to the traditional method of comparing only pairs of data, not only because it is simpler in its mathematical computation, but because a much more accurate assessment of standard error can be made. Thus, the analysis of variance provides a statistic that is sufficiently robust to resist the effects of chance variations due to minor errors in experimental procedure.

The design of the study and the distribution of the resulting data satisfied the conditions underlying the application of the analysis of variance method, which are:

1. Homogeneity of the parent population from which the samples are drawn.

2. Randomness of sampling in the selection of subjects.

3. Homogeneity of variances of the criterion measures.

4. Normal distribution of criterion measures.

Thus, if the null hypothesis was expressed as "there is no significant difference among the test-score means," any significant deviation of the mean square ratio from the normal F-distribution could only be interpreted as a rejection of the null hypothesis.

As shown by the results of the computations on Tables 3 through 5, there was no significant difference among the five groups--corresponding to the five different training devices--with respect to test "a" and with respect to test "c"; however, there was a significant difference among the five groups with respect to test "b"--the routine performance test. Since all other factors entering the learning situation, such as instructional materials, amount of practice, and evaluation procedures were held constant, such a difference could have been due only to the differences in fidelity of the devices used for training.

Thus, it may be stated that when a training device is used in a learning situation in which the acquisition of ability to perform a procedural task is the primary goal, this ability is indeed affected by the fidelity of the device, although fidelity has no significant effects on the learning of theoretical principles or on the ability to analyze deviations from normal states arising during the task performance. Such a statement by itself does not, however, identify the specific states of fidelity and their relative effectiveness with respect to each other. An inspection of the test-score means for test "b"--shown in Table 2--merely indicates that Group III, using a training device consisting of a simple mock-up of the equipment, obtained the highest mean score, while Group V, using a device consisting only of a small illustration of the equipment, obtained the lowest mean score. Therefore, an additional computation had to be performed to test the significance of the differences in means for the individual pairs of treatments.

TABLE 3

ANALYSIS OF VARIANCE

TEST a

	GROUPS I	II	III	IV	V	Sum
N	25	25	25	25	25	125
SX	187	194	202	188	175	946
SX^2	1469.00	1598.00	1691.00	1488.00	1314.00	7560.00
$(SX)^2/N$	1398.76	1505.24	1632.16	1413.76	1225.00	7159.33
Sx^2	70.24	92.76	58.84	74.24	89.00	400.67

$SS_A = 7174.92 - 7159.33 = \underline{\underline{15.59}}$

$SS_W = \underline{\underline{385.08}}$

Total = 400.67

Source of Variation	df	SS	MS
Treatments (A)	4	15.59	3.90
Within Groups (W)	120	385.08	3.21
Total	124	400.67	

$$F = \frac{3.90}{3.21} = \underline{\underline{1.24}}$$

For 1 per cent level of significance, F = 3.47
Thus: there is no significant difference.

For 5 per cent level of significance, F = 2.44
Thus: there is no significant difference.

TABLE 4

ANALYSIS OF VARIANCE

TEST b

	GROUPS					
	I	II	III	IV	V	Sum
N	25	25	25	25	25	125
SX	614	605	642	593	552	3006
SX^2	15192.00	14819.00	16582.00	14263.00	12354.00	73210.00
$(SX)^2/N$	15079.84	14641.00	16486.56	14065.96	12188.16	72288.29
Sx^2	112.16	178.00	95.44	197.04	165.84	921.71

$SS_A = 72461.52 - 72288.29 = \underline{\underline{173.23}}$

$SS_W = \underline{\underline{748.48}}$

Total = 921.71

Source of Variation	df	SS	MS
Treatments (A)	4	173.23	43.31
Within Groups (W)	120	748.48	6.24
Total	124	921.71	

$$F = \frac{43.31}{6.24} = \underline{\underline{6.94}}$$

Since $F_{.01} = 3.47$, the overall null hypothesis is rejected at the 1 per cent level of significance.
Thus: there is a significant difference among the means.

TABLE 5

ANALYSIS OF VARIANCE

TEST c

	GROUPS					
	I	II	III	IV	V	Sum
N	25	25	25	25	25	125
SX	59	62	62	58	54	295
SX^2	173.00	180.00	186.00	167.00	146.00	852.00
$(SX)^2/N$	139.24	153.76	153.76	134.56	116.64	696.20
Sx^2	33.76	26.24	32.24	32.44	29.36	155.80

$SS_A = 697.96 - 696.20 = \underline{\underline{1.76}}$

$SS_W = \underline{\underline{154.04}}$

Total = 155.80

Source of Variation	df	SS	MS
Treatments (A)	4	1.76	0.44
Within Groups (W)	120	154.04	1.28
Total	124	155.80	

$$F = \frac{0.44}{1.28} = \underline{\underline{0.34}}$$

Since F is less than 1.0 there is no significant difference.

The critical differences corresponding to the levels of significance of 1 per cent and 5 per cent were computed by means of the formula cited by Lindquist:[2]

$$d = t \sqrt{\frac{2MS_w}{n}}$$

The results, as applied to the actual differences between the means, are shown in Table 6. From these it is evident that the superiority in performance of Groups I through IV over Group V was highly significant (at the 1 per cent level), as was the superiority of Group III over Group IV. What is somewhat surprising, however, is that Group III, which received training on the mock-up, also performed significantly (at the 5 per cent level) better than Group II, which had been trained in the fully functional flight simulator.

There were no significant differences in performance between Group I, which had received training on the actual aircraft equipment, and Groups II, III, and IV. Only when training-device fidelity was reduced to the very low level of Group V did training effectiveness suffer to a significant degree, when compared with the performance of Group I.

These findings suggested a relationship between the performance-score means of the five groups of a character other than linear. In order to ascertain the actual nature of this relationship, a trend-analysis study was performed.

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[2] *Ibid.*, pp. 90-96.

TABLE 6

ANALYSIS OF DIFFERENCES BETWEEN MEANS OF PERFORMANCE TEST SCORES (TEST b)

Group	Mean
I	24.56
II	24.20
III	25.64
IV	23.72
V	22.08

TABLE OF DIFFERENCES

	II	III	IV	V
I	0.36	1.08	0.84	2.48**
II		1.44*	0.48	2.12**
III			1.92**	3.56**
IV				1.64**

**) Significant on the 1 per cent level, based on critical difference d = 1.85

*) Significant on the 5 per cent level, based on critical difference d = 1.40

Trend Analysis

A trend analysis generally is performed in order to show the orderly relationship underlying a set of variables so as to allow the formulation of a principle, which may then serve as a basis for prediction of the value of dependent variables from any given value of independent variables.

In essence, the problem consists of fitting a curve, whose properties may be mathematically expressed, to a set of existing data. The main difficulty in this endeavor, except in the case where an existing law is being tested, is the selection of a suitable equation.[3]

In approaching this problem in the light of the present study, it was decided to follow the suggestions outlined by Spiegel[4] and to use the freehand method of curve fitting to existing data as a first step in the determination of a suitable equation. The task appeared simply as the plotting of coordinate points showing the relationship between training-device effectiveness, in terms of test-score means, to training-device fidelity, in terms of groups assigned to various devices. However, it immediately became evident that plotting of existing data would have to be based on the a priori assumption that the fidelity of the

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[3]George W. Snedecor, Statistical Methods Applied to Experiments in Agriculture and Biology (Ames, Iowa: The Iowa State University Press, 1956), p. 447.

[4]Murray R. Spiegel, Theory and Problems of Statistics (New York: Schaum Publishing Company, 1961), pp. 217,218.

five training devices, corresponding to the five groups of subjects, could be represented by equal values along the abscissa of the graph. Thus, while test-score means represented "real" values, the designation of equal intervals between Groups I, II, III, IV, and V represented "arbitrary" values. It should be pointed out, however, that the five training devices represented degrees of fidelity that were distinguished by definite and significant characteristics. While it is theoretically possible, of course, to design an infinite number of different training devices to fall within and beyond[5] the five categories used for this study, it is doubtful whether such a proliferation would produce a different type of equation to express the basic relationship between these devices, although the individual values of the equation might clearly be different. In this sense, the choice of five devices for the present study already represents the inclusion of one additional device on each end of the basic spectrum of fidelity, which can be roughly defined as: (1) control plus display, (2) control without display, and (3) neither control nor display.

Based on these assumptions, the values of the actual means (shown by Δ marks) were plotted against their respective groups, as shown in Figure 1. Two hypothetical curves

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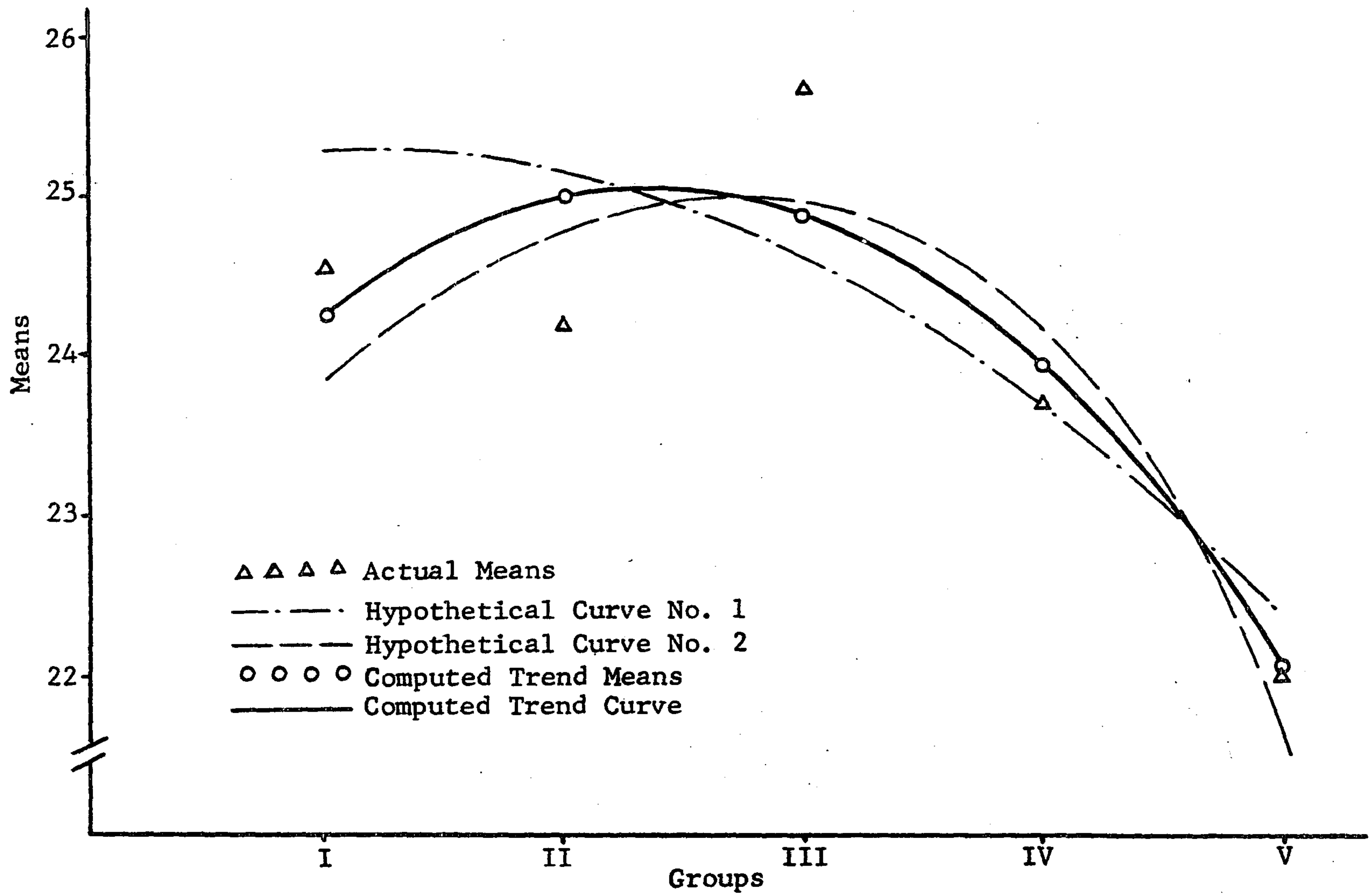
[5]That is, beyond the fidelity of the device of Group V; obviously, there cannot be any fidelity greater than that of the actual equipment used for Group I.

Figure 1. COMPARISON OF COMPUTED AND HYPOTHETICAL TREND CURVES



were then "hand-fitted" to the points (shown as Curve No. 1 and Curve No. 2) to indicate the shape of a possible equation.

Inspection of the hypothetical curves revealed the presence of a trend that appeared to be parabolic. Therefore, it was decided to use the method of least squares to construct a parabola approximating the existing data. To facilitate the computation, the following values were arbitrarily assigned to the distances along the abscissa:

Group I	-2
Group II	-1
Group III	0
Group IV	+1
Group V	+2

It should be noted that the decision to mark the five groups at equidistant points along the abscissa had already been made in accordance with the assumption stated earlier, so that the assignment of values with differences of "1" did not introduce an additional source of error.

The formula for the parabola was $Y = a_o + a_1X + a_2X^2$, with the constants a_o, a_1, and a_2 being determined by solving simultaneously the following equations:[6]

$$SY = a_oN + a_1SX + a_2X^2$$

$$SXY = a_oSX + a_1SX^2 + a_2SX^3$$

$$SX^2Y = a_oSX^2 + a_1SX^3 + a_2SX^4$$

The arrangement of the data for this computation is shown in Table 7.

[6]Spiegel, _op_. _cit_., pp. 221, 222.

TABLE 7

ARRANGEMENT OF DATA FOR COMPUTATION OF LEAST SQUARE PARABOLA

Group	X	Y	X^2	X^4	XY	X^2Y
I	-2	24.56	4	16	-49.12	98.24
II	-1	24.20	1	1	-24.20	24.20
III	0	25.68	0	0	0	0
IV	1	23.72	1	1	23.72	23.72
V	2	22.08	4	16	44.16	88.32
Sums	0	120.24	10	34	-5.44	234.48

As a result of the above computation, the values for the constants were found to be $a_o = 24.91$, $a_1 = -0.54$, and $a_2 = -0.43$, producing the equation $Y = 24.91 - 0.54X - 0.43X^2$. This allowed the determination of trend values for the means corresponding to the five groups, shown in a comparison with the actual means in Table 8.

TABLE 8

ACTUAL VALUES OF MEANS VERSUS COMPUTED TREND VALUES OF MEANS

Group	Actual Value for the Mean	Trend Value for the Mean
I	24.56	24.27
II	24.20	25.02
III	25.68	24.91
IV	23.72	23.94
V	22.08	22.11

Plotting of these computed trend means resulted in the computed trend curve shown in Figure 1. As may be seen, this curve approximates very closely the hypothetical curve No. 2, which had been drawn previously.

To test the goodness of fit of the computed trend curve to the actual data, two correlations were performed. The first of these determined the linear correlation coefficient between the actual values to be r = 0.83, which proved to be significant at the 5 per cent level.[7] The non-linear correlation coefficient, representing correlation between the actual values and the computed trend curve, was obtained as follows:

$$r^2 = \frac{\text{explained variation}}{\text{total variation}} = 0.88$$

$$r = \underline{\underline{0.94}}$$

This was found to be significant at the 1 per cent level, thus reinforcing the hypothesis of a parabolic curve as best expression of the relationship between the dependent and independent variables. The percentage of the total variation that remains unexplained by the assumption of parabolic relationship may be expressed by the ratio

$$\frac{\text{unexplained variation}}{\text{total variation}} = 1 - r^2$$

which equals 0.12, or 12 per cent.[8]

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[7] Using the table of correlation coefficients at the 5% and 1% levels of significance in Snedecor, *op. cit.*, p. 174.

[8] The correlation procedure followed the example cited by Spiegel, *op. cit.*, pp. 261-263.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this study was to investigate the relative effectiveness of five selected training devices with varying degrees of fidelity in the learning of a specific psychomotor task in which manipulative skill was not a primary consideration. The underlying assumption was that the effectiveness of a training device would not necessarily be determined by its fidelity, whether in appearance, function, or both; rather, the effectiveness of the device would depend in large measure on its contributions to the psychological milieu required for the effective learning of the particular task. Such a milieu was seen as an instructional system in which all elements of the learning situation--including the training device--were interacting with the learner in ways that facilitated the modification of learner behavior in the desired direction. With the emphasis on interaction, a training device was deemed to be effective to the extent of its ability to evoke interaction between the learner and the device.

In defining a training device, possession of controls and displays was considered a distinctive characteristic; thus, changes in fidelity--to be significant--would have to consist primarily of changes in control and display functions, and only secondarily of changes in appearance. The five training devices selected for the study represented a continuum of functional and appearance fidelity ranging from optimum, in which case the actual equipment was used for training, to minimum, in which case a small illustration of the equipment served as training device. Specifically, the five devices consisted of (1) the actual equipment with functional controls and displays, (2) a simulator device with functional controls and displays, (3) a mock-up with functional controls but without functional displays, (4) a full-size photograph of the equipment without either functional controls or displays, and (5) a small illustration of the equipment.

It was realized that a comparison of the five devices would yield valid conclusions only if all factors other than device fidelity could be controlled to remain constant. Therefore, a preliminary study was performed with the sole objective of developing and validating standardized procedures for selection of subjects, task analysis, instruction, practice, and evaluation of performance.

The task selected for the study was a procedural task of moderate difficulty, performed on the instrument panel of an aircraft. Activity involved in the task consisted essentially in the performance of certain control movements in a specified sequence, with initiation of each step depending on correct interpretation of results of the previous action as furnished by displays on the panel. In the case of the devices without functional displays, the student was forced to visualize the results of his real or simulated actions; in either case, feedback in the form of the correct response was supplied either by printed responses of a programed text or by spoken responses of a tape recording.

The programed text and tape recording were prepared with the objective of furnishing an instructional procedure that could be applied without variation to each one of five training situations in which the only variable was to be the degree of fidelity of a specific training device. Thus, the programed text and tape recording had to assume all functions normally performed by an instructor--including information input, provision of stimuli, and furnishing of cues, prompts, and responses--and, in addition, had to supply simulated feedback from displays in the case of training devices without such display capability. The development of these instructional materials was based on an analysis of task elements, including specific items of prerequisite knowledge. The same task analysis also provided the basis for the construction of test instruments, designed to allow unbiased evaluation of student performance.

The evaluation procedures were designed to determine the degree of learning in three areas of desired student behavior: (1) understanding of basic principles and system operation, (2) ability to perform the task under routine conditions, and (3) ability to detect and to analyze system malfunctions.

A written, multiple-choice test was used to evaluate knowledge and understanding of principles, while performance tests--rated with the aid of check sheets--served to determine the student's ability to perform the task under normal and abnormal conditions. All test instruments had been extensively examined and modified to insure high validity and reliability before being used in the final form.

Subjects were selected at random from the total student population that already was highly homogeneous in composition; additional selection criteria were imposed in the form of requirements for completion of a course in related subject matter with a final test score of 90 per cent or better, and no prior experience with the type of equipment on which the task was to be performed.

For the preliminary study, an experimental group of sixteen subjects, selected on the basis of the above criteria, received training in the task under study by means of the programed text and tape recording. A control group of sixteen subjects, selected in similar manner, received training in the identical task by means of conventional methods. Both groups used the same training device in the form of a high-fidelity flight simulator and received the same amount of time for instruction and practice. Results of the evaluation of both groups, in terms of test scores on the written test and performance scores on two performance tests on the actual aircraft equipment, showed no significant difference in knowledge and ability levels between the two groups.

On the basis of these findings, it was concluded that the programed text and tape recording were as effective as the traditional methods of instruction in teaching students the principles and practice of a procedural task with the aid of a training device. Therefore, it was decided that the self-teaching materials were suited to fulfill the requirement for constancy of instructional procedures during the principal study, in which the only variable was to consist of the specific training-device fidelity.

Five groups of twenty-five students were selected for the principal study, in accordance with the same selection criteria used during the preliminary study. Each group was assigned randomly to training on one of the five training devices, using the identical instructional materials and being allotted equal amounts of time for instruction and practice. Identical evaluation procedures were applied to each of the five groups, with all performance tests carried out on the actual equipment. The results of the evaluation procedures are presented below.

Results of the Study

The scores for each of the three tests--written, performance, and analytical--were treated as separate parameters so as to detect any differences in the effects of the training received on each of the behavior areas explored by the specific tests.

An analysis of variance of test scores showed that there was no significant difference among the five groups with respect to ability to answer questions on a multiple-choice test concerning underlying system principles, nor was there a significant difference among the five groups in their ability to detect and to analyze deviations from normal operation; however, there was a significant difference among the five groups in their ability to perform the task under routine conditions. When the significant difference was computed and applied to the differences between the test score means of the five groups, it was shown that the performance of the group which had received training on the mock-up was best, while performance of the group which had been trained with the aid of the small illustration was worst. Performance of the groups assigned to the remaining devices was at approximately the same level with respect to each other and subordinate to the mock-up group. These results suggested that a training device of relatively moderate fidelity was not only more effective than devices of still lower fidelity, but was also superior to devices of very high fidelity, at least when used in the context of this study with its emphasis on a procedural task.

A trend analysis was performed and confirmed the curvilinear relationship of the effectiveness of the five devices as expressed by the mean scores of the five groups that had been assigned to training on these devices. Specifically, when plotting the expressions of effectiveness (in terms of mean scores) along the ordinate of a graph, and plotting the expressions of device fidelity (in terms of groups) along the abscissa, the resulting coordinates could be closely fitted to a parabola, with its directrix parallel to the ordinate and its vertex close to the point along the abscissa that corresponded to the degree of fidelity presented by the mock-up. A test for goodness of fit confirmed the parabolic nature of the relationship between the means by showing that the values of the actual means correlated highly with corresponding values on the computed trend curve. The results of the study may be summarized as follows:

1. The relationship of effectiveness to functional and appearance fidelity was shown to be curvilinear and essentially parabolic in nature.

2. The device possessing control capability but not display capability was found to be superior to devices possessing both control and display capabilities, and superior to devices that possessed neither control nor display capabilities.

3. An increase in functional and appearance fidelity beyond a certain point resulted in lowered effectiveness.

4. Effectiveness also decreased markedly when both functional and appearance fidelity were reduced to a low value.

On the surface, such findings may not appear to differ from similar conclusions reached by other investigators,[1] who have shown that when fidelity of a device is increased beyond a certain value, no further increase in the amount of transfer of learning takes place; however, the present study suggests that such a plateau is reached much sooner than has been commonly assumed, and that--if fidelity is increased beyond this "optimum" value--effectiveness of the device may in fact decline. These results support the original assumption, namely that effectiveness of a training device may not necessarily be directly related to its degree of fidelity, but that other factors, such as the ability of the device to involve the learner in meaningful interaction, would enter into any final determination of device effectiveness.

Interpretation of Findings

It is typical of practical learning situations that they tend to elude compartmentalization into one or more existing learning theories. In the attempt to fit fragments of such theories to his problem, the investigator often

[1]For example by R. B. Miller, as cited by William C. Biehl, "Training Programs and Devices," in Psychological Principles in System Development ed. by Robert M. Gagné (New York: Holt, Reinhart & Winston, 1962), p. 374.

constructs his own model, which--albeit not resembling any existing theory--allows conceptualization of processes involved in the specific problem. It was thought that such a model, based on the concept of a man-machine system, might be used in the search for a tentative explanation of the underlying processes responsible for the findings of this study.

In a man-machine system, interaction between the operator and the machine requires an input function, in the form of a control movement by the operator, and an output function, in the form of a display response by the machine. If a training device is to duplicate such a system, it would have to possess all of these control and display capabilities. However, the purpose of a training device is not to be a facsimile of the real equipment, but a device that optimizes those aspects of reality that are most likely to produce high transfer of learning to the real situation. An examination of psychological principles involved in the learning of a task may show that these are quite different from the principles involved in the actual performance of the task, whether in routine operation or as part of further training in order to improve performance skill. Therefore, the roles of control and display functions in training devices must be considered in the light of their contribution to the learning situation, and not as essential features of a simulation process designed to achieve fidelity for its own sake.

Unfortunately, existing knowledge about the specific roles of controls and displays in the learning of a task is scant, leaving it up to the individual researcher to provide his own model. Such an attempt is represented below, in which each task element is seen essentially as a stimulus-response-reinforcement situation in which a cognitive process intervenes in the response pattern. (See Figure 2).

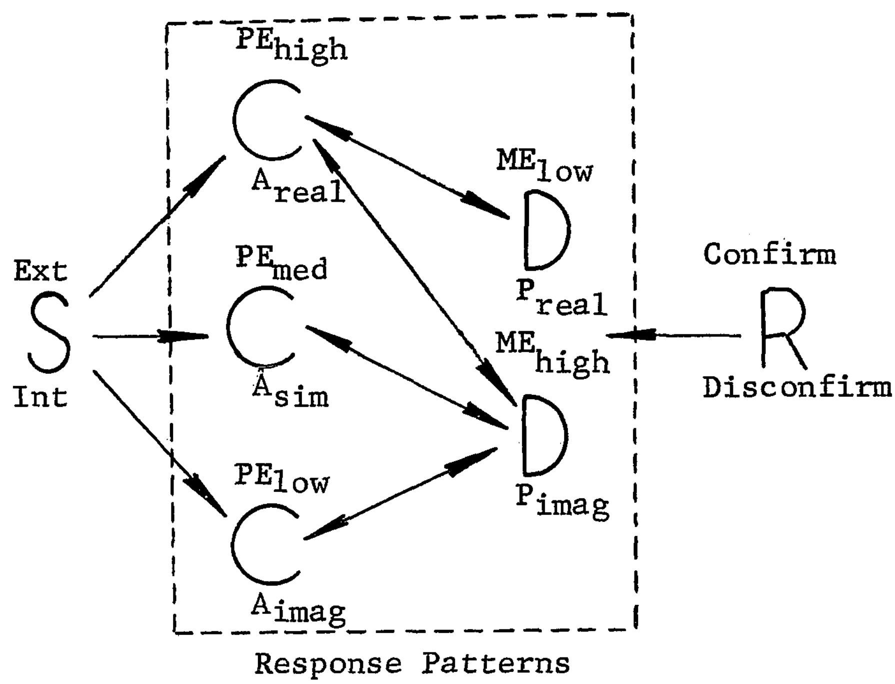


Fig. 2.--Model of task element

The stimulus (S) is depicted as being either external (in the form of a verbal command), or internal (in the form of a memory command). The response is shown as physical movement of a control (C), and mental assessment of a display (D), with reinforcement (R) in the form of verbal confirmation or disconfirmation as provided by the programed text or tape.

Variations in functional control fidelity are shown by three degrees of action requirements (A) for control movements that are either "real" (in the case of the aircraft, simulator, or mock-up), "simulated" (in the case of the full-size panel), or "imaginary" (in the case of the illustration). Corresponding physical effort (PE) required by each of three control types is shown as "high" for the real control movement, "medium" for the simulated control movement, and "low" for the imaginary control movement. Similarly, variations in display fidelity are shown by two degrees of perception requirements (P) for display indications that are either "real" (in the case of the aircraft or simulator), or "imaginary" (in the case of the mock-up, panel, or illustration). Mental effort (ME) required by each type of display is shown as "low" for the real display and "high" for the imaginary display. The various combinations of control and display functions are shown by vectors between the various "C" and "D" functions. As can be seen, only four of the six possible combinations were investigated by the devices used in this study, so that here again one may find implications for the need for further research.

During the introduction, the assumption was voiced that learner involvement through interaction with the training device would be a more important factor in determining the effectiveness of a training device than the fidelity of the device itself. This assumption gains considerable support through inspection of the model, which reveals that learner involvement--in terms of both physical and mental effort--would be highest for a device having real controls but imaginary displays; such a description fits that of the mock-up, which was indeed found to be the most effective of the five devices.

If one chooses to make a quantitative analysis of the parameters PE and ME, arbitrary values may be assigned to each of the functions of PE and ME, so that total learner effort demanded by each device may then be expressed as the sum of the respective pair of values, which in turn may be labeled "effort value." In similar manner, "reality values" may be computed on the basis of assignment of arbitrary values to the functions of parameters A and P. This makes it possible to arrange the five training devices in tabular form with their corresponding "effort values" and "reality values," as shown in Table 9, which is based on the following assignment of values:

$PE_{low} = 1$	$ME_{low} = 1$	$A_{imag} = 1$	$P_{imag} = 1$
$PE_{med} = 2$	$ME_{high} = 2$	$A_{sim} = 2$	$P_{real} = 2$
$PE_{high} = 3$		$A_{real} = 3$	

The tabulation below makes it possible to show the relationship of effort values versus reality values in graphic form.

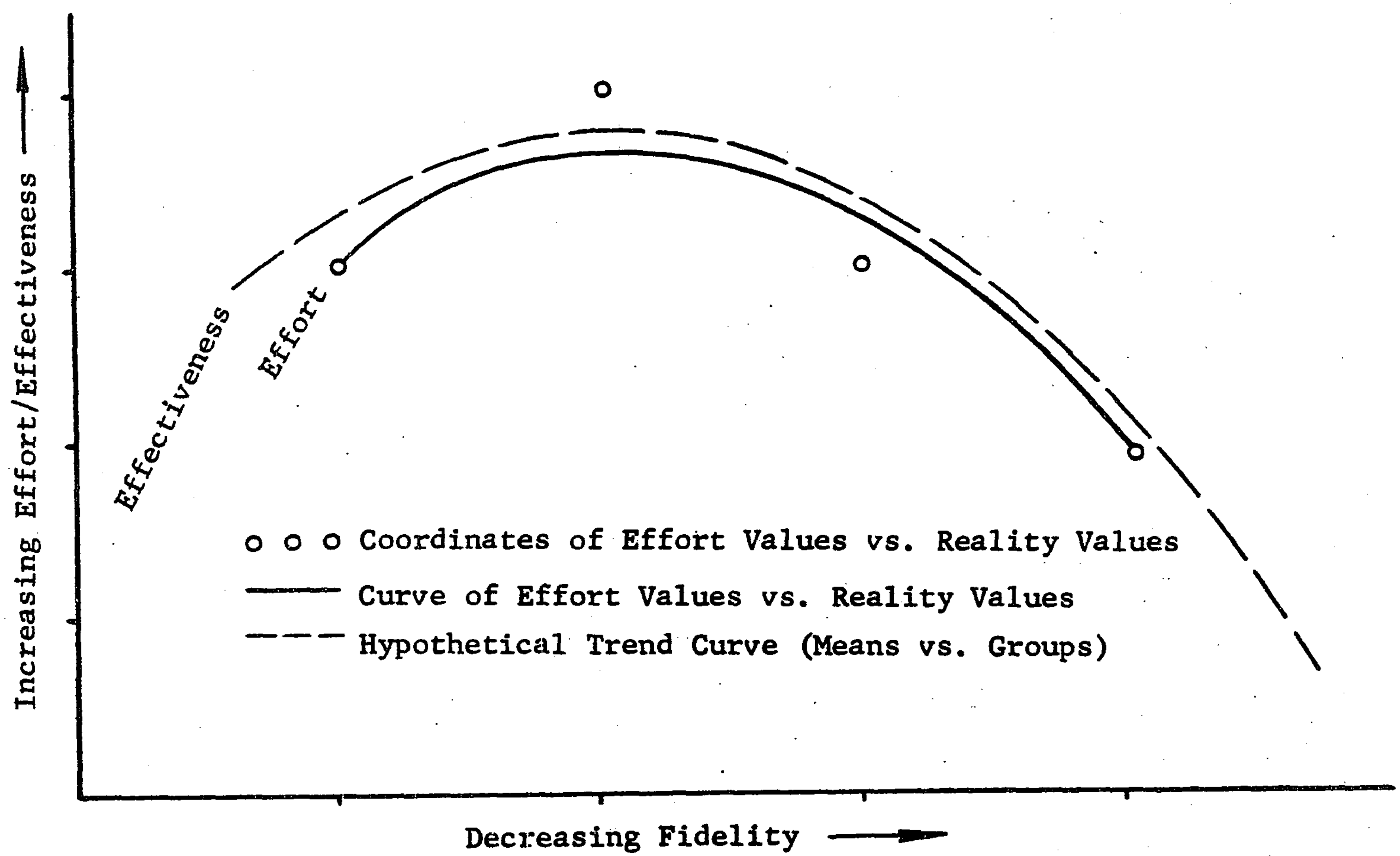
TABLE 9

TYPES OF TRAINING DEVICES WITH CORRESPONDING EFFORT VALUES AND REALITY VALUES

Type of Device	PE	ME	Effort Value	A	P	Reality Value
Aircraft	3	1	4	3	2	5
Simulator	3	1	4	3	2	5
Mock-Up	3	2	5	3	1	4
Panel	2	2	4	2	1	3
Picture	1	2	3	1	1	2

When plotting reality values--representing fidelity--along the abscissa and plotting effort values along the ordinate, the curve that may be fitted to the resulting coordinates closely resembles that obtained by comparing means and groups in Figure 1. Since the dimension "groups" in Figure 1 is an expression of fidelity and "means" represents a measure of device effectiveness, it is possible to consider both effort values and effectiveness as dependent variables of the same independent variable, namely device fidelity. The fact that both curves closely approximate each other thus reinforces the original assumption that device effectiveness is directly related to the degree of involvement of the learner's physical and mental efforts. The correlation between learner effort and device effectiveness is graphically shown in Figure 3, which depicts the curve obtained by plotting effort values versus reality values as contrasted with the hypothetical trend curve obtained earlier.

Figure 3. RELATIONSHIP OF LEARNER EFFORT TO DEVICE EFFECTIVENESS



For both curves, the abscissa may be labeled "fidelity," with decreasing values toward the right, in keeping with the preceding practice. The ordinate may then be used to portray values of effort or effectiveness, with increasing values toward the top. The curves may be labeled directly with the appropriate dependent variable, either "effort" or "effectiveness."

In summary, this interpretation of the findings represents an attempt to support the underlying assumption of this study, namely that training-device effectiveness is dependent on the ability of the device to involve the learner, rather than on aspects of fidelity alone. A model was constructed to allow conceptualization of the learning process, which then led to a quantification of such concepts and the demonstration of a significant relationship between learner effort--elicited by the design of the device--and device effectiveness. Thus, there is strong evidence to prove the original assumption correct.

Recommendations

For the designer and user of training devices, the findings of this study and their tentative explanation suggest that the effectiveness of a training device depends on its ability to involve the learner in physical and mental interaction, rather than on mere resemblance to the real equipment, either in function or appearance. Thus, a training device should be designed primarily from a standpoint of psychological rather than technical considerations, except to the extent that such psychological considerations must depend on some physical properties of the device. In essence, the primary aim in the development of training devices should be the maximizing of their "positive valences"--if one may borrow from Lewin's terminology--by any appropriate means, which may well entail the deliberate reduction of some aspects of fidelity if, in doing so, the valence of the device toward the learner is enhanced. Since a training device represents only one element of a learning situation, it is equally important to devote attention to the development of an instructional program that will make optimum use of the inherent qualities of the device; as has been shown, programing techniques are well suited to this task.

For the researcher, the tentative explanations of the present findings should point the way toward further explorations, in scope as well as in depth. For example, within the framework of the present study, the effects of combinations of simulated or imaginary control functions and real display functions--as suggested by the model in Figure 2--require to be investigated. Furthermore, the effects of different degrees of appearance fidelity should be isolated through separate studies. Replications of the present study should be made under conditions that would allow control of some of the extraneous variables, such as physical environment; moreover, the study needs to be repeated with a variety of training devices, tasks, populations, and methods of instruction. A multi-dimensional experimental design may be found appropriate to such an approach.

A second major area of investigation concerns the relationship of training-device fidelity to effectiveness in the improvement of a skill through continued practice. As has been stated before, the psychological factors involved in the learning of a task may differ fundamentally from those involved in practice activities; for example, while the presence of functional displays was found to be detrimental to learning in the situation cited by this study, it may well be that functional displays are essential in practice activities where immediate effects of control movements must be perceived by the learner in order to minimize delays in the task sequence.

A third area of investigation comprises the search for psychological principles underlying task performance itself, specifically in the ways in which such performance differs when carried out on a training device as contrasted with performance on the actual equipment. Obviously, such investigations are by their very nature relegated to the laboratory; there is, however, a pressing need for findings that have ready applicability to the practical situation in the field. What, for example, are the essential features of real equipment that must be considered in training device design? How can devices be designed to furnish rewards for correct responses, or--if this is not possible--how can such reinforcement be provided by other, external sources? There is little information of this type available to guide the practician.

As has been shown by the review of the literature, research findings in the area of training-device fidelity are marked by their contradictory character. It may be possible that such contradictions are due not to faulty experimental design, but to the present inability to state some fundamental laws governing design of training devices with respect to fidelity.

While it is by no means asserted that the finding of a parabolic relationship between fidelity and effectiveness should be considered a valid basis for such a law (which would require much more proof than could be offered here), such a law would resolve the contradictions of the various findings by pointing out that it is indeed possible to arrive at such seemingly opposing conclusions when devices are selected for comparison from a relatively narrow band of the parabolic spectrum of fidelity. Thus, two training devices may show a relationship of fidelity to effectiveness that is positive, negative, or indifferent, according to their relative position along this parabolic spectrum.

It is hoped that future researchers will consider this at least a theoretical possibility, and that the findings of this study, however incomplete they may be in themselves, will lead them to new insights that may eventually provide a more comprehensive view of this subject.

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APPENDIX I

PROGRAMED TEXT: ENVIRONMENTAL SYSTEM OPERATION

Instructions to the Student. This text has been prepared in order to facilitate the learning of an important preflight check procedure. It is to be used by the flight-engineer student in conjunction with a training device selected by his instructor. A tape recording will be furnished to provide additional practice on the training device. By following the steps outlined in the text and complying with the instructions on the tape, the student should be able to teach himself the entire task without the aid of his instructor.

How to Use this Text:

1. If you are using one of the non-functional mock-ups as a training device, place the transparent number sheet over the environmental control panel and fasten it securely. If you are using only the illustration furnished with the text, a transparent number sheet is already taped over the illustration. After you learn to identify all controls and indicators correctly, you may want to remove the transparent number sheet. The illustration may also be used when learning to identify the components on the control panel in the flight simulator or in the aircraft, in case one of these methods of training is chosen.

2. Take your seat in front of the training device as you would at the flight engineer's station of the actual aircraft. Place the text booklet on the table in front of you. If you are using only the illustration, place it next to the text booklet.

3. Open the booklet to Page 1. Cover the right-hand side of the page with the paper mask. Read the statement on the left side of the page, then proceed to answer the incomplete sentences. When you reach the separation line below each "frame," slide the mask down to that line and read the correct response on the right side of the page. Follow the instructions pertaining to manipulation of controls on the training device, and--if you are using one of the non-functional devices--try to visualize the effects as they would occur on the actual equipment.

4. When you have completed the entire programed text, listen to the tape-recorded instructional sequences. The first of these will give detailed instructions on how to perform each step of the check procedure; the second sequence provides cues and responses at a normal rate of speed.

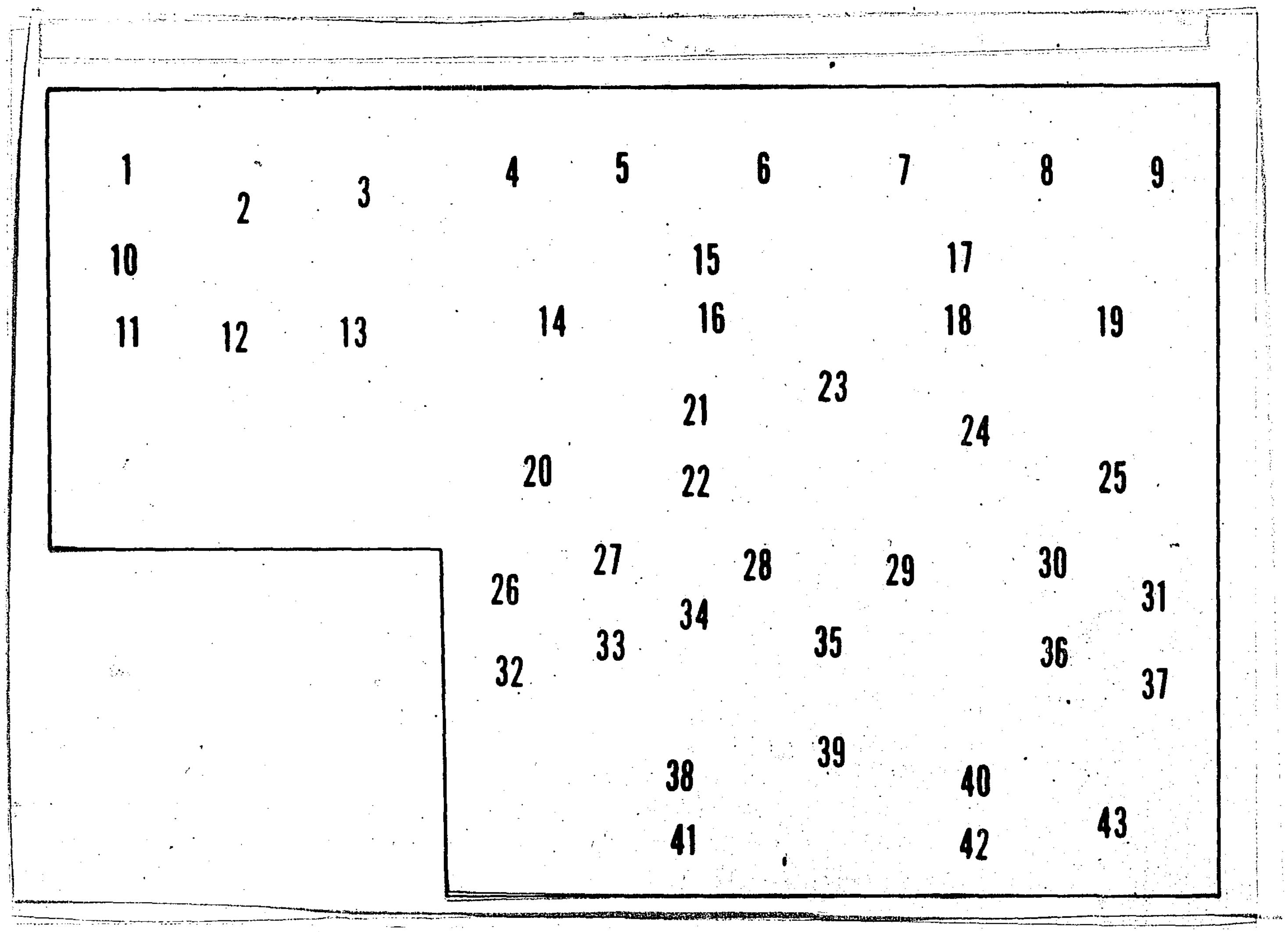

Figure A-1.--Environmental Control Panel

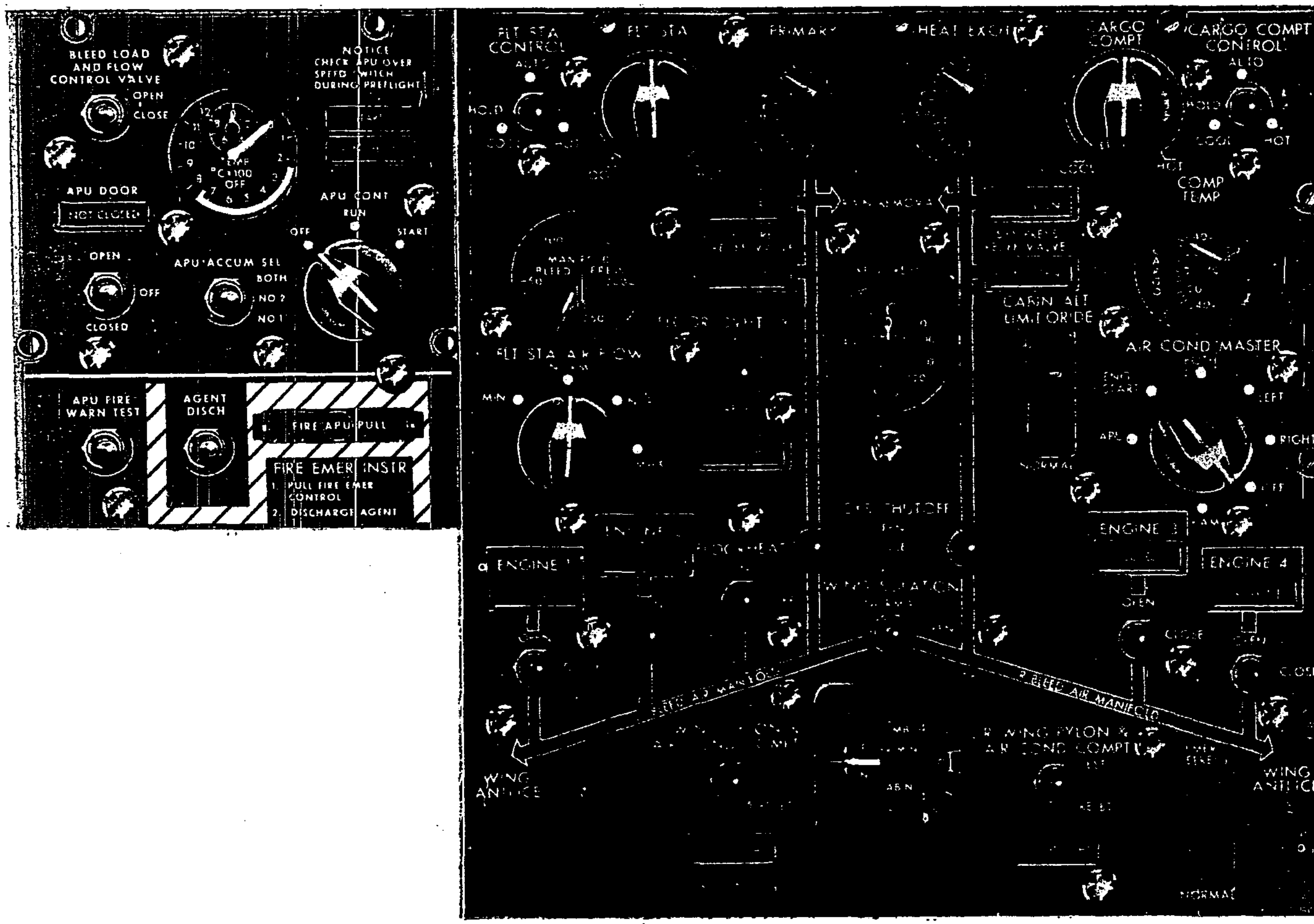

Figure A-1.--Environmental Control Panel

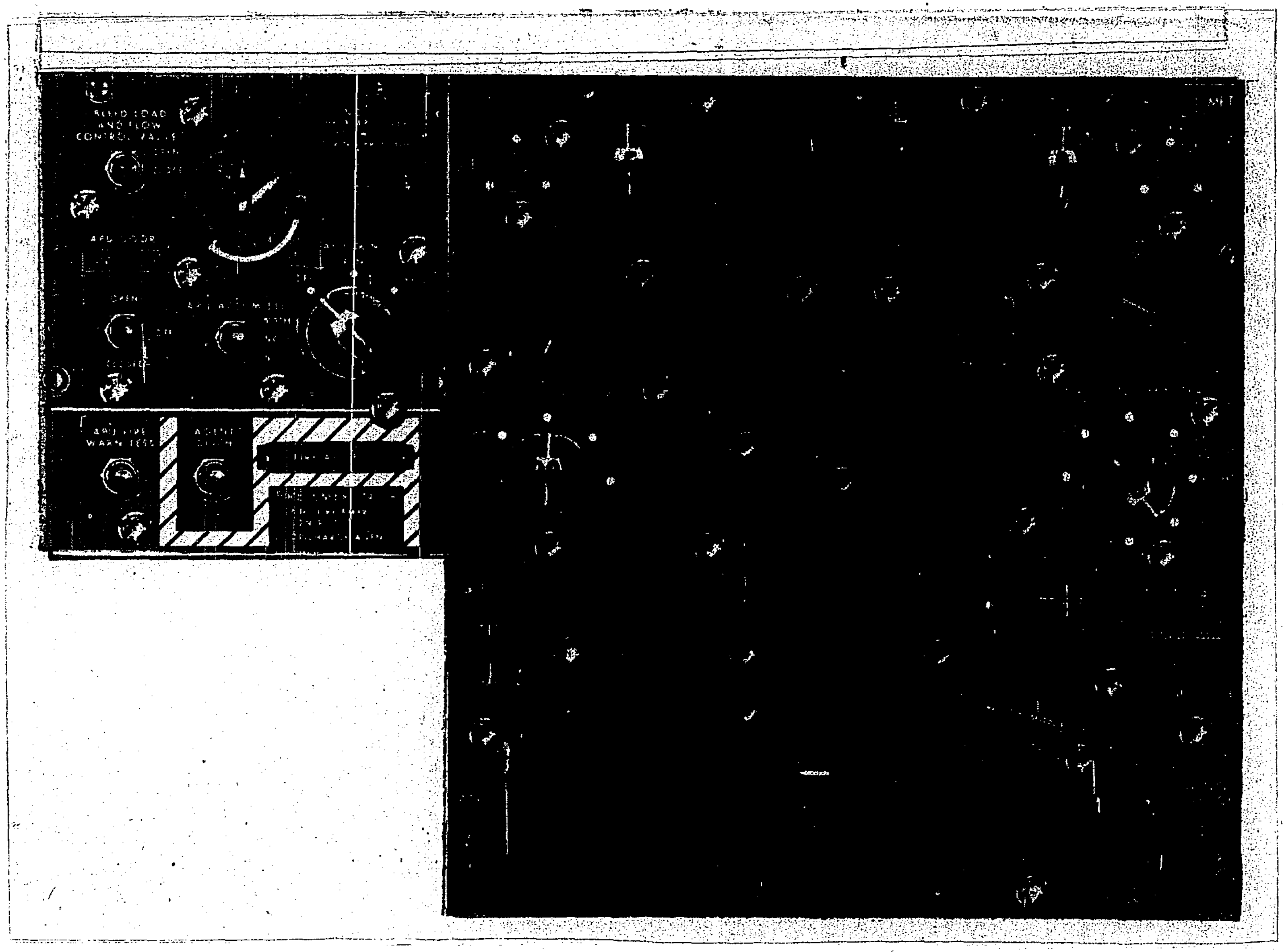

Figure A-1.--Environmental Control Panel

1. The environmental system check forms a part of the Electrical Power-On phase of your preflight inspection.

When this check is performed properly, it will insure the aircrew of proper functioning of the ____________ system. — environmental

---

2. The environmental system of the C-141A serves primarily to furnish bleed air for air conditioning and pressurization. When required, this bleed air may also be furnished to the wing anti-ice system and to the rain removal system.

Air conditioning and pressurization requirements are met through the use of _____ air by the ____________ system. — bleed, environmental

---

3. The bleed air is normally extracted from a gas turbine unit during ground operation, or from the 16th-stage compressor bleed of each of the four fan-jet engines.

During ground operation, bleed air may be furnished by a ___ _______ ____. — gas turbine unit

---

4. Bleed air may also be furnished by one or more of the four ___-___ _______. — fan-jet engines

---

TURN TO NEXT PAGE

5. The gas turbine unit that furnishes bleed air during ground operation is generally referred to as the "APU" or "Auxiliary Power Unit" of the aircraft. If necessary, an external air source may be used.

Throughout the entire check list procedures, the gas turbine unit of the C-141A will be called the ___. APU

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6. Look at the panel in front of you. You will find the operating controls for the APU in the left upper corner. The operating components are numbered 1, 2, 3, 10, 11, 12, 13.

---

7. The items numbered 1, 2, 3, 10, 11, 12, and 13 constitute the _________ controls for the ___. operating APU

---

8. No. 1 is a two-position toggle switch labeled BLEED LOAD AND FLOW CONTROL VALVE.

The control for the BLEED LOAD AND FLOW CONTROL VALVE is a two-position ______ switch. toggle

---

9. The UP position of this switch will OPEN the BLEED LOAD AND FLOW CONTROL______. VALVE

---

10. The BLEED LOAD AND FLOW _______ ______ will OPEN when the switch is moved to the _________ position. CONTROL VALVE UP (OPEN)

---

11. Place your hand on the switch. Move the switch (or simulate the movement) to OPEN the BLEED LOAD AND FLOW CONTROL VALVE. Check the correct response.

You should have moved the switch to the UP position.

---

12. Move the switch (or simulate the movement) to CLOSE the BLEED LOAD AND FLOW CONTROL VALVE. Check the correct response.

You should have moved the switch to the DOWN position.

---

13. From here on we shall refer to this valve simply as the LOAD CONTROL VALVE.

When the APU is operating, opening of the LOAD CONTROL VALVE will admit APU bleed air to the floor heat duct.

The floor heat ____ receives bleed air from the APU whenever the ____ ____ ____ is opened and the APU is operating.

duct

LOAD CONTROL VALVE

---

14. For a schematic of the floor heat duct in relation to the main bleed manifold, see Figure A-2 below.

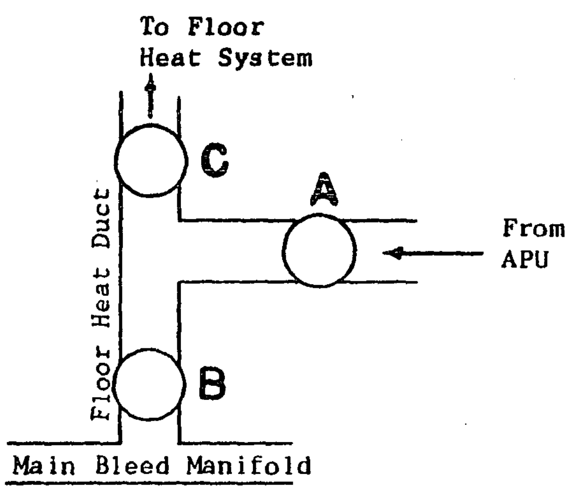

Fig. A-2.--Floor heat duct

As you can see, the APU LOAD CONTROL VALVE (A) furnishes air to a section of the floor heat duct between two valves (B) and (C).

Valve (B)--when in the OPEN position--admits APU air to the main bleed manifold. It is called the FLOOR HEAT SHUT-OFF VALVE.

---

15. In order to furnish air from the APU to the main bleed manifold, valves ___ and ___ must be OPEN. (A) (B)

---

16. This means that the ___ ____ _______ VALVE and the __________ _______ VALVE must be OPEN. APU LOAD CONTROL FLOOR HEAT SHUTOFF

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17. Valve (C)--when in the OPEN position--admits air to the floor heat system. It is called the FLOOR HEAT MODULATING VALVE.

The only time this FLOOR HEAT MODULATING VALVE is opened is when it is desired to furnish bleed air to the _____ ____ system. floor heat

---

18. The FLOOR HEAT MODULATING and FLOOR HEAT SHUTOFF VALVES may be OPENED simultaneously by positioning the floor heat switch (shown at No. 34 on the panel) to the ON position. This is done by moving the switch UP. Normally, both valves will close when the switch is moved to the OFF position.

---

19. Perform the movement (or simulate the movement) required to turn the floor heat system ON, then OFF.

You should have moved the switch to the UP position, then to the DOWN position.

---

20. The FLOOR HEAT SHUTOFF VALVE, shown as (B) in the above illustration, can also be opened by positioning the AIR CONDITIONING MASTER switch (No. 25 on the panel, labeled AIR COND MASTER) to either the APU or ENG START position.

---

21. Moving the AIR COND MASTER switch to the ___ or the ___ _____ position will open the ______ ____ _______ VALVE.

APU
ENG START
FLOOR HEAT SHUTOFF

---

22. When the AIR COND MASTER switch is moved to ENG START, the FLOOR HEAT MODULATING VALVE remains closed, regardless of the position of the floor heat switch. This will allow all the bleed air furnished by the APU to go to the ____ ____ _____.

main bleed manifold

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23. To repeat: the FLOOR HEAT SHUTOFF VALVE may be opened independently from the FLOOR HEAT MODULATING VALVE by positioning the ___ ____ ______ switch to the ___ or to the ___ _____ position.

AIR COND MASTER
APU
ENG START

---

24. The difference between these two positions of the AIR COND MASTER switch is that the APU position will automatically close the four ENGINE BLEED VALVES, through which air is

normally furnished to the main bleed manifold from the fan-jet engines.

Moving the AIR COND MASTER switch to the APU position will close the four _____ _____ VALVES. ENGINE BLEED

---

25. The ENGINE BLEED VALVES are normally controlled by toggle switches, shown on the panel at Nos. 32, 33, 36, and 37. To OPEN any of the four ENGINE BLEED VALVES, the respective toggle switch is moved UP. To CLOSE the BLEED VALVE, its switch is moved DOWN.

---

26. Indicator lights, shown at Nos. 26, 27, 30, and 31, are located above each of the four engine bleed valve switches and will light up the word CLOSED whenever the respective valve is closed, either by its switch or by other means.

Thus, although the engine bleed valve switches are in the OPEN position, when the AIR COND MASTER switch is moved to the APU position the four engine bleed valve indicator lights should indicate that the valves have ______. CLOSED

---

27. The main bleed manifold is separated between right and left wing by a WING ISOLATION VALVE, which is normally CLOSED.

The WING ISOLATION VALVE is normally______. CLOSED

---

28. A toggle switch is used to control this WING ISOLATION VALVE, shown on the panel at No. 35. The two positions of this switch are labeled NORMAL (UP) and OPEN (DOWN).

When the WING ISOLATION VALVE switch is moved UP, it will be in the ______ position, which means that the valve will be ______.

NORMAL

CLOSED

---

29. Perform the movement (or simulate the movement) required to move the switch to the OPEN position, then return it to NORMAL.

You should have moved the switch DOWN, then UP.

---

30. The WING ISOLATION VALVE will open automatically whenever the AIR COND MASTER switch is moved to the APU or ENG START position, regardless of the position of the wing isolation switch.

Thus, if bleed air is available from any one engine, or from the APU, positioning the AIR COND MASTER switch to APU or ENG START will pressurize both sides of the ____ ____ ____.

main bleed manifold.

---

31. The WING ISOLATION VALVE and the ENGINE BLEED VALVES on either the right or the left side of the main bleed air manifold will close automatically whenever an overheat condition occurs in the respective bleed manifold, or in one of the engine pylons (down to the bleed valve) or in the air conditioning compartment on that side.

Thus, an overheat condition in the right side of the environmental system will close the ____ ________ valve and both ____ _____ valves on the right side of the aircraft.

WING ISOLATION
ENGINE BLEED

---

32. Should an overheat condition occur, an indicator light marked LEFT OVHT (No. 41) or RIGHT OVHT (No. 42) will come ON, depending on the affected side.

In addition to this light, an indicator light on the annunciator panel labeled L BLEED DUCT OVHT or R BLEED DUCT OVHT will also come ON, together with the MASTER CAUTION lights.

Thus, if the LEFT OVHT light on the environmental system panel comes ON, it would indicate to the engineer that an overheat has occurred either in the ____ bleed manifold, in the left ___ ___________ compartment, or in either of the ______ for engines No. _ or No. _.

left
air conditioning
pylons 1 2

---

33. Two switches, labeled L WING and R WING PYLON & AIR COND COMPT respectively, (No. 38 and No. 40), serve to test the left and right wing overheat systems and to reset the systems to normal operation after a real or "test" overheat condition.

The switches are moved UP to TEST the respective system, and DOWN to RESET the system. Only momentary actuation to either position is required to initiate the proper action.

Perform the movement (or simulate the movement) required to TEST the left wing overheat system.

You should have moved switch No. 38 to the UP position. Notice that this switch is spring-loaded to the center position when released.

---

34. As a result of moving the switch to the TEST position, you should now be able to visualize the following reactions:

The LEFT_____ light on the annunciator panel comes ON, No. 1 and No. 2 engine bleed valve ______ lights come ON, the _ _____ ____ ____ light on the annunciator panel comes ON, as well as both ______ _______ lights.

OVHT

CLOSED
L BLEED DUCT OVHT

MASTER CAUTION

---

35. An exception to this sequence takes place when the starter button for an engine is IN. If an overheat occurs during this condition, the WING ISOLATION VALVE and the respective ENGINE BLEED VALVES are held open as long as the starter button is IN.

Thus, air will be furnished to any selected engine starter even though an ________ condition has occurred in the bleed air system.

overheat

Perform the movement (or simulate the movement) required to reset the system and visualize the results.

All of the lights mentioned in Item 34. should go out and all affected valves return to their original position.

---

36. A similar overheat protection is provided for the floor heat system. If an overheat is detected in that system, an OVERHEAT indicator light (No. 22) will come ON and the

FLOOR HEAT SHUTOFF and MODULATING VALVES will close automatically.

A floor heat overheat condition automatically closes the _____ ____ _______ VALVE and the _____ ____ __________ VALVE and causes an ________ indication on the environmental system panel.

FLOOR HEAT SHUTOFF
FLOOR HEAT MODULATING
OVERHEAT

---

37. A FLOOR OVHT SYS switch allows testing of that system. The toggle switch (No. 21) has two positions, TEST and RESET, with the former being UP. The switch is spring-loaded to the center position. Only momentary actuation is needed to initiate either action.

Move the switch (or simulate its movement) to the TEST position and visualize the results.

You should have moved the switch UP, causing the OVERHEAT light to come ON and the FLOOR HEAT SHUTOFF and MODULATING VALVES to close.

---

38. Move the FLOOR OVHT SYS switch (or simulate its movement) to the RESET position and visualize the result.

The OVERHEAT light should go OUT and the valves should return to their selected position.

---

39. We shall now proceed to the remaining system controls on the environmental panel.

No. 28 and No. 29 are called SYSTEM SHUTOFF switches.

The function of these switches is to open or close the pressure regulator and shutoff valves that furnish air to the primary heat exchangers, and to allow testing of the pressure relief valves.

These switches are three-position toggle switches. The top position is labeled OPEN, the center position is labeled CLOSE, while the bottom position is labeled TEST. Except for the TEST position, which is spring-loaded to center, the switch will remain in the selected position.

To repeat, the SYSTEM SHUTOFF switches are _____-position switches that serve to actuate the ______ ________ ___ ______ valves and test the ________ ______ valves.

three

pressure regulator and shutoff

pressure relief

---

40. The SYSTEM SHUTOFF switches are the primary means for opening and closing the valves that control the airflow to the left and right air conditioning packs.

When the system shutoff valves are closed, no airflow will be available to the left and right ___ _____________ ______.

air conditioning packs

---

41. The supply lines to the air conditioning packs are shown in schematic representation on your environmental control panel as the two vertical lines extending upwards from the system shutoff switches to the two primary heat exchanger temperature gauges shown at Nos. 6 & 7.

Point at the primary heat exchanger temperature gauges.

You should have pointed at Items No. 6 & 7.

---

42. The principal components of each air conditioning pack are the primary heat exchanger, secondary heat exchanger, refrigeration turbine, and associated valves and temperature controls.

The relationship of the components supplying air to the system is shown schematically in Figure A-3 below.

As you can see, air is delivered to the left and right air conditioning packs from the left and right bleed air manifolds.

Thus, with the SEPARATION VALVE in the normally CLOSED position, the left bleed air manifold will furnish air to the ______________ and the right bleed air manifold will furnish air to the _____ ___ ________ _____.

left air conditioning pack

right air conditioning pack

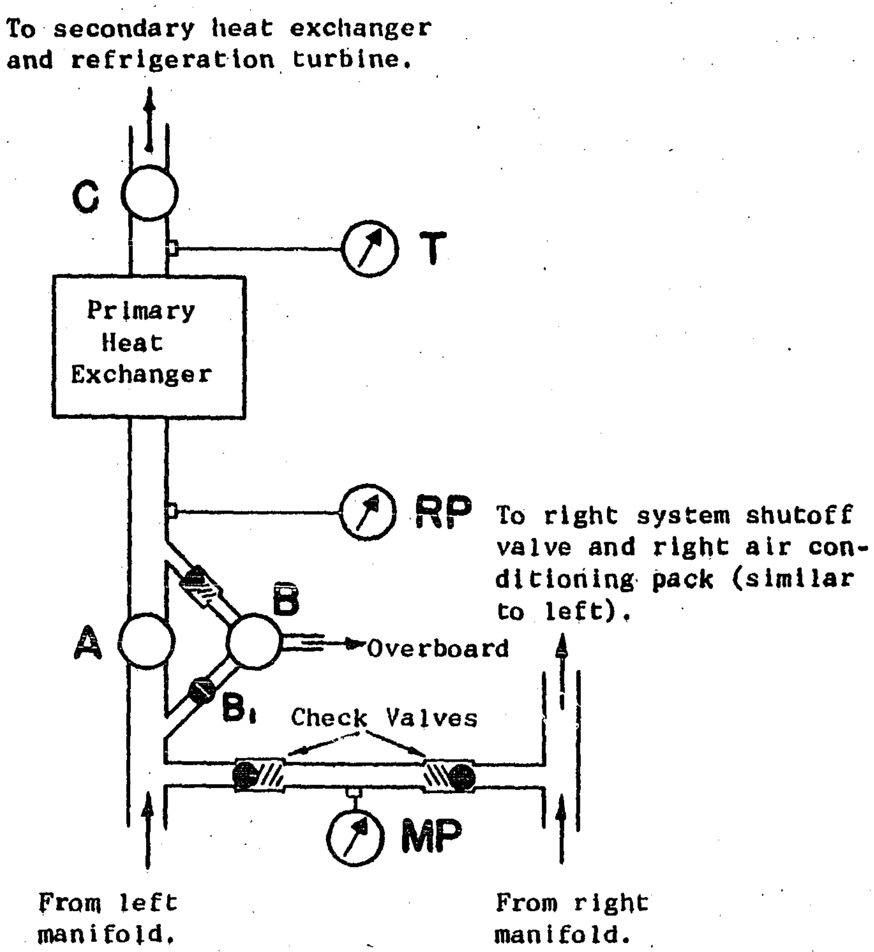

Figure A-3.--Schematic of air supply system.

43. A manifold pressure gauge is connected through check valves to both sides of the main bleed air manifold. The gauge is shown on your panel at No. 14.

Point at the manifold pressure gauge on the panel.

You should have pointed at the gauge shown at No. 14.

---

44. Refer to the schematic of this system (Figure A-3):

As you can see, the manifold pressure gauge, represented by MP, will always read the pressure from either the left or right manifold, whichever is higher.

Thus, if the left manifold pressure is 60 psi and the right manifold pressure is 50 psi, the manifold pressure gauge will read __ psi.

60

---

45. Notice that the manifold pressure gauge will read the pressure in the main bleed manifold, not in the air conditioning ducting downstream of the system shutoff valves.

As stated previously, the system shutoff valves incorporate a regulating feature; this regulates pressure downstream of the system shutoff valves (shown in the illustration as "A") to approximately 70 psi.

Thus, even though the manifold pressure gauge may indicate a pressure of 100 psi, the pressure downstream of the system shutoff valves should not exceed __ psi.

70

---

46. A regulated pressure gauge, shown in the illustration as "RP" and on the panel at No. 23, is a dual-needle instrument that independently registers pressure in the left and right air conditioning ducting, downstream of the pressure regulating and shutoff valves.

Thus, the pressure registered on this gauge for either left or right air conditioning system should not exceed __ psi. 70

---

47. Point at the regulated pressure gauge on your panel.

You should have pointed at Item No. 23.

---

48. Should either system shutoff and pressure regulating valve fail, a pressure relief valve, shown in the illustration as "B," will relieve the air pressure when it reaches 90 to 115 psi.

In case of failure of a system shutoff and regulating valve, pressure downstream of that valve will be relieved by a ________ ________ ______ when pressure reaches __ to ___ psi.

pressure relief valve
90 115

---

49. For example, if the pressure in the main bleed manifold is 150 psi and the left system shutoff valve fails to regulate the air furnished to the left air conditioning system, the regulated pressure gauge (No. 23) will most likely indicate a system pressure for the left system of approximately __ to ___ psi.

90
115

---

50. When either or both of the two relief valves are open, indicator lights reading LEFT OPEN or RIGHT OPEN respectively will come on. These lights are shown on the panel at Nos. 16 & 18.

Point at the two system pressure relief valve indicator lights on the panel.

You should have pointed at Items 16 and 18.

---

51. In order to facilitate testing of proper relief-valve functioning, the TEST position of the SYSTEM SHUTOFF switches will open a small auxiliary valve shown in Figure A-3 as "B_1"; since the system shutoff valve "A" is simultaneously closed, full maniforld bleed-air pressure is available to the relief valve and will open that valve when pressure reaches 90 - 115 psi.

To test proper functioning of the relief valve, the respective SYSTEM SHUTOFF switch must be positioned to ___. This opens an auxiliary valve to allow manifold bleed air to go directly to the respective ______ ______. At the same time, the respective system shutoff valve will be ______.

TEST

relief valve

closed

---

52. When testing the functioning of the left relief valve in this manner, you can expect the ____ ____ light to come ON, provided that the main bleed ________ ________ exceeds ___ to ___ psi. Although manifold pressure may be less than this value, the LEFT OPEN light may come on momentarily during the test due to a pressure surge in the system when the system shutoff valve is closed.

LEFT OPEN

manifold pressure 90 115

---

53. Refer to Figure A-3.

Notice that the system shutoff valve "A" admits air only to the primary heat exchanger. In order to continue the air flow to the secondary heat exchanger, to the refrigeration turbine, and to the aircraft distribution ducting, valve "C" must also be open. This valve is called a FLOW CONTROL AND SHUTOFF VALVE (or, simply, a FLOW CONTROL VALVE) and is normally controlled by the air conditioning master switch.

Thus, in order for the manifold bleed air to reach the air conditioning ducts within the aircraft, both the ______ ______ valve and the ____ ______ valve must be open for the appropriate system.

system shutoff
FLOW CONTROL

---

54. Normally, the right air conditioning pack supplies air to the cabin, while the left pack supplies one-third of its air to the flight deck and two-thirds to the cabin.

Thus, during normal operation, the right pack will not supply air to the ______ ____.

flight deck

---

55. The FLIGHT STATION AIRFLOW control, shown on the panel at No. 20, serves to vary the proportion of air directed to the flight deck.

During the environmental system check, this switch should be in the NORMAL position.

Move the switch (or simulate the movement) to the NORMAL positon.

You should have positioned the switch shown at No. 20 so that it points STRAIGHT UP.

---

56. We shall now return to the functions of the AIR COND MASTER switch.

We have already learned that with the AIR COND MASTER switch in the APU position, the engine bleed valves will be ______, the wing isolation valve will be ____, and the floor heat shutoff valve will be ____.

OPEN

CLOSED

OPEN

---

57. We may now expand this statement by adding that with the AIR COND MASTER switch in the APU position, both FLOW CONTROL valves will also be OPEN.

At the same time, the system shutoff valves are free to assume any selected position.

Thus, when the AIR COND MASTER switch is moved to the APU position and the SYSTEM SHUTOFF switches are in the OPEN position, air from the APU is free to flow to the ___ ________ ____.

air conditioning packs

---

58. The only times the position of the system shutoff valves is affected by the AIR COND MASTER switch is when the latter is moved to the OFF position; at that time, the system shutoff valves are CLOSED regardless of the position of their individual switches. This prevents air from escaping to the air conditioning packs during an engine start, if the SYSTEM SHUTOFF switches have been left in the OPEN position.

Thus, when the AIR COND MASTER switch is in the ENG START position, bleed air will not be available to the ___ ________ ____.

air conditioning packs

---

59. The BOTH, LEFT, and RIGHT positions of the AIR COND MASTER switch serves the primary function of selecting proper positioning of the FLOW CONTROL valves.

Although we will not be concerned with these positions during the environmental system check, we should understand that both FLOW CONTROL valves will be OPEN whenever the AIR COND MASTER switch is moved to ____.

BOTH

---

60. When the AIR COND MASTER switch is moved to LEFT, the left FLOW CONTROL valve will ____, while the right FLOW CONTROL valve will ____.

OPEN CLOSE

---

61. Even though you have selected one of the positions of the AIR COND MASTER switch, (BOTH, LEFT, or RIGHT), bleed air will not be available to the air conditioning packs unless you also move the respective ____ ____ switch to the OPEN position.

SYSTEM SHUTOFF

---

62. As you may already have guessed, the OFF and RAM positions of the AIR COND MASTER switch will ____ both FLOW CONTROL valves. In addition, the OFF position also closes the system shutoff valves.

CLOSE

Thus, in the OFF position both FLOW CONTROL and system shutoff valves are ____.

CLOSED

---

63. Rotate (or simulate rotating) the AIR COND MASTER switch and visualize the effect each position has on the FLOW CONTROL valves and on the SYSTEM SHUTOFF valves.

Check your responses for correctness by referring to the chart on Page 4-9 of your Flight Manual.

---

64. Repeat the same procedure and visualize the effects on the ENGINE BLEED valves, the WING ISOLATION valve, and the FLOOR HEAT MODULATING and FLOOR HEAT SHUTOFF valves.

Again check your response against the chart in your Flight Manual.

---

65. If you have difficulty at this time to visualize the effects of the AIR COND MASTER switch on any of the above components, repeat Steps 20 through 30 in this text.

If not, or after reviewing the suggested steps, proceed with the next item.

Referring to Figure A-4 below, we see a temperature gauge "T" receiving input from a temperature sensor downstream of the primary heat exchanger. This temperature gauge is shown on your panel at No. 6. A similar gauge is provided for the right primary heat exchanger and is shown at No. 7.

Point at the temperature gauges on your panel.

You should have pointed at Items No. 6 and 7.

---

66. It may be seen from the schematic that the temperature gauge for each primary heat exchanger indicates the temperature of the air at the respective _______ ____ ______ outlet.

primary heat exchanger

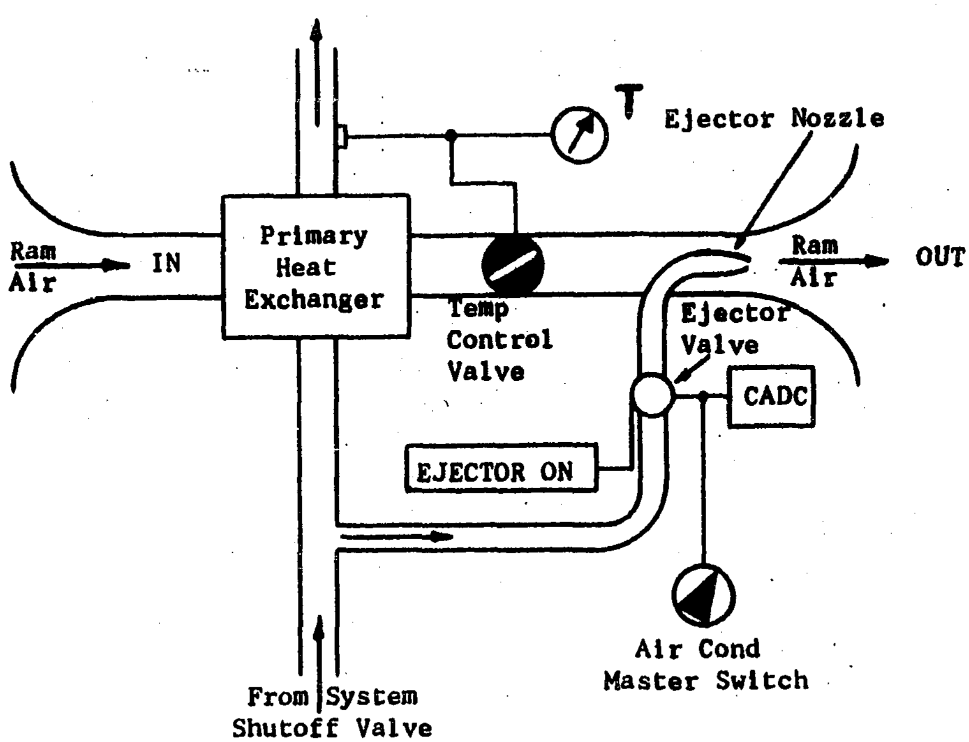

Fig. A-4.--Primary heat exchanger temperature control

67. The temperature of this air is controlled by a primary heat exchanger temperature control that modulates a primary heat exchanger cooling air control valve.

The temperature of the primary heat exchanger outlet air is controlled by the position of a _______ ___ _____ valve. cooling air control

---

68. The cooling air control valve controls the amount of cooling air that is drawn through the cores of the primary heat exchanger through the ram air duct, which constitutes the method of cooling the hot bleed air as it goes through the primary heat exchanger.

The temperature control limits normal heat exchanger outlet temperature to approximately 230°C.

Thus, during normal operation, the heat exchanger temperature gauges should not read in excess of ___°C. 230

---

69. Should the outlet temperature rise to approximately 280°C, the temperature control will signal the respective system shutoff valve to close.

Thus, if the temperature for either heat exchanger reaches 280°C, you may expect the regulated pressure for that system to decrease to ____, indicating that the respective system _______ _____ has closed. zero SHUTOFF VALVE

---

70. Since ram air is insufficient to provide necessary cooling air flow across the heat exchanger during low air speeds, bleed air is tapped off downstream of the system shutoff valve and furnishes air flow through an ejector nozzle in the ram air duct; this then increases the air flow through the ram air duct to effect the necessary cooling.

Cooling air flow across the primary heat exchanger is aided by air from an ______ ______ during conditions of ___ air speeds only.

ejector nozzle
low

---

71. The air flow to the ejector nozzle of each air conditioning pack is controlled by a primary heat exchanger ejector valve, which opens whenever a CADC signal of less than .3 Mach is received while the AIR COND MASTER switch is in any position except APU.

No. 1 CADC furnishes the signal to the left ejector valve, and No. 2 CADC to the right ejector valve.

Thus, when No. 1 CADC senses a speed below __ Mach, the ____ ejector valve should open, provided the AIR COND MASTER switch is not in the ___ position.

.3 left

APU

---

72. Refer to Figure A-4 for a schematic of the primary heat exchanger cooling system. As you can see, the ejector valve controls its associated indicator light, labeled EJECTOR ON.

Point to the EJECTOR ON lights on your panel.

You should have pointed at Items No. 15 and 17.

---

73. You have covered the major components of the environmental panel with which you will be concerned during the environmental system check.

The remaining controls are listed through Step 78 below.

Two temperature control switches, labeled FLT STA CONTROL and CARGO COMPT CONTROL, are located on your panel at Nos. 4 and 9. These are four-position switches that serve to select temperature control for flight deck or cabin, either automatically or manually.

During the environmental system check, these switches should be in the AUTO position.

Move (or simulate moving) the switches to the AUTO position.

You should have moved the switches at Nos. 4 and 9 to the UP position.

---

74. Two rotary switches, located on your panel at Nos. 5 and 8, are labeled FLT STA and CARGO COMPT. When the temperature switches are in the AUTO position, these rotary switches will then control the respective temperature level.

Moving the rotary temperature selector switches clockwise increases the temperature, and vice versa.

During the environmental system check, these rotary switches should be in a normal position (straight up).

Move (or simulate moving) the rotary temperature selector switches and position them to NORMAL.

You should have moved switches Nos. 5 and 8 to the straight UP position.

---

75. A temperature gauge, labeled COMP TEMP, is located on your panel at No. 19. This gauge indicates the temperature in the cargo compartment.

Point to the cargo compartment temperature gauge on your panel.

You should have pointed at the gauge at No. 19.

---

76. Item 24 on your panel represents the CABIN LIMIT CONTROL OVERRIDE switch, which is labeled CABIN ALT LIMIT ORIDE. The function of this switch will be discussed under "Pressurization."

For the purpose of checking the environmental system panel, you need merely make sure that this switch is in the NORMAL position (DOWN), with the red guard in place.

Check the NORMAL position of the CABIN LIMIT CONTROL OVERRIDE switch.

You should have checked that the switch at No. 24 is in the DOWN position with the safety guard in place.

---

77. Item 43 on your panel represents the EMERGENCY DEPRESSURIZATION switch. The function of this switch will be discussed under "Pressurization." During the environmental system check, you need merely make sure that this switch is in the NORMAL position (DOWN), with the red safety guard in place.

Check the NORMAL position of the EMERGENCY DEPRESSURIZATION switch.

You should have checked that switch No. 43 is in the DOWN position with the safety guard in place.

TURN TO NEXT PAGE

78. Item 39 on your panel represents a CABIN RATE-OF-CLIMB indicator.

During the environmental system check, you need merely make sure that the indicator reads zero (horizontally to the left).

Check the cabin rate-of-climb indicator.

You should have checked that the indicator at No. 39 reads zero.

---

79. We shall now be able to revert to the APU control panel and discuss the functions of the APU operating controls.

The function of the BLEED LOAD AND FLOW CONTROL VALVE switch, shown on your panel as No. 1, has already been discussed.

When the APU is operating, moving the switch to the OPEN position will admit APU air to the _____ _____ _____.

floor heat duct

---

80. If you did not answer the above item correctly, you should refer back to Fig. A-2.

APU operation is controlled by an APU control switch, labeled APU CONT, shown on your panel as Item 13. This is a rotary three-position switch with the positions labeled OFF, RUN, and START.

The START position of this switch is spring-loaded to the RUN position.

Move (or simulate moving) the switch to the START position, then release to RUN.

You should have moved the switch at No. 13 to the extreme RIGHT, then released it to the CENTER position.

---

81. To start the APU, the APU CONT switch must be momentarily moved to the START position.

When the switch is released from the START position, it will go to the ___ position. RUN

---

82. To stop the APU, the APU CONT switch is moved to the ___ position. OFF

---

83. When the APU CONT switch is moved to START, a START RELAY is energized and remains energized until 35% rpm is reached.

The start relay furnishes power to open the hydraulic starter valve or valves.

Thus, the starter is cut out as soon as the APU reaches __% rpm. 35

---

84. A three-position APU ACCUMULATOR SELECTOR switch, labeled APU ACCUM SEL and shown on your panel at No. 12, allows selection of either one or both accumulators of No. 3 hydraulic system to supply the hydraulic pressure to the APU starter.

The APU starter is operated by ________ ________. hydraulic pressure

---

TURN TO NEXT PAGE

85. Normally, the No. 1 position (DOWN) is used for start.

If another starting attempt is necessary, the No. 2 (CENTER) position may then be selected.

During extremely cold temperatures, the BOTH position (UP) should be selected to ensure sufficient hydraulic pressure to the starter.

Hydraulic pressure for APU start is <u>always</u> furnished by the No. _ hydraulic system. — 3

Normally, the APU ACCUM SEL switch should be positioned to No. __ for the initial start. — 1

---

86. Move (or simulate moving) the APU ACCUM SEL switch to No. 1.

You should have moved the switch at No. 12 to the DOWN position.

---

87. After the APU CONT switch is moved to START, the APU fuel valves will open and ignition will be supplied as soon as oil pressure reaches 3.5 psi.

Moving the APU CONT switch to OFF closes the fuel valves and de-energizes the APU control circuits.

Thus, fuel is available to the APU as soon as oil pressure reaches ___ psi after the APU CONT switch is moved to _____, and will continue to be furnished until the APU CONT switch is moved to ___.

3.5

START

OFF

TURN TO NEXT PAGE

88. When APU rpm accelerates through 95%, ignition will be cut out.

Thus, during normal on-speed operation, the ignition is ___ ___. — cut out

---

89. A speed control is incorporated in the fuel governor to maintain the APU at the proper operating rpm.

If the rpm should exceed 110%, the governor will shut down the APU by shutting down the fuel flow.

The APU will also shut down automatically in case of low oil pressure or high oil temperature.

Thus, the APU will shut down automatically in case of excessive ___, ___ ________, or ___ __________. — rpm oil pressure oil temperature

---

90. Visual indication of starter cycle and on-speed condition are provided by two green indicator lights labeled START and ON SPEED. The lights are shown on your panel at No. 3.

The START light (upper light) will come on whenever the starter is operating.

Thus, when APU reaches starter cutout speed, the START light will __ ___. — go out

---

91. The ON SPEED light comes ON as soon as the APU reaches normal speed, which is above 95% rpm.

Thus, as long as the APU rpm is above 95%, the __ _____ light is ON. — ON SPEED

---

92. Point at the APU START and ON SPEED lights on your panel.

You should have pointed at the indicator lights at No. 3.

---

93. An APU DOOR switch is shown on your panel at No. 11. This is a three-position switch that controls the operation of the APU air inlet and exhaust doors. This switch is not spring-loaded to any position.

When moved to the OPEN (UP) position, the APU doors will open, provided the aircraft is on the ground.

The CENTER position of the switch is an OFF position. When the APU doors have moved to the selected position, the switch should be moved to OFF.

When moved to the CLOSED (DOWN) position, the APU doors will close, provided oil pressure is below 3.5 psi.

This means that the APU doors cannot be ______ unless the APU is shut down.

closed

The APU doors can be opened only if the aircraft is __ ___ ______.

on the ground

---

94. An indicator light is located above the door switch, shown on your panel at No. 10. The words NOT CLOSED will light up whenever the APU doors are not in the fully closed position.

Thus, with the APU doors open, the NOT CLOSED light should be __.

ON

---

95. Move (or simulate moving) the switch to the OPEN position and visualize the effect. (Aircraft is on the ground).

You should have moved the switch (No. 11) to the OPEN position; the NOT CLOSED light will come on almost immediately. You should have left the switch in the UP position for several seconds to insure that the doors have fully opened before moving the switch to OFF.

---

96. If the doors are left in the OPEN position prior to take-off, action of the touch-down switches on the landing gear will cause the doors to close during take-off.

Thus, you should not be able to ____ the doors in flight.

open

---

97. An EGT gauge is shown on your panel at No. 2. This indicates the exhaust gas temperature of the APU.

During normal operation, EGT should not exceed 704°C.

Maximum EGT is 738°C.

Thus, if EGT exceeds ____°C, you should immediately shut down the APU.

738

---

98. Fire warning for the APU consists of the following signals: (1) a red light in the APU fire handle below the control panel, (2) a similar light in the fire handle adjacent to the entrance door, (3) audible signals in the headsets, (4) a warning sound in the loudspeaker, and (5) a warning horn (if one of the doors in the cargo compartment is open).

Testing of the fire warning system is provided by a TEST switch on the APU fire control panel.

Pulling either of the two APU FIRE CONTROL handles out will shut down the APU and arm the extinguishing circuit.

The agent can then be discharged by actuating an AGENT DISCHARGE switch adjacent to each of the APU FIRE CONTROL handles.

Thus, a fire in the APU will be indicated by red lights in the two ___ ____ _______ _______, warning sounds in the ________ and ___________, and--if one of the doors in the aircraft is open--by a _______ ____; if this happens, the engineer should immediately pull the ___ _____ _______ ______ and actuate the _____ ______ switch.

APU FIRE CONTROL HANDLES
headsets
loudspeaker
warning horn
APU FIRE CONTROL HANDLE
AGENT DISCHARGE

---

99. You are now ready to proceed with the environmental system preflight check itself. Pay close attention to the proper sequence of check items and to the real or imaginary indications that you would expect to see as a result of your control movements.

---

100. The first thing you must do before you can check the environmental system is to start the ___.

APU

---

101. A fire guard must be posted and clear the APU area. If external electrical power is not available, the start must be coordinated with the scanner without use of _________.

interphone

---

102. Since the APU starter utilizes hydraulic pressure from the hydraulic system No. 3 accumulators, it is also important to check that these are properly _______ before starting the APU. — charged

---

103. Assume that external power is available and connected to the aircraft buses, and that the scanner is properly posted.

Before starting the APU, the APU doors must be ____. — open

Move the APU door switch (11) to the OPEN position. The APU DOOR ___ ______ light should be on. — NOT CLOSED

---

104. Return the APU door switch to the OFF position.

Challenge the scanner as follows:

"APU - CLEAR?"

The scanner's response should be:

"CLEAR, ____ _______ _______." — FIRE GUARD POSTED

---

105. With the ACCUM SEL switch (12) in the proper position (normally No. 1), move the APU CONT switch (13) to START and simultaneously start the second hand of your stop clock. The green _____ light should come on. — START

This light tells you that the APU _______ is operating. — starter

---

106. Release the APU CONT switch from the spring-loaded START position. It should go to the ___ position.

RUN

---

107. Monitor the EGT gauge (2) and check for a ____ in EGT.

rise

Notice that AC power is needed to operate this gauge.

Therefore, if you had to start the APU without external electrical power, you would not have had any indication of ___.

EGT

---

108. When starter cutout speed is reached, the _____ light should go out.

START

---

109. As soon as the APU rpm reaches normal operating speed, the __ _____ light will come on.

ON SPEED

Monitor the second hand of the stop clock throughout the start.

---

110. The ON SPEED light must come on within 20 seconds after initial illumination of the START light.

If it does not come on within __ seconds, the APU must be shut down by moving the APU CONT switch to ____.

20

OFF

---

111. When the APU is operating normally, the ________ light should be on, and indication of ___ should be stabilized in the normal (green) range.

ON SPEED

EGT

---

112. Now move to the electrical system panel and check the auxiliary generator frequency and voltage by turning the aux generator switch ON.

If within the green range, the power selector switch may then be moved to AUX if required.

If you do this, electrical power to the aircraft buses will now be supplied by the _________ generator. — auxiliary

---

113. You may now check the fire warning system of the APU.

Move the APU FIRE WARN TEST switch to the TEST position (UP).

You should expect the red lights in both ___ ____ ______ handles to come on, the ___ ____ light on the annunciator panel and both master _______ lights to come on, and a signal to sound in the ________ and ___________. — APU FIRE CONTROL; APU FIRE; CAUTION; headsets; loudspeaker

Since normally at this time the crew entrance door is open, you should also hear a signal from the _______ ____. — warning horn

---

114. Next, check that the nacelle preheat switches are in the OFF position.

This will insure that during the environmental system check bleed air is not inadvertently going to the _______ _______ system. — nacelle preheat

---

TURN TO NEXT PAGE

115. You are now ready to check the controls on the environmental system panel for normal position as follows:

Flight station and cargo compartment temperature control switches (4, 9) should be in the AUTO position.

This means they should be pointing __. UP

The associated temperature selector switches (5, 8) should be approximately centered.

---

116. Flight station airflow switch (20) should be as required, usually in the ____ position. NORM

---

117. Floor overheat test switch (21) - RESET.

You should move the switch momentarily to the _____ position which is ____. RESET DOWN

---

118. This will assure normal operation of the floor heat _______ valve and of the floor heat __________ valve. shutoff modulating

---

119. Cabin altitude limit override switch (24) - NORMAL.

This means the switch should be in the ______ position, which is ____, and the red guard should be __ _____. NORMAL DOWN in place (DOWN)

---

120. Air conditioning master switch (25) - OFF.

The rotary AIR COND MASTER switch should be in the ___ position. OFF

---

121. System shutoff switches (28, 29) - OPEN.

Touch the switches and make sure they are in the OPEN position, which is __. UP

---

122. Engine bleed valve switches (32, 33, 36, 37) - OPEN.

Touch the switches and make sure they are in the OPEN position, which is __. UP

---

123. Check the engine bleed valve indicator lights (26, 27, 30, 31).

The lights should be ___, indicating that the valves are ____. OUT OPEN

---

124. Floor heat switch (34) - OFF.

Touch the switch and check that it is in the OFF position, which is ____. DOWN

---

125. Wing isolation switch (35) - NORMAL.

Touch the switch and check that it is in the NORMAL position, which is __. UP

---

126. Remember that when the isolation switch is in the NORMAL position, the wing isolation valve will be ______, unless the AIR COND MASTER switch is in the ___ or ___ _____ position. — CLOSED; APU ENG START

---

127. Left and right wing overheat test switches (38, 40) - RESET.

Momentarily position the switches to RESET, which is ____. — DOWN

---

128. This will insure normal operation of the _______ _____ valves and of the _________ valve. — engine bleed; isolation

---

129. Emergency depressurization switch (43) - NORMAL.

Check that the switch is in the NORMAL position, which is ____, and that the safety guard is __ _____. — DOWN; in place (DOWN)

---

130. To repeat the steps for the initial panel check, notice that the controls are checked from left to right, top to bottom.

If you have checked all items properly, you should have positioned the controls as follows:

FLT STA CONTROL and CARGO COMPT CONTROL switches - ____. — AUTO

TURN TO NEXT PAGE

131. FLT STA AIRFLOW switch - __ ________. AS REQUIRED

---

132. FLOOR OVHT SYS TEST switch - _____. RESET

---

133. CABIN ALT LIMIT ORIDE switch - ______. NORMAL

---

134. AIR COND MASTER switch - ___. OFF

---

135. SYS SHUTOFF switches - ____. OPEN

---

136. ENGINE BLEED VALVE switches - ____. OPEN

---

137. Check that the CLOSED lights are ___. OUT

---

138. FLOOR HEAT switch - ___. OFF

---

139. WING ISOLATION switch - ______. NORMAL

---

140. L and R WING OVHT TEST switches - _____. RESET

---

141. EMER DEPRESS switch - ______. NORMAL

---

142. If you have made an error in any of the above steps, repeat all items starting with Item 115.

If you have performed all steps correctly, you are ready to proceed with the bleed air and overheat system check.

---

143. Engine bleed valve switches - CLOSED.

You should move the bleed valve switches to the CLOSE position, which is ____. DOWN

You should visualize that the bleed valve CLOSED lights ____ __. come ON

---

144. Engine bleed valve switches - OPEN.

You should move the bleed valve switches to the OPEN position, which is __. UP

You should visualize that the bleed valve CLOSED lights __ ___. go OUT

---

145. AIR COND MASTER switch - APU.

You should move the rotary air conditioning master switch to the APU position, which is __ ___ _______ ____. to the extreme left

You should visualize that the bleed valve CLOSED lights ____ __. come ON

---

146. APU LOAD CONTROL switch (1) - OPEN.

You should now visualize an indication of manifold pressure (14), and--since air is allowed to enter the system shutoff valves--an indication of regulated air pressure on both (L and R) needles of the REG PRESS gauge (23).

Thus, after the APU load control switch is positioned to OPEN, which is __, there should be an indication of air pressure on the ________ ________ gauge and by both needles of the ________ pressure gauge.

UP

manifold pressure

regulated

---

147. Since air is free to enter the air conditioning packs through the system shutoff valves, you would actually feel and hear air rushing from the air conditioning duct outlets.

FLOOR HEAT OVHT SYSTEM - TEST.

Test the system by moving the floor heat test switch to TEST; visualize the results.

You should have moved the test switch to the TEST position, which is __, and checked the illumination of the ________ light for the floor heat system. The manifold pressure and both regulated pressures should read __ psi.

UP

OVERHEAT

0

---

148. FLOOR HEAT OVHT system - RESET.

You should move the switch to the RESET position, which is ____, and check that the manifold and regulator pressures indicate ______ ________.

DOWN

normal pressure

---

149. Right wing overheat test switch - TEST.

You should move the right wing overheat test switch to TEST, which is __, and check that the _____ ____ light comes ON. UP RIGHT OVHT

---

150. Since this action closes the ______ _____ valves on that side and closes the ____ _________ valve, you should also expect the ______ regulated pressure to drop to 0. engine bleed wing isolation right

---

151. Right wing overheat test switch - RESET.

You should move the test switch to RESET, which is ____, at which time you should expect the _____ _________ pressure to return to normal. DOWN right regulated

---

152. Left wing overheat test switch - TEST.

You should move the left overheat test switch to TEST, which is __, and expect the ____ ____ light to come on, and the _____ ________ pressure again to drop to 0. UP LEFT OVHT right regulated

---

(If you have stated "left regulated" as response to the above prompt, you should review the schematic representation of air flow on your panel and study the effect of isolation valve position under this operating condition).

---

153. Left wing overheat test switch - RESET.

You should move the switch to RESET, which is ____, at which time you should expect the _____ _________ pressure to return to normal.

DOWN

right regulated

---

154. AIR COND MASTER switch - ENG START.

You should move the AIR COND MASTER switch to the ENG START position, which is at the _____ position when moving the switch clockwise from the APU position.

first

---

155. Since this action allows the engine bleed valves to open, you should expect the CLOSED lights to __ ___.

go OUT

At the same time, the system shutoff valves should close, which would be indicated by a drop to 0 of the ____ and ____ __________ pressure.

left right regulated

The ________ pressure should read normal.

manifold

---

156. L and R WING OVHT TEST switches - TEST.

Move both wing overheat test switches to TEST simultaneously and check the operation of the bleed valve closing circuit in this mode.

You should expect to see the _______ lights come ON.

CLOSED

---

157. L and R WING OVHT TEST switches - RESET.

Move the switches to RESET simultaneously; the CLOSED lights for all four engine bleed valves should __ ___. go OUT

---

158. APU LOAD CONT switch - CLOSED.

Although this action closes the load control valve, thus stopping the air flow to the floor heat duct and from there to the ________, there is no demand for air flow at this time. manifold

Therefore, allowing for normal leakage of air from the system, you would expect the manifold pressure to _______ ___________. decrease gradually

---

159. To check the manifold and valves for leakage, the rate of decrease of ________ pressure must be checked within certain limits. manifold

---

160. When you actuate the APU load control switch to the CLOSE position, simultaneously start the second hand of your stop clock and check the reading on the manifold pressure gauge. At the end of 20 seconds elapsed time, the manifold pressure should be not more than 15 psi below the original reading.

Thus, if you close the load control valve and observe a manifold pressure reading of 40 psi at that time, the reading should not be less than __ psi after __ seconds have elapsed. 25 20

---

161. If the manifold leakage is in excess of the above limitation, a second bleed-off check may be made. This time you should wait with the start of the second hand until the manifold pressure has bled down to 30 psi after moving the load control switch to CLOSE.

As soon as the manifold pressure reads __ psi, you should start the second hand of your stop clock. Then, following the same procedure as before, monitor the decrease of manifold pressure. — 30

At the end of __ seconds, the manifold pressure should not read less than __ psi. — 20, 15

---

162. If, for example, you find that during the second check the manifold pressure reads 15 psi after only 10 seconds have elapsed, it would indicate that the system is ______ excessively. — leaking

---

163. This completes the environmental system check.

At this time, you may elect to continue APU operation if required for ________ power or for __________ power, or you may shut it down. — electrical, pneumatic

---

TURN TO NEXT PAGE

164. To shut down the APU, proceed as follows:

Place the power selector switch OFF, or to EXT, as applicable.

Aux generator switch - OFF.

APU load control switch - CLOSE.

EGT should be stabilized before shutting down APU.

APU control switch - OFF.

To repeat, the first step in shutting down the APU is -

Power selector switch - ____ or ___. OFF EXT

---

165. Aux generator switch - ___. OFF

166. APU load control switch - _____. CLOSE

---

167. EGT - ________________. stabilized

---

168. APU control switch - ___. OFF

You are now ready to begin the practice exercises with the aid of instructions furnished by the tape recording.

APPENDIX II

TEXT OF TAPE-RECORDED INSTRUCTIONAL SEQUENCE

This tape recording has been prepared in order to assist you in the learning of the procedure for the environmental systems preflight check, comprising numbered items 15 through 18 on the Before Electrical Power-On Check and the first ten numbered items of the Electrical Power-On Check.

It is assumed that an electrical power source is available and connected to the aircraft buses, and that a scanner is in position and in interphone contact with the flight engineer.

Prior to starting the APU, the scanner will have checked that No. 3 hydraulic system accumulators are properly charged, hydraulic fluid quantity is at its proper level, the hydraulic interconnect valve is closed, the APU fire control handle adjacent to the crew entrance door is IN, and the APU has been checked to assure that the doors are open, drains and vents are clear, fire bottle pressure is within limits, and oil quantity is at its proper level. He will also have checked that the green overspeed test light illuminates when the overspeed test button is depressed.

Before starting the APU, you should have performed the following steps:

Batteryswitch - ON. This is Item 15 of the Before Electrical Power-On Check.

Check battery voltage by turning the power selector switch OFF and checking isolated DC bus voltage.

Return battery switch to ON.

Item 16.--APU door switch - OPEN. Move the APU door switch to the OPEN position; the NOT CLOSED light should come on almost immediately. Wait a few seconds to make sure that the doors have moved to the full open position, then return APU door switch to OFF.

The accumulator selector switch should be positioned as required, normally to No. 1.

Item 17.--Electrical control panel - SET. Check that all bus power disconnect switches are in the NORMAL position, auto-load disconnect switches are in the NORMAL position, engine generator control switches are OFF, and CSD disconnect switches are in NORMAL with the red guards in place.

On Sundstrand equipped systems, the CSD overheat lights will be ON, indicating "no oil pressure."

Item 18.--Electrical power - ON. Check that the green external power READY light is ON, check voltage and frequency for all three phases of the external power supply, then move power selector switch to EXTERNAL.

You are now ready to start the APU. For numbered item 1 of the Electrical Power-On Check, challenge the scanner as follows:

"APU - Clear?" The response should be: "APU clear, fire guard posted."

Remember that if external power had not been available, you would have had to coordinate the start procedure without use of interphone. Furthermore, you would have had to use extreme caution, since neither the APU fire warning system nor the EGT gauge would have been operative.

Item 2.--APU control switch - START/RUN. Move the APU control switch to START and simultaneously start the second hand of your stop clock.

The green START light should come on almost immediately.

Release the APU control switch to RUN.

Monitor the EGT gauge.

Check that the START light goes out.

Continue watching the EGT gauge.

Check the elapsed time on the stop clock--you are approaching 20 seconds.

Check the green ON SPEED light. If not illuminated within 20 seconds, move APU control switch to OFF. In this case, starter clutches should be checked before attempting another start.

Normally, the green ON SPEED light will come on well within 20 seconds.

Stop the second hand of the stop clock and reset it to zero.

Item 3.--Auxiliary generator control switch - ON. Position auxiliary generator switch to ON and check voltage and frequency.

Item 4.--Power selector switch - AS REQUIRED. If external ground power was not available for APU start, selector switch may now be moved to AUX. In this case, the OFF lights for MAIN BUS 2 and MAIN BUS 3 would illuminate.

Before proceeding with the next item, make sure that personnel in the cargo compartment are aware that this is a test only.

Item 5.--APU fire warning test switch - TEST. Move the spring-loaded switch to TEST and check that the lights in the APU fire handle on the flight engineer's panel as well as in the APU fire handle in the cargo compartment illuminate, that the APU FIRE light on the annunciator panel illuminates, and that the audible signal sounds.

Release the test switch.

Item 6.--Flight engineer's caution lights - CHECKED. Hold the caution light test switch in the TEST position and check that the caution lights on the navigator's ADS panel and on the flight engineer's panel illuminate, except for the APU START light.

Release the caution light test switch.

Item 7.--Nacelle preheat switches - OFF. Check that all four switches are in the OFF position.

Item 8.--Air conditioning panel - SET. Starting at the top of the panel, position flight station and cargo compartment temperature control switches as required, normally to AUTO. Flight station and cargo compartment rotary temperature selector switches should normally point straight up.

Position flight station air flow switch as required, usually to NORMAL.

Momentarily actuate the spring-loaded floor overheat test switch to RESET, which is down.

Check that the cabin altitude limit override switch is in NORMAL, which is down, with the red guard in place.

Check that the air conditioning master switch is in the OFF position.

Check that the system shutoff switches are in the OPEN position, which is up.

Check that the engine bleed valve switches are in the OPEN position, which is up, and that all four engine bleed valve CLOSED lights are extinguished.

Check that the floor heat switch is in the OFF position, which is down.

Check that the wing isolation valve switch is in the NORMAL position, which is up.

Momentarily actuate the spring-loaded left and right wing overheat test switches to RESET, which is down.

Check that the emergency depressurization switch is in the NORMAL position, which is down, and that the red safety guard is in place.

Notice that the only indicator lights illuminated at this time on the environmental systems panel are the two green EJECTOR ON lights. All other lights should be off.

You are now ready to perform the steps of Item 9 --Bleed air and overheat system - CHECKED--as follows:

Move all four engine bleed valve switches to CLOSE; check that all four CLOSED lights come on.

Return all four engine bleed valve switches to OPEN; check that all four CLOSED lights go out.

Position the air condition master switch to APU; check that all four engine bleed valve CLOSED lights come on. No pressure should be indicated on either manifold- or pressure regulator gauges.

Move APU load control switch to OPEN.

Check for indication of manifold bleed air pressure and indication of left and right regulated air pressure.

Check the floor overheat system by moving the floor overheat test switch to TEST. Check that the OVERHEAT light directly beneath the test switch comes on and that both regulator pressures and the manifold pressure drop to zero.

Release the test switch and check that the overheat light goes out but all pressures remain at zero.

Move floor overheat test switch to RESET and check that all pressures return to normal.

Move right wing overheat test switch to TEST. Check that the RIGHT OVERHEAT lights illuminate on the environmental systems panel and on the pilot's annunciator panel, together with the MASTER CAUTION lights, and that the right regulator pressure drops to zero.

Release test switch and check that indicator lights go out and that right regulator pressure remains at zero.

Move switch to RESET and check that right regulator pressure returns to normal.

Move left wing overheat test switch to TEST. Check that the LEFT OVERHEAT lights illuminate on the environmental systems panel and on the pilot's annunciator panel together with the MASTER CAUTION lights, and that the right regulator pressure again drops to zero.

Release test switch and check that lights go out and that right regulator pressure remains at zero.

Move switch to RESET and check that right regulator pressure returns to normal.

Air conditioning master switch - ENGINE START. Position air conditioning master switch to ENGINE START and check that all four engine bleed valve CLOSED lights go out and that both regulator pressures drop to zero. Manifold pressure should increase slightly.

Move both wing overheat test switches to TEST and check that all four engine bleed valve CLOSED lights illuminate.

Move both switches to RESET and check that all CLOSED lights extinguish.

You are now ready to check the bleed air manifold for tightness as follows:

Note the manifold pressure reading.

Move APU load control switch to CLOSE and simultaneously start the second hand of the stop clock. The manifold pressure should not drop more than 15 psi during a 20-second period. If it does, repeat the check, this time delaying the start of the stop clock until the manifold pressure drops to 30 psi. Pressure drop to 15 psi should not take less than 20 seconds.

If the second pressure check is not within limits, the manifold and all affected valves must be inspected.

This completes the environmental systems check.

Item 10.--APU control switch - AS REQUIRED. If the APU is not needed for the remainder of the preflight check, it may now be shut down as follows:

Check that the power selector switch is in EXTERNAL and that external power is on the line.

Turn aux generator switch OFF.

Check bleed load and flow control switch in CLOSE position.

Check EGT to see that it has stabilized.

Position APU control switch to OFF.

You may now want to repeat this practice exercise in a more rapid manner. The following taped sequence is designed to aid you in performing the environmental systems check at a normal pace.

Again, starting with Item 15 of the Before Electrical Power-On Check:

Battery switch - ON.

APU door switch - OPEN.

Electrical control panel - SET. Bus power disconnect switches - NORMAL, bus tie switches - NORMAL, auto-load disconnect switches - NORMAL, engine generator control switches - OFF, CSD disconnect switches - NORMAL.

Electrical power - ON.

"APU clear?" - "Clear, fire guard posted."

APU control switch - START/RUN. Check for green ON SPEED light illumination within 20 seconds.

Auxiliary generator switch - ON. Check voltage and frequency.

Power selector switch - AS REQUIRED.

APU fire warning test switch - TEST. Check that the lights in the APU fire control handles on the engineer's panel and in the cargo compartment illuminate, that the APU FIRE light on the annunciator panel illuminates, and that the audible warning signals sound in the headset, loudspeaker, and warning horn.

Flight engineer's caution lights - CHECKED. Hold the caution light test switch in the TEST position and check illumination of all warning lights on the navigator's ADS panel and on the flight engineer's panel, except for the APU START light.

Nacelle preheat switches - OFF.

Air conditioning panel - SET. Position all controls as follows:

Flight station and cargo compartment temperature control switches - AS REQUIRED.

Flight station air flow switch - AS REQUIRED.

Floor overheat test switch - RESET.

Cabin altitude limit override switch - NORMAL.

Air conditioning master switch - OFF.

System shutoff switches - OPEN.

Engine bleed valve switches - OPEN. Check that all four engine bleed-valve CLOSED lights are extinguished.

Floor heat switch - OFF.

Wing isolation switch - NORMAL.

Left and right wing overheat test switches - RESET.

Emergency depressurization switch - NORMAL.

Bleed air and overheat system - CHECKED. Accomplish this check as follows:

Engine bleed-valve switches - CLOSED. Check that all four engine bleed-valve CLOSED lights illuminate.

Engine bleed-valve switches - OPEN. Check that all four engine bleed-valve CLOSED lights are extinguished.

Air conditioning master switch - APU. Check that all four engine bleed-valve CLOSED lights illuminate.

APU load control valve switch - OPEN. Check for normal indication of both regulator pressures and manifold pressure.

Floor overheat system - TEST. Check that overheat light illuminates and that both regulator pressures and manifold pressure drop to zero.

Floor overheat system - RESET. Check for left and right regulator pressure.

Right wing overheat test switch - TEST/RESET. Move switch to TEST and check that right overheat lights illuminate on the environmental systemspanel and on the annunciator panel and that the right regulator pressure drops to zero. Move switch to RESET and check that right regulator pressure increases.

Left wing overheat test switch - TEST/RESET. Move switch to TEST and check that left overheat lights illuminate on the environmental systems panel and on the annunciator panel and that the right regulator pressure again drops to zero. Move switch to RESET and check that right regulator pressure increases.

Air conditioning master switch - ENGINE START. Check that all four engine bleed-valve CLOSED lights extinguish.

Left and right wing overheat test switches - TEST/RESET. Move both wing overheat test switches to TEST and check that all four engine bleed-valve CLOSED lights illuminate. Move both switches to RESET and check that all four CLOSED lights extinguish.

APU load control valve switch - CLOSE. Check that the time for manifold pressure to bleed down to 15 psi is not less than 20 seconds. If less than 20 seconds, perform a second check between 30 psi and 15 psi for exact limits.

APU control switch - AS REQUIRED. If external electrical power is available for the remainder of the preflight check and air conditioning is not required, shut down APU as follows:

Power selector switch - EXTERNAL. Check that ground power is on the line.

Aux generator switch - OFF.

Check EGT to see that it has stabilized.

APU control switch - OFF.

This concludes the two practice sessions of the environmental systems preflight check.

If you are using the tape recorder by yourself, please rewind the tape and turn off the recorder.

APPENDIX III

TEST INSTRUMENTS USED IN THE STUDY

A. Multiple-Choice Written Test.

1. During the environmental system check, what indications would you expect when the floor heat test switch is moved to TEST?

   a. Manifold pressure drops to zero.
   b. Both regulator pressures drop to zero.
   c. Both effects described in a. and b. take place.
   d. FLOOR OVERHEAT light on pilot's annunciator panel comes on.

2. During the environmental system check, what indications would you expect when the L WING PYLON & AIR COND COMPT switch is moved to TEST?

   a. Left regulator pressure drops to zero.
   b. Right regulator pressure drops to zero.
   c. Manifold pressure and left regulator pressure drops to zero.
   d. In addition to item c., the engine bleed valve CLOSED lights come on.

3. When checking the pneumatic manifold for excessive leakage, which of the following conditions would indicate an acceptable rate of leakage?

   a. Pressure drops from 30 to 20 psi in 21 seconds.
   b. Pressure drops from 30 to 15 psi in 15 seconds.
   c. Pressure drops from 30 to 10 psi in 20 seconds.
   d. Pressure drops from 35 to 15 psi in 21 seconds.

4. Which of the following valves receive a CLOSE signal in case of an overheat condition in the left air conditioning compartment?

   a. Left engine bleed valves, wing isolation valve, left system shutoff valve.
   b. Left engine bleed valves, wing isolation valve, floor heat shutoff valve.
   c. Floor heat shutoff valve, wing isolation valve, left system shutoff valve.
   d. No. 1 and No. 2 engine bleed valves and wing isolation valve.

5. During the environmental system check, what indications would you expect if the left SYS SHUTOFF switch is moved to TEST while the AIR COND MASTER switch is in the APU position?

   a. Left regulated pressure drops to zero, LEFT OPEN light may come on momentarily.
   b. Left regulated pressure reads same as manifold pressure, LEFT OPEN light stays on as long as switch is held to TEST.
   c. Left regulated pressure drops to zero, LEFT OPEN light stays on as long as switch is held to TEST.
   d. There are no indications since the APU air pressure is less than 90 psi.

6. The wing isolation valve is normally closed; it can be opened automatically by...

   a. ...positioning of AIR COND MASTER switch to BOTH or ENG START.
   b. ...actuation of left or right wing overheat system.
   c. ...positioning of AIR COND MASTER switch to APU or ENG START.
   d. ...opening APU load control valve and floor heat shutoff valve.

7. Floor heat is available whenever there is bleed air pressure available and the AIR COND MASTER switch is <u>not</u> in the ___________ position.

   a. APU
   b. ENG START
   c. OFF
   d. RAM

8. What is the effect if an overheat occurs in the right wing manifold while No. 2 engine starter is engaged during start?

   a. Starter button pops out and start is discontinued.
   b. Bleed valves and wing isolation valve are closed.
   c. Wing isolation valve closes, isolating the right wing manifold.
   d. RIGHT OVERHEAT light comes on, valves stay open as long as starter button is in.

9. What is the purpose of the ejectors in the air conditioning system?

    a. To provide additional cooling for the secondary heat exchangers during low-speed or ground operations.
    b. To provide additional cooling for the primary heat exchangers during low-speed or ground operations.
    c. To assist the water separators in maintaining desired outlet temperature by providing a cooling air flow.
    d. To assist refrigeration-turbine operation during low-speed or ground operations by unloading the compressor.

10. During the environmental system check, when the AIR COND MASTER switch is moved to APU and the APU load control valve is opened, what could be a possible reason for not getting an indication of manifold and regulated bleed air pressure?

    a. FLOOR OVERHEAT SYS switch was not moved to RESET.
    b. Wing isolation valve failed in the CLOSED position.
    c. System shutoff valves have failed to open.
    d. Wing overheat test switches were not moved to RESET.

Correct answers are as follows: 1.c., 2.b., 3.a., 4.d., 5.a., 6.c., 7.b., 8.d., 9.b., 10.a.

Score is obtained by subtracting incorrect answers from perfect score of 10.

B. Performance Test Check Sheet.

1. Electrical power supply . . . . ☐
(Student selects and checks proper power source).

2. APU door position . . . . ☐
(Student checks light indication and waits several seconds before positioning door switch to OFF).

3. APU start procedure . . . . ☐
(Student checks START and ON SPEED lights, times start cycle, and monitors EGT gauge).

4. Temperature control switch positons . . . . . ☐
(Student checks control and selector switch positions).

5. Flight station airflow switch . . . . ☐
(Student checks switch in NORMAL position).

6. Floor overheat test switch . . . . ☐
(Student moves switch to RESET position).

7. Cabin limit control override switch . . . . . ☐
(Student checks switch in NORMAL position).

8. AIR COND MASTER switch . . . . ☐
(Student checks switch in OFF position).

9. System shutoff switches . . . . ☐
(Student checks switches in OPEN position).

10. Engine bleed valve switches . . . . ☐
(Student checks switches in OPEN position and checks that indicator lights are out).

11. Floor heat switch . . . . ☐
(Student checks switch in OFF position).

12. Wing isolation valve switch . . . . ☐
(Student checks switch in NORMAL position).

13. Left and right wing overheat test switches . ☐
(Student moves both switches to RESET).

14. Emergency depressurization switch . . . . . . ☐
(Student checks switch in NORMAL position).

15. Engine bleed valve switches . . . . ☐
(Student moves all four switches to CLOSE and checks illumination of CLOSED lights).

16. Engine bleed valve switches . . . . ☐
(Student moves all four switches to OPEN and checks that CLOSED lights extinguish.

17. Air conditioning master switch . . . . ☐
(Student moves switch to APU position and checks illumination of CLOSED lights).

18. APU load control valve switch . . . . ☐
(Student moves switch to OPEN and checks indications of manifold and regulator pressures.

19. Floor overheat system test switch . . . . . . ☐
(Student moves switch to TEST and checks illumination of OVERHEAT light and that all pressures drop to zero).

20. Floor overheat system test switch . . . . . . ☐
(Student moves test switch to RESET and checks that pressures return to normal).

21. Right wing overheat test switch . . . . ☐
(Student moves switch to TEST, checks illumination of OVERHEAT lights and right regulated pressure drop to zero).

22. Right wing overheat test switch . . . . ☐
(Student moves test switch to RESET and checks that right regulated pressure returns to normal).

23. Left wing overheat test switch . . . . ☐
(Student moves switch to TEST, checks illumination of OVERHEAT lights and that right regulated pressure again drops to zero).

24. Left wing overheat test switch . . . . ☐
(Student moves switch to RESET and checks that right regulated pressure returns to normal).

25. Air conditioning master switch . . . . ☐
(Student moves switch to ENG START, checks that engine bleed CLOSED lights go out and that both regulator pressures drop to zero.

26. Left and right wing overheat test switches . ☐
(Student moves both test switches to TEST and checks that all four CLOSED lights come on).

27. Left and right wing overheat test switches ... ☐
(Student moves both test switches to RESET and checks that CLOSED lights go out).

28. APU load control valve switch . . . . ☐
(Student moves switch to CLOSE and times pressure drop within specified limits).

29. Electrical power supply . . . . ☐
(Student moves auxiliary generator switch to OFF after positioning power selector switch to desired position).

30. APU shutdown procedure . . . . ☐
(Student checks that load control valve is closed, EGT has stabilized, then moves APU control switch to OFF).

Score is obtained by subtracting incorrect responses from perfect score of 30.

C. Performance Test to Measure Trouble-Shooting Ability.

Procedure: Position controls or circuit breakers as outlined in steps 1. through 4. Observe student reactions during repetition of routine system check. Inability to solve any one of the four problems, or overlooking indications of any of the four problems shall be counted as an error. Score is obtained by subtracting number of errors from perfect score of 4.

1. Problem: All four nacelle preheat switches inadvertently left in ON position.

   Result: If not noticed, inability to obtain proper bleed manifold leakage-rate check.

2. Problem: Wing isolation valve circuit breaker tripped while valve is in NORMAL (closed) position. (C/B location M-32, Isolated DC Bus).

   Result: No indication of right regulated air pressure when APU load control switch is moved to the OPEN position.

3. Problem: Floor heat shutoff valve circuit breaker tripped while valve is in ON (open) position. (C/B location K-32, Isolated DC Bus).

   Result: Failure of manifold pressure and regulated air pressures to decrease when floor heat test switch is moved to the TEST position.

4. Problem: Both emergency pressurization switches inadvertently positioned to EMERGENCY.

   Result: Indication of left and right regulated air pressure when air conditioning master switch is positioned to ENG START.

N	Group I Actual Equipment			Group II Flight Simulator			Group III Mock-Up			Group IV Full-Size Panel			Group V Illustration		

Fig. A-5.--Sample score sheet