RD
94
20

FAA/RD-94/20

Research and Development
Service
Washington, DC 20591

Assessment of Night Vision Goggle Workload - Flight Test Engineer's Guide

David L. Green

SAIC
Systems Control Technology Inc.
1611 North Kent Street, Suite 910
Arlington VA 22209

July 1994

Final Report

This document is available to the public through the National Technical Information Service, Springfield, VA 22161

DOT
FAA
RD-94/2
0
c.1

U.S. Department of Transportation

Federal Aviation Administration

FAA TECHNICAL CENTER LIBRARY
00011976

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

U.S. Department
of Transportation

**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

JUL 13 1994

Dear Colleague:

Enclosed for your information is a copy of the recently published report **FAA/RD-94/20, Assessment of Night Vision Goggle Workload - Flight Test Engineer's Guide.**

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-94/18, Civil Use of Night Vision Devices - Evaluation Pilot's Guide, Part I

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

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

DOT Green, David L.
FAA Assessment of
RD-94/2 night vision
0 goggle workload
c.1

COPY — 1

FAA
TECHNICAL CENTER
Atlantic City, N.J.

Technical Report Documentation Page 000 11976 9/12/94

1. Report No. DOT/FAA/RD-94/20	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Assessment of Night Vision Goggle Workload - Flight Test Engineer's Guide		5. Report Date July 1994 6. Performing Organization No.
7. Author (s) David L. Green		8. Performing Organization Report No. SCT. No 91RR-45
9. Performing Organization Name and Address SAIC Systems Control Technology, Inc. 1611 North Kent Street, Suite 910 Arlington, VA 222091		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Federal Aviation Administration Vertical Flight Program Office, ARD-30 800 Independence Avenue, S.W. Washington, D.C. 20591		13. Type Report and Period Covered Final Report 14. Sponsoring Agency Code ARD-30

15. Supplementary Notes
Work was performed under subcontract by Starmark Corporation of Arlington VA.

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-94/18, Civil Use of Night Vision Devices - Evaluation Pilot's Guide, Part I
(2) FAA/RD-94/19, Civil Use of Night Vision Devices - Evaluation Pilot's Guide, Part II.

17. Key Words Night Vision Goggles, Helicopter, Pilot Assessment of NVG's, Pilot Workload		18. Distribution Statement This document is available to the U.S. Public through the National Technical Information Service, Springfield, Virginia 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 79	22. Price

TABLE OF CONTENT

		PAGE
LIST OF FIGURES		ii-iii
LIST OF TABLES		iv
SECTION 1:	INTRODUCTION	1-4
SECTION 2:	INTRODUCTION TO A SUBJECTIVE PILOT EVALUATION CONCEPT	5-20
SECTION 3:	ESTABLISHING SCOPE OF TEST ENVIRONMENTS	21-30
SECTION 4:	SELECTING TASKS FOR EVALUATION	31-40
SECTION 5:	PRESENTING AND EVALUATING SUBJECTIVE PILOT RATINGS	41-52
SECTION 6:	APPENDIX A: TABLES OF CONTENTS FOR EVALUATION PILOT'S GUIDE, PART I AND PART II	54-60
SECTION 7:	APPENDIX B: DIFFICULT VISUAL CONDITIONS DEFINED	61-64
SECTION 8:	APPENDIX C: ALTERNATIVE PILOT RATING SCALE FOR NVG EVALUATION	65-71

LIST OF FIGURES

PAGE

FIGURE 2-1: Characteristics Defining Operational Environment 8

FIGURE 2-2: Characteristics Defining Operational Environment (Cont.) 9

FIGURE 2-3: The Cooper-Harper Pilot Rating Scale 10

FIGURE 2-4: Expanded Definitions Of Pilot Ratings To Be Used For Evaluations Of Flight Control Systems 12

FIGURE 2-5: Same As Figure 2-4 Above - Continuation 13

FIGURE 2-6: Pilot Rating Data Card For Assessing One Aircraft For The Accomplishment Of One Task Under Four Environmental Conditions 14

FIGURE 2-7: Summary Of Assessment Data Collected From Four Pilots Evaluating One Task Under Four Environmental Conditions 15

FIGURE 2-8: Charting Pilot Assessment Data For Four Pilots 16

FIGURE 2-9: Pilot Rating Card For Flight Evaluation Of An Aircraft 17

FIGURE 2-10: Building A More Complete Characterization 18

FIGURE 2-11: Pilot Rating Card For Flight Evaluation 19

FIGURE 2-12: Comparing Assessments Of Unaided Night Flying To NVG Aided Operations 20

FIGURE 3-1: Sort The Data Cards Into Stacks Of Common Pilot Ratings 22

FIGURE 3-2: Assign Each Stack A Letter Code To Denote The Family Of Environments Which Produce A Common Pilot Rating 22

FIGURE 3-3: Plot The Result Of The Test After The Sort Has Been Completed 23

FIGURE 3-4: Sorting A Spectrum Of Environmental Conditions To Determine Relative Stress 25

FIGURE 3-5: Method To Define Environmental Situation To Utilize During A Flight Evaluation 26

FIGURE 3-6: Developing Reference Points For NVG Evaluation 27

FIGURE 3-7: Establishing Workload Limits 28

FIGURE 3-8: Pilot Rating Data For Turbulent En Route Operations At 140 Knots, At Night 29

FIGURE 4-1: Factors To Consider When Defining And Evaluation Visual Operations 35

FIGURE 4-2: En Route Navigation 36

FIGURE 4-3: En Route Navigation (Continuation) 37

FIGURE 4-4: Approach, Landing And Departure 38

FIGURE 5-1: Proposed Application Of Task Evaluation Charts To Support Analysis Of NVG Test Results 42

LIST OF FIGURES
(Continuation)

PAGE

FIGURE 5-2: Data From Four Pilots Flying NVGs On Four Separate Nights Into 14 Different Environments 43

FIGURE 5-3: Example Of Using Four Pilots To Validate Engineering Data Lines 44

FIGURE 5-4: Chart Depicting Anomalous NVG Operations Due To The Introduction Of A Bright White Line 45

FIGURE 5-5: A Comparison Of Day And Night (Unaided) Operations For Increasingly Adverse Winds And Decreasing Visual Range (See Table 5-2) 46

FIGURE 5-6: A Comparison Of An Augmented And Unaugmented Helicopter During Increasing Adverse Winds And Decreasing Visual Ranges (See Table 5-2) 48

FIGURE 5-7: A Comparison Of Night Operations With And Without NVG Vision Aiding 49

FIGURE 5-8: Pilot Rating Data For A Single And Tandem Rotor Helicopter Conducting A Precision Hover Task 50

LIST OF TABLES

PAGE

TABLE 4-1: Example Flight Phases And Primary Sub-Tasks 32
TABLE 4-2: Pilot's Tasks En Route 33
TABLE 4-3: Navigate En Route 33
TABLE 4-4: Arrival At Mid-Point Destination 34
TABLE 4-5: Depart Mid-Point Destination 34
TABLE 5-1: Example Summary Matrix Of Evaluation Objectives 41
TABLE 5-2: Typical Flight Conditions For Comparative Analysis 47
TABLE 5-3: Outline Of Proposed Memorandum Report Of Research Results 52

FAA FLIGHT TEST ENGINEER'S GUIDE FOR COLLECTING AND EVALUATING PILOT ASSESSMENTS OF WORKLOAD AND PERFORMANCE WHILE OPERATING WITH NVGs

SECTION 1
INTRODUCTION

GENERAL

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 (NVGs). This report was prepared to augment a two part pilot evaluation guide, *"Evaluation Pilot's Guide For Collecting Civil Helicopter Pilot Assessments of VFR En Route Operations Involving The Use of Helmet Mounted Night Vision Devices"*, which was prepared so as to introduce subject pilots to the methodology and objectives of an operational flight test project established to assess the suitability of Night Vision Goggles for civil helicopter operations. This report expands on some aspects of the earlier documents and provides suggestions and tools to aid the engineering team in its task of scoping the test, executing the test and evaluating the results.

Part I of the *"Evaluation Pilot's Guide For Collecting Civil Helicopter Pilot Assessments of VFR En Route Operations Involving The Use of Helmet Mounted Night Vision Devices"*, addressed the use of NVGs during en route operations. The flight altitudes addressed were typically 500 feet AGL or higher. Part I also covered the conduct of reconnaissance having arrived at a remote area or any potential landing site with which the pilot was not familiar.

Part II of the *"Evaluation Pilot's Guide For Collecting Civil Helicopter Pilot Assessments of VFR En Route Operations Involving The Use of Helmet Mounted Night Vision Devices"*, treats departures from and arrivals at, as well as take-offs from and landings on airports, heliports and remote sites.

PROGRAM OVERVIEW

The principal task of the FAA team is to determine if there are any unresolved safety issues which would preclude the safe use of NVG's by civil helicopter pilots during operations covered under Part 91 or Part 135.

Primary Safety Issue. 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 the resultant operation safe? The evaluation methodology offered here was formulated with the understanding that the goal of the FAA is to preclude unsafe flight operations, over any portion of the flight. Even if the use of the goggles dramatically improves operational effectiveness throughout the flight, acceptable margins of safety must be maintained during <u>all</u> phases. That is, the introduction of NVG operations must not introduce a fatal (safety) flaw.

In addition, the FAA desires to preclude the introduction of equipments which may be easily misused for purposes not intended, thereby placing passengers and persons on the ground at risk.

The methodology also recognizes that it is acceptable for a very easy (unaided) task to become a bit more difficult as long as the margin of safety is unquestionably adequate. The FAA deals in "Pass - Fail" terms. The evaluation methodology supports the definition of workload - performance trends (involving degrees of goodness or desirability) to insure the "PASS" or "FAIL" judgement is correct. Otherwise degrees of goodness are not a key issue.

Irrational Acts Vs. Blunders. There will always be a few pilots who will undertake irrational operations that they are not qualified to conduct safely. This project can not hope to preclude these operations. On the other hand, this project has a responsibility to investigate the potential for innocent blunders or traps. There are two causal factors for such situations which we will explore as examples. One factor involves errors which are the result of experimentation by operational pilots. A second cause involves an error in basic procedure or a failure to follow procedure. In particular, the failure to flip the goggles up at some point because the pilot forgot. That is, the pilot became very busy with the radio, or the pilot had maneuvered to avoid another aircraft, and forgot.

Importance Of Procedure. Standard operating procedures have been developed to insure that a coherent evaluation can be conducted. Specifically the procedures are meant to define limits for the use of NVGs.

It is important that the flight test determine that potential **violations of these procedures,** whether intentional (experimentation) or unintentional (error of omission), **will not immediately place the pilot in a position where unusual pilot skill or technique will be required to re-establish safe flight** (following standard procedures). Any potential problem of this sort would require special training to qualify to use NVGs in flight.

NVGs Do Not Enable Flight. The philosophy supporting the civil use of NVGs prescribes that goggles will only be used during normal visual flight operations that can be carried out under current regulatory authority. **The use of NVGs will <u>NOT</u> enable any mode of flight which cannot now be flown visually within framework of the 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 a pilot 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.

Proposed Procedures. Suggested procedures have been established in **Part I** and **Part II** of the Evaluation Pilot's Guide (EPG) for pilots to follow in adjusting the NVGs to their eyes. Procedures have also been developed for use during the flight evaluation. These procedures may not initially be 100 percent correct, but pilots will have an opportunity to suggest changes, once the team is sure that they understand the FAA's proposed constraints on the use of NVGs by civil helicopter pilots. **The evaluation pilot's informed ideas for improving the use of the NVGs is sincerely solicited.**

Defining Safe Limits. 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.**

ORGANIZATION OF DOCUMENT

SECTION 1: Introduction

SECTION 2: Introduces the reader to a method for pilots to employ when assigning subjective ratings during evaluations of aircraft in a variety of operational environments.

SECTION 3: Explains how experienced pilots can help define a family of environments to support establishing an orderly and affordable scope of test.

SECTION 4: Helps the test manager select, and initially define, flight profiles and sub-tasks for evaluation in the environments defined in Section 3.

SECTION 5: This section suggests a way to establish an affordable "scope of test" and provides a few additional data plots which illustrate a number of presentation alternatives which can be useful in reporting test results. A memorandum report format is also suggested.

APPENDIX A: This Appendix includes the tables of contents of the two parts of the "Evaluation Pilot's Guide". These tables are provided for references, listing the subjects and illustrations contained in each volume.

APPENDIX B: "Difficult Visual Conditions Defined" contains a brief but insightful review of the factors which influence the ability of a pilot to conduct day or night visual flight operations.

APPENDIX C: This Appendix contains a set of alternative pilot rating definitions which might be employed during a NVG evaluation in leu of the scales presented in Section 2.

SECTION 2

INTRODUCTION TO A SUBJECTIVE PILOT EVALUATION CONCEPT

SUMMARY

This section contains the details of a methodology for collecting and graphically correlating subjective pilot ratings. The process has been tailored to aid engineers in their efforts to define the limits of a given aircraft with respect to the operational environment.

NEED TO ENHANCE SUBJECTIVE EVALUATIONS

The pilot assessment of suitability has historically been a key factor during the evaluation of aircraft by the FAA. The importance of this activity is difficult to overstate. Thus, it is useful to take a brief look at current procedures to establish a common point of departure.

While research pilots and military test pilots tend to employ pilot rating scales, FAA pilots typically do not. The FAA pilot's task is to determine if the aircraft and its systems are safe. They make determinations as to adequacy or suitability of an aircraft for civil operations. There really is little call for pilot rating data per se. In addition, FAA pilots are primarily interested in workload and the basic pilot rating scale is not well suited to such an application. Finally, when the pilot ratings of several pilots are compared, they often do not appear to agree and such apparent disagreements tend to bring the validity of the entire evaluation into question.

In short, the lack of a useable (FAA oriented) pilot rating scale and the historical problems stemming from scatter in the data have produced deterrents to the general use of pilot ratings. These deterrents need to be eliminated before FAA pilots and engineers can be expected to embrace an evaluation method for NVGs which involves pilot ratings.

There are many explanations for disagreements in pilot subjective ratings, and while some scatter in the data is normal, all evaluations should be conducted so as to minimize the scatter in the pilot ratings. This section deals at length with this issue and offers techniques to minimize scatter in the data when a number of pilots are employed on the same evaluation.

The methodology presented in this section is based upon the premise that if an engineer will ask two equally qualified pilots the very same question, the result will be a common answer (pilot rating). A sloppy approach to staging a rating question to a number of pilots will in turn produce scatter in the results. The proposed methodology introduces a discipline to the evaluation process.

Nevertheless, all scatter can not be eliminated, nor should it be. Some apparent scatter in the data is not scatter at all, it is more data. For example, some disagreement in ratings may be explained by examining the background of the pilots. One pilot may be much more qualified in the aircraft than the others. Alternately, one pilot may have used a different piloting technique and effectively changed the task. There is almost always a reason for apparent scatter which is not eliminated by the discipline proposed in the following pages.

PILOTS INTERACT WITH THEIR ENVIRONMENT

Defining The Complexity Of The Task. Pilots conduct operational evaluations by manipulating aircraft as though they were flying an actual (representative but difficult) flight profile. Some evaluations are conducted single pilot, some are two pilot operations. Some flights are conducted with all systems operative, others are conducted with a variety of failures. Some tasks are very relaxed. Some relaxed flight tasks are sometimes made more difficult by the need to accomplish a number of secondary tasks at the same time. Other tasks require a great deal of precision interaction with the vehicle. Regardless of the basic circumstances, if the evaluation pilot is not required to work hard, there will be little potential for the kind of stress required to obtain a useful evaluation of operational flight safety.

For example, a relaxed task such as a cross country flight, 1,000 feet above rolling terrain, bathed in bright sunlight, may not introduce sufficient workload to detect the shortcomings of a given aircraft. Gusty winds will increase the workload. Decreasing visibility will also increase workload. The introduction of factors which produce increasing levels of workload result in stress and enable pilots to find faults which allow them to become more discriminating in their assessments of an aircraft's performance and related operational suitability.

The fact is, pilots train to insure that they are able to cope with adversity in flight. They learn how to fly instrument approaches, and provide compensatory control inputs to suppress the gust response of their aircraft in the real world. Pilots must learn how to fly and deal with failure modes in a variety of environments. Anyone can quickly learn to fly almost any kind of aircraft on a clear day under calm conditions. Darkness, turbulence and aircraft failure modes stress the pilot's ability to maintain safe flight conditions. It seems reasonable that one of the objectives of an operational test should be to provide a pilot with the opportunity to experience a variety of adverse (stressful) combinations of flight environments and failure modes with the intended purpose of accelerating the evaluation process.

Figures 2-1 and 2-2 have been developed to illustrate the variety of unique conditions which collectively define the environment within which a pilot can be expected to fly a rotorcraft. Among other things, these environmental conditions can be used to define a variety of visual conditions.

The presence of turbulence can prevent a pilot from achieving a precision performance. Thus, the introduction of turbulence can reduce the expectations of the pilot to the point where he no longer expects to do well. Here the introduction of turbulence into an event has the potential of masking problems because of decreased expectations. The point: One must be careful in the use of environmental variables. We will return to the environment later in this section.

Waiting for specific meteorological conditions (in the real world) to be repeated to derive similar data on several flights can be a problem, thus the methodology must deal with this issue.

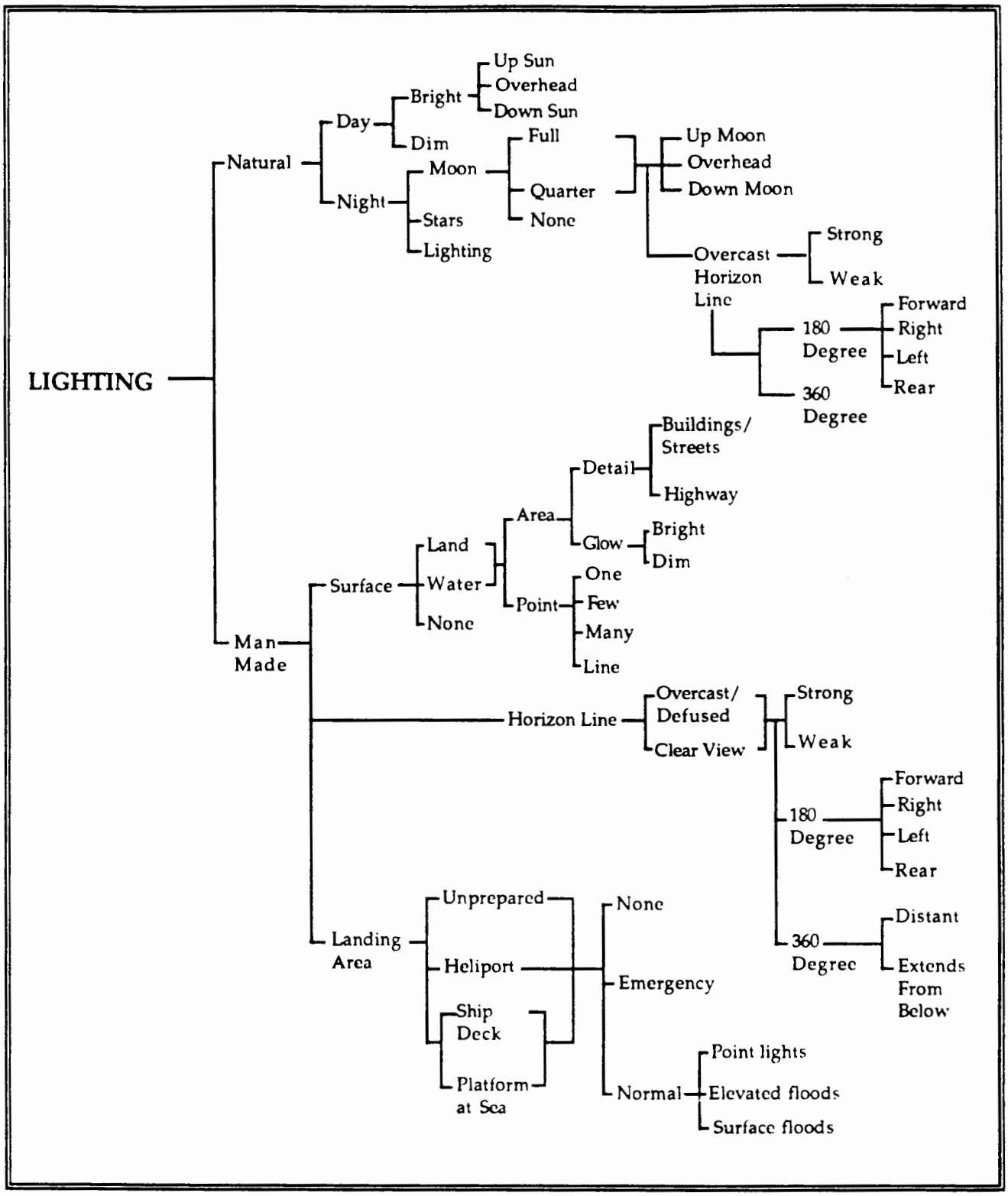


FIGURE 2-1: Characteristics Defining Operational Environment

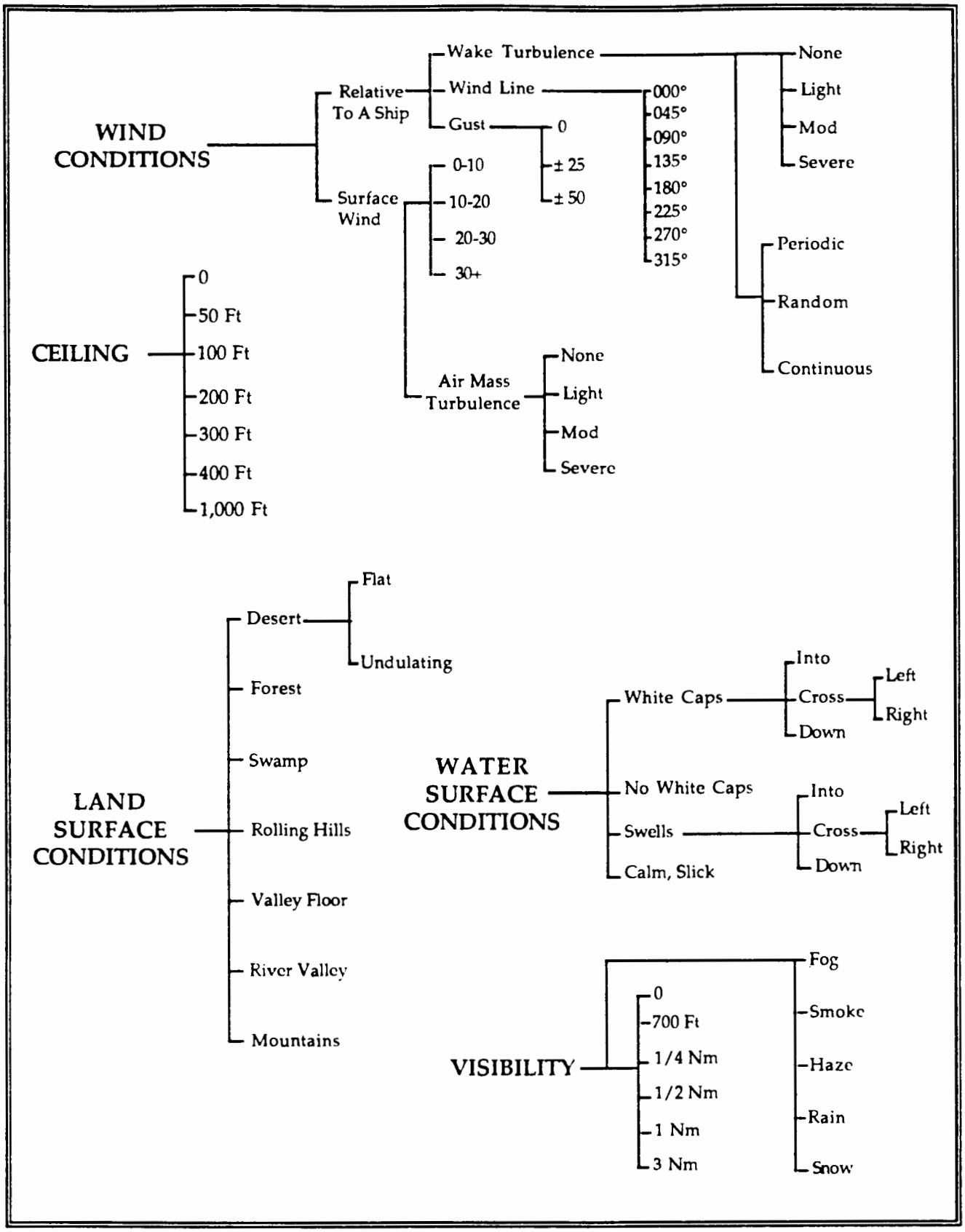


FIGURE 2-2: Characteristics Defining Operational Environment (Continuation)

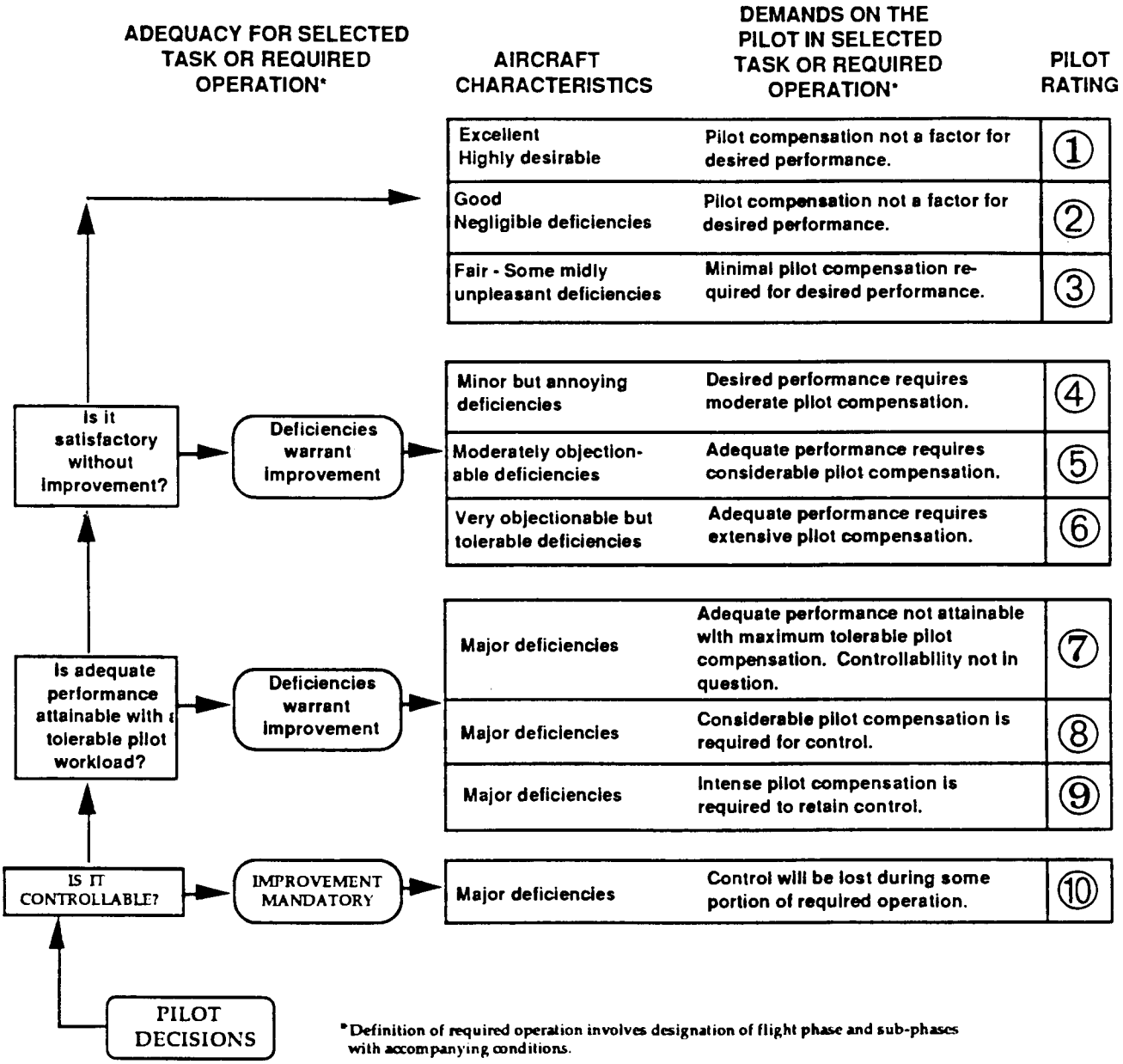


FIGURE 2-3: The Cooper-Harper Pilot Rating Scale

PILOT RATINGS DEFINED

Systematic reports of subjective evaluations typically employ pilot rating scales. The most popular pilot rating scale is referred to as the "Cooper-Harper Pilot Rating Scale" (see Figure 2-3). 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 for the evaluation of NVGs. The range of this scale extends beyond the scope (or typical needs) of FAA evaluations of NVGs.

It is conceivable that the pilot of a certificated civil helicopter may experience a situation which could be assigned a rating of 7, but even 7s should be rare. A rating of 7 means that the pilot was in control, but the pilot was working as hard as possible, and the resulting performance was inadequate.

At the other extreme of the scale, pilot rating of 1 is reserved for highly automated flight control systems and/or extremely relaxed tasks. In summary, pilots actively controlling certificated aircraft (with no system failures) in normal operational environments are expected to assign ratings which range in numerical value between a minimum of about "2" to a maximum of about 5.5. Pilots evaluating automated flight path control, auto-pilots may assign 1 (and 1.5). Serious flight control failures, or very adverse operating environments, or difficult combinations of failure modes and bad environments may produce pilot ratings of 6 or more.

EXPANDED PILOT RATING SCALE

In Figure 2-4, we find a scale which has been expanded to meet the needs of the FAA for the evaluation of civil rotorcraft during civil rotorcraft operations. This rating scale is suggested only, it has not been endorsed by the FAA and there is every reason to expect that it can and should be improved. Never-the-less, the added detail is intended to help a group of pilots produce more consistent results by minimizing the opportunity for scatter in the data due to individual interpretation of the "Cooper-Harper" scale.

When you compare the scale in Figure 2-3 to the scale in Figure 2-4, be advised that they are the same scale. The words in Figure 2-4 are meant to expand upon the words in Figure 2-3. They are intended to provide pilots with a better understanding of the meaning of the very brief statements in Figure 2-3.

Also note that the expanded scale provides definitions for 1.5, 2.5, 3.5, etc., while Figure 2-3 does not. These additional half ratings are not the invention of the author, they have been used from the beginning of time. The use of half ratings is required because most ratings range between 2 and 5. Experience has shown that the rating scale has been used as a kind of short hand for pilots to communicate with engineers and other pilots. It is used to report the results of research which involves many, many variations in the evaluation task or characteristics of the aircraft. The half numbers increase the number of "quality steps" available within a given small range of ratings to allow pilots to achieve the desired discrimination or hierarchic ranking of evaluation situations. These additional quality steps also allow the pilot to more accurately report the impact of variations in the environment on pilot-aircraft performance.

Pilots should not be required to commit the scale to memory, but pilots should make an effort to develop an awareness of the scale. They then should be allowed to look at the scale during the debrief period following a flight evaluation. At this time, the pilot should rate the flight experiences. This process will be developed in detail later in this section.

1.0	Excellent Highly Desirable	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).
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	Good	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.
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	Fair, Some Mildly Unpleasant Characteristics	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.
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	Minor, But Annoying Characteristics	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.
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 2-4: Expanded Definitions Of Pilot Ratings To Be Used For Evaluations Of Flight 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 2-5: Expanded Definitions Of Pilot Ratings To Be Used For Evaluations Of Flight Control Systems (Continuation)

RATING AN APPROACH TO HOVER TASK

Assume that a team of four pilots has been selected to evaluate a helicopter. Their first step is to refresh their knowledge of the aircraft. Once all pilots are familiar and current, the next step is conduct an evaluation flight. The first pilot is "Green" and he conducts the hover-landing task described on the "Pilot Data Card" reproduced in Figure 2-6. Note that the task has been accomplished under four sets of environmental conditions (A, B, C & D).

Each time the pilot conducts the task, the factors which defined the environmental situation were recorded. An assessment was entered for each situation after it was evaluated. In this example, the assessments have ranged from a rating of "2" for a "Clear Day, Calm Air" to a "6" for an "overcast night time" situation.

The pilot's task involves a final flare and hover-landing to a platform on an oil rig in the open sea. The platform landing is considered a confined landing area involving the need for precision operations to avoid obstructions and to properly position the aircraft on the platform.

TASK SHORT TITLE PLATFORM HOVER-LANDING	PILOT DATA CARD Pilot Name: GREEN	SIM FLT ☐ A/C FLT ☒

TASK: *Approach to Low hover in confined area. Landing on a platform one hundred feet above a water surface. Obstructions are present ahead and to the right. Upon landing rotor clearance is 30 feet to closest obstruction. Steel structure rises ahead.*

SITUATION ID CODE	FACTORS DEFINING THE TASK ENVIRONMENT SITUATION	PILOT ASSESSMENT (RATING)
A	Clear Day, Calm Air.	2
B	Clear Day, 10 KT RT Cross Wind.	2.5
C	Clear Day, 10 KT RT Cross Wind, Gusting to 17 KT.	5
D	Night, Overcast, no surface lights, single landing LT, 10 KT RT Cross Wind, Gusting to 17 KT, (see Note 1)	6

OPERATING STATE: Normal
CONFIGURATION: Mid wt, mid C.G., Doors closed

Note 1: Tower obstruction lights, landing pad edge lights.

FIGURE 2-6: Pilot Rating Data Card For Assessing One Aircraft For The Accomplishment Of One Task Under Four Environmental Conditions

TASK: *Normal Flare, Hover-landing onto Confined Elevated Platform Area.*					
ID CODE	PILOT				
	GREEN	BLACK	BROWN	WHITE	
A	2	1.5	2.5	2	
B	2.5	2	3	2.5	
C	5	4	5.5	4.5	
D	6	5	6.5	5.5	

FIGURE 2-7: Summary Of Assessment Data Collected From Four Pilots Evaluating One Task Under Four Environmental Conditions

To continue this example, assume three more pilots fly the same task under the same conditions and they individually complete a data card. They were riding in the aircraft and took turns at the control during each of four flights. Next their findings are summarized in Figure 2-7.

It is obvious that these four pilots did not totally agree, but when we analyze the results, we find the data is quite usable. First, we observe that the weather is never as constant or homogeneous as we would hope. As a result, all pilots probably operated the aircraft under slightly different conditions. Second, it is interesting to discover that Mr. Black is most familiar with the aircraft and has extensive experience operating from platforms and ships at sea, day and night. Conversely, Brown has the least experience with the aircraft and the task-environmental situations evaluated.

The ratings in Figure 2-8 are then the sum results of four pilots evaluating their personal "pilot-machine" performance under four task-environmental situations. The reader must understand that the rating process is personal. It refers to the performance that the evaluation pilot has personally achieved inflight. This performance evaluation is then something of a self appraisal. It is therefore the product of the pilot's skill level at the time of the evaluation and the past personal experience accrued by the pilot prior to the flight event.

Some flying qualities analysts ask pilots to establish a rating which they feel would reflect how the average pilot would evaluate a task. Such an approach is not applicable here. For this methodology to work, pilots must rate their personal performance.

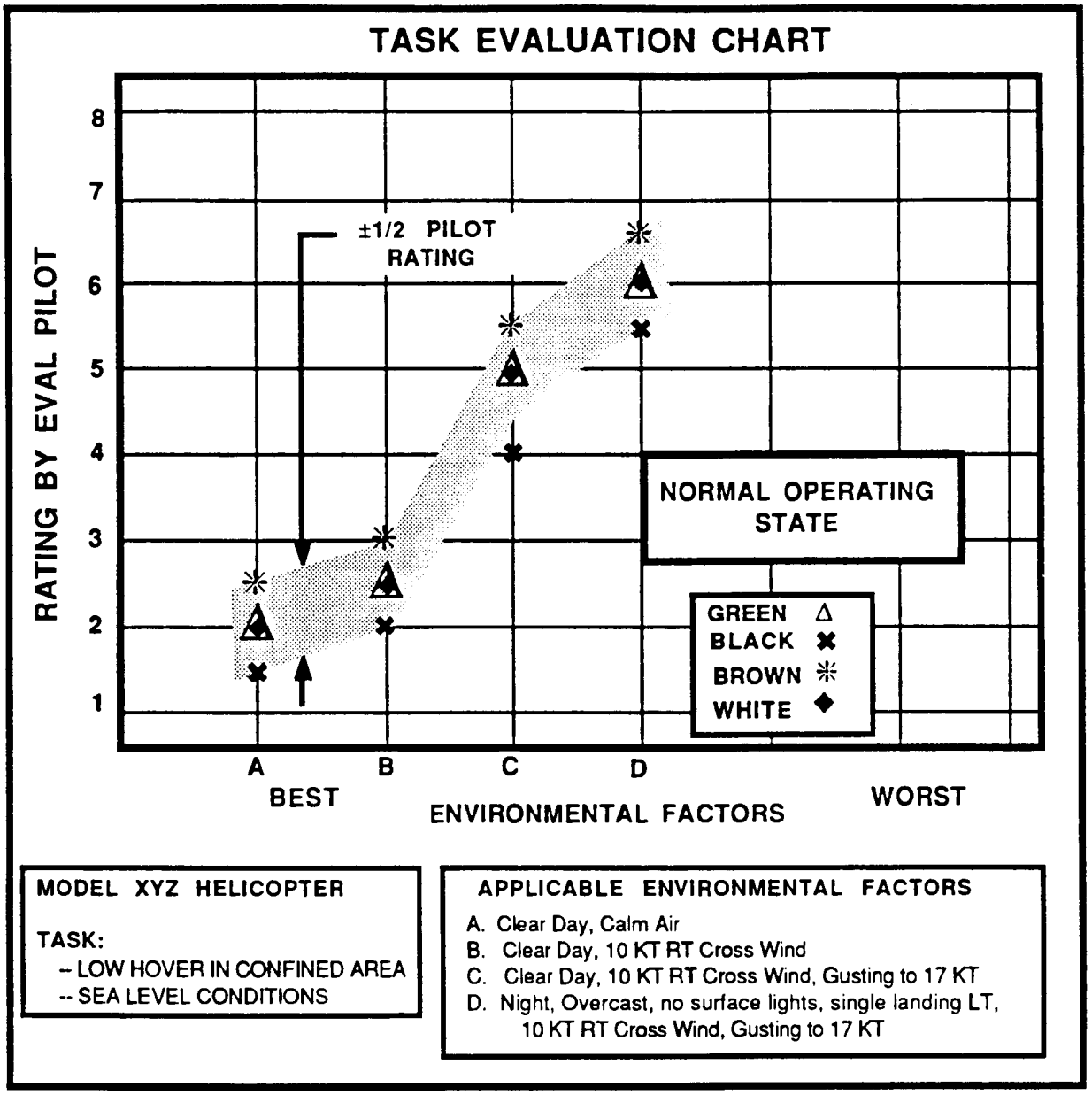


FIGURE 2-8: Charting Pilot Assessment Data For Four Pilots

The results summarized in Figure 2-7 have been plotted in Figure 2-8. This plot illustrates the preferred data presentation format for most comparative analyses. The format has been designed to be easily understood by a broad spectrum of readers, engineers, pilots and administrators. A shaded band has been added to Figure 2-7 to emphasize the lack of scatter.

As noted before, there is some scatter in the data but not a great deal. Experience has shown that the scatter will increase as the environment becomes extremely adverse. A larger scatter band is also possible when pilots are asked to evaluate degraded modes that they do not have a great deal of experience with. Both situations seem to suggest that a lack of pilot familiarly with the task or environment can produce scatter. This apparent uncertainty is both understandable and acceptable.

TASK SHORT TITLE PLATFORM HOVER-LANDING	PILOT DATA CARD Pilot Name: GREEN

TASK: *Approach to Low hover in confined area. Landing on a platform one hundred feet above a water surface. Obstructions are present ahead and to the right. Upon landing rotor clearance is 30 feet to closest obstruction. Steel structure rises ahead.*

SITUATION ID CODE	FACTORS DEFINING THE TASK ENVIRONMENT SITUATION	PILOT ASSESSMENT (RATING)		
		CURRENT OBSERVED	PAST OBSERVED	PROJECTED
A	Clear Day, Calm Air.	2		
B	Clear Day, 10 KT RT Cross	2.5		
C	Clear Day, 10 KT RT Cross Wind, Gusting to 17	5		
D	Night, Overcast, no surface lights, single landing LT, 10 KT RT Cross Wind, Gusting to 17 KT	6		
E	Night, Full Moon, Stars, Hover Lights, 10 KT RT Cross Wind,		3.5	
F	Night, 1/4 Moon, Single Landing LT, 10 KT RT Cross Wind,		5.5	
G	Night, Thunderstorm, 20 KT Wind, Gust to 30			7.5

OPERATING STATE Normal

CONFIGURATION: Mid wt, mid C.G., Doors

Note 1: Tower obstruction lights, landing pad edge lights.

FIGURE 2-9: Pilot Rating Card For Flight Evaluation Of An Aircraft

Figure 2-9 illustrates the next step in the methodology. For this illustration, Green has been asked to evaluate the same hover-landing task for three additional and slightly different environmental situations (E, F, and G). The aircraft is not to be flown specifically to evaluate these situations. Instead the pilot is asked to draw on past experience. Green can relate well to two of these situations because he has personally experienced them in flight. We are not sure exactly when, but in any event, he relates well to these conditions and is easily able to provide an assessment of how well he can fly the aircraft. One situation, "G", he has not experienced in the aircraft being evaluated, but he has flown other aircraft onto similar platforms under conditions approaching those identified with "G". Thus we characterize "G" as a projected assessment. It is in effect an extrapolation. This extrapolation technique is not new, it is widely used during early assessments of military aircraft, every time development testing is initiated.

Here again, a certain amount of scatter in the data can be expected when the assessments of two or more pilots are compared. Projected ratings are subject to the greatest scatter, but even this such scatter can typically be explained and it is normally of little consequence. The scatter in projected ratings of operations involving violent weather at night can be expected to produce scatter on the order of ±2 pilot ratings. On the other hand, the data from an extremely qualified pilot will often fall along the mean of the scatter in the projected data developed by less qualified pilots.

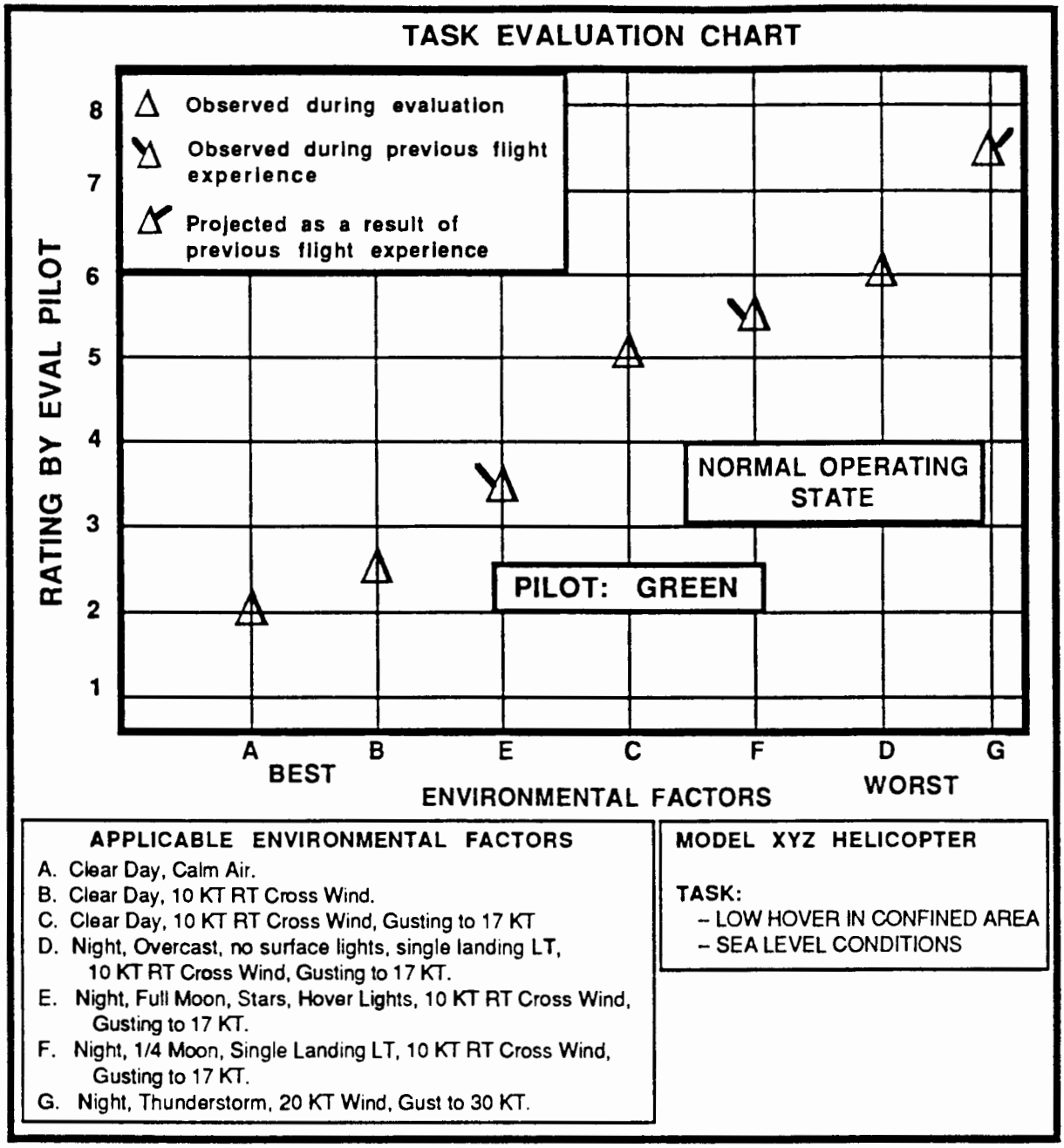


FIGURE 2-10: Building A More Complete Characterization

Figure 2-10 illustrates one way that pilot ratings can be plotted for analysis. Note that the sets of conditions have been ordered across the chart in a way which allows the rating to ascend from left to right. This results in a situation where the sets of environmental factors are becoming more adverse from left to right. This arrangement enhances data analysis and helps the evaluator insure that a complete spectrum of task complexity has been considered.

While the real interest in this evaluation involves night operations, with and without NVG's, the daylight evaluations help to validate the night assessments. While one would not expect to fly NVGs in a thunderstorm, the data point "G" provides a high stress reference point for future consideration.

ASSESSING NVG OPERATIONS

An aircraft - NVG combination can be evaluated by one pilot or a team of pilots. To simplify this next discussion, one pilot (Green) will be considered. Remember that the data in Figure 2-10 represents the best characterization of one helicopter model and one pilot that Green was able to establish. Assume for the moment that the data provided by the remaining pilots would have norminally agreed with Green's data, more or less. This confirms that Green's ratings of the seven different operating environments is sufficiently accurate to use as a base line. In addition, an inspection of the seven operational environments used in the initial evaluation confirms that they probably provide an adequate spectrum of situations to use in the evaluation of NVGs. Assume that these situations are reflown one by one and the pilot establishes an assessment (rating) for each and enters this rating on a pilot data card as illustrated in Figure 2-11. At this point, Green has generated two sets of ratings trying to accomplish the very same task. One set responds to his experience without NVGs and one reports experience with NVGs. It should therefore be possible to plot both sets of (night) data on one chart for analysis. This has been done and the results are presented here as Figure 2-12. Note that the data observed during day operations (and plotted in Figure 2-10) has not been transcribed into Figure 2-12.

TASK SHORT TITLE PLATFORM HOVER-LANDING	PILOT DATA CARD Pilot Name: GREEN			
TASK: *Approach to Low hover in confined area. Landing on a platform one hundred feet above a water surface. Obstructions are present ahead and to the right. Upon landing rotor clearance is 30 feet to closest obstruction. Steel structure rises ahead.*				
SITUATION ID CODE	FACTORS DEFINING THE TASK ENVIRONMENT SITUATION	PILOT ASSESSMENT (RATING)		
D	Night, Overcast, no surface lights, single landing LT, 10 KT RT Cross Wind, Gusting to 17 KT	4.5		
E	Night, Full Moon, Stars, Hover Lights, 10 KT RT Cross Wind,	2.5		
F	Night, 1/4 Moon, Single Landing LT, 10 KT RT Cross Wind,	4		
OPERATING STATE Normal CONFIGURATION: Mid wt, mid C.G., Doors		CURRENT OBSERVED	PAST OBSERVED	PROJECTED

FIGURE 2-11: Pilot Rating Card For Flight Evaluation

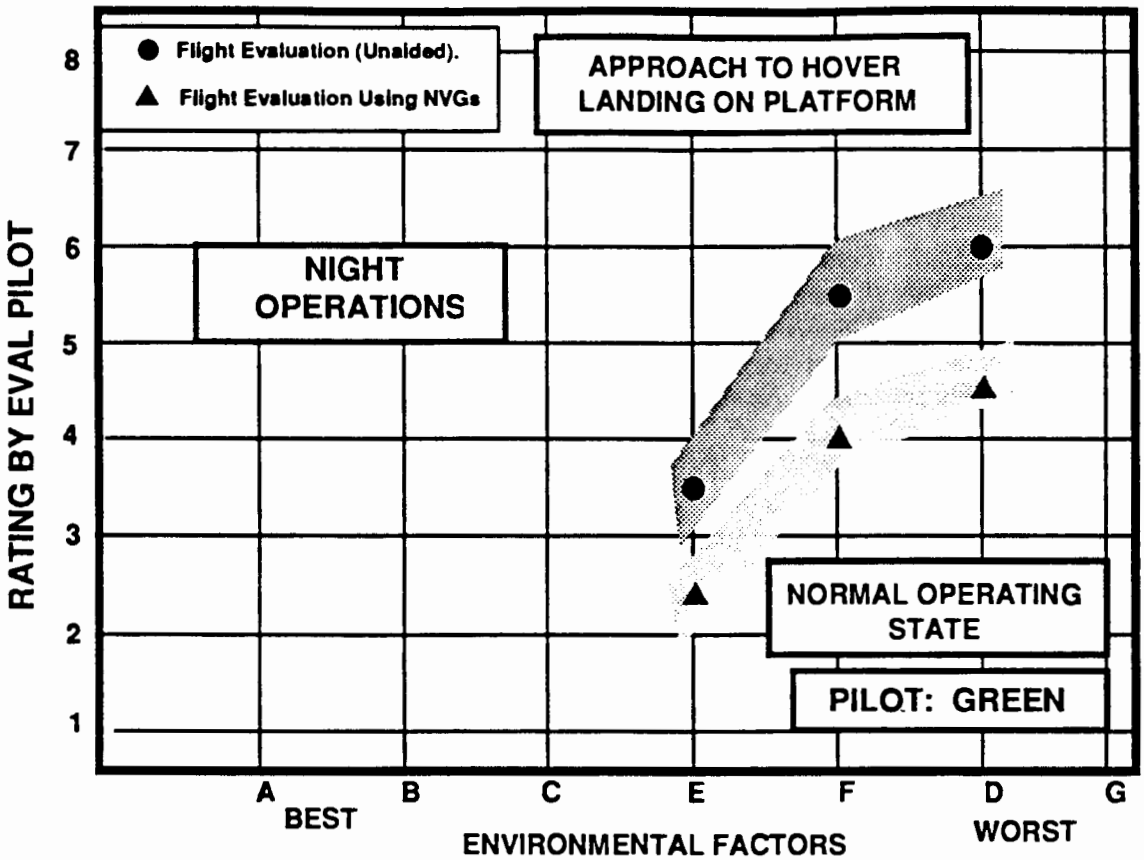


FIGURE 2-12: Comparing Assessments Of Unaided Night Flying To NVG Aided Operations

Inspecting Figure 2-12, one finds that the three pilot ratings established during night NVG operations are 1 to 2 pilot ratings lower than the trend band which bounds the data defined for flight during similar conditions in day and night non-NVG operations.

Briefly, analysis of this chart leads one to conclude that NVGs, used as they were in this evaluation measurably improved the margin of flight safety.

The engineer's job boils down to: (1) defining the flight tasks for the pilot to evaluate and, (2) selecting the environments which can practically be used to stress pilot-aircraft-NVG and determine suitability for civil operations.

SECTION 3

ESTABLISHING SCOPE OF TEST ENVIRONMENTS

INTRODUCTION

In Section 2, the reader was exposed to a methodology which recognizes the impact of the flight environment on the piloting task. Flight test results were recorded and plotted in a way which facilitated the presentation and understanding of subjective ratings and the causal factors supporting the assignment of these ratings.

This section explains how experienced pilots can help develop a family of environments to support establishing an orderly and affordable scope of test. It re-introduces the idea that pilots can call on past experience to provide fair (planning) estimates of the impact of environmental characteristics on their ability to accomplish selected tasks.

This section also introduces the concept of objective margins of safety and objective environmental limits. This line of thought also addresses the inter-connectivity of margins of safety and severe environments which stress-the-pilot-aircraft-equipment combination.

A VARIETY OF ENVIRONMENTS CAN PRODUCE A COMMON RESULT INFLIGHT

If a flight task (approach to a confine area heliport) is repeated during a series of flight evaluations involving 20 different sets of environmental conditions, and the pilot assigns a Pilot Rating (PR) for each environmental condition involved in the series, the results could be reported on twenty flight test cards. One for each time a different environment was rated. If these cards are sorted into stacks of common pilot rating, one finds that there are numerous environmental situation which have produced the same rating (see Figure 3-1). For example, a dark night involving calm air might produce the same rating as a bright day involving a turbulent air mass.

In some situations, the same numeric rating will be assigned for the same reason, in other cases, the same rating will be caused by different reasons. For example, the problem may be precision directional control. In one case, the directional control is a problem because of turbulence. In another case, the directional control problems may be the result of a high cross wind. A pilot rating of 4.5 could be assigned to both the turbulent air mass case and to the high cross wind case. Investigating further, one discovers the cross wind turbulence introduce a very difficult lateral control problem, the high cross wind caused the pilot to run out of directional controllability. Thus the same pilot rating was assigned for two different reasons.

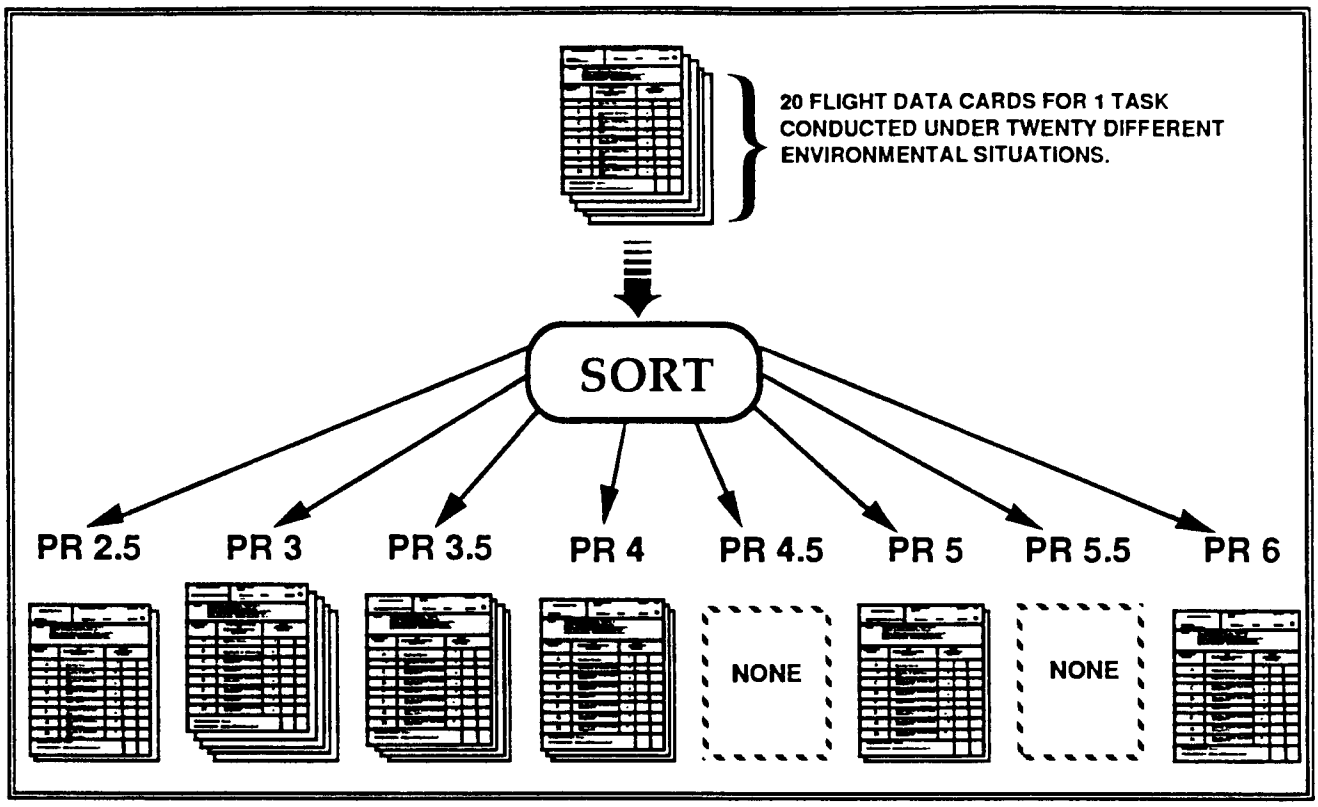


FIGURE 3-1: Sort The Data Cards Into Stacks Of Common Pilot Ratings

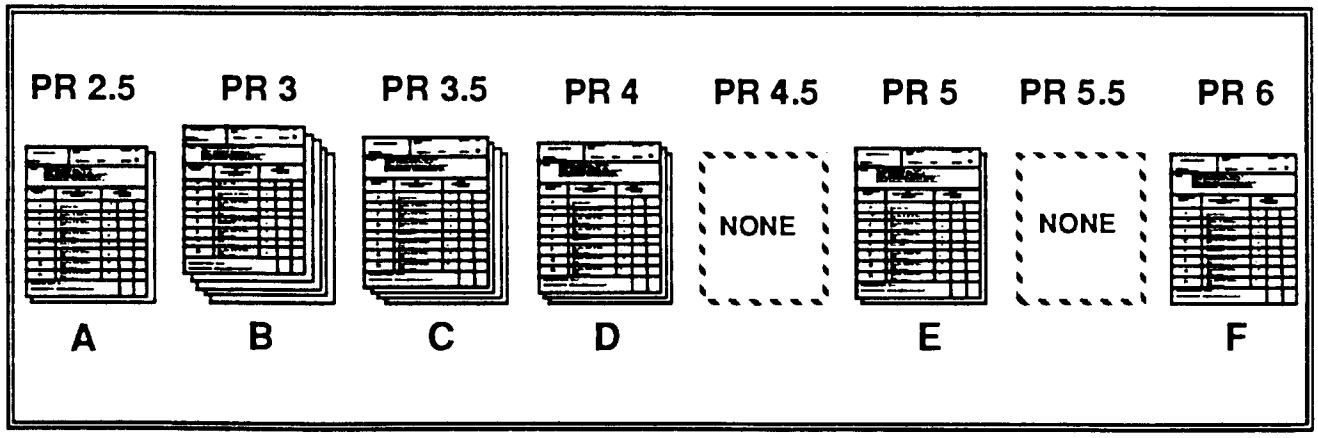


FIGURE 3-2: Assign Each Stack A Letter Code To Denote The Family Of Environments Which Produce A Common Pilot Rating

PREPARING TO PLOT PILOT RATING DATA (AN EXAMPLE)

After the resultant stacks are arranged in sequence of ascending pilot rating (as shown in Figure 3-2), each card stack is assigned a letter ID to facilitate plotting for further analysis. Note that in this example, there are no rating less than 2.5 or greater than 6, and none of the environments tested produced a rating of 4.5 or 5.5. Codes are only assigned to stacks (each stack having one or more cards) of environmental conditions. No code is assigned to either of the voids represented by PR 4.5 or PR 5.5 (in this example).

The result of sorting process has been plotted in Figure 3-3. The orderly ascension of pilot ratings is the result of the discipline introduced through the sorting-plotting techniques. The wide spectrum of ratings (from 2.5 to 6) is the result of a well planned and executed scope of test. As a matter of clarification, if the test program (which produced the data in Figure 3-2) had continued long enough to cover a greater spectrum of environments, one or more cards would have been developed with pilot ratings of 4.5 and 5.5, and maybe even 6.5 and 7.

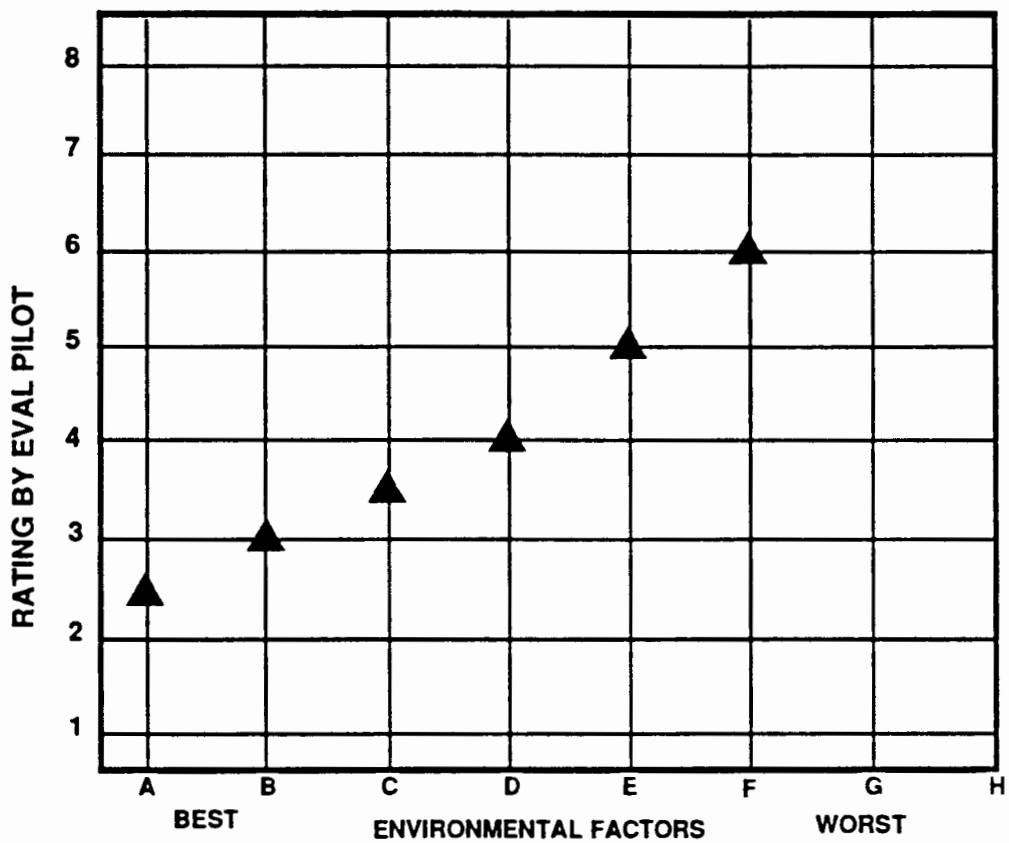


FIGURE 3-3: Plot The Result Of The Test After The Sort Has Been Completed

REASON FOR ESTABLISHING TEST ENVIRONMENTS PRIOR TO FLIGHT

One objective of any flight test program is to accomplish the assigned scope of test in as short a period of calendar time as possible, using the least amount of flight time as possible. When the scope of test is substantially impacted by the environment (as it is here) the test team is obliged to make every effort to predict the environmental variables which will produce the desired spectrum of evaluation stress. That is, the team needs to pick the environmental conditions which will produce the most scientifically important results. It is equally important to avoid repetitive testing in environments of no consequence to the objective of the flight evaluation.

The data which was sorted and plotted in Figures 3-1, 3-2 and 3-3 illustrated how we can sort environments after a flight test program has been completed. The same basic approach can be used to establish a spectrum of test environments prior to the first flight.

PILOTS CAN DEFINE TEST ENVIRONMENTS

Experienced pilots who have flown equipment similar to that scheduled for evaluation can be asked to estimate the difficulty they expect to encounter during flight under a spectrum of probable flight test environments. They will develop their (estimated) ratings by evaluating a mental projection of what they know of the aircraft to be used in the evaluation, the task to be accomplished and the operating environment(s) of interest.

In the case of a night vision aiding system, like the NVGs, many pilots will have gained experience in the military. In many cases, such experience will be sufficient to permit pilots to characterize the degree of difficulty which they can expect to experience using similar devices during civil rotorcraft operations. Most will be able to employ their anecdotal experience and engineering knowledge of improvements in technology to provide a fair estimate of what they expect to encounter in flight. After all, the aircraft should be well known and it responds the same to the environment regardless of how well the pilot can see. Thus the pilot can start off developing a spectrum of environments that represent a spectrum of stress or difficulty and then selectively complicate the task by reducing the pilot's piloting cues.

SELECTING A TASK TO EVALUATE

The difficult part of this methodology involves the selection and definition of tasks to evaluate the environments within which these tasks will be accomplished. The tables and figures in Section 4 have been provided to assist engineers during efforts to develop task definitions and Figure 2-1 provides a wide assortment of environmental factors to select from when selecting environmental situations for evaluation.

Since the significance of environmental factors can only be determined in context with the conduct of a specific task (or flight maneuver), a pilot is requested to select and define a difficult flight task which is germane to the objective of the evaluation objectives. In this case, we'll assume the pilot has selected a precision approach to a confined area. Now ask the pilot to expand the definition of the task he has in mind. Have him describe the maneuver and piloting techniques for future reference. (NOTE: This step needs to be repeated for all tasks of importants to the objective of the evaluation.)

DETAILED METHOD FOR SELECTING ENVIRONMENTS

Next, the pilot is ask to visualize (project himself into flight) and identify all of the visual cues and related environment variables which would have an impact upon the pilot's ability to accomplish the assigned task (use Figure 2-1 for reference). The engineer must work with the pilot to select 15 to 20 combinations of environmental factors. These factors should be selected to introduce a range of stress so that the pilots task is expected to range from very easy to extraordinarily difficult. The final step involves transcribing the sets of environmental factors on to index cards with one set of conditions on each card.

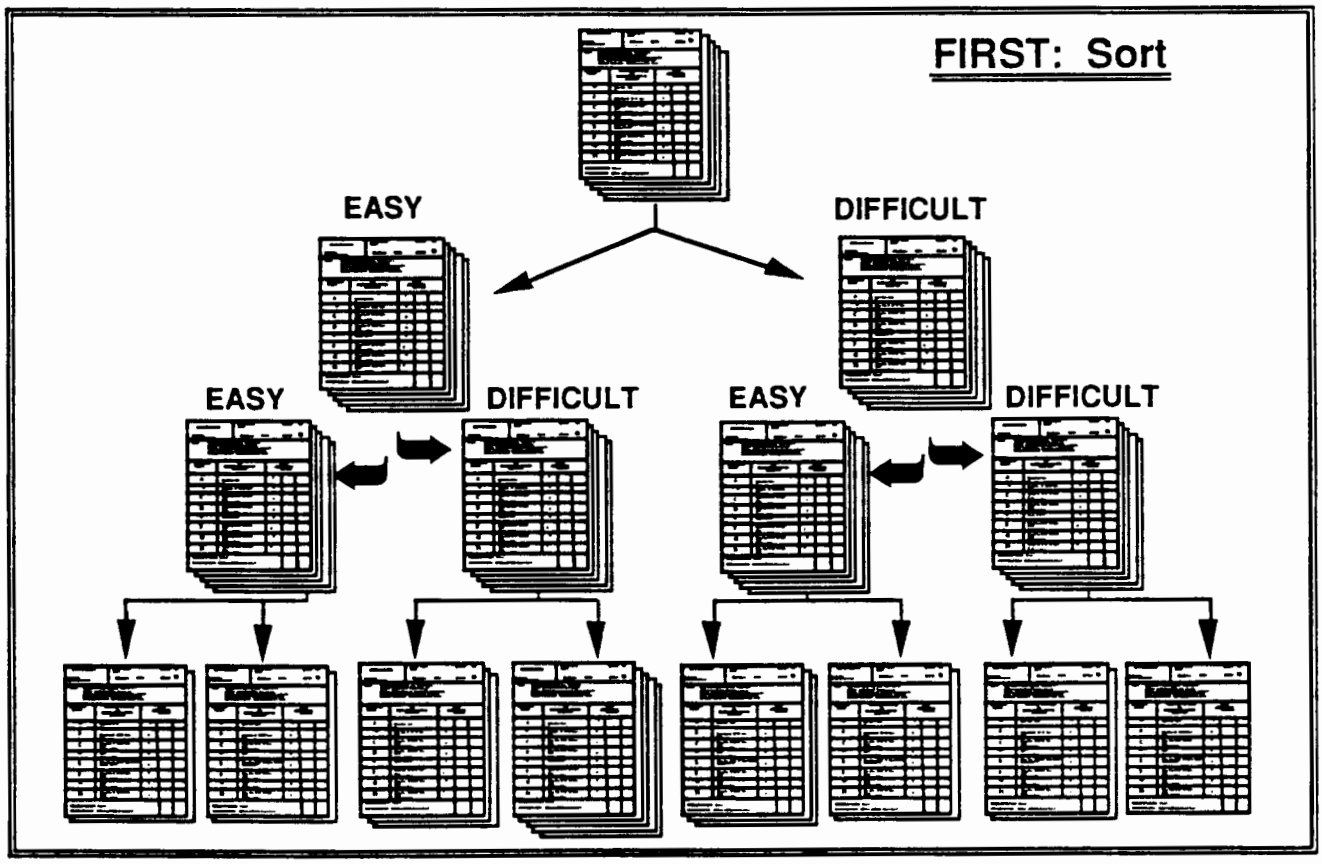


FIGURE 3-4: Sorting A Spectrum Of Environmental Conditions To Determine Relative Stress

Now ask the pilot to group the environments into two stacks. One stack is the "easiest to fly" stack, and the other is the "hardest to fly" stack (See Figure 3-4). This step is repeated until there are approximately eight stacks. Next, the pilot should be ask to select one set of environmental conditions (one card) from each stack. He should pick the card (from each stack) that contains an environment which is the most most meaningful to him. The pilot is now ask to provide a pilot rating for the task he described above while flying in each of the environments defined by each card selected (say one from each stack). Repeat the process until a card from each of the eight stacks has been rated.

Note that two stacks produced ratings of 3.5. This can be expected, it does not represent a problem. There would be a problem if half of the ratings were 2.0 and half were 4.5. Such an eventuality would mean the environmental factors were not sufficiently diverse. There should always be a spectrum of ratings from low to high.

The engineer now has some insight into what the pilot expects to happen in flight for a spectrum of environmental conditions. It is altogether possible that all of this planning/analysis will reveal that the task is a poor candidate task for evaluation in flight because the task is insensitive to the environment and involves very little stress. In other words, who cares? The engineer is interested in identifying realistic but difficult tasks to insure there is no potential safety of flight problems.

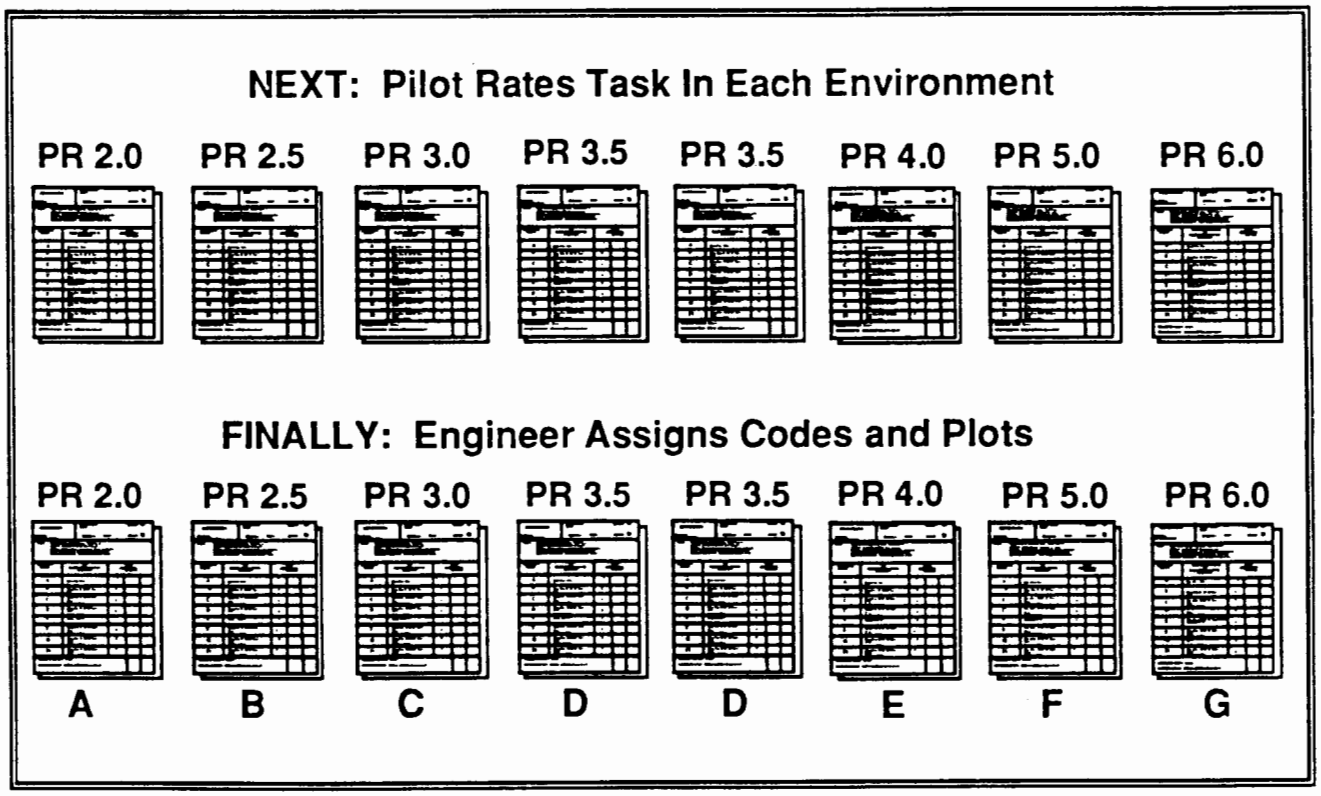


FIGURE 3-5: Method To Define Environmental Situation To Utilize During A Flight Evaluation

ESTABLISHING BASELINE DATA

It seems logical to define the ability of a pilot to fly the subject aircraft during daylight hours before considering the aircraft's suitability during night (unaided) or NVG operations. For example, one might decide to define the aircraft in terms of Pilot Rating for a turbulent day time cruise task conducted at 60 knots and at 140 knots.

To do this, the pilot would fly the aircraft on a clear day with substantial low altitude turbulence. For the purposes of discussion, assume that the evaluation pilot flys on a turbulent day and rates the aircraft as a 3.5 while flying at 60 knots and 4.5 at 140 knots. The aircraft was significantly easier to fly at 60 knots.

One would expect that a pilot flying at night would find it more difficult to fly under the same level of turbulence. Assume that this suspicion was confirmed by our pilot who flew on a clear but turbulent night and rated the cruise task 4.5 at 60 knots and 5.5 at 140 knots. The turbulent day and turbulent night pilot ratings are plotted in Figure 3-6 and provide us with useful reference points for considering the use of NVGs. These are base-line data points. The "day" data points define the best we can expect from this aircraft. The "night-unaided" data points define the worst one should expect. If the NVG actually provide useful vision aid, the related PR's should fall between the day and night-unaided data.

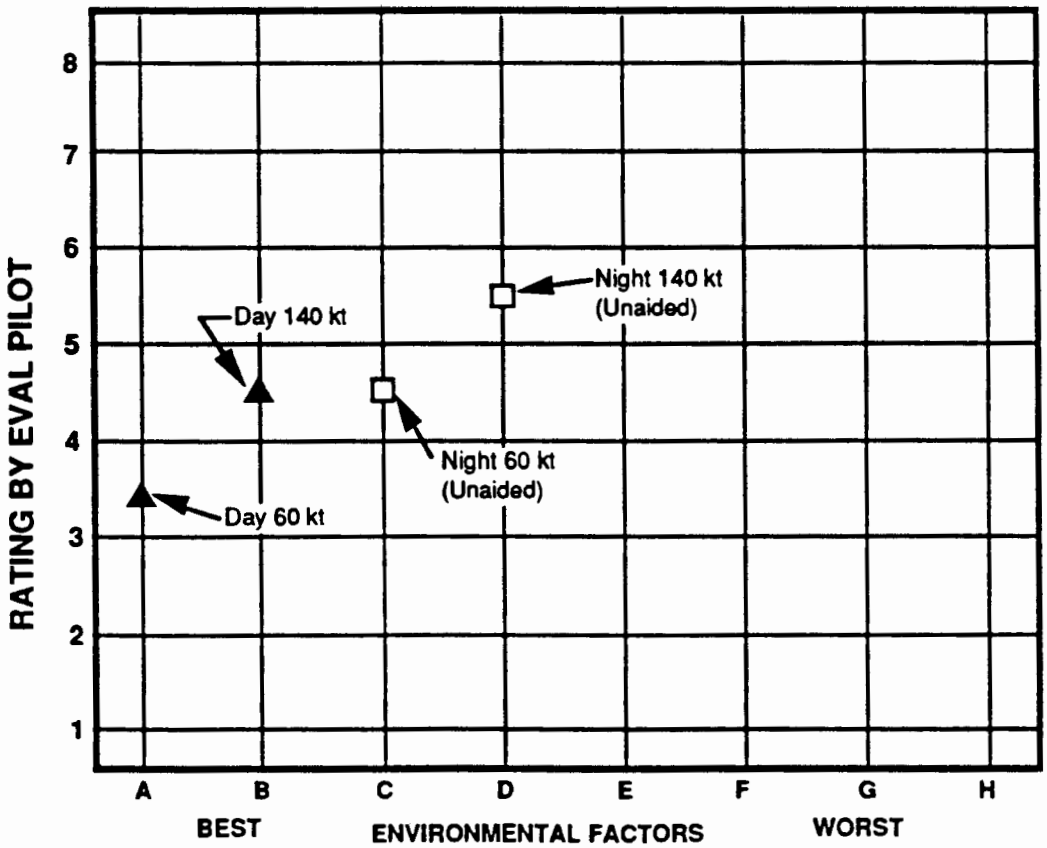


FIGURE 3-6: Developing Reference Points For NVG Evaluation

AIRSPEED CHANGES CAN REDEFINE THE TASK

The data in Figure 3-6 also suggests that a pilot can reduce workload by slowing down; but slowing down is in effect changing the task. That is, the 60 KT task is easier than the 140 KT task. This is alright because slowing down is the sort of alternative action pilots will select if the workload gets unacceptably high. Problems arise in situations where workload relief alternatives do not exist. Alternatives are important because pilots are expected to use good judgement and take advantage of alternatives to reduce workload and insure continued safe operations. Pilots and engineers must always be alert for high workload situations where there are no ready alternatives which allow a workload reduction.

ESTABLISHING OBJECTIVE LIMITATIONS

Most pilots set objective limits for themselves. That is, they use good judgement and elect to avoid operational situations which will require considerable skill or luck and high pilot work load to maintain safe flight operations. For example, while an aircraft can be flown safely at a pilot rating of "6", one can assume that most pilots will avoid routine operations at a pilot rating of 5 or greater. For this example, assume the pilot's objective is to operate at a PR of "4.5" or less. Thus operations at PRs above 4.5 would be considered tolerable, but unplanned excursions to PRs of 5 or more will be avoided and if encountered, they will be terminated as soon as prudently possible. The data from Figure 3-6 has been re-plotted in Figure 3-7 to illustrate the connection between the "objective maximum rating" and the "max PR" for safe flight.

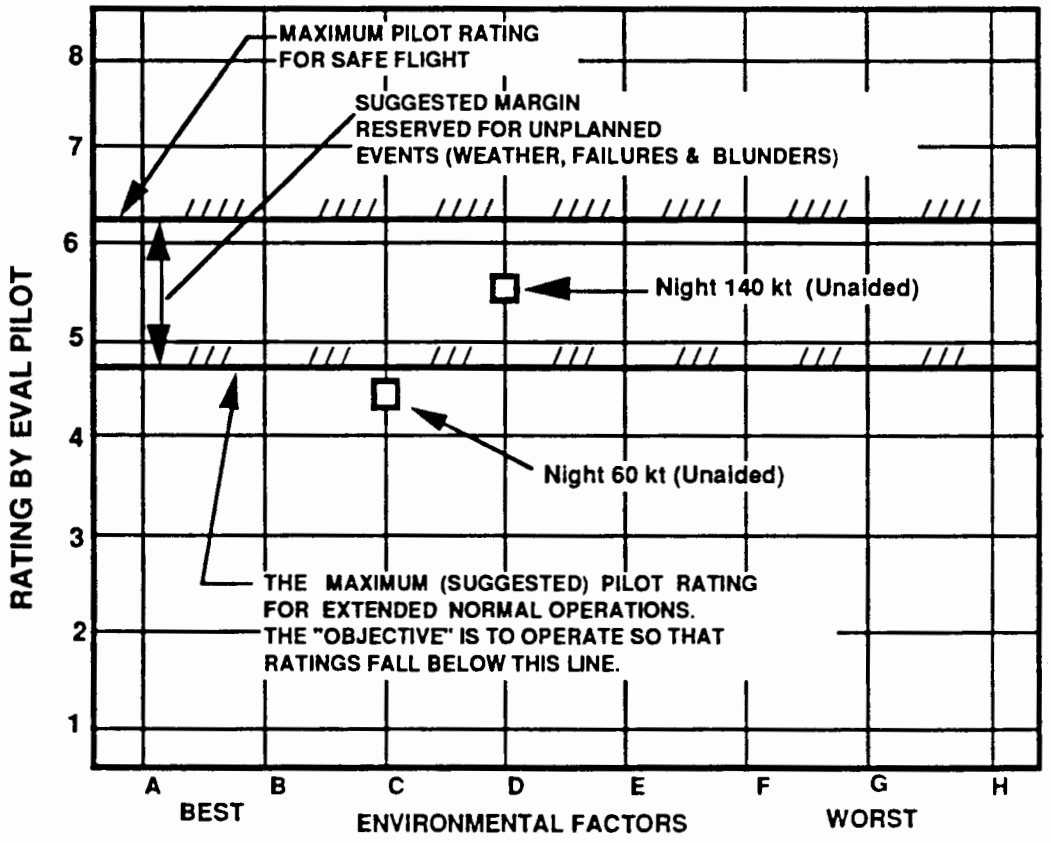


FIGURE 3-7: Establishing Workload Limits

ENVIRONMENTAL LIMITS

Normal VFR night operations are defined in the FARs and in some cases (e.g., EMS operators) additional constrains are imposed. Such limits can be depicted on a graphic as shown in Figure 3-8. This figure suggests that a Part 91 operator can operate into a more adverse environment than a Part 135 (EMS) operator. The FARs can be interpreted as requiring a greater margin of safety for certain types of operation. Regardless of how you look at the reasoning, different environmental limits are routinely established as a function of training, equipment, etc.

Thus limiting (FAR) environments are important and need to be defined and portrayed. The data plotted in Figure 3-8 falls below the max objective PR for operations which observe the environmental limits established by Part 135. In contrast, a pilot rating of "5" has been assigned to the limit environment which Part 91 operators must observe. That does not mean that continued operations under these conditions will result in unsafe flight. It does mean the workload allowed by Part 91 for the subject aircraft is on the high side. Two pilots could reduce the significance of this situation. Conversely, a long flight by a single pilot could expect to result in pilot fatigue and a reduced margin of flight safety, decreasing with time.

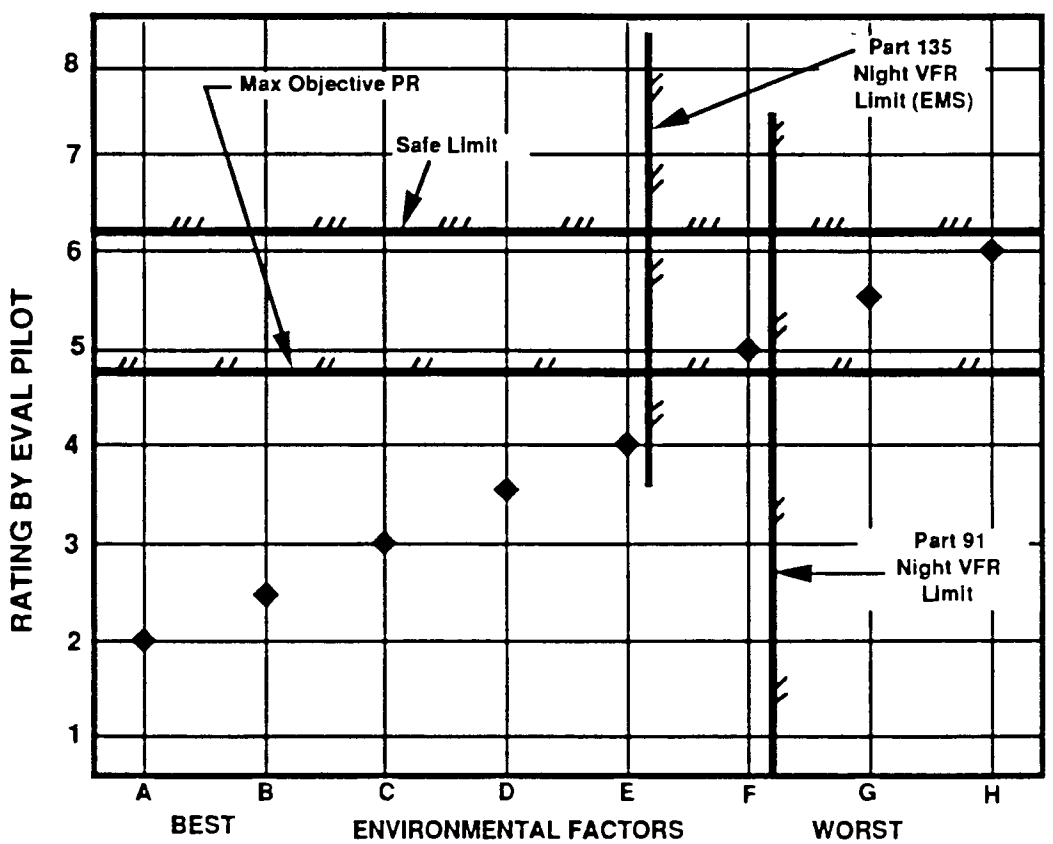


FIGURE 3-8: Pilot Rating Data For Turbulent En Route Operations At 140 Knots, At Night

SECTION 4

SELECTING TASKS FOR EVALUATION

INTRODUCTION

Selecting and defining the most important flight phases is more difficult than most engineers recognize. This section is intended to provide ideas to help the process.

OBJECTIVE OF THE TEST, AN ASSUMPTION

The primary objective of this test program is to determine if the use of NVGs by civil helicopter pilots will prohibitively degrade flight safety. This program should investigate normal flight operations with excursions into unusual operation to insure that adequate margins of safety can be maintained. The secondary objective is to identify the operational advantages and flight safety improvements (if any) which can be realized by the proper use of NVGs.

It is assumed that both of the above objectives must be addressed in context with:

(A) three types of NVGs (Gen II, Gen II+, and Gen III), and

(B) at least four modes of flight:

[1] en route, contact flight,
[2] aided descent to unaided visual flight/high-hover,
[3] wave-off from high hover to departure altitude,
[4] transition to aided flight during climb out to en route, contact flight.

SUGGESTED DEFINITIONS - PHRASEOLOGY

The following are offered as a starting point in the process of developing new terms and definitions to use in the planning and reporting process.

Normal Operations. These are operations which are considered routine. The category includes good and bad conditions, easy and difficult but all within the realm of the expected.

Emergency Operations. When an engine fails, an emergency is said to exist. If the aircraft has four engines, the term "deferred emergency" may be applicable.

Extreme Adverse Weather. When an aircraft enters a weather condition which is unusual and normally avoided by even a highly skilled pilot, and the effect is equivalent to a "deferred emergency", the condition is said to be a situation of Extreme Adverse Weather.

Standard Procedures. Standard Procedures are the procedures taught in flight schools, defined in FAA documentation, included in Operations Manuals, etc. They are learned and practiced.

Precision Maneuvers. Some maneuvers require small inputs, low roll, pitch and yaw rates, with the objective being able to operate in a near equilibrium condition (stabilized flight) at all times, with gradual speed changes. Instrument flight requires this type of maneuvering.

Aggressive Agile Maneuvers. Large control displacements are typically required to accomplish agile maneuvering. Visual maneuvers to avoid obstruction or stop abruptly are such maneuvers (agile maneuvering).

SELECTING TASKS FOR EVALUATION

One of the most important steps to accomplish early in the planning phase involves picking the flight tasks which both: (1) represents the best approximation of the expected flight profile to be flown by the eventual users, and (2) includes tasks which allows the pilot to evaluate all potential (safety of flight) problem areas. Table 4-1 has been developed for use as a starting point for defining the Flight Phases and the typical sub-tasks within each of the phases of flight. The pilot engineer team should construct such a summary to use as a check list. That is, this sort of listing can be reviewed to determine where problems may exist and to determine what sort of flight maneuver (or profile) a test pilot should fly to simulate the projected use of the aircraft and evaluate that use. All alternative tasks may not be evaluated in flight, but all need to be considered.

TABLE 4-1

Example Flight Phases And Primary Sub-Tasks

(1) En route	(2) Arrival
(A) flight control	(A) flight control
(B) contact navigation	(B) contact navigation
	(C) mission reconnaissance
(3) Descent to high hover	(4) High hover to landing
(A) flight control	(A) flight control
(B) circling recon	(B) position for vertical descent
(C) circling descent	(C) vertical descent
(D) deceleration to high hover	(D) lower hover
	(E) touchdown
(5) Remote take-off, climb to en route	(6) Wave-off from high hover
(A) flight control	(A) flight control
(B) lift-off	(B) application of power/initial climb
(C) vertical climb	
(D) acceleration, climb, obstruction avoidance	(C) acceleration, climb, obstruction avoidance

The following Tables (4-2 through 4-5) provide an expanded view of a few tasks which may be considered applicable to the evaluation of NVG operations.

TABLE 4-2
Pilot's Tasks En Route

A. SEPARATION FROM OTHER AIRCRAFT

B. NAVIGATE (CONTACT, CLOSE)

- DETECT SURFACE FEATURES
- ID SURFACE FEATURES

C. AIRCRAFT CONTROL

- MAINTAIN SAFE ALTITUDE
  - = SPEED, POWER MANAGEMENT
  - = SUPPRESS GUST RESPONSE (PITCH & ROLL)
- MAINTAIN SELECTED HEADING
- MANEUVER TO CONDUCT CLOSE CONTACT NAVIGATION
  - = FEATURE DETECTION
  - = FEATURE ID
  - = FEATURE FOLLOWING

TABLE 4-3
Navigate En Route

A. USE ELECTRONIC MEANS

- ❑ BACK-UP WITH CONTACT NAV

B. USE CONTACT NAV

- ❑ BACK-UP WITH ELECTRONIC NAV
  - POINT-TO-POINT EN ROUTE (DR USING ELAPSED TIME)
  - FOLLOW SURFACE FEATURE

C. IDENTIFY DESTINATION

TABLE 4-4
Arrival At Mid-Point Destination

A. CONFIRM ARRIVAL
B. CONDUCT APPROACH RECONNAISSANCE
C. CONDUCT APPROACH
❑ CONDUCT LANDING HAZARD RECONNAISSANCE
❑ DECIDE ON PRE-LANDING FLIGHT PATH
D. HOVER-AIR TAXI-HOVER-LAND OR
E. WAVE-OFF

TABLE 4-5
Depart Mid-Point Destination

A. TAKE-OFF-CLIMB-ACCELERATE
B. LEVEL OFF AT SAFE EN ROUTE ALTITUDE
C. TURN TO EN ROUTE HEADING, PROCEED EN ROUTE

CHARACTERIZING THE VISUAL PART OF A TASK

Figures 4-1, 4-2, 4-3, and 4-4 were developed and are offered as reference starting points to help expand the definition of the pilot's task. These figures provide a summary of man made and natural features which in some cases will provide needed navigation reference data. In other situations, the features may represent hazards to be avoided. In either case, such detail is part of the task and needs to be recorded during flight. Likewise to insure an adequate scope of test has been planned, it is useful to use such detail to define the kinds of terrain which provide different kinds of challenge to the pilot or equipment being evaluated (in a variety of environments).

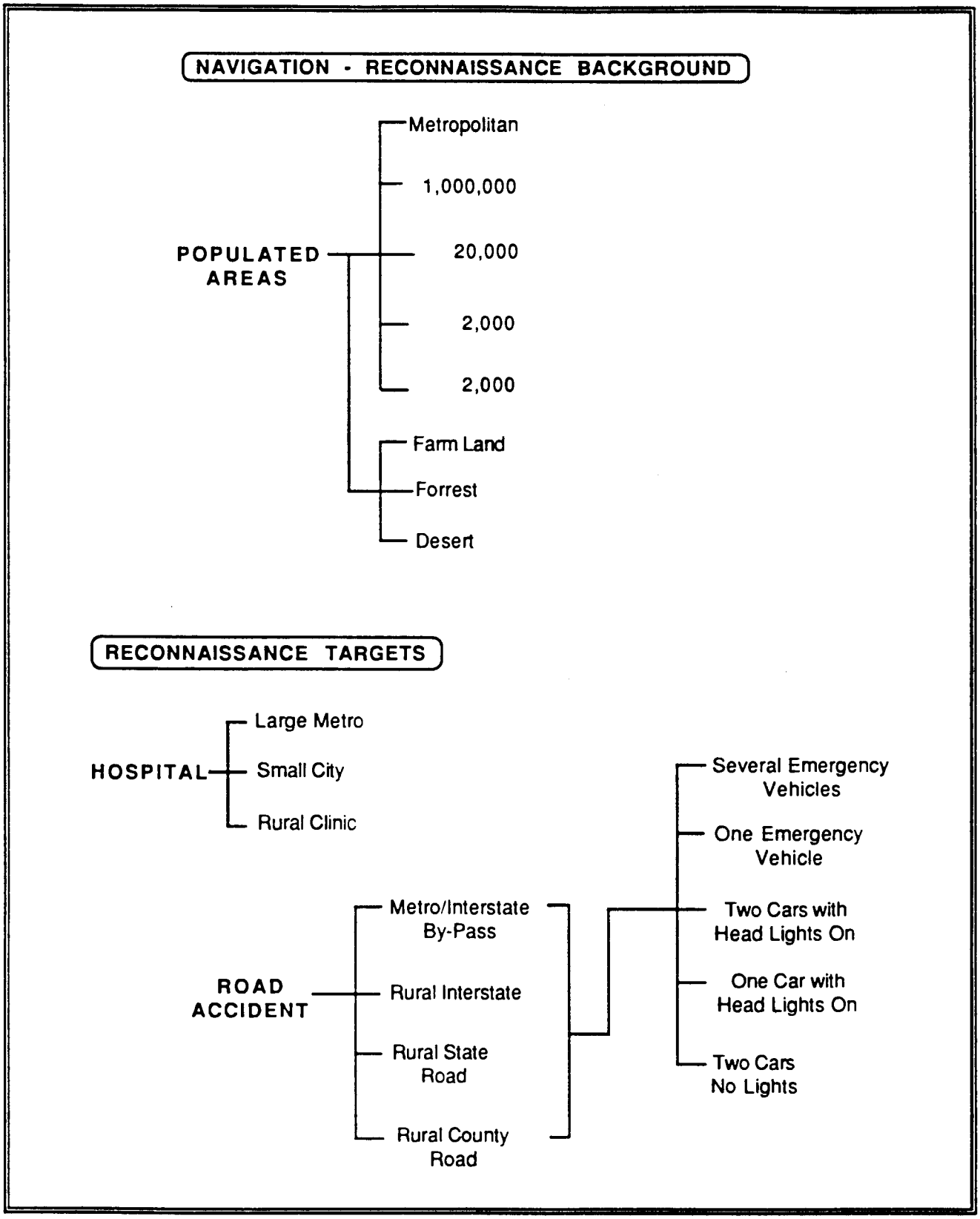


FIGURE 4-1: Factors To Consider When Defining And Evaluating Visual Operations

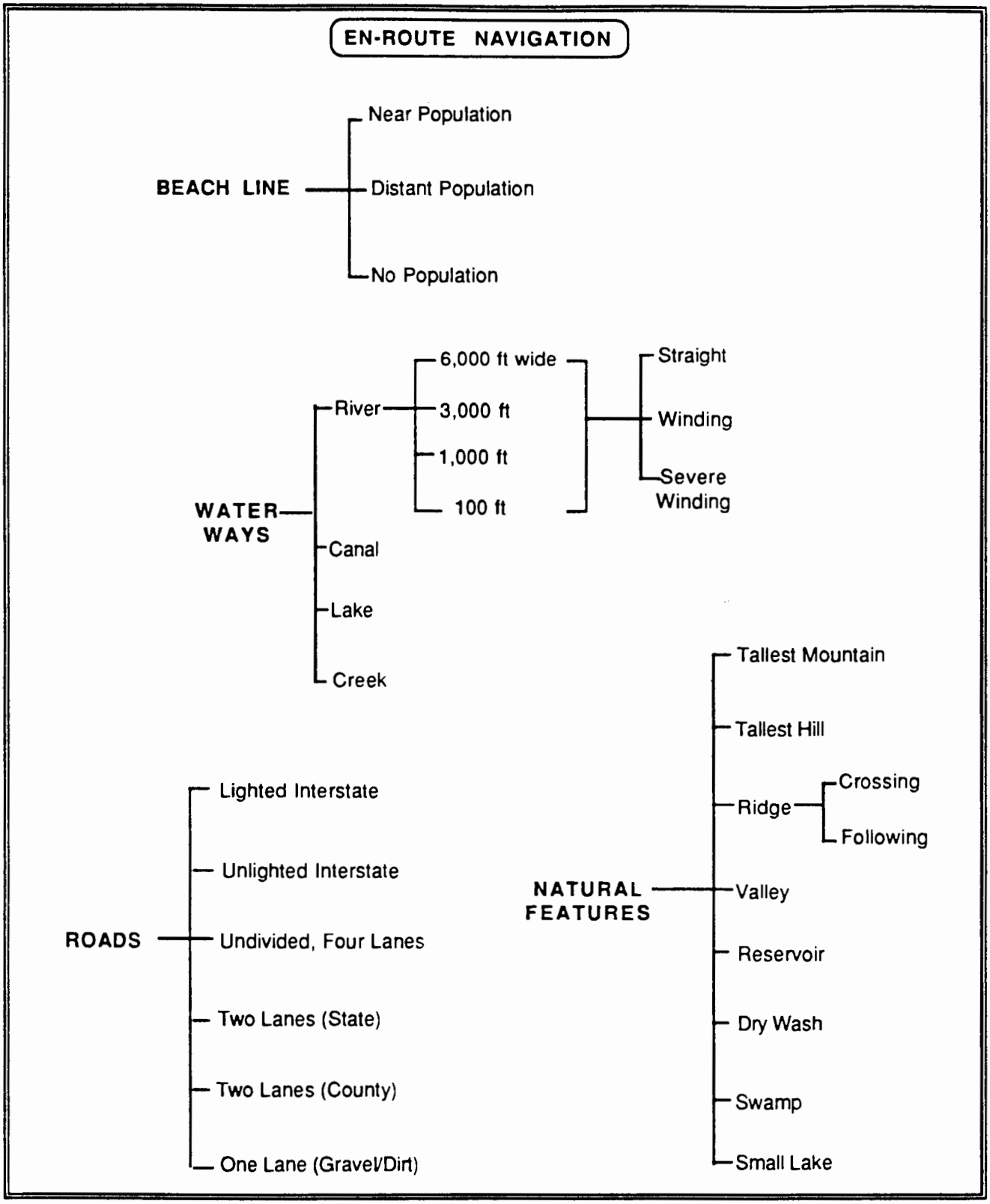


FIGURE 4-2: En Route Navigation

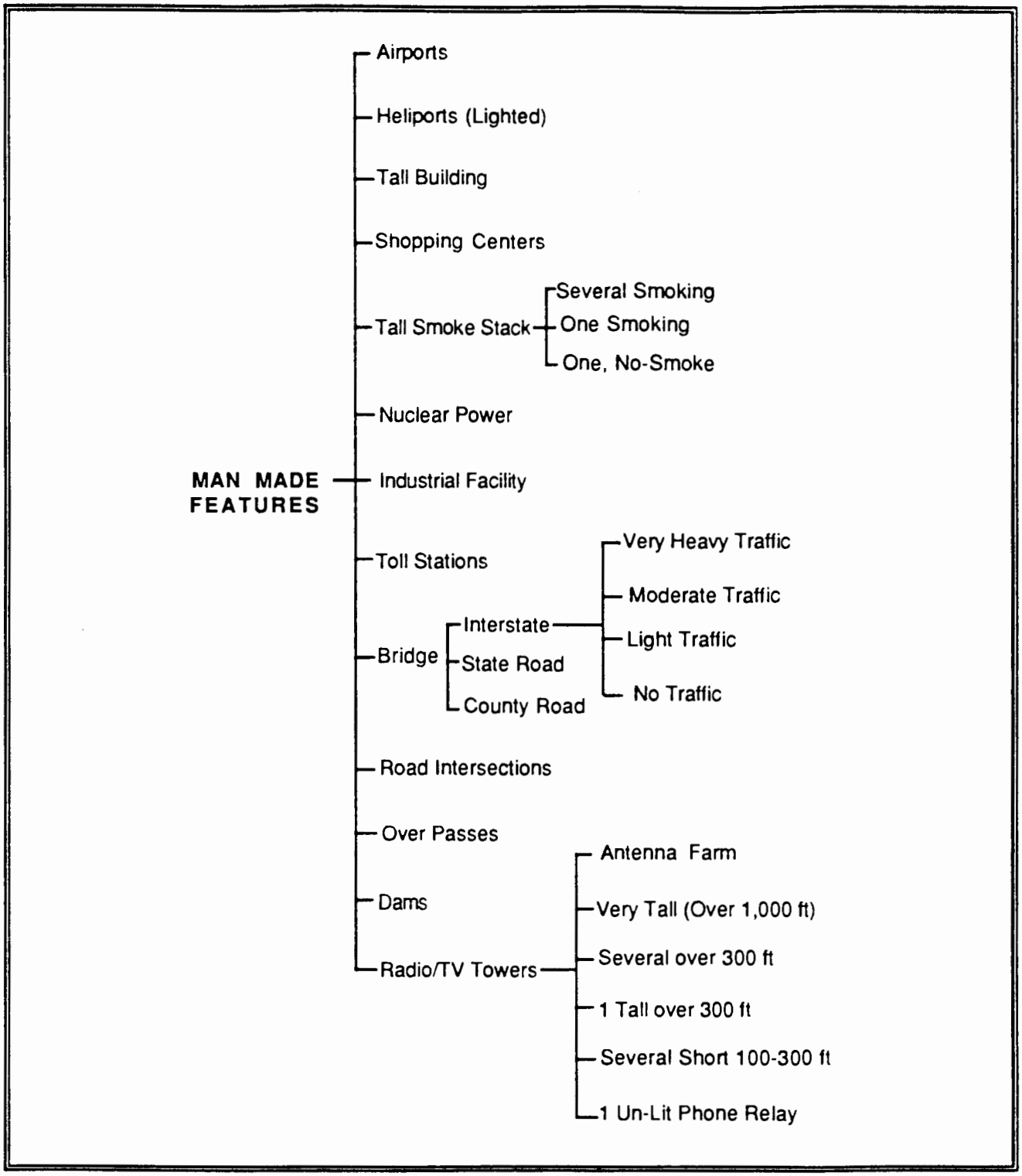


FIGURE 4-3: En Route Navigation (Continuation)

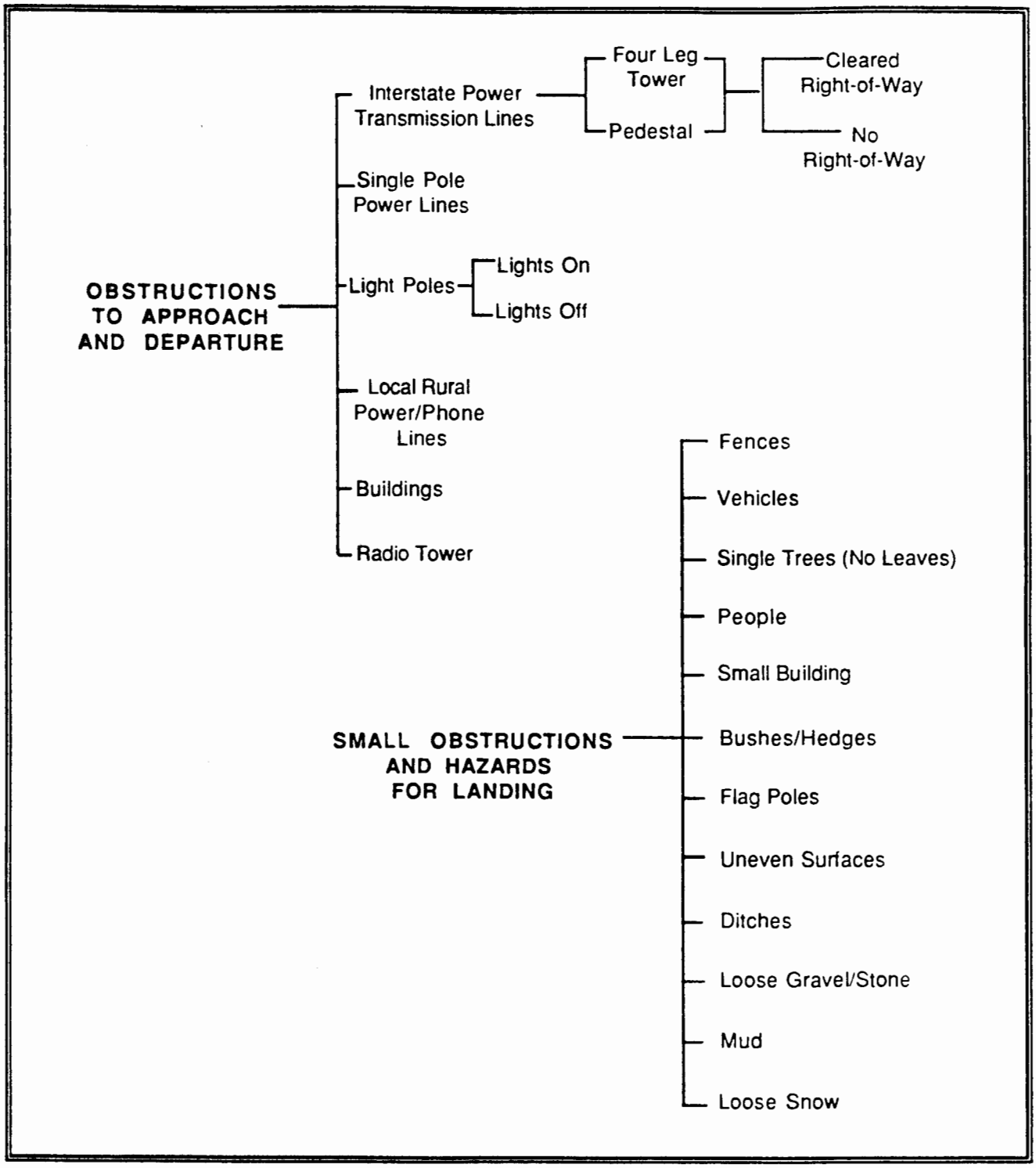


FIGURE 4-4: Approach, Landing And Departure

NORMAL PROCEDURES

Experience has shown that the procedures used to conduct night operations are different than those used to conduct day operations. Logic would also suggest that NVG procedures will also be different than those used for unaided night operations.

Common logic would also suggest that NVG procedures will vary from pilot to pilot if all pilots are not ask to follow standard procedures. Some pilots will have no useful background in NVG operations. Left to their own, these people will experiment and go thru a discovery process which may produce good or bad results. Pilots with extensive Army NOE-NVG experience may attempt to follow procedures which are mandatory for NOE operation but inappropriate for civil operations.

This observation seems to establish a need to define the procedures pilots are expected to follow. These procedures need not be extensive or highly detailed but sufficient to avoid the unnecessary introduction of scatter in the data. That is, there is no need for each pilot to develop procedures through experimentation. On the other hand, there is every reason to expect that one or more pilots (ideally three) should experiment with procedures to define the procedures which will provide the best results.

The need for standard procedures suggest that, once these procedures are established, the procedures will need to be validated prior to commencing the test. Procedures must be selected so as to help the crew accommodate to degraded operations introduced as the result of stress factors.

SUGGESTED PROCEDURES

Procedures have been developed for adjustment of NVGs for civil operations and are included in **Part I** of the "Evaluation Pilot's Guide". **Part I** also includes suggested scanning techniques, procedures for en route operations and for arrival and departure from an objective area. These are provided as a point of departure and should be modified as experience in gained.

Part II of the EPG (Evaluation Pilot's Guide) includes procedures for descent to and departure from:

- Lighted Airport / Heliport
- Brightly Lighted Areas
- Remote (dark) Sites

Both parts of the EPG contain illustrations to aid in efforts to depict the related procedures. In addition, **Part II** contains a series of illustrations which characterizes the use of landing lights, search lights and flood lights during aided and unaided flight.

RECOVERY FROM A PILOT BLUNDER, KEY TO SAFE OPERATIONS

Pilot Will Blunder. The FAA recognizes that pilots will err from time to time. These errors are sometimes errors in judgement or as the result of an event which has distracted the pilot and caused him to break a habit pattern. Maybe the pilot is tired and shouldn't even be night flying. Regardless of the cause, the FAA recognizes such events do happen.

Safety Margin Must Account For An Occasional Blunder. Realizing that such problems occur, the FAA expects that all operations will be conducted with adequate margins of safety. That is, the margin of safety must be sufficient to allow a pilot to recover from a blunder without undue hazard to the passengers, or to the aircraft, or to the people on the ground.

With the above in mind, there is a need to reflect on the potential miss application of the NVGs. It is recognized that an otherwise qualified (but bored or a highly inquisitive) pilot may experiment with NVGs. After some analysis, it would appear that take-off and landing operations represent the conditions where such experimentation could result in unsafe flight operations. This observation dictates that the potential of such operations should be explored.

Evaluation Of Blunders Is Required. Assume the FAA concludes that NVGs should not be employed during take-off or landing operations because of the potential for blunders and or the unexpected introduction of white light into the pilot's field of view during operations near the ground. To evaluate the potential for problems during near ground operations, it is realistic to consider asking evaluation pilots to take-off from both dark and lighted sites as well as land at both dark and lighted sites, using NVG aided vision as the primary vision mode. The pilot may be asked to simulate "blunder" type errors on top of violating the prohibition against using NVGs for approach - landing - take-off. In particular, these trials are explored to determine if there is any probability that a pilot will instinctively react in the wrong way (blunder) when an unexpected light degrades the pilot's NVG (aided) vision. That is, instead of instinctively looking away from a bright light, is there any reason to think a pilot might become fixated on the light, or have any other potentially unsafe reaction? It would seem natural for a pilot to quickly look away from a light which degraded NVG aided vision in an instinctive effort to regain normal aided vision or to switch from aided to unaided vision (looking under or around the goggles). A parallel is found on the highway when a car comes over a hill with its lights on "high", shining into the eyes of the on coming driver. This driver is momentarily blinded, but quickly looks away (sometimes at the edge of the road) until the car passes.

Comparative Potential For Misuse. In another case, a pilot might elect to attempt a landing with NVG aided vision. Is there any possibility that a pilot attempting to land with NVGs will touch down with sufficient drift to cause the aircraft to roll over (or any other such problem) before the pilot can recover to a hover? Is this possibility more likely to happen during NVG operations or when a pilot attempts to land with no lights at all? Which is more likely? Both would violate prudential rules for safe flight operations.

This evaluation must recognize that a pilot who attempts to land into a dark area, with no lights on, is in violation of safe and logical procedures. To attempt to use goggles under such conditions represents a second violation. This dual or compound violation would appear to be an irrational act and may be beyond the scope of interest to the FAA (other than to insure pilots were trained and tested as to their knowledge of the approved constraints for the use of NVGs).

The related questions are so important, there is a need to determine the facts in flight. The idea is to check the reaction of real pilots (in a real flight situation) as opposed to relying on hypothesis.

SECTION 5

PLANNING THE SCOPE OF TEST AND REPORTING TEST RESULTS

INTRODUCTION

This section provides a suggested approach to defining a scope of test to meet test objectives and remain affordable. It also provides a few example data plots which illustrate a number of data presentation alternatives not yet explored. Finally the section suggests a format for preparing memorandum reports of test results.

AN INITIAL SCOPE OF TEST

Table 5-1 identifies three states of the aircraft for evaluation (Normal, Failure #1 and Failure #2). Starting with the "Normal State", the table suggests that the aircraft be evaluated during "Normal" and "Extreme Adverse" weather conditions. A variety of environmental factors are included in "Normal" weather, including some which produce very stressful flight situations. The "Extreme Adverse" weather situation represents a very high stress situation which pilots are expected to first cope with then extricate themselves as soon as possible. In both weather cases, the test team should come up with one or two blunders which a pilot might commit. The blunder associated with good weather and the"Normal State" if the aircraft might characterize the sort of dumb thing an inexperienced pilot might do in a moment of experimentation. In the case where the weather is very bad, the blunder would be represent the act of a highly stressed pilot of normal skill.

TABLE 5-1
Example Summary Matrix Of Evaluation Objectives

AIRCRAFT STATE	WEATHER	STANDARD PROCEDURES	PROBABLE BLUNDER #1	PROBABLE BLUNDER #2
Normal	Normal	(a)	(g)	(m)
	Extreme Adverse	(b)	(h)	(n)
Failure Mode #1	Normal	(c)	(i)	(o)
	Extreme Adverse	(d)	(j)	(p)
Failure Mode #2	Normal	(e)	(k)	(q)
	Extreme Adverse	(f)	(l)	(r)

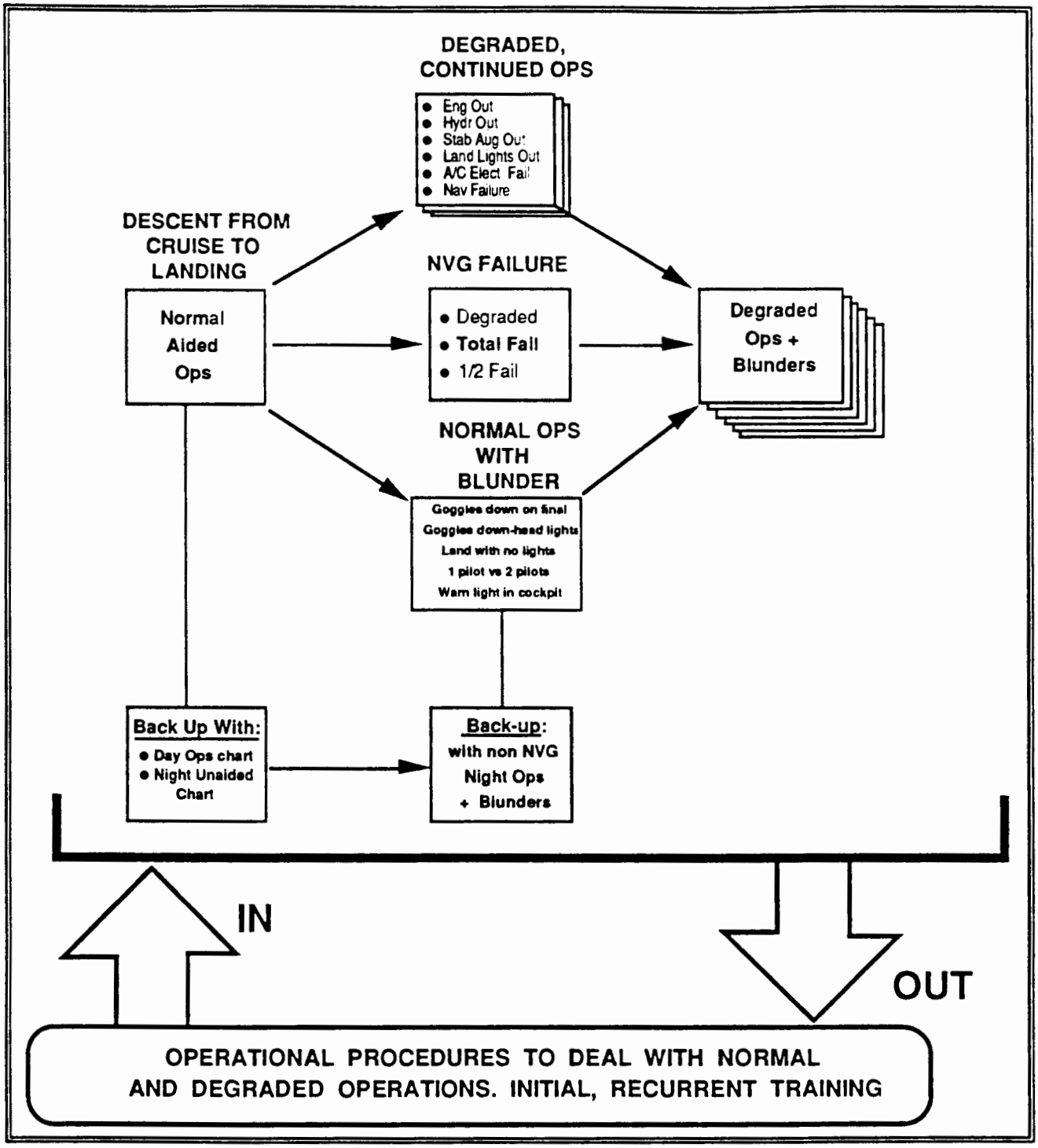


FIGURE 5-1: Proposed Application Of Task Evaluation Charts To Support Analysis Of NVG Test Results.

TESTING TO DISCOVER FATAL FLAWS

Figure 5-1 shows how the conduct of a single task (Descent from cruise to landing) can be evaluated in terms of degraded operations and pilot blunders. The "normal state" will typically never produce an unsafe condition. Unsafe or dangerous conditions will normally become evident when failure modes (sometimes in combination with pilot blunders) occur

under difficult environmental conditions. Thus, the emphasis of any safety-of-flight oriented research (or operational evaluation) should focus on these combinations. The back-up charts depicted in Figure 5-1 are important because they help substantiate the failure-blunder test results. Finally, the operational procedures box at the bottom of the figure highlight the need to establish normal, emergency and blunder-recovery procedures prior to an evaluation. The results of the test allow the procedures to be improved and validated. The procedures become a part of the report of test results.

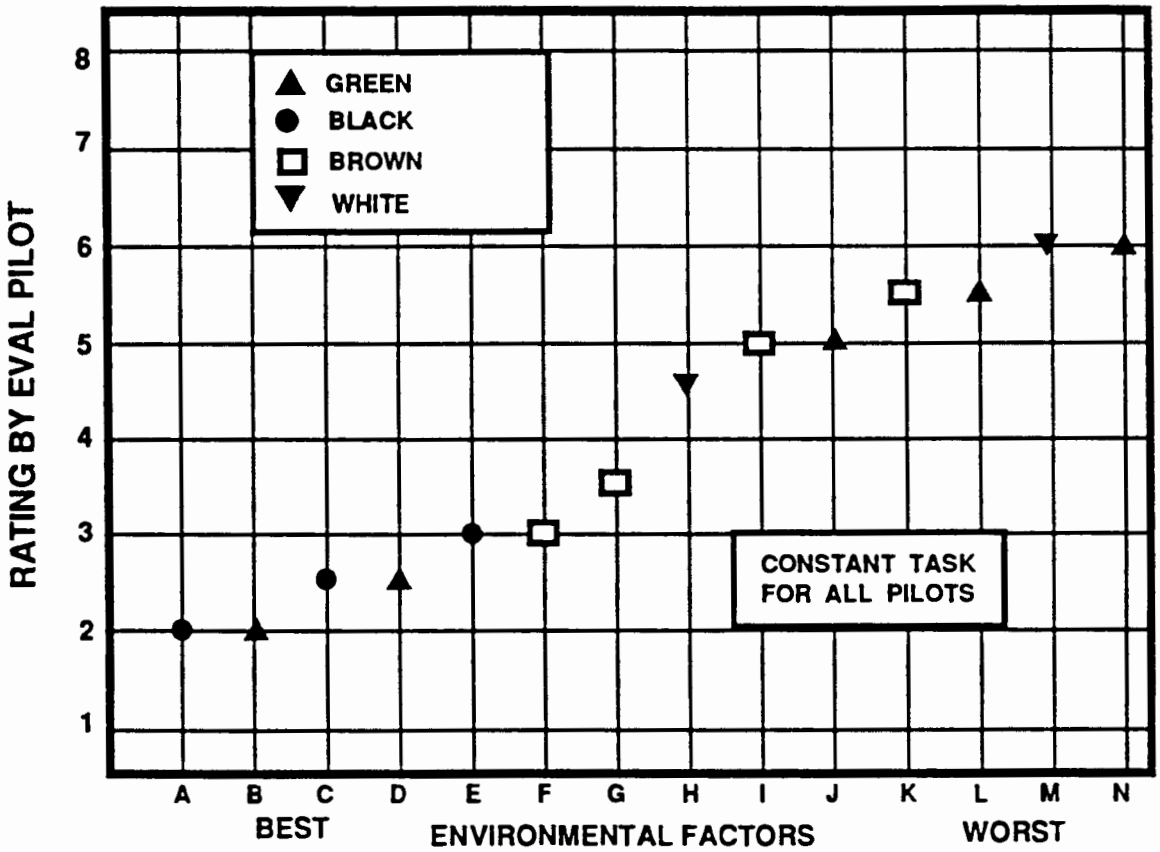


FIGURE 5-2: Data From Four Pilots Flying NVGs On Four Separate Nights Into 14 Different Environments

DEFINITIVE QUICK LOOK

Assume that on any given night, a pilot can evaluate a given task at four locations in a standard operating area. Each of these four locations is likely to produce a different set of environmental factors. In addition, the basic conditions will vary from night to night and during any given night evaluation period. As a result, it will be difficult for 2 pilots to fly exactly the same combination of environmental conditions during consecutive flights. In Figure 5-2, we find that four (4) pilots have collectively experienced 14 combinations of environmental factors. In each case, the conditions were noted and ratings were assigned. These were then plotted in ascending order of stress. This is a good way to use a few qualified pilots to accomplish a definitive evaluation in the shortest period of time and with a minimum of effort.

This approach also allows pilots to collect data and become familiar with equipment/procedures during the planning and "check-out" stage of the test.

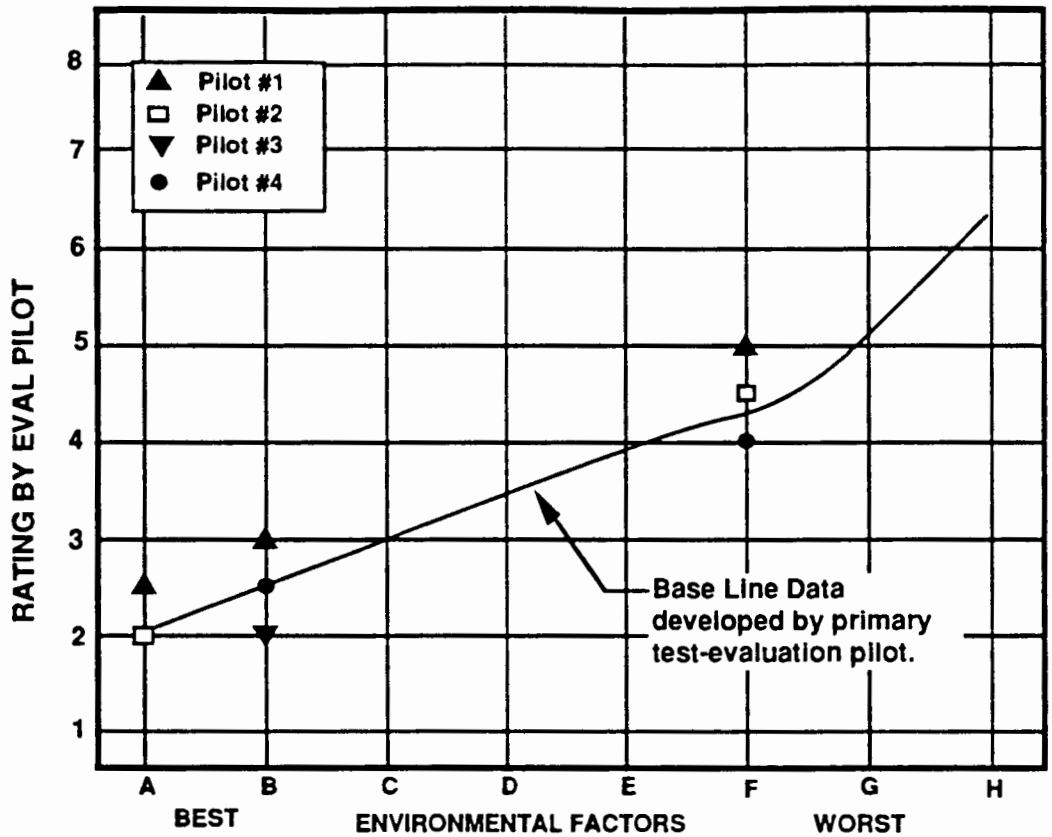


FIGURE 5-3: Example Of Using Four Pilots To Validate Engineering Data Lines

VALIDATING ENGINEERING PILOT ASSESSMENTS

Assume an engineering test pilot or several well qualified operational pilots or a combination of both establishes PR Data lines for a number of stressful operational tasks. Now the question is; how will a cross section of civil pilots compare? This question is answered by flying a representative group of pilots and comparing their reaction. The problem with this is the ability to find all of the environments needed for the flight evaluations.

The answer is found in using the non-FAA pilots to validate the FAA data base. As long as the validation data points generally fall on, or are distributed above and below (in a PR sense) the FAA derived data line, the data line is validated and findings which are developed can be attributed to the general population of civil helicopter pilots (see Figure 5-3).

When the civil data do not match the FAA data line, more flight test and/or analysis is required to resolve the apparent disagreement.

FAA TEST PILOT PROJECTED DATA LINES

Once the FAA test pilot (or pilots) are familiar with the subject aircraft and equipment, and the scope of test has been defined, it should be possible to develop a Task Evaluation Chart for each of the primary evaluation profiles (Tasks) and the blunder events the team expects to consider. These charts will be developed very early in the flight test program. Some of the

data will be based upon actual flight experience but much of the data will be derived from past experience and in some cases, data points will be projected (best estimates). See Figures 2-9 and 2-10 and related discussion to review this concept. As time passes and more data is acquired, the data points will first validate the estimated (or objective performance) and in other cases the new data will cause the earlier estimated data lines to move (up or down).

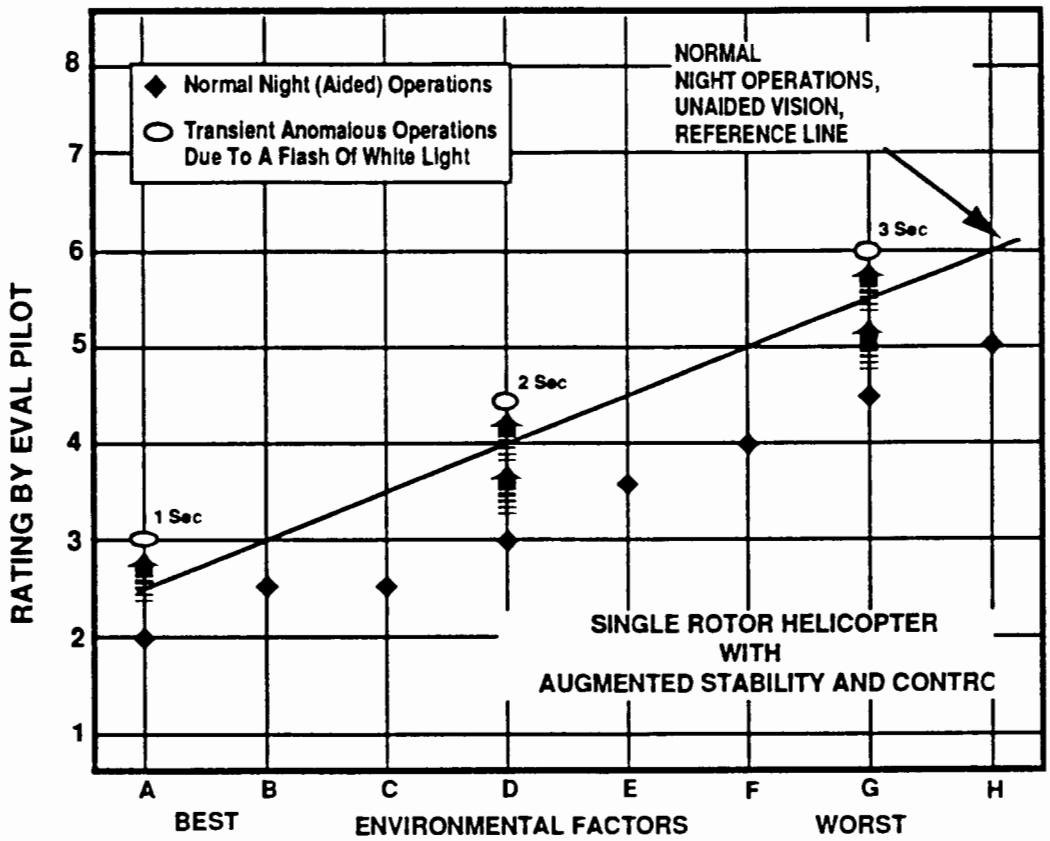


FIGURE 5-4: Chart Depicting Anomalous NVG Operations Due To The Introduction Of A Bright White Light

ANOMALOUS OPERATIONS (BLUNDERS)

The engineer is interested in the impact of certain anomalous (unexpected, blunder type) operations. If someone turned on the headlights of a car into the eyes of a pilot on a final approach to a dark confined area, this would represent anomalous operations. Something which should not happen but which could easily happen and must be considered.

There are three issues to consider here; **First**: What is the most adverse PR applicable to the introduction of the light (or other failure mode)? **Second**: What is the recovery procedure? Get off aided vision? Use a redirected scan and abort? **Third**: In each possible (logical recovery, how long does it take to re-establish normal operations (if normal operations can be established).

This kind of transient operation applies to both unaided and aided operations. It is probably instructive to define the way a pilot responds to a strong white light in the eyes during an unaided approach to a confined landing area. The results could be plotted and compared to the kind of data discussed in Figure 5-4. (**Note**: This type of analysis can be used to evaluate NVG failure modes as well).

TABLE 5-2
Typical Flight Conditions For Comparative Analysis

TEST POINT CODE	WIND & VISIBILITY	I DAY	II* NIGHT UNAIDED	III* NIGHT AIDED
A	7 KT Steady Wind On the nose Unlimited Visibility	Day	Full Moon, Bright Over Shoulder Bright Horizon Line	Full Moon, Bright Over Shoulder Bright Horizon Line
B	Zero wind Unlimited Visibility	Nominal Good Day Light Visual Cues	Decreasing Quantity and Quality of visual cues due to decreased lighting as defined by the unaided eye.	Decreasing Quantity and Quality of visual cues due to decreased lighting as defined by the unaided eye.
C	10 KT Right Cross Steady 3 mile visibility			
D	10 KT Right Cross Gusting to 15 KT 3 mile visibility			
E	15 KT RT/FWD Gusting to 22 3 mile visibility			
F	15 KT RF/FWD Gusting to 22 1 mile visibility, haze			
G	20 KT RT/FWD Gusting to 30 (peak 17 KT Cross component) 1 mile, visibility, rain			
H	20 KT RT/FWD Gusting to 30 (peak 17 KT Cross component) 1/2 NM Visibility Rain		No Sky Lighting No Moon No Star Reference No Horizon Line No Surface Light	No Sky Lighting No Moon No Star Reference No Horizon Line No Surface Light

* Spot light is available under all conditions.

BACK-UP DATA CHARTS

The following explores a series of Task Evaluation Charts which were developed to illustrate how back-up charts can be developed for the purpose of comparing unaided to aided flight, day to unaided night and augmented to unaugmented flight (failure mode). Table 5-2 was developed specifically to support these illustrations.

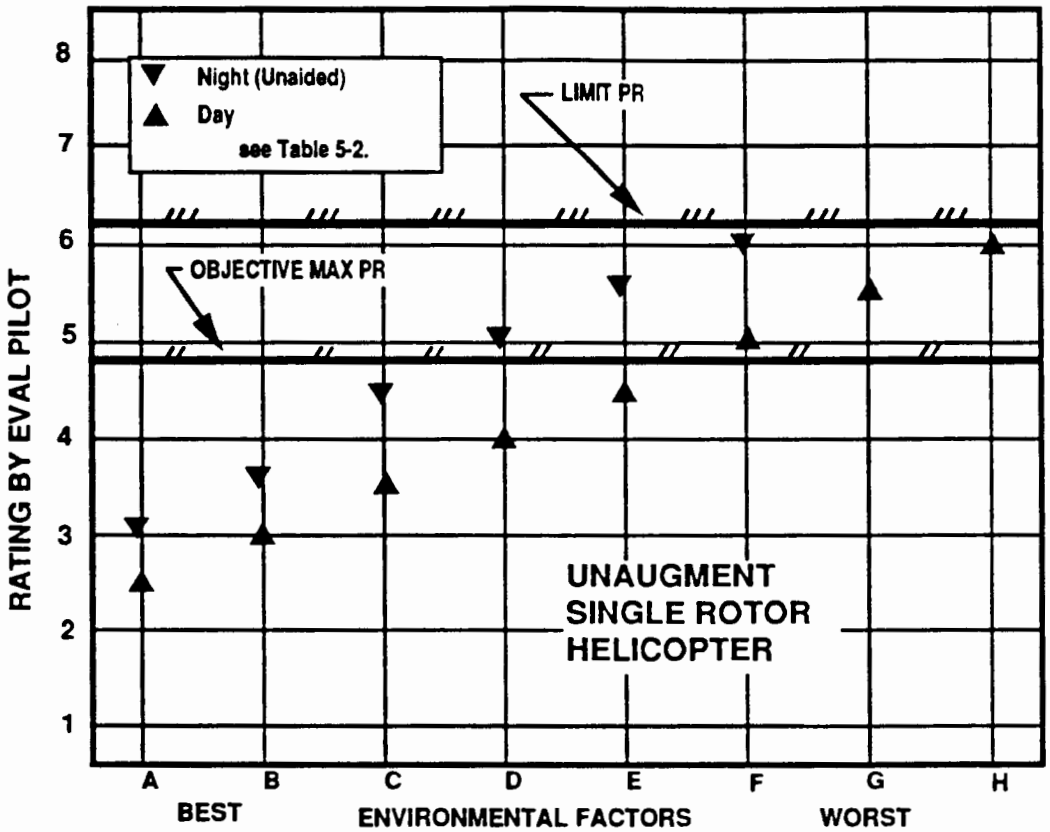


FIGURE 5-5: A Comparison Of Day And Night (Unaided) Operations For Increasingly Adverse Winds And Decreasing Visual Range (See Table 5-2).

DAY VS NIGHT OPERATIONS

The data in Figure 5-5 was developed in response to a flight program which involve the scope of test defined in Table 5-2. The data as much as anything illustrates the combined impact of adverse wind conditions and the loss of visual cues to darkness.

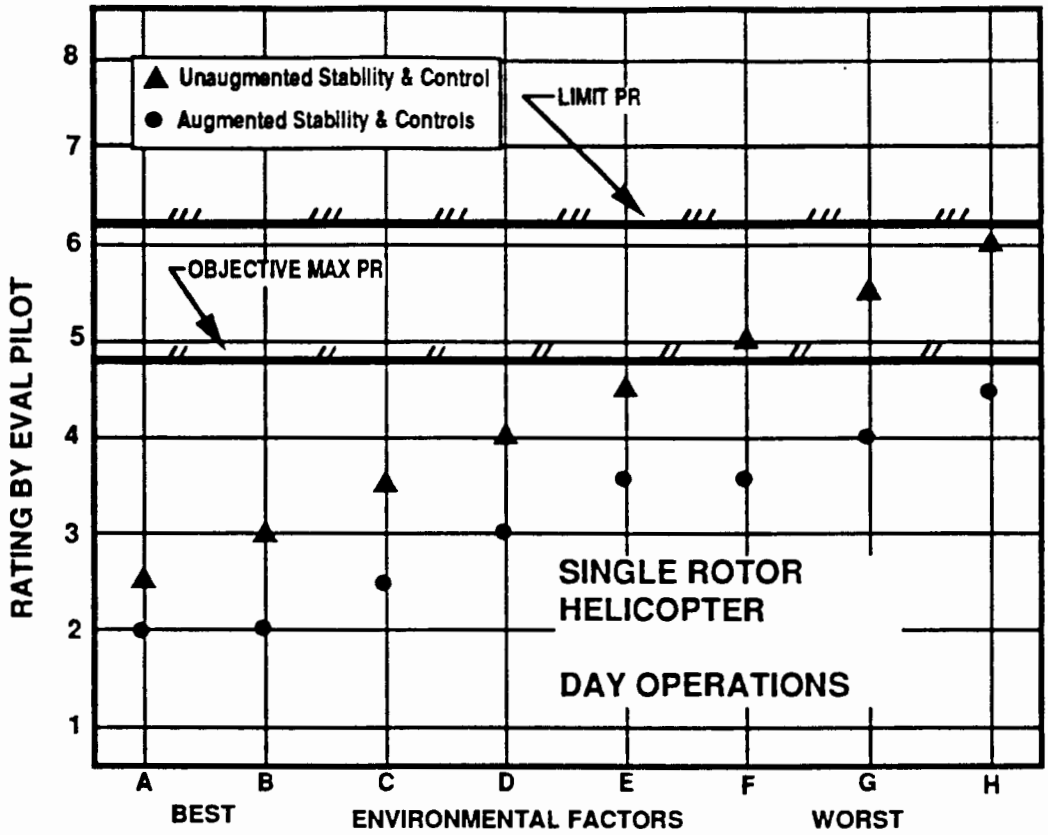


FIGURE 5-6: A Comparison Of An Augmented And Unaugmented Helicopter During Increasing Adverse Winds And Decreasing Visual Ranges (See Table 5-2)

IMPACT OF FLYING QUALITIES

The same scope of test (Table 5-2) was used to evaluate the same helicopter equipped with an excellent stability and control augmentation system. The results of this evaluation are shown in Figure 5-6. The data reflects an expected improvement in flying qualities via improved ratings. The comparison of data recorded during night operations will produce the same results. That is, the augmented helicopter will produce the better pilot ratings.

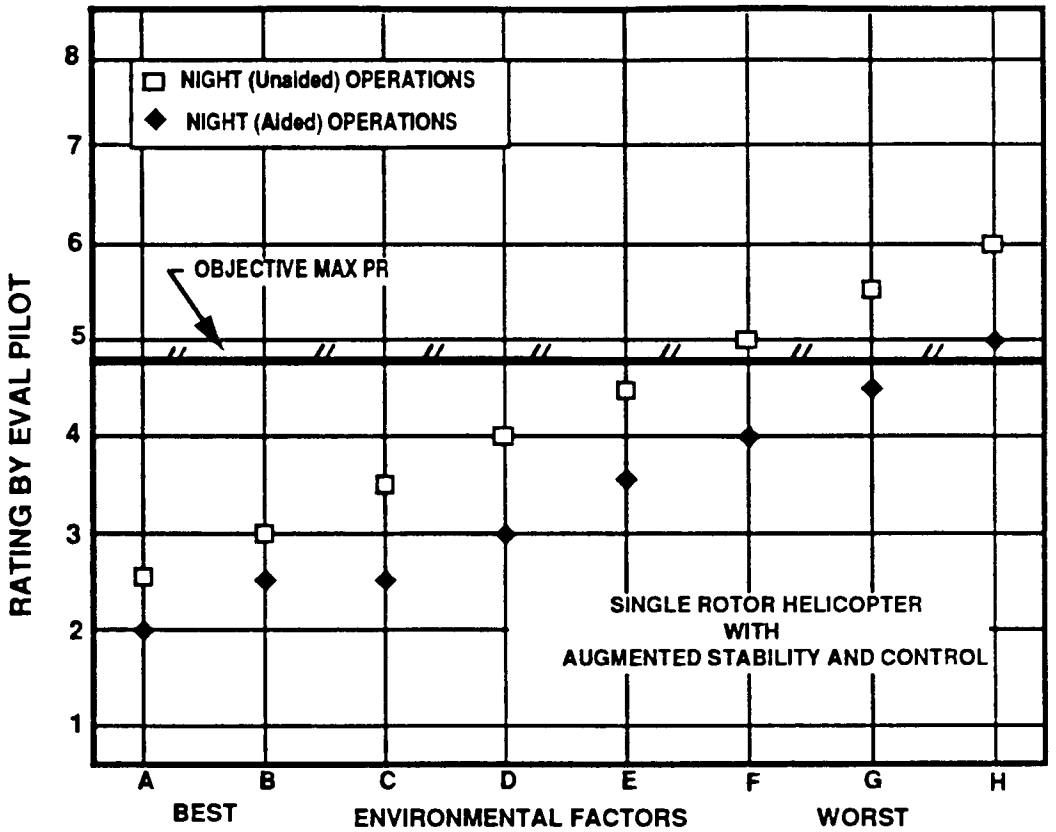
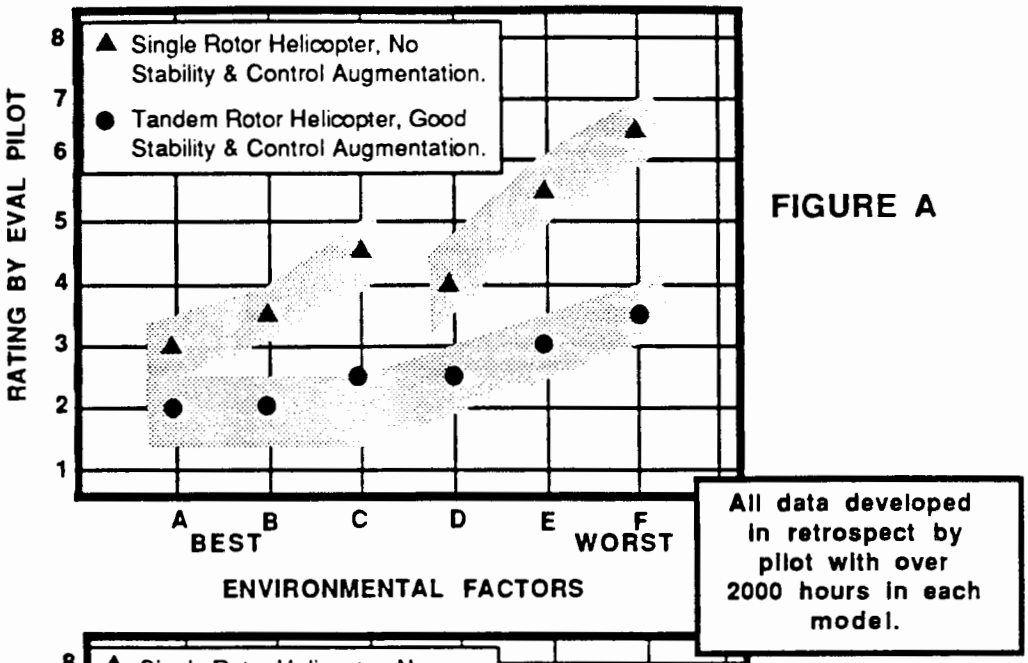
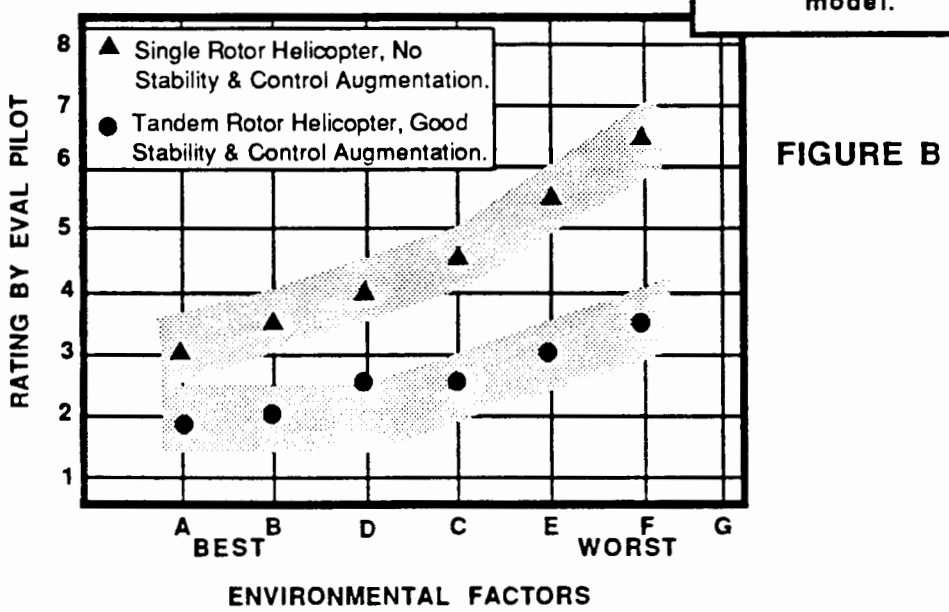


FIGURE 5-7: A Comparison Of Night Operations With And Without NVG Vision Aiding

Figure 5-7 illustrates the potential impact of NVG aided vision on highly augmented helicopters.

Two facts emerge from the preceding two figures. **First:** The benefits gained by augmenting the night visual capability of the pilot is more important to the operations of the unaugmented helicopters than to the augment helicopter. **Second:** The pilot flying the augmented helicopter will probably be able to operate into lower light levels than will the pilot flying the unaugmented aircraft.





TASK: The task involves a precision hover with a sling load being deposited into a very confined area.

A. Day, calm
B. Day, Wind On Nose, 10 KT Gusting to 15
C. Day, Right Cross Wind, 10 KT Gusting to 15
D. Bright Moon, Wind On Nose, 10 KT Gusting to 15
E. Overcast, No Sky lighting, no horizon, large object nearby for reference, Wind On Nose, 10 KT Gusting to 15
F. Overcast, No Sky lighting, no horizon, large object nearby for reference, Right Cross Wind, 10 KT Gusting to 15

FIGURE 5-8: Pilot Rating Data For A Single And Tandem Rotor Helicopter Conducting A Precision Hover Task

AN EXAMPLE OF REAL DATA

A final set of graphics, Figures 5-8A and 5-8B have been included to illustrate how a real pilot evaluated two real but very different aircraft during the accomplishment of a real task. Observe in Figure 5-8A that the ratings dropped from a 4.5 for "C" to a 4 for "D" in the case of the single rotor helicopter and there was no change in the pilots ratings for the tandem rotor helicopter under these two different environmental situations. This means that, in the case of the single rotor aircraft, the condition established by "C" was more stressful than the condition established by "D". That is, the cross wind was important to the single rotor helicopter but insignificant to the tandem rotor helicopter. In fact, the loss of the cross wind was more important in reducing workload than the loss of daylight was to increasing workload.

Thus, the environments should be reordered so that they are progressively more severe from left to right. This has been accomplished in Figure 5-8B and the result is a more orderly plot. One which is easier to compare and analyze by the general public.

BUILDING A CHARACTERIZATION OF THE TEST PROGRAM

The following steps are suggested as a way to initiate the evaluation of civil NVG operations:

(1) FAA Test Pilot(s) fly most important tasks over an extended period of time to build data base.

   a. Checks the appropriateness of operational procedures.
   b. Checks scope of test.
   c. Develops Base Line Task Evaluation Charts.

(2) FAA Test Pilot(s) team:

   a. Evaluates procedures.
   b. Spot checks base line Task Evaluation Charts.
   c. Documents related to operational procedures are improved.
   d. Scope of Test is adjusted.

(3) Operational Pilots are trained in procedures and used to validate data lines generated in Steps 1 and 2.

(4) Results are provided to the FAA to support test and evaluation activities in the regions.

TABLE 5-3
Outline Of Proposed
Memorandum Report Of Research Results

(1) FLIGHT MANEUVER TO EVALUATE

(2) TERRAIN, CHARACTERIZATION

(3) ENVIRONMENT, CHARACTERIZATION

(4) PROCEDURES

- Normal (NVGs up not less than 200 feet AGL and Landing-Hover Lights On Not less than 300 feet AGL)
- Degraded
- Blunder Avoidance

(5) RESULTS

- Normal
  = Blunders
- Degraded
  = A/C Failures
  = NVG Failures
  = Blunders

MEMORANDUM REPORT OF RESEARCH RESULTS

An abbreviated report of test results can be developed around the finding developed for each significant maneuver (task) evaluated. A suggested outline of such a report is included in Table 5-3.

APPENDIX A

TABLES OF CONTENTS FOR EVALUATION PILOT'S GUIDE, PART I AND PART II

STARMARK Corporation

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

SECOND DRAFT : 21 February 1991
REVISED: 25 February 1991

BY

David L. Green
STARMARK CORPORATION
1745 Jefferson Davis Highway, Suite 507
Arlington, Virginia 22202

Under Contract To:

SYSTEMS CONTROL TECHNOLOGY
1611 North Kent Street
Arlington, Virginia 22209

FOR

FEDERAL AVIATION ADMINISTRATION
National Headquarters
800 Independence Avenue, S.W.
Washington, D.C. 20591

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 NIGHTTIME 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

STARMARK Corporation

EVALUATION PILOT'S GUIDE (PART II)

FOR COLLECTING

CIVIL HELICOPTER PILOT ASSESSMENTS OF VFR APPROACH AND DEPARTURE OPERATIONS INVOLVING THE USE OF HELMET MOUNTED, NIGHT VISION DEVICES

FIRST DRAFT: 21 February 1991
REVISED: 25 FEBRUARY 1991

BY

David L. Green
STARMARK CORPORATION
1745 Jefferson Davis Highway, Suite 507
Arlington, Virginia 22202

Under Contract To:

SYSTEMS CONTROL TECHNOLOGY
1611 North Kent Street
Arlington, Virginia 22209

FOR

FEDERAL AVIATION ADMINISTRATION
National Headquarters
800 Independence Avenue, S.W.
Washington, D.C. 20591

TABLE OF CONTENTS

PAGE

LIST OF FIGURES ii

INTRODUCTION 1

PROGRAM OVERVIEW 1

RECOVERY FROM A PILOT BLUNDER 3

DEPARTURE FROM A BRIGHTLY LIGHTED AIRPORT OR HELIPORT 5

PILOT PROCEDURES FOR TRANSITIONING TO BRIGHTLY LIGHTED AREAS 6

ARRIVAL AND DESCENT IN PREPARATION FOR A NIGHT REMOTE SITE LANDING 7

FINAL APPROACH TO A REMOTE LANDING 14

DEPARTURE FROM A DARK, REMOTE SITE 16

LIST OF FIGURES

PAGE

FIGURE 1: CONDUCTING A RECONNAISSANCE OF AN OBJECTIVE AREA.....9

FIGURE 2: ARRIVING AT THE OBJECTIVE AREA.....10

FIGURE 3: INITIAL RECONNAISSANCE FLIGHT PATTERN.....12

FIGURE 4: PLANNING AN APPROACH.....13

FIGURE 5: FINAL APPROACH TO CONFINED LANDING AREA.....15

FIGURE 6: IDEAL NIGHT LANDING TO A PREPARED SURFACE.....18

FIGURE 7: APPROACH TO LIGHTED HELIPORT WITH FIXED LANDING LIGHT...18

FIGURE 8: LANDING AT UNLIGHTED OBSTRUCTION BOUNDED SITE WITH SPOT LIGHT.....21

FIGURE 9: LANDING AT UNLIGHTED OBSTRUCTION BOUNDED SITE WITH SPOT AND HOVER FLOOD LIGHTS.....22

FIGURE 10: LANDING AT NIGHT IN FOUR NATURAL LIGHTING ENVIRONMENTS.....23

FIGURE 11: LANDING IN OBSTRUCTION ENVIRONMENT WITH RIGHT CROSS WIND.....24

FIGURE 12: SIX LIGHTING ENVIRONMENTS ON A CLEAR NIGHT.....25

FIGURE 13: SIX LIGHTING ENVIRONMENTS ON A DARK NIGHT.....26

APPENDIX B

DIFFICULT VISUAL CONDITIONS DEFINED

APPENDIX B

DIFFICULT VISUAL CONDITIONS DEFINED

The term "visual flight conditions" refers to flight conducted under Visual Meteorological Conditions (VMC). This term does not include consideration of lighting. Lighting is not a meteorological condition and therefore is not a factor in defining VMC or Instrument Meteorological Conditions (IMC). The difficulty associated with flight during darkness has long been appreciated but night operations in the absence of any light has never been included in an integrated definition of the operational environment of aviators. The failure to adequately include lighting in the environmental short hand of aviation has produced a long term paradoxical situation for aviators required to fly on moonless nights, under an overcast and over an empty ocean. Even if the measured visibility is 100 miles, the lack of a horizon and the lack of any surface lighting causes the plot to operate under conditions which are more difficult than day operations in an overcast.

Night flight is more difficult for at least two reasons. First, the pilot must use cockpit lighting, drop lights or flash lights to achieve marginal cockpit illumination which is always inferior to the illumination naturally available in the day time. Second, the pilot must ensure safe separation from other visual traffic and at some point the pilot must locate and identify a place to land (at a minimum). This second task can be complicated by reflection in the windscreen. The fact is, that the pilot can concentrate on instrument flight when IMC but must accomplish: (1) the instrument flight task, (2) visual separation and (3) navigation tasks when operating under the difficult visual condition defined above.

Visual operation can be made more difficult by altering the task. For example, the presence of numerous aircraft flying across the pilots field of view can introduce a powerful illusion of turning. Also, if the pilot is required to fly at 100 feet above the water, the instrument flight task becomes a very precise effort, with dire consequences if the aircraft is allowed to fly into the water. The first task is difficult because it involves maneuvering relative to one or two point light sources. The second is difficult because it involves precise instrument flight in the absence of adequate depth perception.

Experience has shown that the lower a helicopter is flown over water, the better it must fly. This requirement to fly low over water was the driving force behind the development of stability augmentation for the SH-34G helicopter, followed by the development of automatic approach to hover and automatic hover, automatic flight control systems (AFCS), for the SH-34J, developments which matured into operational systems thirty five years ago.

The difficult nature of certain types of VMC operations is difficult to articulate. Only recently has there been any effort to formalize the impact of lighting on the piloting task and the need for a way to improve the visual cues or improve the flying qualities (or automate the task). Army pilots use NVG's and FLIR to improve the visual cues. Automation and improved flying qualities must accommodate the remaining need to reduce pilot compensatory workload to a tolerable level while realizing an adequate level of performance.

The term "Difficult Visual Conditions" treats a complex mix of factors, including lighting, weather and details of the task. The task is important because it contributes to the definition of a pilot's need for cues. The equipments on the aircraft, or lack of equipment, impacts upon the performance a pilot can achieve with or without cues. If the pilot cannot see anything, the task must either be: (1) so relaxed that there is no need for cues or (2) the aircraft must be so highly automated that there is no need for cues.

The use of lighting and electronic means to develop visual cues should probably be included in the definition of operations under difficult visual conditions. First, civil operators are expected to employ external lighting to establish visual cues during certain low altitude operations such as take-offs, hovers and landings. Electronic means may be found suitable for augmenting external lighting, but such a finding is beyond the scope of this report.

Day Operations. In the day time, visual cues can be impacted by the presence of fog, haze and precipitation. Visual range appears to be the important issue when defining difficult visual conditions under daylight conditions.

Difficult visual flight in forward flight at high altitude is defined as operations which are not supported by an adequate horizon line across the planned line of flight. At some point, altitude control is redefined from that of maintaining a constant pressure altitude, to selecting flight a path which considers the proximity of the earth surface and the obstructions located there upon. If heading is held constant, a pressure altitude must be selected which insures safe vertical and horizontal separation from obstructions. This type of flight can be conducted by referencing charts and pressure altitude. When the flight altitude will not permit this type of operation, the aircraft must be flown over or around macro terrain features. This requires visual contact with the surface. It logically follows that the closer the aircraft is flown to the surface, the slower it must be flown. At some point, it is either not possible or not desirable to fly over macro terrain features and the aircraft is flown so as to follow the folds of the terrain, flying around some obstructions and over others.

In approaches to hover, hovers, landings, take-offs and departures aircraft are flown at very low speeds. This changes the flying qualities of the aircraft and it changes the way the pilot closes the control loops (the hovering control laws are used as opposed to forward flight laws). If the aircraft is flown at very slow speeds, on the back side of the power curve, an additional set of vertical maneuvering characteristics come into play. The need for visual range is then found to be defined by a variety of factors including power, speed, altitude, terrain characteristics, and the objectives of the flight profile (or task).

In forward flight, at altitude, the pilot needs to have sufficient visibility to control the aircraft, identify and follow terrain (contact navigation), and find and identify the destination or objective of the flight.

At lower altitudes the pilot needs to have additional cues to maintain the minimum safe height above the terrain.

When the pilot slows for hover operation, the pilot requires another set of cues to help compensate for degraded flying qualities and to allow the accomplishment of precision positioning over the ground.

As visibility decreases, the horizon line visible over the nose is defined by the maximum visual slant range to the earth. As visibility decreases, this line is no longer visible over the nose because of the limited view down over the instrument panel. Flying lower allows the pilot to regain this visual reference. Under some conditions the aircraft must be flown slower to avoid overflying the pilot's visibility (and the dynamic ability of the aircraft to follow terrain features). Once the aircraft is very low and very slow, the need for visual range is significantly diminished. If the surrounding cues are strong, a visual range of a few hundred feet is normally more than adequate, as long as the aircraft is at or near zero ground speed. Otherwise the visibility required is that which will allow a pilot to see and stop to avoid an obstruction.

Consider the requirement to hover a small helicopter inside of a small sports arena. The visual range is quite short but the cues for hovering flight are optimized. They are below, above and equally strong 360 degrees around the aircraft. What then defines difficult visual flight in the day time?

As a starting point one can estimate the need for slow speed visual range as the distance which will be covered in the period of time equals to the sum of 5 seconds (allowed for eyes-in, eyes-out detection recognition) and the speed in knots divided by two (for deceleration). [For example, at 20 knots, 5 seconds + 20 kt/2 = 15 seconds. The distance covered in 15 seconds at 20 kts is roughly 510 feet. This would suggest a visual range of 500 feet is required to support safe hover type operations, if a strong visual cue environment exists within the near field of view.] A strong visual cue environment would include trees, rocks, bushes, buildings, runways, heliports, etc.

APPENDIX C

ALTERNATIVE PILOT RATING SCALE FOR NVG EVALUATION

EXPANDED DEFINITIONS OF PILOT RATINGS TO BE USED FOR EVALUATIONS OF FLIGHT CONTROLS AND VISUAL CUES

Revised: 18 December 1990

EXCELLENT HIGHLY DESIRABLE **(ratings for contact flying tasks)**

1.0 With regard to the flying qualities of the aircraft, the pilot feels that **excellent visual cues** are available. The pilot observes a multitude of high quality contact flight cues for flight control, navigation and surface search tasks. **Excellent situational awareness** is maintained using **relaxed, casual** external **scanning** techniques. The aircraft requires essentially no pilot initiated control activity. Flight path control of the aircraft is achieved with an **automatic flight control system** (or equivalent characteristics) that incorporates fail operate characteristics and automatic mode shifting.

1.5 With regard to the flying qualities of the aircraft, the pilot feels that generally **excellent visual cues** are available. The pilot observes a multitude of high quality contact flight cues **for two** of the three visual **tasks** (flight control, navigation and surface search tasks) with **good** visual **cues for** the **remaining. Excellent situational awareness** is maintained using relaxed, casual external scanning techniques. Flight path control of the aircraft is achieved with an **automatic flight control system** (or equivalent characteristics) that incorporates fail operate characteristics and automatic mode shifting. The pilot is expected to make occasional long term trim adjustments in up to two controls during mode shifts and during transitional flight (between flight phases).

GOOD

2.0 With regard to the flying qualities of the aircraft, the pilot feels that a sufficient number of **good external visual cues** are available. These cues allow the pilot to accurately monitor the short and long term characteristics of the aircraft and quickly adjust the trim of the aircraft. The pilot can fly the aircraft through **aggressive** constant altitude, turning and decelerating **maneuvers** in forward flight and slow speed/hover maneuvers **with ease**. There is no tendency to over control the aircraft or make corrections when they are not required. Good situational awareness is easily maintained via the available peripheral cues (eyes in) and brief periods of direct viewing. Occasional small, **very docile errors** are tolerated for extended periods because the available visual cues insure the ability to expeditious return to a zero error condition.

2.5 With regard to the flying qualities of the aircraft, the pilot feels that a sufficient number of good external visual cues are available. These cues allow the pilot to **accurately monitor** the short and long term characteristics of the **aircraft** and make corrections when required. The pilot is able to trim the aircraft and observe the buildup of errors which are known to be characteristic of the aircraft. The pilot is able to observe the error and defer correction with the knowledge that the **error characteristic is docile** and that the visual cues available will unquestionably support an expeditious return to trim.

FAIR, SOME MILDLY UNPLEASANT CHARACTERISTICS

3.0 With regard to the flying qualities of the aircraft, the pilot feels that **fair external visual cues** are available. If the pilot chooses, it is possible to accurately maneuver and trim the aircraft while referencing external cues. The pilot can **effectively control** the short term gust and cross coupling characteristics of the aircraft with **relaxed control techniques.** Two or more controls can be coordinated during power changes and entry into maneuvering flight. The aircraft can be trimmed while referencing external cues only. The need for **pilot compensation** is **predictable** and the flight task is considered easy, but continuous pilot involvement in flight control is required for precision flight. The available **situational awareness is clearly adequate** for the task.

3.5 With regard to the flying qualities of the aircraft, the pilot feels that **fair external visual cues are available**. The pilot has minor difficulty monitoring and containing the error associated with one performance parameter due to the lack of one or more important external cue characteristics. From time to time the **error** in one parameter builds up to a **bothersome** value, **requiring the pilot to observe the cockpit displays** to reduce the error to the desired value, in a timely way for precision tasks. The view of the external surroundings is sufficient and the known displacement from hazards **is** sufficiently well known to insure the pilot that the time required to conduct the **eyes-in-the-cockpit** maneuver control **will not** subject the aircraft to an **unsafe** condition. The available **situational awareness is clearly adequate** for the task.

MINOR BUT ANNOYING CHARACTERISTICS

4.0 With regard to the flying qualities of the aircraft, the pilot feels that the visual cue characteristics are adequate but the pilot must apply considerable concentration and compensation to achieve the desired performance. The pilot has considerable difficulty monitoring two performance parameters due to the absence of one or more important external cue characteristics, and is routinely distracted from the contact flying task to observe instruments to re-establish trim or reduce the residual errors to an acceptable level. The pilot is confident that the contact navigation and/or surface search task performance objectives can be met. The available **situational awareness is adequate** for the task.

4.5 With regard to the flying qualities of the aircraft, the pilot feels that the visual cue characteristics are adequate but the pilot has considerable difficulty monitoring three parameters (pitch, roll, yaw or heave) with sufficient precision. Flight path errors or observed transient attitudes become bothersome and cause the pilot to give up any attempt at precision flight. In cruise flight, the situational awareness continues to be adequate but the ability to search the surface becomes questionable. When conducting level flight maneuvers to facilitate surface search, the pilot occasionally elects to accept a substantial reduction in external scan time to reference the cockpit instruments to reduce flight path errors. The available **situational awareness is adequate** for the task although there may be occasions for concern.

MODERATELY OBJECTIONABLE CHARACTERISTICS

5.0 With regard to the flying qualities of the aircraft, the pilot feels that the visual cue characteristics are adequate but moderately objectionable. The pilot finds it very difficulty to monitor altitude and/or heading and/or speed (with sufficient precision), and conduct precision maneuvers while also conducting surface search or improving situational awareness. During cruise or slowly developing maneuvers, the pilot is able to achieve adequate performance referencing external visual cues, but **failure to stay attentive** to the flight control task can result in an **unusual attitude** or similar **departure from** the desired **flight path**, requiring the pilot to momentarily reference cockpit instruments to recover to the desired condition. The pilot is not comfortable with performance during attempts to conduct precision maneuvers and would normally modify the task to reduce the need for precision or to obtain better cues or to improve the flying qualities of the aircraft and enhance the pilot's ability to achieve the desired performance. This causes occasional **pilot concern for the situational awareness** and is considered a **moderately objectionable situation**.

5.5 With regard to the flying qualities of the aircraft, the pilot feels that the visual cue characteristics are adequate but objectionable because the pilot must spend almost full time in the flight control task to insure flight path adequate performance in context with the pilots ability to visually maintain situational awareness.. The pilot finds it very difficulty to monitor altitude and/or heading and/or speed with sufficient precision and conduct precision maneuvers while also conducting surface search or attempting to update situational awareness. During cruise or slowly developing maneuvers, the pilot is able to achieve adequate performance referencing external visual cues, but **failure to stay very attentive** to the flight control task can result in an **unusual attitude** or similar **departure from** the desired **flight path**, requiring the pilot to momentarily reference cockpit instruments to recover to the desired condition. The pilot is not satisfied with performance during attempts to conduct precision maneuvers and would normally modify the task to reduce the need for precision or to obtain better cues or to improve the flying qualities of the aircraft and enhance the pilot's ability to achieve the desired performance. This causes continual **pilot concern for the situational awareness**, and the pilot considers this an **objectionable situation**.

VERY OBJECTIONABLE BUT TOLERABLE CHARACTERISTICS

6.0 With regard to the flying qualities of the aircraft, the pilot feels that the visual cue characteristics are marginally adequate but very objectionable because the pilot is totally involved in the flight control task to insure flight path adequate performance in context with the pilots ability to visually ascertain situational awareness. The pilot finds that the need to monitor altitude and/or heading and/or speed, in order to accomplish precision maneuvers, causes to pilot to reach a near limit operating condition relative to ability to usefully scan inside and outside. **Failure to stay very attentive** to the flight control task will result in an **unusual attitude** or similar **departure from** the desired **flight path**, requiring the pilot to refer to instrument flight and abort the visual task until the aircraft is once again established in conditions which will allow the pilot to re-establish sufficient (visual) situational awareness to once again pursue the original flight objectives. The pilot is alarmed and expects to encounter periods where the combined effect of piloting performance and situational awareness represent marginally safe flight. **Pilots will not willingly fly into conditions requiring this level of effort.**