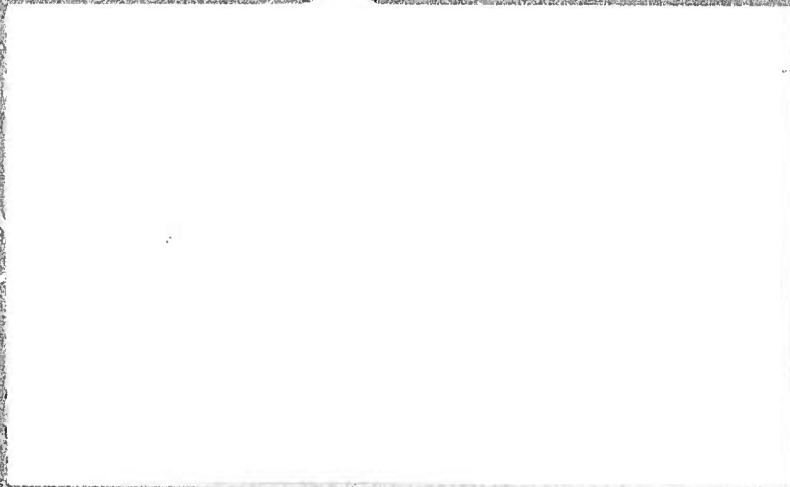


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FINAL REPORT

on

FEASIBILITY OF A NAP-OF-THE-EARTH TRAINER
USING A QH-50D REMOTELY PILOTED HELICOPTER
AND SYNTHETIC FLIGHT TRAINING SYSTEM

by

D. W. Welp, A. S. Chace, and F. A. Tietzel

Sponsored by

PM TRADE
Army Materiel Command
Fort Benning, Georgia 31905
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December 1975

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FOREWORD

This study was supported by PM TRADE, Army Materiel Command, and was monitored by the U. S. Army Missile Command under Contract No. DAAH01-73-C-0142. It represents a limited effort in response to a specific question and is not intended to be a definitive report on this particular subject area.

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FEASIBILITY OF A NAP-OF-THE-EARTH TRAINER
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D. W. Welp, A. S. Chace, and F. A. Tietzel

INTRODUCTION

The executive committee of a recent conference^{(1)*} sponsored by the U. S. Army Office of the Chief of Research, Development, and Acquisition, concluded that

"A nap-of-the-earth capability is broadly recognized as a firm requirement of Army aviation in light of the projected anti-aircraft weapon threat in any future conflict. This operational requirement, coupled with the advent of a new family of Army helicopters, is the basic justification for an intensified program of research on aircrew performance."

"The research program should focus on nap-of-the-earth training to define and improve instructional content, procedures, and devices."

More specifically, they concluded that

"High-fidelity visual simulation techniques need to be developed to support nap-of-the-earth training and performance research."

Six-degree-of-freedom motion simulators, coupled with visual systems, are presently being developed for several U. S. Army helicopters. These systems utilize specially developed video displays which obtain their input from a video camera mounted on a movable gantry viewing a scale model terrain board. Table 1 shows the approximate delivery schedule for prototypes of several of these Synthetic Flight Training Systems (SFTS). Five 2B33 production systems will be acquired. One each will be located at Fort Campbell, Fort Lewis, Fort Bragg, Fort Hood, and in Europe. These systems appear to be promising for nap-of-the-earth (NOE) training. However, the adequacy of the display/scale model terrain board system for NOE training will not be fully verified until more experience with the new systems is obtained.

* References are listed at the end of this report.

TABLE 1. DELIVERY DATE OF PROTOTYPE SFTS
TO FORT RUCKER, ALABAMA

SFTS Designation	Helicopter Simulated	Prototype Delivery
2B31	CH-47	Spring, 1976
2B33	AH-1Q	Fall, 1976
2B38	UTTAS	Fall, 1978
2B40	AAH	Fall, 1979

The development of simulators is motivated by the need for safe, efficient training systems which are less expensive to operate and support than training in the actual helicopter. The SFTS/terrain board systems appear to be a step in this direction, but their acquisition cost is high and they require extensive support facilities. These costs can be justified if there is a high utilization rate and available facilities (as would be the case at training centers), and they provide adequate training. However, they would be difficult to justify at each operational unit site.

U. S. Army PM TRADE (Program Manager for Training Devices) has postulated that it may be feasible to develop a system for training crews to fly NOE by integrating an existing remotely piloted helicopter (RPH) with a SFTS. This system would provide a new method of simulating motion and visual cues. Numerous QH-50D remotely piloted helicopters are currently in storage. The QH-50D was developed as a drone antisubmarine helicopter (DASH) carried aboard U. S. Navy destroyers. These systems should be capable of carrying instrumentation and TV cameras which transmit the RPH motion and scenic environment to a ground station (SFTS).

The objective of this report was to conduct a preliminary study to examine the feasibility of using a sensor-instrumented RPH as part of a closed-loop crew training system, coupled with a SFTS. The system concept is illustrated in Figure 1. For purposes of this report, the term SFTS is intended to include the cockpit(s) and associated visual system for a single crew. For an SFTS utilizing two separate cockpits for one crew, both visual systems would utilize the same video input. Most of the discussion assumes the use of a single camera for obtaining the video image.

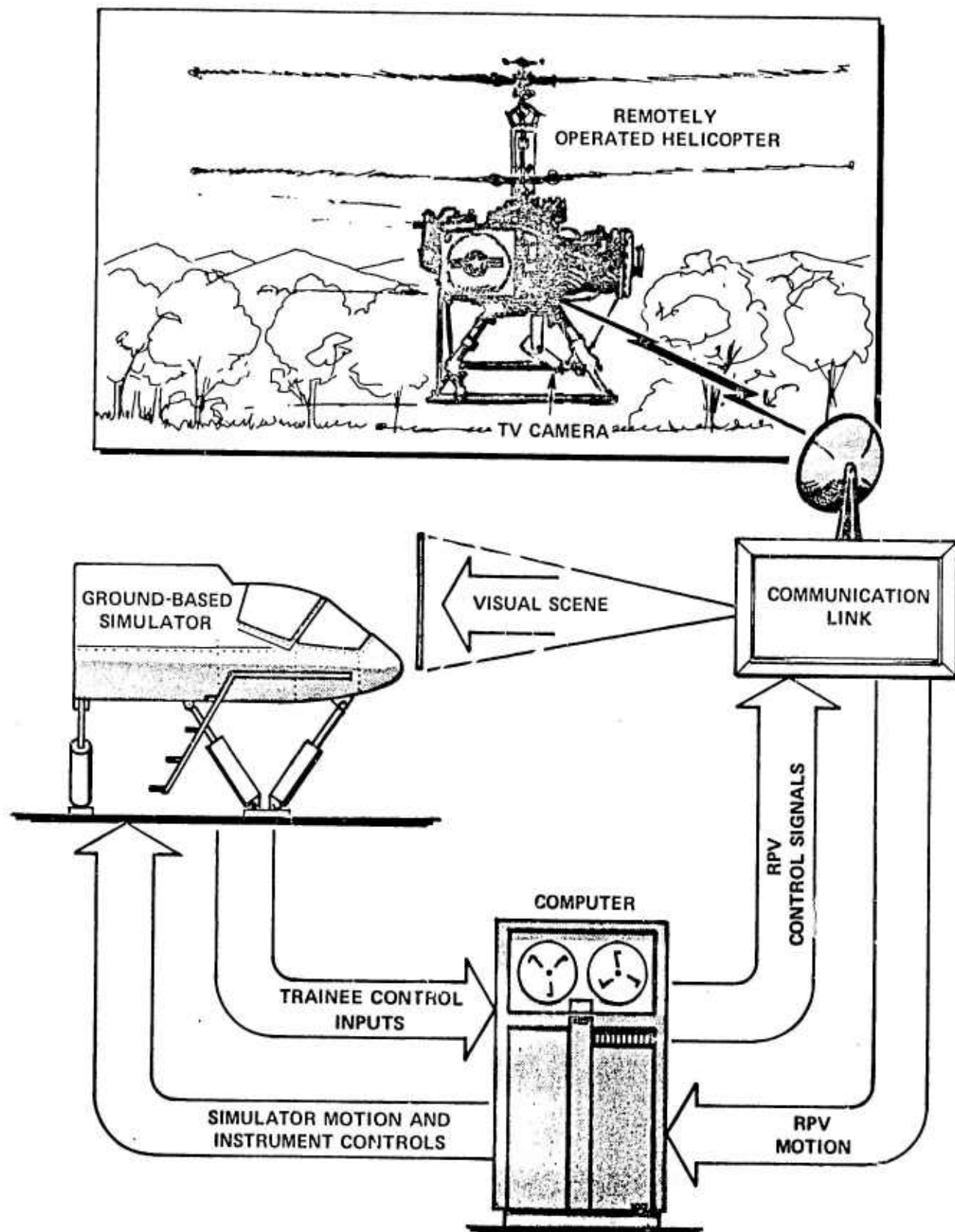


FIGURE 1. SYSTEM CONCEPT OF TRAINING SIMULATOR

Two areas of training are of interest--initial training and proficiency training. Initial training is conducted at only a few sites. SFTS systems with terrain boards and visual systems are being developed for these sites. The QH-50D/SFTS system would be of value for initial training if:

- (1) It provides more cost-effective visual and motion cues than the SFTS/terrain board systems
- (2) The SFTS/terrain board systems are inadequate for NOE training
- (3) The QH-50D/SFTS system offers supplementary training capability not available from the SFTS/terrain board system.

The purpose of proficiency training is to maintain the skill levels of operational crews. Training must be provided for personnel located at numerous sites in the U. S. and overseas. The QH-50D/SFTS system would be of value for proficiency training if:

- (1) It is significantly more cost-effective than use of the actual helicopters
- (2) It faithfully duplicates the environment of the actual helicopter
- (3) It is more cost-effective than alternative techniques for proficiency training.

As part of this study, numerous visits and contacts were made to gather information. Table 2 shows a list of the contacts and the type of information gathered.

This report describes characteristics of the elements of a QH-50D/SFTS system, provides an estimate of costs, describes operational requirements and limitations, and makes recommendations regarding implementation.

TABLE 2. INFORMATION GATHERING CONTACTS

Contact	Agency	Form of Contact	Purpose
Faye Wirth	American Airlines Training Center	Visit	Redifon Visual System
James Scott	Beechcraft (at White Sands)	Visit	QH-50D Flights
Dave Kaplan	Bell Helicopter	Visit	NOE Data
Carl Driskell	PM TRADE-Orlando, Florida	Phone	Helmet-Mounted Display
Lt. Col. Catron	PM TRADE-Orlando, Florida	Visit	SFTS
Ron Hershberger	Sierra Research Corporation	Phone	Telemetry Systems
Everett Smith	Singer-Kearfott	Phone	Inertial Navigation Systems
R. J. Mongeon	United Technology Research Center	Phone	"LOTAWS" Terrain Avoidance
Larry Banks	Allison Division-GM Corporation	Phone	Aircraft Engines
Pete Papadakos	Gyrodyne Company of America	Visit	QH-50D
Dr. Jim Bynum	ARI-Ft. Rucker	Visit	NOE Training
Capt. Beach	Helicopter Flight School-Ft. Rucker	Visit	NOE Instructor
Dr. Paul Caro	HUMRRO-Pensacola, Florida	Phone	SFTS
Clay White	ASD-Wright-Patterson AFB	Phone	Terrain Avoidance Radar
Jim Price	Texas Instruments	Phone	Terrain Avoidance Systems
Col. Visser	MASTER-Ft. Hood	Phone	NOE Pilot
Cliff Meldrum	Singer, Link Division	Visit	SFTS System
Karl Stich	Night Vision Labs-Ft. Belvoir	Phone	Helmet Sights
John Brubaker	Rockwell International	Visit	Navigation Equipment, Radar Altimeter, Camera Mount
Jim Klein	Collins Radio, Div. of Rockwell International	Visit	RPH Autopilot, Air Data Sys.
R. J. Mongeon	United Technology Research Center	Phone	Laser Obstacle Terrain Avoidance Warning System

TABLE 2. (CONTINUED)

Contact	Agency	Form of Contact	Purpose
E. Brodsky	Aeroflex	Phone	Stable Platform for Television Camera
John Class	Philco Ford, Aeronautronic Division	Phone	Stable Platform for Television Camera
Jim King	Rockwell International	Phone	Stable Platform for Television Camera
Graham Wilson	REDIFON Electronics, Inc.	Visit*	Redifon Visual System
Leo Beiser	EPSCO Laboratories	Phone	Color TV Camera
Marv Fischthal	Grumman	Phone	Color TV Camera
Herbert D. Cook	REDIFON Electronics (U. S. Director of Customer Requirements)	Phone	Color TV Camera
Joe Mays	System Research Laboratory	Phone	Color TV Camera
A. J. Romaho	Video System, Incorporated	Phone	Color TV Camera
Lyle Hoff	Beechcraft (at WSMR)	Phone	Emergency Shut-down
Bob Moyer	Terra Com	Phone	TV Data Link
Mr. Sawert	Conic Corp.	Phone	TV Data Link
Jim Apel	Rockwell International	Visit	Integration and Flight Test Costs

* REDIFON Development Manager from England happened to be visiting American Airlines Training Center at the time of our visit.

EXECUTIVE SUMMARY

Objective

U. S. Army PM TRADE has postulated that it may be feasible to develop a system for training crews to fly nap-of-the-earth (NOE) by integrating an existing QH-50D remotely piloted helicopter (RPH) with a synthetic flight training system (SFTS). This system would provide a new method of simulating motion and visual cues. The QH-50D, currently in storage at Davis-Monthan AFB, Arizona, should be capable of carrying instrumentation and TV cameras which transmit the RPH motion and scenic environment to a ground station (SFTS). The system concept is depicted in Figure 1. The term SFTS is intended to include the cockpit(s) and associated visual system for a single crew. For an SFTS utilizing two separate cockpits for one crew, both systems would utilize the same video input.

The objective of this report was to conduct a preliminary study to examine the feasibility of using a sensor-instrumented RPH as part of a closed-loop crew training system, coupled with a SFTS.

Approach

A number of helicopter synthetic flight training systems are currently under development. The 2B33 SFTS, which will simulate the AH-1Q Cobra, contains two independent moving base cockpits. One of the cockpits is used for pilot training. It contains two visual displays; one directly in front of the pilot with a field of view of 47 degrees by 31 degrees, and another with the same field of view centered 53 degrees left. The other cockpit is used to train the copilot; its visual display provides a central 47 degrees x 33 degrees field of view. The image generators for the 2B33 consist of two identical 24 ft by 64 ft model terrain boards scaled at 1500:1. Each model is viewed by a television camera with an optical probe mounted on a movable gantry.

The study of the RPH/SFTS was concentrated primarily on examination of the RPH because of the availability of a SFTS which would be compatible with a visual image from a RPH. As part of the study, numerous visits and phone contacts were made to:

- (1) Become familiar with the SFTS systems currently under development
- (2) Determine the status and characteristics of the QH-50D
- (3) Obtain an understanding of NOE training requirements
- (4) Determine the availability, characteristics, and cost of hardware required to implement the concept.

Summary

The following elements of hardware would be required aboard an RPH to satisfy basic requirements of the RPH/SFTS concept:

- (1) A specialized autopilot which will command the vehicle to translate in the same manner as the helicopter being simulated
- (2) A high resolution color video camera (more than one may be required to obtain adequate field of view)
- (3) A gyro-stabilized, three-axis gimbal system to point the video camera(s)
- (4) A radar altimeter for monitoring terrain clearance and for postflight critique
- (5) A navigation unit for position reporting and postflight critique
- (6) Three accelerometers to measure vehicle acceleration (this information is transmitted to the SFTS motion system to assure that pilot motion is consistent with the video scene)
- (7) A heading-attitude reference system to provide a reference for the camera pointing system
- (8) An air data system for measuring air speed (primarily for use by the autopilot)
- (9) A control receiver and telemetry transmitter
- (10) A wide bandwidth (approximately 30 MHz) video transmitter.

Available transmitting frequencies which can handle the video bandwidth will require line-of-sight operation. This will dictate use of an elevated relay for continuous coverage. In some areas, a high tower may suffice, but in general, another airborne vehicle will be required.

On the ground, the following would be required (in addition to an existing SFTS with a visual display system):

- (1) A RPH control transmitter and a telemetry receiver
- (2) A wide band video receiver
- (3) A ground control station for takeoff and landing control, in-flight safety monitoring, and ground checkout of the RPH
- (4) Extensive software development to format RPH control commands, process RPH telemetry, and drive the motion system consistent with the dynamics of the simulated helicopter and the visual scene obtained from the RPH.

Efficient utilization of the QH-50D/SFTS system would require that two QH-50Ds be associated with each SFTS. Otherwise, approximately half of the available flight time will be taken up with refueling and preflight procedures for the RPH. The experience with the QH-50D is that the ground preparation time is as great as the available flight time. If two QH-50Ds are available for each SFTS, then one can be going through post- and preflight procedures while the other is airborne.

Several operating and support problems will be encountered with the RPH/SFTS concept:

- (1) Restrictions on available areas of training operations are creating severe NOE field training difficulties at the present time. (1) This problem will not be relieved by using a remotely piloted helicopter.
- (2) Loss of vehicles due to flight accidents and equipment failure will be significantly greater than for manned helicopters.
- (3) The RPH system complexity (including communication relay and ground station) will very likely result in equipment failure rates comparable to a full-scale operational helicopter.
- (4) Maintenance support will be complicated by the fact that only one (or a few at most) total systems would be located at each site.
- (5) Weather situations which would restrict operational helicopter flight will also restrict simulator flight. Night flights would require substitution of a low-light TV.

At the same time, many of the useful, automated features of the SFTS, such as malfunction simulation and instant reset and restart, would not be possible or would require additional development cost.

Estimated development and production costs for a QH-50D/SFTS system are as follows:

- \$1,570,000 development cost (nonrecurring) for the RPH
- \$227,000 unit cost for each RPH (of which \$25,000 is unique to the QH-50D)
- \$1,100,000 development cost (nonrecurring) for the ground system (cockpit(s), computer, ground control station)
- \$280,000 unit cost for each ground system and relay communication
- \$1,500,000 for an integrated development flight test program (nonrecurring).

These costs do not include the cost of the communications relay platform and the cost of the SFTS cockpit(s) and associated computer facility. The total nonrecurring development cost shown above is \$4,170,000. The recurring cost for a system (which includes dual QH-50Ds) would be approximately \$734,000.

Conclusions and Recommendations

The QH-50D appears to provide adequate performance to satisfy requirements of a RPH/SFTS system. However, the RPH/SFTS concept is not a cost-effective approach to NOE training. The costs of operating the full-scale operational helicopters and the SFTS/terrain board systems were not examined as part of this study. However, it seems clear that the costs involved with procurement of dual RPH systems, the associated support and maintenance costs, the limitation to daylight operation, and the loss of SFTS flexibility do not make the concept competitive with the terrain board/SFTS systems (unless these systems prove to have severe technical limitations). On the basis of system complexity it appears that the operating and support costs of the QH-50D/SFTS system would be comparable to those of the manned helicopter being simulated.

It is our recommendation not to proceed with the RPH/SFTS concept at this time. If the SFTS systems currently being developed prove to be inadequate for NOE training, the concept could be reexamined in terms of cost effectiveness relative to manned helicopter training. It is our present opinion, however, that the RPH/SFTS concept would not be competitive with use of the manned, operational helicopter, except as training accidents (and thus crew safety) are a factor in the comparison.

We further recommend that a research program be instituted to quantitatively examine the minimum visual and motion system requirements for adequate NOE training. These requirements have not been established and thus make it extremely difficult to make cost-effective decisions in the specification of new training systems.

DESCRIPTION AND COST ANALYSIS OF A QH-50D/SFTS SIMULATOR

General Description

Figure 2 shows a simplified block diagram of a conceptual QH-50D/SFTS system. The trainee pilot applies inputs through the simulator collective, cyclic and pedals. These control inputs are converted to a digital analog of the vehicle motion using the simulated helicopter equations of motion. The computed motion is transmitted through a relay to the RPH where it is separated into translation (lateral and vertical motion and heading) and angular (pitch, roll, and yaw) commands. The translation commands drive the cyclic, collective, and yaw servos through the autopilot to match the lateral and vertical motion of the simulated helicopter. The heading and attitude commands, coupled with the known attitude of the RPH (from the attitude reference system), drive the gyro-stabilized camera mount to match the simulated helicopter angular motion. The video image is returned via a video transmitter and relay translator. Additional information transmitted via the telemetry link from the RPH includes vehicle acceleration, terrain altitude, position, velocity, and several vehicle, engine, and electronic equipment status signals. The SFTS computer makes use of a combination of computed and RPH-measured motion to drive the 6-degree-of-freedom motion system.

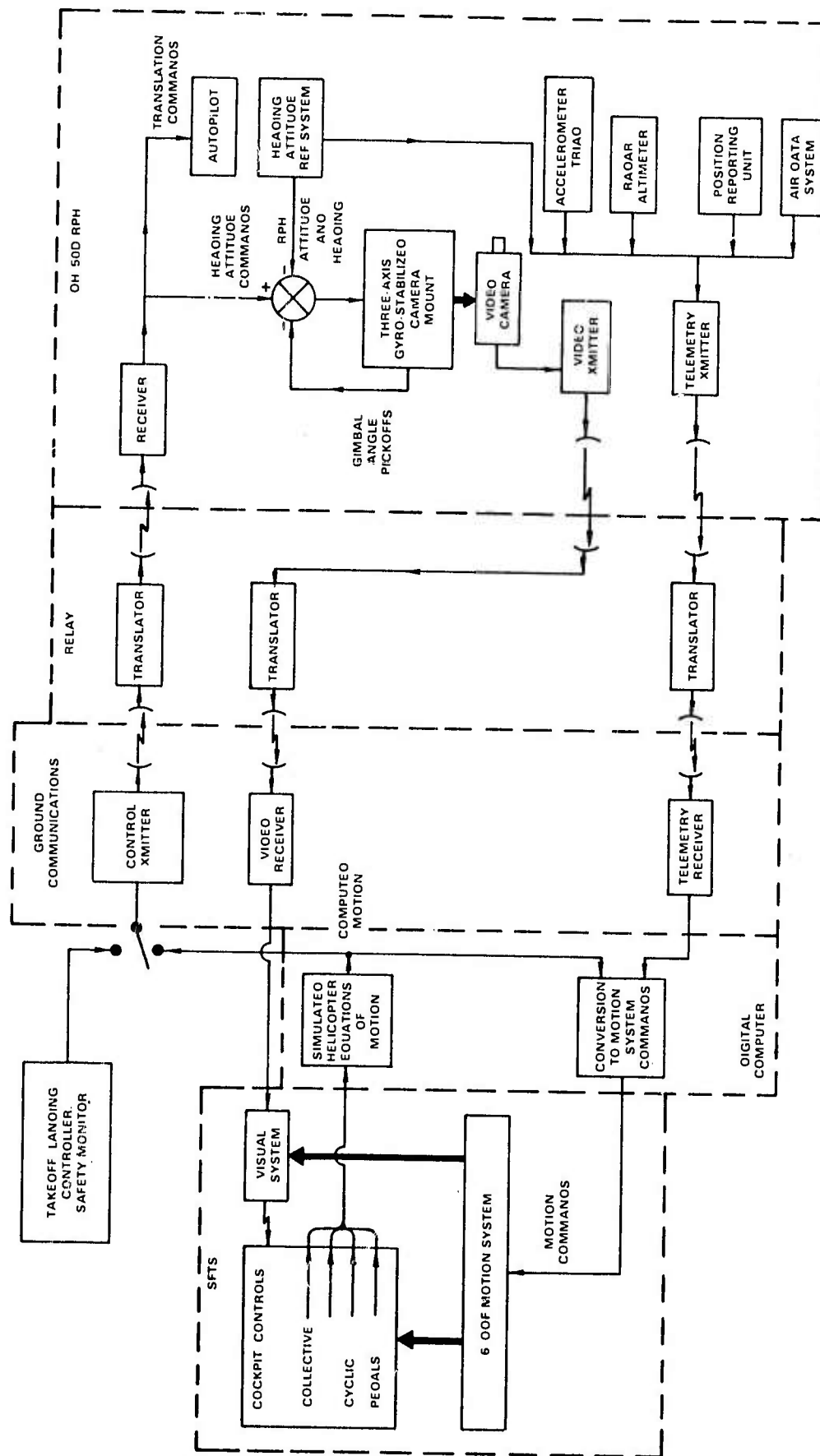


FIGURE 2 CONCEPTUAL QH 50D SFTS SYSTEM BLOCK DIAGRAM

This study was concentrated primarily on the RPH vehicle, rather than the SFTS because of the existence of developmental SFTS systems. Following is a more complete description of each of the QH-50D/SFTS elements.

The Synthetic Flight Training System (SFTS)

Background

The first synthetic flight training system (SFTS) was built by Singer and delivered to the U. S. Army at Fort Rucker in 1971. The system, designated as the 2B24, contains a complex of four simulated cockpits, each mounted on a 5-degree-of-freedom motion system. A single digital computer drives the motion system and instruments within each cockpit to emulate the flight, engine, and system performance characteristics of the UH-1H helicopter. A central instructor station is provided from which trainee performance in all four cockpits can be controlled and monitored. This system does not contain a simulated visual scene and is thus used for instrument flight training only.

An important feature of all SFTS is automatic instruction and evaluation. These features were not available on previous flight simulators. The 2B24 has prerecorded briefings, demonstration of correct flight procedures, automated evaluation of the trainee performance, and a recording and playback mode for the trainee to observe his own flight while the instructor comments.

SFTS simulators for the CH-47 and AH-1Q (Cobra) are currently under development. They are designated as the 2B31 and 2B33, respectively. Both systems incorporate 6-degree-of-freedom motion systems and camera model visual display subsystems.

The 2B33 incorporates two independent cockpits, each complete with its own motion and visual system. This configuration permits independent or joint training for the gunner and pilot. The pilot's station includes two TV panel displays, one centered on the cockpit centerline with a 47-degree-wide by 31-degree-vertical field of view. The second display has the same nominal field of view, but is centered about 53 degrees left of center. A 6.5-degree gap exists between the displays. The gunner's forward visual display is identical to the pilot's forward view.

The image generators for the 2B33 consist of two identical 24-ft by 64-ft vertically mounted terrain board models which are scaled at 1500:1. Each model is viewed by a television camera and an optical probe mounted on a movable gantry.

The 2B31 visual system simultaneously displays a 48-degree by 36-degree field of view to both the pilot and copilot. The scales of the model board are 1500:1 and 400:1. The 400:1 area simulates the detail needed for taxi, low-altitude hovering (i.e., below 25 ft), and confined area landings. NOE flight simulation is a contractual requirement for the 2B31.

Visual System Requirements

It is apparent that good visual cues are essential for NOE flight. In a recent study⁽²⁾ it was shown that pilots look outside the helicopter to obtain visual cues from about 65 to 80 percent of the time during VFR flight consisting of straight-and-level and level-with-turn maneuvers. Good visual cues are also required for low speed and hover flight because of the unique flight characteristics of the helicopter.⁽³⁾ When most vehicles accelerate forward, the operator is pushed backward. However, acceleration of the helicopter is produced by tilting the vehicle in the desired direction and increasing the power. The resultant acceleration remains normal, or downward, relative to the pilot's seat. Thus, the pilot has difficulty differentiating between vertical and horizontal acceleration. The pilot is consequently not able to sense, kinesthetically, when the helicopter starts to translate or is gradually stopping. He must rely upon his visual cues and instrumentation to sense and interpret such motion.

At the present time, the U. S. Army does not have any approved requirements for NOE visual display systems. Desired characteristics can be examined by analyzing the visual information content that the pilot and navigator require when flying NOE missions. The principal considerations are resolution, field of view, depth perception, focus, and color versus black and white.

Resolution. When visually concentrating on a fixed object, an optical image of that object is projected onto the foveal area of the retina. In this region, the eye has maximum capability to detect details of an image. The resolution capability of the eye has been studied in a number of reports. It is primarily dependent upon the contrast between the object and its background. A reasonable estimate for resolution under daytime flight conditions is 3 arc minutes.⁽⁴⁾

During NOE flight, the pilot or navigator will often closely observe objects within the terrain while attempting to identify targets, prominent land features, and safety hazards. The identification process is typically performed by comparing the size, shape, color, shadows, etc., of the objects being observed with a mental image of what the object should look like. Each of these cues varies as a function of the distance from the observer to the object being viewed. On occasion, the distance to the object being studied must be known before the visual cues become meaningful and the object subsequently identified. This situation is particularly noticeable at night when only a few points of reference are available to estimate range. On other occasions, the opposite situation occurs. Visual range estimates are obtained by a pilot comparing the detail of the image with his mental image of what the object should look like at that range. For example, if the pilot recognizes the leaf structure of a tree, he knows that the distance to the tree is close enough to create a potential collision hazard. Distance estimates are also obtained by an observer progressively considering the effects of one object masking or hiding another object. For example, if the view of a telephone pole is partially blocked by a tree, then the observer knows that the telephone pole is further away from him than the tree.

The methods used by an observer to extract required information from a picture are very complex and interrelated as indicated by these simple examples. If the quality of the picture is degraded from that which is observable in the real world, the problem of extracting needed information will be more difficult. The SFTS systems under development at Singer have a resolution of approximately 7 arc minutes in the central area of the display. This is produced with a specially developed camera and display utilizing 1021 scans per frame. It does not presently appear that any less resolution would be adequate for the SFTS/RPH system based on the opinions of people interviewed during this study. It would be very instructive to experimentally examine the effects of degraded resolution on NOE training by reducing the bandwidth of the video information in the SFTS.

Field of View. Field-of-view (FOV) requirements are very difficult to judge. During the course of this study, experienced pilots and instructors in NOE were asked for their opinions regarding field of view and picture quality requirements for a simulator (Reference Table 2). All personnel agreed that when actually flying nap-of-the-earth, they essentially used the entire FOV in the helicopter. In fact, one pilot reported that he wore out the collar on his jacket because of the amount of head turning required for the normal search pattern. Although it was generally felt that a reduction in FOV would be undesirable, the pilots did agree that a simulator with a smaller field of view would provide adequate training. The amount of degradation which would be acceptable could not be answered. Two pilots did offer the opinion that somewhere in the neighborhood of 60 degrees might be adequate, and one pilot and instructor felt that even a smaller field of view might do.

During NOE flights, pilots employ highly agile maneuvers. These maneuvers are characterized by rapid and frequent changes in direction and airspeed. If a wide field of view is available to the pilot, his potential to perform such maneuvers is considerably improved because he is able to use relative velocity and acceleration of the peripheral scene as a means for judging attitude and position and their time rate of change. Figure 3 shows the angular velocity and angular acceleration of a point offset from a constant velocity flight path. Once the pilot has established objects in the visual field that respond as expected along the profile or gradient shown in the plots, he is sensitive to unanticipated variations in acceleration away from the pattern expected for uniform motion (velocity). For example, if the pilot flies past a row of fixed objects, the objects will move through his field of vision with the pattern of acceleration as shown by Figure 3. The pilot, knowing the expected pattern, will be sensitive to any deviation from the expected or experienced pattern. The difference becomes his cue for detecting any change in his flight path. Figure 3 shows that the angular velocity cues of a point being observed in the peripheral vision continues to increase until the observed point is 90 degrees to the direction of travel.

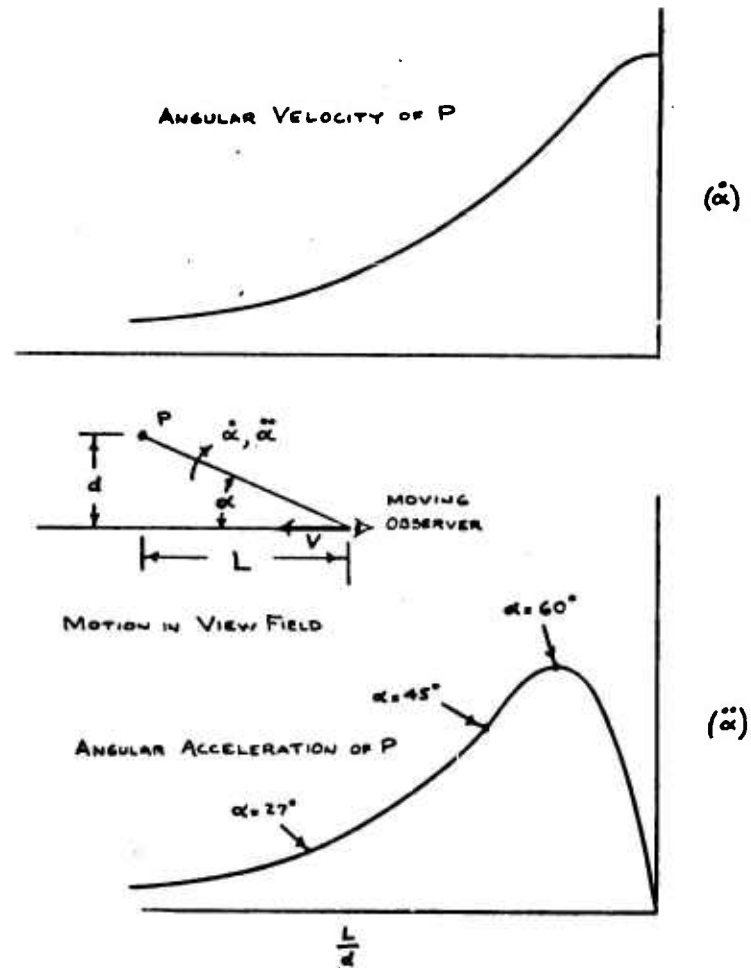


FIGURE 3. ANGULAR VELOCITY AND ACCELERATION OF A FIXED POINT RELATIVE TO AN OBSERVER MOVING AT CONSTANT VELOCITY*

* Taken from Reference 3.

However, the angular acceleration of the observed point is a maximum at 60 degrees to the direction of travel.

The pilot acts in close analogue to a servo control system. To achieve zero error in a control system, the order of control (the number of derivatives taken of the input signal) must be one greater than the highest derivative characteristic of the input itself. The development of pilot proficiency could be considered in terms of the weights given to the error term and its derivatives. In the control of simulated aircraft, it has been shown⁽³⁾ that the novice pilot places more weight on the error term than on its derivatives. However, the experienced and proficient pilot places between two and three times as much weight on the first derivative term as on the error term. He will place, in time, some weight on the second and even the third derivative terms. These conclusions are borne out by recent flight experiments showing degraded hovering ability with a constrained field of view.⁽⁵⁾

In a study performed at Bell Helicopter,⁽⁶⁾ it was shown that, when flying at 80 knots with varying altitudes which averaged about 50 ft above the ground, the pilot has about 20 percent of his time that could be devoted to tasks other than those required to fly the helicopter. At 300 ft, the amount of free time more than doubled. Reducing the pilot's field of view by 40 percent reduced the pilot's available free time by about one half (see Figure 4). These study results are only based upon the performance of three pilots, but the results are significant. They indicate that during NOE flights, a trainee will require a wide field of view, high quality visual presentation.

Pilots and instructors interviewed as part of this study generally agreed that picture quality and field of view compromises would be compensated by the trainee in terms of higher, slower, more cautious flight, and greater workload.

Depth Perception. Parallax occurs whenever an object being viewed from two places changes its position relative to what is seen beyond it. The human eyes are separated by a distance such that parallax effects

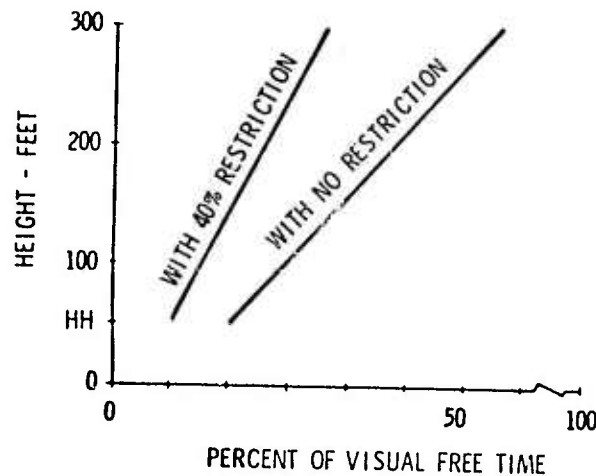


FIGURE 4. VISUAL FREE TIME WITH AND WITHOUT A RESTRICTED FIELD OF VIEW*

are observable at distances up to about 30 yards. Within this range, the human's visual processes utilize parallax effects to estimate the distance to the object being viewed, and to obtain a 3-dimensional understanding of the object. However, the visual display for head mounted and panel systems is obtained by photographing the terrain with only one camera. Consequently, the candidate visual display systems do not preserve parallax.

The lack of parallax cues does not appear to be a serious shortcoming for the NOE simulator according to the opinions of a number of personnel who were interviewed.

Mirror beam splitters are used on the 2B31 and 2B33. They provide a visual picture which is in focus when the trainees eyes are adjusted to look at very distant objects. This visual display gives the trainee a sense of depth and an element of realism. Mirror beam splitters, or other

* Taken from Reference 6.

comparable mechanizations which produce a virtual image of the terrain, should be used for the NOE simulator. Their only slight disadvantage is that objects which are within a few feet of the helicopter will appear in focus at (essentially) infinity. Although this simulation is not exactly correct, it should not adversely effect training to any appreciable degree.

Focus. Cameras used on terrain model boards have a special set of optical elements which adjust the focal plane of the camera so that it lies in the plane of the terrain. The need for this so called Scheimflug correction increases as the optical probe of the camera comes closer to the model. When the camera is 2 millimeters above the model, which is approximately the current state of the art, Scheimflug correction is essential. However, Scheimflug corrections will not always produce a picture where every object is in focus. At low altitudes, vertical objects may appear as being out of focus because they will not be on the focal plane of the terrain. Consequently, the picture provided by camera model boards may very well be out of focus when simulating NOE missions in terrain where there are vertical objects such as trees. The cameras mounted on the RPH should not require Scheimflug correction because the minimum visible range to the terrain will be at least 10 ft.

Color. Display systems which now exist on the SFTS produce a picture in color. Although a color display is not essential, it does provide an additional dimension of realism to the display. Use of color cameras on the RPH significantly affects camera and gimbal system weight and cost. It does not appear that this form of realism can be deleted from the SFTS/RPH without experimental evidence indicating pilot training sensitivity to color. This would be another useful experiment when the SFTS systems are available.

Candidate Display Systems

The proposed concept requires that the cameras located onboard the RPH transmit a picture to the ground-based simulator in real time. TV display visual systems are currently installed on the 2B33 and 2B31. These

systems generically represent the only type of TV display now used in the simulator industry. A picture is typically generated on a high resolution TV display. The picture is then optically projected into the trainee's field of view by mirrors. The field of view and resolution of the displayed picture are dependent variables which are selected as a function of the particular training mission. The field of view is typically limited to 48 degrees by 36 degrees, with a corresponding resolution of 7-15 arc minutes. Wider fields of view are produced by combining a mosaic of display panels.

Head-mounted TV visual displays are currently under development and could provide an alternate means of displaying a TV image. Helicopter pilots have already demonstrated the capability to fly at night with developmental head-mounted display systems. The visual images for head-mounted displays are typically created by combining two TV pictures. One picture has approximately 2-arc-minute resolution over a 5-degree field of view. The other picture covers a 25 to 40 degree field of view and is of lower resolution. The pilot's eye and head movements are separately monitored. Mirrors are controlled by eyeball motion so that the high resolution portion of the picture is always projected onto the foveal area of the retina. In addition, the TV cameras are slewed to correspond to the pilot's head movement.

Neither panel displays nor helmet-mounted systems are ideally suited for the simulator. The panel display systems require inputs from several cameras to obtain a complete field of view. The head-mounted systems do not offer wide peripheral vision. In addition, for training purposes, the head-mounted display systems would have to be carefully blanked in regions where there are visual obstructions and when the pilot looks at the instrument panels.

The most logical initial implementation is to make use of existing SFTS display systems presently under development. The 2B33 is particularly appropriate because it will have a pilot motion system with two displays which can be directly fed by RPH cameras. In subsequent sections, it is assumed that a 2B33 (or equivalent) system is available for interface with the RPH. A baseline single camera system is postulated with an option for a second camera.

Motion System Requirements

In the real world, a helicopter undergoes large displacements. The simulator is limited to only a few feet displacement. Thus, the magnitude and duration of the motion environment, which can be simulated by moving the trainee in one-to-one correspondence with real-world motions, is relatively small. Simulator motion systems produce the illusion of flight motion rather than duplicating the motion. Motion systems are typically designed to produce those angular velocities and specific force cues which a pilot will experience.

Angular rates are observable by a trainee at frequencies of 0.5 rad/sec to 10 rad/sec.⁽⁷⁾ Simulator systems take advantage of the lower threshold of observable angular rates. Specific forces can be sensed from zero to a very high frequency.

A considerable amount of research has been directed toward optimally driving a motion system. The research has been based upon the threshold capability of the human to observe angular motions and various "tricks of the trade", which extend the sensation of motion beyond the physical limitations of the motion system hardware. For example,⁽⁷⁾ lateral side forces that are small compared to the gravitational force can be approximated in a simulator by properly tipping the simulator cab. If the tipping is done slowly, the pilot will not realize he is being tipped, because the motion is below the threshold of observability. Instead, a small component of the gravitational force will be interpreted by the pilot as a side force.

Experience has generally shown that with careful design a simulator can be developed to provide a number of aircraft motion cues for low energy maneuvers. It was assumed as part of this study that the SFTS systems currently under development could provide adequate motion simulation.

Although motion cues are an important aid to training pilots, spatial orientation is acquired primarily through visual processes by observers viewing the outside world and/or instruments. Motion perception primarily compliments visual data and cannot be divorced from simulator

visual cues. Differences between the time a trainee feels and sees the same resultant cue are a very critical factor.

In a recent analytical study⁽⁸⁾, it was found that pilots manipulated their flight controls differently both in displacement and in control force when their visual cues were delayed by 0.1 second. However, their ability to learn a required task was not (statistically) affected by the difference in control. The experimenters offered the opinion that the pilots were able to learn their required skill to a high level of proficiency only by exerting additional effort.

SFTS Computational Requirements

The major portions of a 2B33 appears to be directly usable. However, the digital processing will require significant revision to interface with the RPH. The 2B33 presently utilizes two PDP-11 processors. It is likely that the software could be reprogrammed to format RPH control commands and to develop motion system commands from a combination of internally computed response and measurements from the RPH without additional processor hardware. It is very difficult to judge how much processor capability will be required. There will be a greater processor load required to interface with the RPH than with the terrain boards. However, the additional reserve capability required with the present SFTS systems will very likely be adequate. The processor could also be programmed to process RPH status data and alert the RPH monitor in the event of malfunctions. The effort required for analysis, software design, and reprogramming of the 2B33 computers for compatibility with the RPH system is estimated to be 5-6 man-years (approximately \$300,000). This includes software documentation but does not include modifications and refinements made as part of the initial flight test program.

Remotely Piloted Helicopter

RPH Requirements

For the RPH/SFTS concept, the RPH must be able to duplicate the motion of the simulated helicopter. The NOE mission utilizes virtually all of the low speed flight regime of a helicopter (hover, side and rearward motion, pop-up, etc.). Thus, a fixed-wing RPV would not be acceptable. The short-term

angular dynamics and the exact amount of pitch or roll required to achieve a given translation of the simulated helicopter would be extremely difficult to reproduce in an RPH. Thus, it is expected that a gimbal system will be required to slew an on-board video camera(s). The RPH must carry and provide power for the following equipment to support the RPH/SFTS mission:

- (1) A specialized autopilot which will accept commands from the SFTS and control the vehicle translation
- (2) A high resolution, color video camera (more than one may be required to obtain adequate field of view)
- (3) A gyro-stabilized, three-axis gimbal system to point the video camera(s)
- (4) A radar altimeter for monitoring terrain clearance and for postflight critique
- (5) A navigation unit for position reporting and post-flight critique
- (6) Three accelerometers to measure vehicle acceleration
- (7) A heading-attitude reference system to provide a reference for the camera pointing system
- (8) An air data system for measuring air speed
- (9) A control receiver and telemetry transmitter
- (10) A wide bandwidth (approximately 30 MHz) video transmitter.

Each of these items (and the need for them) is discussed individually in subsequent sections. The total weight of these items will be 400-600 lb. Thus, a mini-RPV class vehicle (50-200 lb) would not be adequate.

Vehicle Selection

The U. S. Army PM TRADE has postulated that the QH-50D RPH is a logical candidate for a RPH/SFTS system. The QH-50D is described in Appendix A. It appears to be a good choice with regard to performance and payload. Very little performance data was obtained. However, from discussions with the developer and personnel operating the vehicle at White Sands Missile Range, it appears to be a very responsive vehicle capable of reproducing the

acceleration of the larger operational helicopters. The QH-50D payload capability is adequate for the proposed concept. All of the equipment described in subsequent sections can be carried with a reserve that could be used for unforeseen requirements (such as ballast for c.g. control), or to ensure adequate performance. It is unlikely that a significantly smaller vehicle than the QH-50D would have adequate payload. Much of the equipment aboard the QH-50D is unreliable and outdated and should be replaced.

The retrofit requirements for the QH-50D are as follows:

- (1) Engine replacement. The present engine is out of production and has a very low time between overhaul (150 hours). The QH-50D has been flown with an available Allison engine (T63-A-700). This engine is presently used on Bell's OH-58 light observation helicopter. New engine cost is approximately \$17,000.* The engine housing and gear drive would have to be retrofitted at an estimated cost of \$5,000.
- (2) Replace rotor shaft. The rotor shaft was designed for a very limited lifetime and should be replaced. Approximate cost is \$1,000 according to Gyrodyne personnel.
- (3) Auxiliary generator. Additional auxiliary power will be required for the equipment aboard the RPH. Approximately 1500 VA of 115-volt, 400-cycle power will be required. It is estimated that this generator will cost approximately \$2,000.
- (4) Fuel shut-off valve. The QH-50D needs a backup fuel shut-off in case the normal command and control system malfunctions. At present, CO₂ must be fired into the engine if the shut-down fails. An engine overhaul is required each time this occurs. The cost for this capability will be minimal.

As can be seen from these retrofit requirements, the QH-50D represents little more than an available bare airframe. There is a possibility of the following additional difficulties with this vehicle:

* Quote from Allison Division of GM Corporation.

- (1) The camera equipment to be mounted on the QH-50D must be slung underneath the center of rotation. Thus, in a pitch or roll maneuver, the initial camera displacement would not be the same as the pilot's eye displacement. This can be partially compensated through the gimbal system by slewing the camera slightly to give the impression of displacement in the proper direction.
- (2) A few QH-50D vehicles have been lost on hot, calm days with a full payload due to power settling. There is a possibility that the counterrotating, tailless configuration is more susceptible to power settling than a conventional helicopter. However, it is not anticipated that this will be a serious problem because the vehicle will be operated at very low altitudes where there should be less tendency for power settling. In addition, the simulator pilot will have sufficient visual and motion information (through the RPH accelerometers) to sense power settling and perform a corrective maneuver.
- (3) The QH-50D is likely to have a significantly different response to windshear and turbulence than a conventional tail rotor helicopter. However, the gyro-stabilized camera mount will remove any rotational disturbances. Translation motion of the RPH (due to turbulence), which is not commanded, must also be felt by the pilot. Onboard accelerometer data transmitted to the SFTS control system will allow compatible motion of the SFTS cockpit. The influence of random winds can be imposed artificially by the SFTS to both the cockpit motion system and camera gimbal/RPH system simultaneously.

Even though it appears that the QH-50D will provide adequate performance with a satisfactory payload capability, there may be other available vehicles which are also appropriate for the RPH/SFTS concept. A choice of any other vehicle will likely encounter a similar degree of problems imposed by the QH-50D. Since the QH-50D will provide adequate performance, no investigation of alternative vehicles was conducted. However, if PM TRADE chooses to pursue the RPH/SFTS concept, alternative vehicles should be considered. A new RPH could also be developed to meet the specific operational requirements of an elevated platform. A special development program would be considerably

more expensive than a program to modify existing vehicles. Little increase in performance capability is expected, and so the development of a special vehicle is not recommended.

RPH Equipment

Performance requirements and the estimated cost of those components which must be mounted on-board the QH-50D are discussed in this section. Except for a few comments concerning the autopilot and camera stabilization systems, this discussion is independent of vehicle selection.

Autopilot. The existing QH-50D control system, which includes an autopilot unit for vehicle stability augmentation, is not readily adaptable for interfacing with the SFTS. As presently configured, the autopilot in the cruise mode accepts heading, velocity and altitude commands. Turns are executed at constant 20-degree bank angles. When the present system is commanded to go from hover to maximum velocity (quick start), it loses approximately 80 ft of altitude before recovering. These problems, coupled with past reliability problems with the autopilot, make it clear that a new design will be required.

The autopilot must convert SFTS commands into stable lateral and vertical motion, utilizing the maximum inherent response capabilities of the RPH. The helicopter does not have to match the SFTS angular motion, because the gimballed camera platform will provide that capability. However, the vehicle yaw angle must be at least loosely constrained to the SFTS yaw, so that the camera is not slewed into a position where the RPH skids are in the field of view. The autopilot must also have a reversionary recovery mode which forces it into a stable climb whenever control communications are interrupted. Although a new autopilot design will be required, the present electromechanical servos should be adequate.

According to a helicopter autopilot manufacturer, development costs would be approximately \$250,000. Unit cost would be approximately \$20,000.

Video Camera. High resolution TV cameras compatible with the SFTS display can be developed weighing approximately 30 lb, less lens, by repackaging and improving existing special purpose cameras built by Scientific Research Laboratories, EPSCO Laboratories, or Grumman. These three organizations have done extensive work in sequential color systems. The camera sensor unit mounted on the gimbal is expected to have a package size of approximately 8 x 10 x 15 inches. The camera control electronic unit would be a separate unit mounted external to the gimbal. Nonsequential camera systems, typical of broadcast compatible systems, would be heavier than the sequential camera unit for the same performance. Processing of the sequential color signal would be required to reformat the information so that it could be transmitted with a reasonable bandwidth. Based on discussions with several manufacturers, development cost is anticipated to be approximately \$200,000. Unit costs for 50-100 units would be in the vicinity of \$25,000.

Camera Stabilization. A three-axis gyro-stabilized mount will be required to point and stabilize the video camera(s). The QH-50D has been demonstrated to be free of typical helicopter vibrations. Thus, it might be possible to hardmount video equipment if the RPH could faithfully duplicate the angular motion of the helicopter being simulated. The development of a flight control system, which could force the QH-50D, or any other RPH, to completely emulate the simulated helicopter, would be very expensive, with a high risk that it could not be done at all. Precise equations of motion do not exist for the QH-50D (nor very likely for any other small austere helicopter). Thus, the form of flight control must be postulated and then refined through extensive, highly instrumented flight tests.

The alternative is to gimbal the camera so that the desired angular dynamics can be imposed on the camera rather than the complete vehicle. A three-axis gimbal system is required for complete motion. However, the QH-50D is sufficiently responsive in yaw that it may be possible to eliminate the gimbal in that axis. Personnel at Bell Helicopter offered the following estimates of maximum angular motion for operational helicopters:

- Angular Excursions

Pitch	± 20 deg
Roll	± 60 deg

- Angular Rates

Pitch	15 deg/sec
Roll	30 deg/sec
Yaw	50 deg/sec.

Several manufacturers who have produced gimbal systems were contacted regarding weight and cost. It appears that a three-axis unit capable of carrying a 30-40 lb camera would cost approximately \$100,000 for initial development and \$40,000 for production units. The weight, including payload, would be approximately 150 lb.

Safety Override. Remotely controlled NOE flight poses real hazards for the remote vehicle. Pilots can be "braver" or reckless without the usual life and death considerations. Hazardous objects such as wire, dead branches, etc., will be less detectable than with the human eye. In addition, the reduced field of view (from that in the operational helicopter), which would normally result in more cautious flight, may instead result in a higher accident rate. It would be desirable to have an automatic terrain avoidance system which could override the pilot under hazardous conditions. Discussions were held with personnel from Texas Instruments and United Technology Research Center regarding possible implementations. Texas Instruments builds terrain avoidance systems for fixed wing aircraft and has recently been adapting them for helicopters. None of the existing systems are capable of operating a few feet from terrain objects. In addition, the Texas Instrument's people felt that it would be virtually impossible to design a system which could properly interpret when to override without severely constraining flight maneuvers.

United Technology Research Center is developing LOTAWS (Laser Obstacle Terrain Avoidance Warning System). This is a developmental system for helicopters for detection of wires, dead branches, etc., at ranges beyond 1500 ft. The system cannot presently operate at ranges under a few hundred feet. They feel that the system has the potential for short-range hemispherical coverage, but that is several years away.

A radar altimeter would provide a limited amount of protection and would be very useful for postflight analysis of pilot performance. Existing AN-APN 194 radar altimeters can be purchased for approximately \$4,000. These units operate from 0 to 5,000 ft, weight 7.3 lb, and require approximately 50 VA of 115 volt, single-phase AC power. They are accurate to within ± 3 ft at minimum altitudes and continue to operate through ± 45 degree pitch and roll maneuvers.

Position Reporting. Range safety requirements in almost any area of operations will dictate that the approximate location of the RPH be known at all times. It is unlikely that the visual image will be adequate because of the very real possibility of getting lost. An independent position reporting system would satisfy this requirement and would also serve as a method for postflight critique.

There are several methods of deriving RPH position. If the communications relay was a manned vehicle, no equipment would be required aboard the RPH. Otherwise, some form of navigation aid would be required. Ground radar tracking is not feasible because of the low altitude flight profile.

Self-contained inertial systems with adequate accuracy (2-5 miles per hour) would cost more than \$50,000. Other forms of position measurement include LORAN, Omega, Global Positioning System, TERCOM, Area Correlators, and the Marine PLRS. The least expensive, available system is LORAN-C/D. These units are capable of 200-ft accuracy and cost approximately \$20,000 for the airborne unit. An investigation would be required to determine if LORAN-C/D coverage existed in the training areas. If not, Omega is a possibility at a comparable price, but degraded accuracy (approximately 1 mile). Neither of these systems require line-of-sight existence.

The Teledyne TDL-800 airborne LORAN Navigation System weighs 30 lb and requires approximately 200 VA of electrical power.

Accelerometers. Vehicle acceleration must be measured and transmitted to the SFTS as an input to the motion control system to ensure that pilot-felt acceleration is consistent with the viewed scene. Inexpensive accelerometers typically utilized in aircraft autopilots should be adequate. These cost approximately \$700 per accelerometer (3 are required).

Heading Attitude Reference System. A heading and attitude reference system is required to provide vehicle heading, pitch, and roll. These angles and their derivations are used by the autopilot. They also provide a reference with which to compare commanded camera gimbal angle position (see Figure 2). The RPH would require the precision and stability provided by the units which incorporate a gravity erected vertical gyro and a directional gyro mounted on a gimballed platform. Several such units are available at a price of approximately \$16,000. The Lear Siegler, Inc. Model 6000A is a typical unit weighing approximately 26 lb and requiring 67 watts of 115 volts, 400 Hz, three-phase wye power.

Air Data System. Air data velocity is required for autopilot gain control and for display to the pilot. Units which provide reasonably good data at low speeds would cost approximately \$1,500. It is estimated that nonrecurring costs to design an adequate installation would be approximately \$20,000. The QH-50D does not presently have an air data velocity system.

RPH Equipment Integration

Table 3 shows a list of equipment which must be carried by the RPH, along with estimated weight and power requirements. In addition to the equipment discussed in the previous section, that list also includes communication equipment described in the next section. In Appendix A it is estimated that the maximum available payload is approximately 850 lb. Thus it is clear that the QH-50D has an adequate payload, even if some ballast is required to control the center of gravity position. A second camera and gimbal system could be added without exceeding the payload capability.

Integration costs can be separated into development (nonrecurring) and unit (recurring) cost. The nonrecurring integration development will include:

TABLE 3. RPH EQUIPMENT FOR THE NOE MISSION

Element	Weight, lb	Electrical Power, Volt amps
Autopilot	30	---
Video camera (each)	50	150
Camera stabilization	110	500
Radar altimeter	7.3	50
Safety override receiver	15	Nominal
LORAN navigation system	30	200
Accelerometer triad	Nominal	Nominal
Heading-attitude reference system	26	67
Air data system	15	Nominal
Auxiliary generator	75	---
Control/telemetry transmitter/ receiver	30	50
Video transmitter	23	100
Miscellaneous cabling, mounting equipment, etc.	30	---
Totals	441.3	1117

- (1) Vendor survey, subcontractor selection, development of subsystem specifications and acceptance procedures.
- (2) Hardware layout design including racks and mounts. This will require careful design to assure adequate video camera gimbal freedom and control of the center of gravity within the acceptable 2-3 in. travel. Some shrouding and protective casing will be required to protect the equipment from rain, snow, and dust.
- (3) Design of the electrical interconnect cabling and connectors, checkout panels, etc.
- (4) Analysis of the flight vehicle characteristics. A complete redefinition of the flight characteristics will be required because of the drastic changes made to the vehicle (new engine, autopilot and payload) and because the vehicle will be operated in a new flight regime (greater pitch and roll excursions).
- (5) Operating and maintenance manuals.

Based on discussions with an aircraft manufacturer with comparable past experience (in both manned and unmanned vehicles) the nonrecurring integration costs are conservatively estimated to be approximately \$1,000,000. A complete set of manuals by themselves was estimated to cost at least \$200,000.

The same manufacturer was consulted regarding recurring integration costs. The following elements are included:

- (1) Wire harnesses (\$5,000-\$10,000)
- (2) Mechanical installation, racks, fasteners, shelves, etc. (\$3,000-\$6,000)
- (3) Final assembly and test (\$5,000-\$10,000)
- (4) Sell-off flight check (nominal).

Some of these costs are higher than might be anticipated because of the limited production quantity (50-100 units). Adding a pad for unforeseen hardware requirements, vehicle refurbishing from storage, etc., it is estimated that the recurring integration costs will be approximately \$50,000 per vehicle.

Communications

The communications between the RPH and the ground units, launch control site and SFTS center, will in most cases, require the use of an elevated relay to maintain the line-of-site data links. Depending upon the terrain of the various operating areas, the distances over which reliable communications must be maintained, and safety systems employed, the relay could utilize a high tower, or an airborne platform (manned or unmanned). It is highly unlikely that a fixed tower will be adequate at many sites. No attempt was made to estimate the cost of the relay platform since it would very likely be unique to each site.

The following communication links will be required:

- (1) RPH command and control (SFTS to RPH)
- (2) RPH telemetry (RPH to SFTS)
- (3) Wide-band TV data link (RPH to SFTS).

These data links must generally operate in the microwave region to obtain available channels and will thus be limited to line-of-site operations.

Command-Control/Telemetry Link

It is likely that some of the existing RPH communication equipment can be utilized. The original QH-50D equipment consisted of a command receiver and decoder (AN/ARW-78) and a telemetry multiplexer and transmitter (AN/AKT-20). The later version of the system included 38 channels of telemetry. There were serious reliability problems with the AN/AKT-20 transmitter and it should be replaced. Sierra Research has modernized and minitiarized this equipment. The telemetry system is a PAM/FM/FM system allowing 38 data items to be monitored. Two channels are CW for monitoring compressor and rotor RPM. The rest are sampled (12 at 32.25 times per second, 24 at 65.5 times per second). The resulting 1935 bits per second PAM wave train modulates a 40 KHz voltage controlled oscillator. This signal is mixed with the CW channels and the composite signal is FM transmitted (10 watts) at S-band (2200-2300 MHz). A new onboard system would cost approximately \$16,000. Relay equipment for the command-control and telemetry link is estimated to cost approximately \$17,000.

Video Data Link

The video link will very likely require approximately 30 MHz bandwidth. For a resolution compatible with the SFTS, the luminance (black and white) signal will require approximately 20 MHz. In the laboratory, the color signals can be sent individually with a similar bandwidth. However, color information does not require near the bandwidth of the luminance intensity. Thus, for video transmission, the technique used in commercial broadcast video transmission can be utilized. This involves multiplexing the color information with the amplitude modulated black and white signal. Approximately 30-35 MHz total bandwidth would be required.

Terra Com builds a communication set which appears to have adequate performance. The system operates in the 1.7 to 2.5 GHz range (tuneable) and has bandwidth adjustable from 5 to 40 MHz. A complete system, including RPH, relay and ground equipment would cost under \$28,000 (\$7,500 for the RPH transmitter equipment, \$7,500 for the ground receiver equipment, and \$13,000 for relay equipment).

RPH Ground Control and Servicing

An RPH Ground Control Station (distinct from the SF will be required to service, check out and monitor the remotely piloted helicopters. The functions required for this ground station are very similar to the capability of the control van utilized by ARPA for the Nite Panther/Nite Gazelle program. The ground control station should be configured to simultaneously support two remotely piloted helicopters (the need for two RPH's is discussed in a later section). The ARPA Nite Panther/Nite Gazelle van controls and services one vehicle at a time. It is a standard 24,000-lb trailer-type van with a modified end to provide good clear vision of the run-up and launch area (see Figures 5 through 7).

From the operator's position in the ground control van, the RPH launch/recovery pilot can visually check the response of various subsystems via hard-wire umbilical connection. After completing these various motion checks, the vehicle is ready for initial start-up and tied-down power checks.

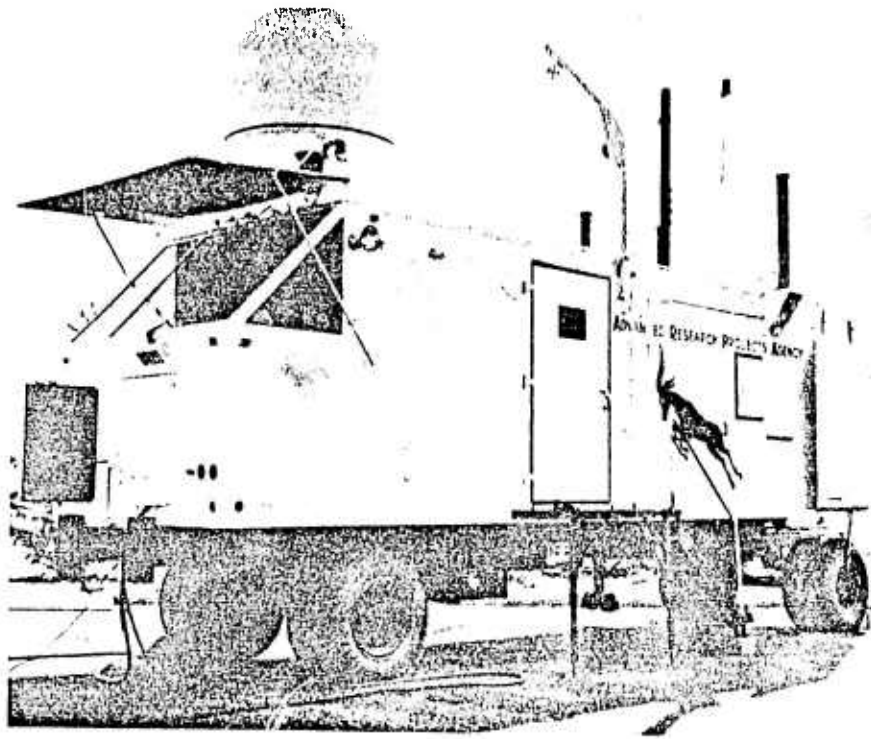


FIGURE 5. GROUND CONTROL STATION USED FOR
FEASIBILITY TEST PROGRAMS

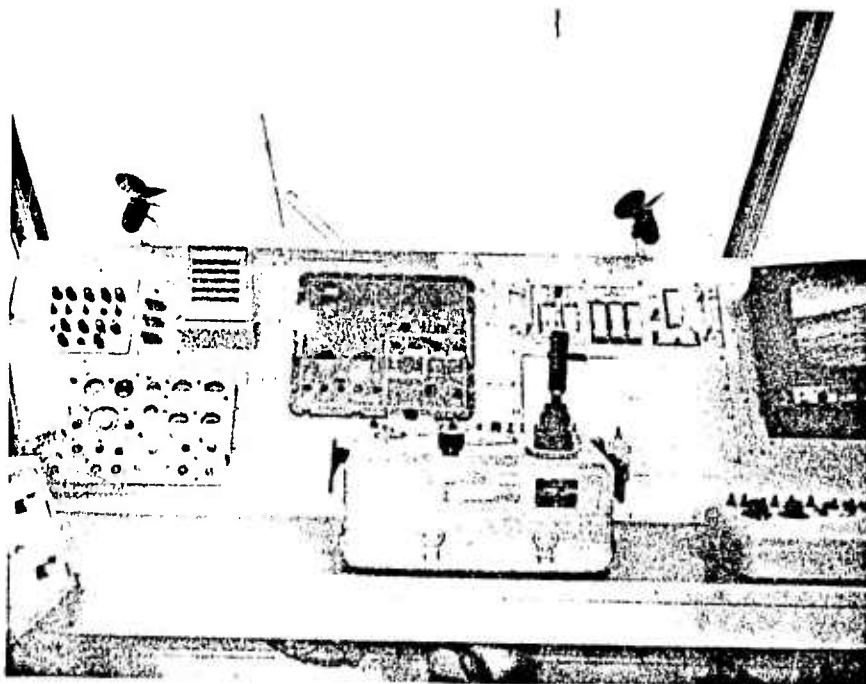


FIGURE 6. GROUND CONTROL STATION, VIEW OF
OPERATOR'S CONTROLS

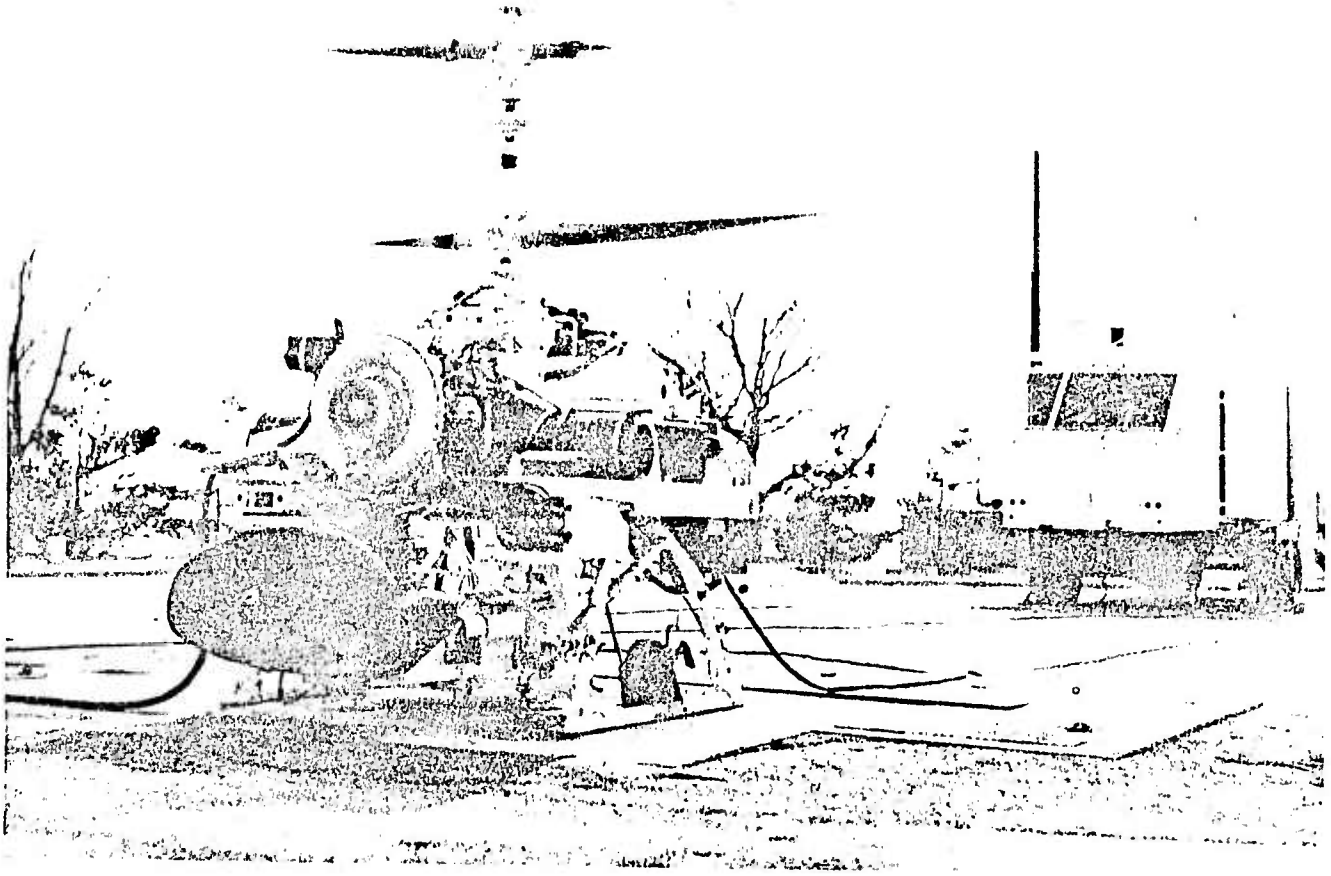


FIGURE 7. TYPICAL PREFLIGHT STATION

Once the vehicle and sensor systems have been preflighted via hard-wire connection, radio command control should be checked. The radio command control check should include direct ground station transmission and ground station transmission via the communications relay. The MASSTER's Unmanned Aerial Surveillance System Test Report (U), dated October, 1971, for the QH-50D stated that:

"Approximately 2 hours per day were required for preflight testing"

"Approximately 1 hour of repair was needed for 1 hour of flight. However, it should be noted that the QH-50D (on-board equipment) was not militarized. The majority of repairs were needed on the sensor systems or in the GCS and not on the actual airframe."

The hourly figures are the result of 66 hours of QH-50D tests (night and day), conducted at Fort Hood during the period June 21 through August 9, 1971. The equipment was operated and maintained by contract personnel with 10 to 15 years' experience in their respective technical areas.

The three vans constructed for the Nite Panther/Nite Gazelle program cost approximately \$650,000 in 1967. The ground equipment required to support checkout, takeoff and landing, status monitoring, safety shutdown and data recording would be approximately equivalent to the equipment in a single van--regardless of whether these functions are integrated with the SFTS or are in a separate building or van. It is estimated that the initial development costs (taking advantage of the original van development) would be approximately \$300,000, with a subsequent unit cost of approximately \$150,000.

Ground System Integration

A complete ground system will require integration of the SFTS cockpits and computer, RPV communications and the ground station control unit. Utilizing an existing 2B33 or equivalent cockpit and computer system, modifications will be required to:

- (1) Accept input from the ground receivers
- (2) Provide output to the command-control communications transmitter

- (3) Provide a link between the pilot's cockpit and the ground control station for handover to the pilot after takeoff and handoff to the ground control station for landing

- (4) Add or modify an existing display panel(s).

In addition, the existing SFTS operating and maintenance manuals will have to be modified. Recurring or unit integration costs include the cost of the ground communications, interface connections with the ground control station, input/output interface with the communications, additional status panels in the SFTS, etc.

These costs are very difficult to accurately judge without a very extensive ground system design study. However, several BCL and contractor personnel were consulted for their estimate of these costs. Based on these inputs, we estimate the development integration costs to be approximately \$500,000 and the recurring or unit cost to be approximately \$100,000.

Integrated Development Flight Test

An extensive flight test program will be required with a prototype system to check out all of the system elements and make necessary refinements. The program would include a step-by-step test program including:

- (1) Examination of the modified QH-50D flight characteristics over the anticipated flight regime under control of the ground control station
- (2) Flight checkout of the individual RPH payload components including autopilot, command/control, telemetry, navigation, camera attitude control, etc.
- (3) Operation via the communications relay
- (4) Control from the SFTS cockpit
- (5) Examination of recorded data for correlation of the RPH motion and video camera scene with that anticipated for the helicopter being simulated
- (6) Analysis of tracking between the cockpit motion and viewed scene.

It is anticipated that extensive modifications to the system (primarily to the SFTS software, RPH autopilot, and camera gimbal control) will be required during the flight test program. The total cost for the flight test program is conservatively estimated to be \$1,500,000. This figure was arrived at after consultation with an aircraft manufacturer with experience in RPV, helicopter and aircraft flight test programs.

Cost Summary

Table 4 summarizes the estimated costs associated with the remotely piloted helicopter. Also shown is a page reference where each item is discussed. The largest expense items are the high resolution color video camera and stabilized mount. A second camera and mount would push the recurring unit cost up to approximately \$300,000.

Table 5 summarizes those costs which are not a part of the RPH. These costs do not include:

- (1) Cost of the platform for the communications relay
- (2) Cost of the SFTS cockpit(s) and associated computer facility.

Total development costs for the QH-50D/SFTS system are estimated to be \$4,170,000.

TABLE 4. ESTIMATED RPH COSTS

Element	R&D Cost, \$1000	Unit Cost ^(a) , \$1000	Reference Page
<u>Elements Unique to the QH-50D Vehicle</u>			
New Allison engine	-	17	25
Exhaust housing	-	1	25
Gearbox	-	4	25
Main rotor shaft	-	1	25
Auxiliary generator	-	2	25
<u>Elements Applicable to Any Selected RPH</u>			
Autopilot	250	20	27
High resolution color video camera	200	25	28
Three-axis, gyro-stabilized mount	100	40	28
Radar Altimeter	-	4	29
LORAN navigator system	-	20	30
Accelerometers	-	2	30
Heading-attitude reference system	-	16	31
Air data system	20	1.5	31
Control/telemetry receiver/transmitter	-	16	34
Video transmitter	-	7.5	35
Equipment integration, manuals, etc.	1,000	50	31
Total	1,570	227	

(a) Assuming 50-100 units.

TABLE 5. ESTIMATED SFTS/GROUND CONTROL STATION
AND COMMUNICATION RELAY COSTS

Element	R and D Cost, \$1,000	Unit Cost, \$1,000	Reference Page
Relay Communications	-	30	34
SFTS Software Development	300	-	23
Ground Control Station	300	150	35
Ground System Integration	500	100	38
Integrated System Flight Test	<u>1,500</u>	<u>-</u>	39
Totals	2,600	280	

System Operation and Maintenance

Operational Considerations

Efficient utilization of the QH-50D/SFTS will very likely require that two QH-50Ds be associated with each SFTS. (The SFTS is intended to imply a system with cockpits for a single crew. If two cockpits are required -- one each for the pilot and copilot -- then each receives identical video input.) Otherwise, approximately half of the available training time will be taken up with refueling and preflight procedures. The experience with the QH-50D at White Sands Missile Range and in previous programs is that the ground preparation time is as great as the available flight time (see Appendix A). If two QH-50Ds are available for each SFTS, then one can be going through post- and preflight procedures while the other is airborne.

There are several operational limitations of the QH-50D concept relative to a terrain board/SFTS system:

- (1) Many of the automatic instruction capabilities of the 2B33 system would be lost unless expensive, specially developed video recorders were added to the ground system. In addition, capabilities such as malfunction simulation and instant reset, restart capabilities would not be possible.
- (2) The QH-50D/SFTS system will be restricted to acceptable weather, daytime flight (unless low-light cameras are added), whereas the terrain board/SFTS systems can theoretically be operated for most of a 24-hour day (excluding scheduled maintenance periods).
- (3) Flying areas for the NOE training, which are presently quite limited for manned helicopters⁽¹⁾, will be even more severe for an RPH. The RPH must avoid areas where there is a likelihood of encountering power or telephone lines and other hazardous objects which are not as likely to be detected on a video image as by the human eye. In addition, restrictions on manned helicopter NOE training caused by proximity to civilian population will be more restrictive for an RPH because of the greater accident hazard. It is interesting to note that contractors presently involved in the conceptual design of an advanced multi-mission RPV have been given guidelines that will not allow training flights in Europe because of the sensitivity to an RPV accident in a populated area.

- (4) Significant costs can be incurred from loss of vehicles due to flight accidents. The low flight altitudes and proximity to terrain objects coupled with a reduced field of view (from that available in a manned helicopter) will produce more hazardous flight conditions. In addition, in-flight failures which would not normally be hazardous in a piloted vehicle can cause loss of the RPH. It is anticipated that loss rates due to these causes would be comparable to present RPV experience (one percent or greater).

System Maintenance

Maintenance requirements would be complicated by the fact that only a few complete systems will be located at each site (a complete system includes a SFTS, Ground Control Station, relay, and two RPH's). This results in inefficient utilization of personnel and added cost for stockage of spares. In addition, the quality of maintenance (which can be translated into amount of down time) is degraded when there are only a few systems because the maintenance personnel do not obtain sufficient experience with the individual subsystems. If there are numerous systems at a site, then the maintenance personnel can specialize on individual subsystems and become much more proficient.

The system reliability is a function of complexity (part count), operating environment and production experience. Much of the equipment which would be carried aboard the RPH has been in production for many years and should be quite reliable. Likely problem areas are the RPH airframe, video camera and stabilized mount. The RPH by itself is less complex than most helicopters which would be simulated (Cobra, AAH, UTTAS, etc.). However, the complete QH-50D/SFTS system (SFTS, ground control station, relay and RPH) is much more complex than those helicopters. Even allowing for the benign environment of much of the ground system, the maintenance requirements for the QH-50D/SFTS will be at least comparable to those for the manned helicopters and much greater than those of a terrain board/SFTS system.

CONCLUSIONS AND RECOMMENDATIONS

The RPH/SFTS Concept

The concept of mating RPV and simulator technology initially appeared very attractive, particularly with the availability of surplus remotely controlled helicopters. The concept appears to have all the advantages of both worlds--the actual world terrain with moving targets, actual lighting and weather conditions, extensive area of operations; with pilot operations conducted in a safe, laboratory environment. However, after closer examination, it appears that the concept also suffers from the worst of both worlds. With regard to the airborne vehicle:

- (1) The remotely piloted helicopter RPH equipment will be expensive to develop and procure.
- (2) Two helicopters will be required for each SFTS installation to obtain the level of utilization which the SFTS can support.
- (3) The communications relay will very likely have to be another airborne vehicle except in flat terrain where the area of operations is not far from the simulator facility.
- (4) Restrictions on available areas of operations, which is creating severe NOE field training difficulties at the present time,⁽¹⁾ are likely to be more severe, rather than relieved, by a remotely piloted helicopter because there is a greater risk of accident.
- (5) Loss of vehicles due to flight accidents will be significantly greater than with manned vehicles.
- (6) The RPH system complexity (including communication relay and ground control station) will very likely result in equipment failure rates at least comparable to a full-scale operational helicopter.
- (7) Maintenance support will be complicated by the limited number of vehicles at each site.
- (8) Weather situations which would restrict operational helicopter flight will also restrict simulator flight.

With regard to the SFTS, much of the present flexibility is lost:

- (1) Many of the useful, automated features of the SFTS such as malfunction simulation, instant reset and restart and hands-off mission playback would not be possible or would require additional development cost.
- (2) Operation independent of outside conditions is no longer possible.

The primary advantages of the concept are:

- (1) Potential problem areas with terrain board fidelity and image focus would be resolved
- (2) Real-world lighting and shadow conditions would exist
- (3) Moving targets operating in realistic scenarios can be readily utilized.

In the "Introduction" it was also postulated that the QH-50D/SFTS system would be of value for initial training if:

- (1) It provides more cost-effective visual and motion cues than the SFTS/terrain board systems
- (2) The SFTS/terrain board systems are inadequate for NOE training
- (3) The QH-50D/SFTS system offers supplementary training capability not available from the SFTS/terrain board system.

While SFTS/terrain board system costs were not analyzed as part of this study, it seems clear that the costs involved with procurement of dual QH-50D systems, the associated support and maintenance costs, the limitation to daylight operation, and the loss of SFTS flexibility do not make the concept competitive with the SFTS/terrain board system.

There is a possibility of problem areas with the SFTS/terrain board system due to lack of scene fidelity and out of focus conditions for close vertical objects like trees. These, or other considerations, may seriously compromise the ability to provide simulated NOE training and cause reconsideration of the QH-50D/SFTS concept. We do not consider the supplementary training capability offered by the SFTS/QH-50D system (high fidelity terrain, real-world lighting, etc.) by themselves sufficient justification for proceeding with the concept at this time. Thus, unless the potential problems with the SFTS system are realized, we feel that the SFTS/QH-50D concept would not be cost effective for initial training.

In the "Introduction" it was also postulated that the QH-50D/SFTS system would be of value for proficiency training if:

- (1) It is significantly more cost effective than use of the actual helicopters
- (2) It faithfully duplicates the environment of the actual helicopter
- (3) It is more cost effective than alternative techniques for proficiency training.

Application for proficiency training would require distribution of the capability to the operational sites, seriously compounding the problems of establishing individual maintenance and support capabilities described earlier. Proficiency training will allow less compromise in the faithful motion and visual reproduction that is allowable for initial training. Thus, more austere versions than described in this report are not practical. Thus, we also feel that the SFTS/QH-50D concept is not cost effective for proficiency training.

Alternatives

This report has concluded that the QH-50D/SFTS concept is very unattractive. Examination of other alternatives was not within the scope of the effort. It now seems that an examination of the relative merits and costs of alternative and postulated innovative techniques is in order. However, this study cannot be effectively accomplished until more information is available regarding simulator technical requirements. There is no adequate evidence regarding the effectiveness of training as a function of simulator characteristics such as field of view, resolution, color, focus, quality of motion system emulation of the real helicopter, scene detail, etc. As a result, the tendency is to specify the best technical performance which the state of the art will allow and accept the associated costs.

The 2B31 and 2B33 will be ideal systems to conduct experiments in these areas to determine how much useful training can be accomplished as a function of these parameters. Complementary experiments might also be performed with the actual helicopter. This information would allow true cost-effectiveness analysis in which performance can confidently be traded for cost reductions. Such a program is strongly recommended.

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1. "Executive Summary", Proceedings on Aircrew Performance in Army Aviation Conference, November 27-29, 1973, U. S. Army Aviation Center, Ft. Rucker, Alabama.
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7. Sinacori, J. B., "A Practical Approach to Motion Simulation", AIAA Visual and Motion Simulation Conference, Palo Alto, California, September 10-12, 1973, AIAA Paper No. 73-931.
8. Cooper, Fred R., Harris, William, T., and Sharkey, Vincent J., "Effects of Visual System Time Delay on Pilot Performance", 8th NTEC/Industry Conference Proceedings, New Concepts for Training Systems, Naval Training Equipment Center, Orlando, Florida, November 18-20, 1975.

APPENDIX A

THE QH-50D "DASH" COAXIAL HELICOPTER

APPENDIX A

THE QH-50D "DASH" COAXIAL HELICOPTER

Introduction

Background

The QH-50D vehicle is an ASW line-of-site drone helicopter designed to operate from destroyers to deliver two target seeking torpedoes. It was designed as a short life-cycle, expendable vehicle. This vehicle, built by Gyrodyne Company of America, is a tailless helicopter using two coaxial counterrotating blades. It is powered with a single turbo shaft engine which is no longer available. There are a number of these vehicles stored at Davis-Monthan AFB, Arizona as surplus government equipment.

The Navy first introduced the QH-50C into the fleet in November, 1962. A total of 373 QH-50Cs were built and delivered to the U. S. Navy "DASH" Program. The first QH-50D was flown in April, 1965. This vehicle with an improved engine and fiberglass blades was introduced into the fleet late in 1965. More than 700 of these vehicles were built. The Navy phased these vehicles out of ASW duty about 1970. However, a limited number were used by the Navy and the Marines during one period of the Vietnam conflict. Initial use was for the Navy's Project SNOOPY, followed by a Marine/ARPA Project QRC Nite Panther. Both of these programs used the vehicle as a remotely controlled sensor platform carrying a TV camera and video data link. The Navy SNOOPY program ran from late 1967, to early 1969. The ARPA QRC Nite Panther Program began March, 1968, and was finished in April, 1968. ARPA then used a number of vehicles in the Nite Gazelle/Nite Panther Program for test and evaluation of various sensors and armament systems. These tests were concluded in February, 1972. None of the ARPA or Navy test programs required much flying time. The ARPA Nite Gazelle/Nite Panther program accumulated a total of about 200 hours over a 2-year period using 12 QH-50Ds; an average of less than 1.5 hours per month per vehicle.

Vehicle Status

There are a number of QH-50Ds available from the storage facility at Davis-Monthan AFB. However, the required support equipment, logistic problems, and limited engine serviceability present some rather severe problems for any projected use where long serviceability and high reliability are prime factors. The situation can be summed up as follows:

- (1) The vehicle electronic equipment is unreliable and has accounted for a number of vehicle losses.
- (2) The engine is no longer in production and the location and quantity of available engine spare parts is unknown.
- (3) The TBO (Time Between Overhaul) on the engine is 150 hours.
- (4) Only three A-PA built ground control stations were built and these are in use by the Army's target program. Ground stations would have to be constructed using equipment removed from destroyers or from new equipment.

The following changes and/or modifications to the QH-50D will be required to make it a reliable vehicle with a reasonable service life:

- (1) Change or modify the electronic equipment used for command and control.
- (2) Install an engine with a longer TBO (an Allison T63-A-700 engine with a 1,000 hour TBO has already been flown on this vehicle).
- (3) Install redesigned rotor shafts.
- (4) Addition of a fuel shut-off valve to shut the engine down when the normal command and control system malfunctions. The present system has the following requirement:

"The lack of a manual fuel shut-off valve on the QH-50D engine makes it necessary to fire CO₂ into the engine if 'engine off' command fails to shut down the drone. After CO₂ has been used, an engine change is required. . . ." (A-1)*

* Refers to the Reference List at the end of this Appendix.

The following ASW related subsystems should be removed to provide added useful payload capability:

- (1) Vehicle flotation system
- (2) Armament provisions
- (3) Ballast.

Original Design Requirements

The original Navy requirements were based on the need to deliver up to two self-seeking torpedoes on an ASW mission under line of sight, visual control from a destroyer at sea. It was expected that in some cases the drone helicopter would be destroyed by its own weapon system, thus the requirement for an expendable drone. The original design concept criteria^(A-2) called for:

- Weapon stores weight of 850 lb
- Thirty to forty nautical mile radius of action
- Maximum mission endurance of 1.7 hours
- Mean-time between loss (MTBL) of 8 hours was deemed acceptable
- Maximum altitude requirement of 1,000 ft above mean sea level
- JP-5 fuel.

RPH System Description

The original Navy QH-50D drone remotely controlled, rotary wing weapon-carrying vehicle was designed to operate from the deck of a destroyer on ASW missions. The vehicle carried two torpedoes having a total weight of 918 lb.^(A-3) These weapons were slung centered underneath the main body and thus had minimal effect on the fore and aft c.g., location. The 52 gallon fuel tank was mounted very close to the c.g. Thus, c.g. movement versus fuel burned was also minimal.

The coaxial counterrotating blade, tailless configuration of this vehicle permits a maximum c.g. travel of 4 to 5 in. ^(A-4) Thus, mounting other equipment for other missions sometimes requires the use of ballast to keep c.g. travel within allowable limits, thus reducing useful payload.

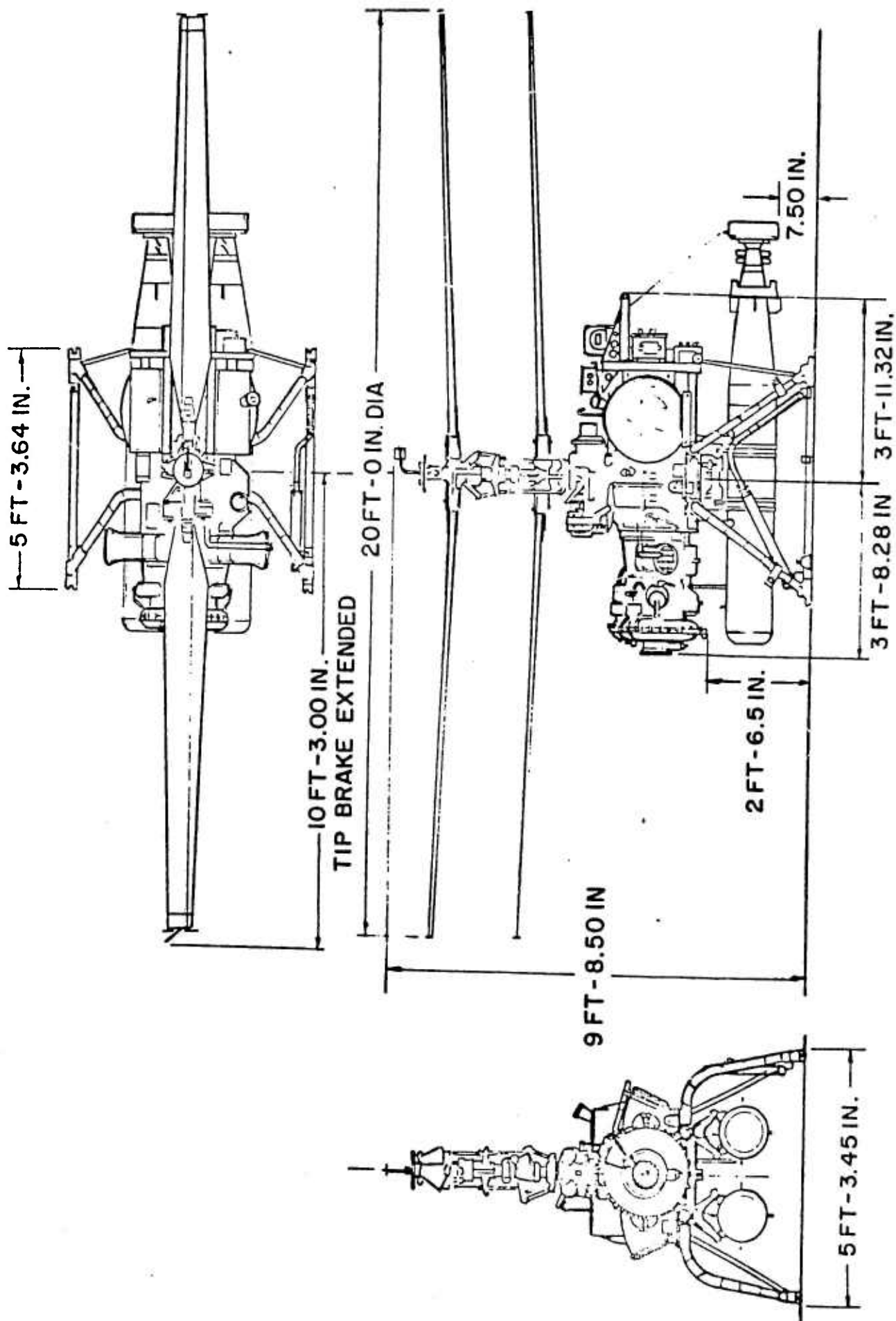
The Navy configured QH-50D with a payload of two torpedoes is shown in Figure A-1. Limits for mounting equipment between the skids are shown in Figure A-2. The QH-50D production weight data are given in Table A-1. The items underlined would be removed and replaced by modified or new equipment needed to support the SFTS mission. Very little original surplus equipment will be usable in the final configuration.

Instruction manuals pertaining to the QH-50D have not been acquired for review, however, a list of NAVWEPs publications applicable to the original Navy QH-50D are given in Table A-2.

Support Equipment

The support equipment for prelaunch check-out and launch was designed for use on-board destroyers and thus, is packaged in water tight boxes and designed for high moisture and high shock environments. All this adds to the cost of original manufacture, service, and maintenance of these subsystems. However, if good, serviceable, exdestroyer equipment can be obtained GHE, it should be less expensive than new or redesigned equipment. These check-out and control units were initially built by Babcock Electronics, Costa Mesa, California. However, some later procurement included units from other manufacturers. The basic QH-50D deck controller is a standard universal controller which the Navy uses for a number of its drone vehicles.

The Navy Training Command added a 14-channel SUPTEL telemetry system to the QH-50D system in order to monitor vehicle status and improve total system reliability. These monitored data provided guides for preventative and/or corrective maintenance. The ARPA program used an expanded telemetry system (OPTTEL) which had 38 channels of data. This system further



QH-50D DRONE OUTLINE

FIGURE A-1. QH-50D DRONE OUTLINE
(Reference A-5)

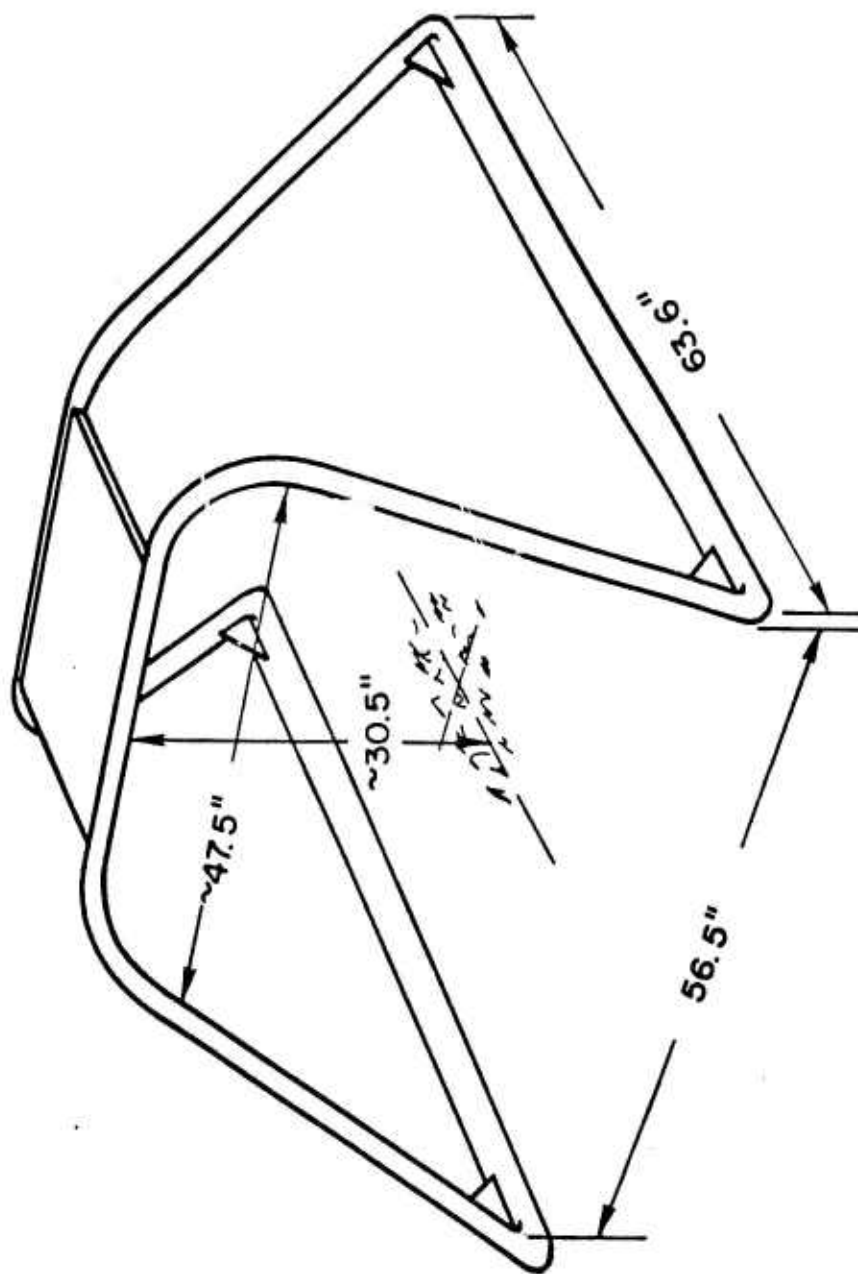


FIGURE A-2. QH-50D UNDERCARRIAGE (Camera Mount Area)

TABLE A-1. WEIGHT DATA-PRODUCTION QH-50D
(Reference A-6)

Weight Empty	
QH-50D Production Configuration	
Rotor Group	140.5 lb
Body Group	77.9
Alighting Gear Group	43.0
<u>Flight Controls Group</u>	125.1
<u>Propulsion Group</u>	477.3
Instrument/Navigation Group	7.6
Electrical Group	34.1
Electronics Group	84.6
Fittings--Tie Down	4.4
Manufacturing Variation	5.5
Weight Empty: Specification	1,032.4 lb

TABLE A-2. NAVWEPS PUBLICATIONS ON THE QH-50D

Title	Publication Code Number
<u>Description, operation, and maintenance of the drone is covered in the following volumes of the Maintenance Instruction Manual:</u>	
General Information and Servicing	NAVWEPS 01-150DHC-2-1
Airframe Systems	NAVWEPS 01-150DHC-2-2
Corrosion Control, Cleaning, Painting, and Decontamination	NAVWEPS 01-150DHC-2-3
Power Plant, Fuel, and Related Systems (Installed Engine Maintenance)	NAVWEPS 01-150DHC-2-4
Automatic Flight Control Set AN/ASW-20	NAVWEPS 01-150DHC-2-5
Operational Telemetry AN/AKT-20	NAVWEPS 01-150DHC-2-6
Systems Integration Information	NAVWEPS 01-150DHC-2-8
Wiring Data	NAVWEPS 01-150DHC-2-9
<u>Data necessary for identification and replacement of parts are listed in the following volumes of the Illustrated Parts Breakdown:</u>	
Airframe Systems	NAVWEPS 01-150DHC-4-1
Power Plant	NAVWEPS 01-150DHC-4-2
Automatic Flight Control Set AN/ASW-20	NAVWEPS 01-150DHC-4-3
Operational Telemetry AN/AKT-20	NAVWEPS 01-150DHC-4-4
Radio Receiving Set AN/ARW-78	NAVWEPS 01-150DHC-4-5
Numerical Index	NAVWEPS 01-150DHC-4-6

improved QH-50D operations by permitting better maintainability. Both of these telemetry systems, built to 1960 period state of the art, had reliability problems of their own; primarily with the AN/AKT-20 transmitter.

The telemetry does not directly improve the reliability of the QH-50D. However, it does permit faster trouble shooting during check-out and provides a recorded recap of vehicle performance, which aids greatly in achieving good maintainability of the QH-50D.

Sierra Research, the manufacturers of the original SUPTEL and OPTEL systems, have updated the OPTEL system to present day state of the art. They have also incorporated a miniaturized multiplexer. These systems, however, are designed for the original rugged "DASH"-type environment.

Special ARPA Program

The ARPA Nite Panther/Nite Gazelle program used the QH-50D as a sensor platform for testing and evaluating prototype sensor and sensor/ weapons systems that would be effective in the Vietnam conflict. This program required a significant amount of land-based testing and data collection. ARPA had three van launch control units built for supporting this program. Something similar would be required for the proposed QH-50D NOE/SFTS Program.

The three ARPA vans were transferred to the Army at the termination of the ARPA Nite Panther/Nite Gazelle program. Two of these vans are presently at WSMR and the third is being requested for support of the WSMR Army Targets Program. Equipment has been cannibalized from these vans and documentation/wiring diagrams have not been located.

PerformanceNavy Use

Limited performance data are available on the QH-50D as used by the Navy. Essentially no vehicle performance data are available on the modified QH-50Ds used by ARPA on the Night Gazelle/Night Panther program. Five QH-50Ds were modified and flown with Allison engines near the end of the Navy's QH-50 ASW Program. Minimal data has been located on the QH-50 with the Allison engine. The final NATC technical report on the QH-50D's performance evaluation contained the data shown in Figures A-3 through A-8.

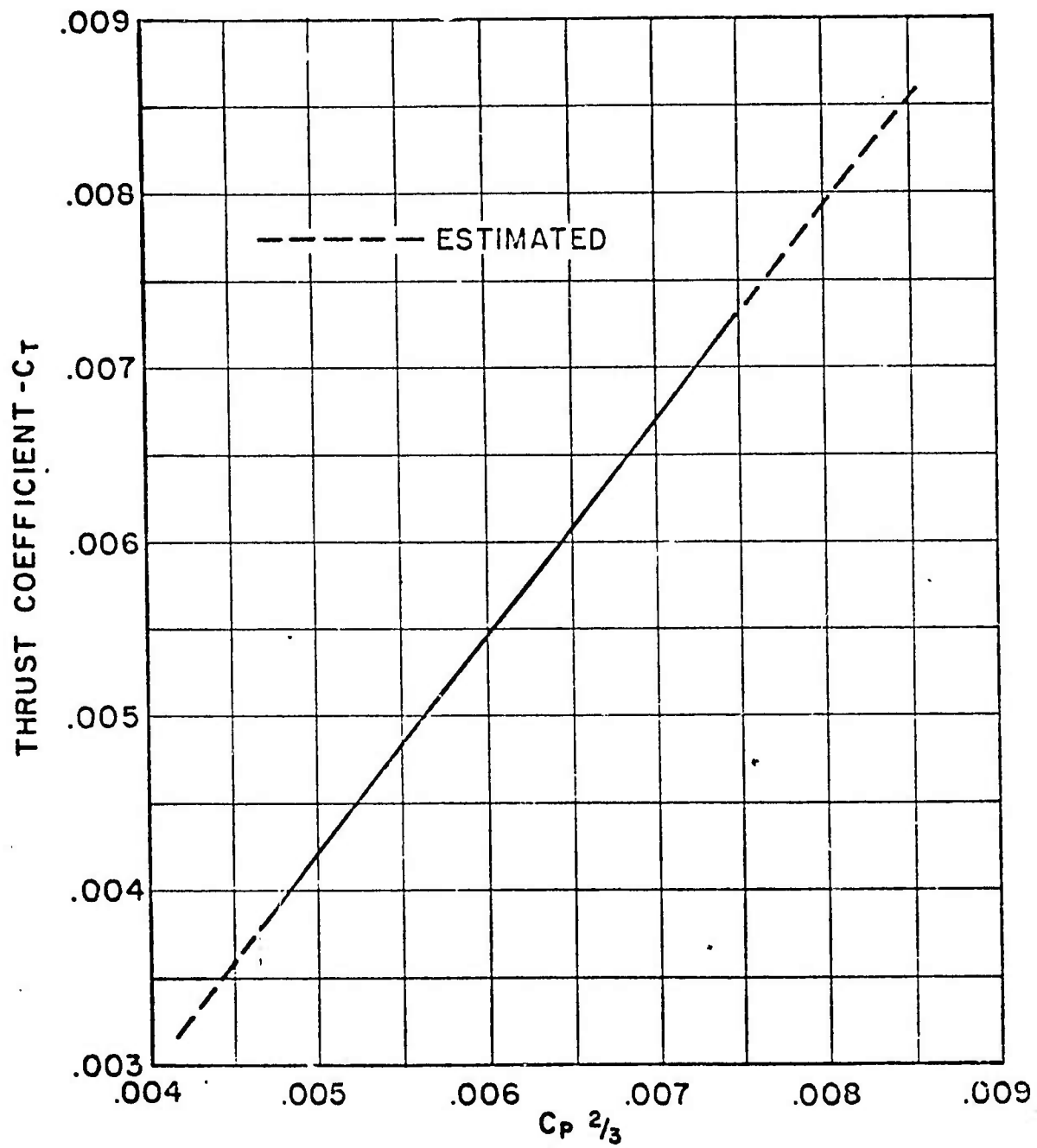
The limited data on the QH-50 with the Allison engine has made it possible to plot Figure A-9. Comparing this with Figure A-7, the 800 ft/min vertical rate of climb point occurs at a gross weight of about 2,235 lb, or a gross weight reduction of about 150 lb. The 800 ft/min vertical climb rate was an accepted performance guarantee value demonstrated by flight tests on a QH-50D with the Boeing engine.

In some cases Navy QH-50D losses were rather high and from unexplained causes. Since most Navy vehicles had no telemetry, there was minimal data to analyze to determine the cause for vehicle loss.

ARPA Use

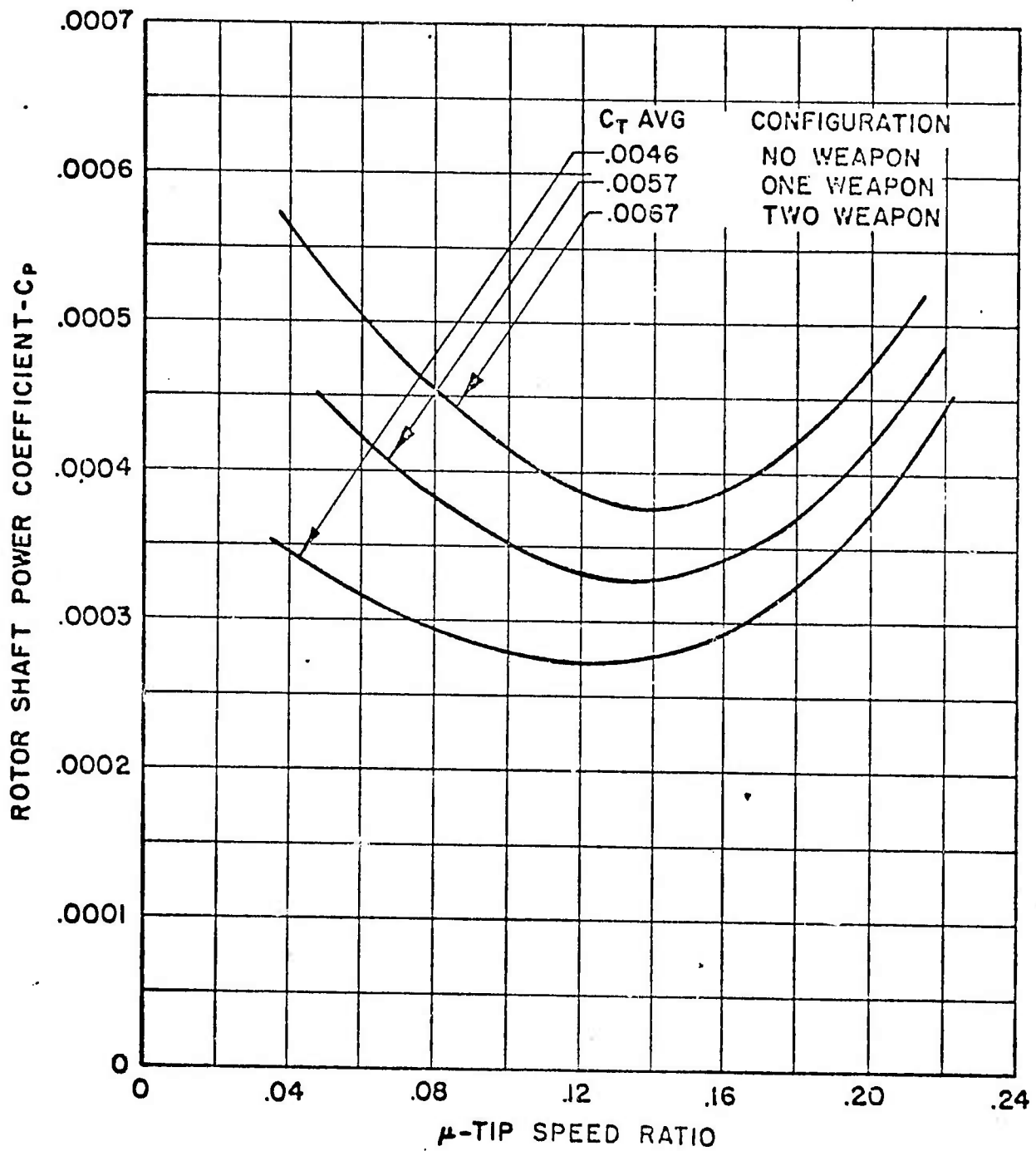
Very little actual vehicle performance data were obtained from the ARPA program. They mainly examined the feasibility of the various QH-50D sensor and sensor/weapon systems to perform a desired mission. Most, if not all of the measured data, was relative to payload performance and/or effectiveness. Numerous changes were made to the basic production QH-50D to improve the sensor and/or sensor weapon system performance.

During the program, loss of a few vehicles prompted action to study the QH-50D reliability and improve those items having low reliability. Also, due to some losses by power settling, flight restrictions were placed on the vehicle to prevent or minimize such losses. The QH-50D was not permitted to hover when winds were less than 15 kts. The power settling



QH-50D Helicopter
BuNo DS 1194

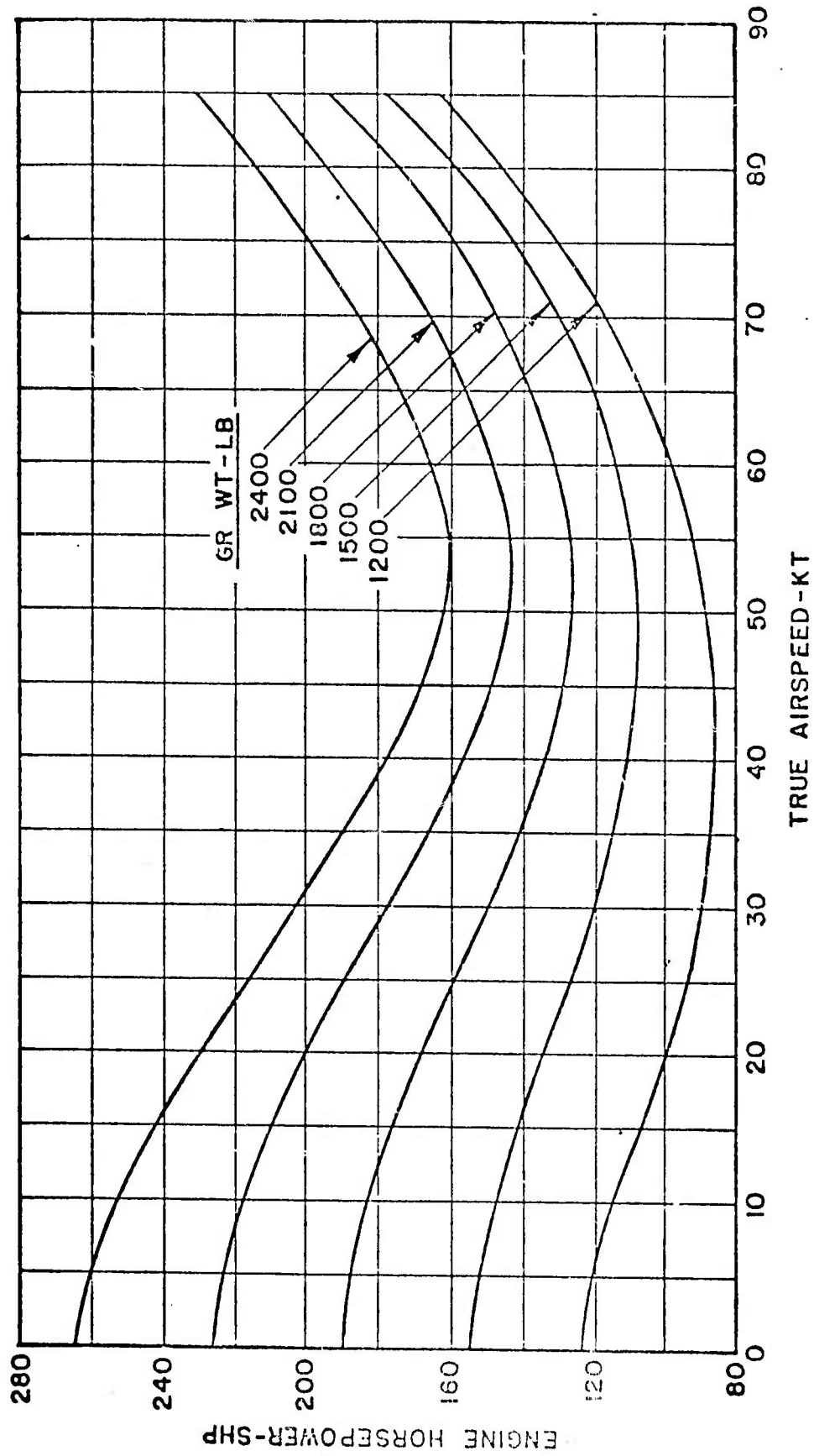
FIGURE A-3. OUT OF GROUND EFFECT HOVER PERFORMANCE
(Reference A-7)



QH-50D Helicopter
BuNo DS 1194

FIGURE A-4. ROTOR SHAFT POWER COEFFICIENT VS TIP-SPEED RATIO
(Reference A-7)

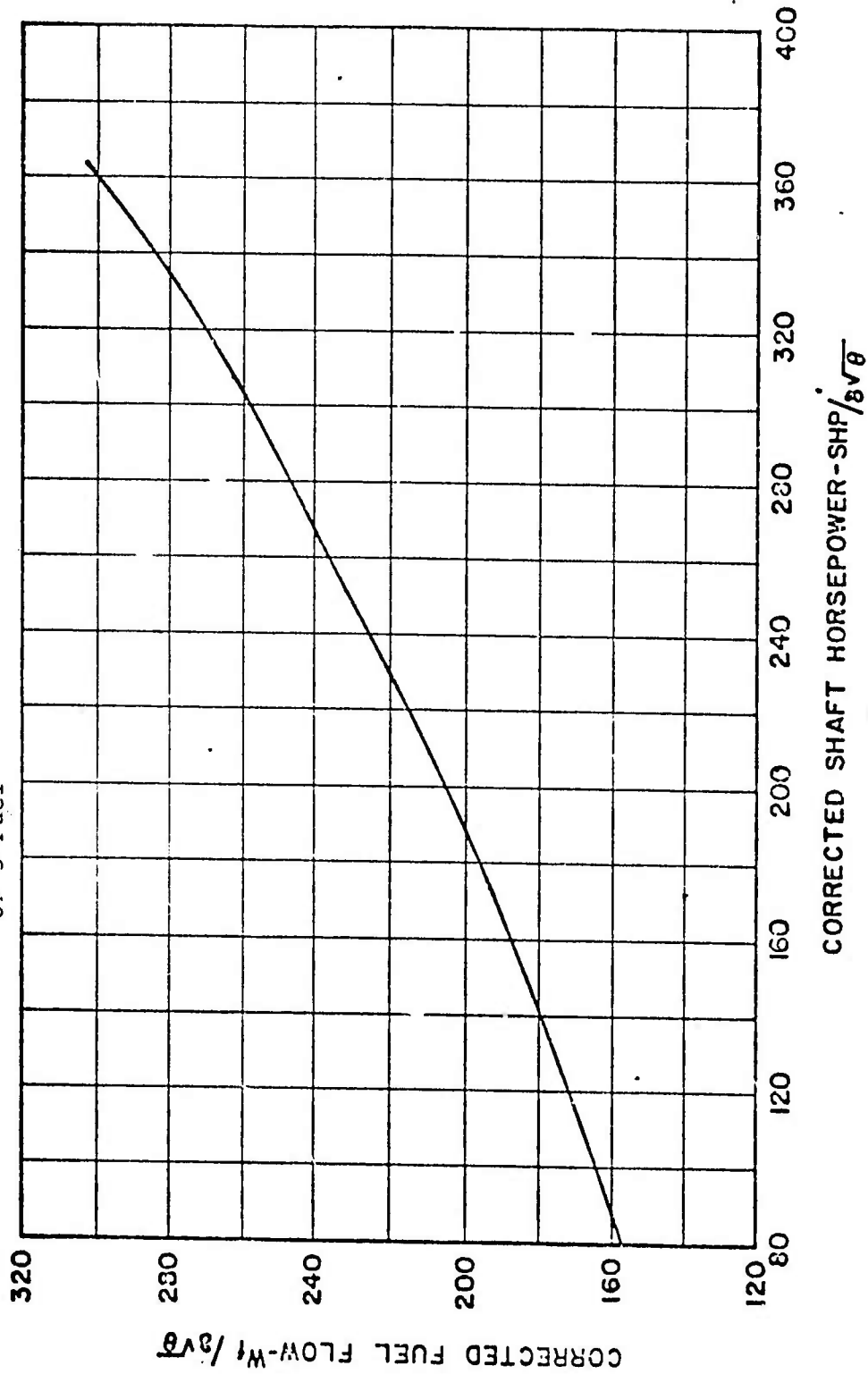
Sea Level
Standard Day
Normal Rotor RPM



QH-50D Helicopter
BuNo DS 1194

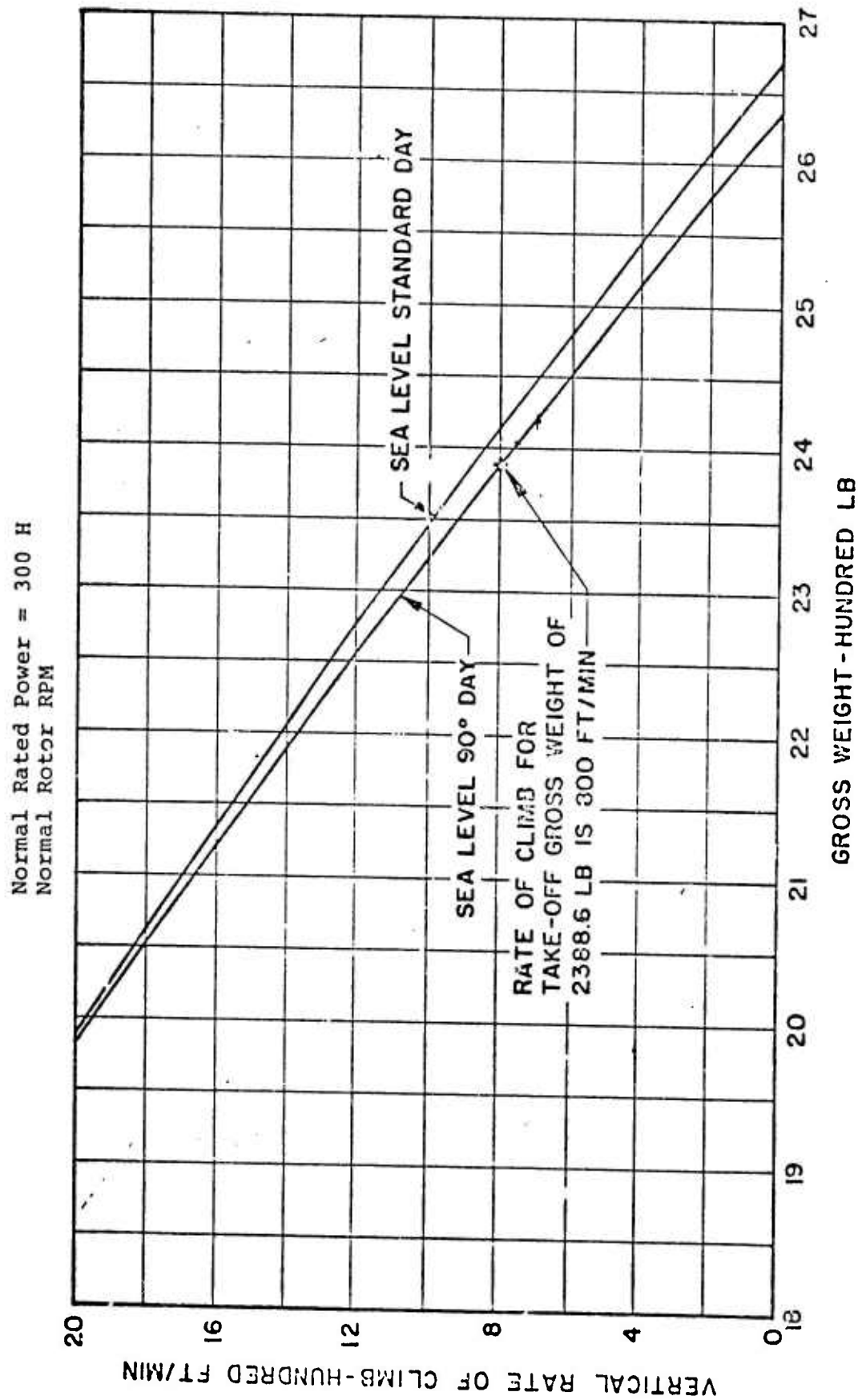
FIGURE A-5. HORSEPOWER REQUIRED VS AIRSPEED
(Reference A-7)

T-50-BO-10 Engine
Bleed Valve Inoperative
Exhaust Deflector Vanes Installed
Engine S/N BO-E10125
JP-5 Fuel



QH-50D Helicopter
BuNo DS 1194

FIGURE A-6. CORRECTED FUEL CONSUMPTION VS CORRECTED SHAFT HORSEPOWER
(Reference A-7)



QH-50D Helicopter
BuNo DS 1194

FIGURE A-7. VERTICAL RATE OF CLIMB VS WEIGHT
(Reference A-7)

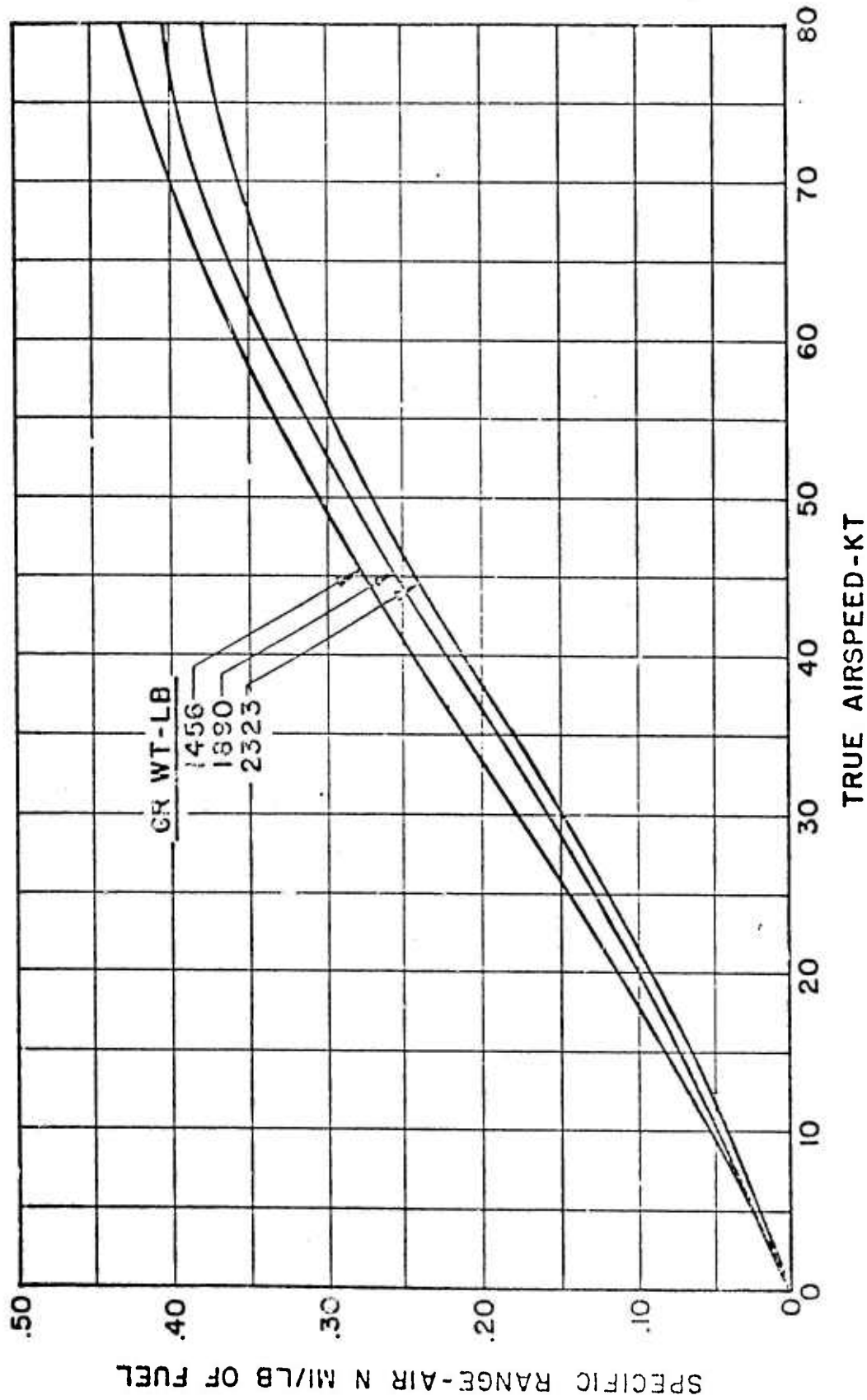
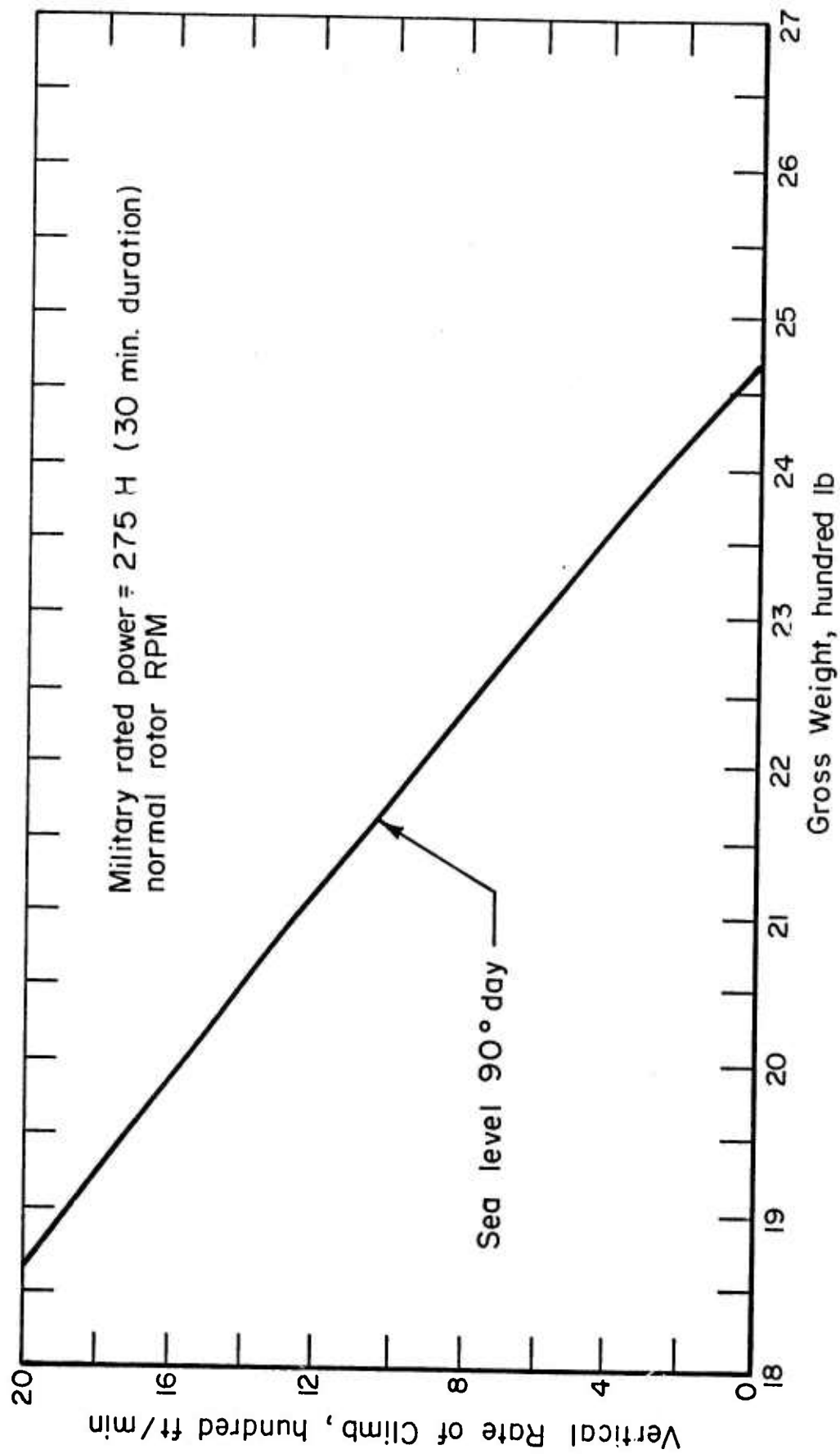


FIGURE A-8. SPECIFIC RANGE VS VELOCITY
(Reference A-7)



QH-50 Helicopter With Allison T63-A-5A

FIGURE A-9. VERTICAL RATE OF CLIMB VERSUS WEIGHT AT SEA LEVEL
(Reference A-8)

condition with its high sink rate results in excessive blade flapping. This condition is catastrophic for counterrotating coaxial blades since blade intersection is inevitable. The following recommendation is quoted from the Investigation Report of Nite Gazelle Drone Accident on July 15, 1971, at Fort Hood, Texas. (A-9)

"A thorough study of the power settling condition and the implementation of appropriate preventive measures should be made prior to any development or deployment of a drone requiring extensive hover or low speed (under 20 knots) operation. Vehicle loss due to power settling, though encountered infrequently in hover operations, would probably inflict unacceptable losses on an operational system."

Power settling may not be a problem for the NOE vision because of the low altitude operations and because the controller would have much better sensor information to anticipate the condition developing.

The ARPA tests did confirm the QH-50D to be a relatively vibration free vehicle as far as sensor response is concerned. Early tests incorporated a TV camera installation with a Dyna Lens attachment. It was later found that the Dyna Lens was unnecessary. Hard-mounted TV and movie cameras provided clear pictures without auxiliary equipment.

Weight Data

The basic production QH-50D "DASH" vehicle has an empty wet weight of 1409.4 lb and a maximum gross weight of 2,330 lb. (A-5) This basic vehicle has 57.4 lb of ASW-related weights, including some ballast that are not needed for the NOE/SFTS mission and thus, can be removed. (A-5)

The reworked empty wet QH-50 for the NOE/SFTS payload will have the following weight changes:

Removal of ASW-related equipment	- 32.4
Replacement Allison engine	- 42.0
New engine rotor interface gear box	~ N/C
Added oil for Allison engine	+ 4.0 .

The resulting available payload for QH-50D/SFTS application is approximately 850 lb.

QH-50D WSMR Operations

Beechcraft Corporation is operating QH-50Ds at White Sands Missile Range, New Mexico (WSMR) for the Army's Target Program. These vehicles are used both for tracking exercises and for actual flying targets for Army missiles.

The operation started in mid-summer with Gyrodyne Company of America furnishing technical support personnel to the WSMR Beechcraft facility for the initial period of operations (through September). The Beechcraft facility has a building which serves as a maintenance hangar, electronics laboratory, and management office. In November, they had two of the three QH-50D, trailer type Ground Control Stations (GCS) on site; neither of which were complete. However, by interconnecting the two units, they had an operating system. The third GCS has been requested to support the WSMR operations.

The initial operation has been mainly one of check-out and repair to get the various systems and subsystems working properly. Much of this has been done under the severe handicap of limited documentation on the systems and subsystems, plus the fact that when some pieces of equipment were removed from the ARPA GCS vans, they were removed by cutting the connecting wires. Beechcraft personnel indicated that they have had to devote considerable time to the logistic problem of locating spare parts for the various systems and subsystems. Many times these were needed simply to replace parts that had been removed from the equipment prior to their receiving it.

Beechcraft had a range safety requirement to install an independent shut-down system (command destruct) on the QH-50D before they could operate the QH-50D at WSMR. This system is powered by dry cell batteries with an independent receiver, operating on a separate frequency. When activated, it shuts off all fuel to the engine, stopping the engine.

The Beechcraft flight requirements on the vehicle are not very severe. They even commented that they have flown the vehicles very cautiously

with no banks in excess of 20 degrees. A summary of their flight activities between July and November 15, 1975, follows:

<u>Vehicle</u>	<u>Number of Flights</u>	<u>Total Flight Time, hours</u>
1	5	~ 4
2	3	2
3	2	2
4	7	4
	<u>17</u>	<u>12 .</u>

Once a vehicle is checked out and operating properly, the operation is as follows:

	<u>Personnel Required</u>	<u>Time, min.</u>
Ground crew (check and move to launch pad)	2	45
Preflight (prior to engine start)	2	10
Prelaunch (engine running)	2	5-15
Flight	1	90 (maximum)
Land, refuel, relaunch	2	40-50* .

The maximum number of flights in a single day (9-hour period) at WSMR has been two. Beechcraft personnel indicated they could possibly push that up to four with their present facility and staff. Their total staff of 7-10 people have supported 34 drone flights (QH-50D and others) during the July 1 through November 15 time period.

* Ground crew must wait approximately 20 minutes for rotors to stop.

Appendix References

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- (A-2) "Some Physical and Operational Characteristics of the QH-50D Drone Helicopter" (U), D-19629-ARPA, Rand Corp., Santa Monica, California, November 20, 1969, Confidential.
- (A-3) Information obtained during visit to Defense Advanced Research Projects Agency, Arlington, Virginia.
- (A-4) Information obtained during visit to Gyrodyne Company of America, St. James, Long Island, New York, September 4, 1975.
- (A-5) "Remotely Piloted Coaxial Helicopter Vehicle" (U), PP-4880, Vol 4, Gyrodyne Company of America, Inc., St. James, Long Island, New York, February 8, 1971, Confidential.
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- (A-7) "Flying Qualities and Performance Evaluation of the QH-50D Drone Helicopter", by P. L. Massaglia, FT-108R-66, Naval Air Test Center, Patuxent River, Maryland, December 9, 1966, Unclassified.
- (A-8) "Remotely Piloted Coaxial Helicopter Vehicle" (U), GCA Control No. 0171-14, Gyrodyne Company of America, Inc., St. James, Long Island, New York (undated), Confidential.
- (A-9) "Investigation Report of Nite Gazelle Drone Accident on July 15, 1971, at Fort Hood, Texas" (U), AMSEL-CT-A, U.S. Army Electronics Command, Fort Monmouth, New Jersey, August 13, 1971, Unclassified.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The objective of the study was to examine the technical and cost feasibility of using a television instrumented remotely piloted helicopter (RPH) as part of a closed-loop helicopter crew Nap-of-the-Earth flight training system, coupled with a Synthetic Flight Training System. The study analyzed and determined the visual, display, motion system and computational (hardware and software) requirements for the SFTS. Requirements for the RPH airframe and avionics were developed. Evaluation of the QH-50D determined that it had sufficient performance capabilities to serve as the RPH. Requirements for communications, RPH		

20. Abstract (Continued)

ground control and servicing and QH-50D/SFTS system integration, test, operation and maintenance are also developed. Cost estimates for each element of the system were developed to evaluate the potential cost-effectiveness. Conclusion of the study was that the QH-50D/SFTS concept for training helicopter pilots in NOE flying techniques was not cost-effective.