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Civil Use of Night Vision Devices - Evaluation Pilot's Guide Part I

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July 1994

Final Report

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Dear Colleague:

Enclosed for your information is a copy of the recently published report **FAA/RD-94/18, Civil Use of Night Vision Devices - Evaluation Pilot's Guide, Part I.**

This report is one of three documents that were developed for evaluating the use of night vision goggles (NVG's) by EMS helicopter pilots. The other two reports are

FAA/RD-94/19, Civil Use of Night Vision Devices - Evaluation Pilot's Guide, Part II

FAA/RD-94/20, Assessment of Night Vision Goggle Workload - Flight Test Engineer's Guide

These three documents were written for a narrow audience of people involved in a specific flight test. However, they do have broader applications in terms of defining a useful way to collect data using non-technical subjects. The approach taken in this testing may provide some creative guidance in other flight tests. These reports are published with that thought in mind.

Using these documents, Government and EMS industry pilots participated in a flight test program to assess the use of NVG's in EMS operations. Information produced by other government agencies with extensive NVG operational experience was also reviewed for its application in EMS scenarios. Results of both the flight testing and the document review are documented in FAA/RD-94/21, Night Vision Goggles in Emergency Medical Service (EMS) Helicopters.

Robert D. Smith
for Richard A. Weiss
Manager, General Aviation and Vertical
Flight Technology Program Office

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16. Abstract
This document was developed to aid in the evaluation of the use of night vision goggles (NVG's) by civil helicopter pilots. This report was used to prepare pilots to participate in the flight test program. The principal task was to determine if there are any unresolved safety issues that would preclude pilot use of NVG's during helicopter operations under Federal Aviation Regulations Parts 91 or 135. Certainly NVG's can enable a pilot to "see better" at night and to accomplish certain flight objectives. However, the question is, is safety degraded during any phase of the flight operation if pilots use these devices. Even if the use of NVG's dramatically improves operational effectiveness, current safety margins must be maintained or improved during all phases of flight.

This report is one of three documents that were developed for evaluating the use of night vision goggles (NVG's) by EMS helicopter pilots. The other two reports are

(1) FAA/RD-94/19, Civil Use of Night Vision Devices - Evaluation Pilot's Guide, Part II
(2) FAA/RD-94/20, Assessment of Night Vision Goggle Workload - Flight Test Engineer's Guide.

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TABLE OF CONTENTS

PAGE

LIST OF FIGURES ii

INTRODUCTION 1

PROGRAM OVERVIEW 1

COMPARATIVE TASK ASSESSMENT 3

THINGS TO THINK ABOUT 4

SHORT TERM CONTROL 5

LONG TERM CONTROL 6

A LOOK AT NIGHT OPERATIONS 7

WHEN DO YOU NOT USE NVGs 8

GENERAL INTRODUCTION TO EN ROUTE PROCEDURES 8

ARRIVAL AND DESCENT TO LANDING, NIGHT FLYING PROCEDURES 16

INTRODUCTION TO NVG ADJUSTMENT AND USE 22

THE IMPLICATIONS OF VISUAL CUES ON PILOT WORKLOAD ASSESSMENTS ... 31

CONTACT VS INSTRUMENT REFERENCE FOR FLIGHT 32

SUBJECTIVE RATINGS AND THE ENVIRONMENT 33

EVALUATING A SPECIFIC FLIGHT TASK 38

EVALUATING HIGH WORKLOAD SITUATIONS 39

PILOT RATINGS DEFINED 40

THE RATING PROCESS 45
Rating A Night Flight Task 45

APPENDIX A: ANVIS AND HUD: A WINNING NIGHTIME DUO 50

LIST OF FIGURES

PAGE

FIGURE 1: VIEW OF TERRAIN THROUGH NIGHT VISION GOGGLES (NVG).....7
FIGURE 2: PLANNING NIGHT VFR FLIGHT.....9
FIGURE 3: ESTABLISHING A PRESSURE ALTITUDE AND RADAR WARNING ALTITUDE FOR EN ROUTE OPERATIONS.....10
FIGURE 4: DIRECT POINT TO POINT OPERATIONS.....11
FIGURE 5: ROUTE SELECTED TO FOLLOW A HIGHWAY.....12
FIGURE 6: ROUTE SELECTED TO FOLLOW LIGHT SOURCES.....13
FIGURE 7: FOLLOWING LIGHT SOURCES EN ROUTE.....15
FIGURE 8: CITY LIGHTS NEAR INTERSTATE HIGHWAY.....15
FIGURE 9: ARRIVING AT THE OBJECTIVE AREA.....17
FIGURE 10: CONDUCTING A RECONNAISSANCE OF AN OBJECTIVE AREA.....18
FIGURE 11: INITIAL RECONNAISSANCE FLIGHT PATTERN.....20
FIGURE 12: PLANNING AN APPROACH.....21
FIGURE 13: ADJUSTMENTS AVAILABLE FOR INSTALLING NVGs ON A FLIGHT HELMET.....23
FIGURE 14: MILITARY NVG ADJUSTMENT PROCEDURES.....24
FIGURE 15: FIELD OF REGARD AVAILABLE TO PILOT.....25
FIGURE 16: PILOT HAS AIDED AND UNAIDED FIELD OF VIEW AT THE SAME TIME.....26
FIGURE 17: NVG OPERATIONS IN A COCKPIT.....27
FIGURE 18: IMPACT OF EYE TO GOGGLE DISPLACEMENT.....28
FIGURE 19: NVG COMPATIBLE COCKPIT LIGHTING.....29
FIGURE 20: SUGGESTED CIVIL NVG ADJUSTMENT PROCEDURES.....30
FIGURES 21A, B, C: CHARACTERISTICS DEFINING OPERATIONAL ENVIRONMENT.....35, 36, 37
FIGURE 22: THE COOPER-HARPER PILOT RATING SCALE.....41
FIGURE 23: EXPANDED DEFINITIONS OF PILOT RATINGS TO BE USED FOR EVALUATIONS OF CONTROL SYSTEMS.....43, 44
FIGURE 24: RECORD THE ENVIRONMENT AND ASSESSMENTS.....48
FIGURE 25: CONSTANTS DURING THE EVALUATION.....48

EVALUATION PILOT'S GUIDE (PART I) FOR COLLECTING CIVIL HELICOPTER PILOT ASSESSMENTS OF VFR EN ROUTE OPERATIONS INVOLVING THE USE OF HELMET MOUNTED, NIGHT VISION DEVICES

INTRODUCTION

An FAA flight test team has been assigned the task of evaluating the use of a family of light intensification systems, generally referred to as Night Vision Goggles (NVG). This report was prepared to introduce subject pilots to the methodology and objectives of an operational flight test project established to assess the suitability of NVGs for civil helicopter operations. You have been given an opportunity to act as a subject pilot in this project.

This document serves to philosophically prepare the evaluation pilot to participate in the flight program. The material also addresses proposed operational procedures and introduces the reader to the use of a subjective rating scale which has been tailored to meet the analytical and reporting objectives of this program.

PROGRAM OVERVIEW

The principal task of the FAA team is to determine if there are any unresolved safety issues which would preclude helicopter flights where the pilot uses NVG's during operations covered under Part 91 or Part 135.

The fact that these devices can substantially aid a pilot to "see better" at night and accomplish certain flight objectives is not in question. The question is, if pilots wear these devices, is safety degraded during any phase of the flight operation? You need to appreciate the fact that the goal of the FAA is to avoid degrading safety, over any portion of the flight. Even if the use of the goggles dramatically improves operational effectiveness throughout the flight, current margins of safety must be maintained.

The philosophy supporting the civil use of NVGs allows goggles to be used during normal visual flight operations, carried out under current regulatory authority. **The use of NVGs will NOT enable any mode of flight which cannot now be flown visually within the framework of existing FAA regulatory authority** . This is in stark contrast to certain military operations such as Nap of the Earth (NOE) flight where the use of NVGs enables flight. NVGs will not enable any flight phase that you will evaluate. This does not mean that the NVGs cannot help you fly safer or more precisely. It means that from a legal point of view, the NVGs do not make flight possible. All operations must meet the stipulations in the FARs, as if NVGs were not used.

This program does not contain any testing of NVGs during take-off, landing, approach to hovers or any other low altitude flight. NOE type flight is in no way a civil helicopter mission requirement, day or night. Helicopter landing/hover lights provide adequate illumination during low speed, low altitude flight associated with take-off and landing operations.

Suggested procedures have been established for you to follow in adjusting the NVGs to your eyes. Procedures have also been developed for you to follow during the flight evaluation. These procedures may not be 100 percent correct, but you will have an opportunity to suggest changes, once the team is sure that you understand the FAA's proposed constraints on the use of NVGs by civil helicopter pilots. **Your informed ideas for improving the use of the NVGs is sincerely solicited.**

Again, while there is no question that NVGs can help pilots see better under certain night flying conditions, there will always be limits to observe and there will always be right and wrong ways to do things. **This evaluation will look for limits, as well as right and wrong ways of doing things.**

Some feel that the use of NVGs substantially enhances flight safety. This is an important issue to consider and certain tasks will be conducted to test this hypothesis. For example, at some point, the attitude indicator may be covered to simulate an indicator failure. You will be ask to fly with and without the aid of NVGs. You will then be ask to determine which results in the safest operation. Part of this evaluation (with the attitude indicator failed) may include recovery from a descending turn (established by the safety pilot while you close your eyes). You will be asked to assess the impact of the NVGs by assigning a rating which reflects the degree of difficulty you experienced in returning the aircraft to steady state, wings level, constant altitude, and constant speed flight.

COMPARATIVE TASK ASSESSMENT

As you read this guide you are asked to remember that one of the objectives of the flight evaluation is the determination of how well you can fly a UH-1 helicopter at night with and without the aid of NVGs. Two flights will be flown to make this comparative assessment. Some pilots will fly with NVGs first and some will fly unaided on the first flight. The flight without the NVGs is used to establish a basis for comparison.

There are three elements to this flight task. **First**, there is the subtask of flying the helicopter; maintaining heading, speed, altitude etc. (flight path control). **Second**, there is the subtask which involves contact navigation from one place to another. **Third** there is the environment; daylight, darkness, rain, haze, the character of landmarks, strength of the horizon line, etc. All of the factors collectively define the piloting task you will evaluate.

The team needs to know how you rate the UH-1 in a variety of environments without NVGs. This is used to establish a starting point or Base Line capability. The engineers need you to evaluate the degree of difficulty involved in flying the aircraft, in routine visual conditions and more difficult visual conditions. The results of this conventional (unaided) flight will allow comparisons to be more accurately drawn after you have also flown with NVGs.

THINGS TO THINK ABOUT

The FAA analysts need to know how the utilization of NVGs changes your task. Does flying become easier or more difficult, or is there no change? Do you change the way you fly? Are you more accurate with or without NVGs? Are you more comfortable with or without NVGs? The question "Why?" can be expected in response to all of your answers. To review, you will be ask to assess the basic flight task twice, once unaided and once while wearing NVGs.

The NVG's may provide you information about the terrain below your route that you didn't have during unaided flight. The goggles may also reduce the stress and the workload associated with flying the aircraft and the mission. Alternately the goggles may complicate the task of short term control of the aircraft. They may make it more difficult to see inside the cockpit the way you would like to. In both cases, the FAA engineers are interested in your ability to fly the aircraft, while trying to accomplish some other task (navigate, etc.). The engineers are also interested in the success you demonstrate in holding altitude, heading, etc., while simultaneously detecting and/or identifying features on the surface below. **The engineers want to know if you can achieve satisfactory performance without exceeding some tolerable level of workload.**

While the objectives of flight are not changed by the addition of the goggles, you may change the way that you visually interface with the environment while pursuing the objectives of the flight. You may use new or different techniques and procedures. You may find you scan the outside world differently. You may modify the way you look for landmarks. You may take advantage of a horizon which is visible through NVGs but not visible without NVGs. You may also elect to stop looking through the goggles when unaided vision produces the best results.

SHORT TERM CONTROL

At some point, you may be asked to evaluate your ability to accomplish the short term control of the aircraft. Such a question relates to your ability to maintain the trim attitude (pitch, roll, yaw) of the aircraft. If the aircraft is operated in calm air this should not be much of a problem. If on the other hand the aircraft is operated in rough air, you may need to spend a significant amount of your attention suppressing the aircraft's response to a gust.

If you are asked to increase power (up collective) abruptly and then quickly reduce power to its original value, the transient movement of the collective will momentarily change the trim position of the pitch, roll and yaw controls. The more abrupt the input, the more the aircraft response will resemble a gust response. The UH-1 will most often fail to return to its original trim attitudes as a result of such a disturbance. When you move the controls to cause the aircraft to return to the original trim condition, you are said to have provided "compensation". The more severe the turbulence, the more you must compensate with short term control inputs. This compensatory effort is part of what people refer to as "workload". We are interested in just how the addition of NVGs alter your workload.

Your short term workload in maintaining pitch and roll attitude can also be increased by moving the directional controls back and forth a small amount. Your safety pilot may elect to make such inputs to simulate a certain kind of turbulence to increase your workload. Should this occur, your job is to try and keep the pitch attitude on the trim value which you have observed will cause the aircraft to continue at a constant speed. At the same time, you will be expected to maintain a wings level roll attitude.

The harder you work at flying the aircraft, the less time you will have to look out side for other aircraft and landmarks on the surface. On the other hand, if the horizon line cue is sufficiently strong, you may feel that you can control the short term of the aircraft with sufficient (adequate) accuracy without spending much time directly viewing the attitude indicator. If you are relaxed, the error may increase, but this may be the preferable situation if the errors never get very large. Of course you do need to observe some pre-determined deviation constraints in any case.

LONG TERM CONTROL

If you are inattentive, or if you are not able to maintain the trim attitude of the aircraft within some limits, a pitch attitude error will eventually cause the aircraft to accelerate or decelerate. The resultant speed change, if left unchecked, will result in a descent (if speed increases) or climb followed by a descent (if the aircraft slows down). This sort of variation in altitude is traditionally referred to as a "long term" response and is characterized as a long term control parameter. Logically, if you have good (tight) short term control, you should have good (constant speed) long term control. If on the other hand, you keep the pitch attitude precisely on the wrong attitude, the aircraft will diverge from the selected speed. This is a trim error and points to a different problem. The questions to you are: Did you achieve your flight control objectives? Could you maintain speed and altitude within your objective limits? In defining limits, the key word is "adequate". You want to perform as well as you can, but the bottom line need is to achieve adequate performance (or better) in all of the sub tasks you are trying to accomplish at any given point in time. And you want to accomplish these performance objectives with a minimum workload. But again, if the workload is tolerable, the FAA will conclude that it is a safe workload.

In general, it is correct to say that it is the long term deviations which kill. Unobserved altitude loss will eventually result in ground contact. Uncontrolled ground contact kills. So, if you start to have problems controlling altitude, you may have a significant flight safety problem. You should make a decision as to what your minimum altitude en route should be and share your ideas on this subject with your safety pilot. If he disagrees, you'll work it out together, but together you should establish this limit as it is one of your performance objectives.

To put workload and flight path error in perspective, it is generally preferable to require a pilot to work hard to accomplish all of the assigned tasking and achieve all performance objectives at an adequate performance level, than to have a situation where the pilot workload is low (the pilot is very relaxed) but the pilot fails to identify a visual fix and

becomes lost. "Lost" is a condition which exemplifies "inadequate performance". The pilot might also assume a relaxed (low workload) posture and fly into the ground.

A LOOK AT NIGHT OPERATIONS

In comparison to daylight operations, the world looks different at night. It follows that we should expect to look for different navigation cues and flight control cues at night. Red barns are no longer red. Green fields are no longer green. They are still there, but they are shades of grey. The same type of change occurs when the night is viewed through NVGs. When the human eye is augmented by NVG's, the pilot can see things that he could not see with the unaided eye. But seeing and immediately recognizing objects may not go hand-in-hand. The pilot must learn how to interpret the scene presented to the eye. The process of learning to interpret a given NVG scene may take sometime, or it may not. Everyone is different.

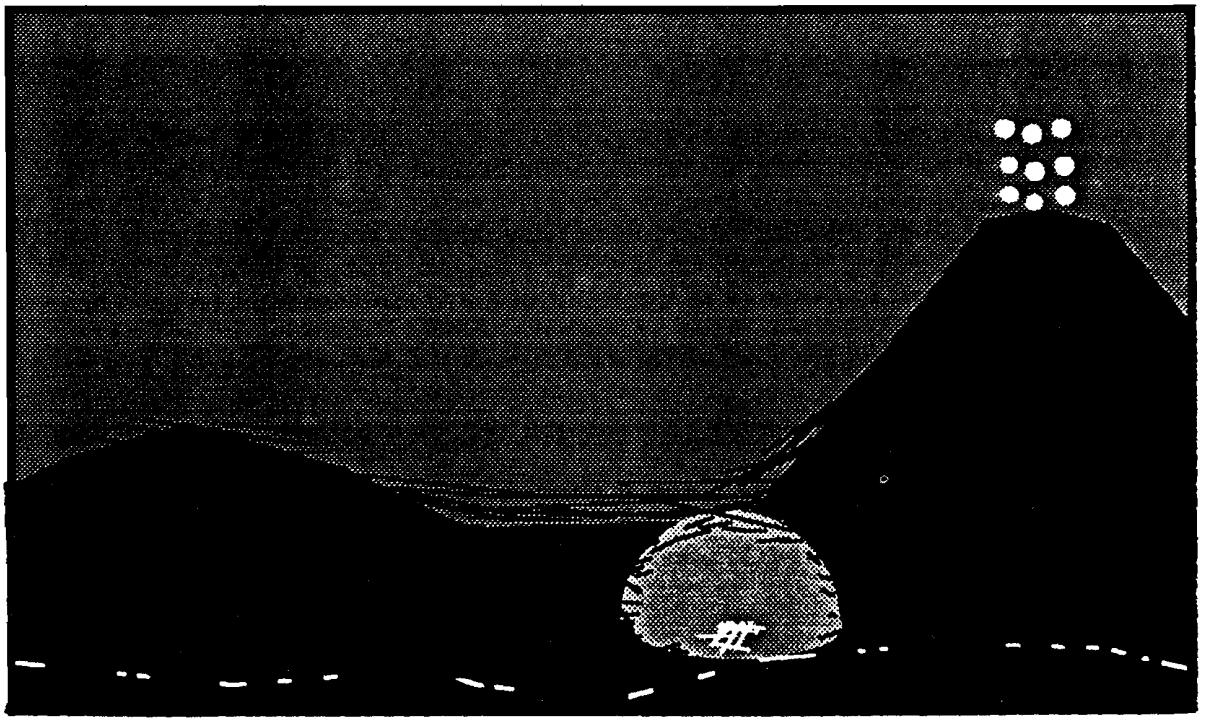


FIGURE 1: VIEW OF TERRAIN THROUGH NIGHT VISION GOGGLES (NVG)

For example, in Figure 1, we see (with the aid of NVGs) a busy interstate highway crossing in front of a small town. To the right, there are three radio towers on top of a small ridge. The

light in the night sky provides an enhanced sky-terrain contrast providing a strong line of departure between the contrasting light levels.

WHEN DO YOU NOT USE NVGs?

You do not use NVGs to look at the instrument panel. You do not need to. You will adjust your goggles so that you can see under the goggles for the purpose of monitoring your radios, flight instruments, engine instruments, etc. In an emergency, if they fail, or if they are not required, you flip them up.

If you fly in the daytime, you don't use NVGs. If you fly over a large brightly lit city with a full moon over head, you may not need to bother with NVGs. If you approach a well lit heliport with your 30 million candle power search light on, landing light on and four hover floods on, you shouldn't need or desire to use NVGs. You should be able to see fine with all the available white light.

If there is almost no ambient light and, with the exception of a few reference lights on the ground, you are looking into the black hole of New Jersey. You may find some use for NVGs, even if they are almost inoperative as the result of a low ambient light level. When you don't have much of a horizon, even a small (NVG enhanced) segment of horizon reference may be very much appreciated. The ability to see the red obstructions lights on your favorite (landmark) radio towers, may show you the way home after a navigation equipment failure. The idea is simple. **You use NVGs when you want to improve your ability to see on a dark night.**

GENERAL INTRODUCTION TO EN ROUTE PROCEDURES

It is extremely important for all pilots who participate in this evaluation to understand that Civil Procedures apply. Military procedures may be used where appropriate but in general the Civil NVG Operations are envisioned to be substantially dissimilar when compared to military operations. **NVGs are used by the military to enable Nap of the Earth (NOE) operations**. That is, without NVGs, night NOE operations could not be accomplished. In

contrast, the civil use of a NVG device is allowed only for the purpose of enhancing the operational safety during flight which is already authorized by FAA regulations. This is a point we have already repeated several times. It is an extremely important point which you must take time to understand.

Lets also revisit the objective of the evaluation. This evaluation is designed to investigate the validity of the assertion that: "NVGs can enhance flight safety and that no flight safety problem is introduced by the use of NVGs."

The following figures provide guidance to you as to the envisioned en route concept of operations. Figure 2 provides a look at the factors involved in planning a safe route and suggests that you should plan a night flight to stay 300 feet above obstructions, 2 1/2 to 5 NM either side of your intended track. What do you think of this? If you have a radar altimeter, where should low altitude warning be set? What about remaining clear of clouds and the visibility issue? Do NVGs make it easier to stay clear of clouds, or is it more difficult? Why?

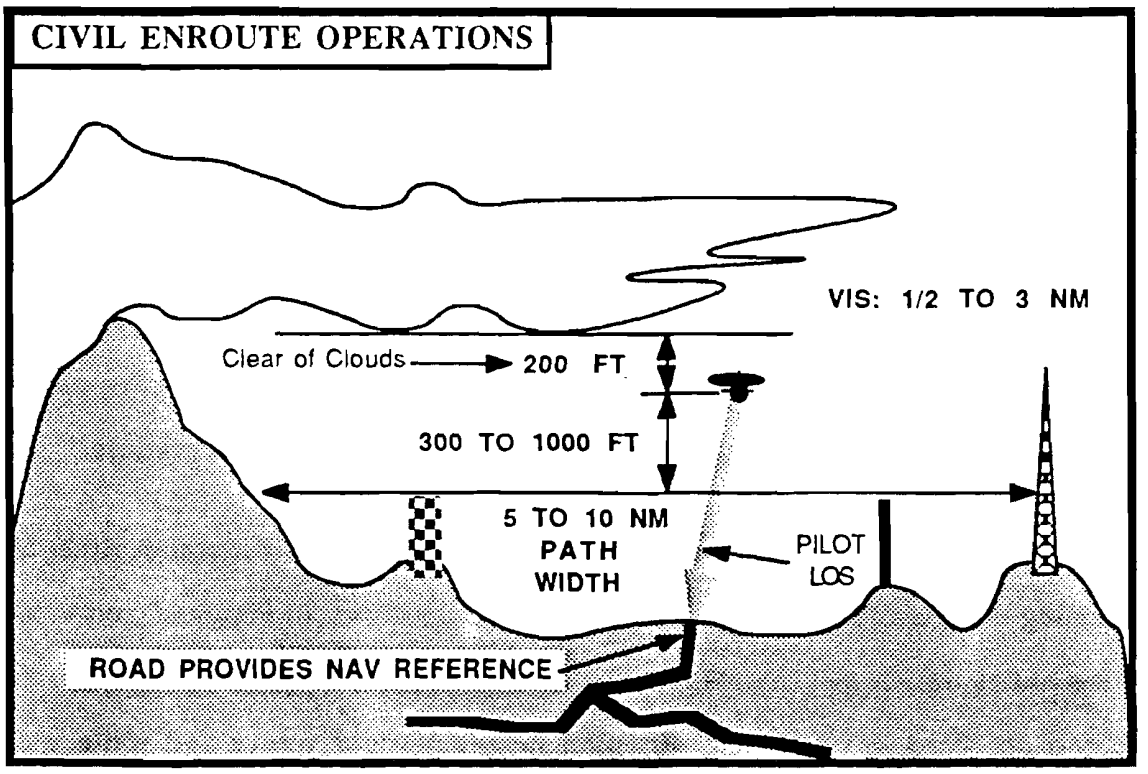


FIGURE 2: PLANNING NIGHT VFR FLIGHT

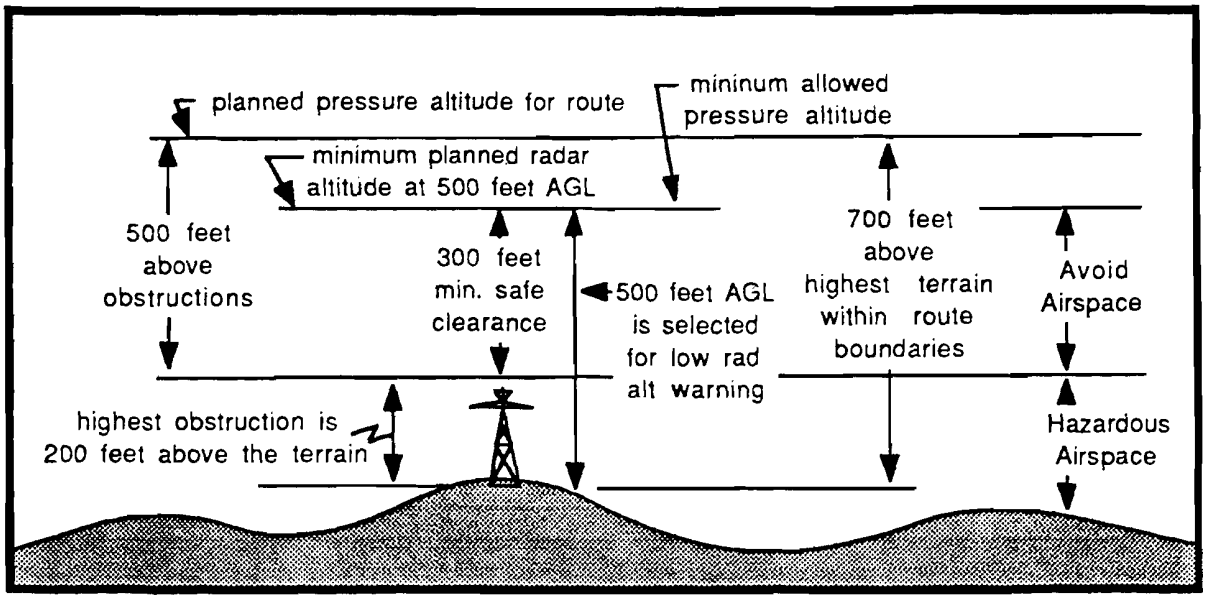


FIGURE 3: ESTABLISHING A PRESSURE ALTITUDE AND RADAR WARNING ALTITUDE FOR EN ROUTE OPERATIONS

Figure 3 indicates that for the planned minimum pressure altitude, the radar altimeter should never fall below 500 feet (to maintain a 300 foot clearance over the highest obstruction along the route if the pilot is inattentive and inadvertently descends below the planned minimum en route altitude). The pilot should plan to observe a 700 foot minimum radar altitude en route providing a planned 500 ft clearance. Each leg of your flight will have a minimum pressure altitude which the pilot attempts to maintain en route. This pressure altitude will, at a minimum, correspond to a pressure altitude which will provide the 700 radar altitude terrain clearance. The radar altimeter should be set to alert you during inadvertent descents to avoid flying into the airspace just above the highest obstruction. A radar altitude alert of 500 feet should keep you several hundred feet above obstructions. A warning light and aurl alert are recommended. Is this an adequate procedure?

Figure 4 illustrates a direct path operation from "A" to "B". This assumes either direct dead-reckoning or electronic navigation is employed to fly direct. In Figures 5 and 6, we see alternative routes drawn. All figures include boundaries for each route to illustrate the width of the corridor used to consider obstruction height. Various routes and route widths can be selected as appropriate to the weather and the installed equipment and operating procedures.

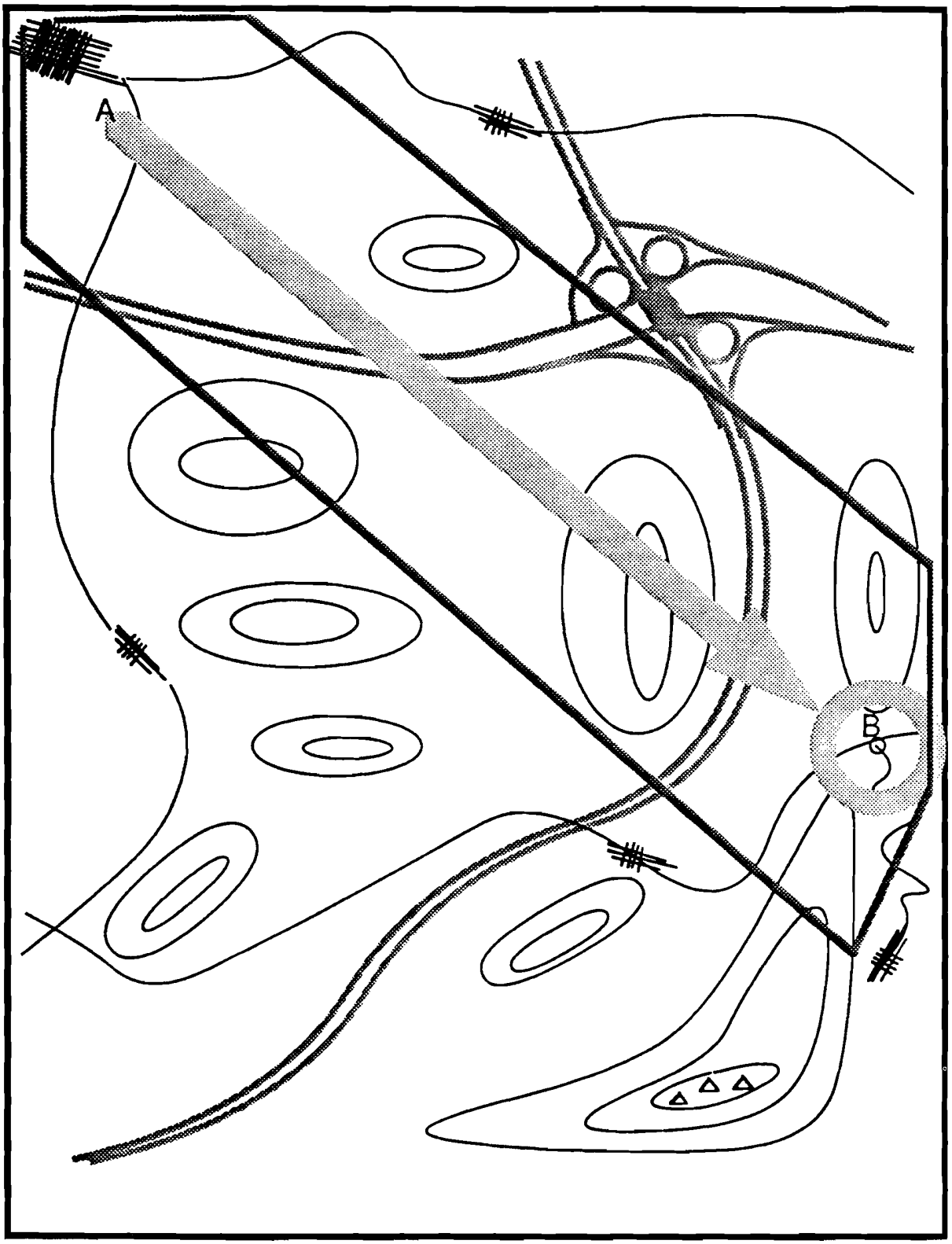


FIGURE 4: DIRECT POINT TO POINT OPERATIONS

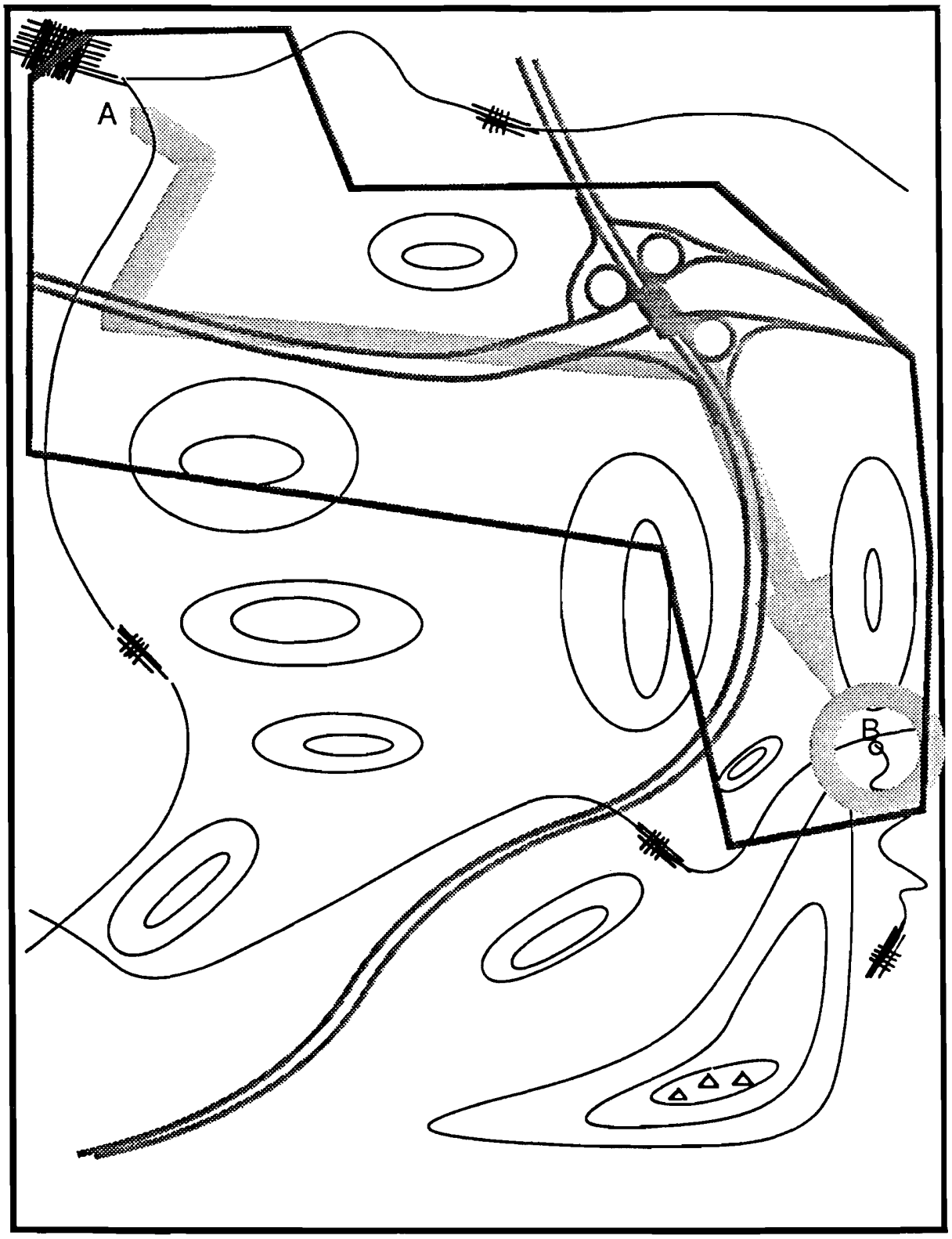


FIGURE 5: ROUTE SELECTED TO FOLLOW A HIGHWAY

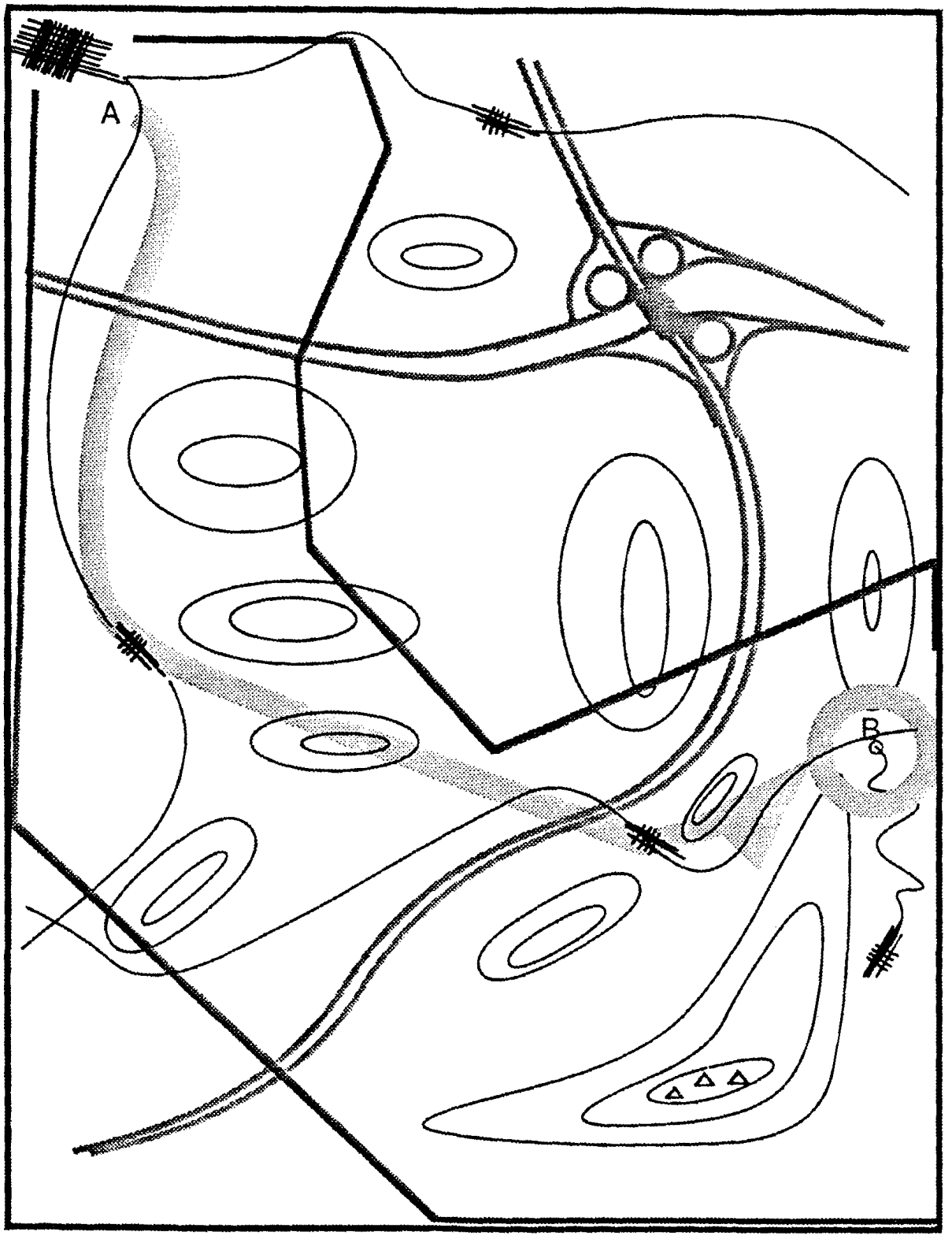


FIGURE 6: ROUTE SELECTED TO FOLLOW LIGHT SOURCES

Figure 7 illustrates the view one might expect to see when approaching two small towns at an altitude of about 700 feet above ground level (AGL). At the far right, three lighted towers are visible. A highway runs perpendicular to the line of sight. Figure 8 illustrates progress along the flight path. These two figures briefly introduce the concept of cross country visual operations at night with NVGs.

Remember, NVGs do not make it possible to fly from A to B. The NVGs are light collectors and amplify the light detected. They are more sensitive to red than to green or some blues. In fact, they are very sensitive to red and this causes red obstruction lights to become very bright. You may see red lights through NVGs which you did not even notice with the unaided eye. Is this a useful characteristic or is it an nuisance factor?

You will see flashing lights as well. Lights on emergency vehicles and anti-collision strobe lights on aircraft can both be observed on NVGs. Steady aircraft lights may get lost in city lights if they present the observer with a low bearing rate. That is, if you are overtaking an aircraft (unlikely in most helicopters) and the aircraft is between you and a city, you may not realize that the tail light is on an aircraft.

All flashing lights should be given special consideration. Red running lights and red anti-collision lights will tend to be prominent in the night sky. The red color will make the red light appear to be closer than a similar white light at the same distance. This is one of the reasons you evaluate lights detected with the aid of NVGs by using your naked (unaided) eyes as well.

FIGURE 7: FOLLOWING LIGHT SOURCES EN ROUTE

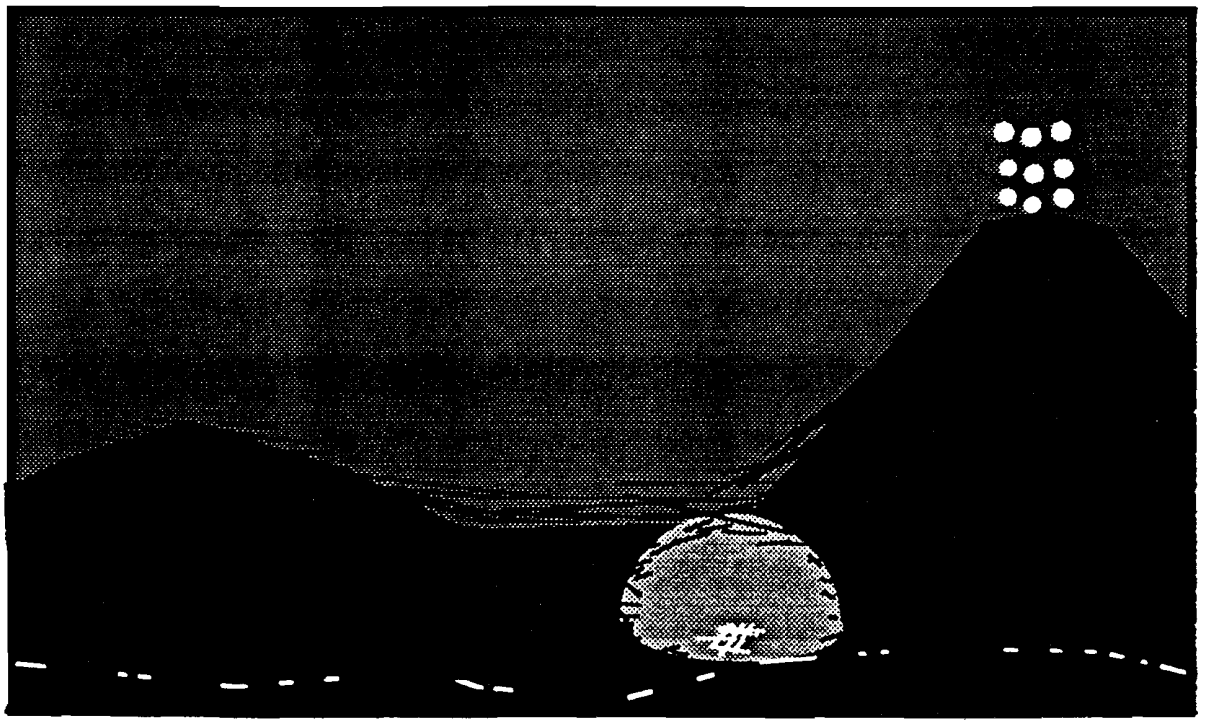


FIGURE 8: CITY LIGHTS NEAR INTERSTATE HIGHWAY

ARRIVAL AND DESCENT TO LANDING, NIGHT FLYING PROCEDURES

Under normal, every-day night operations, a helicopter pilot is expected to arrive at a remote landing site and descend to a safe landing using natural light, lights on the ground and lights on the aircraft. NVGs are not to be used to land or even conduct an approach to a high hover (for this evaluation). Never-the-less, NVGs may be of significant benefit during the arrival, pre-descent phase.

First the pilot must find the landing site. This may mean looking for a lighted heliport or for a police car on a dark highway. Regardless, the pilot must descend to some safe (obstruction clear) altitude and verify the identity of the site and the appropriateness of the site as a potential landing site. This process should include a high and low reconnaissance, to detect obstructions, to plan the approach path and to plan the departure. Trainable search lights, landing lights and fixed landing lights are normally used in this task.

This evaluation does not include the use of NVGs during an approach to a hover. The approach to a hover is adequately provided for via the conventional use of the conventional white lights discussed above. Conversely, the high reconnaissance phase could involve the coordinated use of NVGs and white lights. The military does not use white lights with NVGs. This is to avoid detection in combat, but there is nothing wrong with using some kinds of white lights in the civil environment with NVGs. We are interested in defining the best procedures "to use" and the procedures "to avoid" with ground illuminating white lights from high altitudes. We already know that staring into an auto's head lights with NVGs is not advisable. We also know staring into white lights with the naked eye will destroy night vision and is not recommended. We also know neither case is required. You look away in both cases. Tells us what you observe and how you scan the terrain from altitude, with and without white lights.

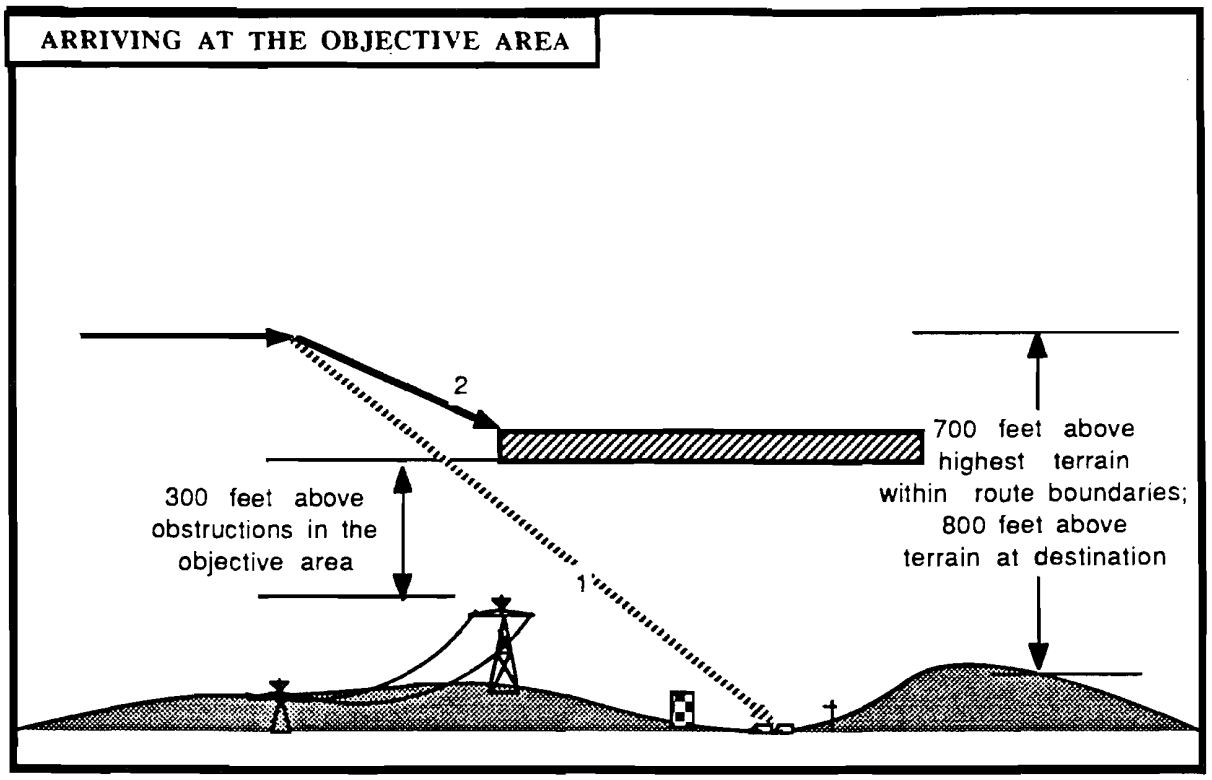


FIGURE 9: ARRIVING AT THE OBJECTIVE AREA

In Figure 9, an EMS helicopter has arrived in the area, conducted a search and has located an accident site (two cars, LOS "1" in Figure 9). Having located the site, the aircraft is flown down to a lower altitude ("2" in Figure 9) to continue a pre-approach, high reconnaissance. White lights are turned on before descending. It is important to make your transition from the dark night environment (with no lights) to the "white lights on" environment, before leaving the obstruction protected altitude established during your pre-flight and observed en route. This is true regardless of whether you wear NVGs or not. If it is a very hazy night, turning a white light on may produce a lot of backscatter. This may eliminate horizon cues and make the operation a bit less comfortable. Do NVGs improve or degrade night visibility when there is a heavy haze and a lot of backscatter?

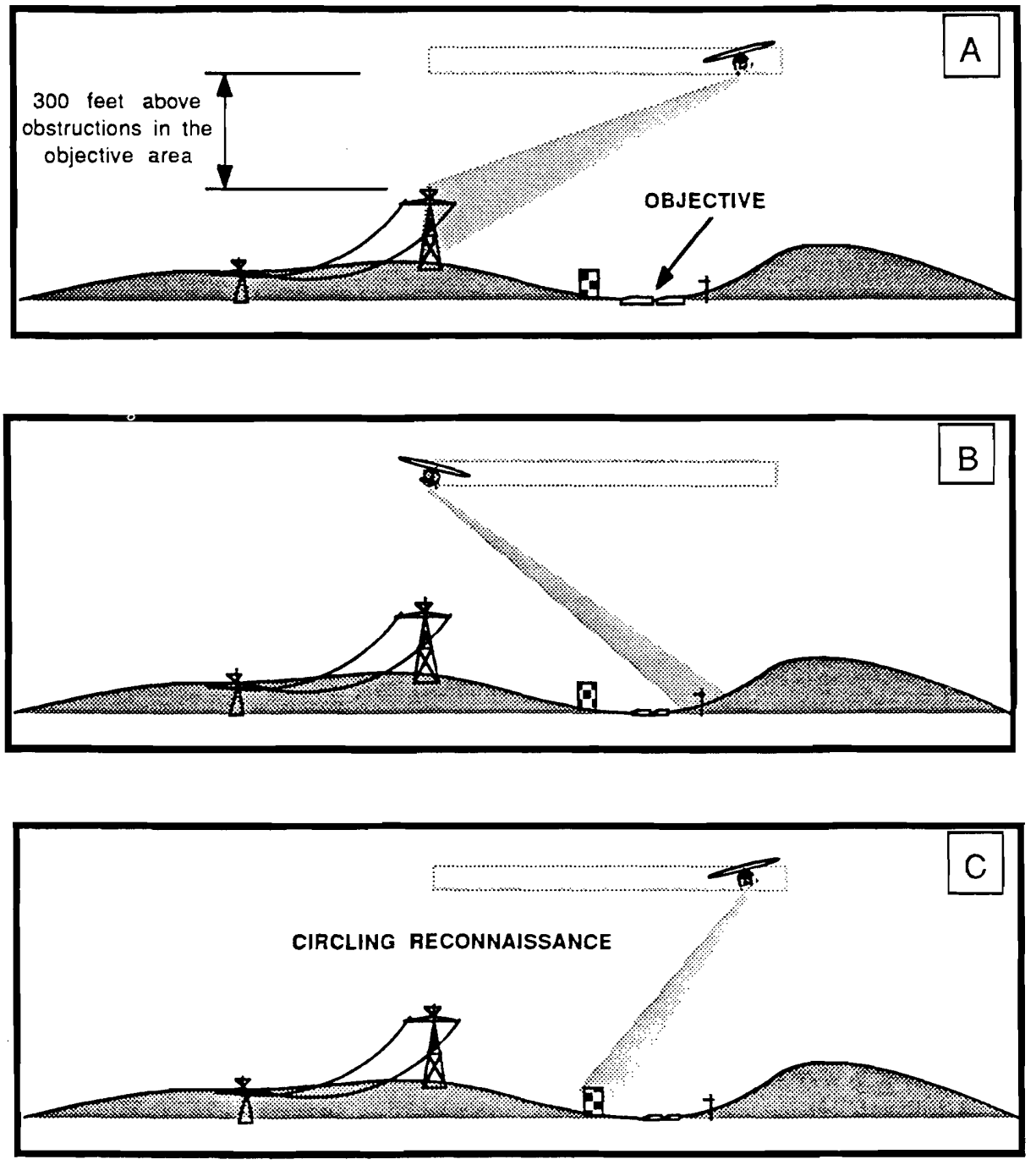


FIGURE 10: CONDUCTING A RECONNAISSANCE OF AN OBJECTIVE AREA

In Figure 10, the aircraft has descended to a lower altitude pre-planned for, use in the high reconnaissance. This improves the ability of the search light to illuminate the immediate area and allow the pilot to detect hazards.

As explained in Figure 10, spot lights can and should be used to look at objects on the ground while the pilot circles above. The pilot can look at the spot on the ground through the goggles and often see more than without the NVGs. The pilot also has the alternative of looking under the goggles and viewing the lighted area unaided. The resultant visual experiences will be different, but complimentary.

The pilot's head (with goggles) can be pointed at a number of different subjects (of potential interest) on the ground much faster and more accurately than the spot light. (The ability to focus the light to get a small or large spot, the candle power of the spot, and the articulation system of the light or lights obviously varies from light to light.)

Some features or objects may be easy to detect and interpret with the unaided eye. Other objects will be invisible to the unaided eye, yet easily detected and evaluated with NVGs. Each alternative viewing method has its attributes and its limitations.

In some cases, it may be desirable to flip the goggles up and out of the pilots eyes altogether. Flying low over a well lit city on a bright moonlight night would probably represent such a case.

When aided and unaided alternate viewing is desired, it may be best to adjust the goggles so that they are available for use in the same way bifocal glasses are used. That is, the pilot might adjust the goggles so that they are up and some what out of the primary eye line of sight. If this technique is used, the pilot's head must tilt forward to allow the pilot to look through the NVGs at the object of interest. While this is not a problem for most pilots, you may find a better way. The bifocal technique emphasizes that there is no requirement for a pilot to continually stare through NVGs, even when they are in the "ready", flipped down position.

OVERFLIGHT OF TERRAIN ALLOWS CREW TO LOCATE OBSTRUCTIONS AND SELECT APPROACH AND DEPARTURE PATHS

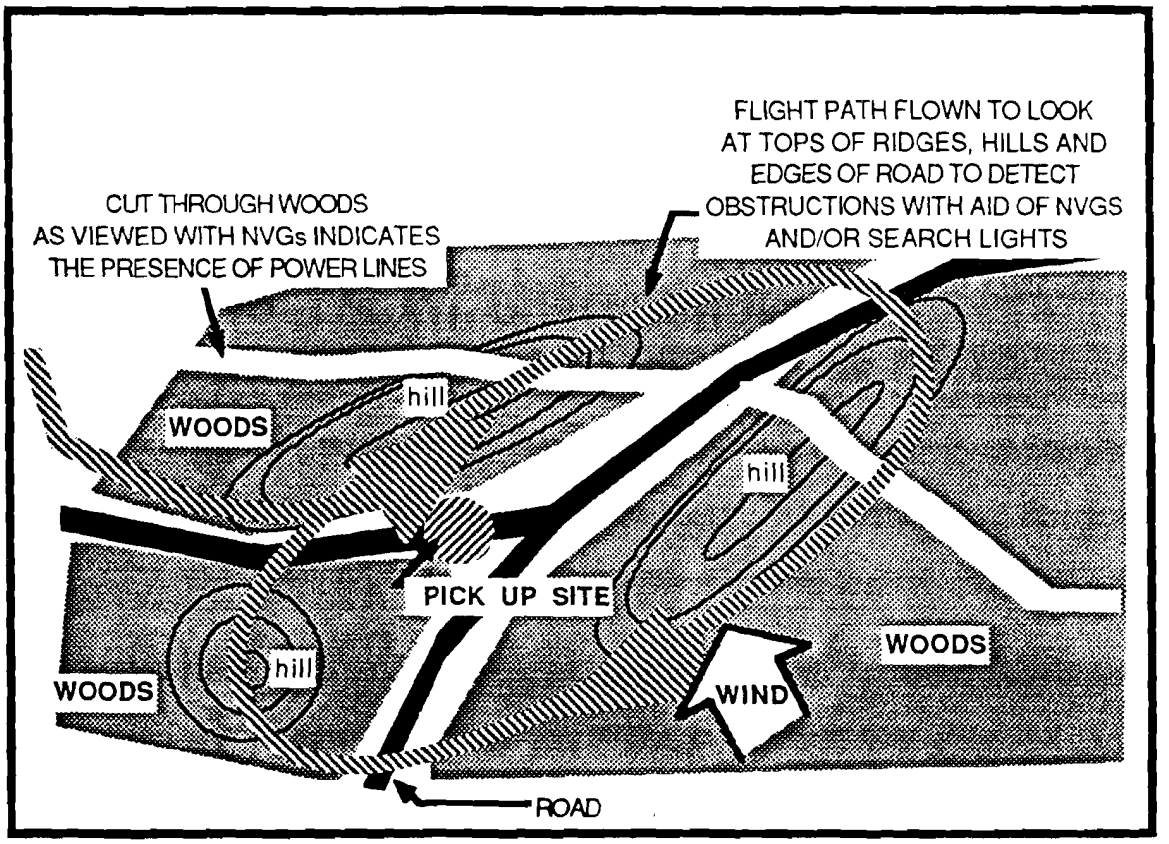


FIGURE 11: INITIAL RECONNAISSANCE FLIGHT PATTERN

This figure allows us to look down at the same scene presented in Figure 10. The pilot is flying an oval reconnaissance pattern and looking for tell-tales such as the cut through the woods which belies the presence of either a pipe line right-of-way or a power line right-of-way. The pilot picks a landing site and studies the terrain to evaluate alternative approach paths and departure paths. The pilot must be alert to the possibility that the wind may change direction and speed as the aircraft descends. The pilot may see a wire on short final and turn to use a different final approach path. Pre-planned alternatives are important.

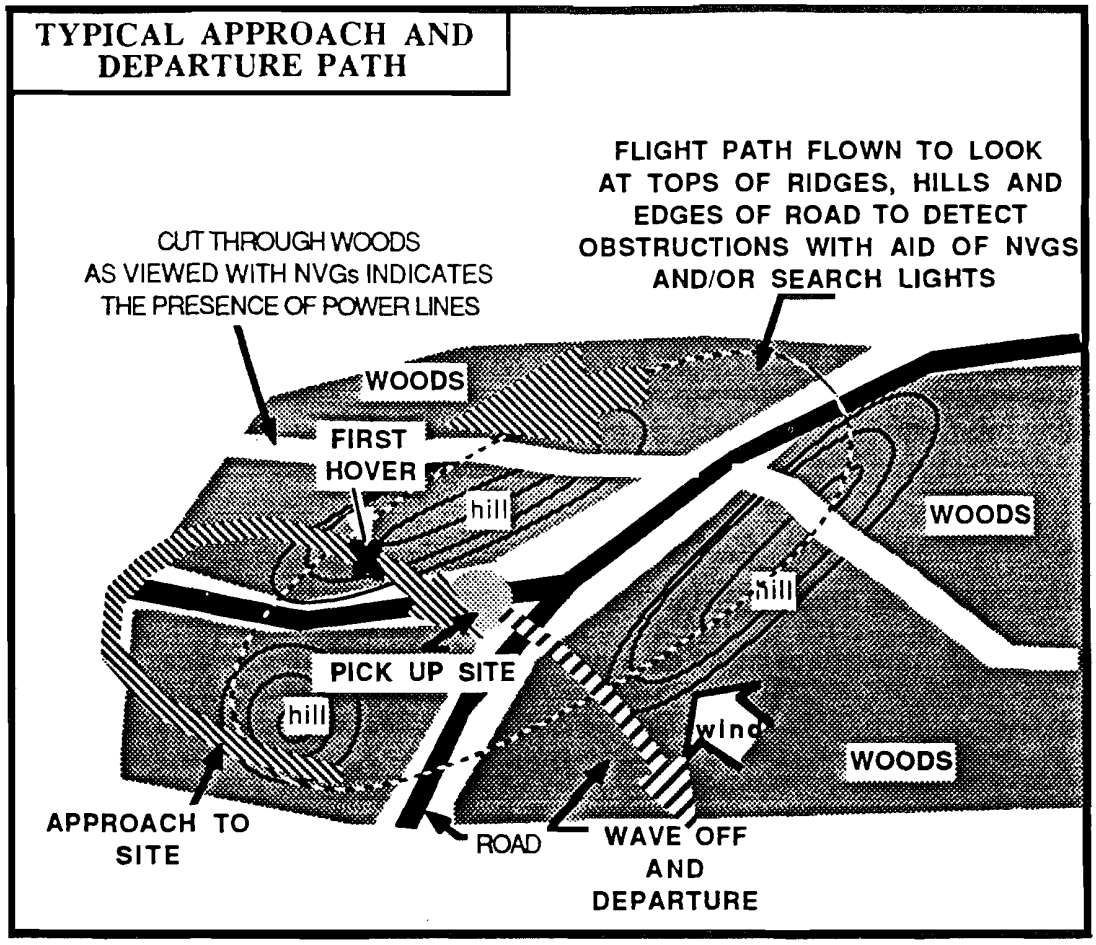


FIGURE 12: PLANNING AN APPROACH

Having completed the low reconnaissance, the pilot has selected a landing site and formulated a plan for conducting an approach. He has also made plans for emergencies (i.e., engine failure on approach), and has selected what looks like the best take-off departure route. The wind, terrain, landing site, obstructions and visibility have all been taken into account during this pre-approach effort.

To summarize, before starting the approach, the pilot may use the NVG's to help find and evaluate the obstructions in the area. This may involve bifocal type viewing where the pilot alternately looks under the goggles at what he can see with the spot light (unaided) and then he looks briefly through the goggles at the same spot, or on the edge of the spot, or elsewhere. When the pilot is ready to conduct the approach, the goggles are flipped up into a stowed position. Next, the floods may be turned on as the approach is commenced.

Although your evaluation ends after the reconnaissance phase (defined by the act of "de-goggling"), it is useful to remember that all lights are normally utilized during the descent-deceleration to a hover-landing. The pilot must sometimes adapt to the massive amounts of light, before descending into the obstruction rich environment.

INTRODUCTION TO NVG ADJUSTMENT AND USE

The following figures illustrate the many factors to consider when preparing to operate with NVGs.

Again it is important to understand that military pilots stare through NVGs when they are in use during NOE operations. **The civil pilot does not fly NOE and does not stare for hours through the goggles.** This fact allows the civil pilot to be less sensitive to some of the human factors issues which are extremely important, even critical to military NOE operations.

While military pilots spend most of their time looking thru their NVGs, they also spend a considerable amount of time looking under and around their goggles. In some cases, a co-pilot spends most of his time looking inside the cockpit, while the pilot in command of the aircraft spends most of his time looking out at the obstructions around him, and he looks at the ground which may be only a few feet away. Many of the NVG accidents have happened when both pilots looked into the cockpit at a warning light at the same time, and no one was actively controlling the flight path around or over obstructions. When operating down and in this extremely obstruction rich environment, it takes only a few seconds of inattention to result an accident.

The capability to conduct unaided operations is of greater importance to the civil pilot because it is this mode of operations which must be maintained to ensure that the operation is being conducted in accordance with the FARs. It is the ability of a pilot to operate above the obstruction rich environment, without NVGs which enables civil helicopter operations.

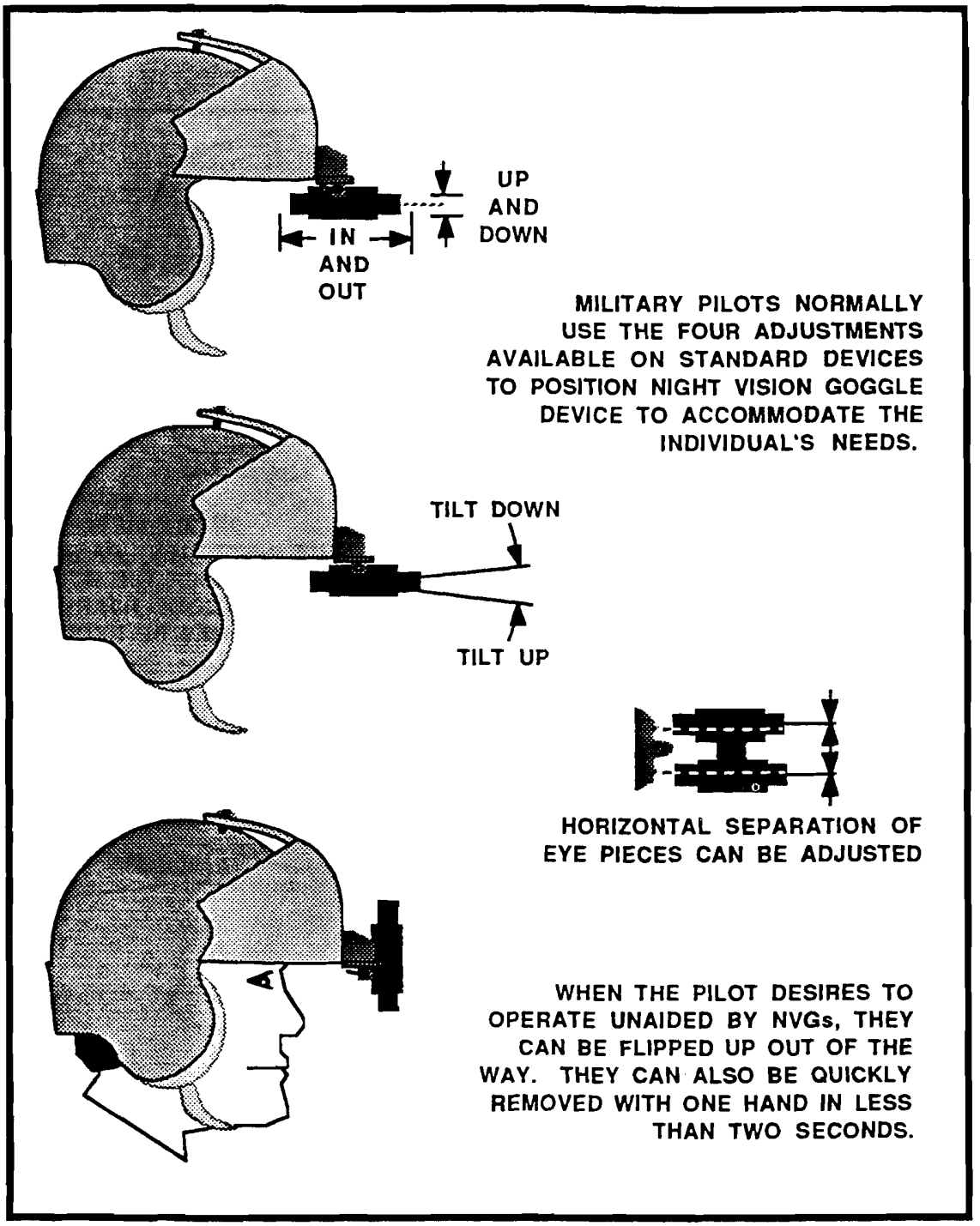


FIGURE 13: ADJUSTMENTS AVAILABLE FOR INSTALLING NVGS ON A FLIGHT HELMET

Figure 13 illustrates the way the goggles are mounted on a standard military helmet and the four basic adjustments. Other adjustments facilitate focus and adaptation of the goggles to the users unique vision requirements.

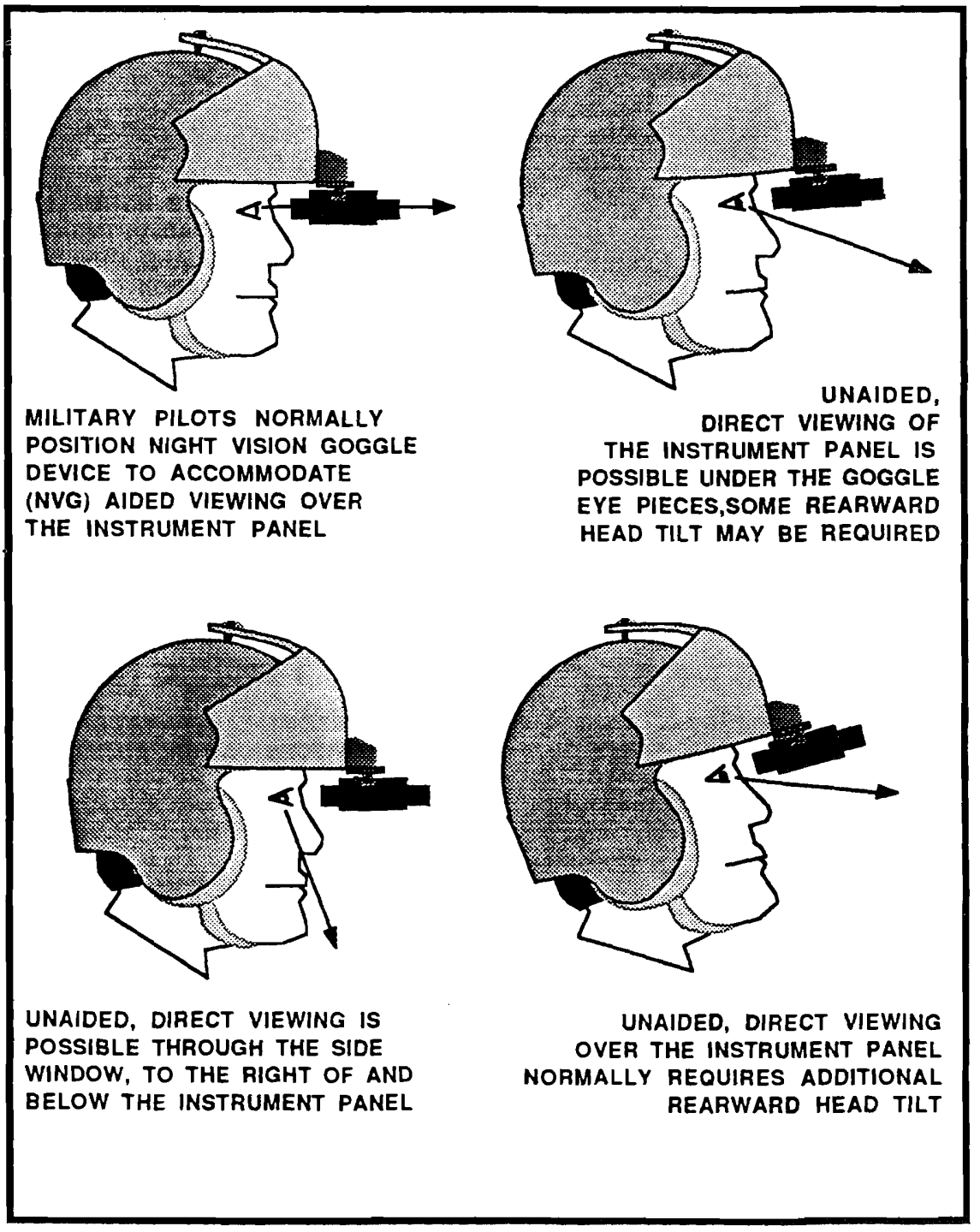


FIGURE 14: MILITARY NVG ADJUSTMENT PROCEDURES

Figure 14 shows how a military pilot, required to fly NOE, looks through the NVGs at the outside and looks under them at things in the cockpit.

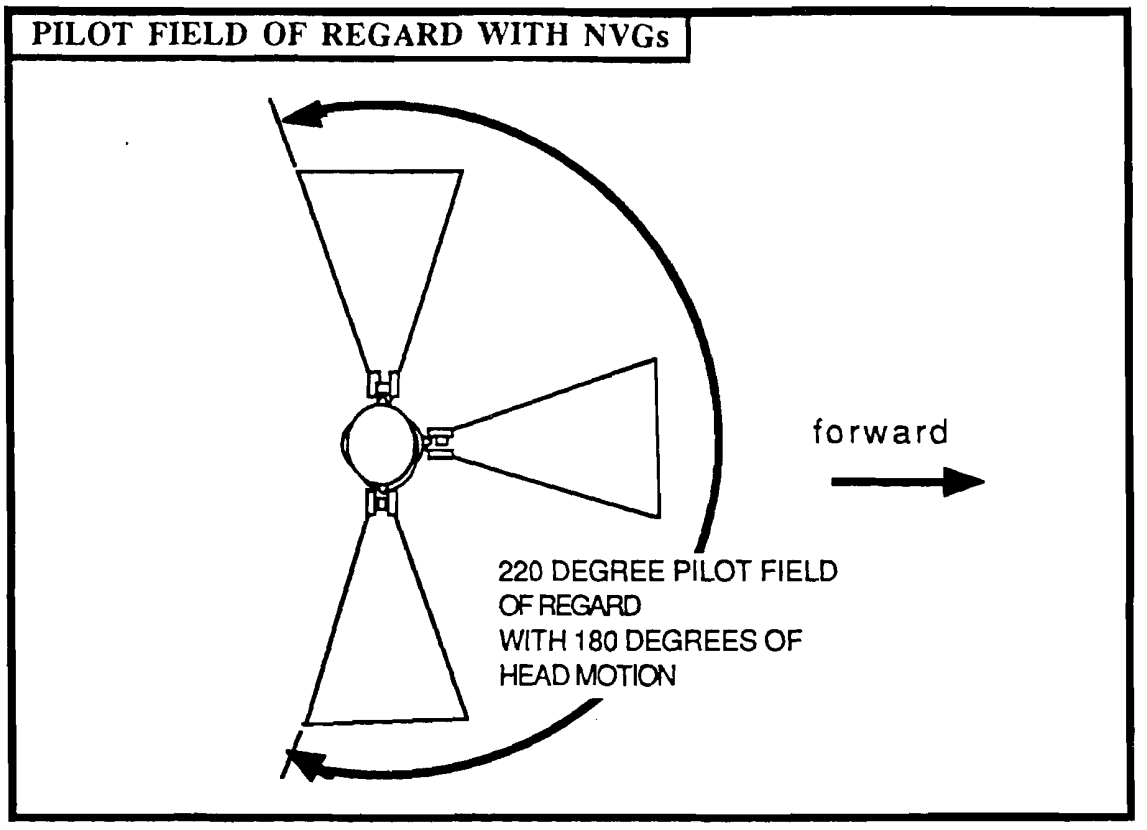


FIGURE 15: FIELD OF REGARD AVAILABLE TO PILOT

The next series of figures will review a few concepts of operation and lead to a set of recommended civil helicopter pilot NVG adjustments. The figure above illustrates the basic fact that the pilot has a rather large field of regard for direct viewing through NVGs. The instantaneous field of view (FOV) will range between 30 and 40 degrees (depending on the distance between the pilot's eyes and the eye pieces of the NVGs. While this is admittedly a limited FOV, it can be argued this constrained FOV is made less important because of the large field-of-regard and because the pilot can rapidly re-point the goggles up and down, as well as back and forth. A spot light cannot be manipulated with this precision and is very slow in comparison. The field of view of a spot light is not that great either, but with all of its shortcomings, pilots prefer the use of the spots to the alternative darkness. The question here is: Is it possible to rapidly and precisely re-orient the line of sight of the NVGs in a way which decreases the need for a large field-of-view or is it too much of a bother? Is it useful to have NVGs as an adjunct to a spot light? If so, why?

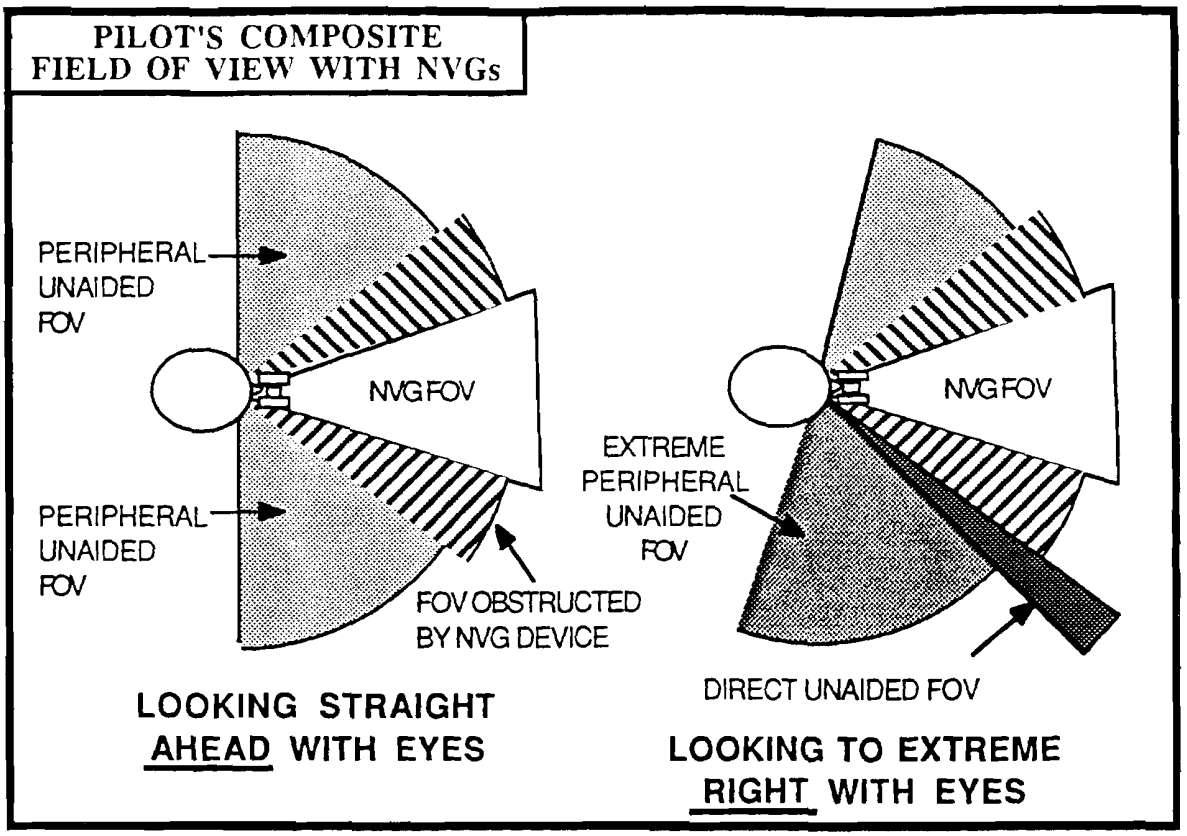


FIGURE 16: PILOT HAS AIDED AND UNAIDED FIELD OF VIEW AT THE SAME TIME

The next figure (16) addresses the variety of vision possibilities available in the horizontal plane of the field of view available to a pilot wearing NVGs for one head position and two eye orientations. This idea of looking around the goggles was first introduced graphically in Figure 14 when the pilot is shown looking under the goggles.

It is obvious from earlier discussions that pilots can look through the goggles to obtain "aided" vision (NVG FOV) while retaining some peripheral unaided vision capability. The question is: What value is the unaided peripheral vision? Can you detect air traffic peripherally out the door windows to your right or left? Can you see warning lights?

Figure 17 introduces the idea of cockpit unique problems. The location and brightness of Fire Warning Lights, the location and dimensions of windshield supports, the height of the glare shield, the point used inside the cockpit (white is reflective) and many other unique problem, need individual treatment on a case by case basis. This evaluation is asking you to evaluate

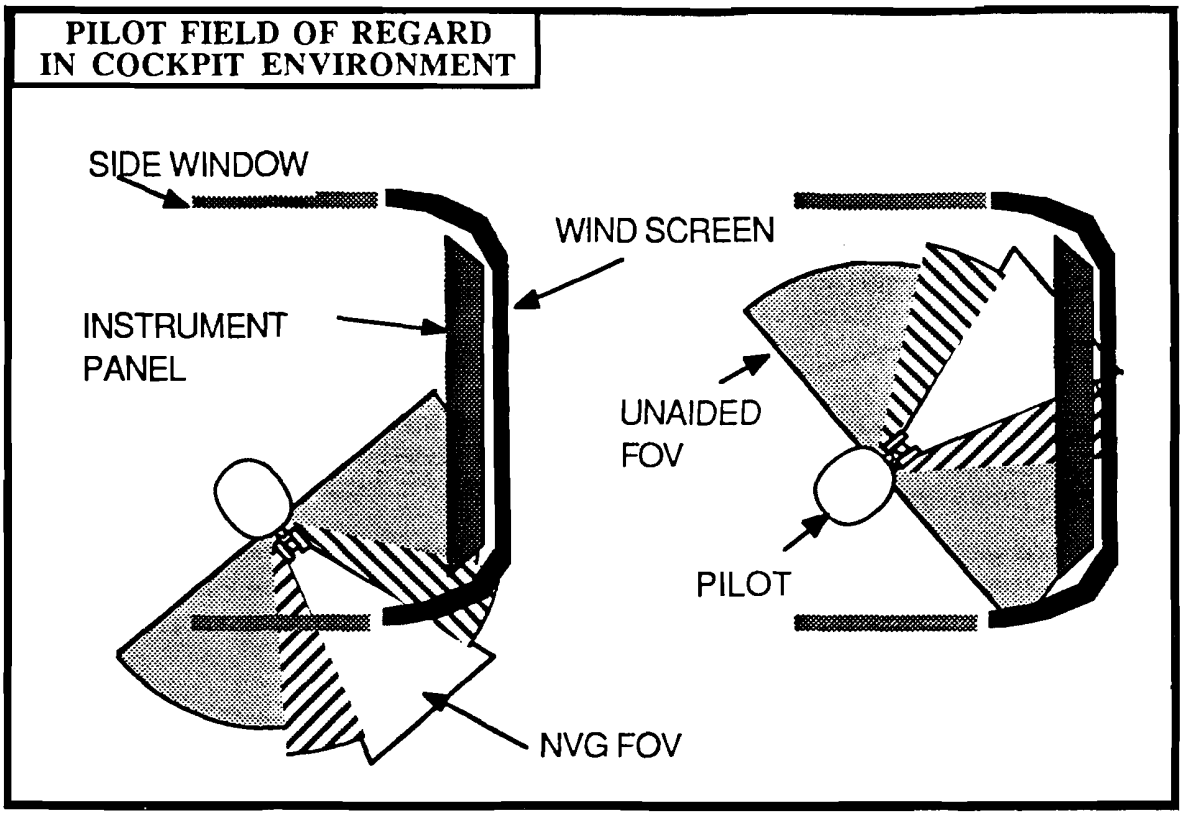


FIGURE 17: NVG OPERATIONS IN A COCKPIT

the situation you actually fly, but it also wants your thoughts on problems which may exist in other cockpits.

Then, there is another mode of viewing around NVGs. Pilots have the ability to look directly at something to the right of the right eye piece or to the left of the left eye piece (or under both eye pieces). This mode of viewing is most important to the need of viewing the instrument panel and general cockpit management. You may have to tilt your head back to see under the goggles. Is this a bother? Do you think pilots are likely to forget to monitor flight instruments because they must tilt their heads back?

The pilot can look from side to side with the NVGs and see through the windows and windscreen. The question is how well can the pilot see the outside through the glass. Are there too many bothersome reflections? Do the windshield supports block the pilots view unacceptably? Can the pilot see inside the cockpit using unaided peripheral vision? Can he see outside with peripheral vision?

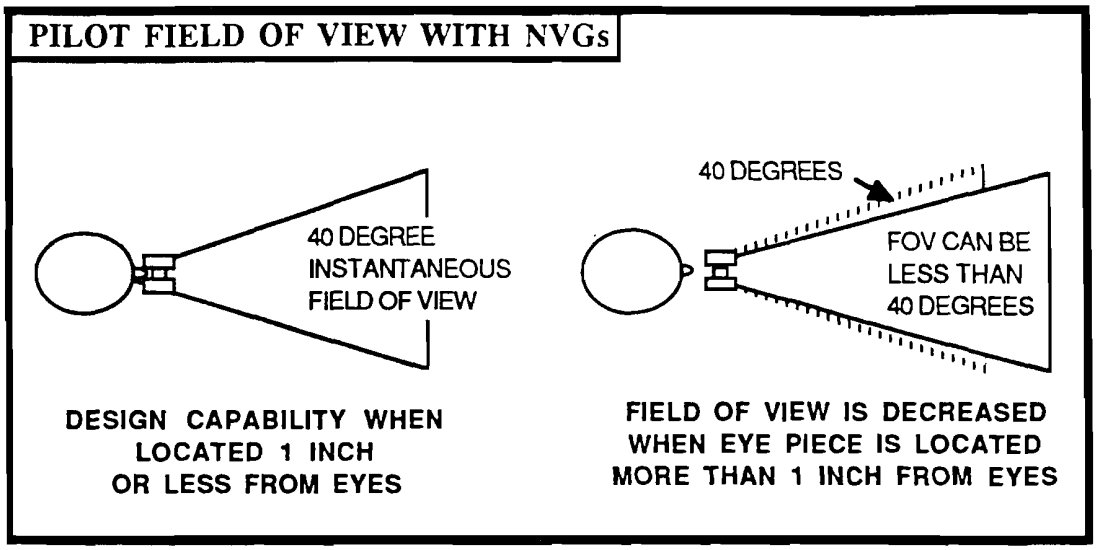


FIGURE 18: IMPACT OF EYE TO GOGGLE DISPLACEMENT

This figure 18 illustrates one of the impacts of moving the goggles out, away from your eyes. The field of view is decreased. This is caused by physical design of the eye pieces. As the goggles are adjusted out and away from the eyes, you can also expect to loose some image detail. For example, leaves on the trees will fade away and you will just see the tree. The degree of detail you desire must then be weighed against the desire to see around and under the goggles. [Note: You can always see around the eye pieces of the goggles. The objective here is to suggest that in the case of civil operations, it may be preferable to trade-away some image detail, and aided field-of-view, for a larger unaided field of view. The evaluation question is: What is the best way to adjust the goggles for civil use?]

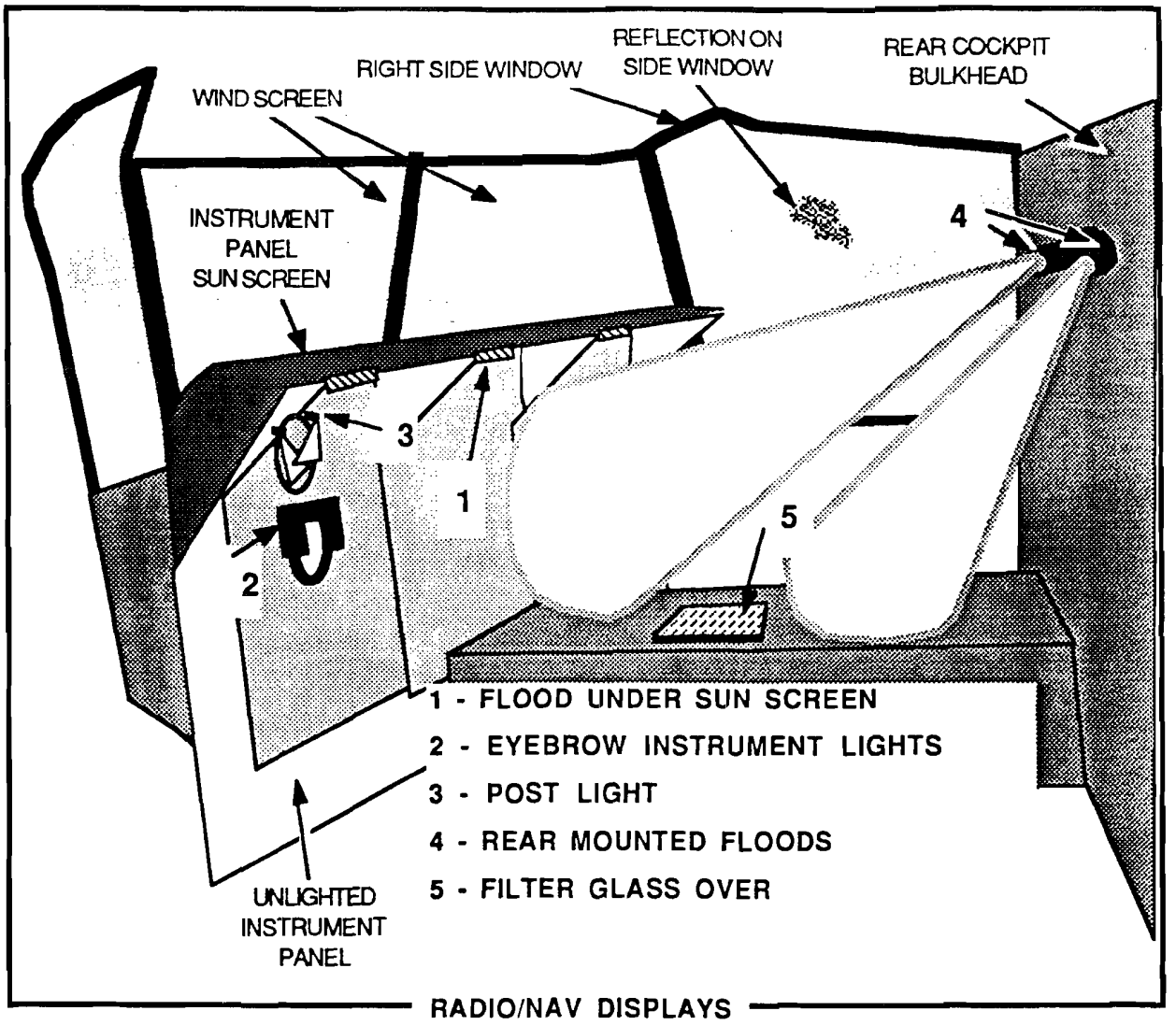


FIGURE 19: NVG COMPATIBLE COCKPIT LIGHTING

One universal issue involves the color and intensity of the light used in the cockpit instrument so that you can see them under the goggles. You are expected to set the cockpit lights so that the light is bright enough for you to read the displays with your unaided eyes, but the light must be kept as low as possible to avoid interfering with your unaided night vision (as you would normally operate) and minimize the impact of the lights on the operation of the NVGs. You should avoid wearing white clothing because it will tend to reflect light from cockpit flood and instrument lights onto the cockpit glass. A white interior will produce the same effect.

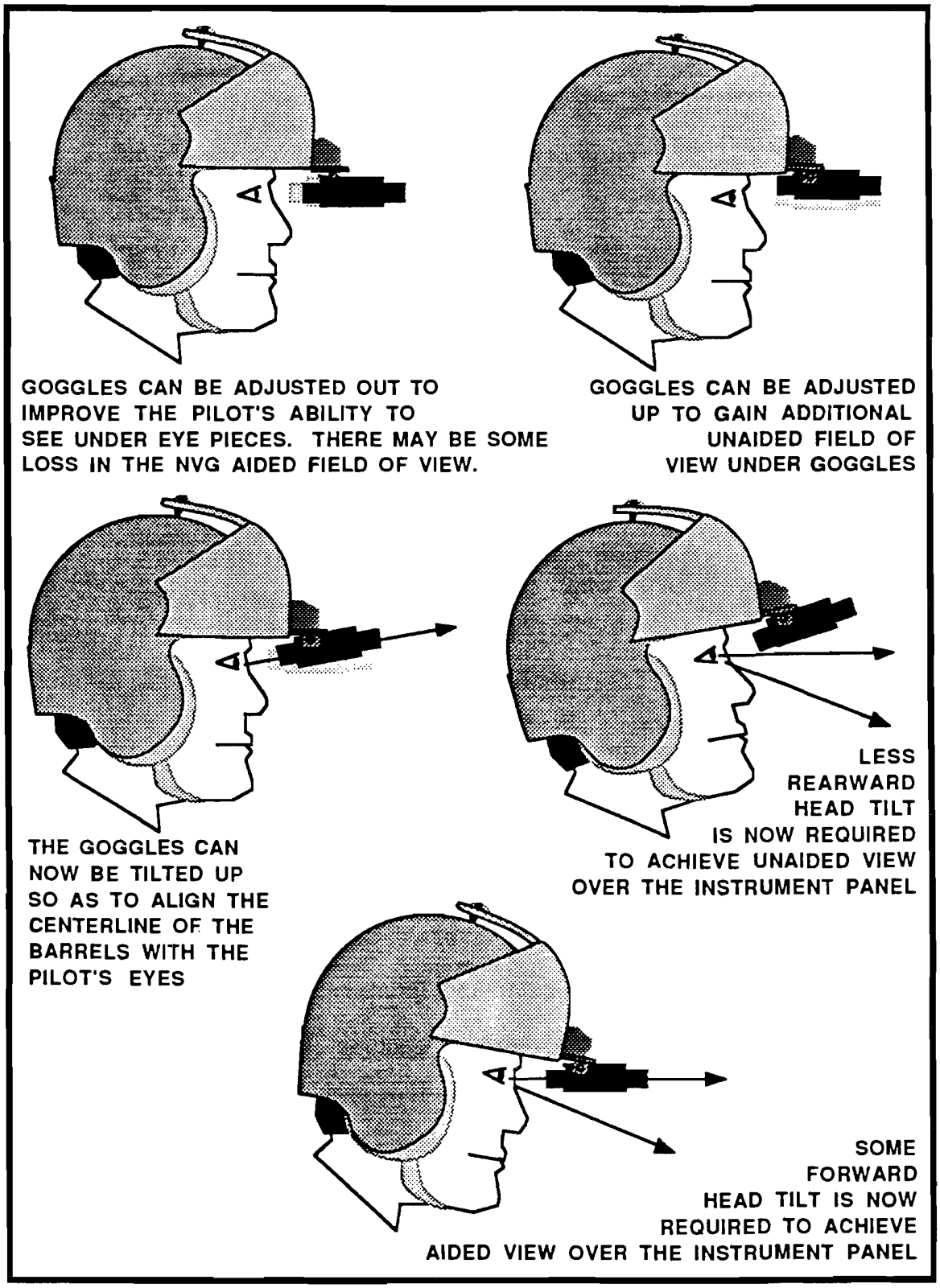


FIGURE 20: SUGGESTED CIVIL NVG ADJUSTMENT PROCEDURES

Note that some people will tell you that if you do not adjust the NVGs exactly as they instruct you, they will not work. Some will also tell you that NVGs don't work above a certain altitude as well. Be advised that they will continue to work. They may present a different set of capabilities and limitations, but they continue to work. When there is no light at all, they will stop working. But you are not suppose to be out flying visually under such condition. When there are no visual references at all, you are really flying instruments. NVGs are not being considered as an aid for instrument flight, only VFR flight when there is some light which can be exploited by the use of NVGs. Figure 20 makes a few suggestions which you may find appropriate for you. Then again, you may not find that this sort of adjustment is either desired or required.

THE IMPLICATIONS OF VISUAL CUES ON PILOT WORKLOAD ASSESSMENTS

Earlier in this guide, we introduced the need to think in terms of short term and long term responses. We considered the need to introduce control inputs to suppress gust upsets and to suppress upsets due to control cross coupling. Now we need to think in terms of how the eyes fit into your ability to introduce compensation. When you suppress a gust response, you must first detect the onset of the gust, next respond with a corrective input (for an appropriate period of time) and finally you retrim the aircraft in hopes it will hold speed, altitude and heading for a number of minutes without any more attention on your part. You need to think about this process. Think about what you see and feel when the aircraft is struck by a gust. What do you look at on a clear daylight flight? What do you look at on a dark night? How does the availability of NVGs change any of what you see?

Well, first of all you use your eyes to observe the buildup in error. You either observe instruments or you observe external (earth reference) visual cues. If you have very strong visual cues you may be able to achieve the desired performance with only an occasional reference to the cockpit displays. If there are no external cues you will typically be required to spend a great deal of your time observing your instruments. If you can clearly see the outside

world, you will have a feeling of spatial awareness or orientation which leaves little doubt as to the location of hazards relative to your immediate flight path. If you are flying under difficult visual conditions (night) you may have poor situational awareness. When the visual cue system is poor, you may feel the need for electronic navigation aids to navigate, and you may elect to concentrate on your flight instruments to achieve or maintain the flight path accuracy you desire.

CONTACT VS INSTRUMENT REFERENCE FOR FLIGHT

Contact flight requires the pilot to fly with reference to the terrain features, natural and man made. This requires the pilot to look out enough to insure that the flight follows the desired course. The pilot must also watch for other aircraft to avoid collision. All of this looking out tends to take away from the time available to look inside at the flight instruments, tune radios, look at charts, etc. This shared scan provides the pilot with two opportunities to obtain flight management cues. The "outside world" provides one opportunity and the cockpit instruments provide the other.

When you conduct your evaluation flight, you need to be aware of the sources of the cues which are most valuable to you. Where are you looking to get your feel for attitude? Do you get the cues you need to fly while looking outside most of the time, or must you spend most of your time scanning flight instruments to minimize the flight path error? If the aircraft tends to roll-off into a turn or pitch-over (nose down) when unattended, can you detect this departure from the trim condition while looking outside, or must you look at the flight instruments to observe this condition?

On a very black night, over an unlit surface on a clear (VFR) night, it may be impossible to fly the UH-1 without spending most of your time on instruments. Over Los Angeles, on a clear night, you can safely fly the UH-1 for hours with only an occasional glance at the instruments. Why? In the "over city" case, the visual cues are so strong that you are able to detect even

the smallest attitude change and quickly make the appropriate corrective input. Small inputs are executed instinctively, before the disturbance can produce an error of sufficient magnitude to aggravate the pilot or interfere with accomplishment of long or short term objectives.

How do the cues you see affect the way you feel about your performance and the progress of the flight. The existence of a feeling of "well being", or the lack of this feeling, is in some measure a reflection of task complexity, situational awareness and the possibility that undetected residual flight path errors exist which could be life threatening . The ability to see the real world seems to contribute substantially to a positive feeling of well being. This positive feeling is in turn reflected as low levels of stress and a decreased probability that the pilot will become fatigued. You are cautioned to remember that a pilot can become highly fatigued even if the pilot's task is limited to monitoring the activity of a fully automatic flight control system. For example, if the auto pilot is flying the aircraft (hands-off) at high speed in a low-level, terrain flight mode, the pilot knows that an error in the terrain following auto-pilot system response could cost his/her life. To feel safe under such potentially lethal conditions, the pilot must conduct a high gain monitoring effort. This will fatigue the pilot. So how do you monitor the progress of this aircraft? Are you tense or relaxed? Why?

SUBJECTIVE RATINGS AND THE ENVIRONMENT

The evaluation methodology explained in the following pages recognizes that pilots can rate their ability to fly an aircraft as a function of a variety of environmental factors and combinations of factors.

This evaluation needs a methodology which is sensitive to the environment because the FAA needs to understand the impact of NVGs on pilot workload and performance under a wide variety of lighting, visibility and air mass conditions.

Figure 21 provides a spectrum of environmental factors which may be used as variables to evaluate a variety of helicopter mission tasks. Look at this figure and picture yourself in a UH-1H, flying 700 feet above the earth surface and trying to follow a river, or interstate highway, or trying to find a specific four lane bridge over a river. Pick the mission objective. Now look at lighting (Figure 21A). Think about how hard (or easy) the flight control and navigation jobs are under several very different lighting conditions. Flight is easiest under bright day conditions. It's a little more difficult with the sun in your eyes. A lot more difficult over water at night under a heavy and low overcast. In Figure 21C, a zero surface wind produces a slick sea and no surface cues, while a 10-20 wind gives you a light chop and good surface definition. Such definition is very useful under a quarter moon but useless under an overcast. The question is: How does your perception of the surface change with the introduction of the NVGs as the light gradually diminishes over an otherwise useful visual reference?

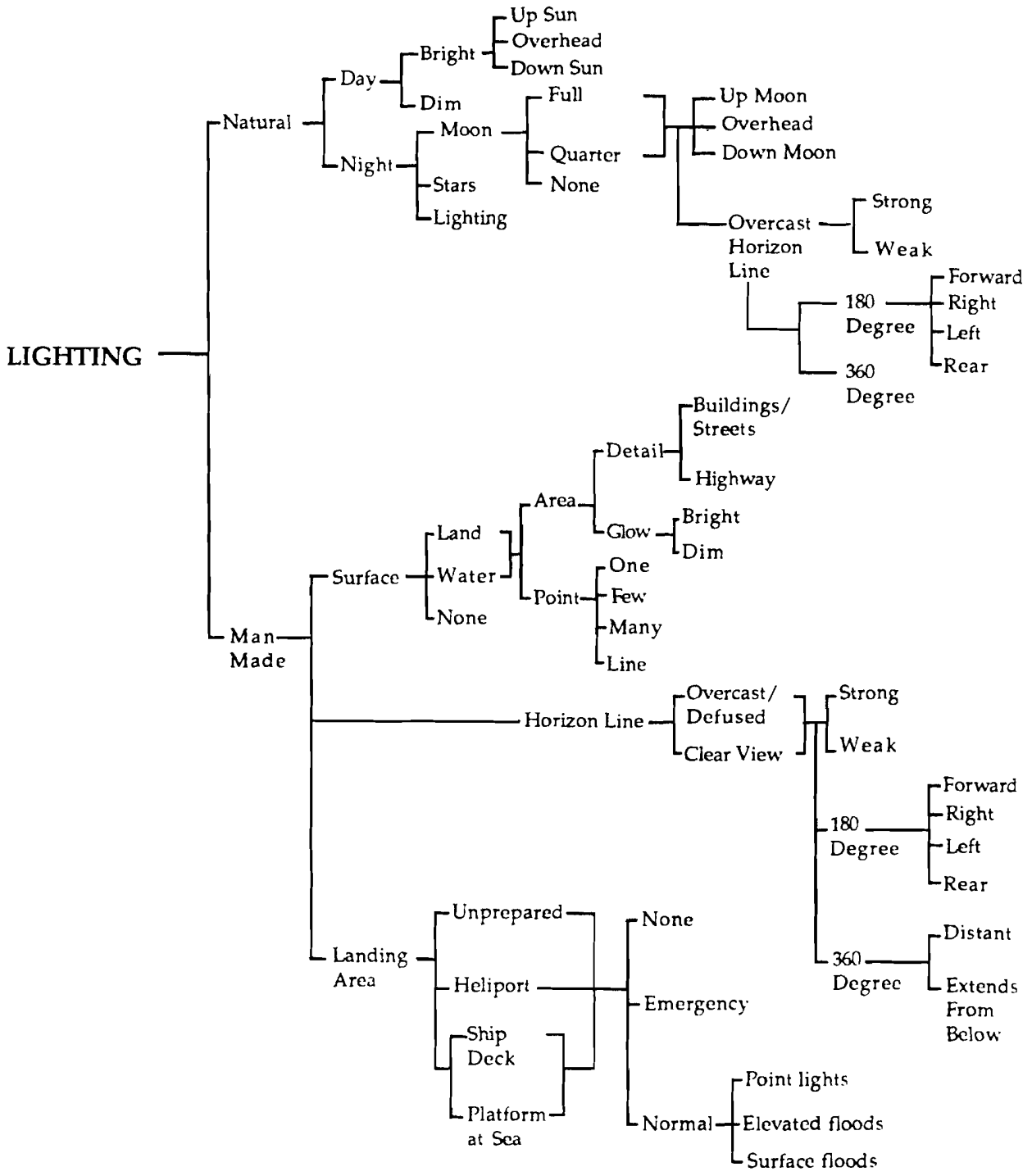


FIGURE 21A: CHARACTERISTICS DEFINING OPERATIONAL ENVIRONMENT

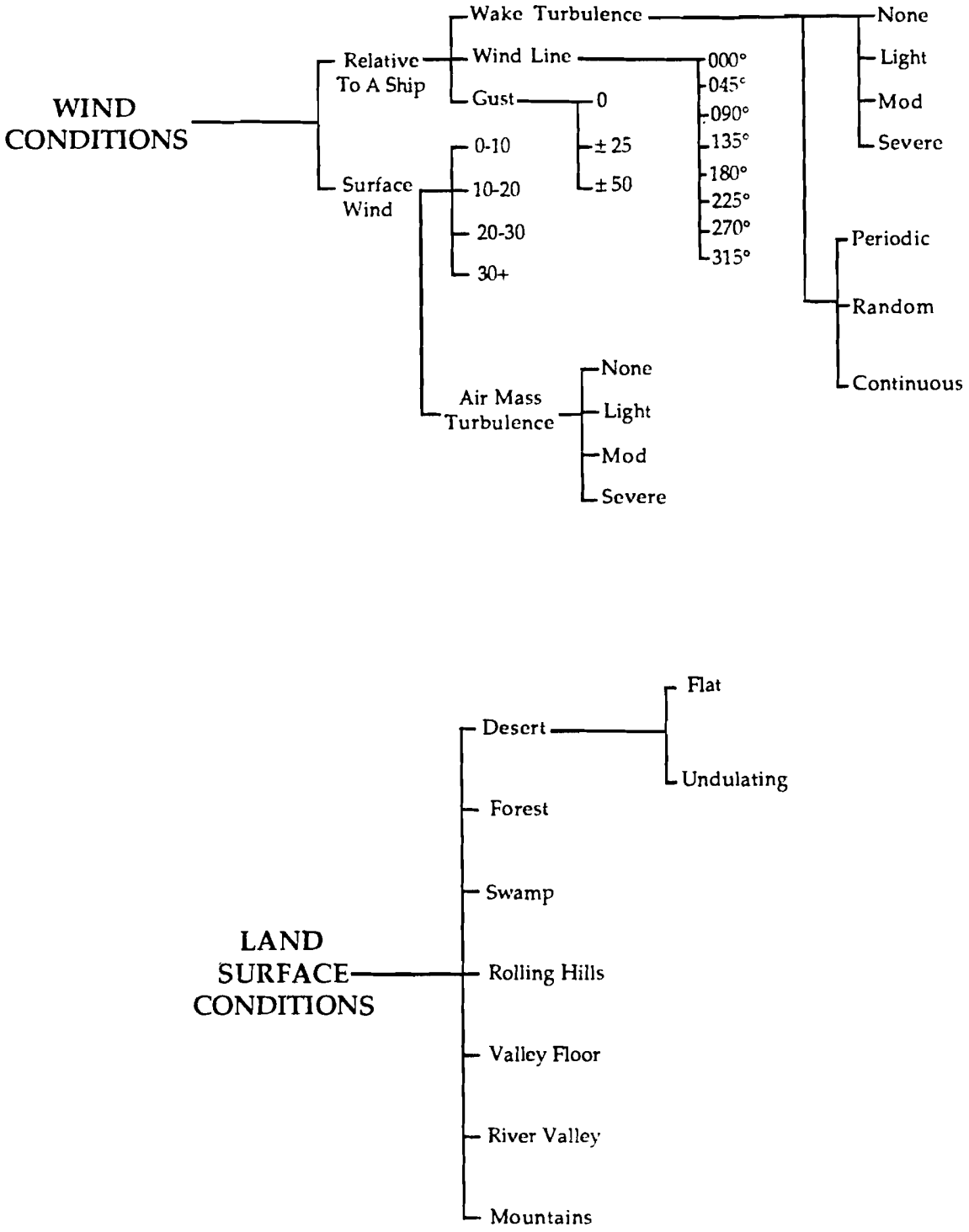


FIGURE 21B: CHARACTERISTICS DEFINING OPERATIONAL ENVIRONMENT

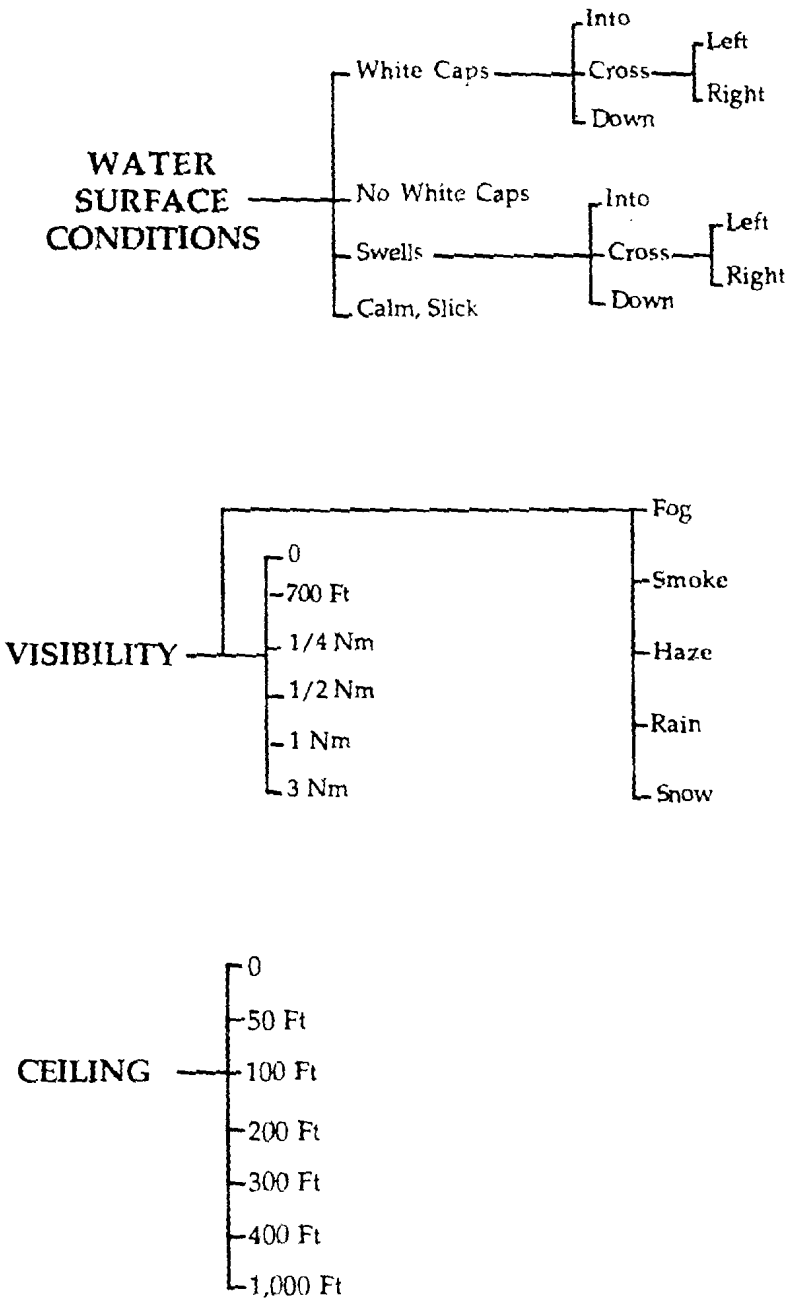


FIGURE 21C: CHARACTERISTICS DEFINING OPERATIONAL ENVIRONMENT

EVALUATING A SPECIFIC FLIGHT TASK

You will be ask to fly a modified UH-1H helicopter around a close course, over and to the north-west of Atlantic City. You will operate the aircraft as a single pilot crew. You may or may not start with a daylight flight. If you are an experienced UH-1 pilot, you will not receive a day flight. Navigating between two lighted cities will probably represent the easiest task you will be ask to perform.

When you arrive in the general vicinity of your simulated objective, you will be required to search for a potential landing site and ask to identify features of the landing area. You may be asked to look for obstructions. You may need to conduct circling flight to accomplish this site reconnaissance. A visual search for wires and other obstructions may be difficult at night.

There will be other tasks to conduct where you are asked to do more than one thing at a time. You will repeat these tasks with NVGs and without NVGs, and you will be asked to assign a rating for both cases. When a pilot evaluates a given task, the pilot is actually rating the most difficult sub-task contained within the primary task. Regardless, the question is: Do the NVGs make the task more difficult or less difficult? Your ratings will reflect your evaluation results.

A series of relaxed tasks such as cross country navigation over a brightly lit metropolitan area may not introduce sufficient workload to determine the value or limitations of NVG viewing. Gusty winds will increase the workload. A decrease in visibility will also increase workload. You may or may not be taxed by the demands of this cross country profile under the conditions which occur on the night you fly. We may need to introduce more workload or stress to obtain data which will allow conclusions to be drawn as to the suitability of wearing goggles on civil VFR flights.

EVALUATING HIGH WORKLOAD SITUATIONS

We all know that helicopter VFR cross country night flying in a UH-1 is a non-demanding, routine task under most environmental conditions. What we need are situations were there is some stress. Stress produced by the environment or by a failure of some sort. We have already touched on the idea of evaluating operations following the failure of an attitude indicator. This is probably one of the best failure modes to consider in that it is a failure which is both possible and probable. To simulate such a failure, the pilot may cover up the indicator. You would rate the flight control task unaided and then aided by NVGs.

The safety pilot can introduce even higher levels of stress by asking you to conduct a more difficult task. For example, he may ask you to close your eyes for a brief period while he maneuvers the aircraft into a descending 30 degree banked turn. You would then be asked to open your eyes and return the aircraft to level flight. This task would be accomplished under the two principal conditions introduced above; night unaided and night aided. [NOTE: The first task with the attitude indicator covered was to simply maintain a steady heading from City A to City B. The second task involving higher stress is to recover from the banked turn.] The recovery task should involve seconds or a few minutes. It is a brief task compared to the first task which involves a longer period (of less difficult flight) of the wings level, en route operations. They are different tasks, but both are important.

When you are asked to provide an evaluation rating, it may be helpful for you to ask yourself to:

(1) Identify the critical sub-task that produced the rating, and

(2) Explain why this subtask was the most difficult (this will lead to the identification of difficult visual conditions, difficult flying qualities, etc.).

The answers to the above questions will often help you select a rating from the narratives in the rating scales.

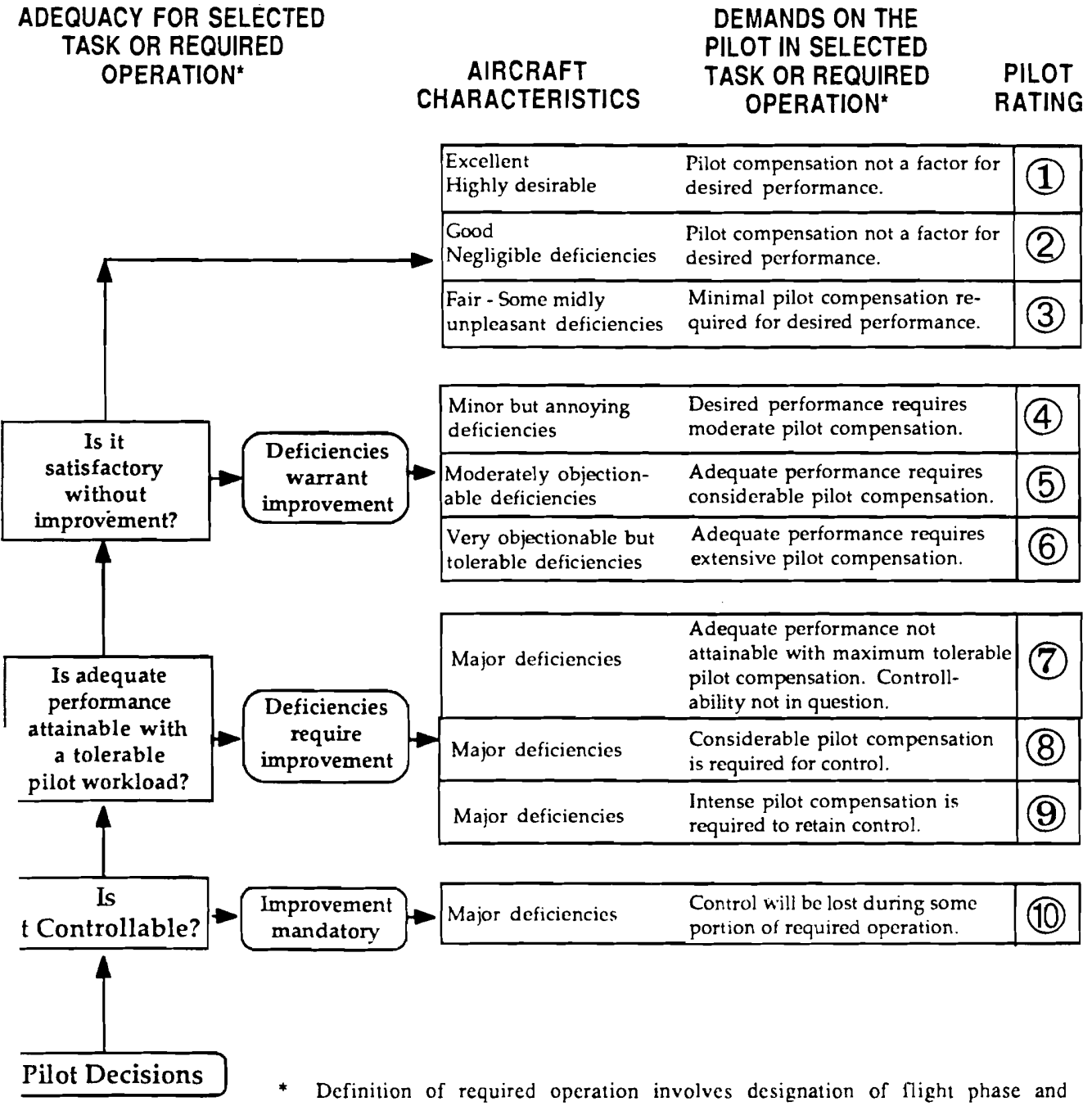
PILOT RATINGS DEFINED

Subjective evaluations such as the ones planned for this program typically employ pilot rating scales. While these scales have been used for years, their use has not been entirely without criticism. The principal shortcoming of the use of these scales has been the scatter in the subjective data which sometimes appears when a number of pilots are ask to evaluate a given task-aircraft combination. There are mathematical ways to smooth or discount this scatter, but this evaluation team desires to minimize the scatter via the use of an improved rating process to be explained in the following pages.

The most popular pilot rating scale is referred to as the "Cooper-Harper Pilot Rating Scale" (see Figure 22). With ratings ranging from 1 to 10, it is the basic scale for most aircraft flying qualities research work accomplished today. This is an excellent scale, supported by forty or more years of experience, but it lacks the detailed definition required to minimize the scatter to the desired levels. An evaluation which is as specific as this one, allows us to add definition to the ratings.

It is important to understand that the scale in Figure 22 is meant to cover the entire range of possibilities which an aviation test activity might elect to evaluate. The range of this scale extends beyond the scope (or needs) of this evaluation. For example, should you, as the result of a personal experiences during an evaluation flight, select a rating of "10" (see Figure 22), this would be interpreted as meaning that somewhere along the way you lost control and the aircraft crashed. You will not be given an opportunity to crash during your two flights. That is, the nature of your VFR, en route, tasks, by definition precludes the possibility that you might encounter a situation which you felt obligated to rate a 10 or even an 8. If you find a significant flaw in the NVG operations which you participate in, you will have ample opportunity to report this finding without the need to use a pilot rating.

You may experience a situation in this test program which you evaluate and conclude should be assigned the rating of 7, but even 7s should be rare. A rating of 7 means that you were still



* Definition of required operation involves designation of flight phase and subphases with accompanying conditions.

FIGURE 22: THE COOPER-HARPER PILOT RATING SCALE

in control, but you were working as hard as you could, and the resulting performance was inadequate. It may also mean that you were working so hard to control the aircraft (because of extreme turbulence) that you didn't have enough time remaining to look outside to locate and identify your objective (a visual way-point). Alternatively, it may mean that you had to work so hard to conduct a ground search (maybe at a lower than prescribed altitude) that you didn't have enough time left to fly the aircraft to stay within tolerable deviation limits in attitude, airspeed, altitude or heading. In this case, you would probably have had much less difficulty controlling the aircraft if you had not been required to conduct an "eyes-out" search for an objective on the surface. Which should come first? Looking out or looking in? We will treat this issue shortly.

At the other extreme of the scale, pilot ratings of 1 and 1.5 are reserved for highly automated flight control systems and/or extremely relaxed tasks. The UH-1 does not have an automatic flight control system, thus a rating of 1 or 1.5 is not applicable to this evaluation. In summary, you are likely to assign ratings which range in numerical value between a minimum of "2" to a maximum of "7" or "8".

In Figure 23, we find a scale which has been expanded to meet the needs of the FAA for the evaluation of Night Vision Goggles during civil rotorcraft operations. It does not include ratings above 8. As explained above, this range is sufficient to define conditions which are of interest to the FAA.

When you compare the scale in Figure 22 to the scale in Figure 23, be advised that they are the same scale. The words in Figure 23 are meant to expand upon the words in Figure 22. They are intended to provide pilots with a better understanding of the meaning of the very brief statements in Figure 22.

We do not require you to commit the scale to memory, but we would appreciate an effort on your part to develop an awareness of the scale. You will be allowed to look at the scale during the debrief period following your flight, at this time you will rate your experiences.

1.0	From time to time, the pilot may instruct the autopilot. System achieves long and short term objective with no pilot input directly to the conventional flight controls; inputs are selected via secondary (electronic) controls. The quality of flight path performance is self-monitored and alerts are provided to the pilot when he needs to take over; first and second failures are fail operate. Automatic mode shifting is provided (i.e., cruise to glideslope or glideslope to go around).
Excellent Highly Desirable	
1.5	From time to time, the pilot may instruct the autopilot. System achieves long and short term objective with no pilot input directly to the conventional flight controls; inputs are selected via secondary (electronic) controls. The quality of flight path performance is self-monitored and alerts are provided to the pilot when he needs to take over; first failure is fail operate: second or third failure one fail passive. Pilot is required to make occasional long term trim adjustments in one or two controls during transitional flight or during mode shifts.
2.0	System achieves long term and short term gust suppression objectives with little or no pilot input directly to the conventional flight controls; inputs are often accomplished via secondary (electronic) controls. The quality of flight path performance is self-monitored and alerts are provided to the pilot when he needs to take over. Monitoring of short and long term response continous but relaxed. Pilot may be required to occasionally adjust one axis/parameter during the performance of precision maneuvers or during major flight path changes.
Good	
2.5	The pilot is continually involved in monitoring the short and long term performance of the aircraft. Deviations develop slowly and in a predictable way, and can be eliminated quickly with relaxed control techniques. Errors generally develop along or about one axis at a time.
3.0	The pilot is continually involved in the short-term control of the aircraft. Two or more controls are typically displaced in a sequential pattern. The aircraft can be trimmed with no more than one parameter/control needing attention at any given time. Control techniques are relaxed and pilot compensation is predictable and easy but requires continuous involvement.
Fair, Some Mildly Unpleasant Characteristics	
3.5	There is a characteristic that occasionally requires heightened attention, potentially disrupting the pilot's scan or control technique and momentarily taking precedent over other tasks. The aircraft is just a bit less predictable, possible because of problems trimming or due to an inconsistent response to gusting winds.
4.0	Moderate pilot compensation is required. For relaxed flight phases, the control activity required is clearly achievable, but the effort produces impatience with the task and fatigue. Adjusting one control may require adjustments in other controls. For precision tasks, the workload contributes to occasional errors and excessive deviation.
Minor, But Annoying Characteristics	
4.5	Moderate pilot compensation is required to achieve desired performance. There are one or more clearly annoying characteristics that make relaxed control clearly unachievable. On occasion, the desired performance is not achieved without considerable pilot compensation.

FIGURE 23: EXPANDED DEFINITIONS OF PILOT RATINGS TO BE USED FOR EVALUATIONS OF CONTROL SYSTEMS

5.0		Considerable pilot compensation is required to achieve adequate performance. For cruise, the control activity required is clearly achievable, but failure to stay attentive may result in the need to recover from an unusual flight condition. In precision tasks, the pilot is not pleased with aircraft performance and, if given the option, would probably fly slower/faster, etc., to improve performance. A pilot would not routinely plan to depart on a flight involving this level of effort.
	Moderately Objectionable Characteristics	
5.5		Adequate performance requires almost total involvement in the flight-control task. Failure to stay attentive will probably result in an unusual attitude. The pilot is confident about performing single flights under this workload, but would not routinely plan to fly an aircraft requiring this workload. If encountered unexpectedly, the pilot would not expect to fly at this level of effort for more than 15 minutes during precision tasks or 120 minutes during non-precision tasks.
6.0		Extensive pilot compensation is required: The pilot is totally involved in control task, scan rate is at its limit, and pilot is moving two or more controls continuously. The pilot is alarmed and expects to experience periods where performance represents marginally safe flight. Pilot would not willingly fly at this level of effort for more than 10 minutes for precision tasks or 60 minutes during non-precision tasks.
	Very Objectionable But Tolerable Characteristics	
6.5		Extensive pilot compensation may not yield adequate performance. Workload is so high and performance is so marginal that the pilot would not continue to pursue the task unless there were no other alternatives. In the landing task, the aircraft will probably experience minor damage, without crew or passenger injury.
7.0		Adequate performance is not attainable with maximum tolerable pilot compensation. Gross control of the aircraft is not in question, however, if the pilot persists at this level of workload, the safety of the aircraft is clearly in question. In the landing task, the aircraft will receive damage and there may be personal injury.
	Unacceptable Performance Characteristics	
7.5		Maximum achievable pilot compensation will not produce adequate performance; even for brief periods. Gross control of the aircraft is sometimes a concern. If the pilot persists, performance will deteriorate due to fatigue, and the aircraft may receive serious damaged. Personnel are at serious risk.
8.0		Adequate performance is clearly unachievable with maximum pilot compensation, even for short periods of time. Considerable pilot compensation is required to retain control and transition to a less demanding task. The ability to transition out may be in question. Crew is at risk but will probably survive.
9.0	Unacceptable Control Characteristics	Adequate performance is clearly unachievable. If the pilot persists, gross control of the aircraft will probably be lost for brief periods and then regained. Maximum achievable pilot compensation may not be adequate to transition to a less demanding mode of flight. Crew and passengers will probably survive with injury even if the aircraft is lost.
10.0		If the task is attempted, control will be lost and probably never regained in time to return to normal flight. Such events typically result in a catastrophic loss of the aircraft.

FIGURE 23: EXPANDED DEFINITIONS OF PILOT RATINGS TO BE USED FOR EVALUATIONS OF CONTROL SYSTEMS (Continuation)

THE RATING PROCESS

RATING A NIGHT FLIGHT TASK

You will be asked to rate several flight tasks. This duty will be accomplish on the ground as a part of your post flight evaluation debrief. Let's review a hypothetical case to see how this process might work.

You are ask to rate a task, something you accomplished in flight. It had a beginning and an end. There were environmental factors, and task objectives (expectation). Finally there were observed results (performance and workload). Think back to the event.

Assume the task may have included a requirement for you to look outside and observe features on the earth's surface. This visual scan task may have been easy or it may have been difficult. Visually finding the lights of Atlantic City should have been an easy task. Identifying a specific set of buildings on a small island might have been a very difficult task, requiring a lot of "eyes-out-search" effort.

Before attempting to assign a rating; think, were you successful in your effort to detect, identify and retain or follow the landmark or series of landmarks involved in the task? This question will often get a "yes" or "no" answer. Or maybe you found some, or a few. We need to know how you judged your performance. Maybe you didn't see everything you wanted to, but you found a sufficient percentage of your objective landmarks to convince you that you were on your pre-planned track. This means that you adequately accomplished your contact navigation subtask.

Next, while you were attempting or accomplishing your navigation eyes-out subtasks, how difficult was it to fly the aircraft? You must refer to the rating scale (Figure 23) and select the numerical rating which best explains your effort level and your performance.

Dry Run: Now we will explore a hypothetical situation involving the evaluation of a flight task, aided and unaided, under three different environmental conditions. Return to page 39 and read the discussion there about how you might be required to evaluate your ability to recover from a banked turn, with and without NVGs. Assume now that you have conducted this task with the NVG's off. You were ask to accomplish this task at three locations in the operating area. The ambient lighting, surface lights and turbulence experienced at each location is substantially different. In "Situation 1", you were over a large, bright, city area, in smooth air. In "Situation 2", you were in an area where the surface is dark, and the horizon is very weak (almost nonexistent) with the exception of the horizon line provided by the lights of a distant small town in a single 30 degree quadrant of your 360 degree horizon. Again, the air mass is smooth. In "Situation 3", you had proceeded to the far edge of the operating area, and there was no horizon line through 360 degrees (to the unaided eye). There were a few surface lights for flight reference but no distant departure line between the surface and the sky, defining the horizon. [NOTE: Remember, the UH-1 responded to the turbulence because it is a lightly damped aircraft which does not incorporate an attitude retaining auto pilot.] This means you had to provide compensation to suppress gust upsets. You had to spend more time in the aircraft control task than you did while flying in the smooth air of Situation "1" and "2".

Now back to the task. The task involved you opening your eyes, recognizing the direction of turn or bank attitude and initiating a recovery by starting to roll out. How did you determine your situation? Did you look outside or did you look at the instruments? When you looked outside, did you use the horizon line? Did you use it as a flight reference? Did you see lights going by as you turned? What did you see? How long did it take? Were you "ill-at-ease" or comfortable with this task? The answers for aided flight and unaided flight may vary. That's OK.

After completing both aided and unaided flight, you should spend a few minutes (as soon as possible) to write down your recollection of the factors defining the environment within which you operated. In the example, we were considering here, you would have written down three sets of environmental factors. One for each "Situation". Having recorded this data, you should have next looked at the rating scale provided in Figure 23. You looked for the words which best described your recollection of the event. [NOTE: If all but one characteristic (in a given definition) was met, you should go to the next highest numerical rating. In other words, if 3 almost matches but doesn't quite, assign a rating of 3.5.]

It is obvious that the environment will change from night to night and area to area. In this case, the operating area is a constant but the ambient lighting from the sky and the city will change with the time of night, the passage of weather and the phase of the moon. Each pilot like yourself will look at somewhat different set of characteristics. The FAA test team has a method which will allow them to correlate all of this data, but their ability to do this depends on you observing and reporting your impression of the visual world and other environmental factors that contributed to the definition of the task you evaluated as a reference. It is important for you to define the factors which you observed to be variables. Turbulence, head wind vs. tail wind, characteristics of the horizon line, are potential variables. They are the parameters of the test which change from night to night, location to location (in the operating area) and the time of night you make your observations. We look to you to note and help us identify and report the variables which you felt were important to you. You might make a series of notes which follow the example provided in Figure 24.

	Pilot Assessment Ratings	
	Unaided	Aided
SITUATION 1: -900 Feet -Bright City, 360 degree horizon reference -Calm Air		
SITUATION 2: -500 Feet -Town lights, 30 degree sector -Calm Air		
SITUATION 3: -500 Feet -Dark Horizon -Turbulent Air		

FIGURE 24: RECORD THE ENVIRONMENT AND ASSESSMENTS

For Example:

Task:	Level Flight at a minimum of 700 ft AGL, constant pressure altitude of ± 100 ft, following interstate highway at 90 knots indicated airspeed.
Aircraft:	UH-1H
Aircraft State:	Failure Mode (Failed Attitude Indicator)
Aircraft Configuration:	No External Equipment, Doors Closed, External Lights (defined) on, Internal Lights On. Center of Gravity, Mid Gross Weight, etc.
Environmental Constants:	Pressure Altitude, OAT, Visibility

FIGURE 25: CONSTANTS DURING THE EVALUATION

It will also be important for you to help your safety pilot document the task you are rating, the Aircraft Configuration, Aircraft State and the environmental constants. The notes outlined in Figure 25 will give you an idea of what this involves. Your safety pilot will do this for you, but he will also let you make inputs.

Your voice comments will be recorded during the flight, so feel free to make observations over the ICS at anytime. Also, you can ask the crew to take notes if you want. Its your flight, but we need to know what impacts you. This information is very volatile, so notes are important to help you and us remember what happened once the flight is history.

APPENDIX A

ANVIS AND HUD: A WINNING NIGHTTIME DUO

Pilot Report

ANVIS And HUD: A Winning Nighttime Duo

Testing night-vision goggles with and without headup display, we travel from Virginia to Arizona, and transition from a van to helicopters.

By David Green

FLYING WITH pilot night-vision goggles (NVG) has become routine, but many experienced pilots see room for improvement. One suggestion is to combine NVG with a headup display (HUD). This small electro-optical system superimposes flight, weapons, and other sensor data on the night intensified image (I^2) of the NVG, or ANVIS (aviator's night-vision system).

I explored that concept by:

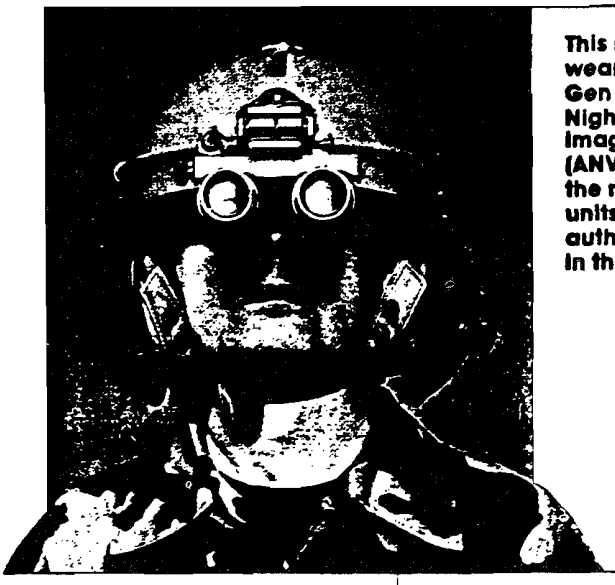
- Conducting a nonflying field evaluation, using a HUD installed on Gen 2.5 ANVIS and a van in the hills of Virginia. The NVG-HUD was from Israel's Elbit Computers Ltd.
- Flying a McDonnell Douglas MD-500E to observe both the characteristics and limitations of flying with NVG, I used a Litton Gen 3 ANVIS, but no HUD.
- In a Boeing CH-46E, flying with an NVIS-HUD made by Systems Research ıboratories Inc. (SRL).

In approaching the NVG-HUD subject, I pped from various experiences. My night-ne flying has included ship landings. I flew e AH-64 Apache at night, using the Martin arietta pilot night-vision system (PNVS), ıth FLIR and HUD images presented on e Honeywell integrated helmet and display ghting system (IHADSS). I also flew FLIR ıad-down in the Sikorsky HH-60D Night awk prototype, and took occasional peeks rough night-vision goggles as they evolved. nave, incidentally, 20:20 vision beyond 18 ches (48 cm).

hat I found

I unearthed from my research the llowing:

- Transitioning to Litton's Gen 3 ANVIS ıs faster than expected. Near surface vegation during hover and slow-speed flight, I ntrolled the 500E easily.
- Scanning far right and far left to spot ıtential obstructions during nap-of-the-rth (NOE) flight is paramount, but reıires discipline and greater pilot workload.
- Looking under or around the ANVIS to ew instruments is relatively easy, but still ı added task for pilots who must scan ıadup for weapons delivery as well as safety.
- The ANVIS-HUD combination holds ıdless possibilities because of the CRT-mpatible images that can be presented.
- The SRL system made closing the loop ı altitude easy, and allowed data to be read ith less deliberate scanning than ıticipated.



This soldier is wearing Litton's Gen 3 Aviator's Night-Vision Imaging System (ANVIS), one of the night-vision units discussed by author David Green in this pilot report.

I was introduced to the Elbit system on an autumn night in the Appalachian foothills. Jim Jarocki, Elbit's rotary-wing system marketing director, equipped his van with a power supply and small computer programmed to exercise the HUD's symbol generator. We drove away from the Washington, D.C., lights for an appropriate environment.

Using its bayonet mount, Jim snapped the HUD display assembly onto the side of the image intensifier for my "dominant" right eye. (It can also be attached to the left intensifier.) This CRT projects display data into the front of the objective lens.

I viewed several HUD formats by pushing switches on the computer that drives the HUD's symbol generator. Computer outputs coordinated various aircraft parameters that could alternately simulate both stabilized and dynamic-maneuvering flight. They simulated outputs from a radar altimeter, airspeed system, heading and attitude gyros, main-transmission torque, navigation system, flight-director computer, and fire-control computer. With this simulation, I could select accelerations and decelerations in cruise and forward-flight attack modes, as well as observe slow-speed and hover operations.

Along a farm road, I looked out over a pasture and at some trees and a farmhouse on a ridge. A small light near the barn shined through the trees. The sky was covered by a thin overcast, and there was no moon and only a few stars.

With the ANVIS focused at infinity, I decided to keep the horizon line aligned with the crest of the ridge about a mile away. As the display's pitch ladder started to elevate and rotate, I rotated and pitched the goggles to keep the artificial horizon on the ridge line. This made the programmed changes in torque, speed, altitude, etc. more meaningful.

I even turned (yawed) right and left to follow heading changes. This was as close to observing the HUD in flight as I could expect without a helicopter. I liked the results.

I also adjusted HUD intensity while looking at areas with different illumination levels. I looked at the farm light with low HUD intensity to see if a halo effect interfered with the symbology. I viewed objects and considered the tasks of detection, identification, and targeting. Finally I looked at nearby objects such as trees, and considered the task of flying NOE and hovering above the trees.

I liked the pitch ladder, a single bar with a numeric symbol under the display's right side to quantify pitch attitude. I would, however, have preferred a larger size numeral.

I also liked the roll-bar angle marks and roll pointer at the display's bottom, and the large digital presentation of heading directly

above the aircraft symbol.

But I would relocate the radar altitude to the primary (center) scan area for low-altitude flight. A power reading during hover or slow-speed operations and numeric data for, say, target range should also be easy to see. A clear display center is nice, but when all data is pushed to the side, a pilot must continually scan the display.

Another matter: with the ANVIS objective lenses set for infinity, I had to focus my eyes "in" slightly to clearly see the HUD symbology. Though HUD data was readable, the alphanumeric data was not real sharp. Both Elbit and other engineers assured me that this characteristic can be improved via an adjustment.

Regardless, the Elbit HUD's projection was readable and didn't degrade NVG performance. And, it was surprising just how much data could be displayed.

Also, all data lines were straight, and data changes (quantity and position) were smooth and continuous. The number of alternate formats were sufficient, declutter modes were logical, and the HUD-intensity range was more than adequate.

In short, the demonstration proved that HUD data can be overlaid on an I^2 display without degrading the ANVIS's utility.

Off to Phoenix

A few weeks later, I traveled to Phoenix. I spent an hour in a night-vision trainer, and two hours flying a MD-500E with the Litton Gen-3 ANVIS.

In a domed simulator at McDonnell Douglas Helicopter Co. (MDHC), I practiced scanning and flight techniques using ANVIS. The cockpit incorporated a 4°-of-freedom right-hand sidearm controller. Its vertical displacement changed altitude; twist control, yaw; and longitudinal and lateral displacements, and speed. With all this stability-and-control augmentation, *flying* was no challenge.

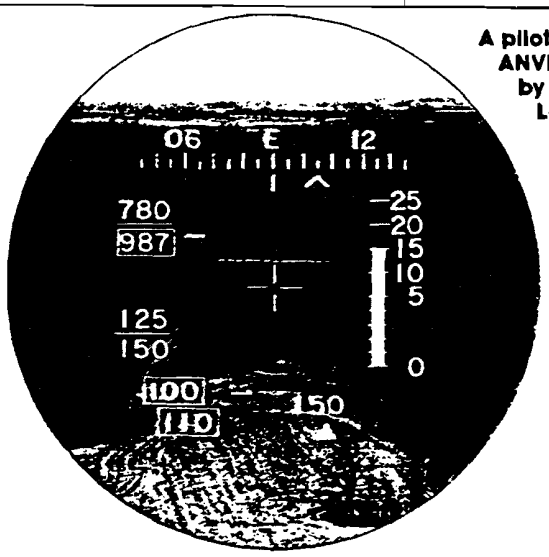
My night-vision task was limited to scanning the "outside world" through what looked to be a 40° field-of-view tube. This useful first step lasted about an hour, and thanks to John Kiselyk and Ed Currier, it was a great learning experience.

Interestingly, the simulator's visual projector followed my line of sight. As I moved my head, the Polhemus head tracker tracked my line of vision, and a high-resolution image was projected on the dome surface precisely where I was looking.

This head tracker could perhaps be used to point weapons or a pilot night-vision FLIR (forward-looking infrared) system.

Light won't amplify

After lunch, Gene Adcock (my host from Litton Electron Devices) briefed me on I^2 at the company's plant in nearby Tempe. Among other things, I learned that a common focal distance for the HUD image and I^2 image could be achieved. I wouldn't have to focus in and out for each image.



A pilot using an ANVIS-HUD designed by Systems Research Laboratories (SRL) will see this type of night-vision image, with flight and navigation data superimposed within the NVG's field-of-view.

I also learned that no one knows how to amplify light. Instead, NVG converts available light to electricity and amplifies the electricity. And this must be done continuously for about 2 million points (on the objective lens) to develop an intensified image at the pilot's eye.

The Gen 3 units operate well when the area viewed is illuminated by only starlight. But all night-vision goggles *do* require at least some light.

I then met my instructor pilot, George Ross. After another short brief, he showed me how to adjust the ANVIS—an uncomplicated and quick process.

Ready to fly

I first adjusted the goggles downward, placing the eyepieces in front of my eyes. With the lights turned off, I adjusted the distance between the two optical housings, so that the two overlapping images became a single, circular image.

Next, I brought the goggles closer to my eyes. I set both lenses for infinity and then adjusted focus for each eye by rotating the eyepieces. Finally, I turned off the batteries, flipped up the goggles, and removed the helmet for the walk to the aircraft.

We flew a fairly new 500E (N369HH). It had an unboosted, mechanical flight-control system, with no electronic augmentation. The aircraft is easy to fly, but doesn't fly itself.

George made some modifications to an otherwise standard 500E. For NVG flying, he taped over the LEDs and placed a blue-green glass filter over a cabin floodlight, which showered the instrument panel with what appeared to be white light.

The flight started from MDHC's flight facility in Mesa as the last glow of Arizona sun faded in the west. I was in the right seat with ANVIS operating, as George steered the 500E to the Goodyear Memorial Airfield, which is usually vacant at night.

Too much data?

Initially, we flew at 1,000 feet AGL over Mesa. I alternately looked through and under the ANVIS to compare the I^2 image with naked-eye viewing. Through the ANVIS, traffic lights were clearly visible for miles, distant mountains were sharply outlined by starlight, and details like orange-tree rows were easily recognizable.

In some ways, the ANVIS provided too much data, much more than I am accustomed. Without goggles, my eyes saw only close-in air traffic, and not mountains, fields, and houses. This, however, made landmarks like a hospital and rotating beacon easier to identify. I obviously wasn't trained to interpret I^2 data, but conclude that images from the unaided eye and ANVIS complement each other, and are more valuable than either individually.

Certain strong lights caused a "blooming" or halo effect through the NVG. A light essentially overdrives the ANVIS amplification process at one point. Both light intensity and color can create these halos.

Slow-speed flight

Goodyear Field was a safe place to experiment. I only had to avoid the ground and sage brush on either side of an old, cracking blacktop runway.

George conducted the initial approach to a hover. I was slightly disappointed; I could see too well. But after tilting my head back to use my naked eye, I found I couldn't see a thing.

We were operating in a "10% ambient light" environment. A full moon overhead equates to 100% ambient light; quarter moon, 25%; crescent moon, 20%; and starlight alone, 10%.

The ANVIS image is clear, but has a sparking texture, as if fine aluminum particles were swimming in a thin emulsion. This, according to George, comes when light levels begin to be inadequate for goggle operation.

While I observed, George started flying in ground effect (IGE), and made several landings and takeoffs, while I adjusted my depth perception. I also developed a scanning (head-swiveling) technique, but quickly observed the difficulty in looking cross-cockpit, past George, to conduct left sideward flight.

Uncomfortable hover

Taking the controls, I eased the machine into a five-foot hover, but quickly discovered I couldn't determine height over the smooth black runway. So, George estimated height,

(Continued on Next Page)

while I adjusted my depth perception. Eventually, I calibrated two heights fairly well—five and 20 feet—and then confidently performed slow-speed maneuvers.

Takeoffs and landings were no problem, because the pilot's eye height in the 500E is relatively close to the surface. I looked straight ahead for my roll, heading, and pitch attitude cues, while viewing surface textures directly ahead to control longitudinal and lateral translation.

I was, however, less comfortable in hover. I was doing something wrong. I swiveled my head right for a cross reference, but that wasn't the solution.

As hover altitude increased, I had difficulty simultaneously concentrating on two sets of cues: the distant horizon cues (upper portion of the field-of-view) and surface cues (lower portion). After several minutes, I learned to scan between the two.

To facilitate this scanning, I adjusted my head, placing the horizon at the top third of the ANVIS display, and surface cues in the lower third. With head angle fixed, I could observe both sets of cues by raising and lowering my eyes (line of sight). A winner. Adding an occasional side-to-side head movement, I was on my way.

I scanned back and forth at roughly ±45° in azimuth to determine a clear flightpath, then performed slalom-type maneuvers up and down the runway. I probably never exceeded 10 knots groundspeed.

Low moon angles

Just as I was getting comfortable, the moon started to rise, introducing another factor. It has quite a visual impact.

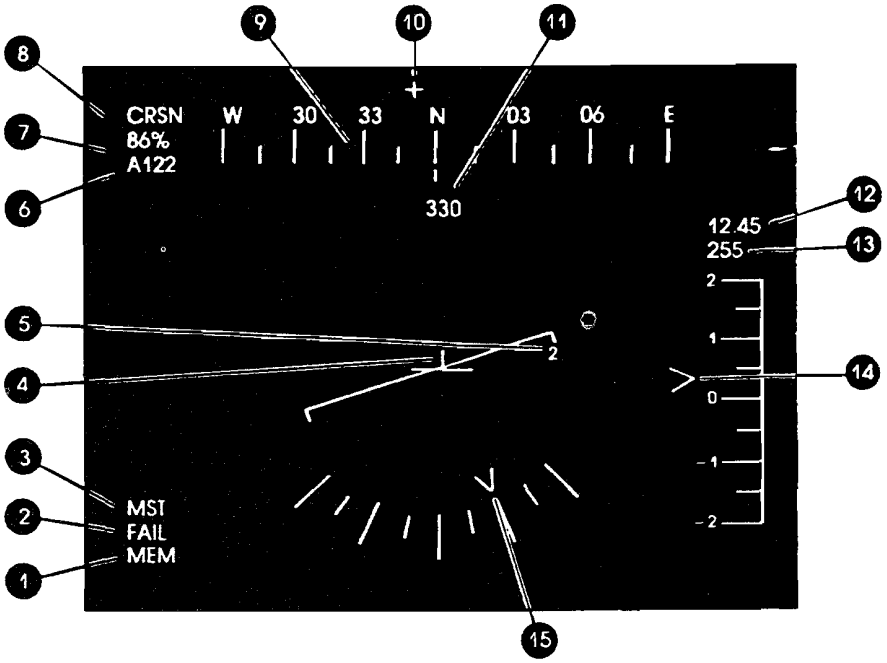
When the moon came into the ANVIS field-of-view, it blackened a portion of the display, and terrain details deteriorated. How come?

The moonlight causes the NVG's to close out light, to reduce brightness, much like the diaphragm on an automatic camera. So I didn't look at the moon. I looked under it, only briefly, and to either side of it, which worked fine for turns on the spot.

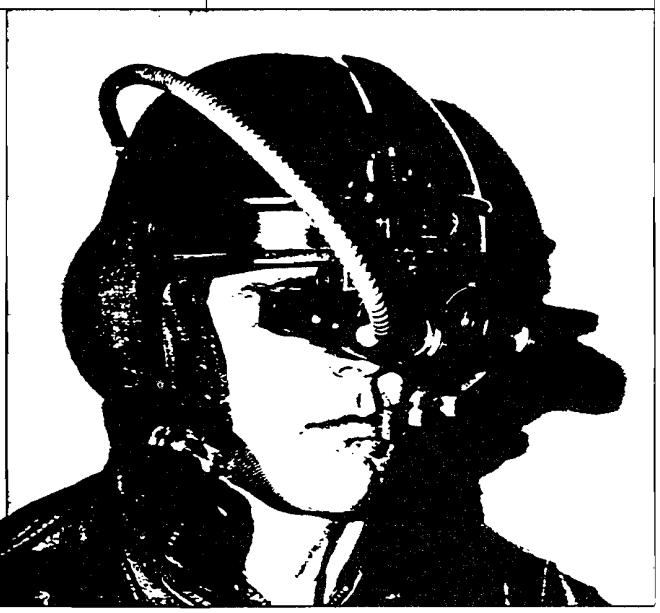
I viewed the instruments by either tilting my head back to look under the ANVIS, or having my left eye look around the left eyepiece at the center pedestal.

Tilting my head was somewhat uncomfortable, but the look-around-the-side technique worked well. Thus, it would seem that the center-mounted instruments in aircraft with glass cockpits would have the same utility for NVG flying as the 500E center pedestal.

Elbit's HUD Symbology During Normal Cruise



1. Doppler in memory state
2. NVG-HUD malfunction
3. Master caution malfunction
4. Center field-of-view
5. Pitch attitude (bird and digital)
6. Velocity (knots)
7. Torque
8. Screen title (cruise normal is shown)
9. True heading
10. Steering indicator
11. True heading (digital)
12. Distance to destination (kilometers)
13. Barometric altitude (feet)
14. Climb rate
15. Roll attitude



SRL's ANVIS-HUD uses a fiber-optic cable that delivers the HUD image to an integrated combiner. Fitted on the NVG lens, the combiner overlays the HUD's amber symbology over the NVG image.

George suggested we fly a pattern, which meant checking speed and power, as well as above-ground altitude. Needle ball? Are you kidding? I had problems.

Pattern work

I tried to push over and increase torque, but couldn't find the torque gauge, and then airspeed. I discovered altitude, but was somewhat intimidated by the longitudinal cyclic control force, which was greater than expected.

I tended to look down when initiating a nose pushover, thus losing horizon and surface cues. It was impossible to judge pitch attitude. I could have used a pitch-attitude indicator while accelerating into forward flight. Finally, with George's encouragement, I got the nose over, accelerated to 80 knots, and leveled off at 300 feet on the downwind leg.

The turn downwind was uneventful because the horizon lighting provided a strong horizon reference for roll and heading control. I initially had trouble finding the runway, however, because it was between me and the moon. I also had to look over the instrument panel from the right seat.

Nevertheless, I eventually detected the runway out of the desert background as an oblong black blob. The approach was normal and hover was stable; I didn't attempt to fly below the earth's surface.

During a second flight around the pattern,

I even found the needle ball. My only challenge was to improve my scan technique while turning through the moon line, and find the instruments.

After the second approach, George took the controls and we headed northeast of Phoenix to a landing site near Sawak Mountain. He had something more difficult in store.

Illumination

We sometimes switched on the running lights. The left red light illuminated a small area left and forward of the aircraft, which I could see from the right seat. The right green light was invisible.

For military helicopters with red cockpit lighting, this could be perilous, because enemy aircraft with image intensifiers can spot you.

For civil helicopters, red light can enhance the ANVIS's usefulness. Searchlights, landing lights, etc. with a red filter could provide illumination. Lasers might be employed to spot wires. Also red lighting could illuminate surfaces and obstructions around heliports.

But you still need a HUD for safe flight through and out of inadvertent IMC (instrument meteorological conditions). I was taught to fly with my head in *or* (not *and*) out of the cockpit, so as to not look at the wrong place at the wrong time.

Wire detection

En route, George purposefully approached electrical transmission lines to demonstrate wire detection and avoidance. We were about 200 feet AGL, with the moon at our two o'clock. I could see large towers several miles away, but no wires.

We descended and turned right after crossing the towers, and for a few seconds, I could see the wires, maybe a half-mile away. Then poles and wires evaporated—just disappeared.

We continued to turn and descend. A few seconds later I saw the towers again, as well as several smaller wooden power poles. At this point, George said the moon elevation angle was about 40°.

Next came the night's big surprise. While looking down in our extended turn, a second massive power-transmission system flashed into sight directly beneath us. We had flown above and parallel to this system without knowing it.

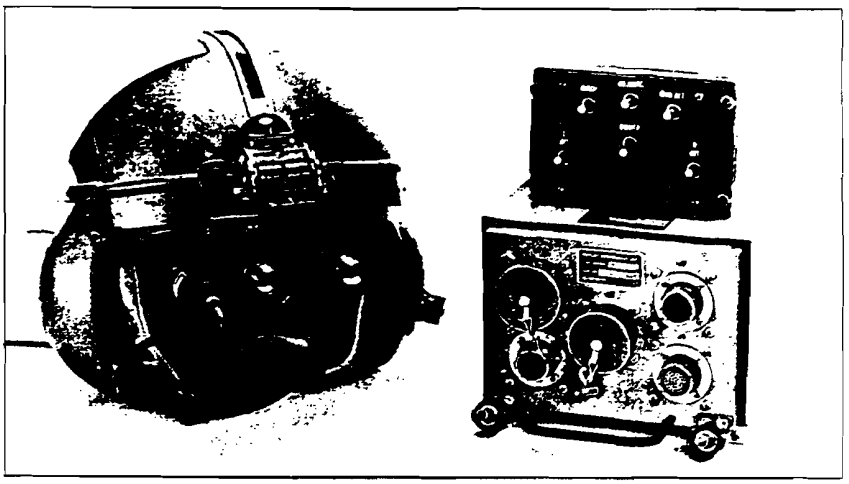
After considerable concentration, with the moon behind me, I could identify the steel towers. They were difficult to see, and they soon disappeared, even though I could see the terrain in detail. This experience, George indicated, demonstrates that moon angles of 70° to 90°, and from over the shoulder, produce the best wire-detection capability.

Sawak Mountain

From time to time, I looked out from under the ANVIS to check how dark it really was. Even with the moon inching up, the terrain lacked suitable definition for flight with the unaided eye.

At the Sawak Mountain landing site, six to eight tire casings were laid in two rows to define a landing area. George landed between the tire rows, and relinquished the controls.

Honeywell's NVG-HUD



Honeywell's ADSS generates flight data symbols for display on an NVG image.

In addition to Elbit and Systems Research Laboratories, there is a third supplier of night-vision-goggle/headup-display (NVG-HUD) units, Honeywell Inc.

The company's Defense Avionics Systems Division, in Albuquerque, N.M., has developed a "retrofit enhancement" for night-vision goggles called the ANVIS Display Symbology System (ADSS). This carry-on, 5-ounce (.14-kg) HUD is mounted on either side of the ANVIS.

The pilot controls Honeywell's ADSS via a control panel that allows him to select program and mode, adjust heading and pitch, select low-altitude warning values, and alter display brightness. Symbol generation is performed in software compatible with the aircraft in which the system is being installed.

The ADSS display is driven by a processor that interfaces with the aircraft systems bus and sensor assemblies. All ADSS symbology is based on Mil Std 1295; the Army Helicopter Improvement Program (AHIP) and Bell Helicopter Textron specification 406-947-317A was used to derive scale factors not specified in 1295.

Although there were fewer cues during landing and takeoff (no more runway cracks), I started to get comfortable with NVG flight. The sage brush and tall Saguaro cactus cast long, dark shadows, which when flying across, gave a good feeling of speed and texture.

> While looking down in our extended turn, a second massive power-transmission system flashed into sight directly beneath us.

I ventured among the brush with confidence, until George reminded me that Saguaros can get up to 30 feet (9.1 m) tall. I more cautiously started to follow a snaking path, flying back and forth across the moon line while heading toward the moon.

Getting NOE scanning under control, I made a sweeping turn to the right without first looking right. There I was, face to face with a granddaddy cactus. A lesson learned: the narrow field-of-view takes away the peripheral detection of obstacles. One must continually swivel the head.

Off again, we flew into the shadows of peaks and ridges. (Flying into large shadows, I believe, has contributed to several NVG accidents. Loss of illumination apparently delivers loss of definition.)

Particularly precarious would be low-level flight over a shadow made by a low-angle moon. The direct light would shut down the goggles and diminish a pilot's depth perception. The solution would be a radar-altimeter display in an ANVIS-HUD.

Over water

George and I next followed the Salt River to a small lake for low-level, overwater operations. It didn't work out.

When the moon reflects brightly from the black glassy water, a radar altimeter is required. Flying low-level, you must regress to either a head-in instrument scan or headup display that presents altitude—and speed if you're hovering.

So, we turned to a large, dry creek bed, which offered little ground definition. Also, the surrounding long, inclined ridge lines diffused the horizon, much like clouds do at night at sea. I could see the need for a headup horizon bar.

Hovering over tree

With two hours of ANVIS time and about one hour of stick time, I felt quite comfortable. I proceeded by flying over an about 20-foot (7.6-m)-tall tree. The trunk was dark and small leaves were white. At about 30 feet AGL, I flew a light circle around the tree, as if positioning for a sling extraction.

(Continued on Next Page)

For cues, I looked down through the right-door window. The tree completely filled the goggles' field-of-view.

I wanted to see if I could conduct such a task while looking down and right for an extended period (several minutes or more). I was surprised. I accomplished this task as if in bright daylight.

On to Quantico

From Phoenix, I went to Quantico, where I was hosted by Maj. Jonathan Vizina, operations test director and chief of Marine Helicopter Squadron 1's (HMX-1's) operational test and evaluation (OTE) section. A two-hour brief included HMX-1 experiences with ANVIS-HUD over a two-year period. The squadron uses SRL and Honeywell equipment.

I flew using an SRL system, so I was also briefed by Jerome Wysong, SRL's night-vision-HUD product manager.

Actually there were two SRL configurations available: one that transfers CRT-generated symbology from a black box to a combining glass mounted in front of a single objective lens, and one that transfers the CRT symbology to an NVG. SRL is currently producing the first model for the U.S. Air Force, for its Pave Low III helicopters and other aircraft. It is based on a concept developed by Dr. Lee Jask and a program managed by Jeff Craig; both are at Harry G. Armstrong Aerospace Medical Research Laboratories at Wright Patterson AFB.

A different design

I flew with the latter configuration, and the experience supported observations on ANVIS-HUD flight made during my field evaluation. But there were a few differences.

Flying NVG in a CH-46E was considerably different than in a MD-500E. It was, for example, more difficult to clear myself to the left.

Unlike the previously used Elbit system, which projects the HUD display into the front of the objective lens, the SRL image was introduced just aft of the image intensifier and forward of the pilot's eyepiece. To accomplish this, a modified NVG eyepiece is substituted for the normal one. (SRL is currently qualifying this configuration under the direction of the Army Night Vision Laboratory, with production deliveries beginning in July.)

The SRL design has a fiber-optic cable delivering the HUD image to the eyepiece. It presented data closer to the display's center than did the Elbit system, and the image was amber, not shades of green.

Wysong felt the modified-eyepiece arrangement held two advantages: the amber color allows pilots to more readily interpret symbology, and by injecting the image to the intensifier's rear, one could read the HUD symbology even if the intensifier for that eye failed.

Into a Sea Knight

Capt. David Mollahan ushered me to the left seat of a CH-46E, and we were off into a beautiful night—a full moon and visibility forever. We departed the USMC air facility for one of Quantico's restricted areas.

Flying NVG in a CH-46E was considerably different than in a MD-500E. It was, for example, more difficult to clear myself to the left because of the 46E's structural framing (around the windscreen and side windows).

Dave flew to a small landing area cut out of a grove of trees, which were some 100 feet (30 m) tall. The surface was wet and cut up by ruts and several drainage ditches, giving us good surface texture and plenty of cues. We landed close to the woods, into a light wind.

I then made a vertical takeoff, hovered for a minute, and departed more-or-less vertically to clear the trees. I quickly pushed to accelerate and turned to a right downwind.

Dave had to cue when to turn because I couldn't see across the cockpit. I was moving my head a lot, trying to clear myself. (Surprisingly, the fiber-optic cable was not in my way during head movement.)

I came to a 20-foot (7.6-m) hover over a dry area (by accident) and landed vertically. The altitude line on the HUD display's right side worked fine.

Once in hover, I concentrated on the outside picture. I picked up slight lateral drift, stopped it, and landed. The H-46 is easy to land.

Using the radar altimeter

The second pattern was to the left. I climbed to 400 feet to see the terrain better, and explore the HUD display during a long, steep approach. During the turn to final, I found the aircraft structure in the way again.

I controlled the sink rate easily by referring to the radar-altitude tape symbol (or thermometer) on the HUD display's right side. Combined with the moon's high angle, this symbol made my descent into the clearing effortless.

From this flight, my concern about having to scan around the display for data diminished. I also found that looking through HUD symbology was easy; I could concentrate on the flightpath and still see the altitude tape and horizon bar.

My last observation is not new for helmet-mounted HUD users. I found that when you roll into a banked turn and keep the vertical axis of your head aligned with that of the aircraft (and its attitude gyros), the HUD shows the horizon bar aligned with true horizon. If, however, you tilt your head, say, to the vertical while the aircraft is banked, the HUD display no longer aligns with the horizon. Initially this is confusing, but experienced pilots say it's no problem.

Regardless, the HUD display complements night-vision goggles. And I believe, it makes flying after dark a safer proposition. ■