NIGHT/REDUCED VISIBILITY CAPABILITY FOR ARMY HELICOPTERS

Ad Hoc COMMITTEE
ARMY SCIENTIFIC ADVISORY PANEL

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Kenneth Clark
Enoch Durbin
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CHAIRMAN

DEPARTMENT OF THE ARMY ADVISORS

Manfred Gale
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JUNE 1973

PREFACE

During the Army Scientific Advisory Panel Meeting held at Fort Hood, Texas on October 5 - 6, 1970, Major General John Norton distributed a set of scientific challenges later presented to the panel as a basic terms of reference for Ad Hoc working group on Project MASSTER. In mid-July a study proposal was submitted as a set of terms of reference to the committee concerning Low Level Flight Operations of Helicopters. This assumed priority over the Project MASSTER effort due to the tremendous depth of study required in the original set of challenges.

It was decided in early 1972 that the additional work level did not directly affect the Project MASSTER terms of reference and therefore, could be and should be separated to form a separate project of the Army Scientific Advisory Panel. This then is a report of the Ad Hoc Committee on Night/Reduced Visibility Capability for Army Helicopters, chaired by Vincent S. Haneman, Jr., Dean, School of Engineering, Auburn University.

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ACKNOWLEDGMENT

The initial membership of this committee included Dr. Finn Larsen, whose untimely death in September 1971 left a considerable void in the committee's perception, and Professor Lawrence O'Neill, whose late winter resignation, due to the press of other panel activities, denied the group his excellent services at the close of the effort. On the positive side of the ledger, the committee has been favored from the outset with the wide range of understanding and technical talents of Dr. Paul Kruse. To this were added the skills and background of Professor Enoch Durbin in August, and the human factors, motivation expertise of Dean Kenneth Clark in November 1971. Throughout, Mr. Manfred Gale of ACSFOR provided the insight necessary from the Army's needs.

Without the help, assistance and counsel of, first Lt. Col. John Zugschwert, and second, Major John R. Gantt, OCRD, this study would have been virtually impossible. As action officers, these gentlemen brought together excellent briefings, which provided significant contribution to the committee understanding.

The many presentations and candid remarks by industry and military were invaluable in formulating any recommendations. Also, the committee was provided physical demonstrations in the field of the various problems which graphically conveyed the limitations of present equipment. To all those who so graciously assisted, the committee is indebted.

The undersigned wishes to personally thank the members of the committee for their perseverance, patience, support, professional skills and energies that they have provided this study and me.

V. S. HANEMAN, JR., P.E.
Chairman

TASS

Tactical Avionics System Simulator is a ground based simulator containing a fully equipped experimental helicopter cockpit. The pilot has both panel mounted pseudo-night vision display and a helmet mounted display. These are connected to a hybrid computer which generates symbology representative of a wide variety of night vision system.

RAVE

Research Aircraft for the Visual Environment is a specially equipped CH-53, configured to simulate a set of night vision sensor/display concepts in a flight-safe manner. The experimental pilot is located in the center of the A/C and has the capability to operate the A/C over its total flight regime. The safety pilots sitting in the cockpit have a control override capability.

INFANT

Iroquois Night Fighter and Night Tracker system is an optical low-light level system for target acquisition and weapons pointing developed by Hughes. It is an air to ground, passive, light amplification, integrated target acquisition and fire control system. Range 1000m recognition, 2500m detection (vehicles), SCAN sector $+15^{o}$ to -75^{o} elev/azimuth $+65^{o}$. 26 systems were purchased - 6 systems at MASSTER, 1 at Night Vision Labs, and the rest of the systems are being removed from aircraft and placed in storage.

SMASH

South East Asia Multi-Sensor Armament System for Huey Cobra is a combination of FLIR and MTI (moving-target indicator) for SEA operations. Developed for AH-1G. It uses radar for long-range target detection and IR for target recognition and weapons aiming. Presently on MASSTER ACCB project testing.

HAC FLIR

Hughes Aircraft FLIR is a competition - first generation FLIR - Army has 4 systems - 3 are at MASSTER, TRI-CAP testing, and 1 at NVL at Aberdeen. It permits wide and narrow viewing of the field in front of the aircraft, $+70^{o}$ azimuth and $+10^{o}$ to -85^{o} in elevation. Weapons system can be slaved to sight.

AGC-FLIR

Aerojet General Corp. FLIR. One of the 3 competitors for system under old SEANITE OPS program. It uses IR passive device. Army has 5 systems.

SU-50

1st generation image intensification goggles - supplanted by the ITT manufactured AN/PVS-5.

SECTION I

INTRODUCTION

In July 1971 the Project MASSTER Ad Hoc Committee was requested to undertake an additional investigation, to identify equipment and systems necessary to provide helicopter pilots with the capability to fly under adverse visibility situations. The study proposal, see Annex A, includes the following statement of the problem:

> "Periods of reduced light (nighttime) and visibility restrict the utilization of the full operational capability of Army helicopters. A requirement exists to provide a capability for Army helicopters to enable them to conduct their normal missions of target acquisition, target engagement, troop life and logistical support at night and during period of reduced visibility."

The terms of reference are:

> "a. Identify the best technological approach or approaches to provide the various mission oriented Army helicopters a night/reduced visibility flying capability commensurate with extension of their normal daytime/VFR mission performance under those conditions.
>
> b. Identify the most promising techniques of providing Army helicopters the capability required to perform the missions of target acquisition and engagement at night and during periods of reduced visibility considering the present state-of-the-art and utilizing one or a combination of sensors/systems.

c. Identify the individual components such as navigation systems, radar altimeters, various sensors, aircraft stabilization devices and displays required to enable Army helicopters to fly and survive in a mid-intensity conflict and perform their individual mission at night and during periods of reduced visibility. Each type of helicopter (by mission orientation) should be considered as a system and the entire family of Army helicopters should not be considered as the "system" under this investigation."

To carry out this task, the committee met six times for information briefings, see Annex B. On four other occasions, short executive sessions were held in connection with other meetings. Finally, there were nine one-man visits to ascertain selected items of information.

The committee submitted an Interim Report to Dr. Marvin Lasser on February 6, 1972, see Annex C, containing observations and recommendations as of that date.

This Final Report consists of recommendations relating to current and future work in the topic area, discussion of the night flying problem and the technical approaches to it, and appendices. In addition to Annex A, B, and C identified above, Annex D - G present technical reports by three of the committee members, Drs. Clark, Durbin, and Kruse, and one report by two colleagues of Dr. Durbin, Drs. Duke and Born.

SECTION II

RECOMMENDATIONS

Many of the items listed in the following recommendations will be found to be either underway, or to have been accomplished as a result of either the interim report Annex C, conversation with responsible personnel, or through evolution of the program. The recommendations placed here are to record the committees' feelings and activities, suggest that action should be taken, and/or support efforts currently underway.

A. Response to the ASAP Study Proposal

Since many of the parameters needed to "Identify the best technological approach or approaches . . . ." are under study at present in the Low Level Night Operations (LLNO) program by ECOM, the following judgments by this committee may be subject to review in the light of findings as experience and data are obtained. It must be emphasized that the data from the man/machine interface evaluations may also alter any presentation mechanism discussed but the basic sensing techniques are felt to be on reasonable grounds.

1. To establish the overall environment presentation, the committee recommends extended study and use of the FLIR systems in the 8 to 14 micron spectral range. In this area, the best potential for visual presentation resolution within present and foreseeable state of the art and for theoretical considerations exists. Advantages include the fact that the system is passive, that considerable effort has been expended, and that some successes have already been obtained. An obvious short fall is the limitation due to inclement weather (rain, snow) reducing the range of vision.

A far reaching program should be established to review all needs for FLIRs such as were delineated by the CDC STASAR study, to review the human factor aspects as revealed by the LLNO study, and to recommend a family of FLIRs for use in helicopters in their many roles. A "material need" was submitted in this area to Department of the Army in December 1972 and is being coordinated at this time.

2. Very little is being done at present in the Army to develop FLIRs for helicopters. The only program of which the committee was aware was the Aerial Scout, which has now been terminated. The residual Night Vision assets (pilot and observer systems) are being transferred to the LLNO total program. It is understood that the pilot system will be installed in the RAVE aircraft, with the Observer system probably assigned to either MASSTER or CDEC for test. The two will be brought together later. It is understood that no funds are being expended in the LLNO study to develop new FLIRs.

3. The committee recommends that the above program include Field of View (FOV) Studies in depth. The angular field of view required increases as the forward velocity decreases. Whereas high speed (120 knot) flight requires only about a 30^{o} horizontal field of view, hover probably requires at least 180^{o}, with 360^{o} desirable. The 30^{o} FOV can be displayed by means of a panel mount CRT. There is no way today to display 180^{o} information in a manner which will be acceptable to the pilot. The best compromise for the field of view problem is a helmet mounted display where the FOV moves as the pilot turns his head. This has serious problems in special disorientation, brown eye,lost night adaption, and eye fatigue. The far reaching program leading to FLIR development for helicopters should also include intensive exploration of helmet mounted display and other techniques for displaying the FOV's required for hover.

4. It is recommended that when improved goggles are available, they should be supplied to all helicopters not incorporating FLIRs. Recent tests at CDEC and MASSTER have established their value although research efforts are needed to provide better depth perception. Although the cost of FLIRs are dropping rapidly, they will continue to exceed tens of thousands of dollars per unit because of system complexity. Thus it may not be possible to put FLIRs in all types of helicopters.

5. A laser or microwave radar is recommended for low level operations to detect wires under all conditions. As in World War II, it is conceivable that wires will be strung such that low level vehicles will become ensnared. To counterthis threat, a thin beam microwave or laser which would detect and warn of a 1/8" wire at a range of one-half kilometer is needed. This is predicated upon twisted pair field wire, 60-90 knot airspeed and pilot recognition of problem within first or second scan of the instrument panel. It does not allow any indecision time and is an absolute minimum.

The frequency range for a microwave radar compatible with antenna size, power requirements and detection resolution indicates studies in the 100 giga hertz range should be pursued. A laser radar could use pulsed Nd:YAG or CW CO_2. The CO_2 laser would have better fog and haze penetration than the Nd:YAG one. The scattering problem at the Nd:YAG wavelength could be mitigated by use of a pulse gated receiver. The first objective is a simple warning device which would indicate an obstacle in the forward flight path and would require a climb maneuver to circumnavigate. Later efforts might consider this system for short range video presentation to backup the FLIR for those situations where environmental conditions deny the use of the FLIR. As noted in Annex G,

the visual resolution obtained from a microwave system is insufficient for pilotage, whereas that from either type of laser is sufficient.

7. A navigation system is recommended for all aircraft. Navigation problems especially at night or in weather present formidable obstacles to successful mission accomplishment. At present, the modified light pack LORAN D has the attributes desired. The limitation due to enemy counter activity the committee recommends consideration of a low cost, light weight inertial system using LORAN D update as ultimate and the lone LORAN D as interim. While economic considerations may limit the number of aircraft that receive the "ultimate" system, operational considerations dictate that each aircraft have some non-radiating navigation device. All the problems of dedicated aircraft, lack of flexibility, limited operations require solution of the navigation problem in the direction of systems for all a/c - low cost, less accurate, modular. It is further recommended that a visual presentation with map coordinates and a "present location" pip on a chart be built into the system.

8. The committee further recommends increased stabilization for a/c involved in night/weather operations. Due to different mission requirements, the degree of stabilization needed will vary from one type aircraft to another. It appeared from this study that full autopilot with heading and attitude hold would be required for all heavy lift aircraft. This is especially needed for flights involving operations which cause complex frequency mode oscillations such as are imposed by sling loads. Directional Stability Augmentation System (SAS) would be the minimum required stability augmentation in all types to minimize crew fatigue, and provide an improved aircraft stability as a base for the above instrumentation.

The pilot's physiological work load limits must be ascertained and blended with the command control data required for these missions.

B. Responses to Overall Problem Area.

Since the ASAP Study Proposal was directed toward specific end items, as opposed to general topics or subcomponents, to accomplish the primary mission under restricted visibility conditions, the committee feels that the following recommendations are germane to the problem area and should be considered in the program.

1. The overall complex study of the problem, which involves the three operations of piloting navigation, and targeting, may be broken into simpler studies of any one of the three to determine the limit boundaries involved. This should be done in several cases of the LLNO effort to expedite findings and reduce costs.

2. The program for study should be designed to attack short range problems and obtain long term solutions to the navigation problem sequentially due to the difficulty in definition of the problem.

3. The hardware should be evaluated in terms of vulnerability by tasking the different equipments over speed and altitude domains and different terrains. This would provide relative performance data to consider the visual aspects, the altitude data and stability augmentation. It is felt that simulator testing would not provide the same depth of data.

4. The analytical work previously sponsored by ECOM should be integrated into the LLNO program.

5. Aircraft differences in flight characteristics, power and mission should eventually be programmed into the LLNO program. In this the use of simulation seems to be worthwhile.

6. The field of vision, the amount of data required to perform hover is a vital entity to establish the instrumentation. The test program must be configured such that the data obtained does not limit itself to the particular equipment tested but provides system and design parameters.

7. The role of the pilot and the pilot/copilot interface must be defined. The decision as to whether the pilot is to be the performer of the activity or to be the monitor of the "auto system" is required. The committee feels that the following statement is worth considering as a tenet, ie "A reasonable solution should utilize the ingenuity of the pilot especially in his decision making capability. This implies that the level of sophistication of the system should be such as to bring the problem down to the point where a reasonably skilled man can operate the system. That any simplification of the problem beyond this merely exchanges the skill which is already available in a man for added complexity in the system . . ."

8. The LLNO working advisory group should draw upon professional experts from outside the government as well as from within.

9. The Army must determine the sensitivity of covertness items such as noise, low altitude, etc.; i.e., how much of one is better than the other, where are the best payoffs?

10. Evaluation of the relative importance of the various system parameters is needed to bring logic to the study.

11. In the present LLNO program there does not appear to be an evaluation of the repetition rate required for visual presentation to the pilot to perform hover and forward flight. It is recommended that this facet be evaluated.

12. A continuous review of the results of the man/machine interface requirements as applied to this task (LLNO) should be accomplished by an outside agency to assure that all areas and questions are covered. Human factors personnel should be a permanent part of the ECOM LLNO working group.

13. It is recommended that instrumentation and displays peculiar to rotary aircraft should be developed. The work load of the rotary wing pilot is far in excess of that of fixed wing pilots. The simple use and application of surplus fixed wing equipment is not cost effectiveness. The critical conditions of engine, rotor rpm, torque should find unique display capabilities. The problem becomes critical for night, low level operations.

14. Stability augmentation for all helicopters is most strongly recommended, especially when the aircraft is to be used in the area of LLNO. The above referenced work load must be relieved to every extent possible to permit the pilot to concentrate on pilotage needs and direction of the aircraft for mission accomplishment as opposed to just keeping the aircraft under control and in the air.

15. It is recommended that the Army establish under OCRD a group to continuously review the activities in the various programs to assure that mutually beneficial material is exchanged and the greatest productivity be enjoined. While many programs are under other agencies, it is vital that the technological review be accomplished in and by the agency charged with R & D within the Army.

16. The existence of a modern fighting force depends so strongly on the use of air that these airborne systems must be equipped to perform at any time. Since the accomplishment of the mission will be

very expensive, it is recommended that most resources available should be placed upon satisfying the technological needs to provide answers for later implementation, not necessarily to building division equipped units.

17. The intelligence briefing provided the committee on possible enemy night capabilities was very sketchy. It is recommended that OCRD require the intelligence community to provide detailed information on all achievements in the airborne area, with respect to night, low level, covert operations, as well as counter capability to the LLNO as presently seen by CDC.

18. Nothing has been said throughout the study with respect to removing fog or low clouds. To be able to do this at will would greatly enhance operational capability. The committee recommends that additional efforts be expended in the area of fog, removal of, creation of, etc. The logical unit to undertake this is the Atmospheric Sciences Laboratory of ECOM. The work in this area is progressing slowly due to lack of adequate funds and lack of official recognition that weather modification is vital to the Army's requirements.

19. Fundamental studies in the area of wire, or similar obstruction, detection is necessary and recommended. The capability to detect at ranges of greater than 1/2 kilometer some thin line (about 1/8" diameter) in the presence of dust, rain or fog is essential. This device must provide minimum signature such that the enemy's ability to detect the presence of the vehicle will not be enhanced over the noise or other signatures.

20. The effort expended by this committee should continue. The areas to be monitored include the LLNO study, night vision

equipment development, systems to detect wires, and cockpit instrumentation.

21. From the presentations, the committee feels that the RAVE aircraft and TASS simulator efforts are the primary efforts of the Army in trying to solve the LLNO problem. It is recommended that strong considerations be applied to the problems of the night vision system and its display. From the LLNO tests, parameters should be available to assist in the design of the System but certain aspects of the problem should and could be approached now. The expertise of the Night Vision Laboratory should make primary contributions to future efforts.

22. The committee feels that further tests on INFANT, the first generation HAC FLIR, the first generation AGC FLIR, or SMASH to evaluate parameters for future designs will be wasted efforts. Tests on the SU-50 goggles are also useless. Such tests should be eliminated. The committee's greatest apprehension in this area is that forecasts of future capability and potential will be made from old equipment, techniques and systems.

23. Tests with the AN/PVS-5, night vision goggles, should be continued as a possible means of providing an inexpensive aid to night flying.

24. The committee recommends that the MASSTER program for two test bed aircraft be approved as rapidly as possible. This will provide space and lift capability to investigate programs and equipment in a troop environment to get current data. This is different from RAVE in which fundamental information is being secured. It is vital that these two program interchange information. RAVE is not a combat system evaluator.

SECTION III

DISCUSSION

This report must be concerned with avenues of approach and areas of greatest promise rather than specific endorsement of individual pieces of hardware because equipment designed specifically to enable a helicopter to fly NOE is available. The results of the ECOM Low Level Night Operations program will influence the design of such equipment.

A. Night Vision System Selection.

In general, the committee is of the overwhelming impression that a capable passive viewing system is mandatory for all mission categories. The details would be altered for specifics, but an ability to have a pictorial representation of the real world seems vital. The technology area that has the greatest promise is the 8 to 14 micron FLIR. It alone offers the ability to fly NOE and to acquire and engage targets under "pitch-black" conditions. However, FLIR's have limits, including inclement weather in which range will be limited, detection of small obstacles such as tall thin poles and wires and equipment maintenance and complexity. The committee finds that no FLIR systems have been constructed exclusively with the pilotage function in mind. Several experimental models have become available for test and evaluation. These have led to varying degrees of success or failure for employment in fields other than the intended application. It is understood that a classified system under test for another purpose has performed well for pilotage and flight control including hover and 20' altitude (NOE) flight.

Tests being conducted under the LLNO program will attempt to establish

sets of parameters to permit the specification of the requisite system. Optimization of field ov view, resolution, range, display size, and power required are a few of the items under review. The effect of forward velocity upon the field of view is that of higher speed, smaller field since the time range of action possible is dependent upon this item. As the forward speed reduces to zero (hover), it is necessary to have 180^{o} field to view to provide the cues necessary, wih the probability that 360^{o} field of view is required if positioning is involved.

The target acquisition problem has conditions which are sufficiently different from pilotage that special consideration must be made. Target acquisition problems are categorized in three ways: detection, recognition and identification. For detection, in which it is necessary to establish a wide search pattern, a wide field of view but only moderate resolution is required. For recognition, it is necessary to have a much finer resolution, and an intermediate field of view will suffice. Identification requires an even finer resolution be made, but this can be done with a fairly narrow field of view. The narrower the field of view, the more stabilized the system must become. These three functions can be accommodated in a single FLIR system with magnifications of 1x, 6x, and 15x.

In order to anticipate direction changes, it is desirable for the copilot to be able to look to either side of the flight path while the pilot looks direction of flight. The FLIR system could have two modes of operation, each optimized for the task at hand, using time share common facilities to the greatest extent possible, see Annex G. The two primary tasks, pilotage and target acquisition and engagement are thus covered.

To act as backup for two of the items above, a lightweight microwave radar or laser radar system is recommended. The degree of complexity will depend upon further definition of task. A very simple, limited range, narrow beam unit which would provide warning of wire, pole or other obstacles in direct flight is possible. Microwave radar would provide an active system for those situations where the scattering and absorption by rain and snow has limited the FLIR. This unit could prove to be an additional flight capability for IFR conditions. On the other hand, a laser radar would provide more precise information on the direction of the wire or pole. These tradeoffs need to be studied in more detail.

B. Psychological Aspects.

While the primary content of this area is expanded upon in Annex D, certain aspects require emphasis to place the overall problem in the correct perspective. Operation of present-day aircraft capable of vertical flight -- especially helicopters, demands considerably more of the pilot than does fixed wing flight. The understanding of what sensory input is required for operation of a vehicle which can move forward in straight and level flight and at the pilot's discretion hover, hold stationary, rise vertically, descend, or even back up is far from complete. The operation of this vehicle under reduced cues, such as in night operations, fog, rain, or snow, places a demand on the pilot to know not only his three linear position aspects, but his three rotational attitudes which are under his direct control.

The situation is especially serious since the pilot can very easily suffer vertigo or become disoriented. This has been shown in

the simulation. With even slight disorientation it will become very difficult to make established flight patterns, and excessive reestablishment of references may have to take place -- such as circling. In a strange area with unfamiliar terrain this would be unacceptable and probably fatal, if not due to physical hazards, then due to enemy activity.

The problems of sensory input demands and disorientation combine with the long series of complex problems concerning the likely behavior of crews of both Protegonists tanks/anti aircraft units and aircraft under combat conditions tend to make the overall problem even more severe. The tests observed to date have not included any simulations which would provide insight into this area. This then should be considered when reviewing the results of various tests being conducted.

C. Aerodynamic Considerations.

The recommendations outlined below are made in an effort to emphasize those issues which seem most significant to the committee. The emphasis is on providing guidelines for immediate programs that should, on the one hand, provide much-needed, quantitative information using existing equipment and, on the other hand, explore the potential merits of future equipment. The results of such programs together with vulnerability estimates are needed to provide the basis for establishing military doctrine on the uses of helicopters as well as for procurement decisions.

The points outlined below discuss those aspects which are common to all night time helicopter missions. Special mission requirements should be kept in mind, but they should not dominate the fundamental investigations. The application of the best emerging systems to specific missions should be explored subsequently.

The functions involved in helicopter flight operations can be divided into three distinct areas: piloting, navigation, and targeting. Navigation involves relatively infrequent updating of position and course information; targeting involves recognition, identification, taking suitable action such as laser target marking or firing of a weapon, and piloting includes all those functions that are involved directly in controlling the flight path of the helicopter. Since navigation and targeting are normally not performed concurrently they can both be handled by the copilot. Under conditions of high work load this suggests a logical division of labor between pilot and copilot. This division also suggests that the problems of navigation and piloting can be explored separately to a great extent. For example, many aspects of existing navigation systems can be compared flying (NOE) during daytime with the navigating copilot "under the hood". On the other hand, piloting problems can be explored without navigating and targeting at the same time, thus simplifying the current study.

D. Comments on the ECOM LLNO Study.

The ECOM Avionics Laboratory approach to the piloting problems of low-level operations at night, using the RAVE aircraft and TASS simulator studies appear well justified to this committee. The goal of the program should be to establish a data base for the specification of future equipment. In the course of this program the question of the required field of vision is to be resolved. In terms of equipment, the RAVE program should not get involved in extensive testing of existing devices. These devices are to be used to establish a base line with the effort directed toward possible improvements and

their evaluation. The main thrust of the program should be in the directions of integrating aircraft flight variable information with a visual image and of evaluating the relative merits of different control augmentation systems. The candidates for the variables to be integrated and the loops to be closed can be established analytically, based on thorough system analysis. The feasibility of using a laser range finder should be explored to obtain the all-important range, and range rate information. The performance achievable with relatively low cost devices should be carefully evaluated with special attention to innovative optical solutions.

The flexibility required by this project supports the extensive use of simulator studies which are less expensive than exploratory flight programs. Simultaneously, preparations can be made for exploring the field-of-vision requirement in flight tests using the RAVE helicopter. This helicopter should use a variable feedback system so that the significance of different degrees of augmentation can be explored. Flight worthy versions of the best systems should be built and flight tested.

The committee is quite pleased after thorough examination of the current LLNO detailed plans. The program is vigorous, well organized and in general in direct pursuit of the basic goal. We would like to offer, however, some additional suggestions.

A. There is some reasonably good analytical work which has taken place and some of which ECOM has supported and is, therefore, well aware of. This analytical work does not appear to be well integrated in the actual experimental program. Such an integration will surely sharpen the planning of the experiments and the insights gleaned from these experiments.

B. A key experimental parameter, excess power available, is important in determining the ability of the pilot to fly the selected trajectory. This element is not being addressed at this time and, therefore, should be included as the program evolves.

C. Aircraft differences and their effects on such flying need be considered. The RAVE aircraft is a CH53, the TASS simulation is for a UH1B. Clearly the aircraft maneuverability characteristics strongly affect the flight trajectory and the ability to fly under conditions of low altitude. Simply, these two aircraft are unlike the Tandem with its high pitch rate capability and the hingeless rotor aircraft with its high control power. These two types of rotor systems may very well be included in future Army aircraft and should therefore be included as the program evolves. Because it is easy to change the simulator, these should be explored primarily in the simulator program. These aircraft differences tend to disappear as the aircraft are loaded to the same levels of excess power, but it is not clear that this will be the case in every tactical situation, hence the differences should be explored.

The difference in aircraft types will also provide differing needs for stabilization systems, vibration levels, inertial forces, and these will affect the ultimate systems which evolve in this program.

Because of the need to coordinate the various efforts, organizational aspects must be considered carefully. Therefore, the organization of the Working Advisory Group to monitor the technical aspects of these programs is to be commended. The group has been charged with the following responsibilities.

1. Discuss and evaluate the technical aspects of any major proposal for work in this area.

2. Make recommendations for changes in scope and/or content of such proposals, if found necessary.

3. Make recommendations of its own.

4. Discuss and evaluate progress of the programs.

It is recommended that the membership of this group might be supplemented by non-government experts.

E. Other Human Factors Considerations.

A systematic choice of a final system for low level night operation of helicopters can proceed only after the resolution of two important points.

1. The structuring of the low level flight path control system depends largely on the decision made concerning the role of the pilot. The options range from the fully automatic system, with the pilot serving as monitor of the system, to the minimal aid system in which the pilot determines error, decides policy, performs control, and monitors the aircraft and its systems. The discussion of the basis for choice among this range of options appears in an appendix.

2. The requirements for such a system can only be established by determining the relative military value of the various modes of reducing vulnerability.

Reductions in altitude, effective temperature, radar cross sectional area, illumination, and sound level all enhance covertness. All are not equally useful in enhancing covertness nor are all these equally difficult to achieve. The sensitivity of covertness enhance-

ment to all these factors needs to be established before a reasonable operating altitude requirement can be established.

Obstacle detection difficulties may in the long run effectively establish operating altitudes. Unless a satisfactory obstacle detection system is devised the operating altitude may well be determined by the height of potential hazards.

The system design of a fully automatic low altitude control system will permit an evaluation of the relative value of each parameter to be sensed.

There is a pressing need for research studies in this area. Such research can diminish the need for expensive testing of equipment alternatives. Such research can provide the basis for future flight path control systems which can reduce pilot training costs, and enhance pilot-machine performance. Some important research questions are indicated in Annex E.

ANNEX A

ASAP Study Proposal

Annex A

ASAP Study Proposal

1. Proposed name: Night/Reduced Visibility Capability for Army Helicopters.

2. Statement of the problem: Periods of reduced light and visibility restrict the utilization of the full operational capability of Army helicopters. A requirement exists to provide a capability for Army helicopters to enable them to conduct their normal missions of target acquisition, target engagement, troop lift and logistic support at night and during periods of reduced visibility.

3. Considerations:

a. The Army presently employs several types of mission oriented helicopters. These include target acquisition aircraft, attack aircraft, trooplift aircraft, and large logistical support aircraft. Mission orientation dictates the tactical employment scenario for each type of helicopter. All these aircraft require the ability to fly at night. Due to their tactical employment, and considering survivability aspects in the forward battle area, some may normally be required to fly at lower altitudes than others.

b. Some Army helicopters may also require a night vision capability to perform their missions besides being able to fly. These capabilities include target acquisition, engagement, and possible hovering, positioning of large helicopters over loads for pickup in dusty areas which limit crew visibility during that particular operation.

c. The Army has investigated numerous ways of providing a night capability to helicopters. The technology demonstrated includes image intensification, low light level television, radar and infrared imagery.

Most demonstrated capabilities have solely addressed target engagement means for attack helicopters. Generally speaking, infrared imagery appears to provide the most promising technology, although each approach investigated to date has certain advantages. Image intensifiers are relatively simple, lightweight, and lower in cost. Radars provide certain target selectivity not afforded by other means.

d. The present state-of-the-art provides numerous ways of displaying sensor imagery. These include flat plate CRT's, wrap-around displays, helmet displays, and "heads up" displays. In order to fly low level, some means of portraying depth perception would be desirable.

e. Consideration must be given to the installation problems associated with system complexity, aircraft capability, weight and balance considerations, and man/machine interfaces. Modifying existing aircraft and system design into future aircraft must be envisioned.

f. Sensor range capabilities are a major consideration when addressing target acquisition and target engagement means where standoff ranges may be critical.

4. Proposed terms of reference:

a. Identify the best technological approach or approaches to provide the various mission oriented Army helicopters a night/reduced visibility, flying capability commensurate with their normal daytime/VFR mission performance under those conditions.

b. Identify the most promising techniques of providing Army helicopters the capability required to perform the missions of target acquisition and engagement at night and during periods of reduced visibility, considering the present state-of-the-art and utilizing one or a combination of sensors/systems.

c. Identify the individual components such as navigation systems, radar, altimeters, various sensors, aircraft stabilization devices and displays required to enable Army helicopters to fly and survive in a mid-intensity conflict and perform their individual missions at night and during periods of reduced visibility. Each type helicopter "by mission orientation" should be considered as a system, and the entire family of helicopters should not be considered as the system under this investigation.

ANNEX B

MEETINGS AND AGENDA

ANNEX B

MEETINGS AND AGENDA

Because of the Ad Hoc Committee on Night/Reduced Visibility Capability for Army Helicopters was formed as an adjunct of the MASSTER committee, the meeting fell into three categories. The six main meetings consisting of information briefings were held for the primary purpose of addressing the helicopter problem. Four other meetings were short executive sessions held in conjunction with either MASSTER committee meetings or a regular ASAP meeting. There were also nine one-man visits for the purpose of acquiring information about a specific problem area. The list follows:

Main Meetings

31 Aug. 1971	Ft. Monmouth	(ECOM Program)
1 Sep. 1971	Aberdeen PG	(LWL Study)
3-4 Nov. 1971	Ft. Hood	(observe Night Low Level Field Tests)
2-3-4 Dec. 1971	Pentagon	(Industry/Service Briefing)
22 Feb. 1972	Wright Patterson AFB	(Foreign Tech Div - AF Low Level Operations)
14 Mar. 1972	Pentagon	(Navy Program, AF AC Proj Intelligence Brief)

Executive Sessions

16 Jul. 1971	Ft. Hood	(MASSTER Committee Received Study Proposal)
7-8 Feb. 1972	Ft. Lewis	(ASAP)
21-22 Mar. 1972	Ft. Hood	(MASSTER Committee Proj QuickDraw, et al)

ONE-MAN VISITS

14 Apr. 1972	Ft. Ord	(MASSTER Committee)
4 Oct. 1971	Pentagon	(Haneman)
12 Jan. 1971	Pentagon	(Haneman)
15 Mar. 1972	Eglin AFB	(Haneman - observe AC 130 instrumentation)
30 Mar. 1972	Ft. Monmouth	(Clark - Briefing on LLNO)
18 Jul. 1972	Patuxent River	(Kruse - Rave a/c)
1 Nov. 1972	Ft. Ord	(Haneman - LLNO)
3 Nov. 1972	Ft. Rucker	(Haneman - LLNO)
26-27 Nov. 1972	Ft. Hood	(Haneman, Test Bed A/C)

Oklahoma State University

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February 6, 1972

Dr. Marvin Lasser
Executive Director
Army Scientific Advisory Panel

Subject: Interim Report - Project Masster Ad Hoc Committee Subsection

Dear Dr. Lasser:

This is an interim report of the Project Masster Committee - subsection Night/Reduced Visibility Capability for Army Helicopters.

The subsection has held four meetings during the time span 1 August 1971 to date. A list of meetings, committee attendees and major objectives is contained in Appendix 1.

As a result of these meetings, of studies conducted by the panel members and of discussions held by this group, the following list of conclusions has been reached and are recommended for Army consideration, as an interim report of the subsection.

1. There appears to be confusion within various sectors of the Army concerning the requirements for night/reduced visibility, low level operations. In addition to the normal statements of requirements, consideration must be given the relative values (sensitivity analysis) of covertness, altitude, sound, radar crosssection, IR signal, camouflage, et al.

2. The establishment of a program at ECOM under the subject title of "Night Low Level Operations" has been reviewed in some depth. The committee endorses this effort and has the following items which it feels should be an integral part of the effort description, intent and goal.

   a. The effort should define the man/machine interface requirements and recommend a system configuration which will achieve the desired capability.

   b. Consideration should be given to reinforce the study capability with experts from industry and universities, as appropriate.

   c. To facilitate solutions to the very difficult problem of human factors, it is recommended that a qualified, forceful representative of the Aeromeidcal Research Laboratory, HumRRO, or the

Human Engineering Laboratory be assigned to this project as a working staff member.

3. The committee has had presentations concerning the Aerial Scout Program. It feels that much mutually beneficial material will be obtained from both the Scout and the ECOM programs. To obtain the greatest productivity, it is suggested that the maximum coupling and cross-fertilization between these programs be made. Efforts to gain close coordination, timely contacts and promotion of productive trends warrant special attention. This is especially important in programs which have vague definitions of requirements and incomplete technological backup. It is further suggested that consideration be given to periodic review of the Aerial Scout and Night Low Level Operation Programs by the representatives of the ASAP.

4. The workload of the pilot of a rotary wing aircraft was very ably presented to the Panel on several occasions. The utilization of instrumentation from fixed wing aircraft in rotary wing aircraft has provided commonality of equipment, but has been a serious detriment to the helicopter pilot. The committee suggests that helicopter instrumentation needs additional study with emphasis on particular instrumentation which will reduce the pilot's workload. The Army should support basic studies on the techniques and material for display and on the pilot adaption to these displays.

5. At present, there are only three principal types of night vision systems which can be considered for night operations. These are the image converters, the low light level television, and the thermal imaging. Of these three, only the thermal imaging systems of the FLIR type should be considered for the helicopter pilotage problem. This is based upon the range limitations of the image converter and the low light level television. Of the FLIR thermal imaging systems, those working in the 8-14 micron region perform the best for very fundamental theoretical reasons. Therefore, only those that operate in this region should be considered. Since the pilotage and navigation requirements differ from the target acquisition and engagement requirements, a single FLIR cannot perform optimally in both roles. It may be possible to employ the same detection and amplification electronics by time sharing for two input optical systems and two display systems.

6. The rotary wing pilot work load, even in clear weather, requires a considerable capability over the fixed wing counterpart. It is necessary in periods of night/reduced visibility to provide the pilot with an aircraft at least as stable as the fixed wing. The emphasis here is especially directed toward stability augmentation devices and design to reduce pilot workload. This includes consideration of full autopilot capability on all aircraft considered for this difficult mission.

7. The committee feels that one of the most salient features of this study is the fact that night/limited visibility operations cannot

be gained without significant investment in the program. There are pacing items which require financial support. This support does not appear to have been accomplished in the past with direction toward the specific goals. The Army must realize that night/limited visibility operations systems are complex, expensive and require funding support of a fairly constant nature to achieve the desired capability. Without this, it is futile to dabble in the periphery.

8. It should be noted that the committee has based its considerations upon the conditions defined but feels that these have been idealized with no enemy counteractivity. The proposed solutions appear to be sensitive to enemy activity and therefore some appraisal of this area must be made to assure the resulting systems will, in fact, be the best possible.

9. As a final and very important last item, the committee recognizes the exceptional effort on the part of Lt. Col. J. Zugschwert and Major J. R. Gantt in providing the integration, interface and ingress for this study to date, -- and specifically the industry-government meeting of December 1-3, 1971. This last item has had direct salutary effect on many of the items listed above already.

The committee wishes to have the Panel officially acknowledge the significant contribution of the Army and Industry participants in the most candid/refreshing meeting above noted.

Kenneth Clark
Enoch Durbin

Vincent Haneman, Jr.
Chairman

Paul Kruse
Lawrence O'Neill

APPENDIX I

1. 30-31 August, 1971 - ECOM, Ft. Monmouth, New Jersey
   Professor Enoch Durbin
   Dr. Paul W. Kruse, Jr.
   Vincent S. Haneman, Jr.
   (Discussed ECOM Program)
2. 1 September 1971 - Aberdeen Proving Ground, Maryland
   Professor Enoch Durbin
   Dr. Paul W. Kruse, Jr.
   Vincent S. Haneman, Jr.
   (Discussed the LWL CAVNAVS Study with the Authors)
3. 2-4 November 1971 - Fort Hood, Texas
   Professor Enoch Durbin
   Dean Kenneth Clark
   Vincent S. Haneman, Jr.
   (Discussed and observed the CCB Tests, with participants -- to review motivational factors in non-combat)
4. 1-3 December 1971 - Pentagon, Washington, D. C.
   Professor Enoch Durbin
   Mr. Mannie Gale
   Dr. Paul W. Kruse Jr.
   Vincent S. Haneman, Jr.
   (Military/industry presentations and conference addressing the terms of reference)

ANNEX D

Special Paper

Psychological Aspects of Low Level Night Operations with Helicopters

APPENDIX D

PSYCHOLOGICAL ASPECTS OF LOW-LEVEL NIGHT OPERATIONS WITH HELICOPTERS

Any overall examination of the problems associated with flying helicopters with reduced cues, as for example in conditions with high dust, in fog, or in night operations, involves a far greater understanding of the sensory input required for the operation of a vehicle that not merely moves forward in straight and level flight, but also may hover or may be required to become involved in a wide variety of unusual operations. Under such circumstances the need for the pilot to be highly sensitive to his precise location in three dimensions is apparent.

The examination of the potential capabilities of helicopter and lowlevel night operations in combat with tanks and other armored vehicles opens up a long series of complex problems having to do with the likely behavior of pilots and tank crews under combat conditions. The analyses that we have observed have failed to take into account limiting conditions in combat that would have substantial effects on the relative superiority of one weapons system over another. For example, the capabilities of a helicopter pilot are substantially reduced when the ground he is covering is in hostile hands. In addition, his willingness to carry through on a combat mission which requires him to expose himself to enemy fire for a critical period of time is not easy to assess when the primary experiments are run over familiar terrain and without hazard. The tank crews have equally serious problems in attempting to provide a simulation for battleground conditions, when they travel with turret open and with a greater interest in checking out their crew performance than in attending to the presence of potentially hostile aircraft.

We applaud the vigor and enthusiasm with which exercises have been carried out, and yet must have some reservations about the amount of information gained from such studies. What is required is a much more stressful setting in which the tests could be run. Yet almost any addition of stress increases hazard to a point that is probably intolerable.

A highly critical component of the entire exercise is related to the ability of a helicopter pilot to maintain himself below the horizon for an appropriate period of time, and then to pop up at the appropriate time, to find a target, and to remain in line of sight long enough to kill the enemy tank. When this exercise is carried out under conditions of very low visibility, the vulnerability of the helicopter is reduced substantially. The question then becomes whether or not the maneuver can be completed successfully without damage due to unintended collision with surrounding terrain. The helicopter pilot also has the problem of finding his way through a terrain, hopefully familiar, under conditions of very low illumination, and to complete his maneuver to the point of attack without damage to himself. Under what circumstances are such maneuvers possible, and what aids must be given to the pilot in order that he succeed in accomplishing them without undue hazard? These questions are not as easily answered for the helicopter as for a high-speed aircraft, for the high-speed fixed-wing aircraft can operate with a very narrow cone of vision ahead, whereas the helicopter pilot must have an acquaintance with the hazards that surround him on three hundred and sixty degrees. Can such communication to the pilot be maintained, and if not, what is the minimum information he must have in order to behave appropriately?

Problems of this sort require much more information about the

entire system of cues required for successfully flying a helicopter. I have found that one of the most useful exercises that I have engaged in has been the visit to Lt. Col. Richards and his staff at Fort Monmouth, to examine the way in which the primary issues related to this matter are being attacked.

One of our problems is that we are dealing with a complex pattern of behaviors, tactics, and combinations of equipment when no single part of the total system is fully understood and prior to the time that we are certain about the varieties of technical devices that can be provided and that will need to be provided to have a total system that works. In spite of that, the total mix of activities now going on seems to me to be appropriate, since each part of the system depends on each of the other parts.

The activities at ECOM are basic to our understanding of the needs of the helicopter pilot for information in order for him to fly without normal daylight visual cues, and to carry out complex missions without the normal redundancy of cues in a well-instrumented cockpit and with full capabilities of clear daylight vision. It is obvious that some reduction in the total set of cues can be tolerated without any substantial loss in function. However, if we are to generate a system for substituting cues provided from technical devices for those that the pilot normally acquires in a clear daylight setting, we need to know which of the cues are critical and which are not. The work that Richard's crew is doing should help a great deal in that regard. Both TASS and RAVE are well-designed test systems to enable us to get a better understanding of the problem.

TASS was about to start its collection of data on a large number of subjects just at the time I was there. I sat in the cockpit and

went through the flight with a very capable pilot. He indicated that the device flew about the same as a bird, and that the problem was realistic. A person can fly a chopper with only a TV screen to watch. He can, that is, if he has a clear picture of an area, and is well acquainted with many of the ground features of that area. For flying at reasonable altitudes, I would think that there is no problem about a person learning to respond to the cues provided and to manage pretty well.

I see two problems. One is the problem of flying at low level and the second is hovering. In both instances a much greater demand is placed on the system than when one if flying a known course with a substantial amount of forward speed. Under these circumstances, a fairly narrow cone of vision is tolerable. When one is flying at a lower level and at slower speed, a much wider range of visual cueing will be required. The device just will not work for hovering. The hovering problem undoubtedly can be solved with no great difficulty if the intent is to lock in on a particular spot on the ground and hold. However, for the sort of needs that we saw for maneuvering around in the exercises at Fort Hood, I think the problem is more severe.

There is also a serious problem with the disoriented pilot. It is very easy to lose the feel for where one is even in the simulation. In unfamiliar terrain with a limited amount of vision an unacceptable amount of circling around might be required in order for a pilot to keep his bearings. Even a slight disorientation makes it very hard to maintain a planned flight pattern.

The preliminary trials of TASS have produced reports from the pilots involved that they become just as exhausted putting in a day's work on the device as they do in normal flying. This worries me still more.

Normal flying carries with it real anxieties about safe flying and enemy fire. If we find that flying using only artificial devices in a laboratory setting where there are no hazards is just as wearing as normal flight with such hazards, what would normal flight with these artificial devices produce in terms of pilot fatigue and pilot levels of anxiety?

The RAVE is reaching a point where experimentation with it can begin. It will make possible a replication in the air of the simulation in TASS using the actual land areas which are simulated in TASS. This will yield some advantages in terms of validating the simulation but also has the additional advantage of testing out the levels of anxiety that a person has when he is flying under such conditions. Again the processes for collecting data seem to be sensibly worked out, but again the issue of determining what is the best measure of flying performance has not been resolved. The work group understands that this will be a major problem, and proposes to use a canonical correlation technique that seems to me to make sense as a start. What this amounts to is the use of a regression model in which there are multiple predictor variables and multiple criterion variables. The problem with this approach is that it is linear, and interactive effects will not show up. For this reason I think there must be a very considerable eyeballing of the data to try to discover some higher order interactions that undoubtedly will occur in a complex task of this sort.

I am at present of the opinion that all of the devices proposed <u>can</u> be used by well-trained pilots to fly at low level and to fly nap of the earth and at low light levels in familiar terrain. I think, however, that there are some very serious problems ahead in making any single

system work. The main difficulty will be deciding on an appropriate system that will take care of the entire class of problems that will emerge in normal tactical operations. A loss of confidence during flight in the accuracy of the devices, a change in signal-to-noise ratio that obscures salient features, any substantial distractions, any feeling of disorientation, or any condition produced by too many signals coming in at once will all conspire to make the pilot respond in a way to increase his safety. Presumably that means that he will rise higher off the ground. In the tactical situation we are trying to understand, that might turn out to be disastrous. What I am suggesting is that there are two classes of problems. One is the problem of enabling the pilot to get his bird into place to perform a particular role and to give him the devices to help him do that. The second is that there must be some form of fallback modes which will provide certain clear and unambiguous signals that will enable the pilot to make immediate responses under emergency conditions, responses that will be optimal in terms of the survival of the pilot and the craft. The first exercise can be simulated. We may get some insights into solutions for the second class of problems by reviewing instances when pilots become disoriented, or when the safety pilot has to take over, or when something goes wrong with the cueing system provided for the pilot in simulations or in actual flight. We will need to make quite detailed studies of these cases on an individual case-by-case basis.

My preceding point was that I believe that we could manage to train pilots to use every device that I have seen or heard described thus far. That does not mean, however, that pilots will use them and use them effectively. I think that effective use will come with built-in redundancy, so that a pilot can verify the signals he gets from one

device with another. IR may be required as a natural auxiliary to low-light television, and we probably will need as well to provide information from 360 degree radar. With more than one mode of cues, a pilot might feel fairly safe in doing some things that he would need to do in a normal night operation, or even an abnormal one. With any less redundancy than this, it may have to be a bright enough moonlight night for him to be able to see with the unaided eye.

The major unresolved question that worries me has to do with the field of vision. I think that has to tie in directly with a more careful analysis of the precise mission of the pilot. This might come from an examination of the Fort Hood experience in daytime, with a question about the sort of information that a pilot must have in order to hover below a crest and then to pop up. I believe RAVE will make it possible for us to collect some data on this point in daytime, and will then give us the opportunity of checking it out with a variety of devices. However, a better explication of the variety of tactical maneuvers that are most effective in daytime would be very helpful in setting the parameters for the studies of the variety of devices that need to be examined for use in low light levels.

I end up fairly well satisfied with the current state of planning for LLNO studies. I believe that we should make a report and then indicate that we think that it is desirable for our study group to exist on a continuing basis at a somewhat lower level of activity while many of the current studies come to completion. We ought to get a chance to look at the actual data collected in the MASSTER exercises at Fort Hood, and to look at the data that come out of the TASS and RAVE studies. The time to do that would be about the beginning of fall.

ANNEX E

Special Paper

Discussion of the Night Low Level Helicopter Flight Problem

ANNEX E

DISCUSSION OF THE NIGHT LOW LEVEL HELICOPTER FLIGHT PROBLEM

I. INTRODUCTION

A systematic approach to the problem of providing aids which will make possible the night operation of helicopters, requires the merger of financial constraints on the problem, the military requirements for a solution to the problem, and the operational constraints on the problem. This systematic analysis can only be provided by government. Systematic approach means more than a systematic approach to the design of specific equipment such as discussed elsewhere in the report but more importantly it means a systematic approach to the statement of the problem and its constraints. The financial constraints and the operational constraints can be readily developed, the military requirements are more difficult to define.

II. OPERATIONAL NEEDS - The Problem Statement

In examining the operational needs, one must consider two aspects. First, the division of labor between pilot and copilot, and second the relative value of altitude in contributing to covertness in helicopter military operations.

a) Division of Labor - there is a division of labor between the pilot and copilot in performing the assigned mission of the helicopter which is quite natural.

The functions involved in helicopter flight operations can be divided into three distinct areas: navigation, piloting, and targeting.

Navigation involves relatively infrequent updating of position and course information.

Targeting involves recognition and identification of the target

such as a landing zone or enemy weapon and after recognition of the target, the taking of suitable action such as laser target designation or firing of a weapon.

Piloting includes all those functions that are involved directly in controlling the flight path of the helicopter.

Under conditions of high work load, this suggests a logical basis for division of labor between pilot and copilot. Since navigation involves relatively infrequent updating and since this updating is not likely to occur during a period in which targeting is an important function, it has been generally accepted that the problems of navigation and targeting are those of the copilot and that the problems of piloting are the function of the pilot. This natural division of labor then suggests that the man machine interface problems of navigation and targeting can be explored separately from the problems of piloting, and that piloting problems can be explored without considering navigating and targeting at the same time. This division of labor does not imply that a system for permitting piloting at low level at night, and a system for targeting and navigating might not employ shared elements.

b) Covertness and obstacle avoidance - It is necessary to make a sensitivity analysis of the relative reduction in vulnerability which is achieved by reduction in the level of sound, or reduction in the IR signature, or reduction in the radar signature or, by reductions in the altitude at which the aircraft is flown.

The incremental covertness which is gained by improvements in each one of these covertness factors will establish where the greatest military advantage can be achieved with the minimal effort. The incremental value of reductions in controlled altitude would permit a value-cost

assessment of equipment required to make such reductions in altitude possible. Data for such an analysis is generally available. Such an analysis would permit a choice of an operating altitude for night low level flight. Since the cost of any system will clearly increase as the altitude is reduced, and since the rate of increase of covertness value will begin to reduce as the altitude is decreased, there will be an optimum choice which will lie somewhere between flying at a moderately high altitude with no assistance, to flying in the nap of the earth with lots of assistance.

In this connection it should be observed that the difficulty in developing adequate obstacle avoidance equipment may actually determine the operating altitude.

III. THE SYSTEM OPTIONS

It is clear from all observations that the skillful pilot can fly readily at very low altitudes at fairly high speed in the nap of the earth if provided with daylight visibility.

It is also apparent that this same pilot can fly somewhat more slowly but similarly at night with minimal lighting when he is flying over very familiar terrain.

The helicopter can be flown automatically at very low altitude by the use of terrain following radar of a fairly sophisticated kind. In this automatic mode certain loops for control need to be closed. These can be altitude and the rate of change of altitude, range of an obstacle, and the rate of change of the range to the obstacle, heading and aircraft attitude. The gains required for each of these loops to achieve a given performance can be established by simulation or by analysis. We know, therefore, that the pilot must close these same loops when he is provided no aid, other than a view of nature. The pilot uses two sensing systems,

a vision sensor which his eyes provide, and an inertial sensor which his body provides.

This sensor data is combined with his knowledge of the aircraft handling and performance characteristics to permit him to control the aircraft. When we ask the pilot to fly at night we deny him the sensing which is available by the vision of his eyes. Knowing that he uses a vision sensor is not sufficient since it does not tell us how the pilot is able to extract from this sensor information required to control the aircraft.

To permit him to fly at night we must provide those cues which he normally extracts from nature by the use of his vision. This restoration can be achieved in many ways.

There are a broad range of options available in structuring a flight path control system. These options extend from that of restoring the pilots daylight vision with artificial illumination to furnishing the aircraft with a completely automatic system with the pilot serving as monitor.

The basic decisions to be made in this structuring of a flight path control system concerns the role of the human pilot. This range of alternatives can be subdivided into four different areas depending on the functions the pilot is asked to perform.

1. Determine the flight path error
2. Decide on a control policy
3. Control the aircraft
4. Monitor the aircraft and its systems

Since the dominant input channel to the pilot is visual, four different classes of displays can be identified depending on how many of these func-

tions are left to the pilot to perform.

The first classification, named "visual image" includes artificial illumination systems, low light level television, infrared imaging. This classification is determined by the requirement that all four flight path control functions must be performed by the pilot, i.e., that measured flight path error information is not available. In this case, the pilot must deduce the necessary loop closure information from a visual image display and a flight path error cannot be expressed explicitly. Such a visual image type display has a handicap because it cannot provide all the visual clues and the resolution which are available to the pilot in good visibility. No perfection of the image can remove this handicap entirely. Considerable improvement can be expected, however, if information about the aircraft itself is superimposed on the visual image.

The second classification is named "error situation display". In this option desired flight path and actual flight path is monitored and flight path error is determined.

Also in this option the pilot performs only the last three functions listed. The explicit availability of this error presents a potential improvement over visual flight path clues since the pilot can be relieved of the complicated mental process of error determination. An ILS type display typically belongs in this class. The error is presented to the pilot but he can and must decide how he wants to correct it.

In this option the pilot decides on control policy, performs the control function, and also monitors the aircraft and its systems.

In the third option for control of the aircraft, normally called a command display, the pilot is relieved of the need to determine control policy.

Based on a predetermined error correction policy, he is told how to control the aircraft and if he executes the commands well, he will always find himself very near the proper trajectory. Depending on the dynamics between the pilot's control and the commanded variable, the pilot performs more or less as a servomechanism.

The fourth option is the fully automatic system. The pilot's function is simply one of monitoring the aircraft and its systems.

Within the display classes using measured information, the addition of error rate and/or other "quickening" information is quite common. It must be considered, however, that the more the presentation is dynamically modified, the less it is a true situation display.

An advanced display system is usually not confined to any single display class as defined above and, correspondingly, it is difficult to identify the pilot's role in the clear-cut terms associated with any one class. Command and error situation may be combined in a heads-up display, for example. The roles of the display elements must be reconsidered in such a case. If for the control of a trajectory variable more than one display element is available, the pilot can be expected to utilize mostly that element which relieves him from the most functions. For example, if both the error and a visual image are displayed, the pilot will not use the visual image to estimate the error himself. He will naturally use the symbol which belongs to the class highest in the "hierarchy" of displays, in the sense that it relieves him of his functions the most. The inclusion of additional presentations of "lower order" would seem superfluous if considered strictly from the point of view of the pilot's functions. Their inclusion in display systems is often required, nevertheless, as a "back-up" and/or "confidence builder".

Since the pilot is ultimately responsible for the crew and the aircraft, the decision making function should not be taken from him normally. This tends to make option classes three and four not terribly attractive. It would be difficult to get pilot acceptance for these options. Experience with fully automatic systems supports this observation. Options three and four are more costly and complicated although they may offer savings in training costs.

On the other hand, accurate flight path control on instruments presents a high work load which is made easier if the pilot is relieved from the function of determining the flight path error. Thus the class of error situation displays may be the most attractive choice. This option may be implemented by a visual image with aircraft slate and error information superposed. With this option there are a multitude of alternate systems.

The aircraft information may include such quantities as attitude, altitude, and airspeed in the simplist form, to more complicated forms which contain:

1. vehicle dynamics situation
2. environment information
3. vehicle motion with respect to environment

There is the choice of presenting the "raw" information with the pilot extracting the desired quantities alternatively or the information can be processed and useful cues can be given in symbolic form perhaps superimposing the display of the environment. This form of display exploits more fully current pilot skills.

The unenhanced "visual image" option is clearly not an attractive alternative. In general the use of artificial illumination will surely

increase the vulnerability of the aircraft and the pilot to enemy action. The pure vision display will surely be quite costly and inefficient since the reproduction of nature sufficiently to permit the necessary cue extraction will probably require the development of three-dimensional sensing and projection equipment.

IV. THE LOW LEVEL NIGHT FLYING SYSTEM

The task of flying a covert flying path involves both piloting the aircraft (time constant < 10 seconds) and navigation (time constant > 30 seconds).

The piloting of the aircraft can be performed either manually or automatically.

The basic system elements in either case are:

1. The Planned Flight Path: In visual flight this is the desired trajectory to be flown; in automatic flight this can be a trajectory at given course and speed at a fixed height above the terrain.

2. The Aircraft Dynamics

3. The Aircraft Flight Path: This is the actual path flown by the aircraft.

4. The Disturbances: Included gusts, turbulence and equipment noise.

5. The Controller: This can be the pilot or an automatic flight control system.

The controller responds to a comparison of

a. The planned flight path

b. The actual aircraft flight path

c. The dynamics and state of the vehicle

d. The disturbances

The controller has to provide for aircraft stabilization as well

as trajectory control. Hence the first simplification possible in a system design of a low level night flying system is to provide for a suitable aircraft stabilization system, so that the controller has only to provide for the low level night flying task, and not for stabilizing the aircraft motions around the trajectory.

For low level flight system design the following initial data must be available.

1. Vehicle dynamic control and performance characteristics

2. Terrain to be followed

3. Specific requirements, i.e., the height above the terrain and how the contours should be followed and the magnitude of the allowable errors, etc.

4. Disturbances, gust and turbulence levels.

From this data one can design a fully automatic system. The design would yield

1. Flight data to be measured

2. Feed back and/or feed forward loops to be closed

3. System sensitivity to disturbances

4. The degree of system performance deterioration which occurs when all quantities are not used.

Such a fully automatic system based upon the specific terrain and error requirements can be used as a performance model to which any proposed manual or semi-automatic systems can be compared.

In visual flight, the pilot derives information about vehicle dynamics, environment, and vehicle motion with respect to the environment from his vision, from inertial forces, and from his experience with the aircraft.

Human operator research has indicated that the pilot performs linearly or nearly linearly. Thus a comparison with a fully automatic model can be made. When the performance of both systems are equivalent, the same information must be used in both systems.

Thus, the fully automatic system design can lead to the development of a display system which amplifies visually that information which is important for flight path control and which diminishes or ignores those aspects which do not contribute to the pilots ability to control his flight path.

The automatic system design will show that the total burden of permitting low level high speed flight at night should not be placed upon the display system. It is quite reasonable to make the helicopter much easier to fly and thus to relieve considerably the burden placed on the display system. The costs of making the helicopter easy to fly may be relatively small compared to the creation of the display system which makes the aircraft flyable using existing controls. Some balance is required between these two technological areas. The final solution will involve a bit of both. Some improvement in the control system and the handling qualities by the use of various feedback devices and some improvement in the vision by the use of suitably enhanced displays. A comparative analysis of these two modes can be the basis of a very simple and useful study.

V. HUMAN FACTOR OBSERVATIONS

There is a large body of human factors to be considered in providing a knowledge which is already available concerning a system which will permit night operation of helicopters. Some of these factors are in regard to the visual image aspects of a solution to this problem:

1. The image which is provided at low altitude must be one to one

with the real world. That is, there must be no magnification at least of the area where the pilot is concentrating his vision.

2. The ratio of control to display must be the same as that which is employed in VFR piloting.

3. Any display system must avoid the possibility of disorientation. This precludes the possibility of moving the region which is displayed to the pilot by means of a vision aiming system. The relation of the display to the aircraft must remain the same.

4. Since only the foveal vision is sharp and the peripheral vision is blurry, it would be reasonable that any vision system might have a variable resolution over the field of view. The affect of this variable resolution being to reduce the cost of the display system or perhaps to increase the field of view of the display system without an inordinately large increase in the complexity of the system. Varying resolution of the order of two to four to one seems to be reasonable and might be acceptable in any system.

5. The information which is finally displayed to the pilot must be in some man compatible form, that is; it must be in reasonable agreement with what is the normal form by which the pilot views nature and determines his piloting. This would tend to minimize the learning time and permit easy transfer from visual to instrument conditions.

It is necessary that if a pilot is to fly a display, that the natural transfer of the information presented in the display to his control motions be similar to that which he uses in visual flight. The operation of flying at high speed and low altitutde is much too tricky to permit the pilot to engage in complex calculations or conversion processes during the control process. Just like riding a bicycle would

probably be impossible by the use of situation instruments, flying helicopters at low altitude would probably be impossible by the use of purely situation displays.

In general:

1. A reasonable solution should utilize the ingenuity of the pilot especially in his decision making capability. This implies that the level of sophistication of the system should be such as to bring the problem down to the point where a reasonably skilled man can operate the system.

Any simplification of the problem beyond this merely exchanges the skill which is already available in a man for added complexity in the system. In this latter class one should include all systems which are command or fully automated types, which do not require anticipation or judgment. If the system is developed to the point where the function required is purely matching, and if the man has no other basis for making judgments, then the system might just as well be fully automated. The additional complexity is trivial at this point.

2. Subtasks might be automated, such as load stabilization while piloting should not. The use of the man or pilot for aircraft control and for decision making and the use of automation for other tasks is reasonable.

VI. EQUIPMENT INTEGRATION

It is not always true that integration of equipment provided for various functions necessarily leads to simpler or less expensive systems. But clearly it must always be considered. The problem of reconnaissance of target identification or target gunnery seems reasonable candidates to be considered for integration of equipment with the piloting equipment. It is not obvious, however, that navigation should be integrated in such

a system. Navigation is a separate function and as has been indicated earlier, the navigation problem is reasonably placed on the shoulders of the copilot. This then suggests that if there is to be any integration of systems that the navigation system should be integrated with the systems which are developed for targeting or for aiding gunnery.

REFERENCES

1. Helicopter IFR Flight Path Control System - AGARD-CP, 86-71, June 1971, Konstanz, Germany.

2. Instrumentation, M.I.T., "Advanced Flight Control System Concepts for VTOL Aircraft, Phase I Technical Report", U.S. Army Transportation Research Command, Fort Eustis, Virginia, TRECOM TR 64-50, October, 1964.

3. Anderson, S. B., et al., "V/STOL Handling-Qualities Criteria", AGARD Report No. R-577-70.

4. Harper, H. P., Sardanowsky, W., Scharpf, R., "Development of VTOL Flying and Handling Qualities Requirements Based on Mission-Task Performance", Journal of the American Helicopter Society, Volume 15, No. 3, July 1970, pp. 57-65.

5. Clement, W. F., Hofmann, L. G., "A Systems Analysis of Manual Control Techniques and Display Arrangements for Instrument Landing Approaches in Helicopters, Volume 1: Speed and Height Regulation", JANAIR Report 690718, July, 1969.

6. Schweizer, G., Stavfenbiel, R., "Regelungsprobleme bei Vertikalstartern unter besonderer Berucksichtigun des Munschen als Regelkreisglied", Luftfahrttechnik Raumfahrttechnik, Volume 15, No. 11, November, 1969, pp. 275-280.

7. Schweizer, G., Seelmann, H. A., "Flugregelung", VDI-Z, Volume 112, No. 9, May, 1970, pp. 573-578.

8. Orenstein, S. B., Lane, R. D., "Terrain Following/Terrain Avoidance Flight With the AH-56A Vehicle", Journal of the American Helicopter Society, Volume 16, No. 1, January 1971, pp. 3-10.

9. Dukes, Theodor A., "An Integrated Display Concept for Helicopters and VTOL Aircraft" Preprint No. 314, 25th Annual National Forum Proceedings of the American Helicopter Society, May 1969, 8 pp.

10. Keane, W., Milelli, J., "Precise IFR Hovering-An Operational Need and a Feasible Solution", Paper No. 19, AGARD Guidance and Control Panel Symposium on Helicopter Guidance and Control Systems, June 1971.

11. Dukes, Theodor A., "An Integrated Display for Trajectory Control of Helicopters and VTOL Aircraft", Proceedings of the 6th Annual Conference on Manual Control Systems.

12. Ashkenas, I. L., McRuer, D. T., "The Vocal Adaptive Controller-Human Pilot Dynamics and Opinion", IRE WESCON Convention Record, 1960, pp. 48-55.

13. Gallagher, J. T., O'Donnell, F. B., "Investigation of the Application of Direct Translational Control to VTOL Aircraft", Journal of Aircraft, Vol. 2, No. 6, Nov.-Dec. 1965, pp. 538-545.

14. Dukes, Theodor A., "Fundamental Aspects of Automatic and Manual IFR Station Keeping of Helicopters", Princeton Pennsylvania Army Avionics Research Program Annual Report, ECOM-02412-2, November 1968, pp. 4-33.

15. Dukes, Theordor A., Sun, Pershing, "A Performance Measure for Manual Control Systems, 7th Annual Conference on Manual Control" USC, L.A., California, June 1971, NASA SP-281.

ANNEX F

Special Paper

Some Guidelines for Research On Low Level Night Operations

ANNEX F

SOME GUIDELINES FOR RESEARCH ON LOW LEVEL NIGHT OPERATION

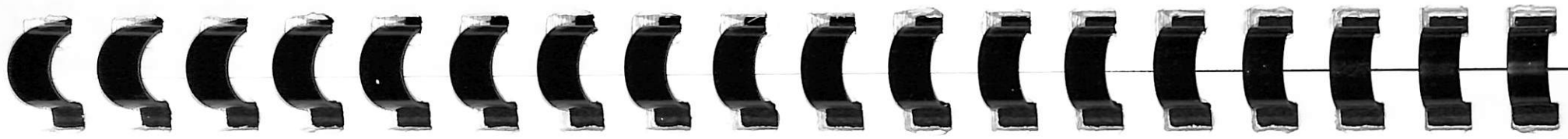
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Department of Aerospace and Mechanical Sciences
Princeton University

The charts and notes on the following pages, written in an informal style, reflect thoughts and insights on the subject of low level night operation. The decision making process of such a complex task extends over a wide range, from tactical to technological. These notes deal with system oriented engineering decisions which have to be made prior to the decisions on specific technological aspects of system elements. The charting of the decision making process and a brief discussion together identify a number of areas where research studies can provide significant missing information.

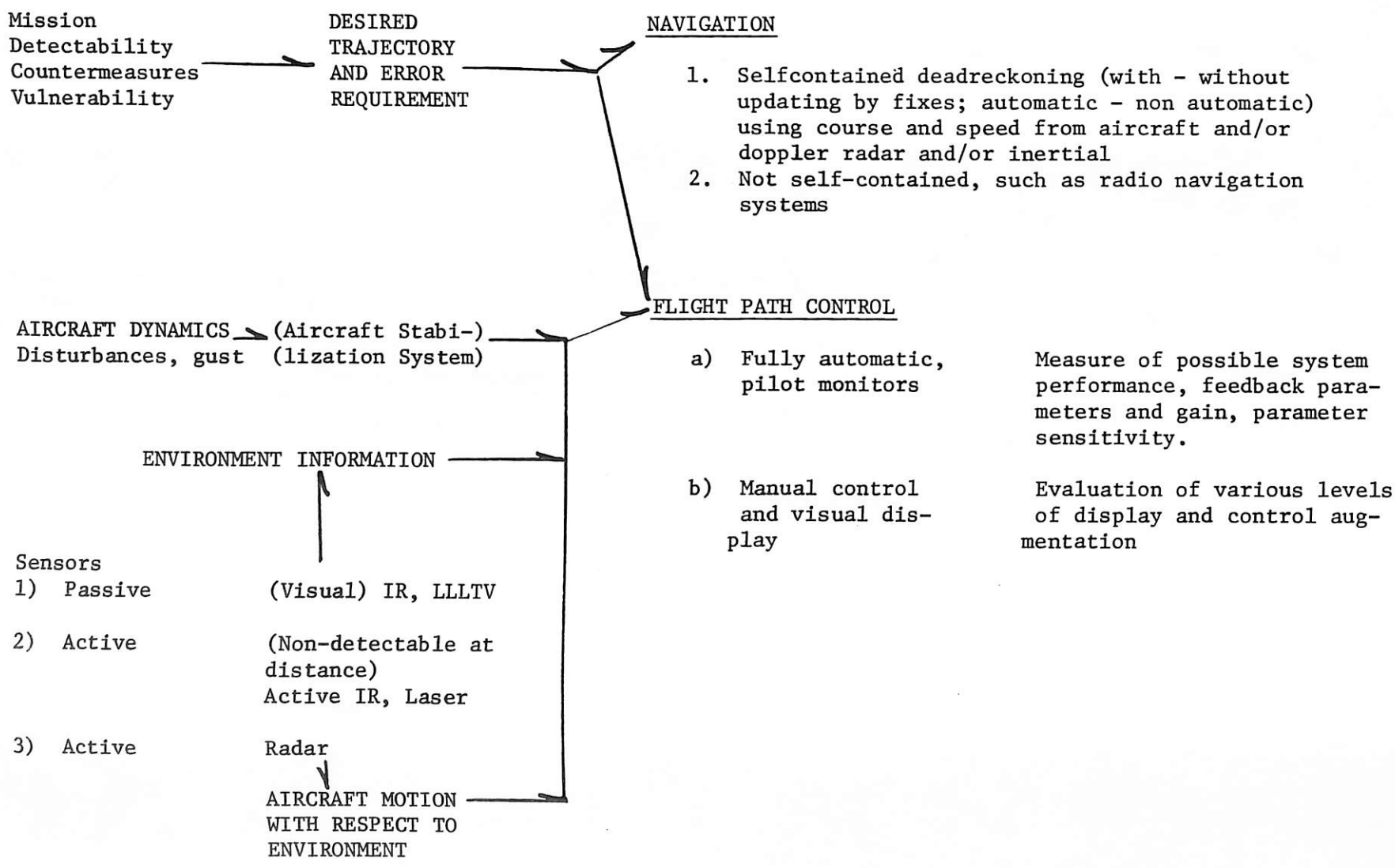
The first chart ties together the major aspects entering in the decision making, listing navigational and flight path control options. The navigational system cannot be chosen based on low level night time flying requirements only. All Army flying has to be considered at least, and perhaps even some other Army operations should be included. Such a broad subject is beyond the scope of these notes. As to the flight path control system, a fully automatic system should be designed to provide a base line for the evaluation of performance and cost of various alternatives with the pilot in the control loop.

The second chart indicates a "decision flow" highlighting five specific crucial topics involving far reaching decisions on the actual control and instrumentation system. A brief discussion on each of the five elements follows the chart with a decisive question stated for each topic. Some

minimal requirements and many thoughts are expressed which should provide guidance for the formulation of a number of research projects aimed at resolving decisive questions in the low level flight task. Man-machine aspects, often ignored or de-emphasized by technologists, are strongly emphasized here since ultimately the pilot has to be responsible for the mission. Pilot acceptance may well require some redundancy in sources and presentations of information.



LOW LEVEL NIGHT OPERATION
ELEMENTS IN DECISION MAKING - A



LOW LEVEL NIGHT OPERATION
ELEMENTS IN DECISION MAKING - B



TOTAL TASK

Decisive question:
Under What conditions is this a 1 or 2 pilot task? (What are the consequences if it is to be a 1 pilot task?)

All investigations must be planned with these decisive questions in mind. Therefore, the navigation and guidance work load is a very significant parameter.

Minimal requirement: A not necessarily straight path must be determined and flown.

The decisive parameters are information (accuracy, with or without course or velocity vector) and display (moving map or visual).

The variations of navigational equipment are of secondary significance and should not be parameters in answering the questions above.

DEGREES OF FREEDOM

"Split axes" or unified flight path control?

Note: The flight path control task is naturally divided into 2 "regions" in terms of time frame.

a) Short time control, involving practically continuous loop closures.

b) Long time guidance decisions, based on navigation.

A separation of the horizontal degree of freedom either involves a very simple desired trajectory (piecewise straight with segments of considerable lengths) or it involves very frequent navigational updating. This might be much easier justified for high speed penetration than for helicopter flying. The helicopter should be able to follow a winding valley, possibly hugging the mountainside.

Minimal requirement: Lateral as well as longitudinal terrain following, with similar accuracy.

The vertical-plane problem should be singled out for initial studies. Concurrently, plans should be worked out for a subsequent 3-dimensional TF study.

RANGE INFORMATION

Decisive question:
Is radar acceptable?

The radar radiation is likely to make radar undesirable. Tests with existing radar TF should be used as a base line.

Research should be aimed mainly at the two remaining alternatives; visual and laser.

DEDUCED BY PILOT

Since pilot deduced information will result in higher average clearance than if range measurement is available, it can be competitive only if it has some significant advantage in at least one of the following aspects: a) cost, b) reliability (complexity), c) pilot acceptance. Therefore, emphasis should be put on those approaches which may offer significant advantages in at least one of these respects. Candidates: goggles, FLIR, LLLTV.

MEASURED

With laser the leading contender for the future (equipment will be required for obstacle avoidance), noise as a function of terrain texture can be expected to be a major limitation. Stationary measurements and math modeling of this aspect are important.

CONTROL

Decisive question:

Is the best possible performance with piloted control a worthwhile compromise?

A study should provide convincing results for the decision whether piloted TF at night is in or out.

PILOT

Even the best piloted performance will result in higher average clearance than automatic TF. Display augmentation (added aircraft state information) and control augmentation (rate and attitude control loops) can be expected to help significantly. Therefore, unaugmented displays only are not worthwhile testing. The emphasis should be on comparing the relative values of different display and control augmentation schemes. Display and control augmentation should be designed based on feedback analysis.

AUTOMATIC

The two most significant aspects of automatic TF are the trajectory laws and the determination of the available aircraft performance and safety margins. Emphasis should be on "suboptimal" trajectories with pilot acceptance as the decisive factor.

Task performance as a function of laser accuracy and noise as well as of terrain texture and of filtering should be predicated by closed loop analysis.

A design method for variable speed flight path control systems should be devised.

AUGMENTATION OF PILOTED CONTROL

Both display and control augmentation are imperative. Results obtained without augmentation would be meaningless because they would not help in the basic decision about the acceptability of piloted night time TF. The night vision devices must be given the best possible chance.

DISPLAYS

Horizon, heading, altitude, climbrate, airspeed and side slip information superimposed on any night vision display can be predicted to be of great significance. (This might be done even with goggles, with the information projected in front of the pilot). A simple symbolic display should be designed to be superimposed on the displays.

CONTROL

Pitch and roll (rate and attitude) feedback loops and automatic coordination may unburden the pilot sufficiently to make the difference between unacceptable and acceptable performance. Such control loops can be expected to be in future helicopters. Therefore, it seems very important to use simulation for this purpose, with possible verification in a variable stability helicopter. -- A one-hand controller could free the other hand for display adjustments, etc.

Test parameters: viewing angle, contrast, attitude, speed.

Decisive question:

Can analytical and simulation results be relied on?

A study should try to establish the credibility of analytical and simulation results by verifying significant differences in flight tests. For this purpose

a) Night vision displays should be faked optically

b) A scheme should be devised with which a three-dimensional profile strip is entered in a computer to be used as terrain in simulating manual and automatic terrain following and avoidance based on "measured" information, including navigation.

SUMMARY

A few areas which are of pivotal significance for decisions on night time low level flying are listed below.

NIGHT VISION DEVICES (GOGGLES, FLIR, LLLTV)

WITH DISPLAY AUGMENTATION	(FLIGHT TEST)
WITH DISPLAY AND CONTROL AUGMENTATION	(SIMULATOR & VER. STAB. A/C)
ANALYSES OF LOOP CLOSURES	(ANALYTICAL)

AUTOMATIC TF

TRAJECTORY LAWS	
AIRCRAFT PERFORMANCE AND SAFETY MARGIN	(ANALYTICAL)
MODELING OF LASER SENSOR	(ANALYTICAL & STATIC MEASURE.)
FILTERING (TERRAIN TEXTURE)	(ANALYTICAL & SIMULATION)
OPERATIONAL RADAR SYST. PERFORMANCE	(FLIGHT TEST)
VARIABLE SPEED FLIGHT PATH CONTROL SYST.	(ANALYTICAL)

NAVIGATION

WORK LOAD AS FUNCTION OF DISPLAY (AUTOMATIC OR MANUAL)	(FLIGHT TESTS)
ACCURACY REQUIREMENTS	

PILOTED FLIGHT W. MEASURED RANGE INFO.

DISPLAYS	
3-DIMENSIONAL TF	(SIMULATOR)
ONE-HAND CONTROLLER	

SIMULATION

3-DIMENSIONAL TASK SIMULATOR	(MEASURED RANGE)
OPTICAL SIMULATION OF NIGHT VISION DEVICES	(VISUAL)
PERFORMANCE AS FUNCTION OF TRAJECTORY LAWS	(AUTOMATIC)

ANNEX G

Kruse Report

The Application of Real Time Night Vision Systems to Helicopters

THE APPLICATION OF REAL TIME NIGHT VISION SYSTEMS TO HELICOPTERS

Paul W. Kruse

Army Scientific Advisory Panel

1. Introduction

The Ad Hoc Committee on Night/Reduced Visibility Capability for Army helicopters has been provided the following terms of reference:

a. Identify the best technological approach or approaches to provide the various mission oriented Army helicopters a night/reduced visibility, flying capability commensurate with their normal daytime/VFR mission performance under those conditions.

b. Identify the most promising techniques of providing Army helicopters the capability required to perform the missions of target acquisition and engagement at night and during period of reduced visibility, considering the present state-of-the-art and utilizing one or a combination of sensors/systems.

c. Identify the individual components such as navigation systems, radar, altimeters, various sensors, aircraft stabilization devices and displays required to enable Army helicopters to fly and survive in a mid-intensity conflict and perform their individual missions at night and during periods of reduced visibility. Each type helicopter "by mission orientation" should be considered as a system, and the entire family of helicopters should not be considered as the system under this investigation.

The mission of Army helicopters are many and varied. Those related to a mid-intensity conflict, of principal interest, are described in Figure 1, taken from the draft report of the analysis phase of the ECOM Low Level Night Operations study. The maneuvers and tasks related to the

missions are shown in Figure 2, from the same report. Common to all of these missions is a requirement to fly "nap of the earth" at night. There are several categories of systems which may be employed to carry out NOE flight, including vision systems, navigation systems, altimeters, and stability augmentation systems. Historically, there has been a partitioning of these systems into two broad classes, the pseudo-visual ones and the state-measuring ones, as shown in Figure 3 from the LLNO draft report. The significant differences between them are illustrated in Figure 4, from the same source.

The present report is concerned only with the pseudo-visual systems. Systems of this type display to the pilot and copilot real time imagery of the world. An ideal system of this type would represent exactly the real world which the pilot perceives looking through the canopy during daylight operation. No system exists which approaches closely to the ideal. Those which do exist approach more or less to the ideal, with performance generally traded off for complexity and cost.

2. Choice of Operating Wavelength - Radar and Microwave Radiometers vs FLIR's vs L^3TV and I^2 Systems

An ideal pseudo-visual system would have the weather penetration capability of radar and the angular resolution of a visible or infrared imaging device. It is not possible to attain both capabilites; either the resolution or the IFR capability must be sacrificed, and of necessity it cannot be the resolution. Thus, the pseudo-visual night vision system must be a VFR system; it can have a limited capability to penetrate haze and fog, but not rain and snow. The reasons follow.

The angular resolution of a pseudo-visual imaging device for use in the piloting task should not be worse than about 5 milliradians. This would correspond to the ability to distinguish 1 meter size objects at 200 meters. Assuming the lens or reflector does not exceed a reasonable size, say 1 foot (30 cm), then the upper limit to the wavelength, set by the diffraction limit, is

$$\lambda = \frac{\Theta D}{1.22} = \frac{5\times10^{-3}\times30}{1.22} \approx 0.10 \text{ cm}$$

$$= 1.0 \text{ mm} = 1000\mu\text{m}$$

In other words, radar systems are ruled out for a pseudo-visual device because their wavelengths in the millimeter region or longer cause their resolution to be too poor. The longest permissible wavelength is 1000μm, but this is not a good choice because the atmosphere is quite opaque to radiation of this wavelength. Indeed, it is not until the wavelength is reduced to 25μm that a "window" opens up. Even this window, extending from 25μm down to 15μm, is not a good (highly transparent) one.

The choice of operating wavelengths for a pseudo-visual system therefore extends downward from about 15μm. Atmospheric limitations are important. The atmosphere must be relatively transparent, since the path lengths of interest may be several kilometers. The atmospheric absorption as a function of wavelength is shown in Figure 5. Note the presence of several windows, including the one between 8 and 14μm. Second, the effects of atmospheric scattering are illustrated in Figures 6 and 7. Note that scattering losses become appreciable at wavelengths shorter than about 2μm. The ability to penetrate haze and fog at 10μm far exceeds that at 1μm.

Imaging systems can be categorized into those "active" ones which depend upon artificial illumination and those "passive" ones which do not.

Truly covert operation rules out active systems. The two types of passive systems are the thermal imaging ones, including the real-time ones known as FLIR's (Forward Looking Infrared) and the near infrared low light level television (L^3TV) and image intensifier (I^2) systems. The thermal emittance of terrain is illustrated in Figure 8. Note that it peaks in the 8 to 14μm window region. When the spectral response of infrared detectors, Figure 9, is convoluted with the atmospheric transmission and terrain emittance, it turns out that the best performance is obtained with systems operating in the 8 to 14μm spectral interval. Modern FLIR's utilize mercury cadmium telluride [(Hg,Cd)Te] infrared photoconductors operating at liquid nitrogen temperature (77°K) whose spectral response is largely confined to the 8 to 14μm interval.

Passive near infrared systems depend upon night sky radiation (airglow) to illuminate the terrain. The spectral emittance of the night sky between 1 and 2.4μm is illustrated in Figure 10. The emittance increases approximately exponentially with wavelength in the near infrared. The spectral reflectance of terrain is illustrated in Figure 11, showing a typical peak between 1 and 3μm. The spectral responses of typical photocathodes for use in L^3TV and I^2 devices are illustrated in Figure 12. Note that none extend past 1.15μm.

The development of semiconductor photocathodes depending upon the Scheer-Van Laar principle will provide a greatly improved wavelength response for use in third generation I^2 devices. These devices will employ the same microchannel plate construction as the current second generation goggles but will have a much greater sensitivity, which will translate into much greater detection range. Because their operating wavelength will still be relatively short, they will exhibit only marginal

improvement in haze and fog penetration over the current second generation goggles. The development of these third generation goggles is now being pursued intensively at Army Night Vision Laboratory.

In comparing near infrared systems with FLIR systems, the following facts emerge. FLIR's operate without the need for night sky illumination, and, therefore, work as well during complete overcast beneath a jungle canopy as in open moonlit terrain. Near infrared devices including L^3TV and I^2 systems suffer performance degradation under overcast and foliage canopy. In general, modern FLIR's are about 2 to 4 times more expensive than L^3TV systems and 10 to 100 times more expensive than the I^2 systems such as night vision goggles. Because the L^3TV systems are complex and expensive, yet do not work well under heavy overcast, and suffer from a much reduced capability for fog and haze penetration, their use in piloting helicopters nap of the earth at night is questionable. If the funds are available for complex systems, then FLIR's should be used instead of L^3TV. For a proliferation type of system, only the goggles offer sufficiently low cost.

In summary, the following points have been established:

1. There is no possibility of a radar or microwave system capable of being employed as a pseudo-visual system with the required 5 milliradians or better spatial resolution.
2. The best FLIR type of system is one operating in the 8 to 14μm spectral region with a detector array operating at 77°K.
3. FLIR's are superior to I^2 and L^3TV devices in operating under all conditions of overcast sky and foliage canopy. They also offer superior haze and fog penetration. L^3TV systems are somewhat cheaper than FLIR's and I^2 systems are far cheaper than FLIR's.

4. L^3TV systems should be ruled out for the helicopter night flying problem because they approach the cost of FLIR's, yet are inferior in performance.

5. Third generation I^2 goggles using semiconductor photoemitters and microchannel plate amplification which are now under development have far superior detection and identification ranges than the current second generation goggles. Their ability to penetrate haze and fog will be inferior to FLIR's. They should be far less expensive than FLIR's and therefore could be employed in a proliferation role.

3. Use of a Single FLIR for Target Acquisition, Target Identification, and Piloting

It would be desirable if a single FLIR could be employed for both piloting a helicopter nap of the earth at night and for acquiring and engaging targets. In general, the piloting problem requires a wide field of view with low resolution, target acquisition a moderate field of view with moderate resolution, and target identification a narrow field of view with high resolution. The resolution of a FLIR is established by the focal length of the optical system and the size of the individual detector elements. Target identification at long range requires a resolution of about 0.2 milliradians with a horizontal field of view of about 4^o. Target acquisition requires a resolution of about 0.5 milliradians with a field of view of about 10^o. Piloting requires a resolution of about 3 milliradians with a field of view of about 60^o. All of these functions require the same number of resolution elements per frame, namely, $\frac{4\pi}{180 \times 0.2 \times 10^{-3}} = \frac{10\pi}{180 \times 0.5 \times 10^{-3}} = \frac{60\pi}{180 \times 3 \times 10^{-3}} = 350$.

Thus they can all be accomplished by an optical system having three magnifications, about 1x for piloting, 6x for target acquisition and

15x for target identification. A zoom optical system operating over this magnification range would be most useful.

It should be noted that it is possible to multiplex the operation of a FLIR in such a manner that different images are presented to the pilot and copilot. The usual frame time for a FLIR system is 1/30 second. Assume that a FLIR were built with a 1/60 second frame time, and which has a moveable mirror inserted in front of the optical system every second frame. Thus for "even" frames the radiation would come directly through the optical system, whereas for "odd" frames the radiation would first be reflected from the moveable mirror before entering the optical system. Employ two displays, one responding to the "even" frames and one to the "odd". Let the position of the moveable mirror be controlled by the copilot. Thus the pilot could see in one direction, say, the line of flight, whereas the copilot could look off in another direction, anticipating changes in flight path, looking for targets, etc. The minimum detectable temperature contrast of such a FLIR would be degraded by no more than a factor of two. Because present FLIR's provide more temperature contrast than is really needed, the overall performance of the system would not really be degraded. It would be far more useful.

In summary this discussion has shown:

1. A single FLIR with a three magnification or zoom optical system can be employed for target acquisition, target identification, and piloting.

2. By multiplexing the input to the FLIR and using different displays for the pilot and copilot, the usefulness of the system is greatly enhanced since the copilot can look to either side of the flight path at the same time the pilot looks along the flight path.

4. Displays

One of the foremost problems in the use of an indirect view system such as the FLIR or L^3TV is the display. The ideal display for the nap of the earth pilotage problem provides the pilot with an image which is a three-dimensional representation of the real world in its true color and size in every direction. Such a display is not possible today and it seems unlikely that one will be available within the decade.

Displays can be categorized in many ways, such as panel mounted, heads up, helmet mounted, or direct view, projection, or narrow screen, wide screen. The common display of today is the z-axis modulated cathode ray tube (CRT), i.e., the usual TV display. TV displays provide the best way today of displaying real time imagery. Their principal drawback is their limited size, about up to a 25 inch diagonal. There is no way that a CRT display can be made larger without going to a greatly increased weight because of the implosion problem. Thus the CRT display, the best method for displaying imagery today, must remain a small display.

It should be borne in mind that the search for a wide screen imagery display has been underway for a long time within the television industry. The "panel-on-the wall TV" has been sought for over two decades, yet TV sets today still employ the conventional CRT. Various schemes have been evaluated over the years, including projection TV, which has enjoyed a certain success in large auditoriums but not in the home, and electroluminescent phosphor displays. In the latter approach, which was investigated thoroughly a decade ago, an electrode matrix on either side of a phosphor layer is sequentially scanned in a raster fashion, giving rise to a moving modulated spot of light which the eye integrates much as it does that from a CRT. There are no electroluminescent phosphor TV

panels being marketed, despite an investment over the years of tens of millions of dollars by the TV manufacturers.

One approach to a wide screen display makes use of light emitting diodes. LED's are becoming one of the most useful techniques for displaying alphanumeric information. These devices emit light, usually but not exclusively, red, when biased in the forward direction. Arranged in a 7 x 5 matrix, they are useful as alphanumeric characters for a price in the neighborhood of a dollar a character.

The LED's can be used in display in two ways. First, they can be arranged in a matrix for direct viewing, each diode representing one resolution element. The cost of such a complex display would be prohibitive. Second, they can be arranged in a linear array and by means of a moving mirror their output swept across a large screen. Obviously the problem here is the duty cycle. If each resolution element were to represent, say, 1 milliradian, and the wide screen display were to encompass, say, 2π radians (180^o), then the duty cycle for each resolution element would be $10^{-3}/2\pi$ or 1.6×10^{-4}. Thus, each diode must have an instantaneous brightness 6,300 times the average brightness of the display as integrated by the eye. If the resolution is required to be, say, twice as good, then of course, the instantaneous brightness must be twice as high.

A wrap-around projection LED display suffers from the need for high reflectivity of the screen on which the display is projected. Thus, a pilot sitting at the apex of such a wrap-around display cannot see through the display to the outside world. This may pose certain psychological difficulties and would be a major problem in the event of power failure of the display. If the screen were made semitransparent,

then the LED display would have to be driven that much harder to make up for the low reflectance of the screen. In any event, the cost of such a display would probably be large, about the same as the cost of the FLIR system employed with it.

One of the newest methods of display is the liquid crystal one. Certain materials, known as nematic liquid crystals, are transparent when unbiased but under electrical bias become opaque and scatter incident light. They do not emit light, but rather modulate the ambient light so as to give a frosted appearance in the region where they are electrically biased. A liquid crystal wrap-around display could be employed in two ways. First, by using a matrix of electrodes between two glass panels separated by about 10 mils containing liquid crystals, the display can be scanned sequentially in a manner similar to that employed for the electroluminescent phosphor display. Such a display would be a true see-through one in the absence of electrical bias. Second, by employing a photoconductive material in a sandwich with the liquid crystal display, no electrode matrix is required. A uniform bias is applied to the photoconductor and to an electrode on the other side of the liquid crystals. The image is formed by sweeping a modulated light beam across the display, causing localized changes in bias on the liquid crystal sheet due to localized changes in the conductance of the photoconductor because of the localized variation in incident light. Such a display when employed with a projection LED system would probably require less brightness from the LED's and would avoid the power failure problem, assuming that the photoconductor is transparent to visible light.

It should be emphasized that both the LED and the liquid crystal display methods are not here today. It is very unlikely that a wide

screen wrap-around display which is satisfactory for use by a helicopter pilot flying nap of the earth at night will be available within the present decade. There are many applications for a wide screen display other than the helicopter one, including panel on the wall television, military situation displays, etc. Much effort has been expended pursuing this subject, with few tangible results to date.

One other type of display of interest is the helmet mounted one, in which the image from a small CRT mounted on the helmet is reflected from a semitransparent mirror in the line of sight of one eye. The helmet is linked either mechanically or electro-optically to the sensor, either low light level TV or FLIR, mounted on gimbals in the nose of the helicopter. As the pilot moves his head, the sensor moves and, therefore, the displayed image moves.

This system does not have a wrap-around field of view, yet the instantaneous field of view can be moved through 180°. Thus it does not provide the peripheral vision which a wrap-around field of view does. The importance of peripheral vision of the pilotage problem has not yet been established. A drawback to the helmet mounted display is the additional weight on the head, which may cause death by broken neck in a crash which would be other wise survivable.

In summary, then, the following points have been established:

1. CRT's are the best small screen display.
2. It is not possible to develop a satisfactory large screen CRT because of the large weight increase required to prevent implosion.
3. The search for a satisfactory wide screen visual display has been going on for a long time for use in panel-on-the-wall

TV, situation rooms, and elsewhere. No satisfactory solution is in sight.

4. Electroluminescent phosphors have not proved satisfactory for wide screen displays.
5. It is unlikely that an LED projection wide screen wrap-around display can be developed within the present decade which will be satisfactory for use in piloting a helicopter nap-of-the earth at night.
6. The nematic liquid crystal display is a promising approach to a wide screen wrap-around display used either matrix addressed or, with a photoconductive sandwich, as a projection system. It is unlikely that a satisfactory system of this type will be available in this decade.

5. Recommended Solution

In view of the above, two solutions to the pseudo-visual system are proposed.

1. Expedite the development of the third generation goggles as a proliferation system to be employed on most helicopters which are required to fly at night.
2. Employ an 8-14μm FLIR system on a limited number of helicopters. Use three magnifications or a zoom lens in order that the single system can be used for pilotage, target acquisition, or target identification. Use either a panel mount CRT or a helmet mounted display. Have two displays, one for pilot and one for copilot, with a multiplex approach so that the copilot can be looking in a different direction from the pilot.

MID-INTENSITY AIRMOBILE MISSIONS

LOH	Night Scout
AH	Anti-Armor
UTTAS	Pathfinder
UTTAS	MedEvac
HLH	Tactical Extraction
MAVS	Surveillance

Figure 1

(From ECOM LLNO Program, Volume 1, Analysis Phase-Plan, March 1972)

MANEUVERS AND TASKS - NIGHT AIRMOBILE MISSIONS

	LOH	AH	UTTAS-PF	MEDEVAC	HLH	MAVS
Unattended Area Landing			X	X		
Precision Hover				X	X	
Bob-Up	X	X				
Sideways Flight		X				
Evasive Dive						X
Terrain Avoidance	X	X	X	X	X	X
Obstacle Avoidance	X	X	X	X	X	X
Terrain Following	X	X	X	X	X	X
Obstacle/Wire Overflight	X	X	X	X	X	X
Enroute Navigation	X	X	X	X	X	X

Figure 2.

(From ECOM LLNO Program, Volume 1 Analysis Phase-Plan, March 1972).

DESIGN APPROACH

Figure 3

Historical Partitioning of Night Low Level Systems. (From ECOM LLNO Program, Volume 1, Analysis Phase-Plan, March 1972).

	PSEUDO-VISUAL		STATE-MEASURING
PERFORMANCE	CLEARANCE ALTITUDE >	CLEAR DAY PERFORMANCE PILOT ONLY	CLEARANCE ALTITUDE < PILOT ONLY PERFORMANCE (ROUGH TERRAIN)
PILOT ACCEPTANCE	VERY HIGH MOST NATURAL SYSTEM		REQUIRES TRAINING TO ACCEPT SYMBOLIC DISPLAYS
CONTROL AUGMENTATION POSSIBLE	STABILITY AUGMENTATION ONLY		FULL SPECTRUM POSSIBLE MANUAL-AUTOMATIC

Figure 4

Significant Differences
Pseudo-Visual and State Measuring Systems
(From ECOM LLNO Program, Volume 1, Analysis Phase-Plan, March 1972).

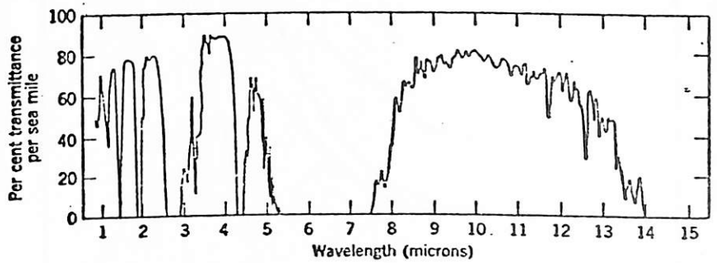


Figure 5. Atmospheric Transmission
(After P. W. Kruse, L. D. McGlauchlin, and R. B. McQuistan, Elements of Infrared Technology, John Wiley & Sons, New York (1962), p. 164.

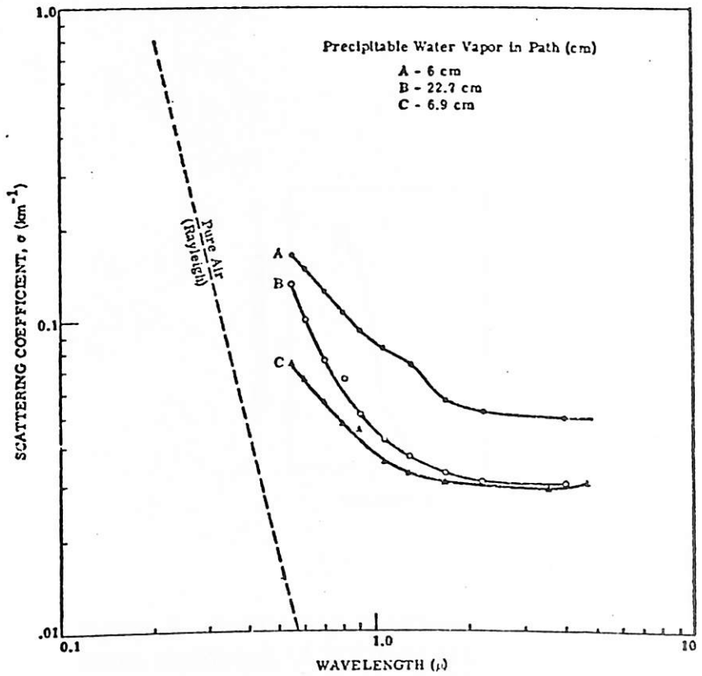


Fig. 6 Scattering coefficient measured over a 16.25-km sea-level, maritime path. Curve B represents a typical summer day condition. (From Handbook of Military Infrared Technology, W. Wolfe, ed., ONR, GPO (1965), p. 209).

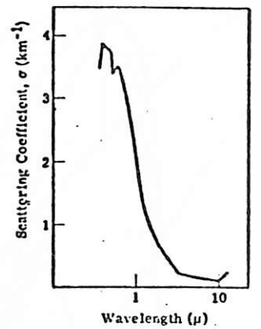


Figure 7. Scattering coefficient for a haze. (From Handbook of Military Infrared Technology, W. Wolfe, ed., ONR, GPO (1965), p. 211).

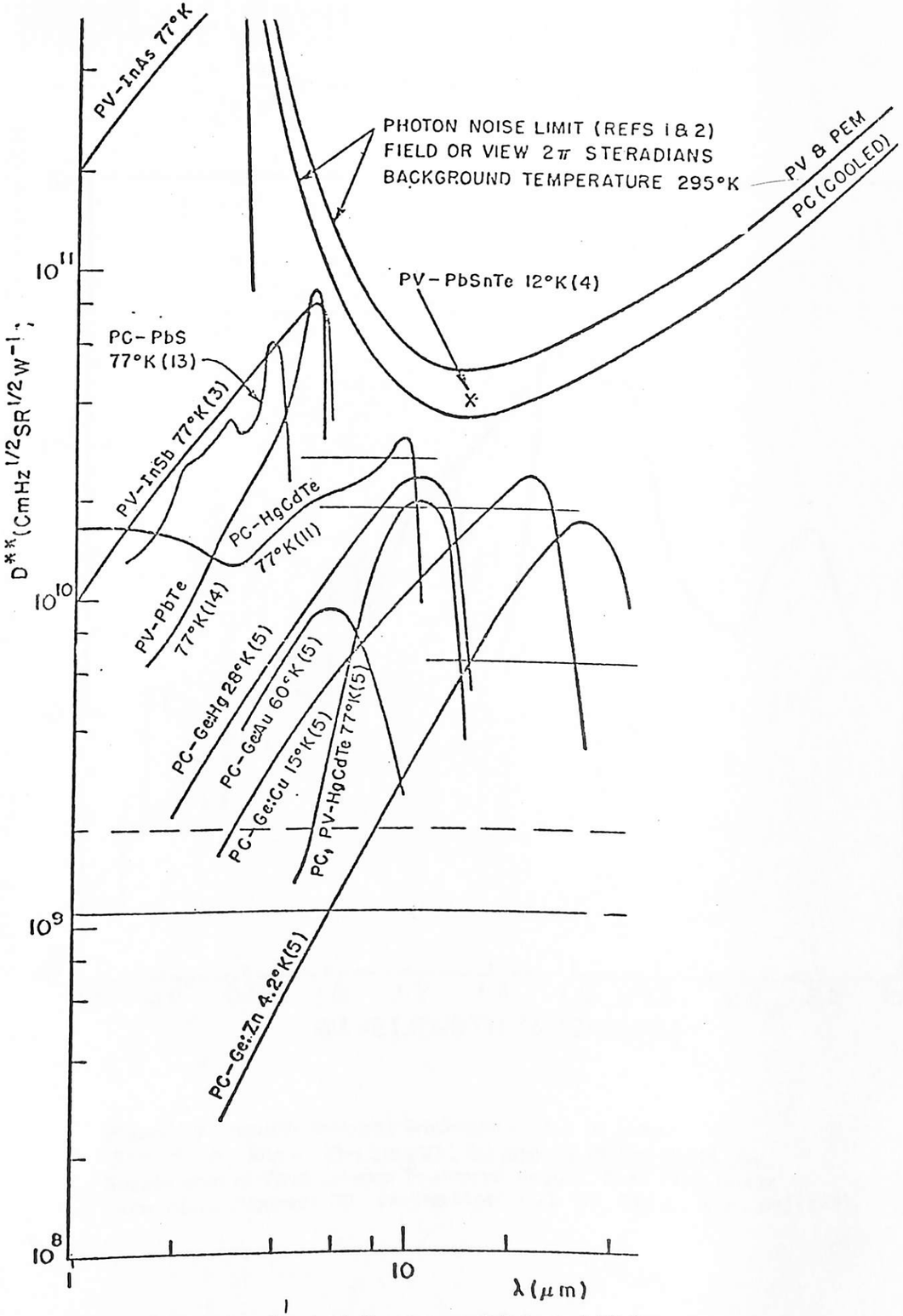


Figure 9. Spectral Responses of Selected IR Detectors.

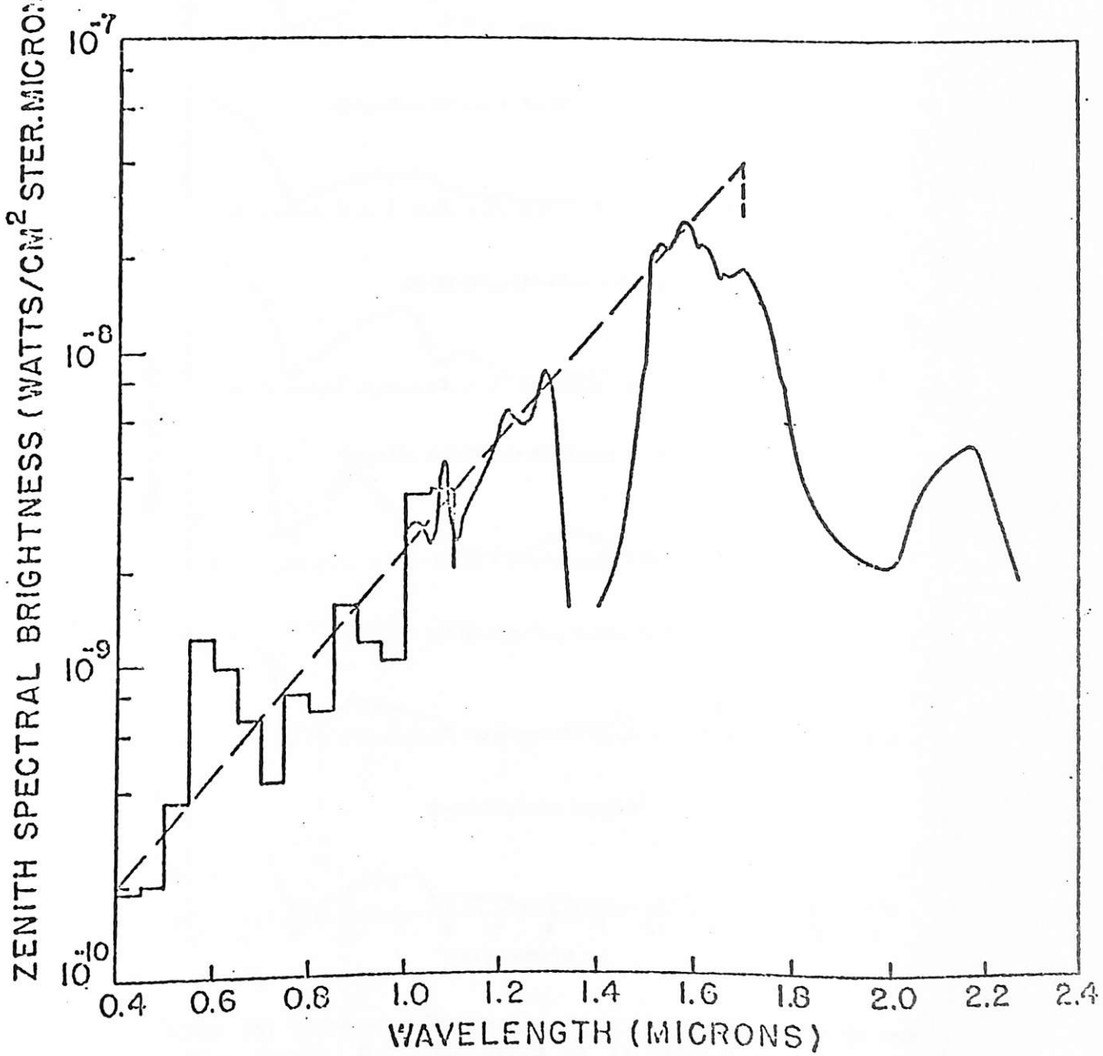


Figure 10. Zenith Spectral Brightness, 0.4 to 2.4μ
(From P. W. Kruse, The Spectral Brightness of the Night Sky. Supplement to First Interim Technical Report, Thin Film Image Converter, Contract DA 44-009-AMC-168 (7), ERDL, Aug. 20,1965).

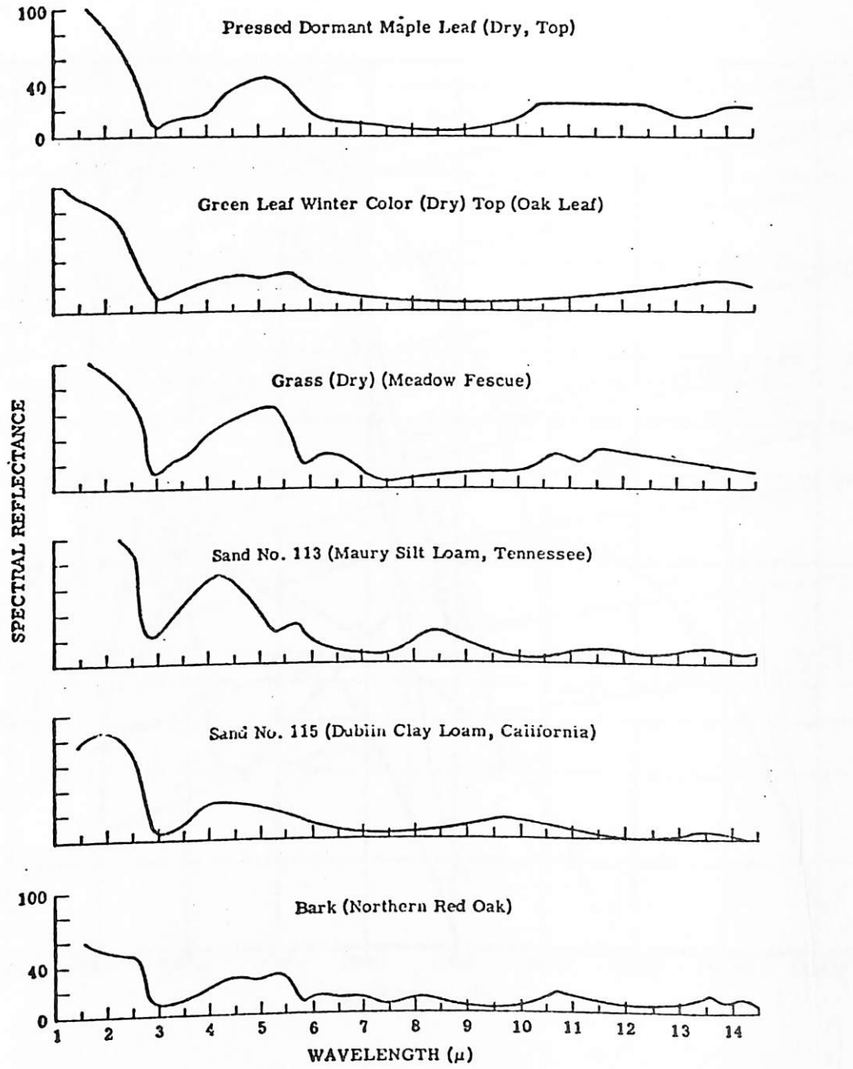


Figure 11. Spectral reflectance of six terrain features in the 1-15μ region. (From Handbook of Military Infrared Technology, W. Wolfe, ed., ONR; GPO (1965), p. 85).

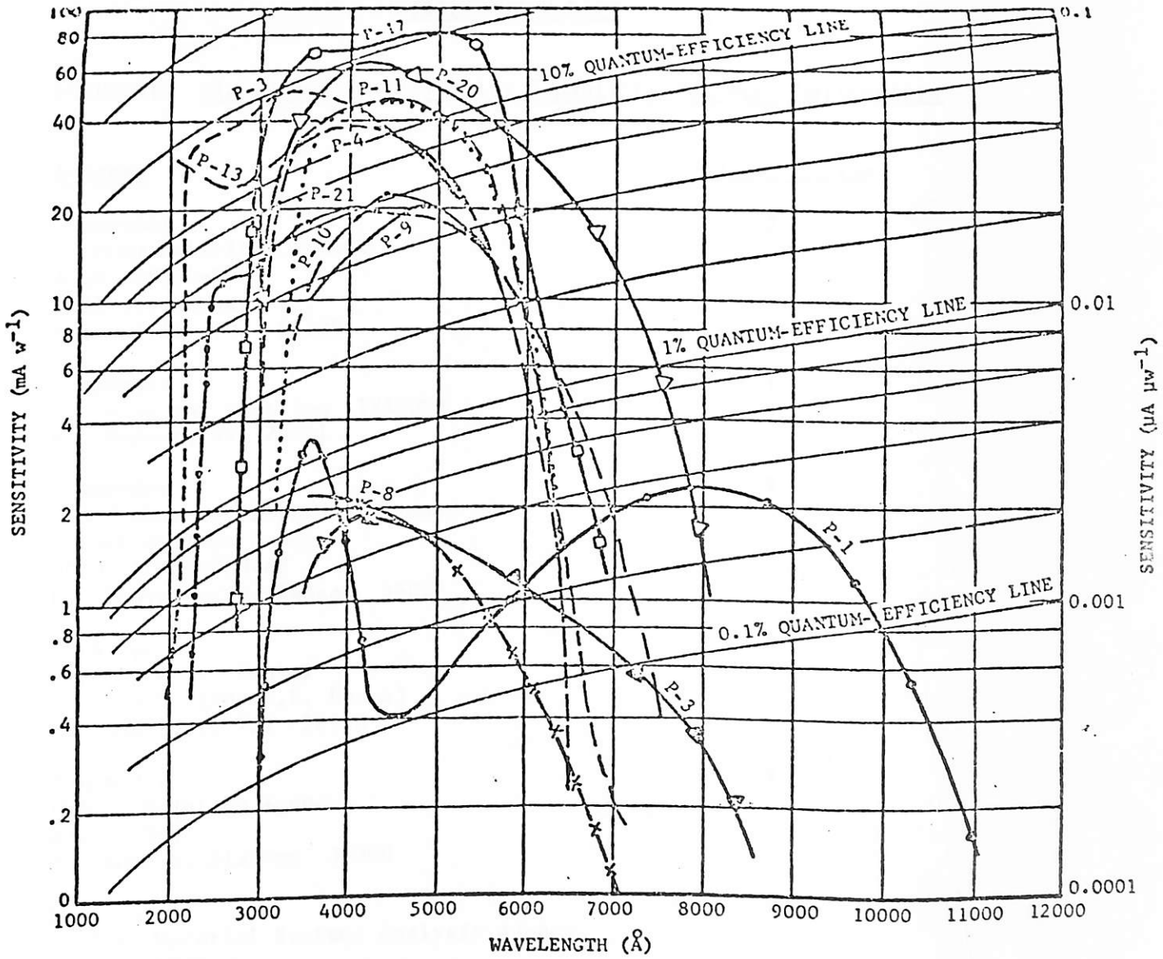


Figure 12. Photocathode Sensitivities

(From Engineering Design Handbook, Infrared Military Systems, Part One, AMCP-106-127, Headquarters AMC (April 1971), p. 3-2111).

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