# COMPARATIVE ANALYSIS OF PART-TASK TRAINERS FOR U. S. ARMY HELICOPTER MAINTENANCE TRAINING

by

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A series of 28 actual equipment trainers, systems trainers and panel devices currently used in U. S. Army helicopter maintenance training were analyzed to develop recommendations for device improvement through modification, augmentation or substitution. The analysis included on-site interviews of helicopter maintenance instructors, examination of helicopter mishap data related to maintenance error and a review of the state of the art in training technology. To synthesize the information obtained, a generic classification scheme for training devices was developed and individual profiles of devices →


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were prepared using 21 operationally defined criteria.

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ABSTRACT

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It was concluded that substantial cost-training benefits could be achieved through propitious use of programmable simulation systems that employ microprocessor technology, modular construction and flexibility in display capability. Specific recommendations were made accordingly.

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Sincere appreciation is expressed to the many instructors, training supervisors and other members of the U. S. Army training and aviation safety community for their unreserved cooperation in the conduct of this study.

We are also most grateful to PM-TRADE for providing continuous guidance and support throughout the project.

Finally we wish to thank the many members of the training device industry who contributed their comments and information to our effort to appraise the state of the art in this field.

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# 1.0 INTRODUCTION

Over the past several years there has been a rapid growth in the level of engineering sophistication and complexity of U. S. Army rotary wing aircraft. This growth has been accompanied by increased system and subsystem costs and increased demands for highly skilled maintenance personnel. The Army's inventory of rotary wing aircraft currently includes seven types of helicopters as shown in Figure 1. The missions of these aircraft include delivery of weapons fire support (AH-1G/Q), air transportation of troops and cargo, and rescue of personnel (CH-47), movement of heavy equipment (CH-54), observation and reconnaissance (OH-6A; OH-58A), transport of personnel, equipment and supplies (UH-1D/H) and flight training (TH-55A).

The increasing cost and complexity of these systems make the use of operational equipment for maintenance training less and less feasible. At the same time the need for effective and efficient maintenance training continues to increase. Thus, it is imperative that cost/training effective alternatives to operational equipment for training be found and that existing training devices be made as effective as possible. The present study was conducted to develop practical recommendations in this regard based on (1) an on-site review of existing maintenance training devices and interviews of instructor personnel, (2) a survey of the state of the art in training technology and, (3) an analysis of helicopter mishap data related to maintenance.

The results indicated that significant cost/training benefits can be achieved by increased utilization of contemporary simulators. Such devices can reduce the number of large,actual equipment trainers needed and can replace the majority of traditional panel boards and other non-interactive devices that are suitable only for classroom lecture/demonstration.

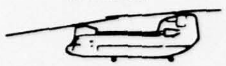
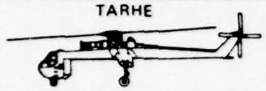
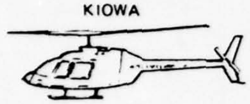
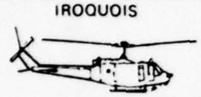
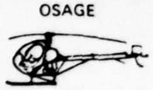
| PRE-FERRED | POPULAR NAME AND TYPE | COMBAT ACCEPT SUBST | LONG-RANGE FOLLOW-ON | Mission |
|---|---|---|---|---|
| AH-1G/Q | COBRA  ATTACK HELICOPTER | UH-1B<br>UH-1C<br>UH-1M | ADVANCED ATTACK HELICOPTER | Delivery of multiple weapons fire support; search and target acquisition, reconnaissance by fire; and troop helicopter support. |
| CH-47 | CHINOOK  CARGO TRANSPORT HELICOPTER (MEDIUM LIFT) | | LIGHT TACTICAL TRANSPORT SYSTEM | Air transportation for troops and cargo; and rescue of personnel. |
| CH-54 | TARHE  CARGO TRANSPORT HELICOPTER | | | Movement of heavy equipment; towing of surface vehicles, recovery of downed aircraft; and by use of detachable pods, *transportation of* personnel, vehicles and equipment. |
| OH-6A OR OH-58A | CAYUSE  KIOWA  LIGHT OBSERVATION HELICOPTER | | ADVANCED SCOUT HELICOPTER | Visual observation and target acquisition, reconnaissance; and command/control. |
| UH-1D/H | IROQUOIS  UTILITY (UTILITY/TACTICAL) TRANSPORT HELICOPTER | UH-1B | UTILITY TACTICAL TRANSPORT AIRCRAFT SYSTEM | Transport of personnel, equipment and supplies; medical evacuation; delivery of protective fire by attachment of appropriate weapons; and instrument flight training. |
| TH-55A | OSAGE  PRIMARY TRAINER HELICOPTER | | OFF-THE-SHELF | Training of military pilots in the basic operation and performance of a helicopter. |

Fig. 1. U. S. Army helicopters and missions.

## 2.0 PROCEDURE

The devices currently employed in training helicopter maintenance personnel range from full scale configurations of operational and simulated equipment that closely approximate actual aircraft, to relatively simple static displays and panel boards. By virtue of its design, each type of device provides a particular set of training capabilities. To aid in the systematic description and evaluation of the training devices, a device classification scheme and set of 21 descriptive characteristics were established. Twenty-eight maintenance training devices then were selected for study. A structured interview format was prepared and on-site examination of devices and instructor interviews were conducted accordingly. Concurrent with the field data collection, a survey of the state of the art in training technology and an analysis of helicopter mishap data related to maintenance were performed.

### 2.1 Training Device Classification Scheme.

For the purpose of this study four major categories of devices (Type I - IV) were defined as shown in Table 1. As may be seen in the table, Type I devices include large, actual equipment trainers (AET's); Type II devices include those three-dimensional configurations comprised primarily of actual equipment components or subsystems and which retain the general spatial arrangement of the operational equipment; Type III devices are those typical "breadboard" panels assembled from actual equipment components; Type IV devices are those in which the primary display is a two-dimensional panel. The latter devices, however, vary significantly in sophistication and complexity. Accordingly, three subcategories were defined as follows: Type IV-A which includes free-standing, hard-wired, non-programmable panels. Type IV-B which includes those panel devices that are partially programmable through dedicated electronic or electromechanical circuitry, and Type IV-C which includes those panel devices that are fully programmable through use of a mini-computer or microprocessor.

TABLE 1 -- Categories of Training Devices

TYPE I Devices

Included in this category are composite actual equipment trainers such as the AH-1G Composite Trainer and the AH-1G Armament Systems Maintenance Trainer. Devices in this category approximate an actual aircraft but may vary from an actual/flyable aircraft in one or more of the following ways:

1. Certain subsystems/components may be absent or replaced by wood or plastic facsimilies, photographs (e.g., instrument panel) etc.
2. Actual aircraft components used may not be airworthy.
3. Sections of aircraft skin may be removed and/or replaced with plexiglass panels to provide visual access to system/components.
4. Components may be truncated or cut away to show internal structure/function.
5. Device may be mounted on skids or castor platform for mobility.
6. Aircraft engine power may be replaced by electric and hydraulic power carts, auxilliary electric motors, etc.

TYPE II Devices

This category of device includes three-dimensional constructions that use actual aircraft components in conjunction with simulated components, where the device is functional and demonstrates operation of an aircraft subsystem. Examples would be the UH-1D Fuel System Trainer (DVC No. 1-71) and the UH-1H Electrical System Trainer (DVC No. 1-73).

TYPE III Devices

Included in this category are all display boards assembled of actual aircraft components and designed to show sequential functions and interactions of the components. Component interconnections may be electrical (wire), mechanical (e.g., control linkage) or hydraulic. These devices are commonly referred to as "breadboards"; the components function but their interconnections may be perfunctory.

TYPE IV Devices

This category of devices differs from the others in two major respects. First, the display portion is essentially a two-dimensional representation of the aircraft or system involved. Second, use of actual components is limited to providing a desired degree of realism. There are three subcategories as described below:

IV-A: Included freestanding, backlighted, hardwired panels that demonstrate system functions, electrical or hydraulic flow, schematics, etc.,; generally include an instructor panel for device operation and problem/malfunction insertions. Devices are not intended for hands-on training, troubleshooting, etc. Examples would be the AH-1G Electrical Systems Display Panel (DVC No. 1-79) and the AH-1G Hydraulic Systems Display Panel (DVC No. 1-80).

IV-B: Includes partially non-programmable control/display devices including hardwired and/or computer operated. These devices generally consist of (1) an animated, backlighted panel, (2) backlighted facsimile of pilot caution light panel, (3) set of large, functional meter displays, (4) a simulated but functional cockpit with selected controls, switches and displays, (5) an instructor console for device operation and problem insertion and, (6) a dedicated computer for device operation. An example would be the UH-1H/T53-L-13A Engine Trainer.

IV-C: This subcategory includes programmable, computer operated training devices such as the EC2, EC3. The basic console and computer may be used with a range of display panels and programmed via magnetic tape for any given panel/system of interest. These devices afford extensive problem/fault insertions, student input and feedback to student input.

## 2.2 Descriptive Characteristics of Training Devices.

To develop descriptive profiles for the training device of concern, twenty-one characteristics were identified and operationally defined as shown in Table 2. The first 10 characteristics pertain to the device configuration and functioning; items 11 through 17 concern the type of skills imparted and provision for student-device interaction; items 18, 19 and 20 pertain to the mode and frequency of device usage; item 21 is the cost range of the device.

## 2.3 Training Devices Selected for Study.

In concert with the Contract Technical Monitor and other cognizant Government personnel a total of 28 devices were identified for study. Table 3 lists the devices by type (as defined in Table 1), the code number of each device as designated in Department of the Army Pamphlet 310-12, Index and Description of Army Training Devices, October, 1975 (with changes dated 30 May, 1975), and the location at which the device was examined (Fort Eustis, Fort Rucker and/or Aberdeen Proving Ground). A picture of each device is presented in Appendix A.

## 2.4 Interview Format.

Instructors of helicopter maintenance and training supervisors were interviewed in the field to identify current uses of the selected training devices, to ascertain the perceived training-effectiveness of those devices, and to obtain suggestions for improvement of present and future devices. The interviews/discussions were guided by the following format:

1. Discussion of the major training objectives associated with use of the device.

2. Major advantages and limitations of the device as seen by the instructor.

3. Possible modifications that would make the device more training effective.

4. Possible additional devices/materials to be used with the main device to increase training-effectiveness.

Table 2 -- Working Definitions of Device Characteristics/Evaluation Criteria

1. Structural fidelity:
   the degree of physical, one to one correspondence of the training device to actual aircraft/equipment.

2. Functional fidelity:
   the degree to which the device represents the functional interactions of systems/components as they occur in actual aircraft/equipment.

3. Motor skills:
   the extent to which the training device allows manual manipulation, removal, disassembly, assembly and/or installation of actual components or simulated components of high structural fidelity (see 1 above).

4. Motor/Cognitive:
   the extent to which the training device facilitates or permits learning/practice of combined motor and cognitive skills, such as troubleshooting or checking in conjunction with physical adjustment of components, etc.

5. Cognitive skills:
   the extent to which the training device facilitates learning/practice of concepts, theory, systems functions, operating procedures, diagnostic and troubleshooting sequences, etc.

6. Fault insertion:
   the extent to which malfunctions, problems, improper control settings, etc., can be caused to occur in the training device for purposes of instruction in fault isolation and/or correction.

7. Programmability:
   the extent to which the basic operating sequences and characteristic of the training device can be varied/modified as a fundamental characteristic of the training device to facilitate instruction and/or maintain correspondence with changes in actual equipment/functions represented by the device.

8. Update/modify:
   the extent to which the training device can be easily and inexpensivley updated to correspond with physical and/or functional changes/modifications in the actual equipment represented by the device.

9. Reliability/Maintainability:
   the degree to which the device functions as intended without malfunction or breakdown and the ease with which it can be kept in, or restored to, full operating capability.

10. Availability:
   the extent to which the device is available for use or procurement in relation to the demand (e.g., number of copies needed for training). Devices in production and in use are considered more "available" than devices that are "under development" or in a prototype stage.

11. Safety:
   the extent to which the device is free of electrical, thermal and mechanical hazards under both normal and improper use.

12. Student-proof:
   the extent to which the device is resistant to damage or decalibration due to tampering or unintentional misuse by students.

13. Student access:
   depending on the intended purpose of the device, the extent to which students have visible and/or physical access to the displays/components being used/demonstrated. A large, classroom display panel would be considered as having high "access".

14. Student imput:
   the extent to which a student can (or is allowed to) physically interact with the device as opposed to merely observing its appearance or operation.

15. Feedback to student input:
   given that a student manipulates, adjusts, applies a tool, meter, etc., to the device, the extent to which the device (a) reacts as would the actual equipment it represents, and (b) provides supplementary information as to the correctness or incorrectness of the student's input.

16. Noise level/environmental:
   operating noise level in decibels.

17. Multi-system flexibility:
   the extent to which the device can be quickly and easily changed to represent/simulate more than a single system. Actual equipment has no flexibility; computer operated, programmable devices with interchangeable display panels have high flexibility.

18. Self-paced use:
   the extent to which a student can operate/interact with the device by himself in learning/practicing designated skills. Student imput/feedback are essential characteristics of devices appropriate for self-paced instruction.

19. Lockstep use:
   the extent to which the device is suited for lecture/demonstration with groups of students.

20. Usage rate:
   the extent to which the device is in use relative to student load and class scheduling. One possible measure of usage rate would be: Number of student-hours of use/Total student-hours per course or relevant course segment.

21. Cost:
   Cost of device computed as (a) initial procurement cost plus (b) cost of subsequent modifications (if any). As a rule of thumb, low cost devices are those $35,000 or less, mid-range cost devices are $36 - $99,000 and high cost are those in the $100,000 plus range.

TABLE 3 -- Training Devices Reviewed

| | Type I Devices | No.* | Location** |
|---|---|---|---|
| 1. | AH-1G Composite Trainer | 1-31 | E |
| 2. | AH-1Q Composite Trainer | -- | E |
| 3. | AH-1G Armament Systems Maintenance Trainer | 1-34 | R/A |
| 4. | AH-1G Armament Systems Trainer | 1-33 | A |
| 5. | OH-58A Composite Systems Trainer | 1-81 | R |
| | **Type II Devices** | | |
| 1. | AH-1G Electric and Hydraulic Systems Trainer | 1-32 | E |
| 2. | UH-1A Flight Control & Transmission Systems Trainer | 1-68 | R |
| 3. | UH-1D Fuel Systems Trainer | 1-71 | R |
| 4. | UH-1D Maintenance Trainer | 1-72 | R |
| 5. | UH-1D Power Plant T-53-L-11 Trainer | 1-37 | R |
| 6. | UH-1H Electrical Systems Trainer | 1-73 | E/R |
| 7. | OH-6A Composite Trainer | 1-63 | R |
| 8. | OH-6A Fuel Systems Trainer | 1-65 | E |
| 9. | OH-6A Power Plant T63-A-5A Trainer | 1-36 | R |
| 10. | CH-47A Tubular Utility Hydraulic Systems Trainer | 1-47 | E |

| | Type II Devices (con't.) | No.* | Location** |
|---|---|---|---|
| 11. | CH-47C Electrical Systems Trainer | 1-46 | E |
| | **Type III Device** | | |
| 1. | CH-47A Hydraulic Board Trainer | 1-50 | E |
| | **Type IV-A Devices** | | |
| 1. | AH-1G Electrical Systems Display Panel | 1-79 | R |
| 2. | AH-1G Hydraulic Systems Display Panel Trainer | 1-80 | R |
| 3. | UH-1B Electrical Systems Panel Trainer | 1-70 | R |
| 4. | UH-1B Fuel Systems Trainer | 1-69 | R |
| 5. | OH-58A Electrical Systems Panel Trainer | 1-83 | R |
| 6. | OH-58A Instrument Systems Panel Trainer | 1-84 | R |
| 7. | OH-58A Fuel Systems Panel Trainer | 1-85 | R |
| 8. | OH-58A Engine Oil Systems Trainer | 1-86 | R |
| | **Type IV-B Devices** | | |
| 1. | UH-1H/T53-L-13A Engine Trainer | 1-89 | R |
| 2. | UH-1H/T53-L-13A Multi-Purpose Engine Trainer | 1-90 | R |
| 3. | OH-58A/T63-A-700 Engine Trainer | 1-99 | R |
| | **Type IV-C Devices** | | |
| | (None reviewed) | | |

* D A Pamphlet 310-12

** E = Ft. Eustis
R = Ft. Rucker
A = Aberdeen Proving Ground

5. Discussion of possible alternatives to the device (e.g., a different type of device).

6. Characteristics/entry skills of the trainee population in relation to effective use of the training device or alternative devices.

7. Mode of instruction (self-paced, lock-step, classroom/laboratory).

8. Observation of the device being used in class, and/or having the device demonstrated by the instructor.

Interviews and discussions were conducted with a total of 37 instructors and other cognizant personnel at the following sites: U. S. Army Aviation Center, Fort Rucker, Alabama; U. S. Army Transportation School, Fort Eustis, Virginia; U. S. Army Aviation Systems Command, St. Louis, Missouri; U. S. Army Ordnance Center and School, Aberdeen Proving Ground, Maryland; PM-TRADE, Orlando, Florida.

### 2.5 State of the Art in Training Technology.

Information concerning presently available training systems was obtained (1) by a questionnaire sent to a sample of training equipment manufacturers, (2) through attendance at the 1976 Convention of the Society of Advanced Learning Technology, Washington, D. C. and the 9th Annual Naval Training Equipment Center/Industry Conference in Orlando, Florida (November, 1976) and, (3) from the general literature on training technology.

### 2.6 Helicopter Mishap Data Related to Maintenance Training.

Helicopter mishap data related to maintenance were obtained from reports published by the U. S. Army Agency for Aviation Safety (USAAAVS), Fort Rucker, Alabama.

## 3.0 RESULTS

### 3.1 On-site Review of Training Devices and Interviews of Instructor Personnel.

Each of the 28 training devices was examined on site by having the device demonstrated by an instructor and/or observing the device while it was being used in class. Direct examination of the devices revealed no significant opportunities for improvement through modification. Minor improvements could be made in the larger items of AET by increasing visual access to components that are presently enclosed. Also, the operating noise level of the large electrical and hydraulic systems is excessive, requiring on-site construction of sound enclosures. This is seen as the only feasible alternative for existing equipment. However, future procurements should specify an upper limit of operating noise, certainly below 90 db and preferably no more than 55 db if possible.

A major limitation of all of the training devices examined was insufficient provision for fault insertion and direct student-device interaction whereby operating and troubleshooting skills could be learned/practiced in a hands-on, self-paced context. Retrofitting the existing devices to provide this capability, however, is judged to be impractical.

The results of the instructor interviews may be summarized as follows:

1. The majority of instructors had a favorable attitude toward the training devices at their disposal. They felt that the devices did meet the requirements of their associated training objectives.

2. A strong preference was expressed for the use of actual equipment for maintenance training. As stated by one instructor "the ideal training device is an actual aircraft". This view, however, was not unanimous.

3. Advantages of the AET's were generally expressed in terms of "being close to the real thing". To the extent that criticism of AET occurred it was directed mainly at those components that had been replaced by photographs, wooden facsimiles, etc.

4. Regarding the capability to insert malfunctions and train diagnosis/troubleshooting on the AET's, most felt that this was "adequate" but that an increase in such capability would be welcomed and utilized.

5. Suggestions for improvements in the existing training devices were limited to minor modifications such as greater visual access to subsystems/components and

a reduction in operating noise levels for certain devices (e.g., the AH-1G electrical and hydraulic systems trainer).

6. There was strong opposition to modification of actual hardware to "make it into a trainer" when the resulting device "would cost more than the original, unmodified equipment".

7. Concerning possible alternatives to AET such as computer operated panel type devices, most had had little or no experience with such devices and, therefore, could not comment on this.

8. Concern was expressed over a trend away from the teaching of "theory" and too much emphasis on rote procedures.

9. At each of the training schools there was concern over the inability of many incoming students to adequately read and comprehend text material, charts, graphs and diagrams. Tape-slide programs were seen as a partial solution to this problem in teaching helicopter maintenance.

10. While the panel type devices (e.g., AH-1G electrical systems and AH-1G hydraulic systems) were considered effective for lecture/classroom use, they were described as being of little or no value in a self-paced mode of instruction. (Self-paced instruction is utilized extensively at Fort Eustis and Fort Rucker).

The foregoing comments indicate a need for device improvement in the following areas: (1) fault insertion, (2) training of concepts/theory and the use of abstract representations (diagrams, graphs, schematics, drawings) in performing maintenance and, (3) capability for student-device interaction consistent with a program of self-paced instruction. That specific alternatives to existing devices were not suggested by the instructors, whereby these needs could be met, is attributed to their lack of experience with the programmable, interactive devices that only recently have become available.

## 3.2 Training Device Profiles.

On the basis of on-site review of the 28 training devices and information provided by the instructors, each device was rated on a three-point scale (positive, intermediate, negative) with respect to the 21 characteristics shown in Table 2. The resulting profiles are presented in Figure 2. To facilitate visual inspection of the profiles the following code was used: a positive rating is represented by an open circle; an intermediate rating is represented by a half-filled circle; and, a negative rating is represented by a solid circle.

The profiles are grouped by type of device as defined in Table 1. Since devices within a given category are of a similar generic configuration, the similarity of profiles within a category, as may be seen in Figure 3, was expected.

Type I

The majority of Type I devices (large actual equipment trainers) all received positive ratings on structural and functional fidelity, negative ratings on programmability, update/modifiability, multi-system flexibility, noise level, student-proof(ness), student input, feedback to student input, and cost ($100,000 or more per copy) with the remaining characteristics generally receiving intermediate ratings.

Type II

The profiles for the Type II devices (three-dimensional assemblies and aircraft subsystems) are less similar to each other than those of Type I devices. These devices generally received positive ratings on structural and functional fidelity, reliability and maintainability, availability, student access and suitability for lockstep use. Overall they received negative ratings on programmability, multi-system flexibility, student input and feedback to student input, and suitability for self-paced instruction. Although these devices are comprised mainly of operational equipment components they serve primarily as demonstration devices. The cost of these devices is in the low to intermediate range (less than $100,000 per copy).

Type III

Only one Type III device was included in this study (CH-47 Hydraulic Board Trainer). Since that device is comprised of operational components mounted in essentially the same relative location as in the aircraft, and since the system is operable, it was given positive ratings

Key:
○ = Positive
◐ = Intermediate
● = Negative

| CHARACTERISTICS / TRAINING DEVICE | AH-1G Composite Tr. (1-31) | AH-1Q Composite Tr. | AH-1G Armament Syst. Maintenance Tr. (1-34) | AH-1G Armament Syst. Tr. (1-33) | OH-58A Composite Syst. Tr. (1-81) | AH-1G Electrical & Hydraulic Syst. Tr. (1-32) | UH-1A Flight Control & Transmission Tr. (1-68) | UH-1D Fuel Syst. Tr. (1-71) | UH-1D Maintenance Tr. (1-72) | UH-1D Power Plant T-53-L-11 Tr. (1-37) | UH-1H Electrical Syst. Tr. (1-73) | OH-6A Composite Tr. (1-63) | OH-6A Fuel Syst. Tr. (1-65) | OH-6A Power Plant 7-63-A-5A Tr. (1-36) | CH-47A Tubular Utility Hydraulic Syst. Tr. (1-47) | CH-47C Electrical Syst. Tr. (1-46) | CH-47A Hydraulic Board Tr. (1-50) | AH-1G Electrical Syst. Display Panel (1-79) | AH-1G Hydraulic Syst. Display Panel (1-80) | UH-1B Electrical Syst. Panel (1-70) | UH-1B Fuel Syst. Tr. (1-69) | OH-58A Electrical Syst. Panel (1-83) | OH-58A Instrument Syst. Panel (1-84) | OH-58A Fuel Syst. Panel (1-85) | OH-58A Engine Oil Syst. Tr. (1-86) | UH-1H/T53-L-13A Engine Tr. (1-89) | UH-1H/T53-L-13A Multi-Purpose Engine Tr. (1-90) | OH-58A/T63-A-700 Engine Tr. (1-99) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TYPE: | I | | | | | II | | | | | | | | | | | III | IV-A | | | | | | | | IV-B | | |
| 1. Structural fidelity | ○ | ○ | ◐ | ○ | ○ | ○ | ○ | ◐ | ○ | ○ | ◐ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ● | ● | ◐ | ◐ | ◐ | ● | ● | ◐ | ◐ | ◐ |
| 2. Functional fidelity | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ◐ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ◐ | ○ | ○ | ○ | ○ |
| 3. Reliability/ maintainability | ◐ | ◐ | ○ | ◐ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ◐ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● |
| 4. Fault insertion | ● | ● | ◐ | ● | ● | ◐ | ◐ | ● | ● | ● | ◐ | ◐ | ● | ● | ◐ | ◐ | ● | ◐ | ◐ | ● | ● | ◐ | ● | ● | ● | ◐ | ◐ | ◐ |
| 5. Programmability | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ◐ | ◐ | ◐ |
| 6. Multi-system flexibility | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 7. Noise level/ environmental | ● | ● | ● | ● | ● | ● | ◐ | ○ | ◐ | ○ | ◐ | ○ | ○ | ○ | ● | ● | ◐ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 8. Update/modify | ● | ● | ● | ● | ● | ● | ● | ◐ | ◐ | ● | ◐ | ◐ | ◐ | ● | ● | ● | ◐ | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 9. Safety | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ◐ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 10. Availability | ● | ● | ◐ | ● | ● | ● | ◐ | ◐ | ◐ | ◐ | ○ | ○ | ○ | ○ | ◐ | ● | ◐ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ◐ | ◐ | ◐ |
| 11. Motor skills | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ | ● | ◐ | ● | ○ | ◐ | ● | ● | ○ | ◐ | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 12. Motor/cognitive | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ | ● | ◐ | ● | ○ | ◐ | ● | ● | ○ | ◐ | ◐ | ● | ● | ● | ● | ● | ● | ● | ● | ◐ | ◐ | ◐ |
| 13. Cognitive skills | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ | ○ | ○ | ○ | ○ | ◐ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 14. Student proof | ● | ● | ● | ● | ● | ● | ○ | ○ | ◐ | ○ | ◐ | ○ | ○ | ○ | ◐ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 15. Student access | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 16. Student input | ● | ● | ● | ● | ● | ● | ◐ | ● | ◐ | ● | ◐ | ◐ | ● | ● | ○ | ◐ | ● | ● | ● | ● | ● | ● | ● | ● | ● | ◐ | ◐ | ◐ |
| 17. Feedback to student input | ● | ● | ● | ● | ● | ● | ◐ | ● | ◐ | ● | ● | ◐ | ● | ● | ◐ | ◐ | ● | ● | ● | ● | ● | ● | ● | ● | ● | ◐ | ◐ | ◐ |
| 18. Self-paced use | ◐ | ◐ | ◐ | ◐ | ● | ◐ | ◐ | ● | ◐ | ◐ | ○ | ◐ | ● | ◐ | ◐ | ● | ◐ | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 19. Lockstep use | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ | ◐ | ○ | ◐ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| 20. Usage rate | ○ | ○ | ○ | ◐ | ◐ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ◐ | ◐ | ◐ | ◐ | ● | ● | ◐ | ◐ | ○ | ○ | ● |
| 21. Cost | ● | ● | ● | ● | ● | ● | ● | ◐ | ● | ○ | ○ | ◐ | ○ | ○ | ● | ● | ● | ○ | ○ | ○ | ○ | ◐ | ○ | ○ | ○ | ● | ● | ● |

Figure 2 -- Profiles of 28 training devices

on structural and functional fidelity. Its negative ratings were for fault insertion, programmability, multi-system flexibility, motor skills, student input, feedback to student input,and cost. This device falls into the high price category.

Type IV-A

The profiles of the eight Type IV-A devices (non-prgrammable panel boards) are very similar. This is to be expected since these devices are physically and functionally similar, varying only in the subject matter displayed and, in specific instances, in the amount of operational hardware (meters, dials, switches, controls) mounted on them to complement the primary graphic/schematic representation. The devices generally received positive ratings on functional fidelity, cognitive skills, reliability/maintainability, availability, safety, student proof(ness), student access, noise level, lockstep use and cost. Most of them had provision for a degree of fault insertion and, accordingly, received an intermediate rating in this category.

None of these panel devices had provision for the following categories and, therefore, were given negative ratings: motor skills, motor/cognitive, programmability, update/modifiability, student input, feedback to student input, multi-system flexibility and suitability for self-paced use. Since these devices employed essentially two-dimensional pictorial, graphic and/or schematic representations rather than operational components, they received a negative rating on structural fidelity. However, those panels that incorporated a noticeable number of operational components (meters, switches, etc.) were given an intermediate rating in this category.

Type IV-B

All of the Type IV-B devices examined were engine trainers. Two were in use (UH-1H/T53-L-13A Engine Trainer, UH-1H/T53-L-13A Multi-Purpose Engine Trainer); one was not being used (OH-58A/T63-A-700 Engine Trainer) because it had malfunctioned and was considered "unreliable" by the instructors.

These devices are a combination of two-dimensional displays and simulated or actual operational equipment in the form of an aircraft cockpit. System operation and sequencing are effected by appropriate logic/relay circuitry and servomechanisms that are operated via an instructor console and/or the simulator cockpit controls.

As may be seen in Figure 2, these devices received positive ratings on functional fidelity, noise level, safety, cognitive skills, student-proof(ness), student access and lockstep use; negative ratings were given for multi-system flexibility, update/modifiability, motor skills, self-paced use and cost.

The two UH-1 systems received positive ratings on reliability/maintainability and usage rate while the OH-58 system received negative ratings in these categories.

Type IV-C

No Type IV-C devices (programmable panel type simulators) were included for direct inspection and evaluation. However, as will be discussed later concerning the state of the art in training technology, these devices represent cost-training effective alternatives/supplements to many of the 28 devices reviewed.

### 3.3 Review of the State of the Art in Training Technology.

Most of the training devices reviewed in the present study were at least five years old and many were produced prior to 1970. In the last three to four years, however, significant advances have been made in information processing and display technology that, when applied to training, afford a substantial gain in cost-training effectiveness over previous designs (1, 2, 3, 4).

Modern technology can provide training systems and devices with virtually any features desired. Microprocessors can store vast amounts of information and complex programs for training. Graphic and alphanumeric data from the computer can be presented on plasma and CRT displays, augmented by high speed, random access transparency projections. Realistic panels that incorporate actual components, displays and controls are available. These panels permit direct interaction between the student and microprocessor/mini-computer in the presentation of problems and feedback of the results of student inputs.

In addition to two-dimensional displays, simulated field equipment and test equipment can be utilized to any desired level of fidelity in the student-equipment-display computer loop. Single or multiple training stations can be operated in conjunction with an instructor station for proper systems control and instructional sequencing. Modular design permits expansion or contraction of the system to accommodate varying training requirements.

Specific system configurations range from desk-top models to large complexes such as that of the integrated radio room of the Trident Submarine. With the programmable computers, training systems can be modified or updated to maintain correspondence with operational equipment. These modern systems are usually safer, quieter and less expensive than the corresponding actual equipment. And, there is an increasing amount of research evidence (31-34) that simulations employing these state of the art techniques are less expensive and are at least as training-effective as actual equipment, more so in certain applications.

The specific advantages provided by modern training technology bear directly on those characteristics for which many of the 28 devices reviewed in this study received negative ratings, i.e., fault insertion, programmability, update/modifiability, student input and feedback to student input, multi-system flexibility, suitability for self-paced use and cost. Table 4 presents six examples of contemporary, interactive training devices that incorporate the foregoing desirable training features. (Note: These examples are intended to be representative of available training technology and their inclusion here is not to be considered as an endorsement). These devices fall into category IV-C as defined in Table 1 (programmable systems using two-dimensional displays). As may be seen in Table 4 the range of sophistication and complexity of such devices is substantial and their cost varies accordingly.

Table 4 -- Examples of Current Training Systems

ADAPTIVE LEARNING SYSTEM/Burtek

This system consists of a universal master console combined with one or more systems training panels. The device is operated by a minicomputer that is programmed using a magnetic tape cartridge. The master console includes CRT display, keyboard, and programmable rear projection slide system. Panels depict systems schematically or isometrically/photographically and contain appropriate switches/meters to simulate checking, troubleshooting, or overall evaluation of the system operation or condition.

PLATO SYSTEM/Control Data Corporation

This is a computer-based interactive system utilizing a large computer (CDC CYBER 70 or 170 Series). The principal vehicle through which the user interacts with the computer is the CDC PLATO terminal which employs a plasma display that presents text and drawings in orange against a black background. Viewing area of the plasma panel is 8.5 x 8.5 inches.

EC 3/Educational Computer Corporation

This is a panel type system operated via an integral, microprocessor computer. The system consists of one or more interchangeable display panels, a control center with digital keyboard and LED display, a microprocessor with a basic 16K memory and a programmable, random access slide projection system. The microprocessor is programmed via 256K word, IBM compatible diskette. The system also includes 8 channels for A/D or D/A conversion and 256 input, 128 output channels.

Optional features include incremented expansion of memory, I/O channels, and A/D, D/A channels; and, the following displays: CRT graphic display with keyboard, graphic/oscilloscope display, plasma display, multiple 35 mm slide projectors (any type), cassette or reel video tape, 8 mm or 16 mm motion pictures. A hard copy line printer is also available.

GETS/General Electric Company

The General Electric Training System is a self-contained interactive training console operated via an integral mini-computer that is programmed by floppy disc. The main components include the computer, an 8.5 x 8.5 inch plasma display with 128 character keyboard and a random access slide projection system that rear projects onto the plasma panel. User interacts with the system via the keyboard or a sonic pen placed in contact with the plasma panel.

AEMT/Honeywell

This Automated Electronics Maintenance Trainer (AEMT) consists of a student station and an instructor station. The essential components of the student station are simulated operational equipment, simulated test equipment, an input device such as a keyboard, a display (CRT or plasma) and an interface between this equipment and a minicomputer.

The essential components of the instructor station are a display, an input device, peripheral equipment for storage of software, data for instruction and simulation, and interface devices for communication with and control of the student station. An important advantage of the system is its complete loop between student (keyboard), display, simulated field/test equipment and computer. In many traditional computer based systems the simulated equipment is not tied directly to the computer as it is in the AEMT.

AUDI/POINTER - Ridgeway Electronics (Hallowell, Maine)

The audi/pointer system is a desk-top console consisting of a viewing screen/surface, a control panel and a magnetic pen. The viewing surface accepts drawn or printed schematics/graphics which are transilluminated by a high intensity point of light. The point of light moves according to a predetermined pattern and rate in response to a program on a magnetic tape cartridge. The tape also presents an auditory instructional narration synchronized with the light source indicator on the display area. The student interacts with the system by placing the magnetic pen in contact with the point of light. Users may prepare their own graphics, voice instructions and indicator light pattern/sequence. No special equipment is required.

From the definitions of device types presented in Table 1 and the ratings presented in Figure 2, a generic profile for each device category was prepared as shown in Figure 3. These generalized profiles provide a basis for comparing the characteristics of device types and reveal direct implications for improvement in cost/training effectiveness.

Most apparent are the limitations of the traditional panel devices (Type IV-A) in comparison to the interactive systems (Type IV-C) such as the Educational Computer Corporation EC-3, the Burtek Adaptive Learning System and the General Electric Company GETS system. In terms of overall cost-training effectiveness the interactive systems make the traditional, non-interactive panel boards obsolete.

A further implication is the potential for reducing the number of large composite trainers (Type I) needed for maintenance training. Where multiple copies of large composite trainers and associated supporting media might normally be employed, a cost/training effective alternative would be to replace part of the composite trainers and most of the ancillary media (slide-tape, etc.) with programmable, microprocessor type devices. For example, an array of 3 composite trainers (Type I), 3 systems trainers, (Type II), 3 hard-wired panels (Type IV-A) and 6 different slide-tape programs at an estimated cost of $2 million could be replaced by 2 composite trainers, 2 systems trainers, and 5 microprocessor (Type IV-C) devices at an estimated cost of $1.5 million, or a savings of $.5 million. While, in actuality, the exact number of devices of one type or another would vary, this example illustrates the order of magnitude of cost savings that could be achieved while at the same time greatly increasing the training capability and flexibility of the overall inventory of training devices.

### 3.4 Helicopter Mishaps Related to Maintenance.

Helicopter mishap data from reports published by the U. S. Army Agency for Aviation Safety (USAAAVS) were analyzed to identify implications for improvement in helicopter maintenance training devices. The reports covered 13,037 mishaps (for the AH-1G, UH-1, OH-6A, OH-58,

| CHARACTERISTICS | DEVICE TYPE* I | II | III | IV A | IV B | IV C |
|---|---|---|---|---|---|---|
| 1. Structural fidelity | ○ | ◑ | ◑ | ● | ◑ | ● |
| 2. Functional fidelity | ○ | ○ | ○ | ○ | ○ | ○ |
| 3. Reliability/ maintainability | ◑ | ○ | ○ | ○ | ◑ | ○ |
| 4. Fault insertion | ● | ◑ | ● | ◑ | ◑ | ○ |
| 5. Programmability | ● | ● | ● | ● | ◑ | ○ |
| 6. Multi-system flexibility | ● | ● | ● | ● | ● | ○ |
| 7. Noise level/ environmental | ● | ◑ | ○ | ○ | ○ | ○ |
| 8. Update/modify | ● | ● | ◑ | ● | ● | ○ |
| 9. Safety | ◑ | ○ | ○ | ○ | ○ | ○ |
| 10. Availability | ● | ◑ | ○ | ○ | ◑ | ○ |
| 11. Motor skills | ◑ | ◑ | ◑ | ● | ● | ● |
| 12. Motor/cognitive | ◑ | ◑ | ◑ | ● | ◑ | ◑ |
| 13. Cognitive skills | ◑ | ◑ | ◑ | ○ | ○ | ○ |
| 14. Student proof | ● | ◑ | ○ | ○ | ○ | ○ |
| 15. Student access | ◑ | ○ | ○ | ○ | ○ | ○ |
| 16. Student input | ● | ● | ◑ | ● | ◑ | ○ |
| 17. Feedback to student input | ● | ● | ● | ● | ◑ | ○ |
| 18. Self-paced use | ● | ● | ◑ | ● | ● | ○ |
| 19. Lockstep use | ◑ | ◑ | ◑ | ○ | ○ | ○ |
| 20. Usage rate | ◑ | ○ | ○ | ◑ | ◑ | ○ |
| 21. Cost | ● | ◑ | ○ | ○ | ● | ◑ |

Figure 3 --Generic profiles of device types.

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* As defined in Table 1.

CH-47 and CH-54 helicopters) compiled over various reporting periods from 1 July 1969 through 31 December 1975. Additional data as reported in Flightfax, from March through August, 1976, (12-29) were also examined.

The overall proportion of mishaps attributed to maintenance error was found to be only 5.7 percent. Because of this and the diversity of specific mishap causes reported, no pattern or constellation of parameters could be identified that would bear directly on modification or improvement of maintenance training devices. A summary of the mishap data and accident reports examined is presented in Appendix B.

## 4.0 DISCUSSION

The object of this study was to develop specific recommendations for improvement of helicopter maintenance training devices. One question was whether existing devices could be modified to improve their training effectiveness. In reviewing each of the 28 training devices, the instructors were asked specifically how the device could be altered to improve its usefulness. With the exception of improving visual access to components of the large, composite trainers by removing sections of the skin and replacing them with plexiglass, no modifications of any consequence were identified.

Large items of electrical and hydraulic equipment were found to have high operating noise levels that interfered with communication during training. This problem had been reduced in part by encapsulating the noise sources with sound absorbing material either on the trainer or in adjacent enclosures. Where major remodeling of existing AET's, or future procurements are contemplated, acceptable operating noise levels should be specified. A reasonable upper limit of operating noise is 55 decibels. This would permit conversing in a "very loud voice" at distances of up to 12 feet (30).

A second avenue explored for training device improvement was that of augmentation, i.e., using additional equipment in conjunction with the primary training device. Here, any significant alternatives would have to extend beyond the ancillary devices such as slide-tape programs, video tape, etc., already in use at the training schools. One such device was identified. It is the Audi-Pointer system described in Table 4. The device is interactive, programmable and is designed for self-paced instruction on schematic diagrams, charts and drawings. It would be an excellent supplement to maintenance training where students work with large items of AET or on a bench with operational components.

A third alternative for improvement of training devices is that of substitution, i.e., using a different type of training device in place of one or more already in use. In effect this would be to replace items of actual equipment for training with simulations and/or to replace existing simulations with others that are more cost-training effective. Certainly from a cost standpoint it is desirable to reduce the number of large, composite (Type I and II) training devices needed. And, as was pointed out in section 3.3 of this report, traditional, hard-wired panel devices (Type IV-A) are prime candidates for replacement by Type IV-C programmable, interactive devices (which are of comparable cost at today's prices). In thus replacing (phasing out) the traditional panels there will be a concurrent reduction in the need for AET's because the interactive systems will absorb a significant amount of the training now done on the AET's. At a minimum, time now spent on AET's for student orientation, familiarization, procedures training, and theory of operation will be covered more efficiently on an interactive simulation system.

This is not to say that such systems should replace all AET. On the contrary, AET is necessary at some point in the training cycle. The issue is to determine where that point is and which training objectives are best achieved by it. As training requirements move from "nuts and bolts" toward the more cognitive aspects of understanding electronic, electrical and hydraulic systems, and the acquisition of diagnostic and troubleshooting skills, the programmable interactive training devices become more appropriate than actual equipment. Such devices integrate into a single system much of the media that are traditionally used in an ancillary manner (e.g., slide-tape programs, programmed texts, etc.) while affording a substantial degree of student-system interaction and feedback of results. Furthermore, since such systems are designed for self-paced use, they free the instructor to concentrate on critical areas and to provide more one-on-one instruction.

An argument against replacing operational equipment with simulation is that a certain amount of "realism" or structural fidelity is lost. However, in view of the limited hands-on practice, diagnosis and troubleshooting afforded by existing AET's, as reflected in the device profiles presented earlier (Fig. 2, 3), the gains in cost-training effectiveness far outweigh any loss accruing to reduced structural fidelity.

In summary, the devices currently used for helicopter maintenance training can be improved by substituting modern programmable simulators for some of the large composite trainers, systems trainers and hard-wired panels. In so doing, the following benefits would accrue:

(1) greater opportunity for self-paced instruction with immediate feedback of results.

(2) more effective instruction of procedures, diagnosis and troubleshooting.

(3) more efficient use of instructor time.

(4) integration of various media currently used separately.

(5) increased safety to students and instructors.

(6) reduced ambient noise.

(7) reduced power requirements.

(8) greater flexibility in training presentations including updating and modification.

(9) no loss of capability to teach motor skills provided adequate complement of AET is retained.

(10) reduced cost.

## 5.0 CONCLUSIONS

The following conclusions are drawn with regard to U. S. Army helicopter maintenance training devices:

1. The existing devices have several shortcomings including high cost and limited capability to implement established principles of learning theory, e.g., self-paced instruction, student-device interaction, and feedback of results.

2. Possible improvements through modification of existing devices are very limited and take the form of greater visual access by replacing sections of housings, skin, etc., with plexiglass; reduction in operating noise levels, and updating by replacement of appropriate components.

3. Current instruction with AET typically requires use of ancillary media such as tape-slides, video, hard-wired panel boards, breadboards and miscellaneous printed materials. This contributes indirectly to the overall cost of training based on AET.

4. Use of large, composite trainers for orientation, familiarization and training on components/subsystems is not cost effective in view of alternatives provided by simulation.

5. Use of AET for training electronics troubleshooting and maintenance is not cost effective in view of alternatives provided by simulation.

6. Physical fidelity of AET does not automatically guarantee optimal training effectiveness or transfer of training to the field. Procurement of AET should be subjected to the same criteria/justification of cost/training effectiveness as currently placed on simulation.

7. Recognizing the need for the development of basic motor skills in the use of tools and installation, removal,

etc., of equipment/components, some amount of AET will remain essential. However, AET should not be used at the expense of other vital aspects of training such as the opportunity for repeated practice of skills, continuous testing of knowledge gained, self-paced training and feedback of results.

8. The state of the art in training technology offers significant alternatives or supplements to AET. The key elements of the state of the art are its microprocessor technology; interactive displays including plasma panels, CRT's and programmable, high speed, random access projection systems; modular design for system expansion or contraction; and multi-system capability via interchangeable display panels and computer/microprocessor programmability.

9. The single best approach to improvement of helicopter maintenance training devices is to expand the utilization of programmable, microprocessor simulators in conjunction with properly selected items of AET. Such systems:

(1) cost roughly one-tenth that of a large, composite trainer.

(2) significantly reduce the need for traditional, hard-wired panels and ancillary tape-slide programs.

(3) operate in accordance with established principles of training/instruction.

(4) are safer and quieter to use.

(5) require less space and power than actual equipment trainers.

(6) are easier and less expensive to modify and up-date.

## 6.0 RECOMMENDATIONS

The following recommendations are made with respect to the 28 helicopter maintenance training devices studied.

Type I

1. AH-1G Composite Trainer and AH-1Q Composite Trainer

It is recommended that each copy of this trainer procured in the future be supplemented with four or five interactive panel type simulators with the object of reducing the total number of composite trainers needed, i.e., where two copies of the composite trainer might otherwise be procured, substitute one copy of the trainer and four or five simulators. It is further recommended that, if and when the student load exceeds the present capacity of existing composite trainers and additional equipment is contemplated, the aforesaid simulators be obtained in lieu of additional composite trainers.

2. AH-1G Armament Systems Trainer

While this device is capable of firing a live ammunition it is not so used. It is utilized primarily for pilot orientation and preflight checks. Considering its minimal present use for maintenance training and the fact that maintenance personnel have limited access to weapons systems under operational conditions (typically during and immediately after firing) where they might improve their skills on the job, it is recommended that basic training and orientation be relegated to an appropriate, less costly simulator.

3. AH-1G Armament Systems Maintenance Trainer

This device is used to train electronic and electrical trouble-shooting and correction. Much of the internal circuitry of the operational/test equipment is not necessary for training purposes. Student-system interfaces can be appropriately simulated at a substantial savings in cost, with concurrent improvement in training device reli-ability/maintainability.

4. OH-58A Composite Systems Trainer

The recommendations made above for the AH-1G Composite Trainer apply equally to this device: each copy should be supplemented with 4 - 5 interactive simulator (Type IV-C) devices to reduce by half the number of composite trainers needed.

Type II

1. AH-1G Electrical and Hydraulic Systems Trainer

This device was found to be non-cost/training effective. It is large, extremely noisy (ear protection is required) and expensive. It has little provision for student practice or interaction, and minimal capability for fault insertion. At the time it was examined it was inoperative due to malfunctions.

It is recommended that the training objectives for this device be reviewed and reallocated to less expensive, more effective operational part-task trainers or simulators. It is recommended further that major refurbishment of the device or procurement of additional copies not be undertaken without a detailed consideration of the foregoing alternatives.

2. UH-1A Flight Control and Transmission Trainer

This device is used for demonstrating operation of the flight controls and transmission system. It should be improved by providing greater visual access to the gear assemblies and other unexposed components.

3. UH-1D Fuel System Trainer

This device demonstrates effectively the operation of the UH-1D fuel system. However, it is essentially a demonstrator and students do not disassemble, adjust, or otherwise physically interact with it. The device cost approximately $50,000 when it was purchased in 1968. If and when it is to be replaced it is recommended that its training functions be allocated to an interactive panel type simulator.

4. UH-1D Maintenance Trainer

This device is judged to be appropriate. No recommendations for modification or replacement are made.

5. UH-1D Power Plant T-53-L-11 Trainer

This device is a dynamic model of the T-53-L-11 engine. It is considerably less expensive than the operational equipment and, because of its complexity and dynamic features, it could not be effectively replaced with a two-dimensional representation. Its configuration is judged to be appropriate for its training objectives.

6. UH-1H Electrical Systems Trainer

No modifications or substitutions are recommended for this device. Its configuration is judged to be appropriate for its training objectives.

7. OH-6A Fuel Systems Trainer

No modifications or substitutions are recommended for this device. Its configuration is judged to be appropriate for its training objectives.

8. OH-6A Fuel Systems Trainer

This device is a three-dimensional static display comprised of actual and simulated fuel system hardware. It should be phased out in favor of a high quality two-dimensional representation.

9. OH-6A Power Plant T63-A-5A Trainer

This device is a dynamic model of the T63-A-5A engine. It is considerably less expensive than the operational equipment and, because of its complexity and dynamic features, it could not be effectively replaced with a two-dimensional representation. Its configuration is judged to be appropriate for its training objectives.

10. CH-47A Tubular Utility Hydraulic Systems Trainer

The design and use of this device are judged to be appropriate. No recommendations for modification or substitution are made.

11. CH-47C Electrical Systems Trainer

The design and use of this device are judged to be appropriate. No recommendations for modification or substitution are made.

Type III

1. CH-47A Hydraulic Board Trainer

To the extent that this device is used by students to practice installation, removal and adjustment of components it is judged to be appropriate. To the extent that it serves only as a demonstrator, it should be phased out and replaced by a dynamic, two-dimensional, representation retaining only those three-dimensional actual equipment components deemed necessary.

Type IV-A

All of the following traditional panel devices should be phased out and replaced with interactive, programmable systems employing single or multiple (interchangeable) panels:

1. AH-1G Electrical Systems Display Panel (1-79)
2. AH-1G Hydraulic Systems Display Panel Trainer (1-80)
3. UH-1B Electrical Systems Panel Trainer (1-70)
4. UH-1B Fuel Systems Trainer (1-69)
5. OH-58A Electrical Systems Panel Trainer (1-83)
6. OH-58A Instrument Systems Panel Trainer (1-84)
7. OH-58A Fuel Systems Panel Trainer (1-85)
8. OH-58A Engine Oil Systems Trainer (1-86)

As shown previously (Figures 2, 3), interactive devices (Type IV-C) are superior to the traditional panel devices (Type IV-A) in fault insertion, programmability, update/modifiability, student input, feedback to student input, multi-system flexibility, self-paced use and in teaching motor/cognitive skills. While the initial procurement of an interactive system may be somewhat higher than a single traditional panel device, the cost-training effectiveness would be significantly greater for the interactive system. In some instances, the initial cost of the interactive system would be less than that of the traditional panel device since the latter cost about $40,000 to $75,000 per copy.

Type IV-B

1. UH-1H/T53-L-13A Engine Trainer

2. UH-1H/T53-L-13A Multi-Purpose Engine Trainer

3. OH-58A/T63-A-700 Engine Trainer

The three devices reviewed in this category were engine trainers, used primarily to train pilots in proper engine starting and operating procedures and to train maintenance personnel to recognize and troubleshoot malfunctions. The UH-1H Trainers received very favorable comments from instructors. The OH-58A Trainer was reported to be functionally unreliable and was not in use.

These devices cost approximately $250,000 each when purchased in 1968. Although a simulated cockpit is provided with each, whereby a student can interact with the system, they are essentially classroom demonstration devices. Whether or not the cost of such devices is justified on the basis of pilot training is beyond the purview of the present study. As a procedures trainer for maintenance personnel, however, their cost can not be justified in relation to the training benefits provided. If such devices are to be continued for use with pilots, it is recommended that the present practice of including maintenance personnel be continued. However, from the standpoint of training maintenance personnel apart from pilots, or in the absence of access to these large engine training devices, the starting, operating and troubleshooting procedures can be trained more effectively, and at 70% to 80% less cost (of equipment) with smaller programmable systems. Accordingly, the latter alternative is recommended if and when the foregoing conditions occur.

Type IV-C

No training devices in this category were reviewed on-site.

* * *

## 7.0 REFERENCES


1. Modrick, John A., Arnold F. Kanarick, Richard W. Daniels and James A. Gardner. AEMT: Technology Issues in Simulation for Maintenance Training. in King, W. J., and J. S. Duva (eds) New Concepts in Trainers and Performance Aids. NAUTRAEQUIPCEN IH-255, October 1975.

2. Siecko, Nicholas A., Maintenance Readiness Through Effective Simulation Training. Proceedings of the Ninth NTEC/Industry Conference 9-11 November 1976. Naval Training Equipment Center, Orlando, Fla. 32813.

3. Wright, Joann and Jane Campbell, Evaluation of the EC II Programmable Maintenance Simulator in T-26 Organizational Maintenance Training. Report No. NADC-75083-40 Naval Air Development Center, Warminster, Pa. 18974, 15 May 1975.

4. Malone, Thomas B., Jack J. DeLong, Raymond Farris. Advanced Concepts of Naval Engineering Maintenance Training, NAUTRAEQUIPCEN REPORT 74-6-0151, Naval Training Equipment Center, Orlando, Fla. 32813, 13 July 1975.

5. Index and Description of Army Training Devices, Pamphlet No. 310-12 (C-1), Headquarters, Department of the Army, Washington, D. C., 30 May 1975.

6. AH-1G Mishap Experience Report, United States Army Agency for Aviation Safety, Fort Rucker, Al. 36360, January 1973.

7. UH-1 Mishap Experience Report, United States Army Agency for Aviation Safety, Fort Rucker, Al. 36360, March 1974.

8. OH-6A Mishap Experience Report, United States Army Agency for Aviation Safety, Fort Rucker, Al. 36360, October 1973.

9. OH-58 Mishap Experience Report, United States Army Agency for Aviation Safety, Fort Rucker, Al. 36360, December 1974.

10. CH-47 Mishap Experience Report, United States Army Agency for Aviation Safety, Fort Rucker, Al. 36360, June 1975.

11. CH-54 Mishap Experience Report, United States Army Agency for Aviation Safety, Fort Rucker, Al. 36360, April 1976.

12. FlightFax: United States Army Agency for Aviation Safety, Fort Rucker, Al. 36360, Vol. 4, No. 19, 3 March 1976.

13. __________ No. 10, March 1976.

14. __________ No. 22, March 1976.

15. __________ No. 23, 31 March 1976.

16. __________ No. 24, 7 April 1976.

17. __________ No. 26, 21 April 1976.

18. __________ No. 29, 12 May 1976.

19. __________ No. 30, 19 May 1976.

20. __________ No. 33, 9 June 1976.

21. __________ No. 34, 16 June 1976.

22. __________ No. 35, 23 June 1976.

23. __________ No. 36, 30 June 1976.

24. __________ No. 37, 7 July 1976.

25. __________ No. 38, 14 July 1976.

26. __________ No. 40, 28 July 1976.

27. __________ No. 42, 11 August 1976.

28. __________ No. 43, 18 August 1976.

29. __________ No. 44, 25 August 1976.

30. McCormick, E. J., Human Engineering, McGraw-Hill, New York 1957.

# APPENDIX A

Pictures of the Training Devices Selected for Study



BEST AVAILABLE COPY

## AH-1G COMPOSITE TRAINER

DVC 1-31 585

FSN None

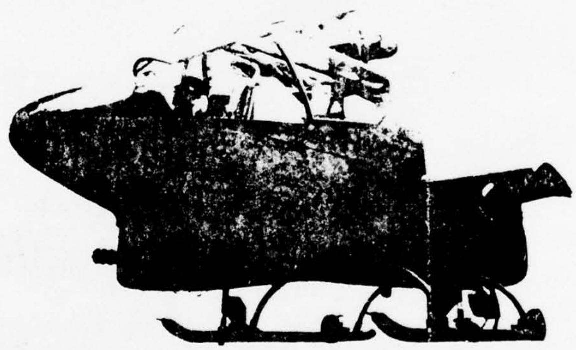
DVC NO. 1-31

Pam 310-12

## AH-1G ARMAMENT SYSTEMS TRAINER

DVC 1-34 597

FSN None



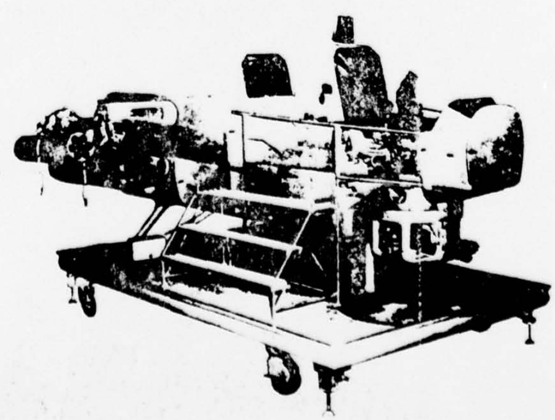
DVC NO. 1-34

Pam 310-12

## AH-1G ARMAMENT SYSTEMS MAINTENANCE TRAINER

DVC 1-33 587

FSN None



DVC NO. 1-33

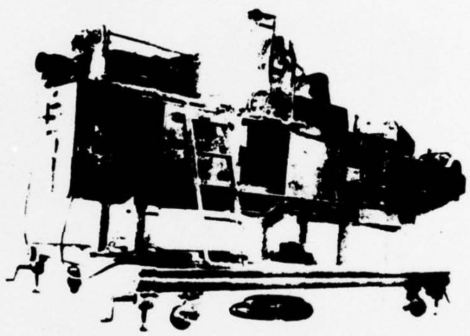
DVC NO. 1-81

Pam 310-12

## AH-1G ELECTRIC AND HYDRAULIC SYSTEMS TRAINER

DVC 1-32
5A6

FSN None



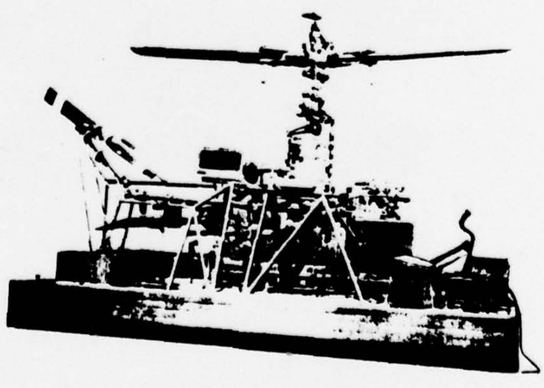
DVC NO. 1-32

Pam 310-15

## UH-1A FLIGHT CONTROL AND TRANSMISSION SYSTEM TRAINER

DVC 1-68
2A19

FSN None



DVC NO. 1-68

## OH-58A COMPOSITE SYSTEMS TRAINER

DVC 1-81
OH-58A

FSN None

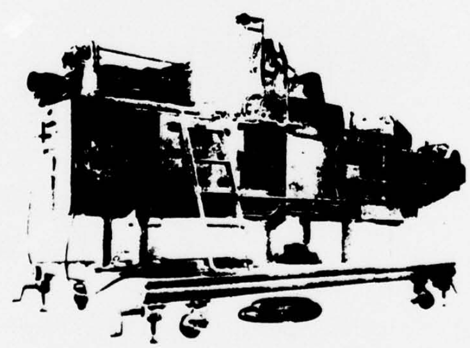
DVC NO. 1-81

Pam 310-12

## AH-1G ELECTRIC AND HYDRAULIC SYSTEMS TRAINER

DVC 1-32
506

FSN None



DVC NO. 1-32

Pam 310-12

## UH-1A FLIGHT CONTROL AND TRANSMISSION SYSTEM TRAINER

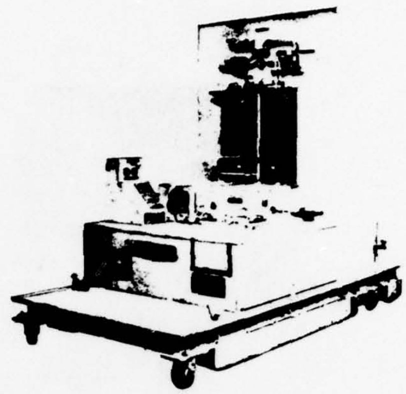
DVC 1-68
2A19

FSN None

DVC NO. 1-68

## UH-1D FUEL SYSTEM TRAINER

**DVC 1-71** **FSN None**

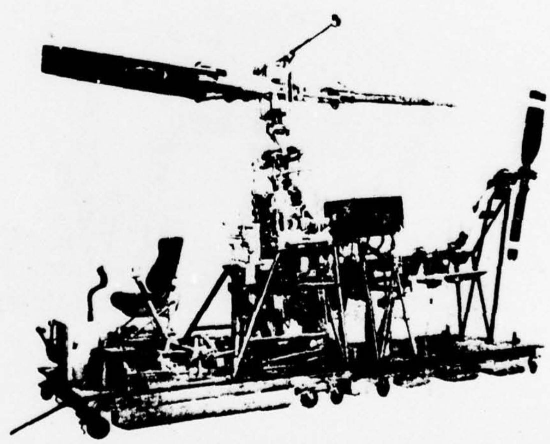


DVC NO. 1-71



## UH-1D MAINTENANCE TRAINER

**DVC 1-72** **FSN None**

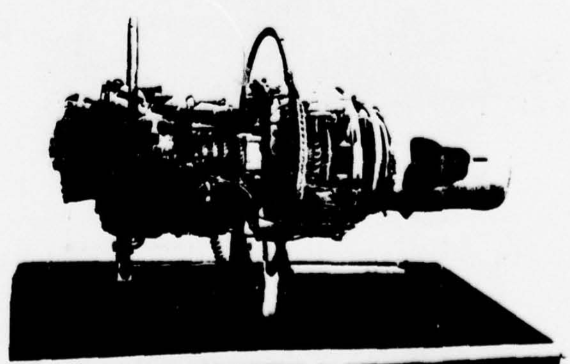


DVC NO. 1-72



## UH-1D POWER PLANT T53-L-11 TRAINER

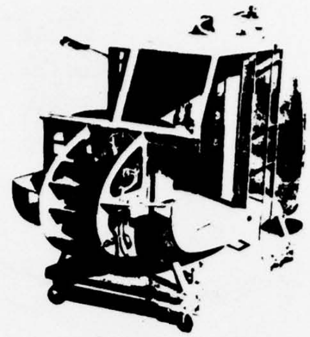
**DVC 1-37** **FSN None**



DVC NO. 1-89

## UH-1H ELECTRICAL SYSTEM TRAINER

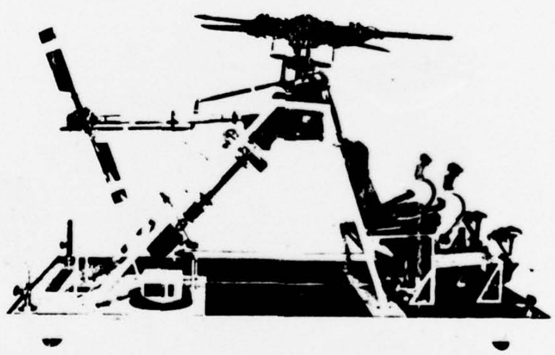
DVC 1-73 NSN None





## OH-6A COMPOSITE TRAINER

DVC 1-63 FSN None

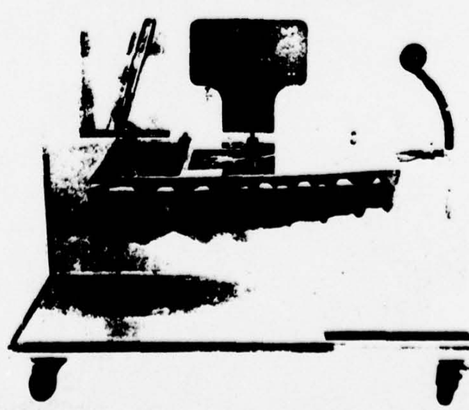


DVC NO. 1-63



## OH-6A FUEL SYSTEM TRAINER

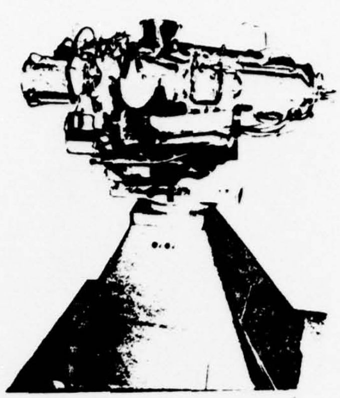
DVC 1-65 FSN None



DVC NO. 1-65

## OH-6A POWER PLANT T63-A-5A TRAINER

DVC 1-36 FSN None

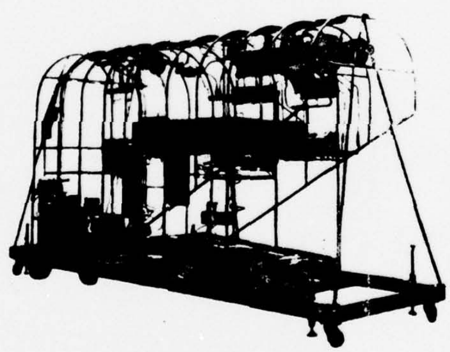


DVC NO. 1-36



## CH-47A TUBULAR UTILITY HYDRAULIC SYSTEM TRAINER

DVC 1-47 FSN None

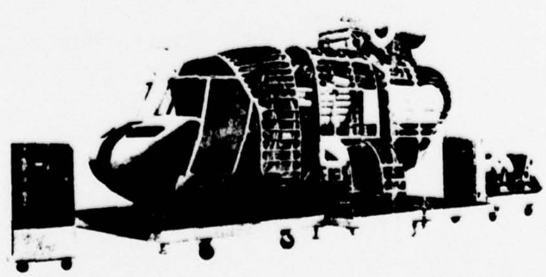


DVC NO. 1-47



## CH-47C ELECTRICAL SYSTEMS TRAINER

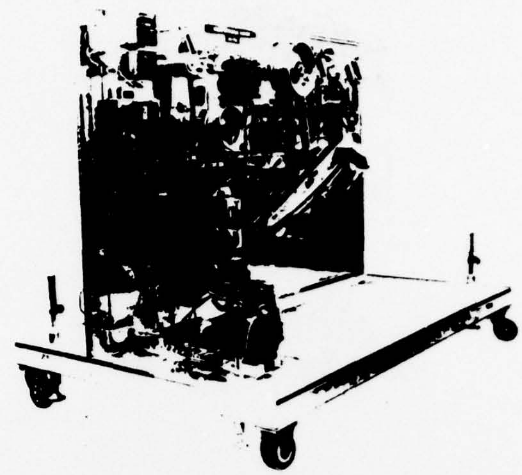
DVC 1-46 FSN None



DVC NO. 1-46

## CH-47A HYDRAULIC BOARD TRAINER

DVC 1-50 FSN None



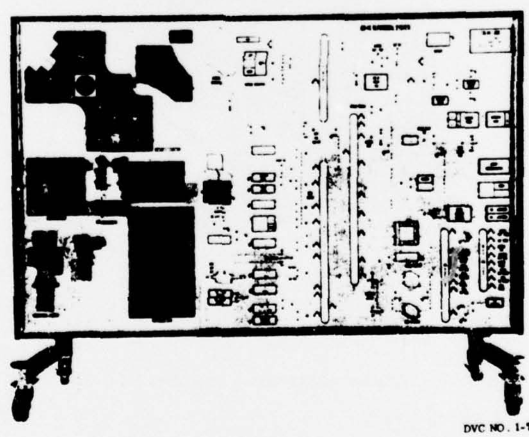
DVC NO. 1-50



## AH-1G ELECTRICAL SYSTEMS DISPLAY PANEL

DVC 1-79
AH-1G

FSN None



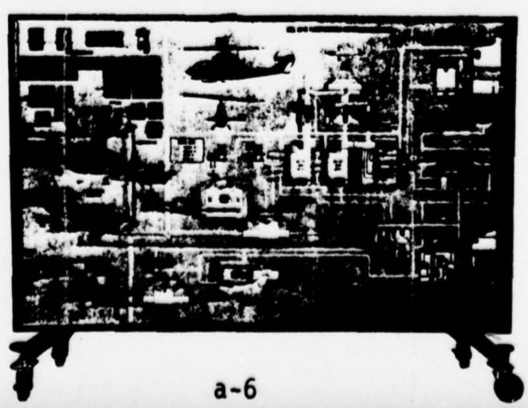
DVC NO. 1-79



## AH-1G HYDRAULIC SYSTEMS DISPLAY PANEL TRAINER

DVC 1-80
AH-1G

FSN None

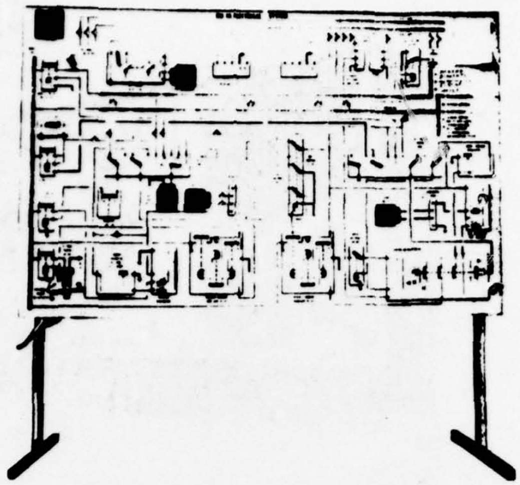




DVC NO. 1-80

**UH-1B ELECTRICAL SYSTEM PANEL TRAINER**

DVC 1-70 FSN None

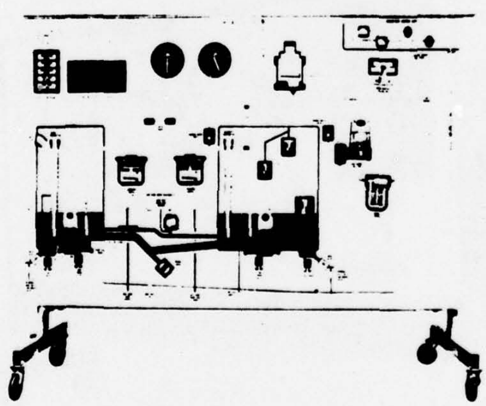


DVC NO. 1-70

Pam 310-12

**UH-1B FUEL SYSTEM TRAINER**

DVC 1-69
2A19 FSN None

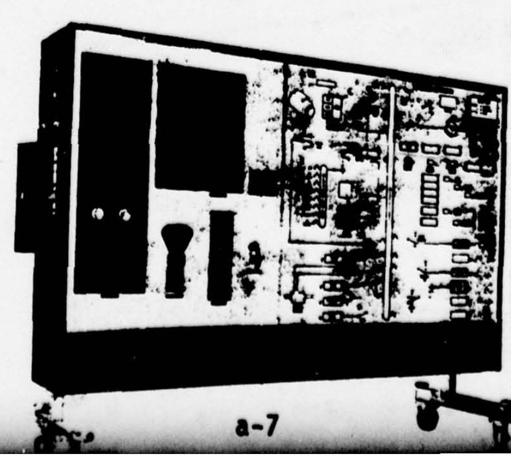


DVC NO. 1-69

Pam 310-12

**OH-58A ELECTRICAL SYSTEMS TRAINER**

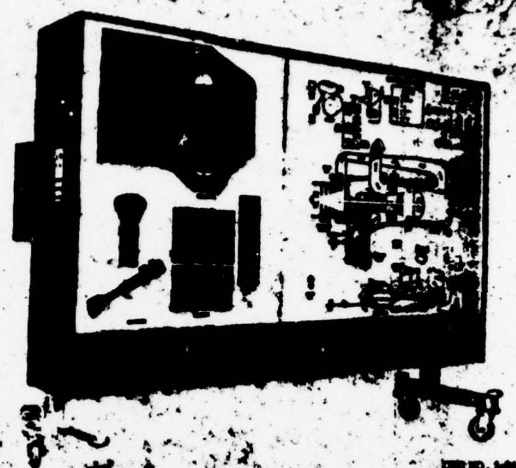
DVC 1-68
OH-58A FSN None



OH-58A INSTRUMENT SYSTEMS PANEL T[illegible]

DVC 1-[illegible]
OH-58A

FSN None



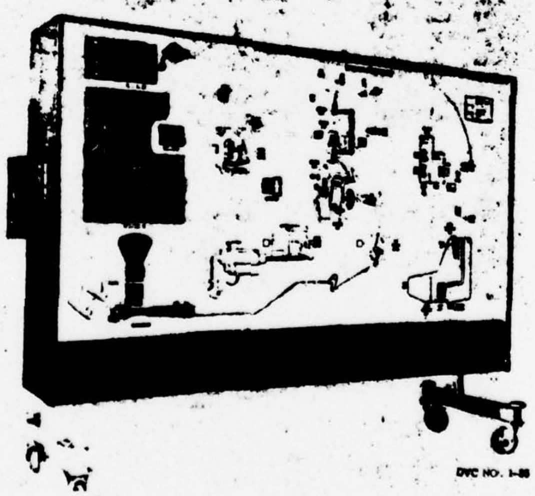
DVC NO. 1-[illegible]

Pam 310-12

OH-58A FUEL SYSTEMS PANEL/TRAINER

DVC 1-[illegible]
OH-58A

FSN None



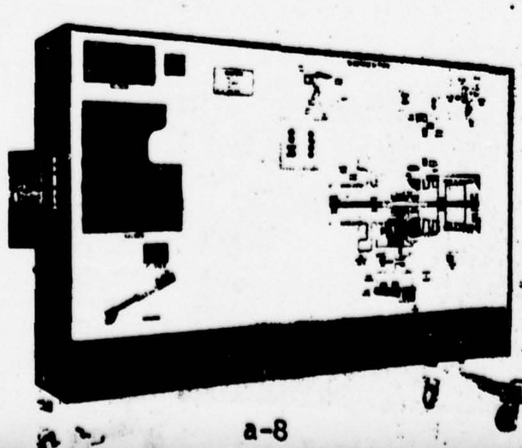
DVC NO. 1-[illegible]

Pam 310-12

OH-58A ENGINE OIL SYSTEMS TRAINER

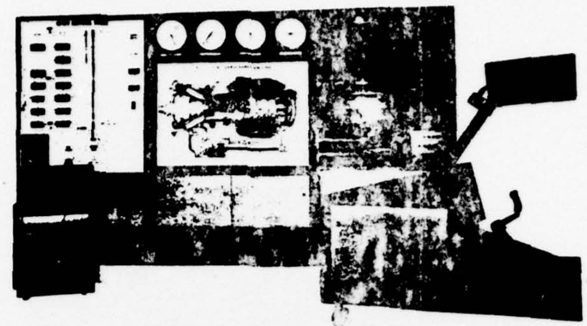
DVC 1-[illegible]
OH-58A

FSN None



## UH-1H/T53-L-13A ENGINE TRAINER

**DVC 1-89** **FSN None**
**2A27D**

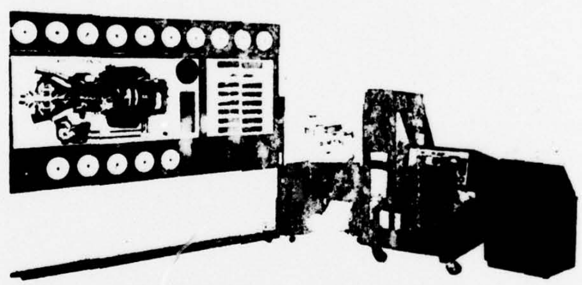


DVC NO. 1-89



## UH-1H/T53-L-13A MULTI-PURPOSE ENGINE TRAINER

**DVC 1-90** **FSN None**
**2A27A-1**

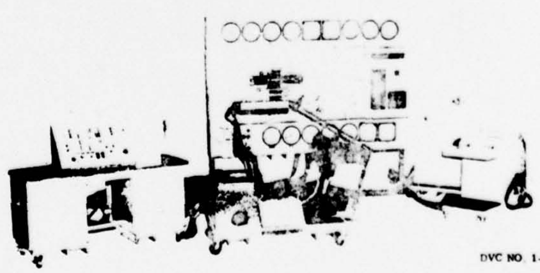


DVC NO. 1-90



## OH-58A/T63-A-700 ENGINE TRAINER

**DVC 1-99** **FSN None**
**2A27E**



DVC NO. 1-99

# APPENDIX B

## Helicopter Mishap Data Related to Maintenance

## Appendix B

### Helicopter Mishap Data Related to Maintenance

Helicopter mishap data compiled from reports published by the U. S. Army Aviation Agency for Aviation Safety (USAAAVS) is presented in Table B-1. The reports (references 6-11) were for varying periods between 1 July 1969 and 31 December 1975 for the AG-1G, UH-1, OH-6A, OH-58, CH-47 and CH-54 aircraft.

As shown in Table B-1, of a total of 13,037 mishaps reported, 738 (5.7%) were attributed to maintenance error, 6803 (52.2%) to material malfunction/failure, 3772 (28.9%) to crew error and 1724 (13.2%) to "other". The total mishaps included 1043 fatalities, 2053 injuries and an estimated financial (material) loss of $269,641,333.

Table B-2, compiled from mishap reports published in Flightfax, for March through August, 1976 (references 12 - 28) illustrates the diversity of specific causes associated with helicopter mishaps.

Table B-1 -- Summary of Helicopter Mishap Data

| Aircraft | AH-1G | | UH-1 | | OH-6A | | OH-58 | | CH-47 | | CH-54 | | TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mishap Reporting Period | 1 July 1969 through 30 June 1971 | | FY 1971, 72 and 73 | | 1 July 1967 through 30 June 1971 | | 1 Jan 1972 through 31 Dec 1973 | | FY 1971 and FY 1972 | | 1 July 1972 through 31 Dec 1975 | | | |
| Cause Factor | NO. | % | NO. | % | NO. | % | NO. | % | NO. | % | NO. | % | NO. | % |
| Maintenance | 68 | 6.4 | (392.)* | (5.5) | 104 | 5.2 | 69 | 7.5 | 101 | 10.7 | 4 | 4.5 | 738 | 5.7 |
| Material | 754 | 71.6 | 3984 | 55.9 | 848 | 42.5 | 425 | 46.2 | 714 | 76.0 | 78 | 88.6 | 6803 | 52.2 |
| Crew Error | 199 | 18.9 | 1746 | 24.5 | 668 | 33.5 | 143 | 15.6 | 101 | 10.7 | 5 | 5.7 | 3772 | 28.9 |
| Other | 32 | 3.0 | 1010 | 14.2 | 375 | 18.8 | 282 | 30.7 | 24 | 2.6 | 1 | 1.1 | 1724 | 13.2 |
| TOTAL MISHAPS | 1053 | | 7132 | | 1995 | | 919 | | 940 | | 88 | | 13,037 | |
| Fatalities | 92 | | 666 | | 93 | | 29 | | 162 | | 1 | | 1043 | |
| Injuries | 129 | | 1290 | | 362 | | 53 | | 131 | | 88 | | 2053 | |
| Cumulative Accident Rate Flying Over 100,000 Hours | Not reported | | 13.9 | | 50.8 | | 7.0 | | 11.7 | | 3.3 | | | |
| TOTAL MISHAP COST | $51,400,000 | | $148,632,942 | | $31,023,000 | | $4,297,331 | | $31,815,271 | | $2,472,789 | | $269,641,333 | |
| Reference No. | 6 | | 7 | | 8 | | 9 | | 10 | | 11 | | | |

* estimated as 5.5% of total mishaps

Table B-2 -- Sample of Maintenance Mishaps Reported in FlightFax (February through August 1976)

| Ref. | Aircraft | Event* | Description |
|---|---|---|---|
| (12) | AH-1 | FL | Contaminated hydraulic system. |
| (12) | AH-1 | PL | Chips in $90^0$ gearbox - input quill had been improperly shimmed during assembly at depot. |
| (13) | AH-1 | PL | Coaxial cable jammed between right pedal and right wall - misrouted cable. |
| (14) | AH-1 | PL | Ruptured transmission oil line - locally manufactured hose assembly was wrong material and wrong length. |
| (14) | AH-1 | PL | Failure of internal transmission oil filter gasket - oil filter cover had been improperly torqued. |
| (17) | AH-1 | PL | Master caution light and forward fuel boost light came on - improperly connected cannon plug. |
| (23) | AH-1 | PL | Loss of transmission oil pressure -- suspect filter gasket mounting bolts improperly torqued. |
| (28) | AH-1 | PL | Low transmission oil pressure - incorrect torque applied to oil line fitting. |
| (14) | UH-1 | PL | Failure of internal oil filter gasket - gasket had been reinstalled instead of replaced as per TM. |
| (15) | UH-1 | PL | Battery fumes entered cockpit - voltage regulator had been set too high. |
| (15) | UH-1 | PL | Voltmeter reading 30 volts during flight - voltage regulator had been set too high. |
| (27) | UH-1 | Incident | Hole in tail rotor drive shaft cover-ratchet and mallet had been left under No. 4 tail rotor drive shaft, causing damage to drive shaft, hanger bearing and drive shaft cover. |
| (27) | UH-1H | Accident (total) | Material failure of No. 1 hanger bearing due to fretting and corrosion - (contributing factor) improper maintenance procedures and quality control in inspection of hanger bearing during removal and reinstallation 10 hours prior to flight and until failure. (New improved hanger bearing has been approved). |
| (15) | OH-58 | PL | Binding in tail rotor pedals - tail rotor out of rig. |
| (22) | OH-58 | FL | Air line from fuel control to accumulator had come loose. |
| (28) | OH-58 | PL | Grinding noise from engine compartment -- suspect improper installation of free-wheeling unit seal. |
| (28) | OH-58 | PL | Titanium chips in engine - engine was 286 flight hours past due for rebuilding. |
| (12) | CH-47 | PL | Hydraulic fluid leak - locknut on hydraulic pump tube fitting improperly torqued. |
| (18) | CH-47 | PL | No. 1 engine work platform came open - crew failed to insure that all cowlings were secured before flight. |
| (28) | CH-47 | PL | No. 2 flight boost failed causing loss of No. 2 hydraulic system - due to installation of 15 psi line instead of required 3000 psi line. |
| (15) | CH-54 | PL | Transmission oil loss - cracked fitting at transmission oil line reducer assembly. |
| (16) | CH-54 | PL | Hydraulic leak - chafed pressure line at No. 1 flight boost pump. |
| (15) | OH-58 | PL | Tail rotor controls stuck in right pedal position - plug for KY28 was lodged between tail rotor control tube and avionics pedestal. |

* FL = Forced landing
PL = Precautionary landing