A PROGRAM FOR DETERMINING FLIGHT SIMULATOR FIELD OF VIEW REQUIREMENTS

MAJ R. YEEND, USMC
Project Pilot
and
MR. D. CARICO
Project Engineer
Rotary Wing Aircraft Test Directorate
Naval Air Test Center, Patuxent River, Maryland 20670

ABSTRACT

This paper discusses a test approach for determining the optimum field of view of a flight simulator visual system as a function of aircraft mission. The program is intended to provide the information needed to decide which portions of the aircraft's total field of view should be simulated and which can be disregarded. The approach consists of three phases: drawing board evaluation, aircraft ground testing, and flight testing. The procedure is described using the CH-46 helicopter as an illustrative example but it is applicable directly to any aircraft, fixed or rotary wing. Pilot qualitative ratings are obtained for each simulated visual configuration during specified flight maneuvers. Results from the CH-46 program indicated that a pilot/copilot oriented visual system limited the training potential for both crewmembers. The optimum configuration for the CH-46E operational flight trainer was a pilot oriented visual system.

BACKGROUND AND PURPOSE

1. Following the lead of commercial aviation, the U.S. Navy is rapidly expanding its use of flight trainers (Operational Flight Trainers and Weapons System Trainers) for pilot training and proficiency. This has been made possible by improved flight fidelity achieved through accurate duplication of actual aircraft characteristics and the addition of peripheral equipment such as audio systems, motion bases, and more recently, visual systems.

2. A visual system can significantly expand the types and quality of training possible in a flight simulator. For example, a realistic visual system provides the potential for training in the takeoff and landing regimes of flight -- two areas of high pilot workload and increased accident potential. However, this increased capability is not realized without cost as a visual system represents a significant percentage of the total expense of a trainer.

3. There are several types of visual systems for flight simulators. Each has its own particular advantages and disadvantages, as summarized in table 1.

TABLE 1.

Type	Description	Major Advantages	Major Disadvantages	Primary Areas of Applications
Computer Generated Image Night/Dusk System (Calligraphic)	TV type picture generated by a computer and special purpose digital processing equipment from a mathematical model.	High fidelity with real-world Low initial cost (1/2 to 1 Million) Low operating cost Wide FOV with multiple displays Scene changes made with software changes	Low light level display	Takeoff and landing
Day/Night System (Raster Scan)		Wide FOV with multiple displays Scene changes made with with software changes More scene content capability than night/dusk system	High initial cost (3 to 4 Million) Reduced fidelity in day scene compared with real-world Moderate operating cost	
Camera Model	Closed circuit TV picture of a scaled model of the problem area	High scene detail	Limited FOV and problem area Limited depth of focus Moderate initial cost for single channel (1 to 3 Million) Moderate to high operating cost	Low altitude slow speed maneuvers (Nap-of-the-earth flight)
Area of Interest	Camera model with high resolution target imagery superimposed on a low resolution sky/earth background	Almost unlimited FOV High resolution for target imagery	High initial cost (3 to 4 Million) High operating cost	Air to air combat

4. Ideally, the pilot flying a simulator would be presented a field of view (FOV) identical to that of the actual aircraft. However, due to cost and hardware limitations, current systems only present a limited portion of this total FOV. Program managers must assess the tradeoffs between training effectiveness and cost of a visual system when establishing the FOV requirements. Test and evaluation personnel can provide helpful information by determining which portions of the total FOV must be simulated and which could be eliminated, based upon mission requirements. This paper describes a test and evaluation method to give the program manager the information he needs to make an informed decision. No attempt is made to discuss in detail the advantages/disadvantages of visual system type or the effect of scene content and quality on pilot performance. Visual-system fidelity is discussed in detail in references (a) and (b).

COMPUTER-GENERATED IMAGERY VISUAL SYSTEM

5. The test approach presented in this paper applies directly to any visual system displaying less than the actual aircraft FOV. However, a Computer-Generated Imagery (CGI) system is used as the basis for discussion since the CH-46E Operational Flight Trainer (OFT) used a CGI system. A brief explanation of the CGI system is presented here to introduce terminology which is used later in this paper.

6. For a CGI system, a mathematical model of a particular visual scene is programmed into a computer. This scene must be mathematically defined in terms of a finite number of straight line segments or edges. The larger the capacity of the computer, the greater the number of edges available and, therefore, the more detailed the scene can be. The computer output is directed through Cathode-Ray Tubes (CRT's), similar to television picture screens. These CRT's are called windows, which is what they appear to be to the pilot in the simulator. The number of separate scenes the computer can generate simultaneously determines the number of channels a system can have. Thus, a simple system with two CRT's, one for the pilot and one for the copilot, each showing the same identical picture, would be a two-window, one-channel system. The copilot's window requires no additional computer capacity as its scene is just a repeat of the information put into the pilot's window. This two-window, one-channel system is called a pilot/copilot visual system, since the focal point of one display is the pilot's eye position and the focal point of the other display is the copilot's eye position. The pilot is not able to see the copilot's display nor is the copilot able to see the pilot's display.

7. A visual system with two CRT displays, each showing different scenes, is a two-window, two-channel system. If the focal point of both displays is the pilot's eye position, the system is called a pilot-oriented or pilot-only visual system. A display located in the copilot's front windscreen in a pilot-oriented system provides a distorted scene to the copilot.

8. The number of channels that can be used for a visual system is limited by the system's computer capacity and the size of the displays and supporting structures. Increasing the number of channels decreases the average scene content of each channel, as a given computer is capable of generating only a finite number of edges, and these must be divided among the channels. The fewer edges there are in a scene the less detailed and more cartoonish it will appear. Repeater windows which give the same picture as another require no additional computation capability, and in some applications, can be used to give the copilot or instructor a visual display without sacrificing scene quality.

DETERMINING FIELD OF VIEW REQUIREMENTS

GENERAL

9. If program cost restraints dictate a number of data channels and displays less than required to simulate the full aircraft FOV, then the optimum arrangement of visual displays should be determined by the flight test program presented in this technical paper. With results from such an approach, the program manager will be able to make meaningful decisions on cost and required visual system capabilities. In addition, squadron personnel will be able to determine what mission tasks should be included in their training syllabus. The amount of training degradation with limited displays can also be determined.

10. The mission and operating environments of the aircraft have an impact on the visual system FOV requirements. The FOV requirements can vary significantly among simulators for different aircraft due to the different mission environments of the aircraft. For an Anti-Submarine Warfare helicopter, adequate FOV representation of the shipboard landing task is essential for proper training. Reference (b) discusses an evaluation of the SH-2F Weapons System Trainer (WST) where there were training limitations due to inadequate FOV. For a Marine assault helicopter, duplication of the shipboard environment is also important, but the primary emphasis would be placed on FOV considerations relative to typical landing zones, particularly those in a confined area. Reference (c) discusses the evaluation conducted to determine the FOV simulation requirements for the CH-46E OFT.

TEST APPROACH

11. The test approach for evaluating simulator FOV requirements is logically divided into three phases: drawing board, ground test, and flight test. In these phases, configurations of candidate window displays are evaluated. As the program progresses through these stages, changes to display configurations become increasingly difficult, so attention given to the early stages can result in payoffs later.

Drawing Board

12. This is essentially a cut and paste "what do you think" sort of exercise in which pilots experienced in

the aircraft to be simulated and engineers familiar with visual system characteristics discuss possible visual display groupings and decide upon a number of candidate configurations to evaluate. To accomplish this, diagrams of the aircraft FOV from design eyepoint are drawn on a graph, which has vertical and horizontal FOV angles as ordinate and abscissa, respectively. An example of such a graph from the pilot's design eyepoint for the CH-46 helicopter is presented in appendix B. Graphs of this format can be produced readily by the FOV Evaluation Apparatus (FOVEA) described in appendix C. To evaluate a visual system for the copilot, FOV graphs must be created with the FOVEA from the copilot's seat since the presentation may not be the same from the different design eyepoint. The pilots arrange cutouts of the candidate window displays on the FOV graph. The engineers advise the group as to the technical feasibility of the proposed configurations, as limited by physical dimensions of the units, necessary overlap for adjacent units, or potential alignment problems. Generally, each pilot will have a different opinion on the relative importance of certain windows. This is due partly to individual differences in pilot technique and partly to the variety of missions each pilot has flown. Thus, if a multi-mission aircraft is being simulated, pilots experienced in each of the missions should be included in the evaluation. However, the evaluation group should be kept small enough to allow each pilot's opinion to be weighed and still come to an agreement within a reasonable amount of time. Once the candidate display configurations have been decided, it is appropriate to begin working directly with the aircraft.

Ground Testing

13. The first step in the ground test phase is to draw the candidate window display configurations on the aircraft windscreen. The FOVEA is very useful in sighting and documenting the appropriate window locations. Once a complete window display arrangement is sketched, the pilots make a preliminary appraisal. Generally, a number of minor relocations or adjustments are desired at this stage and they can still be accomplished with relative ease. At this stage it is also possible (and highly desirable) to eliminate some of the candidate configurations. From the sketches on the windscreen, amber cellophane (AMBERLITH) is cut into shapes to fit the canopy with openings where the proposed windows would be. An example used in the CH-46E OFT program is presented in appendix D. Using blue lens goggles (Device 1-F-4-b), the pilots can get a good idea of what the corresponding simulator FOV will be. The amber portions of the canopy windscreen will appear black while the pilot will be able to see through the display window cutouts and determine the suitability of each configuration. Modification to the configurations now becomes increasingly difficult but will continue to be necessary if an optimum arrangement is to be obtained. At this stage, it is still feasible to have a relatively large number of pilots participate in the evaluation, but in the flight phase, time and financial constraints will probably limit the number of evaluators.

Flight Testing

14. The final phase in determining the FOV requirements is to fly the aircraft with a minimized number of candidate window display configurations. Each configuration should be evaluated by at least two pilots for a series of specified mission tasks. An example of appropriate mission tasks for the CH-46E medium assault helicopter is contained in the evaluation sheet presented in appendix E. The acceptability of the FOV in accomplishing these tasks is rated by the pilot on a scale of 0 to 5, when 0 represents the degree of difficulty in performing a maneuver with no windows at all or as would be typical in instrument meteorological conditions and 5 represents the degree of difficulty in performing a maneuver with the actual aircraft FOV. Typically, each configuration will show strengths for some tasks and weaknesses for others. After flying each configuration, the results are evaluated and one of the configurations, or more likely a modification of it, is selected as the best. Time should be allocated in the test program to fly this "final" configuration to determine if it, in fact, offers everything expected of it. The project evaluation team will then be confident that the recommended configuration offers the best possible training potential within the constraints allowed.

FOV Considerations

15. As discussed in paragraphs 6 and 7, the visual system may be pilot or pilot/copilot oriented. If the decision for a one-pilot or two-pilot system is not made during the "drawing board" or ground test phases, it should be accomplished early in the flight program. It is not satisfactory to orient front windscreen displays for both pilot and copilot. A single front display will limit the copilot to forward flight profiles with little capability to fly curved approaches or to perform precision flight requiring outside periphial visual reference. Reference (c) reported that a pilot/copilot system for the CH-46E OFT limited both the pilot and copilot. The configuration consisting of a copilot front, copilot left side, and pilot right side was described by the copilot as more frustrating than useful when performing typical H-46 missions, with the single exception of a straight-in instrument approach to a roll-on landing.

16. An adequate vertical FOV is essential for a helicopter trainer. The lower edge of the front displays should be close to the bottom of the windscreen for adequate look-down capability during steep approaches and flares, precision hover, slow speed In Ground Effect flight, and ship landings. The initial "drawing board" position of the pilot's front display for the CH-46E OFT, reference (c), was shifted downward to enable the pilot to keep sight of the landing spot. The restricted FOV of the SH-2F WST, particularly in the lower look-down angles, created problems in precise hover, low-speed flight, and frigate landings as reported in reference (b). Reference (c) reported that flight test results verified the pilot chin window display was important in the proposed H-46 OFT visual system when the helicopter was near the ground and moving.

17. Items that should be considered for the top of the displays for helicopter OFT's include the horizon in forward flight and the rotor tip path plane for ground operation or confined area landings. Simulation of maneuvers involving large forward control inputs and typical autorotative entries require a FOV display above the normal level flight horizon.

18. Horizontal FOV requirements are also dictated by mission requirements. Flight operations requiring 360 deg turning patterns (i.e., plane guard, Magnetic Anomaly Detection trapping, etc.) or both left- and right-hand shipboard approaches with traffic monitor will require substantially more horizontal FOV than forward flight cruise and straight-in landings. Visual information aft of the pilot or copilot 90 deg position in the CH-46 provided only low priority information, as reported in reference (c).

Safety Precautions

19. As in any flight test program, certain safety considerations should be addressed during the flight test phase. The amber cellophane installed in the windscreen of the aircraft causes negligible degradation of visibility in clear or cloudy daytime light conditions but seriously hampers the pilot's visibility at night. Therefore, these flights should not be flown at night. Also, the safety pilot should not use sunglasses or a shaded visor during the evaluation flights since these also restrict visibility through the amber cellophane. Since some window display candidate configurations may severely restrict FOV in some quadrants, the crew chief should be specifically briefed to pay particular attention to these quadrants and advise the pilots of traffic or obstacles.

SUMMARY

20. This test approach for determining flight trainer visual system FOV requirements, described using the CH-46E OFT as an illustrative example, can be applied directly to any aircraft, either fixed or rotary wing. It provides the evaluation team, program manager, and squadron personnel with information on the impact of FOV on mission training potential. There are other visual system considerations beyond the scope of this type of evaluation which have a significant impact on visual system fidelity and training potential. Among these are scene content and quality, image realism, aliasing tendencies, and visual system/trainer interface. Defining simulator FOV requirements is only one part of the problem but an important early step in the process.

APPENDIX A

REFERENCES

(a) NAVAIRTESTCEN Technical Memorandum 77-1 RW of 27 April 1977, A Program for Increased Flight Fidelity in Helicopter Simulation.

(b) NAVAIRTESTCEN Technical Report RW-11R-77 of 31 March 1978, Flight Fidelity Evaluation of the SH-2F Weapons System Flight Trainer (Device 2F106).

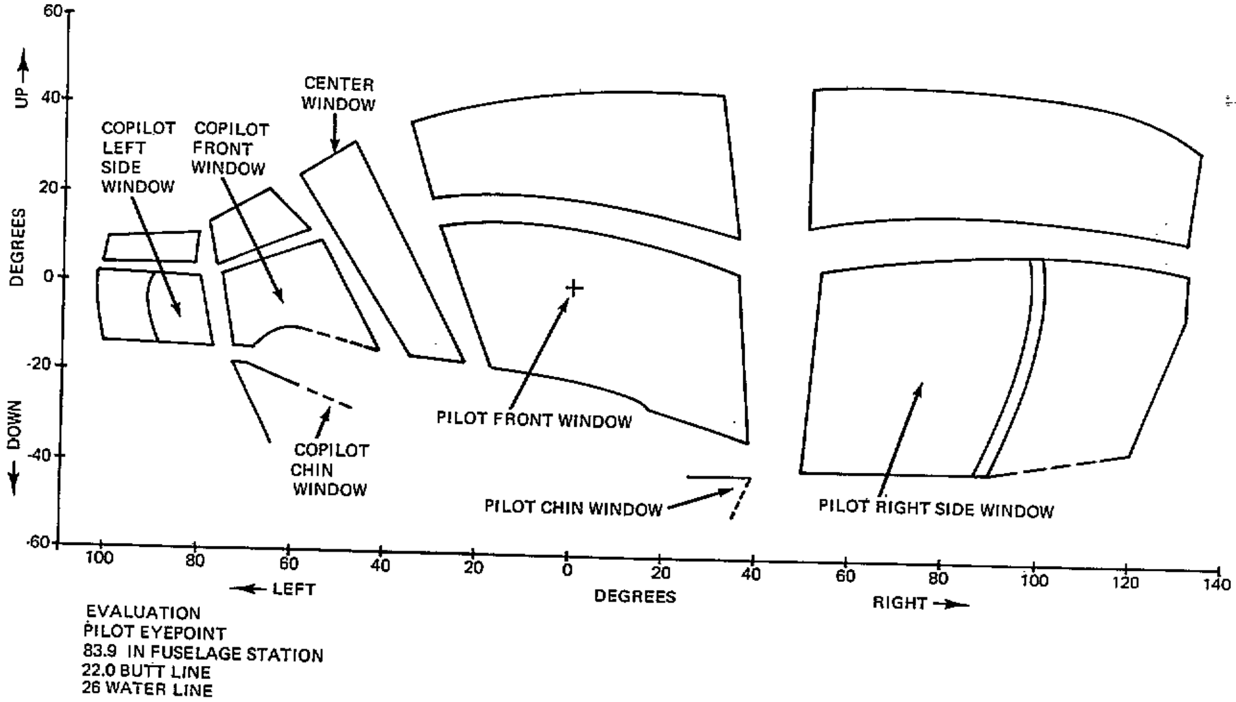
(c) NAVAIRTESTCEN Report of Test Results RW-41R-77 of 8 March 1978, CH-46E Operational Flight Trainer Evaluation, First Interim Report.

RELATED ARTICLE

(d) NAVAIRTESTCEN Technical Memorandum TM-78-2RW of 12 April 1978, Environmental Requirements for Simulated Helicopter/VTOL Operations from Small Ships and Carriers.

APPENDIX B

CH-46 COCKPIT FOV FROM PILOT'S EYEPOINT



APPENDIX C

FIELD OF VIEW EVALUATION APPARATUS

1. The Field of View Evaluation Apparatus (FOVEA) is an instrument capable of measuring, recording, and graphically plotting the angular subtense of objects relative to the design eye reference point of crew stations. Its principal application is the measurement, for evaluation and verification purposes, of the external FOV of aircrew stations. It is designed for use in both mock-ups and actual aircraft crew stations and generates the FOV plots required for verification of data submitted in accordance with MIL-STD-850B. It also has utility in the evaluation of visual obstructions to the line-of-sight to controls and displays, documentation of simulator visual system FOV, verification of control/display location relative to the primary visual areas for caution/warning displays, photographically recording from the desired viewing position (design eye), and identification of deficiencies or enhancing characteristics during FOV evaluation tests.

2. FOVEA consists of a commercially available programmable desk-top calculator and X-Y plotter, a servo-driven TV sensor element, a TV monitor, a joystick for sensor pointing control, and associated electronics on adapter brackets for positioning the sensor in the crew station seat. A magnetic tape cassette recorder and hard-copy printer are integral features of the calculator and provide for data storage and hard copy printout of measured data. The system software provides for initial setup alignment, sensor positioning error compensation, and selection of plotter output options of rectilinear plots, equal area projection, and tangent plots for generation of landing vision data. A polaroid camera is included to obtain photographic records of the TV monitor display.

3. Test setup requires placement of the TV sensor on the crew station seat pan (figure 1) and adjustment of the sensor to coincide with the design eye location for the crew station. Alignment procedures verify the accuracy of sensor positioning. The sensor pointing angle is controlled remotely by the joystick control (figure 2). Data were acquired by the operator tracing the outlines of visual obstructions (e.g., canopy rails, windscreen bracketry, instrument panel) by tracking with the center of the FOVEA sensor, represented by a cursor on the TV monitor. After data acquisition, the desired output options are selected via controls on the calculator and the data are presented graphically on the X-Y plotter.

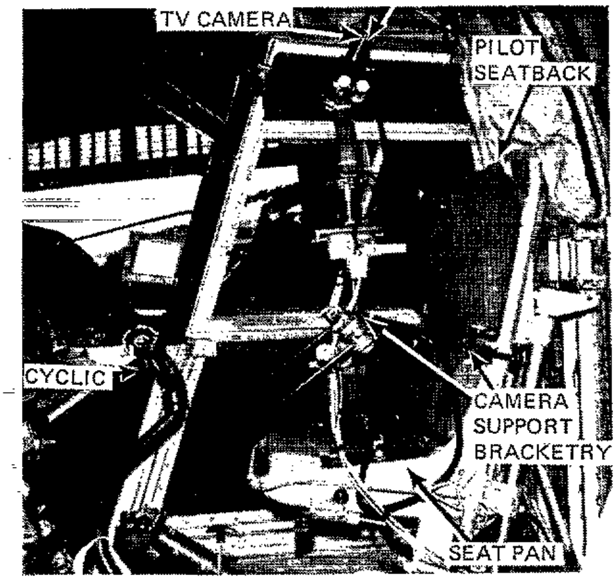


Figure 1
FOVEA TV Camera Mounted in Pilot's Seat of H-46 Helicopter

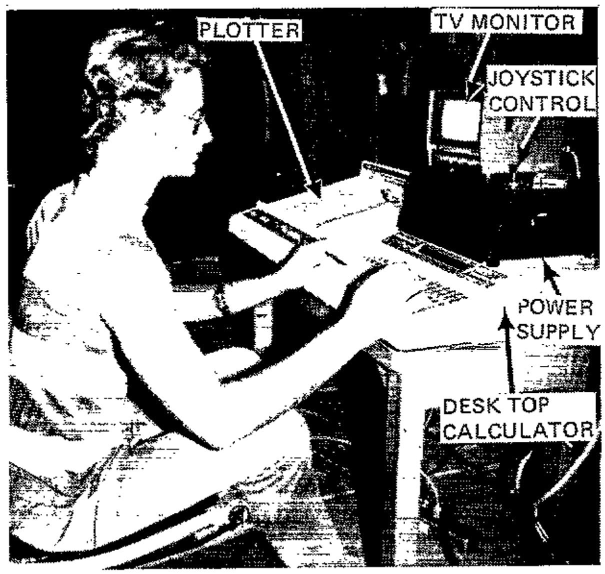
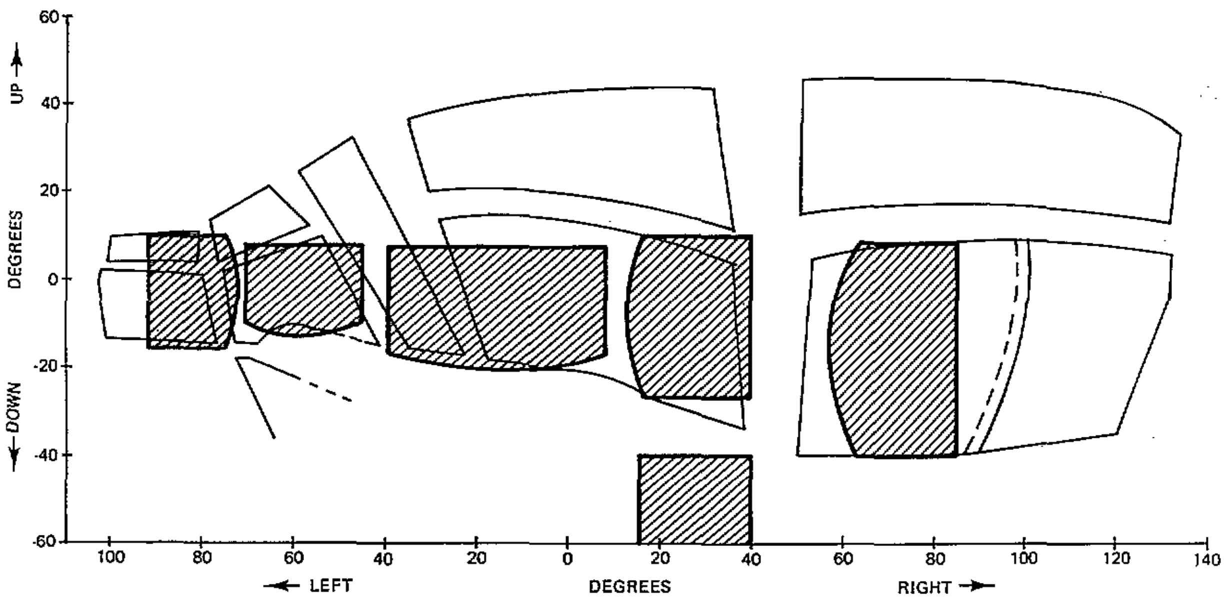


Figure 2
FOVEA Control Equipment Positioned in H-46 Helicopter Cabin

APPENDIX D

COCKPIT LAYOUT FROM PILOT EYEPOINT FOR
PROPOSED SIX-CHANNEL, SIX-WINDOW
CGI VISUAL SYSTEM FOR CH-46E OFT



APPENDIX E

SAMPLE MISSION TASK EVALUATION SHEET
(USED IN CH-46E OFT VISUAL SYSTEM EVALUATION)

Aircraft Type	BuNo	Time T.O. Time Land	Date	Flight No.	Card No.
Crew Name	Weight	Station	T.O. GW Land GW		T. O. CG Land CG
Visual Test Configuration			Aircraft Configuration		
Weather	Wind	Visibility			

Maneuver		Pilot Rating
Ground Taxi	Forward Aft Left Right	
Hover		
Air Taxi	Forward Aft Left Right	
Forward Flight	Level Left Bank Right Bank	
Confined Area Landing		
Normal Approach	Left Right	
Precision Approach	Left Right	
LPH Approach	Left Right	
360 deg	Left Turn Right Turn	
Autorotative Approach	Left Right	
Autorotative	Entry Recovery	
Quick Stop		
External Pickup		
External Drop		

ABOUT THE AUTHORS

MAJOR ROBERT YEEND, USMC, is a Flight Instructor at the U.S. Naval Test Pilot School, Naval Air Test Center, Patuxent River, Maryland. Prior to joining the instructor staff at the Naval Test Pilot School, Major Yeend served at the Rotary Wing Aircraft Test Directorate as project officer for the CH-46E OFT, Device 2F117, flight fidelity evaluation. He holds a B.S. degree in physics from the University of Portland and the M.S. degree in general science from Oregon State University.

MR. DEAN CARICO is an Aerospace Engineer in the Rotary Wing Aircraft Test Directorate at the Naval Air Test Center, Patuxent River, Maryland. He has been the project engineer for the flight fidelity evaluations of Devices 2F106 and 2F117. Mr. Carico holds a B.S. degree in aerospace engineering from the Virginia Polytechnic Institute and State University and the M.S. degree in aerospace engineering from Princeton University.