

NASA Conference Publication 3156  
DOT/FAA/RD-92/2

# NASA/FAA Helicopter Simulator Workshop

(NASA-CP-3156) NASA/FAA HELICOPTER  
SIMULATOR WORKSHOP (NASA) 187 p

N93-30673  
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N93-30691  
Unclas

H1/01 0158878

*Proceedings of a workshop held at  
the Biltmore Hotel,  
Santa Clara, California  
April 23-26, 1991*



**NASA**

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# NASA/FAA Helicopter Simulator Workshop

*Edited by*  
William E. Larsen  
Federal Aviation Administration  
Ames Research Center  
Moffett Field, California

Robert J. Randle, Jr.  
Richard S. Bray  
Sverdrup Technology, Inc.  
Ames Research Center  
Moffett Field, California

John Zuk  
Ames Research Center  
Moffett Field, California

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**NASA**

National Aeronautics and  
Space Administration

**Ames Research Center**  
Moffett Field, California 94035-1000



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**PART I**

**EXECUTIVE SUMMARY**



# NASA/FAA HELICOPTER SIMULATOR WORKSHOP

## PART I: EXECUTIVE SUMMARY

William E. Larsen,\* Robert J. Randle, Jr.,\*\* Richard S. Bray,\*\* and John Zuk†

Ames Research Center

### SUMMARY

A workshop was convened by the FAA and NASA for the purpose of providing a forum at which leading designers, manufacturers, and users of helicopter simulators could initiate and participate in a development process that would facilitate the formulation of qualification standards by the regulatory agency. Formal papers were presented, special topics were discussed in breakout sessions, and a draft FAA advisory circular defining specifications for helicopter simulators was presented and discussed. A working group of volunteers was formed to work with the National Simulator Program Office to develop a final version of the circular. The workshop attracted 90 individuals from a constituency of simulator manufacturers, training organizations, the military, civil regulators, research scientists, and five foreign countries. A great amount of information was generated and recorded verbatim. This information is presented herein within the limits of accuracy inherent in recording, transcribing, and editing spoken technical material.

### INTRODUCTION

A NASA/FAA-sponsored helicopter simulator workshop was convened (23-26 April, 1991) at the Biltmore Hotel in Santa Clara, California. The purpose of the workshop was to support the Federal Aviation Administration in clarifying qualification requirements for rotary-wing flight-training simulators and to review the draft Advisory Circular, "Helicopter Simulator Qualification," AC 120-XX written to implement these requirements. Funding for this and other project activities were provided by the the FAA's Vertical Flight Special Programs Office, ARD-30, in support of the National Simulation Program Office, ASO-205. These activities are authorized and funded by Interagency Agreement DTFA01-88-Z-02015, Rotorcraft Simulator Technology, between the FAA and NASA, June 15, 1988.

Three important purposes were identified that could best be served at a workshop consisting of knowledgeable and interested representatives of the training simulator community. First, the workshop would provide a forum. In rotary-wing flight simulator training and technology there are many indeterminacies, and there is no systematic method for the formulating and resolving of questions

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\*Federal Aviation Administration.

\*\*Sverdrup Technology, Inc., Ames Research Center.

†Civil Technology Office, NASA Ames Research Center.

relating to the ability of simulators to accomplish the training required by FAA regulations (Title 14 CFR). A primary goal of the workshop would be to elicit expert opinion and experience in an effort to define those questions and to cull from the attendees' presentations and comments some guidelines for an approach to their resolution. Subsequent documentation and dissemination of this information would make a substantive contribution to simulator qualification efforts and to the guidance of future research and development.

Second, the workshop would provide a context for public preview and comment on the draft Advisory Circular, 120-XX, October 22, 1990, "Helicopter Simulator Qualification." The attendees would be those professionals for whom the Advisory Circular is of immediate concern. They would be a pool of candidates for membership on a working group, requested by the manager of the National Simulator Evaluation Program, that would be responsible for developing the final form of the Advisory Circular.

Third, the workshop would serve to collect valuable information which would be documented and disseminated. The NASA/FAA simulator qualification project is not currently a research project with long-term goals but a circumscribed effort dependent on existing technical information, driven largely by the need to produce a valid and consensus Advisory Circular and training regulations. The workshop was conceived as a source of "data" which would (1) help in the finalization of the draft Advisory Circular, (2) increase the helicopter community's awareness of and concern with training simulator issues, and (3) perhaps identify further research and development objectives. The results of the workshop would be documented in two parts, this Executive Summary, and Part II, Workshop Proceedings and Session Compendium. Both parts would be distributed to all attendees.

## **WORKSHOP STRUCTURE**

Seventeen speakers were invited from the helicopter training simulator industry and from the military to present formal papers over the first day and a half of the conference. Three panel discussions (breakout sessions) were scheduled on the afternoon of the second day and three more on the morning of the third day. The panel session topics were:

- A. Training Limits, Allowances, Future
- B. Scene Content and Simulator Training Effectiveness
- C. Low-cost Training Alternatives: Part-and Full-Task Trainers
- D. Dynamic Response and Engineering Fidelity in Simulation
- E. Current Training: Where Are We?
- F. Aero Modelling.

Panel sessions D and F were combined into a single session at the request of the panel members because of the similarity of their content and the overlapping expertise of the discussants.

The panel moderators and participants were instructed that the intention was to promote a free-flowing discussion in which all contributions were welcomed and desired. At the completion of the breakout sessions each session moderator summarized the discussions that had taken place.

On the afternoon of the third day the manager of the National Simulator Evaluation Program, Mr. Ed Booth, chaired a meeting of the conference-at-large at which he invited comment on the draft Advisory Circular, 120-XX. He also formed a volunteer working group from the assembled participants to meet with him at a future date to work on the finalization of the draft Advisory Circular.

The welcoming address was presented by C. Thomas Snyder, Director of Aerospace Systems, NASA Ames Research Center. Mr. Snyder presented a short history of simulator development at Ames.

The keynote speaker was James D. Erickson, Manager, Southwest Region Rotorcraft Directorate, Aircraft Certification Service, FAA. Mr. Erickson noted that rotorcraft simulation has not kept pace with fixed-wing simulation. He said that the military successes with simulation would be given attention and that the importance of developing useful, acceptable, and objective standards in the civil sector would be emphasized.

## **PRESENTATION ABSTRACTS**

The duties of moderator of the formal-paper sessions were ably executed by Mr. James McDaniel, Manager, Vertical Flight Program Office, ARD-30, FAA Headquarters. Seventeen speakers made presentations at the workshop. Abstracts of the presentations follow. Cliff McKeithan's paper, which was not originally scheduled, is also abstracted.

1. **HELICOPTER SIMULATOR STANDARDS.** Edward Boothe, Manager, FAA National Simulator Evaluation Program.

The initial advisory circular was produced in 1984 (AC 120-XX). It was not finalized, however, because the FAR's for pilot certification did not recognize helicopter simulators and, therefore, permitted no credit for their use. That is being rectified, and, when the new rules are published, standards must be available for qualifying simulators. Because of the lack of a data base to support specification of these standards, the FAA must rely on the knowledge of experts in the simulator/training industry. A major aim of this workshop is to form a working group of these experts to produce a set of standards for helicopter training simulators.

2. **HELICOPTER SIMULATION: AN AIRCREW TRAINING AND QUALIFICATION PERSPECTIVE.** Richard A. Birnbach, Manager, Air Carrier Training Branch, FAA Flight Standards Service.

This paper reviews some of the unique considerations that distinguish the commercial rotary-wing domain from its fixed-wing counterpart and that should give the FAA cause to proceed cautiously in drawing upon its fixed-wing experience. A major point: device qualification should be accomplished in a context of an overall training and qualification system. This approach would take as its starting point a detailed analysis of rotary-wing missions and tasks from which proficiency objectives can be systematically developed.

3. ROTORCRAFT MASTER PLAN. Peter V. Hwoschinsky, FAA Vertical Flight Program Office.

The Rotorcraft Master Plan contains a comprehensive summary of active and planned FAA vertical flight research and development. Since the Master Plan is not sufficient for tracking project status and monitoring progress, the Vertical Flight Program Plan will provide that capability. It will be consistent with the Master Plan and, in conjunction with it, will serve to ensure a hospitable environment if the industry presents a practical vertical-flight initiative.

4. SIMULATORS FOR CORPORATE PILOT TRAINING AND EVALUATION. Curt Treichel, Manager, Training for Corporate Aircraft, United Technologies, Inc.

Corporate aviation relies heavily on simulation to meet training and evaluation requirements. It appreciates the savings in fuel, money, noise, and time, and the added safety it provides. Also, simulation provides opportunities to experience many emergencies that cannot be safely practiced in the aircraft. There is a need to focus on the advantages of simulator training over aircraft training and to provide appropriate changes in the regulations to allow the community to make it possible for users to take full advantage of simulation.

5. TRAINING EFFECTIVENESS ASSESSMENT: WHERE ARE WE? Greg McGowan, Manager, West Palm Beach Learning Center, FlightSafety International.

Over 9,000 pilot training courses have been conducted at FSI using the Bell 222 and Sikorsky S-76 simulators. Through the use of FAA exemptions, these simulators can be used for certain training and checking credit. The history of the development and use of commercial helicopter simulators and the opportunities for their increased utilization and use were explored.

6. CURRENT TRAINING: WHERE ARE WE? Gerald Golden, Director of Training, Petroleum Helicopters, Inc.

Petroleum Helicopters, Inc. maintains a staff 750 helicopter pilots. The initial, transition, upgrade, and recurrent training for these pilots requires a significant financial outlay. Since a major portion of that training is done to satisfy the requirements of FAR 61.57, "Recent Flight Experience, Pilot in Command" and 135.297, "Pilot in Command: Instrument Proficiency Check Requirements," much could be accomplished using an approved simulator. However, it is imperative that credit be given for training time spent in the simulators and that the device be realistic, practical, and affordable.

7. HELICOPTER SIMULATION QUALIFICATION. Brian Hampson, Director of Engineering Administration, CAE Electronics.

CAE has extensive experience in building helicopter simulators and has participated in group working sessions for fixed-wing advisory circulars. Against this background issues that should be addressed in establishing helicopter approval criteria were highlighted. Some of these issues are not immediately obvious and may, indeed, be more important than the criteria themselves.

8. HELICOPTER SIMULATION: MAKING IT WORK. Barry Payne, Aviation Network (NZ) Limited.

The opportunities for improved training and checking by using helicopter simulators are greater than they are for airplane pilot training. Simulators permit the safe creation of training environments that are conducive to the development of pilot decision-making, situational awareness, and cockpit management. This paper defines specific attributes required in a simulator to meet a typical helicopter operator's training and checking objectives.

9. HELICOPTER TRAINING SIMULATORS: KEY MARKET FACTORS. John McIntosh, Vice President, Hughes Simulation Systems.

Simulators will gain an increasingly important role in training helicopter pilots only if the simulators are of sufficient fidelity to provide positive transfer of skills to the aircraft. This must be done within an economic model of return on investment. Although rotor pilot demand is still only a small percentage of overall pilot requirements, it will grow in significance. This presentation described the salient factors influencing the use of helicopter training simulators.

10. TRAINING EFFECTIVENESS ASSESSMENT: METHODOLOGICAL PROBLEMS AND ISSUES. Kenneth Cross, President, Anacapa Sciences.

The U.S. military uses a large number of simulators to train and sustain the flying skills of helicopter pilots. Despite the enormous resources required to purchase, maintain, and use those simulators, little effort has been expended in assessing their training effectiveness. One reason for this is the lack of an evaluation methodology that yields comprehensive and valid data at a practical cost. Some of these methodological problems and issues that arise in assessing simulator training effectiveness, as well as problems with the classical transfer-of-learning paradigm were discussed.

11. DETERMINING THE TRANSFERABILITY OF FLIGHT SIMULATOR DATA. David Green, President, Starmark Corporation.

This paper presented a method for collecting and graphically correlating subjective ratings and objective flight test data. The method enables flight-simulation engineers to enhance the simulator characterization of rotorcraft flight in order to achieve maximum transferability of simulator experience.

12. PROGRESS THROUGH PRECEDENT: GOING WHERE NO HELICOPTER SIMULATOR HAS GONE BEFORE. Richard J. Adams, Vice President, Advanced Aviation Concepts.

Helicopter simulators have been approved by means of special exemption; there are no FAA standards for simulators used in training or airmen certification checking. The fixed-wing industry provides a precedent which can be used for expediting implementation of helicopter simulators. The analysis in this paper is founded on the experience with that precedent and is driven by a clear definition of helicopter user needs for (1) improved training at lower cost, (2) more comprehensive emergency training at lower risk, (3) increased fidelity of transition and instrument training compared with low-cost aircraft alternatives, and (4) certification credit for improved simulator training.

13. TRANSFER OF TRAINING AND SIMULATOR QUALIFICATION. Jack Dohme, Research Scientist, U.S. Army Research Institute.

Transfer of training studies at Fort Rucker using the backward-transfer paradigm have shown that existing flight simulators are not entirely adequate for meeting training requirements. Using an *ab initio* training research simulator, a simulation of the UH-1, training effectiveness ratios were developed. The data demonstrate it to be a cost-effective primary trainer. A simulator qualification method was suggested in which a combination of these transfer-of-training paradigms is used to determine overall simulator fidelity and training effectiveness.

14. VALIDATION AND UPGRADING OF PHYSICALLY BASED MATHEMATICAL MODELS. Ronald Du Val, President, Advanced Rotorcraft Technology.

The validation of the results of physically-based mathematical models against experimental results was discussed. Systematic techniques are used for: (1) isolating subsets of the simulator mathematical model and comparing the response of each subset to its experimental response for the same input conditions; (2) evaluating the response error to determine whether it is the result of incorrect parameter values, incorrect structure of the model subset, or unmodeled external effects of cross-coupling; and (3) modifying and upgrading the model and its parameter values to determine the most physically appropriate combination of changes.

15. FREQUENCY RESPONSE TECHNIQUES FOR DOCUMENTATION AND IMPROVEMENT OF ROTORCRAFT SIMULATORS. Mark Tischler, Rotorcraft Group Leader, Army Aeroflightdynamics Directorate, Ames Research Center.

Pilot-in-the-loop characterizations are most naturally formulated in terms of end-to-end frequency responses, so a frequency-response-based method is the natural approach to assessing simulator dynamic fidelity. A comprehensive frequency-response approach used heavily by Ames Research Center researchers was described, and results were presented from a number of simulator fidelity assessment studies. Those studies included UH-60 mathematical model validation and upgrade, ASTOVL linear model extraction, and documentation of the Vertical Motion Simulator (at Ames Research Center) motion and visual system characteristics.

16. BANDWIDTH AND *SIMDUCE* AS SIMULATION FIDELITY CRITERIA. David Key, Chief, Flight Control Branch, Army Aeroflightdynamics Directorate. Ames Research Center.

The potential application of two concepts from the new Handling Qualities Specification for Military Rotorcraft was discussed. The first concept is bandwidth, a measure of the dynamic response to control. The second is a qualitative technique developed for assessing the visual cue environment the pilot has in bad weather and at night. *SIM*ulated Day Usable Cue Environment (*SIMDUCE*) applies this concept to assessing the day cuing fidelity in the simulator.

17. METHODOLOGY DEVELOPMENT FOR EVALUATION OF SELECTIVE FIDELITY ROTORCRAFT SIMULATION. Cliff McKeithan, Georgia Institute of Technology. (Authors: Major William D. Lewis, Dr. D.P. Schrage, Dr. J.V.R. Prasad, Major Daniel Wolfe).

This paper addressed the initial step toward the goal of establishing performance and handling qualities acceptance criteria for realtime rotorcraft simulators through a planned research effort to quantify the system capabilities of "selective fidelity" simulators. Within this framework the simulator is then classified based on the required task. The simulator is evaluated by separating the various subsystems (visual, motion, etc.) and applying corresponding fidelity constants based on the specific task. This methodology not only provides an assessment technique, but also provides a technique to determine the required levels of subsystem fidelity for a specific task.

## COMMENTARY

The workshop presentations and discussions evoked a broad range of pertinent background and experiential information, problem definitions, and problem solution guidelines. Some of the more significant of these are summarized below.

1. There appears to be a ready worldwide market for simulators and training devices. Although the military has hundreds of simulators, little has been done in the civilian market as a result of lack of enabling legislation for helicopter simulators. There are only two helicopter simulators in the United States that have been provisionally approved by the FAA, the Bell PH 222 and the Sikorsky S-76B. These are approved by exception for considerable credit toward pilot certification, but the pilot must still pass a checkride in the helicopter. These simulators are sophisticated devices in terms of, for example, their dynamic models and motion systems. At the other end of the market lies a generic, fixed-base training device that can be used to teach and review all of the visual helicopter flight maneuvers and techniques, along with systems functionality and navigation. This type of device offers the manufacturer the most flexibility in providing all of the helicopter fidelity and functionality at the lowest cost without having to comply with FAA AC-120 XX.

2. A report (Abstract #9) of a survey of the simulator market indicated that only eight so-called high-end (\$12 million to 25 million) simulators are needed worldwide over the next decade. Many more (100 to 200) lower-end devices (\$1.0 million to 1.2 million) could be supported. Rotary-wing training managers emphasized this in their desire for approval of less expensive part-task training devices in earning credits toward meeting regulatory requirements. In addition to helicopter training simulators, the industry and government should move out on issues related to tilt-rotor/wing and the regulations, infrastructure, and technology issues that will be of consequence in the mid to late 1990's. Timing of FAA action is consistent with market forecasts and the needs of helicopter operators.

3. There was a general feeling that the full capability of current helicopter simulators was not being exploited owing, perhaps, to some hesitancy on the part of the authors of regulatory requirements. The regulations and exemptions as they stand today still discourage industry from using the simulator to its fullest potential. Many maneuvers and emergency procedures cannot be safely done in the aircraft but can be done safely, repetitively, quickly, and economically in a simulator. Thus, a desire was expressed to expand the uses of simulators to allow credit for the training of tasks from more emergency procedures through instrument ratings to crew coordination and resources

management. As one attendee stated: "the couple of things that cannot be done well in the simulator are nothing compared with the many things that cannot be done [at all] in the aircraft." Also, the more that credit is withheld for training and checking done in simulators the more it is a disincentive to use them.

4. A boost in support of helicopter simulator utilization will be provided by a new proposed rule, NPRM, Part 142, which will authorize and regulate **Certificated Training Centers**. The objectives of the new rule are to increase simulator use, eliminate simulator exemptions, standardize training, and standardize FAA oversight of trainers through a centralized, national training program approval process. The new rule will cross air-carrier and non-air-carrier lines, and no distinction is made between fixed-wing and helicopter simulators. In an effort to maintain a broad perspective the rule would not specify in any detail differences in use of helicopter and fixed-wing simulators. Rather, the FAA would issue a certificate to the training center based on a set of training specifications which could be changed much easier than changing the certification. Part 142 will train to existing standards of Parts 61, "Certification: Pilots and Flight Instructors," 121, "Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft," and 135, "Air Taxi Operators and Commercial Operators," and may be expandable to Parts 63, "Certification: Flight Crewmembers Other Than Pilots," 133, "Rotorcraft External Load Operations," 137, "Agricultural Aircraft Operations" and possibly others. Parts 121 and 135 operators contracting with Part 142 training centers would not have to duplicate any part of the training program. Part 142 will either replace Part 141, "Pilot Schools," or complement it, in which case Part 142 schools would cooperate with Part 141 schools in finding mutually satisfactory arrangements for training students. This alternative will be presented in the NPRM and comments will be solicited.

5. There is a dichotomy of training philosophy and opinion with respect to the amount of credit that should be allotted to simulators as opposed to aircraft for skill demonstration. The regulatory agencies, though enthusiastic and motivated to grant approval for more simulator training and checking, must proceed cautiously, supported by empirical evidence, in the interest of safety, and training relevancy, and in view of potential liability in a litigious society. On the other hand, industry is also enthusiastic about increased use of simulators in lieu of the aircraft in the interest of safety, relevancy, and economy, and its representatives point out that these interests, based on their experience, will be better served by more use of simulators that offer much more versatility in terms of task and maneuver repertoire than can the aircraft. The aircraft, as a training device, is severely limited. Exemptions should still be sought in the interim before the publication of Part 142 (perhaps late 1992).

6. At a seminar in 1987, *Vertical Flight Training Needs and Solutions*, co-sponsored by the FAA and the Helicopter Association International, it was determined that human error-related accidents were the greatest problem the helicopter industry faced. Up to 80% of all helicopter accidents were in one way or another caused by human error, not by deficiencies in flying or control skills, and simulator training along with decision-making training was seen as an effective way to help reduce this kind of accident. The helicopter pilot frequently is under the pressure of a high workload situation and engages in a variety of industrial-commercial tasks, such as sling operations, flying crane, airtaxi, offshore oil platform work, high-altitude slope work, and cattle/wildlife herding that are inherently difficult and potentially dangerous. These are seldom "canned" or routine maneuvers and

therefore require good decision-making and judgmental skills. This kind of training, reminiscent of line-oriented flight training and cockpit resources management training in the fixed-wing world, requires neither high dynamic fidelity nor a type-specific simulator; a generic model (low-end cost) would be more than sufficient. The expanded use of and increased FAA credit for training in more generic simulators (training devices) was a pervasive issue at the workshop (see below).

7. The expanded use for credit of simulators in fixed-wing training, which has been successful under the Part 121, Appendix H, Advanced Simulation Plan, was frequently referred to. However, the application of fixed-wing simulator technology to rotary-wing training has some drawbacks. The different maneuvering capabilities of helicopters with omni-directional flight in proximity to the ground appears to require more capability in the visual scene than is currently available. The complaints are that the simulated visual cues do not adequately support veridical perception of altitude and altitude rates. This is mainly attributed to lack of good textural cues and to restricted fields of view, particularly in the downward direction, since the ground plane must be extrapolated by the trainee from the forward-oriented, perspective-drawn visual scene. Other attendees felt that existing simulators do give effective training down to the ground. These opinions probably should be tempered by consideration of the kind and skill level of the training being given. This caveat would appear to apply to all discussions of the contribution to training of all the simulator subsystems.

8. Physical simulator fidelity is desirable, but functional fidelity (training effectiveness) should be the goal. The lack of a systematic method within the civil rotary-wing community for determining simulator cost and training effectiveness makes it difficult to predict the levels of fidelity that are required for meeting (or exceeding) training performance and regulatory standards except through user experience; this is a long-term, unsystematic, and possibly biased process.

9. Current simulator design is hardware technology-driven. However, high fidelity of individual components of the simulator such as handling qualities, motion, and the visual scene does not of itself guarantee high training effectiveness. In the absence of discriminatory data, the effort to provide high fidelity is a current default position based on inferential logic. The proof of simulator efficacy is transfer-of-training from simulator to aircraft at reasonable savings and return on investment. Controlled studies of these outcomes in the civil community are neither available nor planned.

10. Training industry representatives expressed interest in joining NASA and the FAA in addressing the issue of transfer-of-training studies as a screening strategy for the selection of behaviors trainable in simulators for credit. This could be done by using current training facilities, training personnel, and trainee pools. None of these three potential participants (training industry, NASA, FAA) currently has a unique capability in the area of formal transfer-of-training and training assessment studies of large populations but probably could share in the planning, cost, management, and technology applications of such efforts.

11. Our current difficulty in relating engineering simulator fidelity to training excellence also presents difficulties in the specification of test values and tolerances for the proposed advisory circular for simulator qualification.

12. It is recognized that the body of descriptive data obtained during the development of a helicopter is rarely adequate for definition of an accurate simulation model. Later flight tests to

gather the necessary data tend to be very expensive. The FAA prefers that these data be generated by the manufacturers of the aircraft, but simulator manufacturers have on occasion relied on third-party tests. The absence of data necessarily increases reliance on pilots' subjective assessments.

13. NASA and the military have been making increased use of a flight-testing technique known as "frequency-sweep" that produces data, at modest cost in flight time, that is well-conditioned for use in helicopter modelling. The technique can be applied to the complete simulator, including motion and visual systems, for comprehensive verification of simulator fidelity.

14. Blade-element rotor modelling was recommended as the way to insure the fidelity of the simulator dynamic response and a strong point was made regarding the rapidly decreasing cost of computer capacity to accommodate such models. Again, because of uncertainties in the description of the aircraft, and the uncertain correlation between dynamic fidelity and training efficiency, this position was contested to some degree. Less complex models cannot be discarded out-of-hand until more evidence is available that the added complexity is training-justified.

15. There appears to be a consensus that a maximum visual scene and cockpit motion transport delay of 100 msec is a realistic specification for helicopter simulators. This more rigorous constraint than imposed on fixed-wing trainers reflects the higher control band-width typical of helicopters.

16. The value of expensive and complex motion systems is questioned when their contribution to training is considered. A bad motion system is worse than no motion system at all, and the contribution of a motion system to training may be highly task-dependent. The research literature seems to support this position, but, other than for the advantageous cueing of disturbance motion over simple maneuver motion, it has not been determined which sets of tasks can be better trained using motion cueing. Simulation of the vibration modes is recognized as a valuable contributor to simulator subjective fidelity.

17. The need for a wide field-of-view and abundant scene detail in simulation of hover tasks is recognized. It is also recognized that the visual simulation represents about half the cost of a modern simulator. This cost is especially high if the two crew members are provided with equivalent fields. Particularly, considering some of the new lower-cost visual systems being demonstrated, there exists a strong challenge to develop more cost-effective systems identified by a careful assessment of training needs and aircraft/simulator training time trade-off.

18. Collimation of visual scenes, a source of increasing simulator initial cost and upkeep, may be of questionable value in comparison with real image displays. They do provide a dramatic illusion of great distance and of a large "gaming" area; however, the localization of all picture elements at optical infinity leads to perceptual difficulties in estimating size and distance at short ranges, say, 10 ft (wheels on ground) to 50 ft (hover), the crucial range for helicopter maneuvering near the ground. This effect, coupled with limitations in the downward field of view and texture, make it difficult to localize the ground plane and to perceive altitude and altitude rates.

19. It is recognized that because of visual and motion cueing limitations, simulated tasks, particularly those in proximity to the terrain, are harder to fly than the real task, even if the aircraft model itself is of very high fidelity. The extent to which this presents an obstacle to effective use of the simulator was the subject of brisk discussion. Some voices supported the addition of compensation (for example, stability augmentation) to effect a more realistic work load in the critical tasks.

20. The hearing session on the draft of the Advisory Circular 120-XX for the qualification of helicopter simulators was cooperative rather than contentious, probably a result of the wide latitude given to industry participants in voicing their viewpoints throughout the previous 2 days of the workshop. Mr. Boothe had no problem in recruiting 30 volunteers to make up a panel to assist him in the further refinement and finalization of the circular. Several areas for further review were suggested and will be pursued by the volunteer working group. They seemed united on the need for the proposed advisory circular and the enabling FAA regulation; and the draft circular appeared to be a workable document for their efforts. The first meeting of the panel was scheduled for 23-25 July, 1991 in West Palm Beach, Florida.

## **EPILOGUE**

The individuals of the NASA/FAA project team who were responsible for the inception, organization, and execution of the Helicopter Simulation Workshop are indebted to panel moderator David A. Lombardo for his unsolicited reflection of their intentions. In part, he said:

In the early days of aviation the designer was the trainer and the user. Most things were done by trial and error, including aircraft design, pilot certification and standards, and pilot training. . . . Fortunately, that trend is slowly changing with the old guard passing the torch to new, better technologically informed replacements. The new emphasis is on user involvement in the initial design of hardware, software, and liveware training and certification. This symposium is an example of that emerging trend.”

The NASA/FAA project team members would like to extend to all workshop participants a very sincere expression of gratitude for their involvement in the workshop. Your enthusiasm and willingness to take responsibility for the future of simulator training by bringing your expertise to bear on a difficult technological area is greatly appreciated. We will extend a modest return-of-favor by delivering to you in a timely manner the planned workshop documentation.



## MESSAGE FROM THE CONFERENCE CHAIRMAN

BILL LARSEN

I wish to thank you for participating in the recent Helicopter Simulator Workshop and for making it such a success. Without your contribution the workshop would not have been possible.

It is clear, considering recent advances in training simulator technology and your statements during the workshop, that we will see enabling legislation that will provide increased credit for ground-based training. To some extent, this is already taking place, as reflected by the proposed rule making of Part 142 Title 14 CFR entitled "Certification Training Centers," the National Simulator Program Offices' Draft Advisory Circular No. 120-XX, "Helicopter Simulator Qualification," the recently published special FAR 58 "Advanced Qualification Program," and the FAA's National Plan for Aviation Human Factors.

For reasons, the simulator has become the aircrew training and checking tool of choice. This view was very apparent at the recent workshop. Along with the advances in simulator and training equipment technology has come an increasing awareness of the need for a systematic approach to device and training system design and specification. The emerging realization is that simulators and training devices are more than just an example of modern engineering technical excellence: they are quintessentially devices for the enhancement of human behavior.

The FAA certifies personnel, equipment, and procedures. The equipment certified includes aircraft, simulators (aircrew training/checking devices), and other equipment used in the NAS. Traditionally, the FAA has qualified flight simulators on the basis of engineering criteria that reflect the extent to which the characteristics of a given system are equivalent to those of the aircraft. Training transfer effectiveness—the extent to which an individual who meets a standard of proficiency in the simulator

can be expected to exhibit a known level of proficiency in the aircraft—has been assumed. This approach has proved satisfactory for high-fidelity simulations, but it is appropriate that additional factors be considered in establishing qualification criteria for training devices that rank lower on the physical fidelity continuum.

The FAA regulatory mission requires a sound basis for qualifying such equipment in training program and airman certification applications. Operators have been encouraged by the advanced qualification program to be innovative in designing training systems and equipment. Equipment used to establish or to maintain currency must be evaluated and approved against a set of criteria established by the FAA administrator for a particular qualification level. In this regard it is imperative that research be conducted to establish scientifically solid evaluation criteria that will be applicable to all such devices subject to FAA qualification.

The program's goal is to determine what level of simulator or training device is necessary to achieve a given training objective so that an aircrew member can qualify for credit toward regulated flight training. The amount of simulator training that is necessary to satisfy flight training requirements currently is determined by regulation. The regulation reflects the assumption that the more realistic the simulator the greater the value of the training. However, the level of the fidelity of represented parameters (e.g., visuals, handling qualities, motion) that is required to satisfy these regulations has not been empirically determined.

The transcribed and edited versions of the speaker's presentations follow. Summary statements of the separate panel discussions and a list of workshop attendees appear as appendices.



Bill Larsen served as a test pilot in the Air force and worked for 27 years in the aerospace and computer industries and with NASA. During that period, Mr. Larsen participated in R&D programs related to military and commercial transport aircraft and various missile systems, and served as engineering director for the design and development of a main frame computer. At NASA, he developed and conducted flight experiments for the Apollo spacecraft. Since joining the FAA in 1974, Mr. Larsen's work has encompassed cockpit alert and warning systems, an ATC simulation system, digital avionics systems, and fault-tolerant digital aircraft systems. In addition, he has conducted extensive investigations into the effects of electromagnetic threats to aircraft systems, including fly-by-wire and fly-by-light digital flight control systems. Mr. Larsen has served on several technical committees, and has participated in and organized several Digital Avionics Systems Conferences sponsored by the IEEE and AIAA. He has a B.S. degree in mechanical engineering and B.S. and M.S. degrees in electrical engineering from the University of Washington.

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# WELCOME

C. THOMAS SNYDER

Good morning, ladies and gentlemen. It is a pleasure for me to welcome you to this Helicopter Simulator Workshop on behalf of NASA and the FAA. I am sure that many of you in the audience are aware that the relationship between NASA and the FAA here at Ames Research Center has been a very strong one over the years, especially in simulation. The purpose of the workshop today is to assess the state of simulation technology, especially that of helicopter simulation, and to define a path leading to the qualification of helicopter training simulators. We see NASA's role in this process as one of support to the FAA, and we are pleased to be a part of this process in that sense. We believe that it has important implications for the entire vertical flight community.

Now, I mentioned this very close relationship between NASA and the FAA. I have had a first-hand involvement in that activity, especially during my early years as a researcher at Ames. So I hope you will bear with me while I reminisce a little about the changes we have seen in simulation over 25 short years.

The genesis of the NASA-FAA relationship really goes back to the early 1960s here at Ames and to a very visionary and a very energetic FAA employee from the Western Region named Joe Tymczyszyn. I am sure many of you know Joe. It is with a really warm spot in my heart I remember Joe predicting how simulators could be applied to expedite and simplify the certification of new classes of aircraft, to understand their operating characteristics before they really became hardware, and to get a jump on the process. I remember, too, the energy he put into pursuing that goal, as a result of which the NASA-FAA research program was established.

One of our first activities was to set up a simulation of a DC-8 to validate the idea; a kind of mock certification was conducted with that simulation. The hardware was basically a fixed-base transport cockpit with a rather crude single-window external visual display (fig. 1).

The display was generated by a moving-belt model runway viewed by a servo-driven TV camera that created

a black and white picture projected onto a screen, and viewed through a collimating lens (fig. 2). I remember all the trouble we had keeping the servo system tuned up to do a job that was more than it was designed for. From that relatively successful experiment we moved on to examine supersonic transport flight characteristics and the certification criteria related to them.

In 1969, the large-motion-base six-degrees-of-freedom Flight Simulator for Advanced Aircraft, or FSAA as we came to call it, was commissioned (fig. 3). With that came digital computation (up to that time we used analog computation) and much improved visual displays of the model terrain-board type. The very large ( $\pm 50$  ft) lateral travel of this simulator was excellent for studying lateral directional characteristics of large aircraft and for studying the effects of engine failure. So there was a lot of work done in those areas.

Following the demise of the U. S. Supersonic Transport program, attention was directed toward Concorde certification, and a very successful program was conducted with the joint authorities that contributed to the special conditions for the Concorde. It was also during that time frame that the FAA decided to establish a field office at Ames, and that office has continued to this day. The certification criteria simulation work was then directed to questions related to the introduction of wide bodies, the Boeing 747, and later to STOL certification criteria. The FSAA was also used during that period in the competitive evaluation of the proposals leading to the XV-15 tilt-rotor research aircraft. That was the first such use of a simulator, to my knowledge

In 1980 the six-degrees-of-freedom Vertical Motion Simulator (VMS) was introduced (fig. 4). It has  $\pm 30$  ft of vertical travel,  $\pm 20$  ft of lateral travel and six degrees of freedom. It is the real workhorse of our activity today.

It was also at about that time that we transitioned to computer-generated visual displays and multi-window external scenes. In addition to continuing research on powered-lift STOL and VSTOL aircraft using this

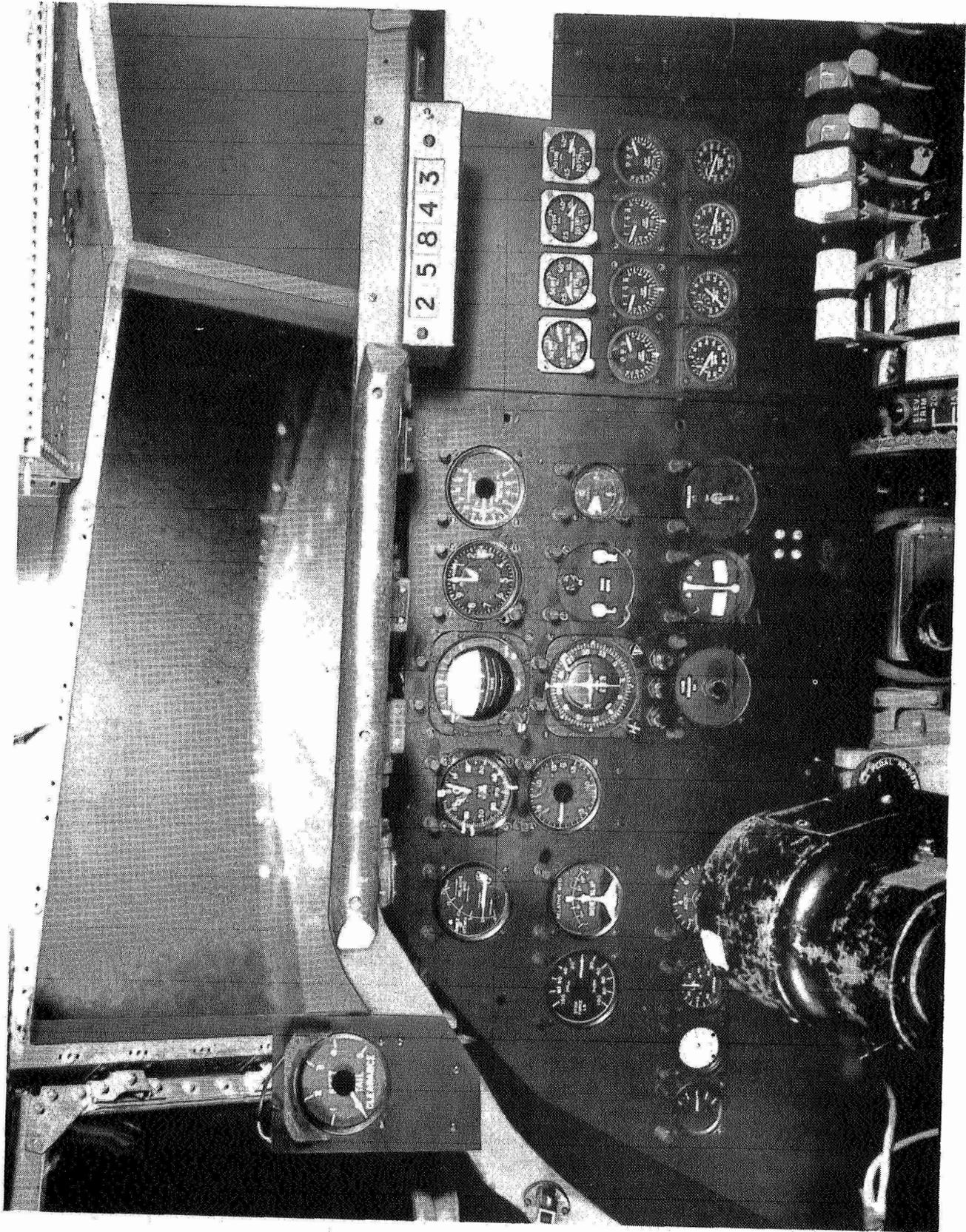


Figure 1. Fixed-base transport simulator.



Figure 2. Moving-belt visual image generator.

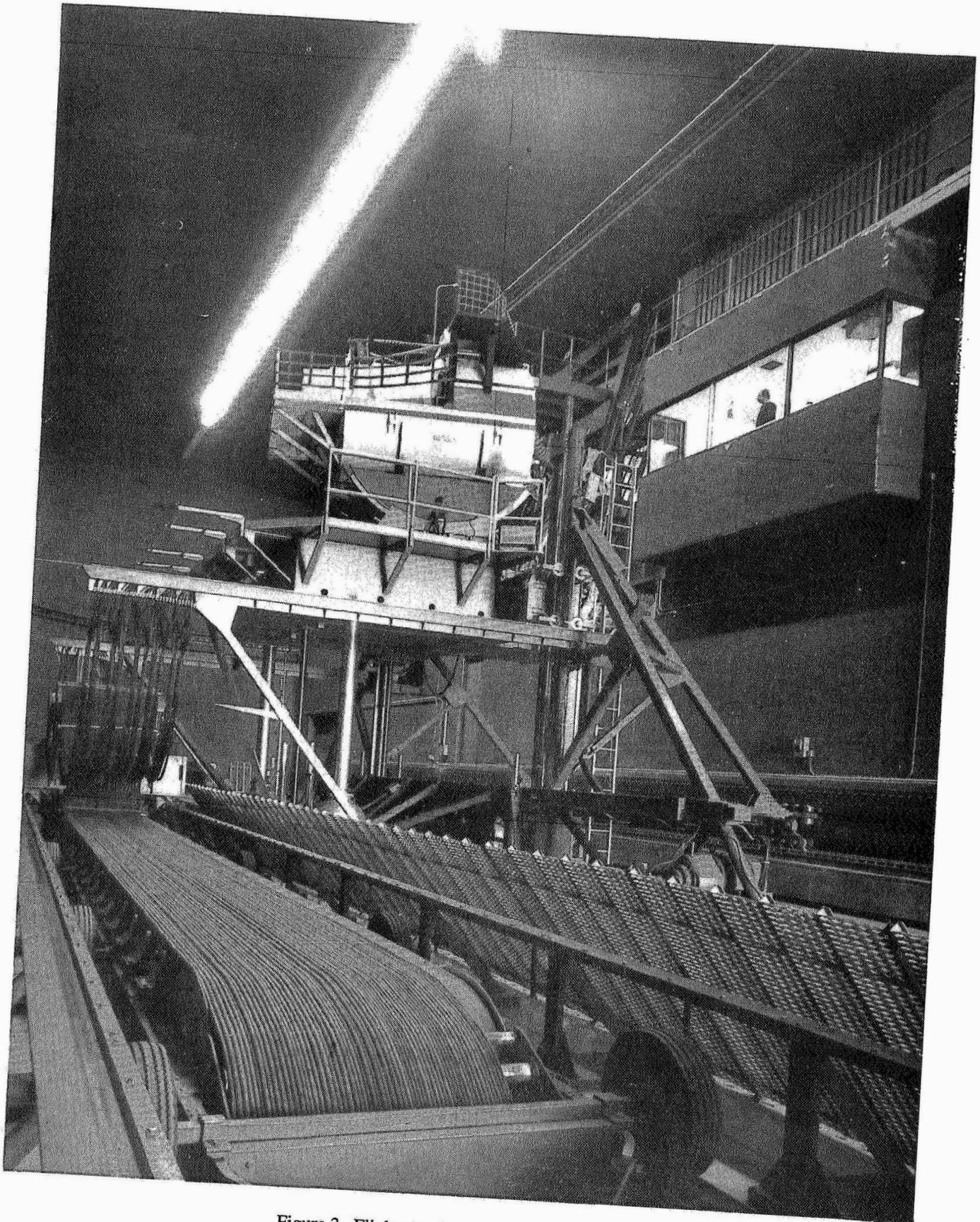


Figure 3. Flight simulator for advanced aircraft.

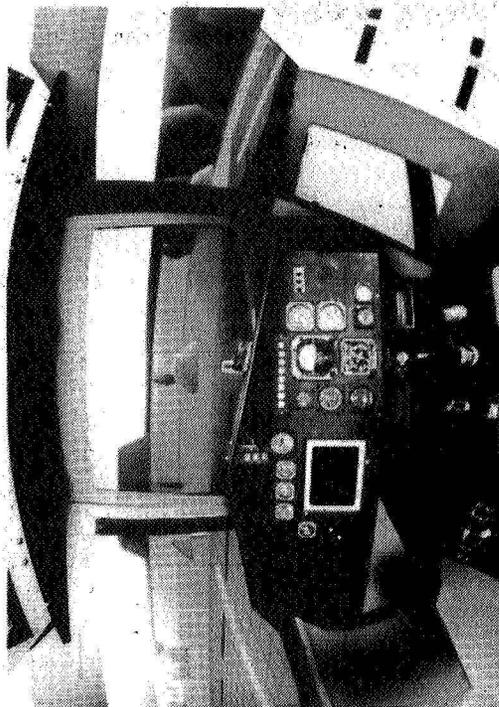
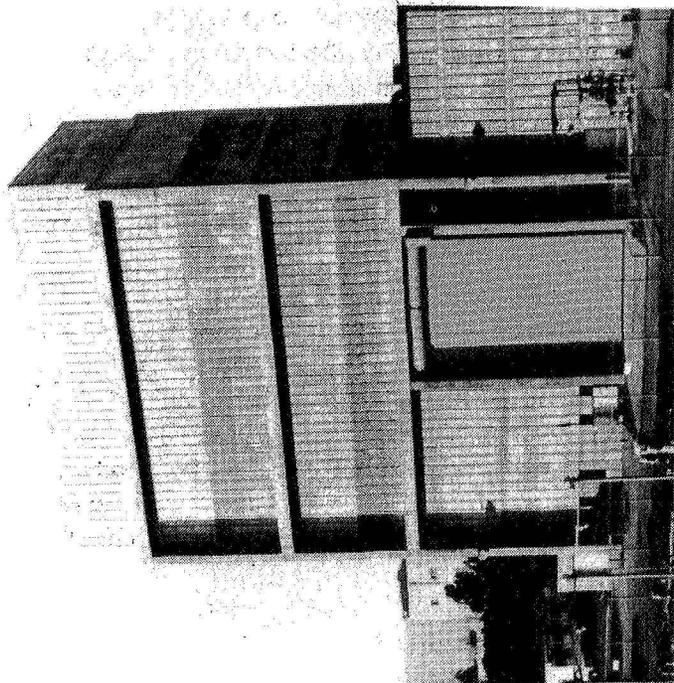
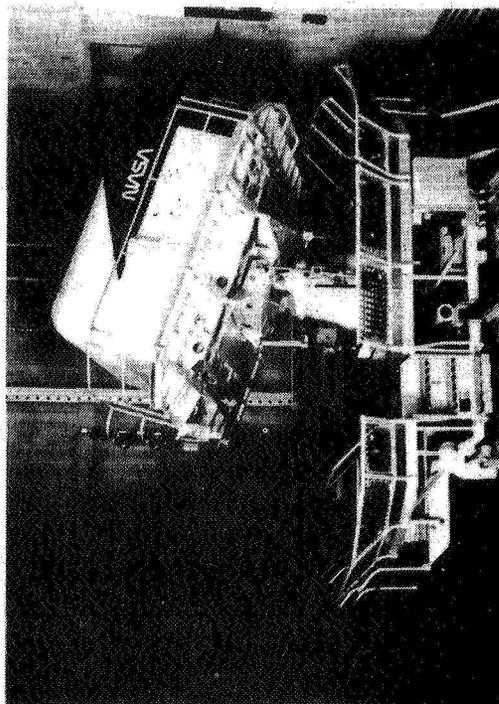
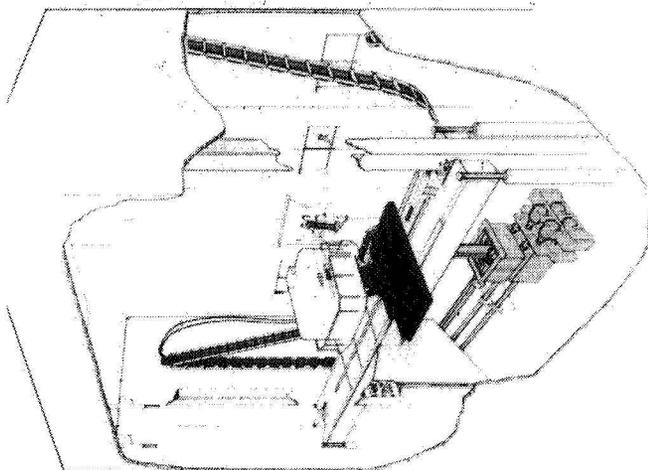


Figure 4. Vertical motion simulator.



simulator, the VMS became quite popular for rotorcraft research and Space Shuttle approach and landing investigations. Regarding the Shuttle, the landing gear and ground reactions were simulated to such a degree that, for

example, the effects of blown tires, of runway surface (landing on a lake bed versus concrete runway), of anti-skid system design changes, and of nose-wheel steering could be studied. This was also the first use of the VMS

as a training tool. The Shuttle folks have continued to use the VMS about twice a year, six weeks each entry, to cycle through all the pilot-astronauts in a combined systems-development and training activity.

Getting back to the subject of rotorcraft simulation, the VMS was also used, quite successfully, in the development of helicopter IFR certification criteria, in the development of Army Light Helicopter design specifications, and in Army helicopter accident investigations. It is currently being used to investigate Civil Tilt Rotor approach criteria and how these are affected by various levels of control and display sophistication and winds.

Also during the 1980s, a new simulation capability was established expanding further our FAA relationship. This was the introduction of the Man-Vehicle Systems Research Facility, a simulation facility with two transport cockpits (fig. 5). This facility provides very high fidelity representation of total missions and is used for studying the human factors issues in the aviation system. I would say that about two-thirds of all the work that is done in that facility is done jointly with the FAA.

In the 1988-89 period we developed, with the Army as partner and CAE as contractor, the Crew Systems R&D Facility (fig. 6) to address helicopter crew-station design issues—driven in the near term by the one-versus-two-crew LHX issue. This simulator is also a full-mission simulator, which allows the flying of complete missions as a member of a scout attack helicopter team with all the threats represented. That is a very significant capability. Another special feature is its visual display capability, with its virtually unlimited field of view provided by a helmet-mounted display. It is a very impressive system.

Over the years, simulator visual displays have been significantly improved and been made increasingly compelling. The effects of disharmony between visual cues and motion cues on the human body, factors in simulator sickness, become increasingly apparent. The simulators I talked about earlier are being used in a joint research program designed to shed more light on that particular subject.

A final topic I would like to discuss is research directed at the human factors issues associated with the use of pilot night-vision devices. Apparently, both the Army and the FAA are interested in this topic. Civil operators have asked for certification to enable them to use such devices in various aspects of their civil missions. As a result, research is being conducted in the simulators at Ames and in the Cobra helicopter (fig. 7) to address these issues.

In summary, we have seen major changes in simulation technology and in the way simulators are used. Those of you in the commercial simulator business have seen an enormous number of changes and have implemented a number of very significant technological advances over the years. During this period Ames and the FAA have enjoyed an excellent relationship, one in which rotorcraft simulation has played an increasing role.

As a result, we are certainly pleased to cohost this Workshop with the FAA. I want to wish all of you a very productive meeting and a pleasant stay in the Bay Area. I hope that later in the week you will avail yourselves of the opportunity to visit Ames Research Center where you can see some of the hardware I have spoken of this morning.

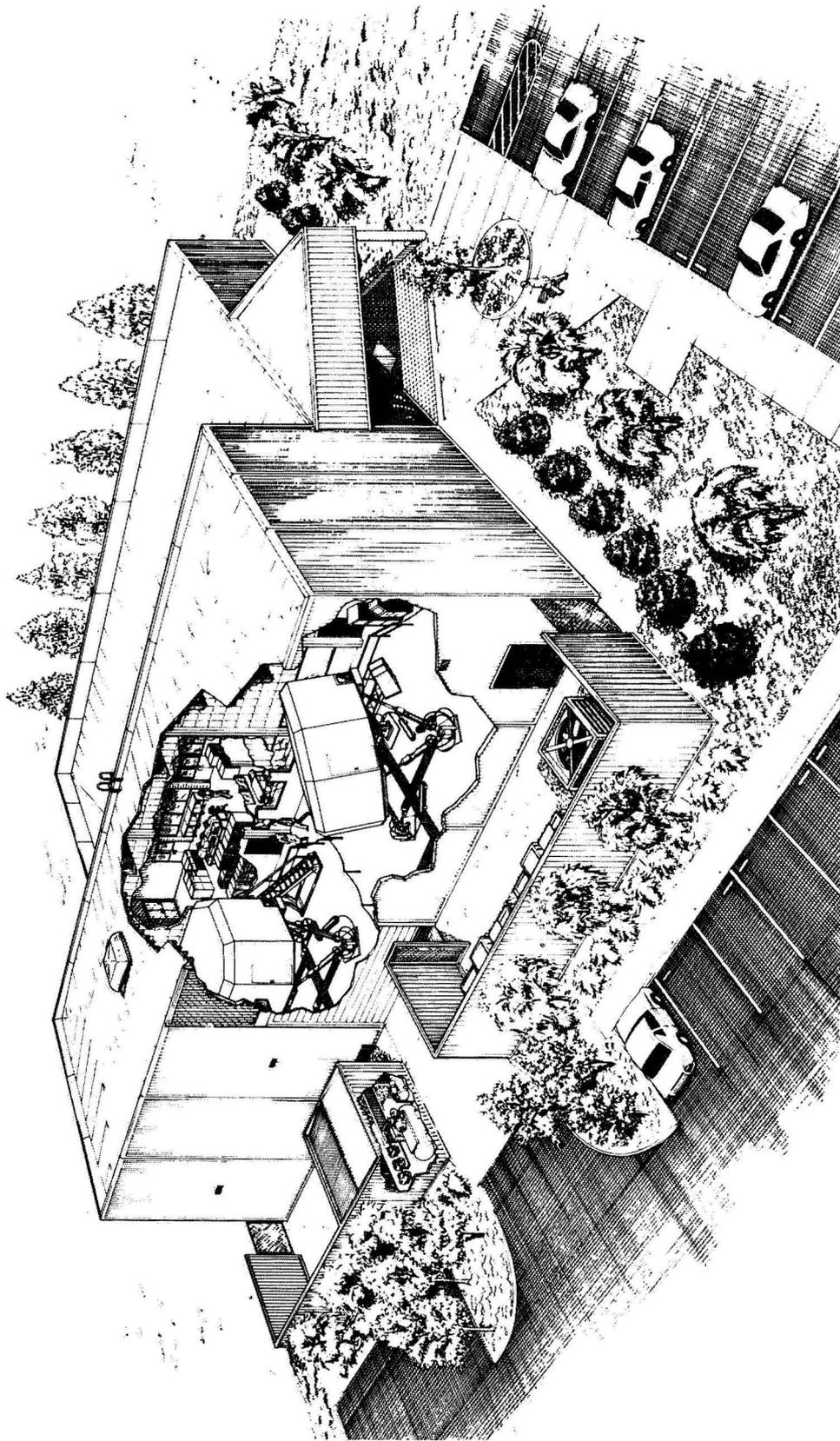


Figure 5. Man-Vehicle Systems Research Facility.

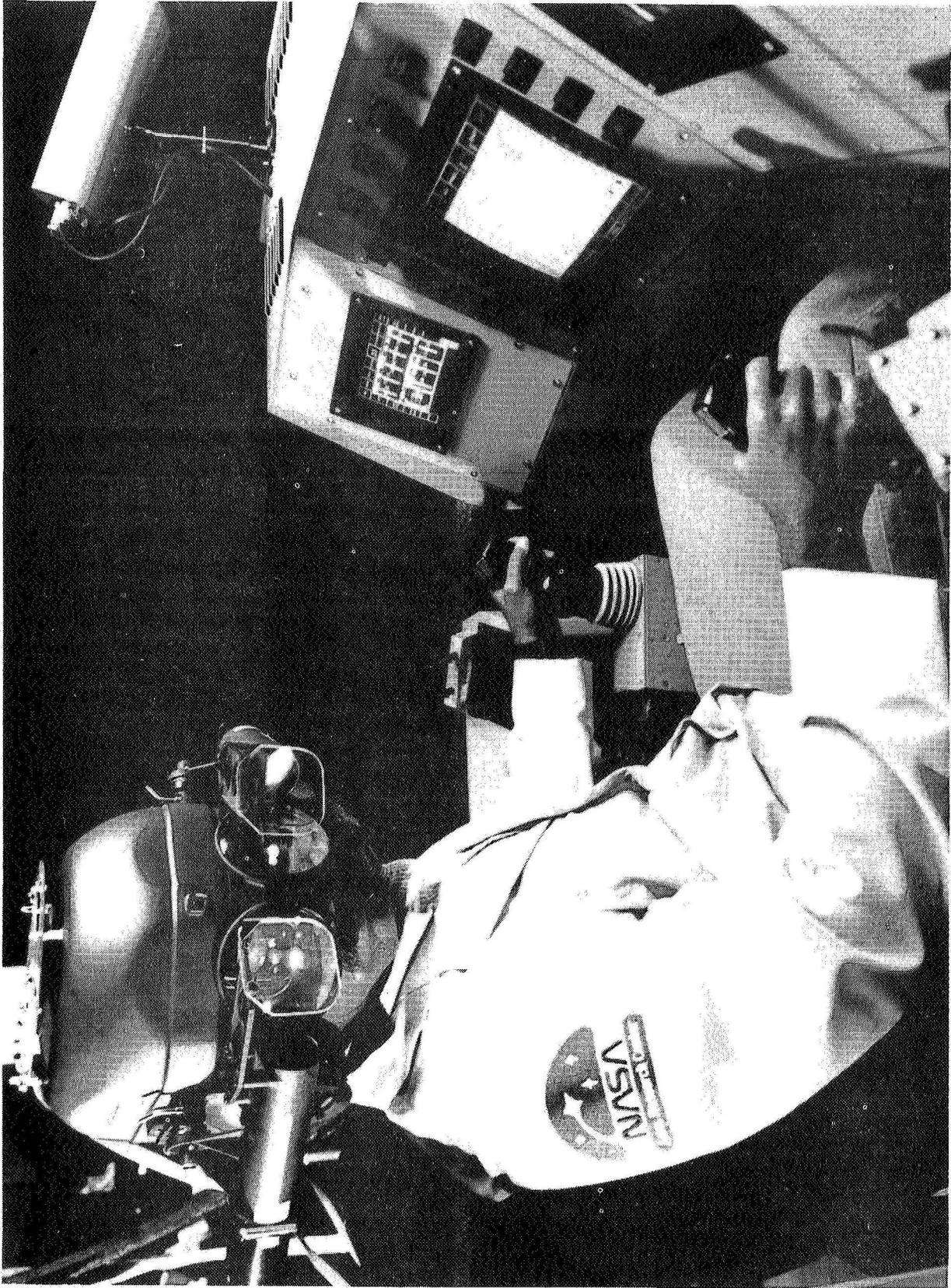


Figure 6. Crew Station Research and Development Facility.

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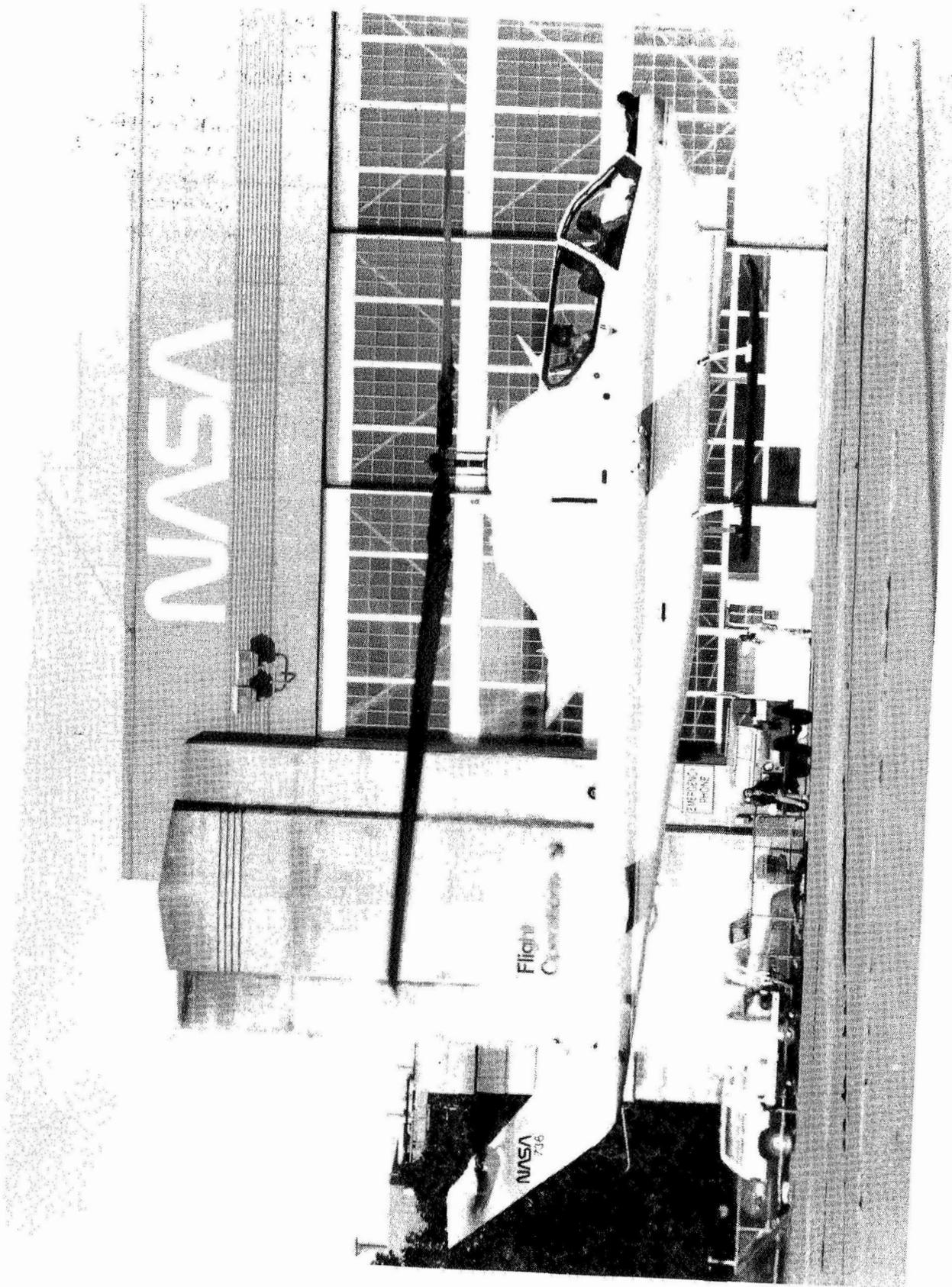
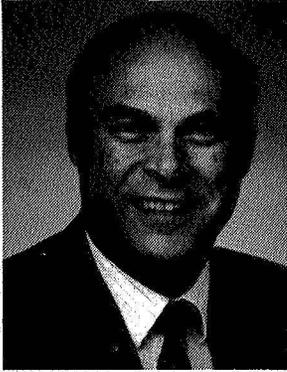


Figure 7. TH-1S Cobra.

WELCOME



C. Thomas Snyder has been Director of Aerospace Systems at NASA Ames Research Center, Moffett Field, California, since 1985. He is responsible for a broad program of research and technology development in the areas of advanced aircraft concepts and systems, human-machine system integration, and automated systems. Mr. Snyder also has operational responsibility for the National Full-Scale Aerodynamics Complex and major simulation facilities. He has a master of science degree in aeronautics and astronautics and the degree of Engineer in Aeronautics and Astronautics from Stanford University. Mr. Snyder is a former member of the Board of Directors of the American Helicopter Society, and was the 1986 recipient of NASA's Exceptional Service Medal.

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## KEYNOTE ADDRESS

JAMES D. ERICKSON

I must admit I am new at this business of keynote addressing, but when I was asked to speak at this workshop I gladly accepted. I like to talk about things that I have strong personal feelings about, and simulation is certainly a subject that qualifies.

I always like coming out here to Ames. I like to see the latest and greatest in tomorrow's technology, and I like to see advanced hardware, hardware that really flies and really performs. I like being in and around the R&D community. It is always interesting, it is always inspiring, and it is always exciting to be with R&D people and to hear people like Tom Snyder tell us what state the technology is in. I know a lot of you work in R&D-related jobs as well.

One of the things that I learned is that if you take material from only one source, it's called plagiarism, but if you take it from several sources, it's research. I have learned, too, that without management support you cannot implement programs that make all the sense in the world and that with management support you can implement programs that make no sense at all. And that is not at all unique to the R&D community.

I want to concentrate on three things while I am here: (1) how far the business of rotor simulation has come, (2) what are some reasons why it is not where the transport airplane simulation is, at least in terms of use, and (3) what are we trying to accomplish here. I think sometimes when you are frustrated by the inability to make progress as fast as you think you should, it is particularly useful to reflect back on what has been accomplished.

I remember my first exposure to simulators. It was in 1961, a fixed-wing aircraft, fixed-based T-37 simulator. Thirty years ago! I thought it was the neatest thing I had ever seen. I had had a couple of rides in the aircraft and I thought this thing was magic, it was so real. And believe me, a fixed-base simulator can be real. I don't know how much motor sensing is provided by the eyes; I am sure some of you here can tell me that, but I think it is a very high percentage. And let me tell you about a personal

experience. It's a true story, a little story about Jack Cayot. Jack is a past manager of the FAA office here at Ames. He managed the office for many, many years. He was a person with a flight-test background like me and Ed Boothe. I happened to be out here flying on a simulator program several years ago and Jack was so excited, because NASA had the first daylight four-tube visual display that had been developed for rotorcraft. There were three tubes across the front, one in your direct field of view, one to give you a little more perception forward, the side one for lateral sensing. But the fourth tube was the real key, it was focused downward to provide contact with the surface, something that rotorcraft pilots can understand. Revolutionary stuff back then.

Unfortunately, it had not been put on a motion simulator yet, and it was sitting on the floor of a very large storage room downstairs in the simulator building. Jack kept apologizing because it was a fixed-based system. He kept saying, "I wish we would let you see it on a motion system." Well, when we got down to the simulator, I got in. I got the thing into the air, manipulated the controls for a while, and made a couple of patterns around the airfield that they had there. Even though the pictures were kind of cartoonish, I was amazed at how much I felt I was really in a helicopter.

One test of my burgeoning pilot skills at that point was to do sideward flight. I positioned myself in front of a row of hangars and started doing sideward flight, faster and faster toward the left. I was right in front of a row of hangars and there was a lot of detail on those hangars; you could see knobs and doors and windows, that sort of thing.

The four-tube visual display took a lot of computer capacity in terms of the computers of that era. It so happened that the control drivers for the control system for the simulator also came from the same computer network. Things were flashing by the window at a pretty good clip, and if I had known a little bit more about computers I

would have surmised this was eating up a whole lot of computer capacity, but I didn't.

When it came time to begin slowing down there was no response. I started moving the controls toward the hover position, back to the right. But things just kept progressing faster and faster to the left. Soon the controls were against the full right stop and still we went faster. I was okay, because every once in a while I looked around the room, looked at the concrete floor and at all the junk piled around the room. Jack was standing directly behind me. He was holding onto the seat, looking over the seat to coach me through this new bit of technology. When I looked back to show everyone that the stick was full right and that we were still moving faster and faster to the left, I saw a panic-stricken Jack Cayot holding onto the back of the seat with terror on his face, genuine terror, and standing in a body position preparing for a crash. It looked kind of silly. Here I was looking back at a man with years of flying and testing experience standing on a concrete floor in a room piled full of junk preparing to crash. I will never forget it. It was powerful evidence to me of the very great power of visual systems.

Getting back to the T-37 simulator I flew 30 years ago, I thought it flew remarkably well. The technology existed back then, minus the visual systems to simulate instrument control motions and noise so that you thought you were flying the real aircraft. There were vacuum tubes and big rooms were needed to hold them, but the basic technology was the same.

The other day a pilot said to me, "You know, these helicopters are starting to fly like simulators." These helicopters are starting to fly like simulators. That says to me that we have come a long way. I don't know if that man was saying that artificial control systems are making aircraft sort of feel artificial, or that the simulators are just getting better and getting more like the aircraft. I failed to ask him. But simulators are now able to fly very much like the aircraft. Why, we are even effectively using simulators to design an aircraft's control system before the aircraft ever flies. Who could have thought 30 years ago that we could be doing that?

But I would argue that today's simulators are valuable tools even if they did not fly like the aircraft. It is important that you know the value of what you have. Like the story of two ladies walking along a Fort Worth sidewalk. This is a true story. I am from Fort Worth. They are walking along when a frog jumps out in front of them. They tried to get around the creature but he said, "Don't pass me by. Kiss me and I will turn into a Texas oil man."

One of the ladies picked him up, put him in her purse and closed the purse. The other young lady said, "Aren't you going to kiss him?" "Heck no," the other one said, "a talking frog is worth a lot more than a Texas oil man."

So you have to recognize the value of what you have. Several pilots have said that FlightSafety's 222 simulator does not fly like the aircraft, and I guess I have contributed a few comments like that myself. That does not mean the simulator is not a very valuable training tool, or that it is not a valuable simulator. The simulators today have a wonderful capability to not only simulate but to surpass or to extend what is possible in the aircraft. Let me explain.

There are diabolical training scenarios known to rotorcraft pilots who have flown simulators that cannot be duplicated anywhere else. Things like critical instrument failures, high-side governor failures on twins, twin-rotor failures, progressive engine and transmission failure, those kinds of things. Failures like these cannot be set up with any degree of credibility and safety in the aircraft. But a simulator can actually give the pilot the opportunity to experience something very close to real-world symptoms and real-world conditions, and to train the real-world motor skills necessary to deal with such problems should they occur in the aircraft. With today's simulators you can equip the pilot to recognize and deal with symptoms that he or she would otherwise see in the aircraft for the first time only under actual emergency conditions. What a marvelous tool. You can give crews the experience base to deal with these situations before they ever happen in the real world. How many of you are rotorcraft pilots? Oh, my goodness. You could have a pilot's convention here.

In my experience there is nothing quite like a high-side governor failure in a twin-engine rotorcraft. For those of you who are not pilots, let me explain. In a twin-engine rotorcraft, the two engines share the job of powering the rotor. If a high-side governor fails, one of the engines loses its governing capability and begins to put in excess power. When the good engine senses that the other engine is overspeeding the rotor, it begins to decrease its torque and power. Now, if the pilot isn't paying close attention, the initial symptoms can cause him to think there has been an engine failure. As a result, he will treat the good engine instead of treating the engine that has had the failure. Experiencing such a failure in a simulator, and talking it over with the crew and with the instructor, can prepare a pilot for the real thing, even for something as subtle as a high-side governor failure. Simulators are great tools. I think we all agree with that. But I probably need to add

that some rotorcraft simulators do fly just like the real aircraft. I had a testimonial to that from Jack Hart this morning about one of those simulators and how good the fidelity really is. But back to one of the issues I promised to talk about: Why hasn't rotorcraft simulation progressed to the same level of development and use as transport airplane simulation?

I think there are a couple of simple answers to that question. Up until 15 years ago, an IFR flight in a civil helicopter was almost unheard of. Sure, the military was doing it, because you don't prepare to fight a war only on clear days. Even in the military, however, IFR was the exception, not the rule. So the commitment to simulation of rotary-wing flight came much later than it did in the commercial airlines where IFR for every aircraft and for every crew was a necessary condition for doing everyday business.

The fixed-wing pilots were taught IFR flying at an early stage, particularly in the military. Those who transitioned to rotorcraft brought IFR skills with them. But today there are many civil helicopter pilots who do not have instrument ratings. Many of the civil missions are utility VFR applications for which an IFR simulator has only limited value. Thus, the late start in rotorcraft simulation: the lack of a mission that demanded IFR capabilities on every flight, particularly on the civil side.

I think we have to remember that the fixed-wing experience is out there as a benchmark for us and, needless to say, we have to be alert so that lessons learned in transport airplane instrumentation in use of simulators are not repeated. The technology is on hand. Pilots report that the XV-15, the S-76, and V-22 all have excellent fidelity. It's not a matter of mastering the technology to make the devices fly like real aircraft. I said earlier that we were pretty much on our way with the T-37 simulators many years ago. That technology was brought forward very effectively by the military programs and by all the military pilots who were trained with those marvelous machines many, many years ago. The job has been handled well in terms of technical development, but the technology has not been able to master and reduce the cost of simulation.

I believe there are great opportunities to lower the cost of simulation. I don't have the answers, but I do know that if Jack Cayot could be convinced he was about to crash while standing on a concrete floor in a store room, there are possibilities for decreasing the cost of motion systems. I do know that as long as simulators cost more than the aircraft they are simulating, there will be an economic disincentive to simulation. I know, too, that we are making wonderful advances in every area of electrical and digital technology so that there are opportunities on the horizon for reducing the cost of everything that the pilot sees in simulation. I know that there is a lot we can do, and that what we can do in this area is inherently good for the advancement of the state of the art of rotorcraft simulation. And it will lead us to a point where everyone can afford to send every pilot through simulator training on a regular basis. There is a challenge and an opportunity here. There is a challenge that I would make to each and every one of you: when talking technology over the next three days, include the word "cost" somewhere in your thoughts. I am not sure we always do that. And it is my opinion that that is where many of the opportunities lie. We have come a very long way in mastering the technology and in articulating the standards for design. The opportunity is in mastering the cost of those technologies and managing the costs imposed by the standards that we require.

I would like to say just a couple of words in support of Ed Boothe's public meeting, which I understand is going to be on Thursday. We in the FAA really seriously need your thoughts and your best words and your wisdom on that activity. It is important that we in government not make decisions in the dark. When we do, they are inherently bad decisions. Please come to that meeting prepared, and please express your thoughts in the meeting. The FAA is counting on you.

I hope each of you has an exciting and productive conference. In glancing over the agenda this morning I saw a whole variety of interesting subjects dealing with people, technology, theory, equipment, and standards. I am anxious to hear the presentations and I look forward to meeting many of you while I'm here.

KEYNOTE



James D. Erickson is manager of the FAA's Southwest Region Rotorcraft Directorate. He has served as assistant manager of the Southwest Region Rotorcraft Directorate, as manager of the Southwest Region Helicopter Certification Branch, and as flight test pilot for the Southeast Region Engineering and Manufacturing Branch. Mr. Erickson is a graduate of the Air Force Academy and of the Air Force Test Pilot School, and holds the Airline Transport Pilot Certificate. He is a member of the American Helicopter Society.

**PART II**

**WORKSHOP PROCEEDINGS AND**

**SESSION COMPENDIUM**



## 1. HELICOPTER SIMULATOR STANDARDS

EDWARD M. BOOTHE

I will reiterate some of the things that Jim Erickson said, but my main purpose is to discuss the work that has been done on the Helicopter Simulator Advisory Circular, 120-XX.

First I would like to thank all of you for being here and for supporting this activity. I know it is quite an effort for you, and not without expense. But, as Jim said, we in the regulatory business certainly need your support and input; in fact, we can't do our job without it.

I would also like to recognize that we have a good deal of international support. We have friends and representatives here today from New Zealand, the United Kingdom, Canada, and France. That is a fine representation, and it is appreciated. If I failed to mention a country that is represented it is only because I didn't meet that representative this morning.

I want to briefly describe where we are on helicopter simulator standards. As Jim said, the advantages of simulation have long been enjoyed by the airplane community, and the use of simulators has expanded steadily. Since 1980 there has been an average annual increase of 14% in the inventory of airplane simulators used by the entire U.S. Air carrier and corporate aviation industry. I think that is pretty remarkable: there were about 88 simulators in 1980, which were, by today's standards, not very sophisticated, and just a month or so ago we exceeded 300 simulators that are in service to U.S. industry. But that capability has not been available to the civil helicopter community. I know a good deal of simulation capability has been available to the military services but not to the civilian community.

The need has been pointed out in previous meetings and workshops, and I think it is becoming obvious. In fact I just read on the way out here that some people are referring to aircraft as part-task trainers. And I think that is true. As Jim mentioned, there are so many things that one can do in simulator training and checking that simply cannot be done in aircraft. At a recent meeting, a paper from Norway described an incident in a Super Puma.

There was a tail-rotor failure at hover, but the crew recognized the failure immediately, recovered with no damage to the aircraft and no injuries to the crew. Complete credit for that quick failure recognition and quick recovery was given to the crew's practice of that precise failure in the simulator. It is this kind of event that causes the aircraft to be called a part-task trainer. You cannot do the whole job of training in the aircraft. Moreover, there is a big and favorable cost factor involved in simulator training.

But getting on with this, the history of trying to establish some civil standards for helicopter simulators goes back at least to the meeting we had in Atlanta in 1984, at which time we had a fairly general review of the state of the technology. The following year we had a working group that did produce a draft advisory circular for helicopter simulator standards, but it never progressed. One of the reasons, I think, was because the federal regulations that control training and checking for airmen do not recognize any credits for helicopter simulators.

Then just last year the Royal Aeronautical Society had a seminar on helicopter simulation and again the interest and the need were indicated and the use of simulation at that time in North Sea oil operations was pointed out. Of course that is more of interest, you might say, to the United Kingdom and, in this case, Norway, where a number of simulators are in use. But there are only two civilian helicopter simulators in use in the United States, and I think that is because the FAA permitted use of helicopter simulators for pilot certification only by exemption. So there is no general credit. Consequently there are no current standards, which is why we are here.

Those two simulators, although being limited in their applications, still are quite valuable in their use. The Bell 222 has no hover credits, and it was qualified by using an old interim standard that we were working on. What we really did was have four expert pilots (I think Jim Erickson might have been one of them) who flew the aircraft for a few minutes and then performed the same

task in the simulator. They then went back to the aircraft and then back to the simulator.

Those of you who have in the past been involved in handling-qualities work understand, I am sure, that after 20 minutes you might as well get out of that device and into the next one since pilot adaptation time is usually quite short.

The next one was the S-76. At that time we did have the interim draft standard that was produced in 1985. But because nobody expected that, there really were no data for the aircraft, at least not to the extent that we needed them, so we used what data were available. We did the same routine that I just mentioned with some expert pilots, and we qualified the simulator and developed an exemption through a petition from FlightSafety for credits for that simulator. And in fact, you can do most of an ATP certification check in that helicopter simulator with only about three or four follow-up maneuvers for validation in the aircraft. So we know it can be done.

So why try again now? We still only have two simulators. I think in the last five years we have certainly increased our knowledge and our experience. Some of the questions we had about standards five or six years ago, we now have answers to. One small example is control loading. Six years ago when we said you have to simulate the break-out forces in a helicopter control system, most people in the business said we couldn't do that. But I know for a fact that today we can do that and that we can do it quite well. And it will stay constant, not changing as each person uses the machine.

I think here today we are going to follow up on these past issues. But another very important thing is happening: the FARs are being revised. There is a new draft Part 142 that primarily addresses training centers. The notice of proposed rule-making for that effort will be available this summer with, we hope, a rule by some time in late 1992. It will permit training and checking credits for helicopter simulators. I think that is primarily going to be started at the higher levels of pilot certification. But at least that is really where we are in airplane simulation. There are not many simulator credits for the lower levels of pilot certification; they are all pretty much at the upper levels.

One objective of our efforts this week is to form a working group of experts who will meet as necessary to address these issues and to establish standards and guidance. This process has worked exceptionally well, although slowly, with airplane simulators. And the development process for airplane simulator standards is cer-

tainly applicable to helicopter simulators. Over the past 15 years the standards for helicopter simulators have progressed such that they are almost as remarkable as the technology, but the idea has been to keep them in step with the technology.

In 1978 we did the first crude landing approval in a simulator. And now we are doing total pilot training and checking in simulators, and the standards have been revised to reflect that. The working group process has worked; in fact it worked to the extent on the latest airplane standard that that standard has been accepted as the core of international standards for airplane simulators. We hope that will become an International Civil Aviation Organization (ICAO) policy or handbook for international use for commonality and qualification of airplane simulators. The point is the process should be equally applied to helicopter simulators.

It is hoped that the working group membership we seek will represent a broad range of the community of aircraft and simulator manufacturers, users, and operators. And, of course, the final customers, the training experts, the technical societies, and the regulatory authorities must be represented. We would like the group to be limited to about 30 members; our experience shows that with more than that, it is very difficult to make progress. In fact, on the international working group, Brian Hampson, who is the chairman for the Royal Aeronautical Society, has made a special effort to limit the size of the group. I thank him for that, and I think a great deal of the progress that has been made is a result of keeping the same members meeting after meeting and because we have limited the group to those same members. Even so, we still rehashed a lot of stuff.

As Harry Reasoner once put it, helicopters are different. Some pilot tasks are more demanding in the helicopter simulator than they are in helicopters. We have noticed that the hover and low-speed tasks have been the most challenging to simulate. That is one reason the Bell 222 is not qualified for that, although it probably could be with some updates. Progress was made in that area, however, so that the S-76 is so qualified. Not all pilots agree that that should be true, by the way, but that is the nature of these kinds of activities, I think.

Not all simulators need to be qualified for all tasks, so we will be looking at a number of levels of simulators. We have tried to keep those levels aligned with what has been successful for airplanes, mainly so we can keep the record straight. And we'll be working later in this

Workshop to form the group that will follow through with this effort.

So, if you would be kind enough, then, please review the draft document. It is modeled, in terms of general policy and structure, on the airplane document. But that is a matter of style, not content. And we would like to

pursue that approach because we have spent years actually finalizing that format and structure. Nevertheless, the technical content is certainly something that needs to be addressed, and addressed in fine detail. I will look forward to hearing from you on Thursday when we form the standards working group. Thank you.



Edward M. Boothe is manager of the FAA National Simulator Evaluation Program, Atlanta, Georgia. He is responsible for ensuring that all simulators used in checking U. S. civilian airmen meet appropriate standards. Before joining the FAA, he was a research engineer and engineering pilot at Calspan Corporation, where he performed airplane handling-qualities research and control-systems studies. Mr. Boothe has a masters of science degree in aerospace engineering from Texas A&M University, and has an Airline Transport Pilot Certificate with ratings in Boeing 757/767 airplanes. He serves on the AIAA Flight Simulation Technology Committee, and is an Associate Fellow of the AIAA and a Fellow of the Royal Aeronautical Society.

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## 2. HELICOPTER SIMULATION: AN AIRCREW TRAINING AND QUALIFICATION PERSPECTIVE

RICHARD A. BIRNBACH AND THOMAS M. LONGRIDGE

FAA goals for the training and qualification of commercial aviation rotary-wing airmen are no different from those in the fixed-wing categories—to improve safety through effective training and checking. Flight simulators have been successfully employed for this purpose in the air carrier community for a number of years, and the FAA has developed an explicit set of regulatory compliance requirements in that regard. The recently established Advanced Qualification Program (AQP) expands the regulatory boundaries for device-based fixed-wing training and aircrew qualification, by allowing for families of devices lower on the equipment complexity continuum than the traditional categories of flight simulators. Although our understanding of the issues involved in qualifying synthetic devices for such applications is becoming increasingly mature, this circumstance is decidedly not yet the case for rotary-wing application. We wish to review some of the unique considerations which (1) distinguish the commercial rotary-wing domain from its fixed-wing counterpart, and (2) motivate the FAA to proceed cautiously in extrapolating from our fixed-wing experience in establishing qualification requirements for helicopter simulators. It is proposed that the issue of device qualification should be considered in the context of an overall training and qualification system. Rather than focusing solely on the isomorphism between the engineering characteristics of the synthetic device versus the aircraft, such an approach would integrate engineering and behavioral criteria. Ideally, a decision strategy on helicopter simulator fidelity requirements would include consideration of the proficiency objectives on which airmen would be trained and qualified using the device.

Good afternoon ladies and gentlemen. I'm honored to have an opportunity to share my views, and more importantly the views of the Federal Aviation Administration, of our regulatory goals for the use of helicopter flight simulators and helicopter flight-training devices.

Although I may spend a lot of time and energy highlighting the differences in helicopter and airplane requirements later in this presentation, I am going to start by saying that the FAA's regulatory goals for flight simulation are exactly the same for helicopters as they are for airplanes. These goals are to increase safety in flight operations, to ensure attainment of reasonable aircrew proficiency standards, and, through better trained crews, to foster the safe and efficient growth of the aviation industry. The FAA recognizes that flight simulation is a proven and effective means of attaining these goals.

The FAA considers its experience in flight simulation to be a positive example of how the industry and government can cooperate to achieve their sometimes diverse goals. Through foresightedness, dedication, and plain hard work, we, both government and industry, have made the use of airplane simulators one of the most successful programs ever undertaken to increase safety and efficiency. Our simulation programs have been an unqualified success.

Aircrews recognize and appreciate the use of flight simulators because of their proven ability to enhance the crew's performance. The FAA, airlines, and the traveling public benefit immeasurably from the safety improvements simulator training has brought to day-to-day operations. Before simulation came into widespread use, required airline training activities contributed substantially to airport congestion, delays, and noise problems, as well as to other environmental issues. In today's airline training environment, air-traffic control doesn't have to accommodate the training that is done in simulators, and aircraft and fuel resources are conserved. We anticipate even greater progress in these areas with the advent of increasingly sophisticated but low-cost flight-training devices. At the FAA, we see no reason for any lesser degree of success in the use of helicopter flight simulators and flight-training devices. Interestingly, this has not yet occurred.

Let's take a quick look at where we are in the FAA with respect to helicopter flight simulation. The helicopter simulator has no detailed regulatory basis, such as the airplane simulator has in Appendix H of Part 121. The operating and airman certification regulations do not have provisions for use of helicopter simulators that parallel those of airplane simulators. However, we do have a draft helicopter simulator qualification advisory circular which has been used as an interim standard in approving two civil helicopter simulators. I participated in the evaluation of these simulators and would like to share my thoughts and observations about them with you. I believe we should be cautious in extrapolating from our airplane flight-simulator and flight-training device experience. I also feel that the overall training and qualifications systems for helicopters are not directly equivalent to airplane training systems.

Helicopters not only look and sound different than airplanes do—they have different missions and require different crew skills. Although helicopters can be used for some of the same mission tasks as airplanes, they also can do missions an airplane could never accomplish. Helicopters are capable of operating in natural and man-made environments that are prohibitive to airplane operations. Helicopter pilots must learn how to control their aircraft in any possible combination of directions of flight. The helicopter's mechanical and electronic equipment combinations have complexities not usually found in airplanes of equal size. All these factors enable the helicopter's wonderful freedom of navigation. However, they also introduce a high potential for risk in helicopter operations that must be recognized and accommodated through effective crew training. These differences have a critical influence on the design of helicopter simulators and on the overall design of any helicopter crew training and qualification system.

Let's compare the issues that differentiate helicopter from airplane operations. In general, airplanes are used for transportation of persons or cargo between airports. Missions that airplanes and helicopters share include training, recreational flying, crop planting and protection, pipeline and power-line surveillance, livestock surveys, aerial photography, aerial search, and surveying, as well as short-range transportation between airports. Helicopters are the primary means of air transportation between off-airport landing sites and are also used in construction work, law enforcement, emergency medical transportation, and rescue operations. The special operations that

helicopters can perform that airplanes cannot are too numerous to list.

Helicopter crews may be called on to perform all these missions in the same physical environment that airplanes usually operate in. However, in many instances, helicopter missions are performed in environments not shared by airplanes. There are substantial differences in the characteristics of the many landing and surface operating areas used by helicopters. In contrast, airplanes always use some form of level runway with cleared approach and departure paths. Except at permanent heliports and airports, helicopter crews must reconnoiter, select, and execute every detail of the surface operation without benefit of airport engineering and improvement activities. In many cases, helicopter operating sites are not located in controlled airspace and have only limited support from the air-traffic control systems, federal navigational aids, and weather reporting and forecasting systems.

In addition to dealing with a more complex operating environment, helicopter crews must cope with the handling characteristics of the helicopter that permit its nearly unrestricted mission capabilities. The very features that make the helicopter so versatile also increase the difficulty of its operation when compared with airplane flying. Airplane and helicopter flight-path management and control characteristics are different. Airplanes can't fly sideways or backward. Helicopters, of course, can fly in any direction. The crew knowledge and skills required for sideward and rearward flight are not a consideration in airplane operations.

Most airplanes share a lot of common handling qualities. For example, the basic handling qualities of a Cessna twin are not very different from those of a single-engine Beechcraft. This can't be said for helicopters. Handling qualities may substantially differ from one helicopter to another. Compared with airplanes, helicopters are a rather unstable aircraft with high work loads. Airplanes are mechanically simple devices when compared with helicopters. This increased mechanical complexity requires helicopter crews to learn and understand a greater number of abnormal and emergency procedures. Helicopter pilots would be quite surprised to check out in a new helicopter without learning how to cope with failure of anti-torque control. How many fixed-wing pilots have been taught what to do if rudder control fails?

Each of the differences I've mentioned can have a profound effect on helicopter flight-simulator and flight-training-device design. Is a direct extrapolation of our experience with airplane simulators may, there, be

inappropriate. Let's summarize what should be accounted for in helicopter simulator design.

First, let's consider the conditions that apply to airplane and helicopter simulators. Both require accurate simulation of aircraft system operation, IFR en route navigation, IFR and VFR terminal-area navigation, and airport surface operation. A second list applies to additional helicopter flight-simulation device design considerations. This second list of considerations includes VFR en route navigation, lateral and rearward flight, offshore operations, water surface operations, amphibious operations, urban congested-area operations, slopes, confined areas, flight-path obstructions, autorotations, and power-off landings.

Let's assume that in the near future we determine what helicopter simulators and training devices should be capable of and let's further assume that the FAA publishes a final version of advisory circulars for helicopter flight simulators and helicopter flight training devices. What can we use them for? In their present state, the Federal Aviation Regulations, Pilot Test Standards, and other regulatory documents permit only very limited use of helicopter simulation. Therefore, when we develop criteria for helicopter simulators and training devices, we are only half finished with the job at hand. We need to determine what the appropriate proficiency objectives are for helicopter crews and amend the FARs to enable device-based training and checking for those proficiency objectives.

Which should we develop first, the helicopter crew qualification standards, helicopter flight-simulator and flight-training device standards, or the enabling Federal Aviation Regulations? Tom Longridge and I believe we should view these three tasks as an integrated job that requires development of helicopter crew qualification standards, helicopter flight-simulator and flight-training-device criteria, and development and implementation of changes to Federal Aviation Regulations in support of modern helicopter training and qualification requirements. We believe that we can and must take a systematic approach to the development of an overall training and qualification system, because without systematically developed crew qualification standards and enabling FARs, we have no means to ensure that we will effectively be able to employ any helicopter-simulator or training-device criteria.

To determine what skills helicopter pilots need to accomplish their job, we need to take a look at the mission-related tasks today's helicopter pilot must master.

Qualification standards for helicopter crews can be developed and adopted for use in an integrated training and qualification system which is designed to include the flight simulator and flight-training device as essential tools for learning and evaluation.

Given the environment in which helicopters operate, their flight characteristics, and many mission tasks, high-fidelity helicopter simulation is technically very challenging. For the average commercial operator, it may in fact simply be too costly. For that reason recommendations on fidelity requirements should carefully weigh cost versus benefit in light of the purposes for which these devices will be used.

Flight simulation, by definition, always represents some degree of abstraction from reality, for the simple reason that a simulator is not an aircraft. Therefore, there will always be some degree of compromise on realism. So, a fundamental issue is the decision criteria on which basis such compromises should be determined. Certainly engineering criteria, such as the extent to which the simulator's display system duplicates the actual aircraft's field of view, or the aeromodel duplicates the actual aircraft flight characteristics, are a very important consideration in any such decision process. However, from a training and qualification perspective consideration of how the device is to be used is of equal importance. We feel that for helicopter simulators and flight-training devices, because of their many unique characteristics, a sensible decision strategy on fidelity issues must integrate both engineering and behavioral criteria.

MR. TREICHEL: Regarding Part 142 in the proposed rule-making, is there some kind of advisory team or committee that is being made up that some of us could get involved in to make sure that everything is running along as smoothly as this effort is?

MR. BIRNBACH: During one of the breaks I am going to introduce you to Warren Robbins who is here with us from the General Aviation Division. Part 142 is the product of an advisory committee. It was not quite an advisory committee when they put it together, so I would rather not talk about it to any great extent, but it included people from the simulation industry and from the training centers and the helicopter industry. And it is not a bad document. But I will get you together with Warren and you can talk directly about it. Anybody else? Yes, sir.

MR. RUTKOWSKI: You only have two simulators approved right now. What is the requirement . . . how many other operators out there do you have with the need

for that kind of fidelity? How big is the need out there to build this type of device?

MR. BIRNBACH: I cannot answer that for the Part 61 operators except for one thing. I know that what we call a Part 91 operator has a little problem in exposing the assets that they have. If someone owns an S-76, a Bell 222, or an SA-360 type of machine, it is really tough to go out and ask them to do tail-rotor failures and touch-down autorotation in these things. The insurance company knows it and FlightSafety's Greg McGowan can tell you. The real problem is the industrial-type operator, the off-shore operator, the air taxi, the external load operator. These people have a little difficulty with what simulation is available to them and they cannot do the kind of tasks they need to do for their pilots. So it is difficult to answer your question from my perspective. There is not a lot of demand right now in the 135 world for helicopter simulators.

MR. RANDALL: Over the last 30 years I haven't seen a lot going on in behavioral science things. I think it is desperately needed when we transition into helicopter simulators.

MR. BIRNBACH: Let me try to answer that as best I can. First, I don't want to throw the baby out with the bath water. I don't want to restart this whole issue of what should come first and what should come second. With respect to the level of helicopter simulation available to us, that would be covered by the draft advisory circular. I think we are smart to go ahead with that right now, and the rule-making projects that we have in hand will support the use of those types of simulators. Where we really need to make sure we do this is in regard to part-task trainers or training devices. It is going to be very important to us, especially in rotary-wing, but just a little bit less so in fixed-wing training devices. How do we give part-task credit? Last year the FAA came out with an integrated human factors program. We came up with a plan which is in the final approval stage. In that plan are work resumes

and intents to go out and do research on these issues. We need to do some research, we need to come up with the processes for giving credit for part-task devices. Then we need to do something about clarifying the rules. I do not see that happening in the next 6 months, but I see the first steps being taken to do it.

MR. WALKER: We have been dealing with helicopter simulator operations, and one of the issues that's been of most concern to me is in your decision criteria. In particular, I always see a problem with having part-task data that are tailored to support simulator development. Is the regulation that you are addressing going to deal with this issue?

MR. BIRNBACH: We have talked about these things between Ed Booth's shop and mine and some others, on several occasions where you talk about flight-test data to support simulator development. And there are two issues here. One is to technically assimilate a flight training device by being able to measure what it looks like, what it sounds like, and what it does.

The other is to figure out what credit you can give to the training requirement. There is no doubt in my mind that the high end of those engineering criteria is extremely important and that we have had success in simulator qualification relying on this.

I do not know what to do with this decision point that we talked about here, and looking at how we use this engineering criteria as opposed to transfer of skills criteria, is when we get down into the lower-order devices. I just do not know how to do it. We have some people who have a lot of good ideas on how to determine what to do, but until we do that I think we are going to have to rely on some of our successes. We just cannot argue with the success that we have had in fixed-wing simulation and in these two rotary-wing simulators in relying on flight test data as our beginning point. I do not know what else to say to you there.



Richard A. Birnbach is manager of the Air Carrier Training Branch at FAA headquarters in Washington, D.C. He is responsible for FAA policies, procedures, and regulations on airline training and qualification for aircrew personnel. Mr. Birnbach served as pilot in the U.S. Army, where he earned ratings in both rotary- and fixed-wing aircraft. Following combat duty in Viet Nam, he was an instructor pilot at the Army Aviation Center, Fort Rucker, Alabama. Mr. Birnbach is the author of the FAA's Air Carrier Operations Inspector's Handbook.

### 3. ROTORCRAFT MASTER PLAN

PETER V. HWOSCHINKSY

I would like to talk about the vertical flight program and give you some insight into the bigger picture. Jim Erickson mentioned why simulation use for rotorcraft is not at the same stage as it is for scheduled airlines. We are working toward the day when the term "scheduled airline" includes rotor-borne flight as well. I would like to speak of our planning efforts that we hope will help make this happen. Maybe we can prove to Ed Boothe that we can get there from here.

In 1975 the Rotorcraft Task Force (ROTAF) was created to address issues associated with industry growth and to provide a forum for communication between government and industry. As a result of that task force's recommendations, the first rotorcraft master plan was published in 1983, updated annually through 1987, and again published in November of 1990 after extensive rewriting and reformatting. Although the master plan contains a comprehensive summary of vertical flight goals, it alone is not sufficient for tracking project status and monitoring progress; the Vertical Flight Program Plan (VFPP) will provide that capability. The FAA Executive Board recommended establishment of a vertical flight program focal point and preparation of the VFPP to tie together all vertical flight activities.

The Board also stipulated that the plan should be consistent and that the policy direction from the FAA must be ready to ensure a hospitable environment when industry presents a feasible vertical flight initiative. The Board agreed that the program should proceed in two phases, with the initial version of the VFPP covering the Phase 1 time frame.

Congress has shown interest in the potential that vertical-flight technology may hold for helping to solve some of the nation's problems, especially transportation problems. Hearings on the civil tilt-rotor were held in 1987 and 1990 by the House Transportation, Aviation, and Materials Subcommittee. In 1989 and 1990 both the House and Senate Armed Services Committees held hearings on the V-22 at which the Department of Defense

was requested to provide a report on civil applications for the aircraft.

In development of the Reconciliation Act of 1990, Congress requested a blueprint for additional research needed to develop an economically feasible civil tilt-rotor aircraft. The study would also identify and describe the types and numbers of facilities needed to sustain an economically feasible tilt-rotor fleet and would specify changes in ATC procedures that must occur if the benefits of the tilt-rotor aircraft are to be realized.

Proof of further congressional interest is the Mag Lev/Tilt-Rotor Study currently being conducted by the Office of Technology Assessment. The Administration's national aeronautical R&D goals include an action plan to enhance the safety and capacity of the National Airspace System through advanced automation, electronics technology, and new vehicles concepts, including vertical and short takeoff and landing aircraft. In Moving America, the emergence of new technology such as the civil tilt-rotor is emphasized for its potential to provide transportation in dense corridors. The Office of the Secretary has requested that analysis be conducted into feasible alternatives. These studies are ongoing today. The civil tilt-rotor is considered a practical alternative for dense-corridor passenger transportation. Finally, the Administration has approved the development of a joint FAA/Industry Rotorcraft Master Plan.

State and local governments have shown great interest in the tilt-rotor as a mode of transportation that may reduce airport congestion and provide considerable time savings. To date, \$3 million has been awarded to various states and cities, and to the Port Authority of New York and New Jersey for tilt-rotor feasibility studies and vertiport studies to investigate a potential intercity transportation system.

The hierarchy of plans that will be used to develop the VFPP is based on the National Transportation Policy endorsed by the secretary of transportation and the FAA's own National Aviation Policy for developing the air

transportation system through the next century. The three capital plans which support those established policies include the Capital Investment Plan (CIP), Research Engineering and Development Plan (RE&D), and the National Plan for Integrated Airport Systems (NPIAS).

The next level in the hierarchy is represented by two plans that are organized along functional lines, the Aviation System Capacity Plan, and the Rotorcraft Master Plan (RMP). In other words, there are these cross-cutting plans which may contain projects that receive their support from each of the capital plans in the previous tier, while at the same time providing for funding contained in these capital plans.

The levels below the RMP contain the two specialized documents that will relate specifically to vertical flight: the VFPP and project implementation plans (PIPs); and Contractual Flight Program Plan and PIPs. Not all of the projects in the VFPP will warrant a PIP, only those involving a large degree of intra-agency and interagency coordination and effort. The VFPP will integrate projects from two other primary vertical flight documents, the RMP and the National Civil Tilt-Rotor Initiative (NCTRI) implementation plan. This process will eliminate unneeded overlaps and gaps and provide cross-plan coordination.

The RMP coordinates existing programs and new actions needed for vertical-flight aircraft to reach their full potential within the NAS. Strategies and projects to accomplish vertical flight goals are divided into three issue areas: (1) infrastructure, including heliport and vertiport development; (2) NAS integration aircraft technology; and (3) pilot training and certification. Successful implementation of the RMP depends on the joint commitment of federal, state, and local government agencies and industry. Checkpoints described in the RMP provide the initial basis for ensuring that this common commitment exists at major investment decision points. The RMP appendix summarizes FAA and industry activities.

In 1988 the FAA initiated a comprehensive review of the 1987 version of the RMP. The review involved cooperation between the FAA and representatives of the rotorcraft industry. Efforts were refocused to emphasize NAS capacity enhancement using vertical flight. Integration of a civil tilt-rotor into the nation's air transportation system was a key element of the revised plan's strategy for accomplishing that goal. The revised version of the RMP was published in November 1990.

Vertical-flight technology has the potential to enhance NAS capacity at a fraction of the investment that

would be necessary to build new or improved commercial airports. This potential is the underlying reason for the initiatives presented in the RMP. The RMP will be implemented incrementally, with checkpoints existing at the end of each phase to measure how the system is performing relative to the plan's goal. Resource commitments will be made on a quid pro quo basis with this plan being used to provide justification for committing resources to high-priority rotorcraft projects. By 2010 rotorcraft could provide as much as 10% of the intercity passenger operations capacity in the NAS. That would mean that rotorcraft would then account for 5 million of 50 million annual operations, and for 105 million of more than 1 billion enplaned passengers.

As mentioned earlier, implementation of the plan is divided into phases, with a major investment decision needed at the end of each. Between now and 1996 a successful demonstration of the civil tilt-rotor would be accomplished, along with development of one or more heliport/vertiport networks. Between 1997 and 2000 the focus would be on the transitioning of vertical flight activities more to the private sector, with the FAA providing technical assistance as appropriate.

After 2000 and beyond 2010 the FAA would hand off responsibility for most vertical flight activities to industry, as scheduled passenger service matures and expands. The RMP implementation phases (fig. 1) illustrate the relationship between the rate of investment of federal resources and the corresponding operations growth. As shown, there is about a five year lag between the necessary investment and the time that operations growth becomes evident. This time line shows the checkpoints in the RMP that will be used at the end of each implementation phase to evaluate system performance and to determine whether major investments in planned activities should be made or not. That is, should we proceed as planned to the next phase of implementation.

The milestones in the plan for 1990 and 1991 are listed in table 1. With reference to milestone 3, the FAA Rotorcraft National Survey is complete, and the publication of the survey results is expected soon. These data will help the FAA improve the services it provides to system users, as well as improve rotorcraft forecasts, which serve as a foundation for planning and developing future strategies. The other milestones include improving the public image of rotorcraft, defining heliport networks capable of supporting various rotorcraft applications, especially scheduled passenger service, and beginning preparations for tilt-rotor demonstration. I would like to

# Investment Drives Operations Growth

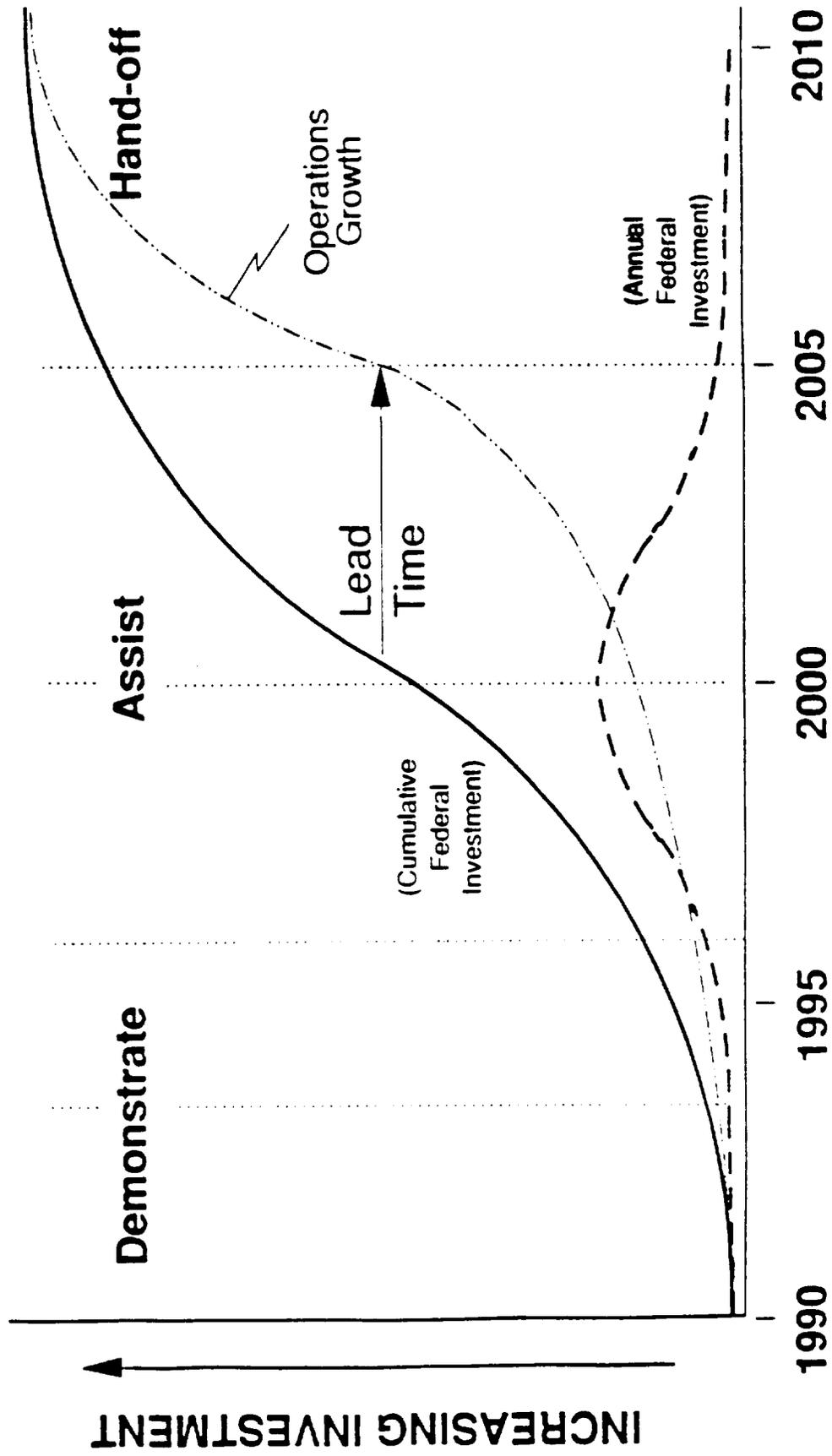


Figure 1. RPM implementation phases.

Table 1. RMP milestones: 1990-1991

All vertical-lift aircraft	Civil tilt rotor
1990	
1. Rotorcraft focal point	
2. Rotorcraft public image program	
3. Program data systems	
1991	
4. Heliport networks defined	6. CTR demonstration sites chosen
5. Rotorcraft simulator certification criteria	7. Route structure guidance

Table 2. RMP milestones: 1992-1993

All vertical-lift aircraft	Civil tilt rotor
1992	
8. Rotorcraft public image improving	11. Funding for vertiport development or improvement
9. Rotorcraft TERPS complete	12. Civil tilt-rotor pilot program
10. Initial helicopter route charts	
1993	
13. Heliport networks operating	16. Route network complete (CTR demonstration)
14. U.S. helicopter sales grow	17. Operator chosen for CTR demonstration
15. Scheduled helicopter service	

add here that a recent slip in the military's V-22 development schedule has necessitated a similar slip in the civil tilt-rotor development. Rescheduling some of these milestones will be necessary as a result. They will be accurately reflected in the VFPP and in the next revision of the RMP.

Table 2 shows the milestones for 1992 through 1993. Activities during this period will include developing sufficient heliports to establish one or more networks, completing preparations for a civil tilt-rotor demonstration, and operating schedules for helicopter service. In addition, work and emphasis on rotorcraft TERPS will be completed; emphasis on improving the public image of rotorcraft will continue. This phase of the plan focuses on operations, support, and enhancements. It will also determine whether activity levels warrant commitments to expand significantly the use of vertical-flight aircraft as a NAS capacity enhancement tool. Specific accomplishments will include adding to and improving heliport/vertiport networks and evaluating the success of helicopter passenger services and the tilt-rotor demonstration.

The overall objective of this phase is to establish 100 public-use heliports and vertiports by the year 2000. Milestones leading to that checkpoint might include certification of the civil tilt-rotor for passenger operations, the

beginning of scheduled intercity passenger service by vertical-lift aircraft, and public-use heliports/vertiports in all major hub metropolitan areas. Reaching any of these milestones would constitute an impressive achievement for vertical flight and mark a significant departure from its current applications in NAS.

In 1988, members of Congress clearly recognized the civil potential of technology advances exhibited by the XV-15 and V-22 and requested development of a plan for integration of tilt-rotor technology into the civil air transportation system. In response, the FAA assumed the lead role in launching the National Civil Tilt-Rotor Initiative (NCTRI). A five-point program to speed the introduction of tilt-rotor technology into the national air transportation system was formally started in August 1988, including establishment of a national focal point for tilt-rotor activity, the tilt-rotor program office, and a memorandum of agreement between the FAA and DoD to expedite acquisition of test and engineering data from the V-22 program.

The NCTRI implementation plan was drafted in the fall of 1989 to spell out the actions necessary to successfully implement the initiative. Included in that document were the tasks and projects to be carried out, a tentative schedule of major milestones, and preliminary cost estimates. In the NCTRI implementation plan, all of the

program tasks were grouped into four elements, or pillars, supporting the accomplishment of the demonstration projects and full integration of the CTR into the national air transportation system. These four pillars were aircraft development, public acceptance, infrastructure, and certification.

A series of six major milestones was spelled out in the plan, beginning with preparations for a civil operational demonstration period and ending with full integration into the NAS in December 2010. Critical factors affecting the success of the tilt-rotor program included congressional support, completion of the V-22 full-scale development, test, and evaluation program, and early industry and operator commitments. Other important information in the plan included a list of roles and responsibilities by office or organization, costs to government and industry, both in terms of yearly expenditures and cumulative estimates, and alternative aircraft development options that could be used to achieve the tilt-rotor development if the V-22 program was interrupted or discontinued.

Let's discuss in some detail the VFPP. The purpose of the plan is to ensure a hospitable environment when industry presents a feasible vertical flight initiative. Also it will develop detailed project plans for the period 1991 through 1994, which is the Phase 1 period; outline planned activities for 1995 through 2000, the Phase 2 period; and incorporate the contents of the RMP, the NCTRI implementation plan, and data from other appropriate plans into one comprehensive document. The primary objective of this plan is to make it possible to track project status and costs accurately and continually, something we are not now able to do. In this way, we will always know where the program stands. In addition the VFPP will provide cross-plan coordination, eliminate overlaps and gaps in existing plans, define schedules and resource requirements, and establish roles and responsibilities for the various participants in the plan. The plan will be organized in this format, with the bulk of the information contained in the project plans for Phase 1.

Increasing the role of vertical flight in the national transportation system is a cooperative venture requiring a successful partnership between government and industry. It is the government's role to create and enhance the cli-

mate in which the rotorcraft industry can continue to expand and realize its full potential, but it is up to the private sector to take advantage of opportunities to achieve commercially successful rotorcraft services. The plan will be prepared by using a matrix-type organization. The vertical flight special program office will be the overall program coordinator, and the matrix offices will be responsible for providing project managers, for project plans, and for project reporting. Primarily, the types of inputs needed from project managers are schedules, resources, and project status reports.

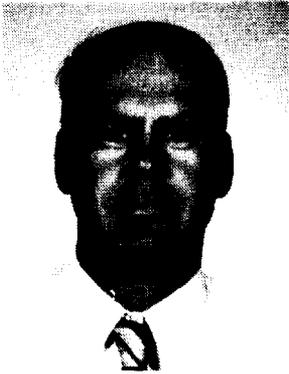
The plan will be updated yearly. In addition, quarterly status reports will be required from the managers, and quarterly meetings will be held to discuss problems and unresolved issues. The management of the plan will conform to the agency guidelines promulgated for program management. In this case under the line organization of ASD and ARD, the director of the Vertical Flight Program will serve as program manager. That office will have overall responsibility for assembling, monitoring, and coordinating the plan. Relationships with the various matrix team members will be in accordance with written operating agreements.

Vertical flight project manager will supply project details to the Vertical Flight Program Office for inclusion in the plan. They will be supplied with a sample format for submission of their input.

Finally, the Vertical Flight Program schedule is shown below.

- |                                     |                  |
|-------------------------------------|------------------|
| 1. Brief Associate Administrators   | Mar. 11-15, 1991 |
| 2. Brief and train project managers | Mar. 18-22       |
| 3. Develop project plan data sheets | Apr. 5           |
| 4. Review/modify project sheets     | Apr. 12          |
| 5. Prepare integrated schedule      | Apr. 26          |
| 6. Prepare resource annex           | Apr. 26          |
| 7. Deliver office-level draft       | May 10           |
| 8. Deliver associate-level draft    | Jun. 14          |
| 9. Final plan approval              | Jul. 19          |

It is out of date for developing the plan itself. We finished the last briefing to the associates on April 19, so that item (1) is out of date. We still hope to meet the publication date for the first plan, which is the end of July.



Peter V. Hwoschinsky is Technical Manager of the FAA's Vertical Flight Program. He was program manager of the FAA's Aircraft Separation Assurance Program, the Aircrew Performance Enhancement and Error Reduction Program, and the Rotorcraft Technology Program. He earned bachelor and masters of science degrees and the advanced degree of Engineer of Aeronautics and Astronautics at the Massachusetts Institute of Technology. He has published eleven training manuals on aeronautical decision-making and pilot judgment training.

#### 4. SIMULATORS FOR CORPORATE PILOT TRAINING AND EVALUATION

CURT TREICHEL

First, I would like to thank Bill Larsen, Vickie Gardner, and their team for organizing this seminar and workshop. I would like to thank each of you for being here to share your expertise. And I would like to give special thanks to all of those very talented individuals and teams that have given us the simulators we use today. We've come a long way from the School Link and ANT-18 Blue Box.

You know, I'm kind of surprised this meeting received approval to be held in the San Francisco Bay Area, what with all of the faults around here. Apparently we accepted the notion that while the experts continue trying to improve the earthquake tolerance of the local buildings and highways, the area's many good characteristics make it a very desirable place to visit, work, and live. If only Greg McGowan had so much luck getting approval for his simulator—even though they may have a few faults.

I first became familiar with "simulators" for pilot training and evaluation when I started instructing at the University of Illinois, Institute of Aviation, in 1968. There I learned to use a School Link and ANT-18 Blue Box in conjunction with a classroom, chalkboard, and an Aeronca CH7FC airplane to train and evaluate candidates for the Private Pilot Airplane Certificate. Shortly after arriving at Illinois, we acquired several Link General Aviation Trainers, or GATs, to add to our inventory of learning resources. These GATs even had communication radios, VORs, ILS, and ADF. Now that was progress! Next we replaced the CH7FC Aeroncas with brand new modern Piper Cherokee 140s, which also had modern radios, including VORs, ILS, and ADF. More progress! At Illinois, we also modified the program to require students to train in pairs, so that for every hour of experience they gained at the controls, they spent another hour in the back seat watching and learning as the other student received training. More good progress!

I left the University of Illinois in 1979 to join the United Technologies Corporate Aircraft Department. During my 12 years with UTC, I have observed our pilots receive simulator training and evaluation for the Beechcraft King Air, Cessna Citation, Rockwell Sabreliner, Gulfstream III, Gulfstream IV, Boeing 737, Boeing 727, and the SK76 helicopter. Talk about progress, I was a part of it now!

United Technologies is a firm believer in the crew concept, utilizing cockpit resource-management philosophies all the time. All of our pilots complete the United Airlines/Scientific Methods Cockpit Resource Management course and they also participate in FlightSafety's Practical Cockpit Management programs. The progress continues!

UTC presently operates 10 aircraft, including 2 SK76Bs, 2 Cessna Citations, 4 Rockwell Sabreliners, 1 Gulfstream III, and 1 Gulfstream IV. All of our pilots are assigned to fly two different types of aircraft, the result being that our 16 SK76B pilots also fly the Citation, Sabre, or Gulfstream as their other aircraft. Most fly the SK76 and a Sabre or Gulfstream to provide each of our pilots with one "go somewhere far and fast aircraft" and one "go slow and come home every night" aircraft.

Several years ago when we reduced our fleet size, we sold some fixed-wing aircraft, including the B-727 and B-737, and increased our SK76B "fleet" from one to two. We had two options: lay off eight very experience fixed-wing pilots and hire eight helicopter pilots or train those eight fixed-wing pilots to also be helicopter pilots. Keep in mind these eight airplane pilots all hold the Airline Transport Pilot Certificate, Airplane Multi Engine Land, with Type Ratings in at least several jet aircraft, and thousands of hours of experience. Well, we did the right thing. We developed a program, in conjunction with Flight-Safety, to cross-train those eight pilots onto the SK76B, joining the eight pilots already flying both fixed and

rotary wing. The fixed-wing-to-SK76-helicopter program is shown below.

We encountered two situations during the program that suggested our progress in pilot training and evaluation had taken three giant steps backward. The first was learning that these pilots could not earn their Helicopter Instrument Add On Rating in the SK76B simulator. Now here's a simulator with every gadget our aircraft has—just what our pilots need to know about if they are going to fly IFR in the SK76. But...oh no...the SK76B simulator is not approved for this. In fact **no exemption for this has ever been granted for even an airplane simulator**. So there we were, professional ATP fixed-wing pilots, thrashing about in a Hughes 300 helicopter for two more weeks (most of that time trying to get somewhere where the necessary Nav aids could be found) earning a Helicopter Instrument Add On. No EADI, no EHSI, no DDAFCS, no EEC, not much of anything relevant to our IFR needs.

And do you know, that Helicopter Instrument Add On qualified those guys to fly IFR in any number of other types of helicopters, most of them far more complex than

the Hughes 300. Now, let me tell you—that SK76B simulator is certainly as useful as a Hughes 300 for training and evaluating a pilot earning a Helicopter Instrument Add On rating, especially since the rating is category- and class-generic, and not specific to just one type of aircraft. So, while those of us in this room were busy “studying the issue,” those eight pilots and their passengers were short-changed. They were not provided reasonable access to modern technology.

The second suggesting of a definite lack of progress in recognizing the value of today's simulator for pilot training and evaluation was when we learned they could not take their ATP Rotorcraft Helicopter Add On flight check in the SK76B simulator.

Those eight pilots have regularly attended FSI pilot recurrent-training twice a year, once for their airplane (Citation, Sabre, or Gulfstream) and once for the SK76B. Each session includes 3 to 5 days of very thorough classroom and simulator training. Operationally, they are flying both left and right seat, VFR and IFR, out of such places as the several very tight Manhattan heliports and the very busy New York Kennedy and LaGuardia airports.

Task	Location	Weeks needed
1. Instrument written exam	East Hartford (Rentschler Airport)	1
2. Commercial add on Hughes 300 for about 5 weeks (and classroom)	Vero Beach, Florida	5
3. Instrument add on Hughes 300 for about 2 weeks (and classroom)	Vero Beach, Florida	2
4. SK76 familiarization SK76 exterior and interior familiarization SK76 familiarization flight	East Hartford	1
5. SK76 pilot initial SK76 simulator and classroom	West Palm Beach International	2
6. SK76 line checks SK76 route familiarization including heliports, helipads, helistops, ATC, navigation	East Hartford	1
	Total	12
7. Left seat SIC only Flying about half of the flights left-seat		6 months
8. SK76 pilot recurrent SK76 simulator and classroom		1 week
9. Left or right seat SIC Flying about half of the flights right-seat		18 months
10. ATP rotorcraft/helicopter add on written		
11. SK76 Pilot recurrent SK76 simulator and classroom		1 week
12. ATP rotorcraft/helicopter SK76 type rating check		

After 2 to 3 years of this experience, they are more than ready to add the Rotorcraft Helicopter Category and Class to their Airline Transport Pilot Certificate along with the SK76B Type Rating. Ideally, they should be able to complete their flight check while attending the FlightSafety SK76B Pilot Recurrent program, where a professional instructor/examiner could observe all of their cockpit resource-management and flying skills. In fact, in the normal 9 hours of simulator flying that a crew does during recurrent training, the vast array of IFR situations and systems malfunctions far exceeds what could ever be done in the aircraft.

Once again, while we continue to "study the issue," those eight pilots, and many more like them, along with their passengers, are being shortchanged because they cannot complete their ATP/Type Rating checks in the simulator.

Keep in mind that conducting the check in the aircraft (1) requires putting a \$5 million dollar aircraft out of passenger service for half a day; (2) flying as much as 4 hours to get to the examiner, take the ride, and fly home (cost: \$5000+); (3) causes the pilot to be unable to do many of the very important tasks normally done in the simulator; and (4) places both the aircraft and its occupants in a high-risk situation.

Now wait until you hear what the SK76B is **not** approved to do for the ATP/Type Rating flight check. Certification credit is **not** approved for the following: (1) 360 turns at a hover, (2) normal takeoff from a hover, (3) manually flown precision approach, and steep approach to, and landing at, a helipad. Remember the 7 weeks of a Hughes 300 flying that occurred 2 to 3 years earlier? Well, they hovered and they hovered and did

pedal turns then. I cannot imagine any pilot with the experience necessary to apply for the helicopter ATP not being able to hover, do pedal turns, fly a steep approach, or do a simple ILS approach.

Folks, we must focus on the many values the simulator has to offer, and stop dwelling on its few shortcomings, especially when those shortcomings are not relevant to the particular level of training and evaluation at issue.

The SK76B simulator has many, many advantages over the aircraft, for training, or, conversely, the aircraft has many shortcomings when compared with the simulator. Yet, we are very willing to approve training and evaluation in the aircraft while at the same time being extremely critical of the simulator.

We must also not forget that any training resource, be it chalkboard, textbook, aircraft, or simulator, is only part of a total training and evaluation program, and the instructor/examiner is generally the critical difference between a good program and a poor program. If only the instructor/examiner received as much attention and funding as the aircraft and simulator do.

Let me summarize with the following four points:

1. We should continue to design and build highways and buildings that are earthquake-proof.
2. We should continue our quest for the perfect simulator.
3. We should accept the present-day San Francisco Bay Area, even with its faults, as a very desirable place to visit, work, and live.
4. We should accept the present-day simulators, even with their faults, as at least equal to, and in many cases, superior to the actual aircraft as a pilot-training and evaluation resource.



Curt Treichel is manager of training at the Corporate Aircraft Department of United Technologies, Inc. He is responsible for the training of 130 administrators, aircrew, cabin attendants, maintenance technicians, and managers in a corporate flight department operating 12 aircraft, including the SK76B. Mr. Treichel has studied transfer to training from simulators to aircraft for the University of Illinois Institute of Aviation. He has a B.S. degree in business administration from Defiance College and an M.S. degree in vocational and technical education from the University of Illinois. He has Airline Transport Pilot certificates for Airplane Multi-Engine Land and Rotorcraft-Helicopter, and ATP-type ratings for the CE-550, NA-265, and SK76.



## 5. TRAINING EFFECTIVENESS ASSESSMENT: WHERE ARE WE?

GREG MCGOWAN

I would like to thank NASA and the FAA for allowing FlightSafety to participate in this workshop. What I hope to do is set a framework for your participation in the panel discussion that we will be doing on Thursday. I know with all the presentations going on there are a lot of questions you will not have the opportunity to ask or get answers to. I think the panel discussions will provide an opportunity for that kind of participation.

Concerning the Workshop itself, I look at it from an objective standpoint. Even though we are focusing on simulators and on certification criteria and so on, I think we should be looking at how to provide tools for instructors and companies like FlightSafety, to better serve end users like Curt Treichel and Jerry Golden, for example, in providing safer pilots and safer aircraft operations.

As an overview to this we will take a look at an introduction and historical review, not spending much time on the first three or four points. From a historical perspective, I think it is important to see where we have come from and why we got started in the first place and where we are now. Because we are using commercial helicopter simulators, we have to ask, how efficient are they and how can we optimize their utilization?

As far as where we are, I think we have to define that question in terms of a reference point. We have been beating around the bush about this a little bit, but I think this Workshop is really concerned with—or at least I am concerned with—commercial helicopter simulators in the United States. I had an opportunity to fly the LHX check simulator about 2 months ago. That simulator is a completely different animal. It represents some great technology, and interesting things are going to come out of it. However, I think the emphasis here must be on commercial helicopter simulators. We also need to define the environment. Are we talking about cost, safety, fidelity, and effectiveness of training? I think those are important issues that need to be looked at. No one of those issues is more important than another; it depends on the end users' requirements, on what is most important to them. I would

like to take a look at some of those things today briefly, and in more detail in the panel discussions.

From a historical review standpoint, why did we even get involved with commercial helicopter simulation? Back in the 1970s, Bell Helicopter and Sikorsky Aircraft decided to build, for the first time, a commercial helicopter that was not merely a military derivative, the Bell 222 and the S-76, respectively. The customers they perceived to make up the market for those helicopters really consisted of two groups, corporate and offshore, or corporate and utility. Certainly there were segments of both of those markets that were going to require a simulator in training the pilots and maintenance technicians for those aircraft. And it was the position of both Bell and Sikorsky that it would be necessary to have a simulator-based training program as part of the overall marketing effort for those helicopters.

That is why the first commercial U.S. helicopter simulators were built. You might say the helicopter manufacturers, therefore, are the ones who provided that initial impetus to simulator development. But it is really the end users, the Curt Treichels and Jerry Goldens, the people who use the simulators who drive that market. Without that market requirement, the manufacturers would not have spent the money on developing simulators.

Initially, when a simulator-based training program is part of a manufacturing agreement, such as we have with Bell and Sikorsky, the first course to be developed is initial training, which is then quickly followed by recurrent training.

I am proud to say that we are now getting into what I call generic training, using simulators that are designed for specific aircraft, but using them in a generic way. For example, there are the Emergency Medical Service (EMS) helicopter pilot recurrent course and the instrument refresher courses. We have pilots flying Augustas and small Bell products, as well as the Aerospatiale products, which don't have simulators, enrolled in courses in which they are using an S-76 or Bell 222 simulator to get as

much as they can out of a simulator-based training program. They are practicing things like crew coordination, cockpit management, and instrument procedures. The technology is developed to the point that we can duplicate the actual aircraft, but we tend to forget the other applications that we used years ago in the Links and Dehenel trainers and the training devices, which are still applicable in the current generation of simulators.

We are really only talking about three simulators. We have two aircraft for which there are certified simulators, those being the 222 and the S-76B. There is also a third training device out there that did some ground breaking on its own from an exemption standpoint, and that is the S-76A.

More accurately, the S-76A is for all practical purposes a training device. It is the most sophisticated training device I have ever seen.

At the end of 1990, there were 174 Bell 222s, and 319 S-76 aircraft worldwide. A total of 3,747 pilots were trained in the Bell 222 and 5,096 were trained in the S-76; that is, in all types of training between 1980 and 1990. The check ride numbers are 354 for the Bell and 2,333 for the S-76. The reason I point this out is because there are significant opportunities for data collection here. Therefore, these two pilot training devices were used to train almost 9,000 pilots and to give about 2,700 FAR checks. A breakdown of those check rides shows virtually all of the 61.57 instrument competency checks (1,296) were done in the Bell 222 simulator. There are reasons for that I don't need to go into, but the primary one is that the 61.58 PIC check is not required in the Bell 222; as a result, the best thing you can do is a biennial flight review or instrument competency check.

The 61.57 instrument competency check totals (1,296) are from a combination of the Bell 222 and the S-76. The low numbers of 135.293 (129) and 135.297 (121) checks are a result of our doing them for only a couple of years.

Regarding the commercial helicopter simulators—without going into a lot of detail, I certainly will provide syllabuses for any of the courses to anyone who wants them; just give me a call and we will mail them out.

The initial training course is 2 weeks long. It was certainly the first course developed for either of the S-76 simulators, or for the Bell 222, for that matter. Most of the recurrent training courses are 4 days long. We do have specialized courses of 3 and 5 days for certain operators and special requirements. One of the points I want to make here, though, is that before we had our first exemp-

tion, our generic courses, things like the recurrent training and the initial training we were doing, were well attended, even though the pilots were getting absolutely no credit whatsoever. I think that that is an important point for all of us to remember: the end user, the pilot, the operator, the company, recognized the value of the training, and they were willing to pay for it in many cases without any checking credit, without any training credit whatsoever. On the other hand, I think we also need to realize that just because they have been doing it does not mean they are going to continue to do it, especially as costs go up.

Figure 1 shows what we call a pilot proficiency record. Actually, it is a five-page document. This is what our instructors use to evaluate pilots undergoing training and checking at the Center. It is a part of the pilot's training record. The shaded items are those that would be required for an ATP check or for a pilot command 61.58 proficiency check. I believe the regulation reads that the same items and maneuvers that would be done for the initial issuance of type-rating would be required or recommended for 61.58 pilot proficiency check.

The unshaded items are those things pilots are required to complete during our course of instruction, which, by the way, is FAA approved. They also receive what is called a flight-safety proficiency card. It has been mentioned that we did so much more than required. For example, on engine malfunction, the high-side governor failure was mentioned. We have them do high-side and low-side governor failures. They cannot do those in the aircraft, and it is something pilots make mistakes on. They can get that experience only on the simulator. That is what simulator-based training is all about. We can talk about this more in the panel discussion, if we get a chance.

A little history of the exemptions might be in order. Exemption 4609 was issued in January 1986 (table 1). I think we started the request in early 1984, I think we first had a meeting up in Washington, D.C. It took time, because we were breaking new ground; but we eventually got it for the S-76 training device and for the Bell 222 simulator, with which we do the PIC check and flight review. Numerous prerequisites and recency-of-experience requirements are stated.

In almost all cases, even with fixed-wing simulators in which checking or training are done, an approved course of instruction is included. You don't just go out and use these simulators to do a check ride. There is an approved program of instruction; the same is true for this exemption. For example, aeronautical experience from C .61 requires 50 hours in the last 12 months, 5 hours



Table 1. Exemption 4609

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1. Exemption issued 28 January 1986
2. Applicable to S-76 training device; Bell 222 simulator
3. Prerequisites/recency requirements:
  - Approved training course
  - Aeronautical experience (61.161)
  - 50 hours preceding 12 months in type
  - 5 hours PIC last 60 days, make and model
  - 3 takeoff and landings last 90 days
4. Amended 23 June 1988 to include S-76B level C simulator

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PIC, and three takeoff and landings in the last 90 days. The customer base we are addressing has no problem meeting these. It was amended in June to include the S-76 simulator. I am using those terms loosely because they don't really apply. We cannot call it a level C; it is an approved helicopter simulator. That is the proper terminology, but if you use it people ask you so many questions it is better to call it a level C and not have to explain all this.

Exemption 5067 was issued 29 June 1989; it is applicable to level C simulators. It is an outgrowth of the approval we got with the simulator, and it is approved for conducting the checks shown in table 2. Those pilots undergoing these checks have to certify that they have, for example, done three slope takeoffs and landing within the last 90 days. This is not a real big problem when you consider that runways are usually crowned and therefore have some degree of slope. The other prerequisites include 100 hours in the preceding 12 months, 10 hours in the S-76, 50 hours in the preceding 6 months, visual inspection, 360° pedal turn in hover, normal takeoff from hover, manual flown precision approach, and steep approach and landing.

As soon as an exemption or regulation requires that a pilot do anything in an aircraft, with respect to checking or training, you will eliminate a certain segment of that population that would otherwise train in the simulator. They won't train in the simulator because it costs you about \$2,500 an hour to fly the aircraft. And it can cost even more if travel is involved in getting to the examiner. So a lot of these decisions are based very much on economics. That's something that we need to talk about in the panel discussion.

A question that really needs to be asked is how effective are commercial simulators? Objectively, I think more research is needed. That is one reason I showed you the

Table 2. Exemption 5067

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1. Exemption issued 29 June 1989
2. Applicable to S-76B level C simulator
3. Approved to conduct the following:
  - 61.56: 24-month flight review
  - 61.57: Day/night landing currency
  - 61.58: 12/24-month PIC check
  - 61.163: ATP rotorcraft (90%)
  - 135.293: Recurrent testing
  - 135.297: Instrument proficiency
4. Prerequisites/requirements:
  - Approved training course
  - Three slope takeoffs/landings 90 days
  - 100 hours preceding 12 months (10 hr S-76)
  - 50 hours preceding 6 months (5 hr S-76)
  - 61.163 ATP/add-on, flight test in S-76
  - Visual inspection
  - 360° pedal turn in hover
  - Normal takeoff from hover
  - Manually flown precision approach
  - Steep approach and landing at heliport

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numbers that we have. The people are coming to train, and as a result the opportunities for collecting data are there. At FlightSafety we certainly are not experts at collecting data. I don't know what kinds of questions to ask these people or what kinds of maneuvers to ask them to see and duplicate.

There is one thing I want to mention when talking about duplication. When we are evaluating these simulators and we go out and fly the aircraft and we come in and fly the simulator, we need to fly that helicopter at night. We need to be doing those 360° pedal turns in a hover at night over a runway similar to what we have in the aircraft, or in the simulator. I realize in some cases we are looking at breakout forces and things that don't really make a difference visually. But when you are subjectively evaluating the overall quality of a simulator I think it is unfair to go out in the daytime with all the daytime visual cues and compare it with a night visual system.

Subjectively though, I think the simulators are very good for a number of reasons. We have the data, we have the pilots, and we have a lot of FAA pilots that have gone through training who can tell you about the level of instruction, the kinds of things that can be simulated, the maneuvers that they can do in the simulator and then compare with the actual aircraft. We have some people say the simulator doesn't hover right, and we have others

who say it hovers just like the aircraft. That is why we need to collect more data and find out what the weaknesses and strengths are.

We also need to keep in perspective the overall idea that there is a lot more positive to be said about the simulator than negative. The article I mentioned earlier about the helicopter that went down in the river off of the Wall Street heliport is a good example. This is a quote from the pilot, Sandy Kaplan. "The engine quit on departure. We didn't have enough power to continue. We just went down, just like we practiced at FlightSafety—you bet!" That is an example of the benefits they gained from training received in a simulator that they could not have received in the aircraft.

Lastly, how are we going to optimize the effective utilization of helicopter simulators? We already talked about some of them. I think we need to look at the regulations and to have an opportunity for giving the two different types of check rides so you can substitute things that can be done in the simulator for things that perhaps cannot be done in the aircraft. In other words, maybe one low-side governor failure and one high-side governor failure and an engine fire could equal one 360° pedal turn in a hover—for lack of a better example. We need to look at the philosophy of simulator use.

That includes looking at things such as I just mentioned. We need to do a better job of training our instructors. We have problems as a company, as a simulator trainer company that uses instructors for simulator training. We need to better educate those instructors, we need to do a better job of training them in cockpit resources management, in how to do a better job of debriefing to get as much as we can out of the training tools. I refer also to cost. For example, Jerry Golden and Curt Treichel—they are the one who ultimately decide whether they will use the \$10-million and \$12-million simulators that we train with.

MR. McDANIEL: By the way, I flew that approach to Wall Street and landed in the water as well. I did it in his simulator a couple of weeks ago. We practice doing those things and we did it successfully the first time we tried it in the simulator. And after going through the procedures with instruction, we did high-side governor failure, we did low-side, tail-rotor failures, fixed pitch, all of those things. Quite frankly we were not always successful on our first attempts on those things in the simulator. But anyhow, the thing is, there is some excellent instruction out there that is available with this kind of thing. As we said, we had a number of discussions but active conversa-

tions on the usefulness of it, and I am convinced that it is a very useful training instrument and something that we need to get credit for and bring into the system. That is really why we are here.

MR. CARVER: Just three observations on that very excellent rundown. There is a lot of thought in what you said.

First of all, as far as training and checking are concerned, everybody wants credits for training devices or simulators or whatever. Of course the observation of pilot regulators is that pilots need more training than that which a regulator requires, so as long as training is not negative, then most regulators would support what you have just suggested, that is, without necessarily having credits, because it is the commercial public transport company that is responsible for the pilot training, and what the regulator wants is really a snapshot of something at the end.

As far as effectiveness is concerned, there are one or two other points. Effectiveness depends on the fidelity of the simulator, on its maintenance records above all. There is a thought there with regard to the complexity of the device and what effort the company is willing to put into its maintenance, and the ability and imagination of the instructor-examiners. I definitely agree there with you.

And finally, I am not a rotary pilot, but as far as the simulator is concerned, rotary really requires more piloting skills, so I think we have to be careful when giving licensing credits to a simulator. But certainly the generic, the human factor is certainly an area in which it is useful.

MR. MCGOWAN: Those are good points. I hope you come to the panel discussion because those are the kinds of things I think we need to talk about. That is the whole ideas of this presentation: to whet your appetite for that panel discussion.

MR. LOMBARDO: When I first went to work for FlightSafety back in 1979 and 1980 in the King Air program, one of the things that I was very dismayed to discover was that the training for the instructor was very minimal, and there was an assumption, which it appears will continue through the 1990s, that if you are a good pilot you must be a good instructor. And what Curt will testify to is we did the job with the Blue Box and we can do a better job with more sophisticated equipment, but what industry needs, and I have had a devil of a time trying to convince anybody of, is guidelines for a structured training program for people who are going to instruct in simulators.

Typically what happens is we find somebody who is typed in the aircraft or has experience in the aircraft and

we put him in the box and assume he knows how to teach in a simulator. These people tend to fall into one of two categories: (1) those who use the simulator exactly as they use the aircraft, in which case they underutilize the equipment; or (2) those whose approach is let's see what I can do to them today, who overload the students. I am not a helicopter pilot; I am a fixed-wing pilot. Still, I would say that what needs to be done in the helicopter industry is to develop the guidelines for, or formulate a committee to put together, a program to teach people how to teach in simulators. You can do more with a good instructor and less accurate piece of hardware than you can do with a highly accurate piece of hardware and a poor instructor.

**MR. McGOWAN:** I agree with that last point that you made, totally. I will say that more than 4 years ago FlightSafety finally recognized part of what you said and developed an instructor development course that all of our instructors now go through. It is a 5-day course, standardized, taught in one location in Texas, and all of our instructors have to go through it.

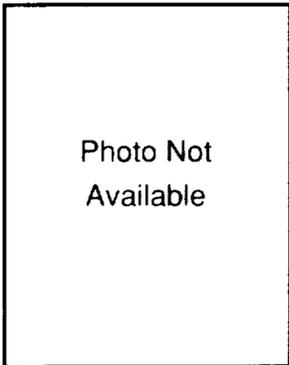
There is a recurrent instructor course. It is not a do-all and end-all for the problem you are talking about. The Center is also ultimately responsible, through standardization, to ensure that the instructor is using these tools effectively. The FAA also has a part in that. Once you become a pilot-proficiency examiner you have to undergo check rides and they actually sit in on the check ride or a portion of it. A lot of the checks we do are progressive checks, and they have an opportunity to criticize or make comments on how you are doing your job, whether you are doing it effectively or not. These are important things. We could have a whole workshop dedicated to the subject of instructor training.

**MR. McDANIEL:** I agree with your point that a good pilot does not necessarily make a good instructor. I

have known many very good pilots who are not very good at instructing. I would say that a good instructor pilot probably does have the skills to be a good simulator instructor. But there are differences between instructing in the actual aircraft and in the simulator and some strengths of the simulator, some capabilities of the simulator, make instructing in the simulator different from instructing in the real aircraft. I think we all appreciate and recognize this. I agree, you do need some kind of instructional program for the simulator instructor so he can best take advantage of the strengths of simulator use.

**MR. CLENNEY:** I agree 100%, because I also have been an instrument flight examiner in both airplanes and helicopters. When you start giving an instrument flight examination in a simulator, you are also now air-traffic control, and you have to plan your air-traffic control so it will be realistic for your pilot. the pilot is busy, but the instructor is busier. So I highly endorse this idea.

**MR. McGOWAN:** You are absolutely right. That is one of the things that have to be done in your instructor training. Probably the most difficult thing to teach an instructor is how to think further ahead than he or she has ever thought before because you have to be the ATC function, you have to be the Center, and you also have to, in some cases (for example in the EMS recurrent course) play the role of doctor, nurse, or EMT in the back of the helicopter during a loft scenario. It is a really busy job and it is actually, from a planning standpoint, much easier to do in the aircraft, because then you are really at the mercy of the system. You either get the ILS approach or you don't. In a simulator you have to plan for it. If you haven't done the proper planning, in the simulator there is no system to take care of you.



Greg J. McGowan is manager of FlightSafety International's West Palm Beach Learning Center, which conducts all factory-authorized pilot and maintenance training for the Sikorsky S-76 helicopter, as well as Learjet-35 pilot training and generic maintenance training. The Center trained more than 1,000 pilots and technicians last year. Mr McGowan has a master of science degree in technological systems management from the University of Southern California. He was a rated pilot in the Air Force where he flew various types of helicopters. Mr. McGowan was the flight safety project pilot responsible for the acceptance and delivery of the Bell 222 simulator, the first helicopter simulator that was FAA-certified for commercial use. He has an Airline Transport Pilot license, Instructor rating, and Flight Engineer license, and has more than 5,000 hours of flight time and instructional experience in helicopters and simulators.

## 6. CURRENT TRAINING: WHERE ARE WE?

GERALD GOLDEN

I appreciate very much being asked to speak at this simulator workshop. I am here purely as a 135 operator and a trainer of pilots. I am not going to even begin to try to address the technicalities involved in building, designing, or certifying a simulator. It's not my bag of tricks. However, I do believe it is very important that operators participate in this kind of seminar, because we are going to be the ultimate user of the product of this process. And by that I mean the advisory circular as well as the simulator itself. I am probably not going to use all the time allotted because I have only about three points that I would like to make and I can make them fairly short and sweet. Then we can go on to something else.

Initially, what I am going to say may sound like an advertisement for Petroleum Helicopters, Inc. (PHI). But it is not intended to be that; it is just an effort to try to show you the scope of what we actually do. If you will just bear with me you will understand my approach in just a second.

Most of the people in the industry have heard of Petroleum Helicopters, but very few understand what we do and how we go about getting it done. We have about 2,400 employees, of whom about 800 are mechanics, and about 750 pilots. And we have 17 bases scattered across the Gulf of Mexico, from Rockport, Texas, to Mobile, Alabama. We operate about 300 helicopters, and we fly VFR and IFR up to about 175 miles offshore. The day is coming when our nearest IFR alternate will be the Yucatan Peninsula. There are oil leases, drilling leases that far offshore that have been sold; they are just waiting to be drilled. That day is coming. So the world we operate in is undergoing constant change, too. We also operate 10 F-76s in support of EMS base hospital programs. Collectively, we and our competitors operate approximately 600 helicopters every day in the Gulf of Mexico, primarily in support of the offshore petroleum industry.

To crew our 300 helicopters, which comprise seven different makes and models, our 750 pilots require about 1,700 to 1,800 check rides per year. Those are recurrent

training check rides, and have nothing to do with transition, upgrades, or initial—that sort of thing. Just the recurrent training of the 750 pilots. Two hundred fifty pilots operate under instrument flying rules. These 250 IFR crewmen receive about 500 check rides, each of which takes about an hour and a half. Some are quite a bit longer, depending on where the aircraft is based and where the precision approach is located. This equates to about 750 flight hours annually just to maintain our IFR crews.

To give you an idea of the cost to us as a user, the average direct operating cost of the aircraft is about \$1,750 per hour. That does not include the costs of our facilities, insurance, or other expenses involved. The recurrent training needs just described cost about \$1.3 million per year. This figure does not address the FAR 61 recent-experience requirement; this is purely the Part 135.297 check ride. And we are required in many cases to maintain this Part 61 recent-experience. I am talking about the 6, 6, and 6 (6 approaches, 6 hr instruments, in last 6 months).

Where are we now with our training needs? Virtually as we speak, we are in the process of upgrading 10 crewmen to the status of IFR, SICs. To do that will take about 120 flight hours, an average of 12 hours each. That is about \$21,000 apiece, or a total of \$210,000 in direct operating costs alone. This summer we are going to upgrade an additional 18 pilots, 12 of whom will go to PIC standards and 6 to SIC standards. This is going to require approximately 216 hours, at a cost to us of about \$378,000.

The point I am trying to make is that we do this without a simulator. I wish we were using a good, authorized simulator. Obviously it would provide not only what I think would be a better trained crew, but it would go a long way toward reducing our costs.

Just as a note of interest, I am working with Flight-Safety right now to try to purchase about a 100-hour block of simulator time at our Cleveland base. We won't get

simulator training credit from the FAA, because I am going to use a BE-200 simulator, which is all they have. The truth of the matter is it will cut down my time, it will cut down the cost, and I am going to do it whether the FAA recognizes it or not.

This should provide a glimpse of the tip of the iceberg of the training needs that we have at PHI. If you stop and think about that, with 600 helicopters out there, of which we have 300, obviously this is only about half the cost that is involved. So in answer to an earlier question about the potential use of a simulator like this, we would probably use it about 1,250 hours a year if available and affordable. By available I mean fairly accessible, at a nearby location.

Before PHI leases or operates any simulator on a regular basis, there are criteria that the simulator has to meet. This is because our costs are already so high that the use of a simulator must help me reduce those costs, as well as provide that extra level of training. I understand fully that a pilot who has been trained and retrained in a simulator gets many opportunities to do a lot of extra practice of various maneuvers. I have been through the S-76 over at FlightSafety; it is a phenomenal piece of machinery as far as I am concerned.

Any simulator we use must be approved for credit toward the training that we do. We do FAR 135.293 check rides, and it should be possible to do some of that in a simulator. But we should be able to do all of the FAR 135.297 check rides in that simulator. The simulator must be practical. By that I mean that in addition to the usual IFR features that we think about—the ILS, the VOR, the SDFs, the other type approaches—the simulator must address offshore flying techniques.

Specifically I am talking about airborne radar approaches, HEDA let-downs and what is referred to as offshore standard approach procedure (OSAP). All of these approaches use a combination of interface with weather-avoidance radar and the LORAN. These approaches are fairly commonplace and they are fairly simple, but they must be checked in an ongoing check-ride program. These approaches are part of the reason why our check rides are so long just for an FAR 135.297 check. If the aircraft is based in Lafayette, Louisiana, it is about 40 miles to the Gulf, but it's about 50 miles to a place where I can execute a radar airborne approach. I have to get over the water to do that.

I might comment here on the practicality of something that was mentioned earlier, the necessity to do visual-reference maneuvers. I am not totally convinced

that the simulator should be able to do a slope landing. I do not think it should be able to do a confined area, and I am not interested in doing an autorotation. I would not dream of trying to do Part 133 external loads in a simulator. Those are ground-reference maneuvers, and they are maneuvers that are best practiced, in my opinion, in a helicopter. Those are specialized procedures. I want no part of trying to certify a pilot to do slope landings in a simulator. To me, it's just not necessary. I want to do the other things, like we said, the high-side and the low-side governor failures, things I can't simulate in a helicopter.

The final criteria that a simulator must meet before PHI or any other operator is going to use it, have to do with cost. I heard mention earlier about \$12 million simulators. I would like to own a \$12 million simulator. In Lafayette, Louisiana, the use rate would be fairly high, because of the number of pilots there. And yet the bottom line is this: that 2,000 hours a year is not going to cause Greg McGowan to put a \$12 million simulator in Lafayette. These simulators are simply priced totally out of the reach of operators such as ourselves.

I cannot afford to buy, even over the long term, a \$12 million simulator. I would like to have one nearby that I could use, though. Contrary to what our monthly lease rates might indicate, there is not a whole lot of markup in offshore helicopter transportation prices.

The final point that I want to make is concerned with the advisory circular itself. The stated purpose of the advisory circular is not to mandate, but to provide a way to do things. Well, there have been advisory circulars over the years that were designed to be just that, advisory, that wind up being regulatory because there is no other accepted way to do what those advisory circulars approve. I am referring to Advisory Circular 90.80 as a good example.

For a long time we did airborne radar approaches offshore, routinely, day in, day out. Advisory Circular 90.80 gave an acceptable way to do airborne-radar approaches. The truth of the matter was the advisory circular was based on a piece of equipment that was not available to the public. There was no way we could comply with the Circular. Since it was not mandatory we just went about our business. But one day the FAA said if you are not doing it according to 90.80, you cannot do it anymore, so get into compliance. That is the point I am trying to make. When the advisory circular is written, you need to put yourselves in the users' shoes so you understand their needs, as well what Dick Birnbach said this morning about writing the "paper." He made the comment, "I don't

use them, I don't fly, I only write the paper." Well, we had better consider the people who have to use the advisory circular, as well as the simulator itself. That basically concludes what I have to say. I will be happy to take whatever questions you have.

MR. McDANIEL: In talking with different people about what is required of a simulator and what is not, there are questions such as is motion good, is visual good, and do you need motion. And in one of your comments about the advisability of having a simulator to do slope-type operations, autorotations, etc., you mentioned external loads. I guess my question is if the simulator has the fidelity, and can do those things, is it of value to have that capability? I would take it as a given that, yes, you would want to confirm that training capability or the capability of the pilot to conduct those operations in the aircraft. But is it of training value to be able to do that when it is cheaper to do it in a simulator? You made the statement that it is of no value to you and that you do not care to see that in a simulator.

MR. GOLDEN: Here we get into engineering. The engineering and design features that have to be built in that will realistically represent a sling-load are going to be phenomenal. The same thing is true of a slope. I don't think what you see in a simulator when doing a slope operation is going to have any real bearing on what it is like in the real world of helicopters. So how much does this cost? It comes down to money. Sure, given enough time, given enough engineering, we would come up with a simulator that does a fair or reasonable job of simulating slope. But is it really necessary for what I need to do? The S-76A simulator, which has been available since 1971, does a phenomenal job of everything I need to do except for the LORAN radar interface.

MR. HWOSCHINSKY: You said you are a trainer of pilots, but you are a trainer of instructors as well. How would you envision the use of simulators in training your instructors, particularly given the fact they need to know the limitations of the equipment itself?

MR. GOLDEN: A good question. I cannot possibly do all the training that PHI requires. I have 17 instructors working for me and I can tell you that the training of those 17 instructors is ongoing continually. It is necessary. The training they have to go through is nonstop. Training an instructor for a simulator is something I have never done in a full-blown motion simulator, but I bet Greg [McGowan] can tell you about that.

We did build in-house several years ago what we call a 206 procedures trainer; there is only one like it that I am

aware of. This device is capable of doing hot starts, premature light-offs, and fires; you can simulate malfunctions through the use of switches. It does not fly, and none of the flight instruments move. But all the problems associated with starts, in-flight routine, emergency sort of stuff, you can do on this simple little device. We had problems with the way we were doing things in that simulator, however. We had to work a pretty good scenario just teaching the guys how to use that simple training device. I hesitate to think how many flight instructors or simulator instructors FlightSafety has and how much their training bill is just to qualify to maintain those instructors. It has to be staggering.

MR. WARTH: I run into your helicopters all the time.

MR. GOLDEN: Not literally.

MR. WARTH: I was interested in the aircraft operating cost you mentioned—the \$1700 per hour. Does that include instructor time?

MR. GOLDEN: No, just the operating cost of the machine. That was an average for three helicopters. The cost for the S-76 is considerably higher than that.

MR. WARTH: Oh, really? I was interested because for our two Coast Guard helicopters we have a cost of about \$1,200 an hour. Sounds like a similar basis of cost. And it is only about \$120 an hour for the simulator, so there is a big cost benefit for us to use the simulators we have.

MR. GOLDEN: Greg, can I have some of that \$120-an-hour simulator time?

MR. WARTH: If you want to fly an H-3 or H-65, sure.

MR. GOLDEN: I don't. Sorry.

MR. WARTH: I am also curious about autorotation.

MR. GOLDEN: In the simulator?

MR. WARTH: Right. That is a big thing for us.

MR. GOLDEN: Well, the second time I went over to FlightSafety to fly the S-76A, we spent probably 35 or 40 minutes doing autorotations. I forget the instructor's name now, but he said look, what you do is you descend down to 100 feet (this may be correct, it may not be), 20° nose up, go down 20 feet, and pull a pitch and land, so I did exactly that. Just glued myself to the gauges, went down and did what he said and the autorotation was successful. The other person who was with me was a full-blown captain who probably had about 15,000 hours of flight time. He could autorotate virtually everything that flew, but he spent the next 35 or 40 minutes trying to get one to come out right on the S-76. I maintain that

exercise did not help him in that particular respect. I am positive about how the man autorotates. He simply was not good at flying a simulator.

MR. WARTH: In that case it was a question of the fidelity of the simulator.

MR. GOLDEN: Probably. I am not all that impressed with ground-reference maneuvers in a simulator. But I don't think in any ATP check ride that a pilot who has that level of experience should be required to demonstrate a 360° turn.

MR. WARTH: How about entry-level pilots who have to do IFR autos? If you are going to train pilots in simulators, presumably you are going to train . . .

MR. GOLDEN: I am talking about the touchdown portion of the autorotation. I think that would be best performed in the aircraft.

MR. WARTH: I understand. Thank you.

MR. BOOTHE: I just wanted to mention that your experience in the S-76A is probably one of the reasons why it is not a qualified simulator. It is a training device. That gets to a point that made this morning: the device has to support the training or checking maneuver that is to be done. We had this same experience with airplanes. I remember in one of the first Level C simulators, we could not land Phase 2. The instructor said, well, just stay about 200 feet, pull throttles to auto, pull attitude 8°. We said we do not land the airplane like that. I think that is the same thing you are experiencing.

MR. GOLDEN: I would like to respond to that just in part. There are so many other things that the simulator will do that I think we should be able to receive recognition and credit for doing those. Granted, if I have to do a touchdown autorotation, which I don't, by the way, then I should be able to do that in the aircraft. But I am not required to do that in the aircraft, and therefore I should not be required to do it in the simulator for certification purposes.

MR. BOOTHE: I agree with that, I just wanted to touch on the four maneuvers. As somebody pointed out, maybe they are the wrong four. As regulators we are conservative. Kind of like turtles, we stick our noses out just a little bit before we stick our necks out. I think that is really what we are talking about with the S-76B. We never before in the civil segment qualified a simulator of

that sophistication. And if you recall, when we started with airplanes we had four maneuvers, I think, that had to be completed in the airplane. That went on for years until finally in 1978 we got to landing maneuver, then advanced simulation plan, and we still had growing pains. In fact, the Royal Aeronautical Society is having a meeting in November about the extent to which we can trust simulation. I think it is a good subject.

But we needed something to validate what was just done in the simulator and I will admit that the selection of those maneuvers was somewhat arbitrary. But we did not feel we were at the point where we could just say go do an ATP check in that simulator, the first one ever. We had never qualified one before, and we did not have adequate data. We made up for that with the routine that I mentioned this morning. And so we were very conservative about it. Maybe we have enough data now—that's the other thing. There were supposed to be data kept and I think Greg has some of them. A local office of the FAA was to look at how successful we are in that process, at how many pilots fail to transition behavior that was demonstrated in the simulator to the aircraft. And I don't know how much of that we have, but maybe it's time to ask the question again. I don't want you to think we are stuck with four maneuvers for ever and ever; we are not.

Regarding the question, why can't you do an instrument competency check or instrument rating check, a petition would help. We do look at those. Thank you.

MR. MCGOWAN: Warren talked to me before we started back. I think we need to clarify that. What Curt [Treichel] was mentioning in his presentation is an instrument add-on and we did not make application for an instrument add-on. What we did make application for was certified-flight-instructor-instrument-helicopter in the simulator. And that is what the statement that Curt quoted in his presentation was about. We were denied that. We did make a request for an exemption for certified-flight-instructor-instrument-helicopter. One of the reasons we were given for the denial of the application was that it had never been done in a fixed-wing simulator. So Ed [Boothe], you are right, we never have asked for an exemption to the helicopter instrument add-on, but we did make it for certified-flight-instructor-instrument.





Gerald T. Golden is the director of training for Petroleum Helicopters, Inc. He is responsible for the training of more than 1,550 pilots and mechanics. In his 23 years at PHI, Mr. Golden has established one of the most aggressive and successful PDM/CRM courses in the helicopter industry. He conducts classroom instruction and flight instruction, and gives FAR 135 check rides on a regular basis. Mr. Golden served in Viet Nam as a pilot in the 1st Air Cavalry Division, and has accumulated more than 10,000 hours in 20 types of helicopters.

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## 7. HELICOPTER SIMULATOR QUALIFICATION

BRIAN HAMPSON

I think the one thing that all of us have in common here today, and I believe I am quite safe in saying this, is that we are all supporters of the view that simulators are an acceptable, if not essential, method of training and checking aircrew, and that includes helicopter aircrew as well. After all, I believe that is the reason we are here this week, to discuss how the use of simulation may be defined in respect to the training events for which it is deemed appropriate, the level of the technology to be used, and the criteria that will enable us to get the simulator approved. From these bases will fall out the design of the simulator, and this will in turn be constrained by the technology available, which in turn will perhaps lead us to modify the use and the criteria baselines.

So as you will see, to some extent we are going to go around in circles. I think this is to be expected at this phase of our deliberations, but I believe there are some things we all should understand from the outset which will help reduce the number of circles we are going to describe this week. I base my comments on my experience in a similar type of exercise for fixed-wing aircraft in which I participated both on the international and national levels and also as a result of the knowledge I have of the difficulties faced by the simulator manufacturers in building and designing a simulator for any aircraft.

We are fortunate in having a pattern in the fixed-wing training and evaluation criteria from which we may start. AC 120-40B is a well-debated and currently used document known to most of us. However, as most of you who have reviewed the draft AC 120-XX prepared for this study can attest, slavish adherence to 40B will not produce a good helicopter document. And I am not leveling any criticism at the FAA in this area.

For example, in attempting to get a direct read-across, but also by taking note of the unique situation of rotary-wing aircraft, the objective tests defined in this draft circular total over 800. And that is quite an impractical number for any operator to attempt to run, either on an ongoing basis or at the time of initial or recurrent inspection.

I suggest, therefore, that we must begin by using the format of 40B, perhaps, but then, by analyzing the important aspects of helicopter training and competency checking, define the set of objective tests to ensure that the device is capable of meeting these training requirements. To the objective test must be added, as in 40B and its predecessors, both functional and subjective tests to ensure the necessary realism. We found in the international forum that we had to modify our baseline document to take into account specific training requirements of other national operators. A good example I think was the Australians, who have a requirement that their pilots demonstrate they can do a rejected takeoff of maximal overweight. They naturally said if we are going to check somebody on a simulator doing this, we have to ensure that the simulator correctly represents a rejected takeoff of maximal overweight. I think that gives us a pattern of what we should be doing here later in the week.

If we agree on this, then we must take a closer look at these objective, functional, and subjective tests. Each test will consist of a description of the test, a statement of the acceptable tolerance between the flown data and the simulator's response, that is, the validation, the flight condition or conditions under which the test is to be conducted, and finally, perhaps, some indication as to the method of proving that compliance. For instance, is a time-history necessary or will a snapshot do? You may think that this is a simple enough matter, but those of us who have been involved in the fixed-wing regulatory criteria discussions know only too well that the method of actually carrying out the test is as important as all the other aspects of that test. Again, to give an example, insistence on totally integrated or end-to-end tests where the control input is applied without tolerance, and the output, that is, the result of the input on the aircraft, is measured to be accurate within a given tolerance, is rarely practical within currently available technology.

The greatest problem is the manner in which the aircraft data are collected or presented. To again use an

example from the fixed-wing area, if the data are obtained by plotting, say, the force or displacement of the control column and its effect on the surface, and if then a second plot is obtained by taking a displacement of the control surface and plotting its effect on the aircraft path, it will be quite impossible to match the simulator's results by putting an input to the simulator control column and measuring the effect upon the simulator's flight path, unless the tolerances are generous. That is, it's quite impossible if you are going to apply the same sort of tolerances as those that are now specified. To be fair, this is not the manner in which rotary-wing checkout data have been presented in the past, but the accumulation of tolerances on the aircraft owing to differences in manufacture, maintenance, age, ambient conditions, and indeed even the data-measuring equipment, would ensure that the end result is very much less accurate than that usually permitted by the defined tolerances of the simulator. What is essential is a practical realization of the problems involved and the manner in which the data have been provided. In the fixed-wing world where aircraft manufacturers have been collecting this type of data for many years now, it has been generally accepted that without spending huge sums of money, the currently available data-gathering equipment and instrumentation are capable of an accuracy that is satisfactory for aircraft certification purposes and even for its intelligent use in performing checking. However, it is often not accurate enough to validate total end-to-end system operation in a simulator.

To many of us in the study group, the use of the term "application of good engineering judgment" is an essential part of understanding how a simulator may be said to meet the approval criteria.

For the last few minutes I have addressed a particular issue which in part concerns data and how they are used. I believe a much more fundamental problem in the simulation of a helicopter is the amount and the type of the design and checkout data which are available. For many years now the operators of simulators, the bodies representing them, and the manufacturers of simulators for fixed-wing aircraft have been trying to define a minimum standard for the data that are to be supplied for these purposes. The third edition of the IATA Data Document was published in 1990. It is the result of several years of effort by people very experienced in the manufacture, testing, and use of fixed-wing simulators. And it enabled some progress to be made in defining acceptable criteria for the fixed-wing simulator. Few, if any, rotary-wing aircraft manufacturers come anywhere close to meeting similar

standards which may have been defined, but I do note with pleasure that the data analysis document provided by Augusta for the A-109 simulator indicates that they may be an exception to this criticism. Cost is only one of the reasons given for the failings of the aircraft manufacturers. Because helicopter simulator approvals have not been such a prominent item as the fixed-wing ones until now, it is easy to understand why the scope and accuracy of helicopter data packages have been inferior to even the mediocre fixed-wing packages. What must be accepted is that any move toward defining higher criteria for evaluation, testing, and improvement in the training obtained from helicopter simulators will require an order of magnitude of improvement in the data being supplied.

It has been said that the average helicopter data package is the equivalent now of what the fixed-wing data package was 15 years ago; some would even say 20 years ago. A continuation of this approach is not commensurate with the building and evaluation by a regulatory authority of a helicopter simulator equivalent to even Phase 2, Level C standards. The success of the FAA's Advanced Simulation Plan for fixed-wing aircraft is well-known, but I hazard a guess that it would not have been so effective in reaching its goal of zero flight-time training were it not for the work put in by the IATA Flight Simulation Committee in defining the required level of data.

Unfortunately, IATA has not, to my knowledge, convened a committee to set up similar data standards for rotary-wing aircraft, although the "Aircraft Data and Support Requirements Document for Aircrew Training Devices," produced in 1988 by the Naval Training Systems Center, does address some of the issues, including those of the data requirement for rotor-map and blade-element models. This general deficiency must, in my view, be rectified as part of the exercise on which we are about to embark.

I would now like to give some examples of the areas that I believe are insufficiently addressed in current data packages. First, helicopter data packages frequently do not include any models at all and, hence, no proof-of-match document. It is left to the simulator manufacturer to design these. This is not the most efficient way of solving this problem and may lead to greater variations in the simulation of one manufacturer's product and another's than is now the case for fixed-wing aircraft.

Second, the inherent instability of the helicopter is known to all those who attempt to fly it. Most modern types have stability augmentation systems which are used full time. The data covering operations without the

systems in use are sparse, yet this is an area of prime importance to training.

Third, vibration is likewise a fact of life in helicopters. Indeed, operation is frequently constrained by the need to avoid and suppress critical vibration frequencies. But the data provided on those vibrations are rarely comprehensive.

Fourth, flying operations of helicopters, especially operations close to the ground or to the surface of water, require accurate modeling of the downwash and knowledge of the prevailing conditions. This in turn requires very accurate recording of ambient conditions with a larger number of parameters being recorded at a higher frequency than is now common.

Based on the analysis document provided by Augusta, which I mentioned previously, it would seem that they at least accept that none of these difficulties is insurmountable. It is this recognition of the need for a level of data commensurate with modern techniques and technology that is required. However, it is unfortunate that this is in exact contravention to the view I have heard expressed here today and in many other forums of this sort, that is, the matter of reducing cost.

You cannot get this level of data and this level of simulation without spending a lot of money. Some of the issues of cost have been raised this morning and indeed in the last paper. Something like 60% of the cost of a fixed-wing Phase 3 simulator goes not to the building of the simulator but to providing the data package and the aircraft parts and avionics that go into that simulator. And that is a problem I don't see any way of overcoming simply, if we are to provide the degree of simulation that is expected of a Phase 3 device. So we are faced with a \$12 million or more bill for a Phase 3 helicopter simulator. That's not to say we cannot produce Phase 2, Phase 1, or even flight-training devices at less cost. It is a matter of, as the last speaker said, looking at the return you are going to get.

To put this in context, we heard some figures mentioned earlier about the price of operating a simulator. If you take the cost of operating an airplane and compare it with the cost of operating a simulator, it is a ratio of about 10-to-1. To give you the top-end example, if you look at the cost of ownership of a 747 simulator on a per-hour flying basis, which includes the amortization, the cost of the device, and the building in which it is housed and all the utilities it needs, you come up with an operating cost of about \$450 to \$500 an hour. If you go to the airplane and use the same criteria, that is, cost of purchasing the air-

plane, cost of the crew, the increased cost of maintenance caused by the effects of the repeated landing cycles on the engine, the wheels, the brakes, and the undercarriage, and the additional insurance costs, it is an accepted fact in the fixed-wing world that the cost of operating a Boeing 747 for 1 hour of training is \$16,000. As I say, that is a top-end one. On an average we are talking about a cost ratio of 10-to-1 in operating the airplane over the simulator.

Now, obviously for somebody who is only operating two or three airplanes, they have a problem. And I think we need to get the thing into proper perspective. Unless you think I am being unduly pessimistic, let me hasten to reassure you, we believe the manufacturers have proved their ability to provide highly accurate simulations of some of the most advanced helicopters currently in operation. These have, almost without exception, been built as military programs and have been successful because additional data have been provided through simulator data-gathering exercises on the aircraft and by a large investment of pilot and design engineer time in tuning the models or final results to meet the objective assessments of the pilots. Such expensive methods will probably not be acceptable to the average civil helicopter operator, who in most cases will not have the resources of the military nor of the large fixed-wing aircraft operators.

Yet despite holding this view, I can also add that because of the special circumstances surrounding some of the training problems for helicopters, there may be no other alternatives. For example, in the relatively high speeds encountered even in large transport airplanes, the human vestibular system is easily fooled into believing that the onset cues or short-term changes produced by the motion platform are being sustained. With the helicopter's low-speed operations, the combination of visual cuing and motion cuing may not have such a good effect.

I believe the motion cues become more important in a relative sense, because the rate-of-change cues from the visual scene at low speeds are small. Not all of my colleagues will agree with this point of view and that, in itself, is sufficient reason for raising the subject now.

The adoption of an advisory circular to control the evaluation and approval of helicopter simulators is specifically designed to remove all but the smallest amount of subjectivity and to permit recurrent inspections to be carried out from an objective baseline. The first of these aims may be impossible to obtain until better data are available. And the second may prove impractical and probably unacceptable to the regulatory authorities.

My point in raising the issues I have addressed in this presentation is to warn against falling into the trap of thinking that all that is necessary as an outcome of this workshop and the ensuing working group for the advisory circular is the definition of the training events and the evaluation criteria. Both of these items are essential to the task at hand, but they will be negated unless we also address the problem of the data and how they are to be used.

It has taken some 12 years to reach that conclusion in the fixed-wing world. I submit we cannot afford to give the same amount of time to helicopter simulators. Thank you very much.

MR. CARVER: Brian, is not today's problem with helicopter data collection and the construction of the document similar to the one which has been sent out here by Ed [Boothe] and his compatriots and the same situation

we were in with fixed-wing where actually we have all managed working together to achieve everything that is required. Are we not, by using your suggestion, choking off development for the future?

MR. HAMPSON: I think there is some value in what you said, Paddy. My only comment really on what you have said is that we have a different group of players here. And what I was trying to do in my paper, and I am sure you support the view, is to try and read across some of the experience we got in the fixed-wing world so we do not have to spend 12 years in the helicopter case, as we did in reaching the conclusion we reached in the fixed-wing case. And I certainly would not want to choke off anything, but there are some exercises, were we to go back 12 years, in the fixed-wing case that we would almost certainly do differently. I do not think any of us who have been involved in it would disagree with that.



Brian P. Hampson is director of Engineering Administration for CAE Electronics. Mr. Hampson has been with CAE since 1982, following a 26-year career flying for BOAC/British Airways. He has been a member of the FAA working groups on AC 120-40B and 120-45A and on CAP 453 in the United Kingdom. He is also chairman of the RAeS conference currently seeking to establish international criteria for flight simulators.

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## 8. HELICOPTER SIMULATION: MAKING IT WORK

BARRY PAYNE

The benefits of flight simulation are well documented. The evidence is in daily practice throughout the world, but so far is confined mainly to fixed-wing aviation. Yet, the opportunities for improved training and checking using helicopter simulators are greater than for airplane pilot training. For example, simulators facilitate training environments conducive to the development of pilot decision-making, situational awareness, and cockpit management, all skills that are essential to a reduction in human-error accidents.

Accident data compiled from New Zealand's Air Transport Division mirrors data and reports from the NTSB, the FAA, the U.S. Army, and the Canadian helicopter operators. These data indicate that most helicopter accidents involve complacency or lack of training in how to handle the "chain of errors" that generally results in an accident. New Zealand studies confirm that most helicopter accidents in that country are also caused by pilot error, that these are not confined to any group of experience levels, and that 65% of the causes listed are not specific to the helicopter type. It is also worthy of note that helicopter accident rates have not seen significant improvements even though the machine's reliability has improved.

Studies from around the globe readily confirm what helicopter operators already know—the rate of accidents is too high and human error is the leading factor in aviation mishaps involving professional pilots.

Eighty percent of the world's helicopters are single-engine types operating almost exclusively in VMC and performing everything other than a flight from one airfield to another. Today's helicopter pilots operate in environments that require a wide range of skills that were not likely to have been addressed in traditional training. Most operators are conscious of this and do their level best to manage risks. However, for a great many this task has its own special difficulties.

For example, how effective can you be when the operation utilizes 28 helicopters comprising six different

types flown by 86 pilots of various nationalities all working in a foreign country and scheduled on flexible tours to perform a wide range of tasks in an environment that could involve sea-level jungle operations or mountains typically at 9,000 to 12,000 feet with temperatures of ISA +20. In these circumstances, for helicopters operators based in Papua, New Guinea, training and checking have their own special problems.

Likewise, a typical operator in New Zealand may operate two helicopters, both different types. These could be flown by two full-time and two part-time pilots. Any pilot may be expected to spray potato crops before breakfast, sling drilling material and supplies late morning, undertake a corporate mission in the early afternoon, and be called upon to consider a medivac after dark. A small Australian operator with one helicopter type may be supported by two casual pilots who also supply their services to at least three other operators, and in the course of their duties fly several different helicopter types on a variety of tasks, each with its own peculiar standards.

Although the examples used here are focused on the southwest Pacific area they illustrate a point that is common to a great deal of the international helicopter fraternity. That is, the use and variety of operational tasks expected from a helicopter are many times more varied and considerably more complex than those involving airplanes. Additionally, the commercial and economic reality of our industry will continue to ensure that even more innovative ways will be found to increase helicopter utilization. The risk-management difficulties faced by the average helicopter operator therefore can be quite complex. This task is often further exacerbated when the best solutions must also confirm with a regulatory requirement, the roots of which may have been specifically designed for an IFR airplane operation between airports.

Any pilot involved in training and checking commercial helicopter pilots can forecast with relative accuracy the types and circumstances of accidents that will occur within various operational roles. For example, it can be

said with assurance that within the month, somewhere in Papua, New Guinea, a pilot with more than 1,500 hours flight time and the benefits of recent sling-loading experience will be involved in an accident as the result of pilot error while sling loading. The circumstances will not be new. It may be the result of a skid having caught in a net while lifting off, or a rotor-strike while attempting to recover from a downwind approach without releasing the load. Whatever the cause, it will not be a new one, but a well-tried one repeated. In New Zealand this winter we can again expect a helicopter pilot to enter a cloud while trying to remain visual and as a result lose control and crash. The human-error accident, unfortunately, is the easiest to predict.

A study of New Zealand helicopter accidents from 1980 through 1989 showed that fewer than 10% of the human-error causes could be considered peculiar to the helicopter type involved. Very few accidents involving helicopters have a cause limited to only one specific manufactured type.

The reduction of human error is the most fertile area for an improvement in our helicopter accident rates. Universally the helicopter accident rate is managed by means of training and checking programs, the minimum requirements of which are usually determined by civil aviation regulations or rules. However, it is the quality and content of this training that will determine if the helicopter accident rates remain constant or are reduced.

Since there are obviously far more applications for commercial helicopters than for airplanes, there would seem to be a requirement for a greater diversity of skills among helicopter pilots. This strongly suggests a greater need for quality recurrent training with an emphasis on the occurring factors as evidenced in accident data. It is in this role that the helicopter simulator has its greatest future.

The airplane simulator has proven the benefits of simulation in imparting quality training. A study by United Airlines concluded that training in the flight simulator was 150% more effective than training in the actual aircraft. Simulator development for the airplane industry has been driven by cost benefits and regulatory compliance. Identical factors would also power a helicopter simulator industry. Cost-effective simulation, together with rules that would recognize training credits, would be sufficient for many operators to move their training and checking in the direction of helicopter flight simulation. The principal element involved is that the needs of a typi-

cal helicopter operator are very different from those of an airplane operator.

The use of helicopter simulation as a pilot recurrent-training tool has the potential to reduce accident rates, which has not, so far, been achieved using currently applied methods. For example, a sling-load training exercise with a pilot who incorrectly judges the wind direction and attempts a downwind approach could not be continued beyond a very early stage, for the risk to machine and occupants would be too great. In the aircraft, the training captain may establish the gravity of a given situation; however, the pilot concerned may not recognize a similar situation in the future because it was not prudent to repeat the exercise. The same exercise conducted in a simulator could be continued to conclusion and then repeated to illustrate the cues that could be used to recognize a similar situation again. Such training methods usefully demonstrate the benefits of procedures, decision points, etc.

Like a great many of the skills a helicopter pilot must maintain, sling-load training is not entirely helicopter-type-specific. The same background skills and experiences are applied to all sling loading regardless of what helicopter type is being operated. The same analogy can be made for many helicopter tasks ranging from hovering to mountain flying. To be effective, helicopter simulation must meet the broad needs of the 80%, mostly single-engine, VFR-only segment of our industry.

Based on our own experience, the evolution of simulation software, hardware, and visual systems can currently provide realistic and cost-effective helicopter simulation. Present technology can field a fixed-base cockpit, equipped with 150° day/night visuals and capable of mountain flying, sling loading, elevated heliports, etc. Such a device can be operated at costs that equate favorably with light turbine helicopters. Results can verify effectiveness. It is a fact that right now helicopter simulation has the capability of providing operators with the best risk-management tool available.

The conflict occurs when a definition of helicopter simulation is required in order to satisfy present rules and regulations. Immediately, comparisons are made with airplane simulators built to satisfy regulatory requirements for type transition, recurrent, and route training and checking. Although such requirements will fulfill the needs for a segment of the helicopter industry they fall wide of the mark when compared with the majority needs.

The establishment of our helicopter flight simulator in New Zealand first highlighted some of the difficulties that have yet to be resolved. In the absence of local policy

and relevant regulations, our air Transport Division looked to the FAA for assistance. As a consequence, we can foresee the very real danger that specifications and requirements applicable to the airline industry will be applied to helicopter simulation. Such an approach to rule making would no doubt keep helicopter simulators well out of reach of those 80% who need them.

By way of example, New Zealand's aircraft civil register lists approximately 330 helicopters (Australia has around 4,000). Typically, these constitute a mixed fleet of various types and models engaged in a wide variety of operations. As a comparison, the combined value of New Zealand's helicopter fleet would not exceed the value of two Boeing 747 airliners. Advanced training and checking technology translates into very costly equipment which has to be justified against relative values.

The answer may well lie within the significant research work that has been undertaken since the advent of modern flight simulation. Sufficient verification by authorities such as Alfred T. Lee and Paul W. Caro has removed the blurred distinctions that exist between training technology and flight-simulation technology. To provide characteristics of the helicopter that do not support that training objective is to increase the cost of the system for cosmetic rather than training purposes. Acceptance of such criteria will be fundamental to ensuring cost-effective helicopter flight simulation.

New helicopter-simulator criteria are vital and they should be in place now. A great many of the skills required by helicopter pilots are not type-specific and indeed could, for that matter, be accomplished in a generic simulator. Hovering, sling-loading, confined-area landings, mountain flying techniques—the list goes on. When using a simulator to check a pilot's emergency procedures in the event of an engine failure while carrying a sling load, the position of the cargo release becomes a mere detail if the pilot did not even consider releasing the load.

There are many important skills that contribute to safe helicopter flight. They apply to all pilots regardless of the type of aircraft or style of operation. Their relative importance, however, may be different for each crew member and operation. These are skills that are highly suited to be learned and practiced in the course of simulator training and checking exercises. They are:

1. Cockpit distractions
2. Stress management
3. Use and function of checklists
4. Communication skills

5. Workload assessment and time management
6. Decision-making and judgment
7. Management of flight resources
8. Managing people
9. Flight planning and progress monitoring
10. Pattern (chain of events) recognition

The state-of-the-art visual systems, such as the IVEX VTS 1000, can provide realistic cueing sufficient to conduct simulated day-time operations including hovering exercises. When such visual systems are integrated with a fixed-base cockpit exhibiting genuine helicopter characteristics, there begins to emerge a practical training tool fully capable of influencing the unfavorable accident statistics generated by the helicopter industry.

Although the practical benefits and training effectiveness of helicopter simulators can be argued, widespread acceptance of such devices by operators will largely depend on the results of rule makers and the training and checking credits available to offset the use of actual aircraft instead.

MR. LOMBARDO: Several times today I have heard this recurrent theme about the procedures, that it is not so important that the simulator be exact in terms of hardware. There is a piece of research that just came out, in the most recent issue of the Human Factors Journal, and I will quote it in my paper tomorrow in the low-cost session. But for the benefit those of you who cannot attend that session, a researcher has taken a group, split them in half, had one group learn to deal with the conceptualization of a piece of equipment, and then they went on to try and do the task on that equipment. Another group learned to do the procedure, but on a piece of equipment that wasn't the same as that used for the final tasks. Guess who won? The group that practiced the procedure won over the group that was familiar with the hardware. They were more readily able to adapt a known procedure to another piece of hardware than they were just to shift the concept of how something works.

So that recurrent here is a very, very strong theme. That is what I think we are looking for—the procedure.

MR. PAYNE: I agree with you. We can illustrate the point that every year somebody ends up autorotating a helicopter and putting it on the ground when it was perfectly serviceable to begin with. That is, it was perfectly serviceable up to the minute that it touched down. What the pilot saw and reacted to was what he thought was an engine failure. All his training taught him to do autorotation, touch-down autorotation. But the opportunity doesn't occur often enough to break down bit by bit what is

actually happening. So every year, your statistics, our statistics, show that if anyone who has a gauge failure and who doesn't pick that up as a gauge failure reacts to an engine failure, rolls the throttle back like they do in practice every time and carry on to the ground and usually muck it up.

And a simulator can help identify that. It will certainly provide the training in identifying the problem and, again, it can be a turbine simulator. It does not have to be one particular type.

MR. WALKER: I seem to see a difference in opinion about the requirement for ground contact maneuvers between you and the PHI paper [Gerald Golden, Petroleum Helicopters, Inc.]. Is that true?

MR. PAYNE: Well, I can understand any operator who says I don't want my equipment being smashed onto the ground. There are even experienced instructors who may not have the judgment, the continued day-after-day judgmental skills to ensure that an operator's very valuable equipment can exit a touchdown autorotation in a 100% serviceable condition. And I can understand any operator who says I don't want my equipment being subjected to that risk for training. That is a reality of life. So it does not obscure the fact that touchdown autorotations, I believe, are a very necessary part of training.

Our simulator does a pretty good simulation of a touchdown autorotation, although the last couple of feet are not all that realistic. But it becomes a lot more realistic when winding on the throttle at 100 feet and recovering with a flow through. What's more, you don't have to fly the circuit in between to reposition the helicopter. Again, you start from 2,000 feet. You can do repetition autorotations that have a lot of training value. My opinion is that the autorotation is a skill that the pilot must have, and maybe a simulator is a way of providing it with less risk.

MR. KATZ: This is a combination of a comment and a question. I very much appreciate and like what was said here about the skill being, generic—I think the term was not used, but this is what it meant. Many of the skills are not type-specific. And therefore adherence, fidelity to a particular type, is not essential to get the training benefit. And I would like to throw out the suggestion that maybe you don't really have to adhere to any particular type, and maybe the most cost-effective way to reap training benefits for generic skills is in a generic simulator which may be a physically correct helicopter, which nevertheless does not correspond to any actual type.

MR. PAYNE: Thank you, I agree with you. And it certainly makes the collection of data to produce the model much easier. Thank you.



Barry W. Payne has worked extensively in the field of recurrent pilot training and human factors. He qualified as an aircraft engineer, airplane pilot, and helicopter pilot while a member of the Royal New Zealand Air Force. Following his military service, Mr. Payne worked in various general aviation roles throughout the southwest Pacific and Asia. He is a licensed aircraft engineer, an A-category instructor pilot with instrument rating, and has more than 10,000 flight hours. His company, Aviation Network (NZ) Limited, operates a Bell 205/UH-1H simulator which is used to train military and civilian pilots.

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## 9. HELICOPTER TRAINING SIMULATORS: KEY MARKET FACTORS

JOHN MCINTOSH

The training services and training equipment industry has been working in partnership with NASA and the FAA to constantly improve the ability of people in the air transportation network to perform their missions. This workshop is but another step in bringing technology and performance standards to bear on the training of helicopter crewmen in the civil sector. Your review of and contributions to the draft FAA Advisory Circular for Helicopter Simulator Qualification can significantly affect the quality and cost of pilot training for years to come.

I don't know whose idea it was when the FAA came out with its first Advisory Circular for fixed-wing simulator qualifications. You all remember "Appendix H." Whoever it was, ought to get a medal! That development established standards that have saved uncountable millions of dollars, provided a basis for vastly improved training, and provided a model copied around the world and by our own military in some procurements. Extending that precedent to vertical-lift aircraft is consistent with the advances in helicopter simulation technology and with the future demands on helicopter pilot training.

I wish to present an analysis of that future demand and to discuss some of the factors that will influence the market for helicopters and simulators. I will also touch briefly on other vertical-lift market offerings, including tilt-rotor and tilt-wing aircraft.

My sources include interviews with major helicopter and vertical-lift aircraft manufacturers, NASA studies, interviews with industry providers of training services and equipment, trade journals, and other published data on aircraft operating costs.

There are a number of factors that will influence the future demand for helicopter simulators. Chief among these will, of course, be the demand for civil helicopter aircraft and the types of the units sold and their missions (fig. 1).

The forecast shown in figure 1 covers the period 1991-2000. Although the delivery of civil helicopters looks relatively flat through this decade, notice the trend

toward light twins and intermediate helicopters. Light twins are defined as aircraft under 6,000 lb, and intermediates comprise the range of 6,000 to 15,000 lb. Most of the simulation equipment built to date has been for aircraft in these two categories.

The delivery of 5,330 aircraft in this decade will roughly break out at one-third domestic and two-thirds worldwide, with the hot markets being in densely populated areas such as Japan, the rest of the Pacific Rim, and Europe. There are some who feel that a critical juncture will be encountered in the 1994-1995 period, one that will be brought on by basic decisions on how to handle air-transport systems overloads. One scenario, which I will discuss later, could distort the delivery picture radically and impose heavier demands for simulator training in the last half of the decade. With that, let's take a look at some of the forces that shape the demand in the helicopter market (table 1).

There are several factors that are favorable to the helicopter market. The export business remains strong and is growing in densely populated areas. These are areas where all means of surface and air transport are becoming overburdened. Additional interest for emergency medical services and public sector helicopter utilization is also related to population growth, required response times, and available capital.

Conversely, the lack of infrastructure rather than overtaxed, developed infrastructure, is going to influence growing helicopter demand in Third World nations. There is no question that a possible up side scenario to the forecast shown in table 1 does exist and that it could kick in in the mid-1990s.

While development of the economies of Eastern Europe will provide market expansion, the supply side will be developed also the civil competition from the U.S.S.R. and other sources. Eurocopter could be a synergistic giant compared with the founding partners of Aerospatiale and MBB. The infrastructure for vertical lift is also growing along with helicopter demand; it includes



Figure 1. Ten-year civil helicopter forecast: 5,300 aircraft by weight class.

Table 1. Market forces

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Positive forces
1. Export possibilities are growing
High-density population areas
Third World development
Eastern Europe trading
2. Vertical lift infrastructure is expanding
3. New vertical-lift technologies may provide explosive growth to passenger and package express possibilities
4. More reliable rotorcraft with reduced operating costs
Negative forces
1. Environmental concerns
2. Safety and public image
3. Availability of capital investment
4. Competing technologies

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pads, facilities, and, now, vertiports. Vertiports like the one planned for downtown Dallas can handle transitional vehicles such as tilt rotor and tilt wing, as well as helicopters.

If the newer "tilt" technologies are successful in penetrating the public sector passenger and cargo markets, and if the air-space regulations and infrastructure are properly developed concurrently, then there will be a fall out of additional helicopter demand capable of exploiting the same facilities and the same regulatory climate. For helicopters to position themselves for this market share the good work now being done to reduce seat-mile costs and to improve reliability, perceived safety, and environmental compatibility must be continued (table 1).

It may have been all right for President Reagan to stand near his helicopter with his hand cupped over his ear saying "Sorry Sam I can't hear your question," but most folks do not take kindly to noisy machines belching exhaust in their neighborhoods. It gets particularly alarming when one of those machines makes an emergency autorotation down into a busy intersection. The public will have to be convinced that helicopter use can be expanded in a safe, environmentally compatible manner before they will vote the funds for helicopter purchases by police or for medical services or facility construction. Given the right technology, they might accept vertical-lift aircraft, at least as much as they do fixed-wing aircraft.

Capital is hard to find right now and it will continue to be so until debt loads are relieved and GNP's are on the rise again. This isn't the financial climate for getting a loan to build a beer hall in Baghdad, but investments that make sense, show a return, and are in the best interest of government, industry, and the public can still be managed.

Planning, combined with technology, can benefit vertical lift.

There will be competition for the funds and project support. Take the Boston-New York-Washington corridor for example. Reliever airports, additional runways, helipads, magnetic rail systems, and bullet trains will all be competing for the same pot of money.

Aside from all the light singles driving the training and private use numbers, the market continues to be driven by the working needs of the oil industry (table 2). By and large, the helicopter remains a working tool whose price is justified by the revenue returned for the task to be performed. Today its sales and use are still affected by a poor public image as a vehicle for general transportation. That image could change in the 1990s, but several factors will have to be overcome (table 3).

The seat-mile costs of helicopters are about twice those of regional fixed-wing aircraft, and the "tilt" technologies will bring that disparity down from 2 to 1 to about 1.2 to 1.4 to 1. Obviously other economic issues remain to be dealt with. Progress toward resolution of some of them is promised by the cost model of a complete door-to-door transportation scenario that applies a cost factor to the total time saved, as the air-traffic control system and facilities are further tuned to city-center-to-city-center operations. As the infrastructure grows to offer more possibilities, the economic model will improve as well.

Bear in mind, however, that other competitors for the traveler's dollars will not be standing still as constants in the economic model. They will be moving hard to capture public and private capital.

Table 2. Civil helicopter market segments

Segments
Training
Petroleum and industrial
Public service
Emergency medical services
Executive/corporate
Passenger
Comments
7,400 helicopters now flying in United States; main driving force: petroleum industry
Public service, including law enforcement, operates 1,400 units in 335 agencies
174 emergency medical services programs operate 231 units

Table 3. Vertical-lift passenger traffic market: factors opposing

1. Vertical-lift technology must overcome:
Noise and other environmental concerns
Seat-mile cost disadvantage
Lack of dependable IFR operations in icing conditions
Negative public image of safety and reliability
2. Air-traffic control systems must be changed to accommodate higher volume vertical-lift IFR traffic in vertiport infrastructure
3. Other modes of transportation are competing for private and public capital:
Reliever airports
Bullet trains

Today's congestion makes the case for civil tilt-rotor and tilt-wing research (table 4). The air-travel delays today at those 21 airports are estimated to cause a \$5 billion annual loss. By the year 2000, this grows to 50 airports with this magnitude of delays. Eight-four million dollars, the rough cost of an extra runway, is enough money for several helipads and for the tilt-rotor aircraft to use them. That structure, if it happens, will pump helicopter sales as well. It could very well be that the first working example of this will occur in the densely populated Japanese travel sector. The industry study team, studying tilt-rotor missions for NASA, reported that a single new airport would cost \$4 billion to \$6 billion. For half that cost, they estimated that an entire network of 12 urban vertiports could be built along with 165 40-seat tilt-rotor aircraft.

High fidelity and cost-effective training will continue to gain in importance in the vertical-lift market we have been looking at.

You all know that simulator fidelity isn't legislated or wished into being. The right data must be modeled in the right way and implemented on equipment capable of executing the model and cues in real time.

The forces acting on the vertical-lift market, which we have reviewed today, will create a continuing training demand. The trends indicate that the training will continue to shift toward simulation equipment and that the training will be provided by full-service training companies. Some key people are expecting a significant increase in simulator-base training demand in the 1995-1997 period.

As was true in the fixed-wing experience, the acceptance and use of simulator-based training will be influenced by simulator fidelity, economic advantage, and a regulatory environment that permits credits for the training given. Helicopter simulation fidelity (table 5) is more difficult to achieve, in some ways, than is fixed-wing fidelity.

To begin with, rotors present a unique problem, given their flexibility and varying angles of attack. The

Table 4. Vertical-lift passenger traffic market: factors favoring

- |  |
|--|
| 1. Twenty-one airports now have delays of 20,000 hours annually. Predicted: by 1997, 33; by 1998, 41     |
| 2. By the year 2000, prediction is for a 32% increase in jet transports and a 74% increase in passengers |
| 3. Half of today's commercial fleet is used for flight segments of less than 500 miles                   |
| 4. Situation worse in Europe and Japan   |

Table 5. Simulator training: fidelity

- |                                      |
|--------------------------------------|
| 1. Aircraft data and data collection |
| 2. Modeling techniques               |
| 3. Visual and motion cues            |
| 4. Standards for performance         |
| 5. Training program design           |

blade-element solution offers an improvement over the process of tailoring a rotor-map-based design. Its use, however, requires model solution speeds unheard of in fixed-wing simulator configurations.

Unfortunately, the modeling and data problems don't end with the rotor. Fuselage aerodynamic data are difficult to gather and to document for slow forward air speeds, in wind, and in hover. Today, engineers have to "twiddle" with induced velocities, and there is a need for more data for translational lift. In slow-speed regimes, more and more and more resolution is required. Thirty-two-bit, floating-point computers will be needed.

Helicopter motion and visual cues are more complicated than they are for fixed-wing aircraft. Field of view is greater, with down-look angles that are important. Also important in helicopter training is the fidelity of onset and vibration cues.

Perhaps the biggest technical problem is the unavailability of binocular vision in the visual system. The low approach to the ground of a fixed-wing aircraft is fast enough to reduce the effects of this lack of height cue, but a helicopter hover to landing or autorotation is quite another matter. Confined-area vertical cues help, but the fidelity problem still exists.

We should all remember that a qualified simulator is still but a tool in a pilot-training program. The program itself must be designed, by the certificate holder or training-services company, to a high degree of quality and cost effectiveness.

Let's see if we can quantify some of the costs (table 6). I have made these reasonable assumptions as a basis for comparing simulator training costs with the

alternative of training in the helicopter. These costs (fig. 2) do not include any adjustment for the fact that simulator training hours can be more highly concentrated and can include training in recovery from a number of emergency or otherwise abnormal situations. Certainly there is more realism in the real-world environment, but there is more safety in the simulator.

Summing up key simulator market factors, I would conclude that fidelity is strong but with some key issues revolving around data collection and visual simulation remaining to be solved (table 7). The cost equation is practical and the demand is reasonably strong with mid-decade factors coming into play that could capture the attention of manufacturers.

Table 6. Simulator training: cost/hour assumptions

- |  |
|--|
| Light twin with simulator cost twice that of actual aircraft |
| 1200 flight hours and 3500 simulator hours                   |
| Depreciation over 10 years                                   |
| Crew compensation and insurance not included                 |

Table 7. Helicopter simulators: key market factors

- |                                   |
|-----------------------------------|
| 1. Fidelity of simulator training |
| Data and models                   |
| Equipment technology              |
| Training programs                 |
| 2. Cost of simulator training     |
| Versus training in aircraft       |
| Trend                             |
| 3. Training demand                |
| Vertical-lift market in the 1990s |
| Helicopter demand factors         |
| Trends                            |

Today there are only a few civil helicopter simulators that would fall into a classification covered by the FAA draft Advisory Circular that is under consideration at this workshop (table 8).

Table 8. Civil simulators

Bell 222
Bell 212/412
Sikorsky S76A
Sikorsky S76B/A
Boeing Vertol 234
Aerospatiale 332L
Sikorsky S61N

The forecast for new simulators in this decade is shown in table 9.

Table 9. Simulator forecast: 1990-2000

1. Light singles and twins, less than 6,000 lb	4
2. Intermediate, 6,000 to 15,000 lb	3
3. Medium to heavy, more than 15,000 lb	1
4. Other vertical-lift	
Tilt rotor	1
Tilt wing	1
Total	10

Whether these predicted buys are actually made will depend on all the market forces we have discussed today, not the least of which is the final form and implementation of the FAA rules for simulator qualification.

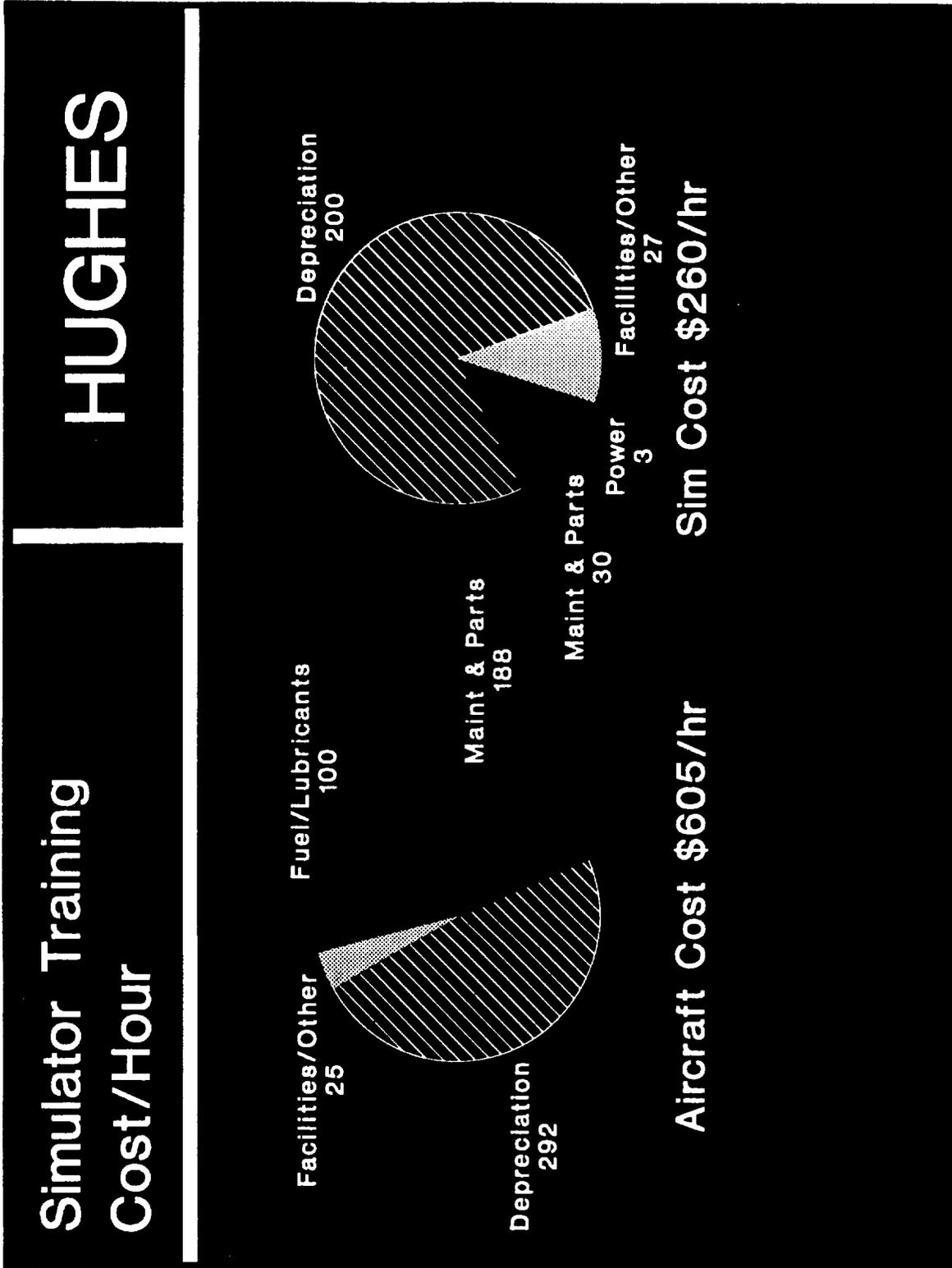


Figure 2. Simulator training: cost/hour.



John D. McIntosh has worked in training and engineering for 37 years. He is vice president of Hughes Simulation Systems, Inc., Arlington, Texas. Mr. McIntosh has held executive positions at a number of major companies, including Link, Atkins and Merrill, FlightSafety Simulation, and Reflectone. While at FSE, Mr. McIntosh formed a team with the University of Michigan and produced the first true blade/element simulation for training.

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# 10. TRAINING EFFECTIVENESS ASSESSMENT: METHODOLOGICAL PROBLEMS AND ISSUES

KENNETH D. CROSS

If any one of you has talked with a person who has recently examined the literature on helicopter simulator training effectiveness, I'll bet you dollars to donuts that they were positively shocked by the small amount of research that has addressed this important topic. The persons I have talked with ask me, "How can it be that the military has invested enormous sums in helicopter simulators without having solid empirical data on how effective they are and how they should and should not be used?"

Although there is a host of reasons for the lack of data on helicopter simulator effectiveness, it is my contention that one of the most important is the lack of an evaluation methodology that yields comprehensive and valid training-effectiveness data in a timely manner at an affordable cost. Accordingly, my comments today are aimed at identifying some of the methodological problems encountered in assessing the training effectiveness of helicopter simulators and some of the issues that must be addressed in developing solutions to these problems.

Before proceeding, it is important to acknowledge that my comments reflect the perspective of a behavioral sciences researcher (table 1). It is also important to acknowledge that my views have been greatly influenced, and perhaps biased, by my experience in considering the training needs and problems of Army aviators. I have attempted to make all of my comments relevant to civilian aviation, but I cannot promise that I have been completely successful.

Because time is short, I have limited the focus of my comments. The methods I discuss are ones that I consider suitable for assessing the cost and training effectiveness of a new, production-model simulator for initial skill-acquisition training. These methods may or may not be suitable for collecting the data needed to support the simulator design decisions that must be made in the early design phase of a simulator development effort. Similarly, the methods may or may not be suitable for assessing a simulator's effectiveness for skill-sustainment training.

Table 1. Perspective and scope

Perspective
Behavioral sciences research
Army aviation
Focus
New production model simulator evaluation
Initial skill acquisition (basic/transition)
Important topics not addressed
Predicting training effectiveness from engineering data
Utility of simulators for proficiency checking
Utility of simulators for skill sustainment training

Three important topics that I have not attempted to address except in passing include the feasibility of using engineering data to predict training effectiveness, the utility of simulator for proficiency checking, and the utility of simulators for skill-sustainment training.

I will commence with a brief description of what I refer to as the "classic" transfer-of-training methods and an illustration of the types of data generated by them. Then, I will describe what I consider to be the key shortcomings of these methods. Finally, I will describe a methodological approach that, in my view, is more effective and efficient than the classic approach.

It is important to emphasize that the approach I propose does not eliminate the need to measure empirically the extent to which training in the simulator transfers to the parent aircraft. Rather, the approach is intended to insure that the simulator is functioning optimally and that the simulator training method is near optimal before an expensive transfer-of-training study is performed. Believe me, a researcher's worst nightmare is to complete a transfer-of-training study costing hundreds of thousands of dollars, only to discover that the simulator was not functioning properly or that the trainees were given the wrong kind or amount of training in the simulator.

It is also important to emphasize that many of the methods and ideas I discuss are not new. If anything I have to say is truly a novel idea, it is the sequence in which the methods are used and the specific purposes for which they are used.

Figure 1 illustrates the classic transfer-of-training research design. One group of trainees—the control group—receives no simulator training. The purpose of the control group is to provide information about the amount of time required to achieve proficiency through aircraft training alone. In addition to the control group, there are one or more groups of trainees who receive some amount of training in the simulator before being trained to proficiency in the aircraft; these groups are referred to as experimental groups. This illustration assumes that there are five experimental groups that differ only in the number of hours of training they receive in the simulator—5 hours, 10 hours, and so on. All groups are trained to the same level of proficiency in the aircraft, and the number of aircraft hours required to reach proficiency is recorded.

A simulator is training-effective to the extent that simulator training reduces the amount of aircraft training required to achieve proficiency in the aircraft. In short, a simulator is training-effective to the extent that simulator training hours replace aircraft training hours. The hypothetical data presented in figure 2 illustrate the well-established relationship between the amount of simulator training the trainees receive and the amount of training required to achieve proficiency in the aircraft. The control group trainees, who receive no training in the simulator, require an average of 50 hours in the aircraft to reach proficiency; trainees who receive 5 hours of simulator training require only 40 hours in the aircraft to reach proficiency. This negatively decelerating monotonic function illustrates the simple fact that each increment in simulator training time yields progressively less savings in aircraft training time. Data of this type are interesting, but are not sufficient to determine what amount of simulator training is optimal.

Cost data must be brought to bear in deciding how much simulator training is enough. Figure 3 shows the relationship between the amount of simulator training and total training costs, or, its mirror image, cost savings. In producing this figure, I used the hypothetical training-effectiveness data shown in figure 3, along with the Army's current estimates of the cost of an hour of Blackhawk simulator time and the cost of an hour of Blackhawk aircraft time. As you see, the simulator and aircraft costs

are \$338 and \$1,424 an hour, respectively. The cost curve shows that very little cost reduction is realized from simulator training beyond 10 hours. If cost is the prime consideration, total cost can be minimized by giving each trainee 15 hours of training in the simulator. However, if aircraft are unavailable for training, as many as 25 hours of simulator training can be given without increasing total training cost appreciably.

So, how can one find fault with a method that yields data like these? Let's consider some of the problems.

Table 2 lists some of the key shortcomings of the classic transfer-of-training method. First, the method yields only a composite measure of training transfer. This would not be a problem if the simulator were equally effective for training every maneuver. However, what is more likely is that training transfer for some maneuvers will be large and positive whereas training transfer for other maneuvers will be negligible or even negative. If this is indeed the case, the composite measure of training transfer is an underestimate of the simulator's optimal training effectiveness. Stated differently, the cost effectiveness of the simulator could be increased by eliminating training on those maneuvers for which training transfer is negligible or negative.

Second, the relatively high cost of transfer-of-training studies prevents the use of this method for optimizing the various components of the training system. When the first version of a production simulator appears on the scene, there are going to be many uncertainties about how best to set it up and use it. For example:

1. Are all components of the simulator functioning as they were designed to function?
2. Are there ways the simulator components can be adjusted or modified to increase the simulator's training effectiveness?
3. What maneuvers should be trained, in what order should the maneuvers be trained, and how much training should be given on each maneuver?
4. What is the best method or procedure for training a given maneuver?
5. What is the best way to employ the instructional support features available on the simulator?

Although these questions are of critical importance, it would be prohibitively costly to answer them through classic transfer-of-training studies. Another more efficient method is required for this purpose.

The third shortcoming is that transfer-of-training methods are not suitable for assessing some simulator training applications. Although a simulator may be highly

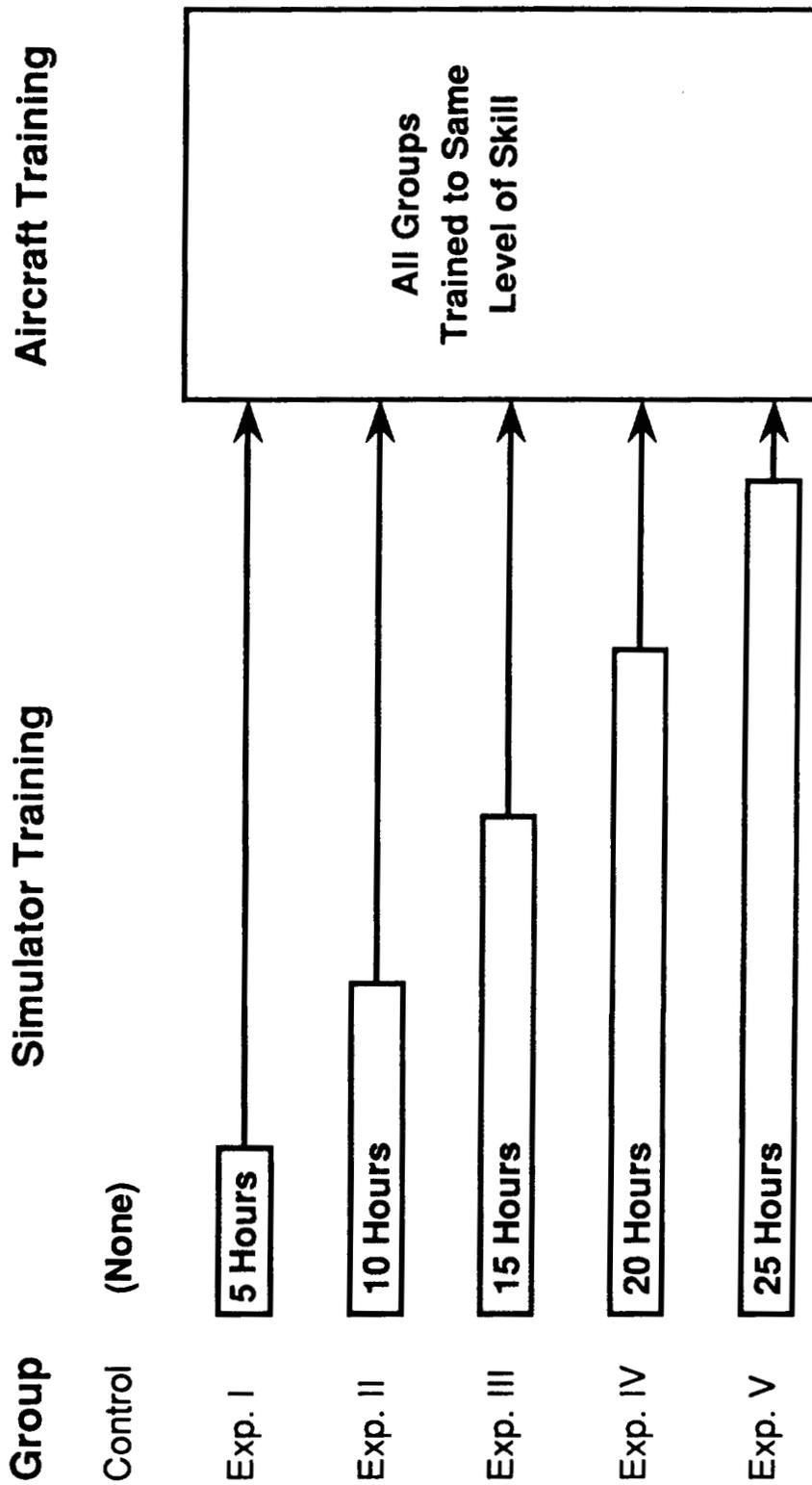


Figure 1. Classical TOT research design.

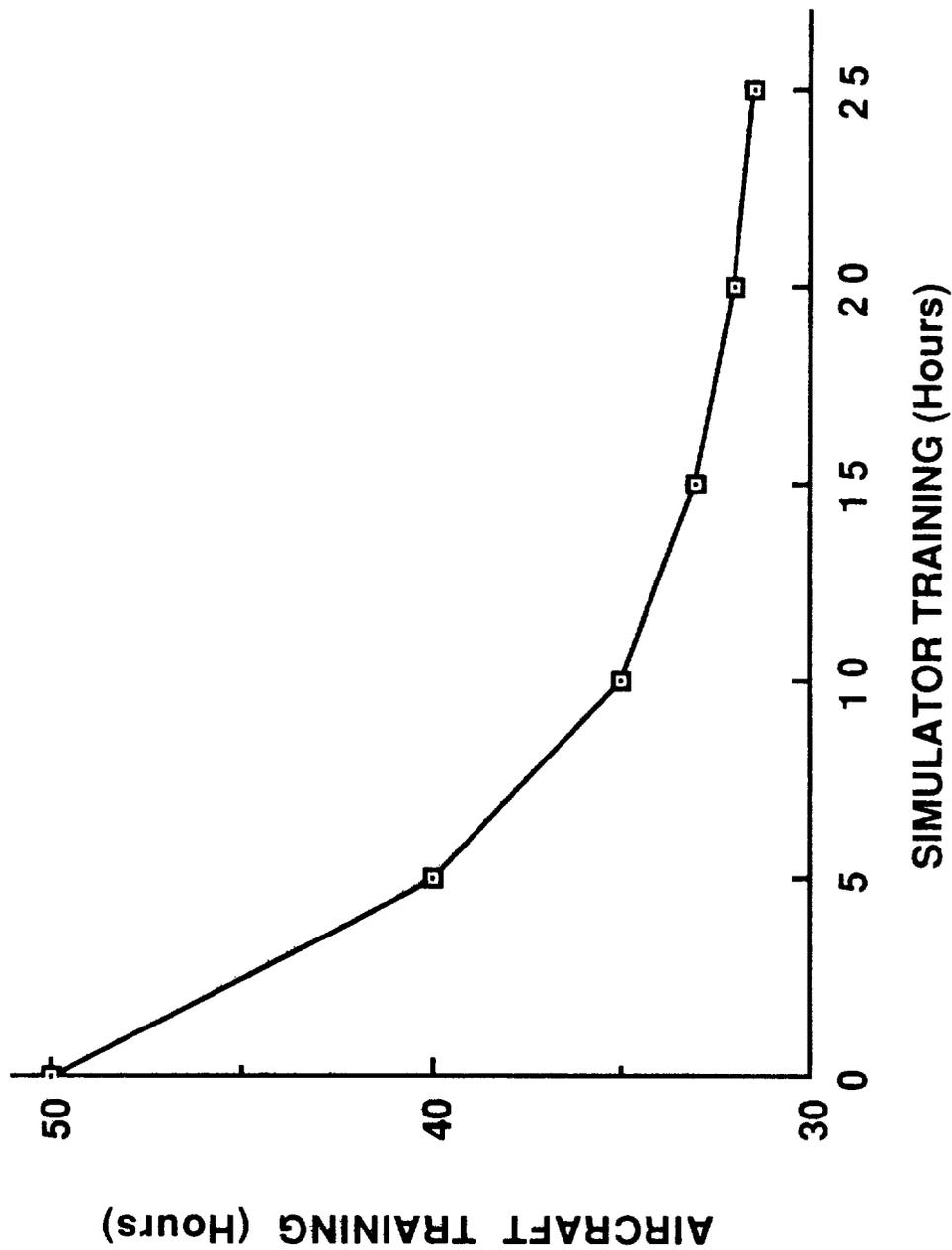


Figure 2. Aircraft training hours to criterion as a function of prior simulator training (hypothetical data).

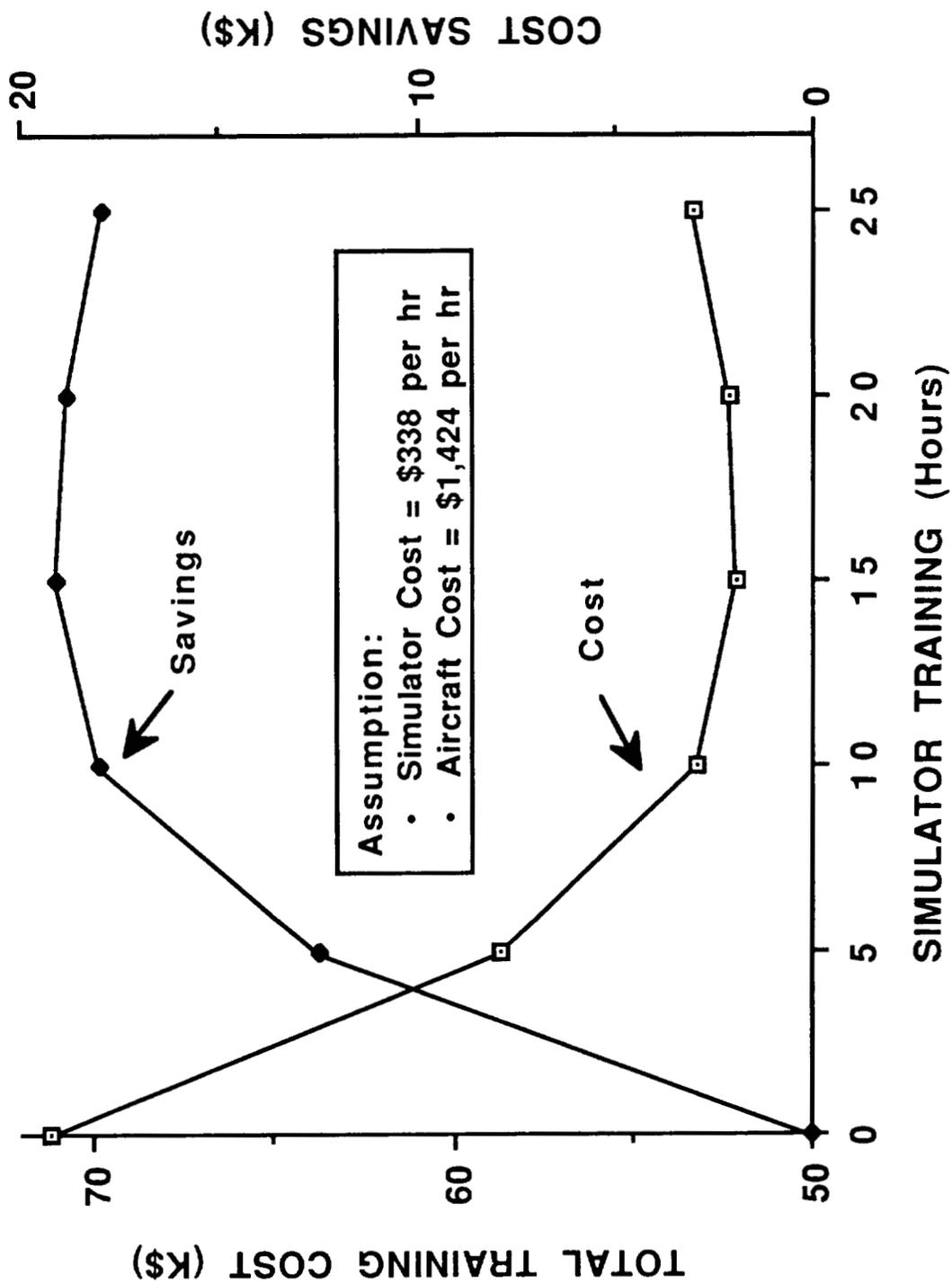


Figure 3. Total training costs/savings as function of simulator training hours (hypothetical data).

Table 2. Key shortcomings of classic transfer-of-training method

1. Yields only a composite measure of training transfer
2. High cost prevents use for optimizing training system
Simulator set up and functioning
Type and sequence of maneuvers
Training method and instructional support features
3. Unsuitable for assessing some simulator training applications

effective for training maneuvers that are too hazardous to perform in the aircraft, it is not possible to measure the extent to which such training transfers since it is not possible to measure how well pilots can perform these hazardous maneuvers in the aircraft. For example, it is probably too hazardous to measure in the aircraft a pilot's ability to recover from such emergencies as a brown-out or white-out, a dual engine failure, a complete loss of tail-rotor effectiveness, or a severe wind shear.

There are other maneuvers and conditions for which proficiency measurement in the aircraft is excessively costly, even if the risk is acceptable. For instance, measuring pilots' ability to perform takeoffs and landings at high surface elevation may be costly if the research is not conducted at a location that is close to mountainous terrain. Also, because visibility conditions in the real world cannot be controlled, it may be excessively costly to measure pilots' ability to perform maneuvers under specific degraded visibility conditions.

The flow diagram shown in figure 4 illustrates my views about the type, sequence, and purpose of research studies that, together, may eliminate some of the shortcomings of the classic transfer-of-training methods. This approach to simulator evaluation is the result of a large amount of thought and a small amount of data collection, so it is not presented here as a proven research method. Although my colleagues and I believe the approach is workable and sensible, I invite all of you to critique the approach and to let me know what doesn't make sense to you.

The four small shadowed boxes in figure 4 identify four types of research studies that I consider necessary for the efficient assessment of a simulator's training and cost effectiveness; the boxes with the rounded corners identify the purpose served by each of the four types of studies.

As you can see in the upper left corner, the purpose of the analytical studies is to identify maneuvers for which training transfer cannot be assessed either because the maneuver clearly cannot be trained in the simulator, or a pilot's proficiency on the maneuver cannot be measured in the aircraft without unacceptable risk or cost. For obvi-

ous reasons, these maneuvers must be excluded from a transfer-of-training study. The purpose of the next two types of studies is to insure that the simulator and the simulator training are near optimal before a transfer-of-training study is commenced. Because of the limited amount of time available, I will not comment further on the analytical studies. Instead, I will use the time I have left to discuss the rationale and procedures for the three remaining studies: backward transfer, in-simulator skill acquisition, and modified transfer of training.

The idea behind a backward-transfer study is a simple one (table 3). If forward transfer is the extent to which training in a simulator transfers to the parent aircraft, backward transfer must be the extent to which training in the parent aircraft transfers to the simulator. If the skills required to perform a maneuver in the parent aircraft are the same as the skills required to perform that maneuver in the simulator, one would expect a high degree of backward transfer. If backward transfer is not high, it is reasonable to assume that something about the simulator is not right. In short, the fundamental premise is that a low backward transfer indicates one or more important shortcomings in the simulator. About 30 years ago, Jack Adams and his colleagues at the University of Illinois considered the feasibility of using measures of backward transfer to predict the degree of forward transfer. Although backward transfer may indeed be a reasonably valid predictor of forward transfer, it is important to emphasize that predicting forward transfer is not the purpose for which backward-transfer studies are proposed here.

The procedure for conducting a backward transfer-of-training study is simple and straightforward. The first step is to select pilots who are highly experienced in the parent aircraft and who have had little or no experience in simulators, especially in the simulator being evaluated. The next step is to evaluate each pilot's proficiency in the aircraft for each maneuver to be evaluated in the simulator. The third step is to measure the pilots' initial proficiency on each maneuver in the simulator. Initial proficiency refers to how well the pilots perform on no more than the

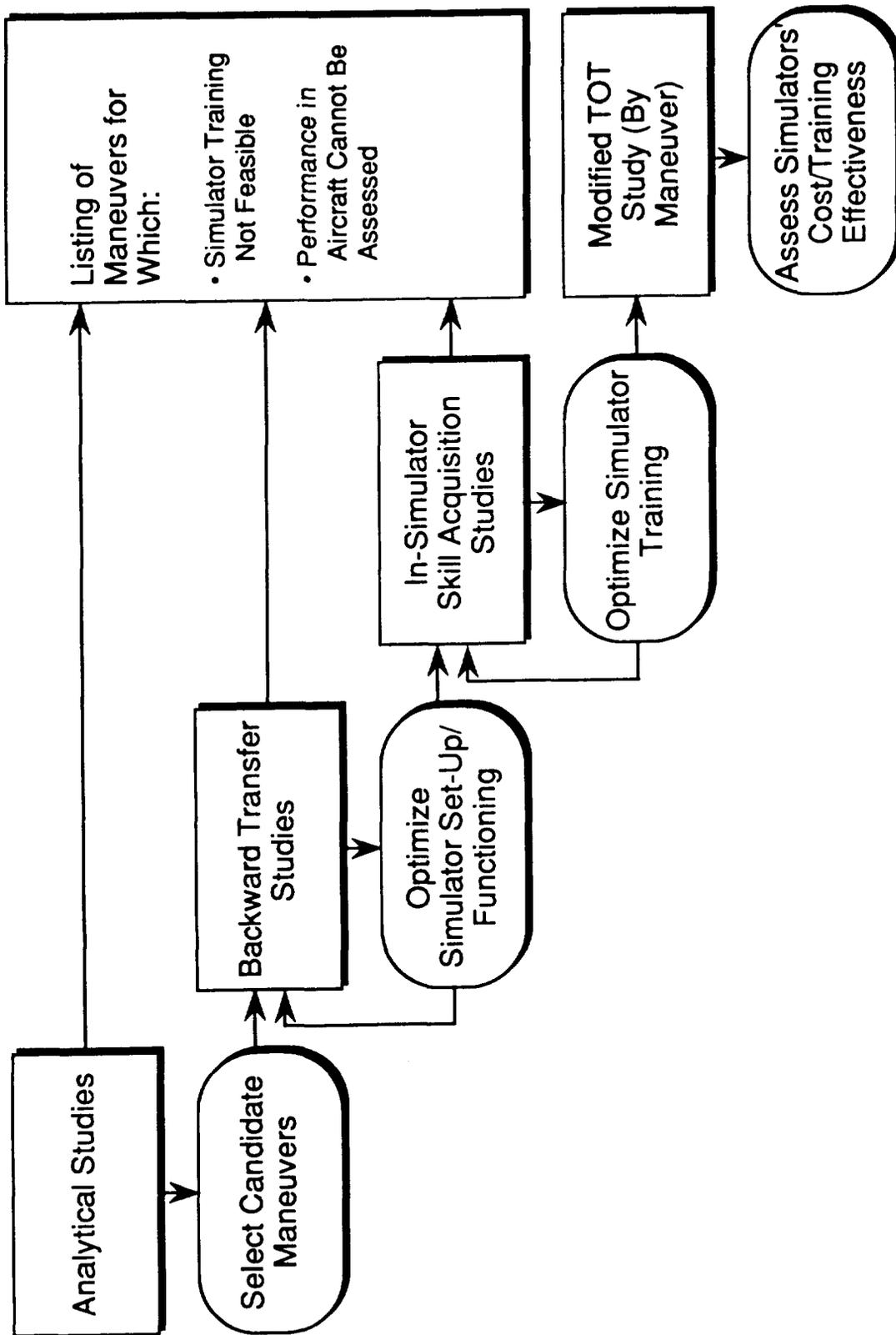


Figure 4. Type/sequence/purpose of evaluation studies.

Table 3. Backward-transfer studies

Concept	Measure aircraft-to-simulator transfer (experienced aviators)
Premise	Low backward transfer indicates simulator shortcomings
Procedure	Select pilots with long aircraft experience and no simulator experience Assess task proficiency in aircraft (desirable) Measure initial task proficiency in simulator (one to three iterations) Assess backward transfer Interview pilots
Benefits	Efficient (time and cost) Yields diagnostic data about simulator shortcomings

first three attempts. There is a substantial amount of evidence that indicates that experienced pilots are able to adapt very quickly to even substantial differences between the aircraft and the simulator; as a result, a pilot's performance may quickly become contaminated by simulator-specific learning. The fourth step is to assess the degree of backward transfer by comparing simulator performance with aircraft performance, published performance standards, or both. The final step is to question pilots about the reasons for any poor performance in the simulator.

If the results reveal simulator shortcomings that can be eliminated completely or in part, the simulator can be modified and backward transfer can be measured again for the maneuvers that were performed poorly.

Backward-transfer studies have two important benefits. First, they are highly efficient in terms of both cost and time. If necessary, further cost reductions can be realized by eliminating proficiency measurement in the aircraft. The results of our backward-training research indicate that proficiency measurement in the aircraft is useful but not essential. Second, backward-transfer studies yield data that are useful in determining the reasons for poor simulator performance. In addition to the judgments of the participating pilots, much can be learned about simulator shortcomings by studying the types of errors made in performing a maneuver and the manner in which simulator performance differs from aircraft performance.

Figure 5 presents an example of the kind of results that can be expected from a backward-transfer study. The study was the first step in evaluating the effectiveness of the AH-1 Flight and Weapons Simulator for sustaining proficiency on emergency touchdown procedures. The 15 pilots who participated in the study were highly experienced AH-1 instructor pilots.

The solid bars show the mean ratings for performance in the aircraft; the cross-hatched bars show the mean ratings for the first attempt to perform the same maneuvers in the AH-1 simulator. A rating of 1 indicates clearly unacceptable performance—a crash, a hard landing, landing short, and so on. A rating of 7 indicated the level of performance that the evaluators expected of the average AH-1 instructor pilot.

The ratings of aircraft performance indicated that the various emergency touchdown procedures differ in their inherent difficulty—the simulated anti-torque failure appears to be the most difficult maneuver, and the shallow approach to a running landing appears to be the least difficult maneuver. You can see that the ratings of simulator performance are far lower than the ratings of aircraft performance. More important, there is little correlation between the simulation ratings and the aircraft ratings. For instance, although most aviators performed standard autorotations very proficiently in the aircraft, no aviator received a rating higher than 1 on a standard autorotation in the simulator.

Although these results are not definitive proof that the AH-1 simulator is ineffective for training emergency touchdown procedure, they leave no doubt that the simulator and the aircraft differ in ways that may have a major influence on training effectiveness. In truth, it is not possible to examine these findings without worrying about negative transfer.

Table 4 shows a tally of the IP's spontaneous comments about the factors that contributed to the poor performance in the simulator. It can be seen that most of the IPs attributed their poor performance, in part, to the lack of visual cues needed to operate near the ground. The

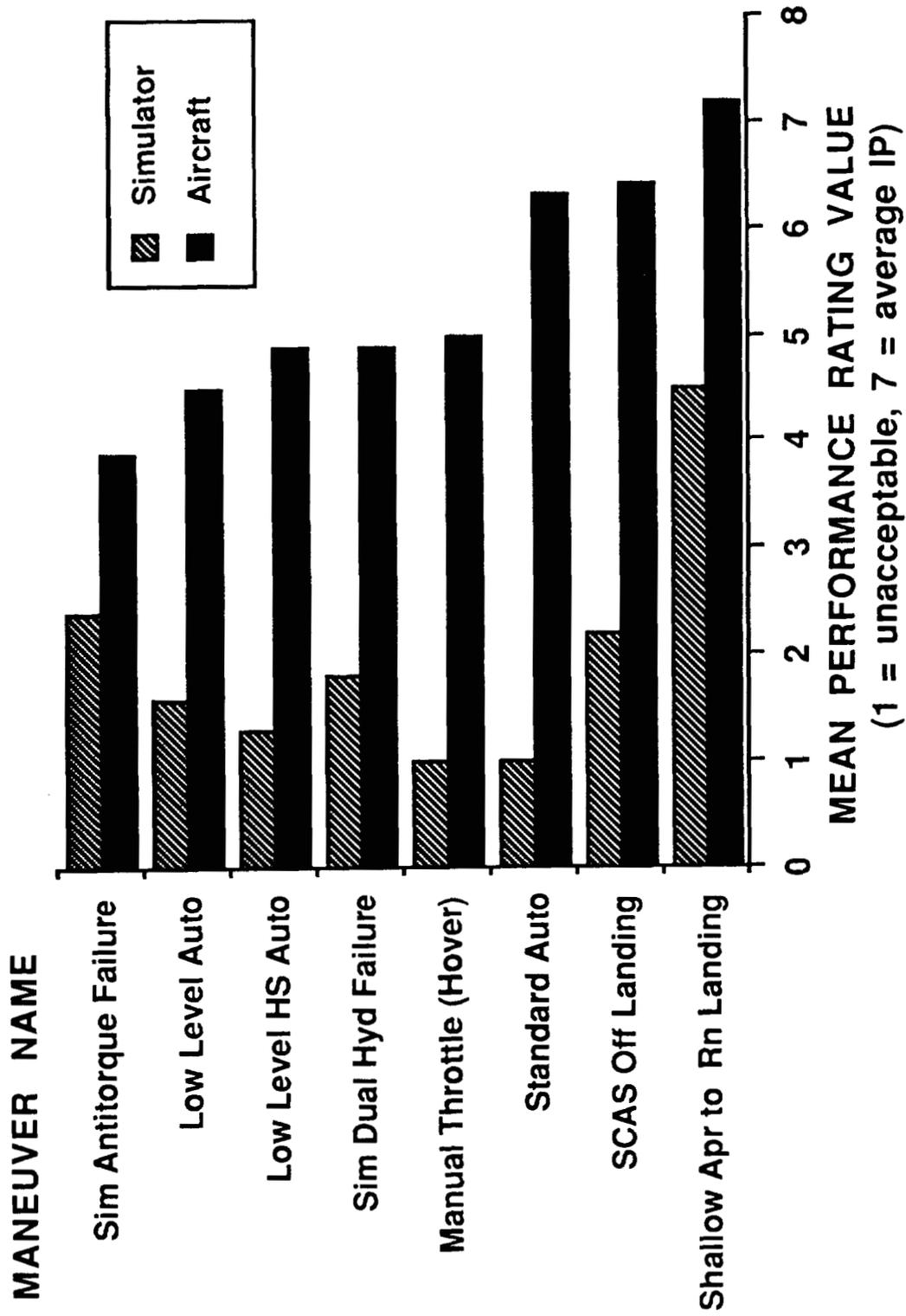


Figure 5. Example of backward transfer results.

Table 4. Factors contributing to low backward transfer<sup>a</sup>

Lack of visual cues
Visual display blurred near ground (100%)
Unable to judge altitude near ground (94%)
Insufficient visual cues to maintain hover (87%)
Entry point difficult to judge (81%)
Lack of peripheral cues (69%)
Unrealistic response to control inputs
Response to collective inputs (75%)
Response to cyclic inputs (63%)

<sup>a</sup>N = 15 for all percentages.

study was conducted in one of the early AH-1 simulators that was equipped with a camera-model-board visual system. The comments of the IPs are consistent with the results of tests that have shown that the camera-model-board system has poor focus and resolution when the probe is located very close to the model board. Table 4 also shows that most of the IPs identified unrealistic response to collective and cyclic inputs as an important contributor to poor performance in the simulator.

Although pilot judgments have not always proved to be highly reliable sources of information about simulator functioning, it would be foolish to ignore judgments that are as consistent as the ones shown here.

As I define the term, an in-simulator skill-acquisition study is a study performed to determine (1) how much

simulator practice is required to gain proficiency on a given maneuver, and (2) the maximum level of proficiency that can be achieved (table 5). The recommendation to conduct skill-acquisition studies is based on two premises. The first premise is that the cost effectiveness of a simulator can be degraded significantly by inefficient simulator training. Inefficient simulator training may be the result of such factors as (1) too much or too little simulator training, (2) the use of inefficient training methods, and (3) the expenditure of an excessive amount of time on training maneuvers for which skill acquisition is very slow. The second premise is that skill acquisition data can be used to optimize simulator training.

Before proceeding, I would like to comment briefly on a couple of issues. The first is the importance of determining the optimal amount of simulator training for each maneuver. It is obvious that money is wasted when training on a maneuver is continued beyond the point at which performance asymptotes. What is not so obvious is that overtraining on a maneuver may actually reduce training transfer. Jack Dohme, an Army Research Institute researcher at Fort Rucker, has shown me unpublished data that strongly suggest that too much simulator training on a maneuver can, in fact, reduce training transfer.

On the other hand, there are reasons to believe that too little simulator training on a task may create problems of a different kind. The problems stem from the fact that some minimum level of proficiency on some maneuvers is

Table 5. In-simulator skill-acquisition studies

Premises
Cost effectiveness of simulator degrades by training inefficiencies
Too much/little simulator training
Ineffective training methods
Time spent training maneuvers for which skill acquisition is slow
Simulator training can be optimized using skill acquisition data
Procedure
Select trainees (novice and experienced aviators)
Measure practice-iterations/time-to-criterion as function of maneuver type/sequence, training procedures
Benefits
Yields data with which to specify near-optimal training
Maneuver sequence
Practice iterations
Training procedures
Efficient (time and cost)
Identifies maneuvers that should be excluded from simulator training

required to learn other, more complex maneuvers efficiently. For example, instructor pilots claim that efficient learning of out-of-ground-effect hover is not possible until a student is reasonably proficient at performing in-ground-effect hover.

The second issue is the importance of establishing optional training methods. Many persons believe that all simulator training should be conducted in the context of a training scenario that approximates an aircraft training flight. Training in the context of a scenario of this type invariably wastes a lot of time in traveling from one point to another. For instance, training on approaches and landings in a simulator need not require the trainee to fly the entire traffic pattern in order to get the needed practice on the final approach and landing. Using the simulator's "initial condition set" to place the simulated aircraft on the final approach leg can greatly increase the number of practice iterations that can be accomplished during a training period. Although training method is certain to have a major effect on training efficiency, few studies have been conducted to assess the relationship between training method and rate and level of skill acquisition in the simulator.

Now let us discuss the procedures for conducting skill acquisition studies (refer to table 5). The procedures are simple. The first step is to select the pilots who are to participate in the study. Normally, the study would be conducted only with novice aviators who have no experience in the simulator. However, we have found it useful also to investigate the skill acquisition of pilots who are highly experienced in both the simulator and the parent aircraft. The use of experienced aviators is an efficient way to determine the maximum level of proficiency that is possible for a given maneuver.

The second step is to measure the number of practice iterations and the amount of training time required to reach a prescribed level of performance on each maneuver. Since the purpose of the skill-acquisition study is to optimize training methods, the practice iterations and training time would be measured as functions of such independent variables as type of maneuvers, the sequence in which maneuvers are trained, and the training procedures used.

Skill-acquisition studies have three kinds of benefits. As I have already mentioned, the main benefit is that the data can be used to specify a near-optimal training method before a transfer-of-training study is commenced. The second is that skill-acquisition studies are very efficient relative to transfer-of-training studies. A third benefit is

that the data can be used to identify maneuvers that should be excluded from simulator training because skill acquisition in the simulator is slow or nonexistent.

I would like to take a few minutes to show you the results of a skill-acquisition study we performed on the AH-1 Flight and Weapons Simulator (fig. 6). The ultimate objective of the study was to assess the utility of the simulator for sustainment training, so we measured the simulator skill acquisition of experienced AH-1 pilots rather than trainees. Because we had not conducted skill-acquisition studies before, we assumed that experienced pilots would require no more than 10 practice iterations to reach proficiency on any task. So, the entire schedule was set up to obtain data on only 10 iterations. This assumption turned out to be grossly incorrect. In fact, more than 10 iterations were required to reach proficiency on most maneuvers. As a consequence, it was necessary to use regression analysis to project the number of practice iterations required to reach proficiency. Figure 6 shows projected iterations to proficiency for each of 15 maneuvers. For three maneuvers, there was no measurable learning during the first 10 iterations, so no projections could be made for the maneuvers. For the remaining maneuvers, the projected numbers of iterations to proficiency varied from 9 to 27.

Results such as these are useful for making decisions about the kinds of maneuvers that should be trained in the simulator and the amount of simulator time required to accomplish training on each maneuver. In addition, such results lead to some interesting questions about the design and function of the simulator. For instance, why do skilled aviators require so many trials to master normal approaches and hover tasks in the simulator?

The final and most critical study in the sequence is a transfer-of-training study. Table 6 shows my views about ways in which the classic transfer-of-training method can be modified to produce more useful data. Some involve changes in the simulator training and some require changes in the aircraft training.

There are three ways in which simulator training should be changed. First, I believe that all trainees should be trained to a prescribed level of proficiency in the simulator rather than receive some pre-defined amount of simulator training. Second, the amount of simulator training should be varied by varying the number of maneuvers trained rather than spreading fewer and fewer hours of training over some fixed number of maneuvers. And third, I believe that good estimates of cost effectiveness are possible only if the researcher is careful to record the nonproductive training time spent in the simulator. The

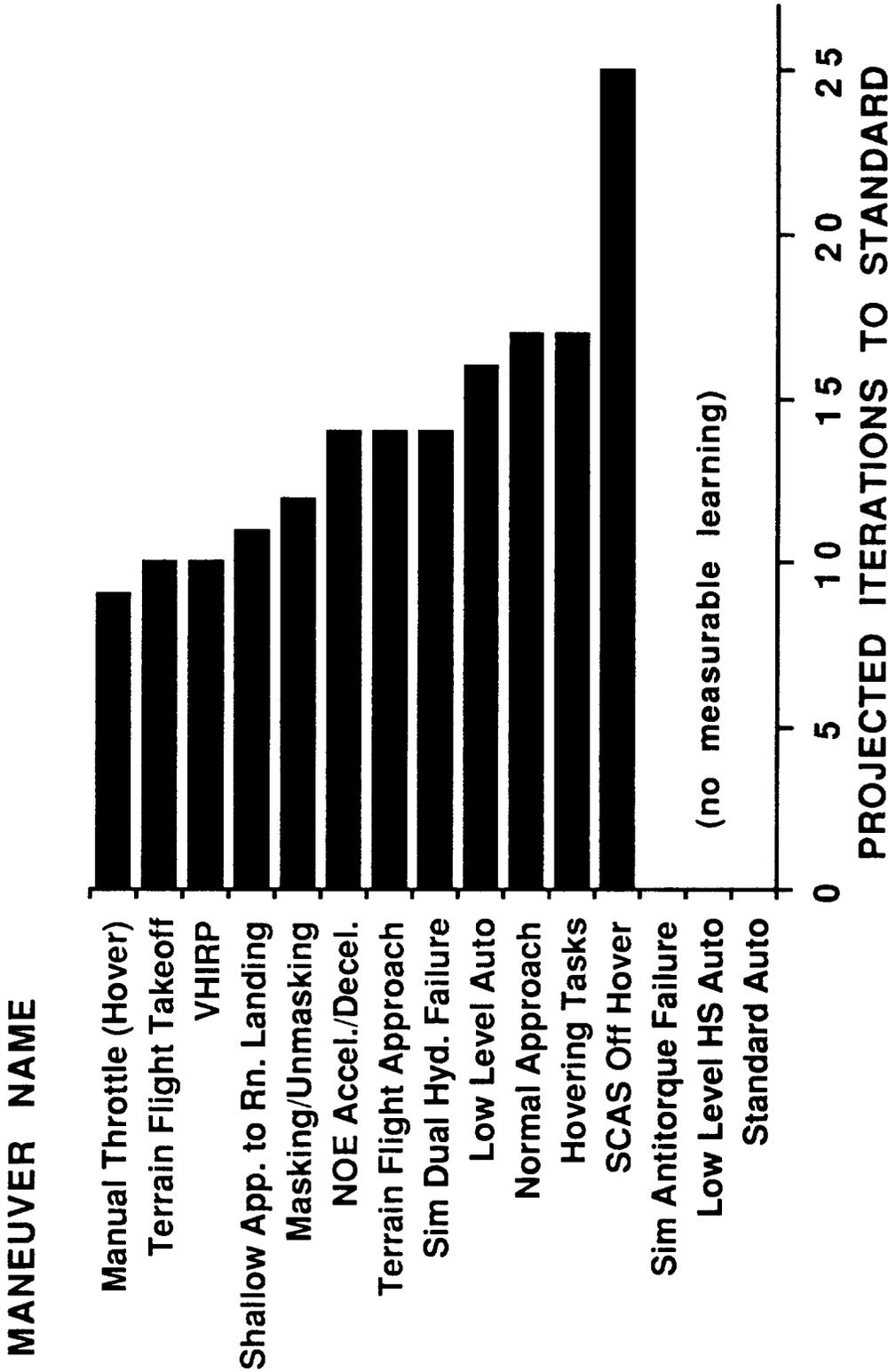


Figure 6. Example of in-simulator skill acquisition results.

Table 6. Modified transfer-of-training study  
(key differences from classic TOT study)

Simulator training
Train to proficiency on each maneuver
Record nonproductive training time
Crash re-set
Repair
Procrastination, etc.
Aircraft training
Record iterations to proficiency for each maneuver
Record nonproductive training time
Transit and refueling
Performing maneuvers already mastered
Procrastination, etc.

apparent cost of simulator training can be increased substantially by such extraneous events as crashes, simulator failures, and procrastination by instructors or students.

Next, consider the aircraft training procedure. I think it is essential to monitor and record iterations-to-proficiency on each maneuver trained in the aircraft. During aircraft training, a trainee simply cannot avoid performing certain maneuvers even though they already have been mastered. For instance, a trainee cannot accomplish a training flight without performing at least one takeoff and one landing. Hence, the total number of maneuver iterations performed during aircraft training is not determined by a trainee's training needs alone. In short, the effect of simulator training on the amount of aircraft training required cannot be determined without knowing the point at which the trainee reached proficiency on each maneuver.

As was true for simulator training, I believe it is necessary to record nonproductive training time for aircraft training. The quality of the aircraft cost data can be improved by subtracting from total aircraft hours the amount of time spent traveling between training sites, the time spent refueling, the time spent performing maneuvers already mastered, the time wasted because of procrastination, and so on.

A transfer-of-training study with the changes recommended here should provide the data needed to determine transfer-of-training by maneuver and by blocks of maneuvers. Moreover, the cost effectiveness of a simulator can be computed as a function of the specific maneuvers trained in the simulator. Finally, the cost-effectiveness

estimates will not be confounded by unproductive time spent in the simulator, or in the aircraft, or both.

That concludes my remarks about training effectiveness assessment. Before inviting questions I would like to thank the sponsors of the workshop for giving me an opportunity to test my views before such a large body of experts. And, I would like to thank those of you in the audience for your kind attention.

MR. MCGOWAN: On these backward-transfer-of-training studies, how do you account for a situation in which a maneuver, let's say AFCS-off flight in a helicopter simulator, may actually be easier in the simulator than it is in the aircraft, and how would you catch that in such a study? Does that question make sense?

DR. CROSS: Yes, Greg, your question certainly does make sense. And you have pointed out one shortcoming of backward-transfer studies. The results of a backward transfer study enable you make a one-sided decision. If you have a high degree of positive transfer you cannot conclude that everything is right with the simulator. It is possible that a task is so easy to perform in the simulator that it doesn't even come close to representing its corresponding task in the aircraft. In the example you gave, I don't know exactly why AFCS-off flight in a simulator is easier. I don't remember that our results show that to be the case.

MR. MCGOWAN: No, I am not saying that is the case. I am just saying that could be the situation.

DR. CROSS: Oh, I see. My answer is still relevant. If you have a task that is unrealistically easy to perform in the simulator, it is unlikely that the simulator would provide effective training on that task. Unfortunately, backward-transfer studies are not effective in identifying that kind of problem. Such a problem might be revealed by in-simulator skill-acquisition studies, and most certainly would be revealed by transfer-of-training studies.

MR. HART: You used the Huey simulator, which apparently only poorly duplicates the helicopter. If you did the same study, let's say with a more modern simulator, would you get similar results? It seems to me that the problem in backward transfer has to do with the lack of authenticity of the simulator itself. Is that accurate?

DR. CROSS: No, it is not. I may have said Huey; if I did, I apologize. The backward-transfer and the in-simulator skill-acquisition studies were conducted in the AH-1 flight simulator, which is far more sophisticated than the old Huey simulator.

**MR. HART:** But again, wouldn't the results vary significantly as the quality of authenticity improves? Is that not an accurate statement?

**DR. CROSS:** It is perfectly accurate. That is the fundamental premise underlying all these kinds of studies that I have discussed today.



Kenneth Cross has been engaged in human factors research for 27 years. He has been at Anacapa Sciences since 1970 and now serves as Anacapa's president. Dr. Cross has formal training in research psychology and statistics; he received his doctorate degree from Kansas State University. Before joining Anacapa Sciences, he was research coordinator at the Naval Missile Center's Human Factors Laboratory. His research has dealt mainly with human performance in complex military systems. Much of Dr. Cross's time over the last ten years has been spent conducting studies of Army helicopter training at the U.S. Army Aviation Center, with emphasis on assessing the effectiveness of training conducted in helicopter simulators.

## 11. DETERMINING THE TRANSFERABILITY OF FLIGHT SIMULATOR DATA

DAVID GREEN

The ability of rotorcraft pilots to hover and maneuver with agility in slow speed flight has placed unique and complex requirements on simulator manufacturers to demonstrate the authenticity of their product for the purpose of gaining rotorcraft training credit.

The FAA's evaluation of a simulator's capability is further complicated by the fact that the FAA does not have the resources to collect and compare the static and dynamic flying-qualities data that are required to conduct a comprehensive analysis. As a result, the FAA resorts to the practical approach of assigning qualified pilots to fly a flight simulator for the purpose of determining its value as a training device. Restated, pilots and engineers operate and otherwise evaluate flight simulators and render opinions about the adequacy of the simulator in terms of its proposed use and the credits requested. There are many other important objective measures of adequacy, but the importance of the subjective evaluation conducted by the pilot cannot be overstated.

This subjective portion of the evaluation may be enhanced by following the procedures suggested below. The details of a method for collecting and graphically correlating subjective ratings will be presented. The process has been tailored to aid engineers in their efforts to define the training value and limits of a given simulator with a substantially improved degree of confidence.

The FAA pilot's job is to define the simulator. Ideally, the pilot should be able to characterize the simulator in a format that can be understood by engineers and regulators. The evaluation pilot's insight into the real aircraft and its operational applications can be useful in helping engineers establish an appropriate scope of test to insure that the important flight phases and environmental conditions are considered.

The evaluation of rotorcraft flight simulator devices during up-and-away operations is seldom critical to the determination of overall suitability. This is because the aircraft is generally stable, and the quality of the visual

scene is often not critical to the learning experience. In contrast, the slow-speed regime is critical because most helicopter-unique training experiences occur in the slow-speed regime. In addition, the helicopter is least stable at these speeds, and the visual-motion system cues are most difficult to reproduce.

Relaxed slow-speed maneuvering high above the ground decreases the demand on the visual scene. In contrast, precision hover operations, low over a textured surface, place the greatest demand on the simulator's visual scene and motion system. In short, the evaluation pilot must investigate the authenticity of the simulator during a variety of maneuvers, including precision hover and during aggressive maneuvers, such as quick stops and inadvertent, uncommanded heading reversals (weather-cocking into a tailwind).

Although simulators are also very useful for teaching emergency procedures (such as tail-rotor failure), the validation of these events in a simulator dictates the use of quantitative data to determine reasonableness. A quantitative analysis is the only practical validation technique for such an event since there is normally little opportunity for pilots to build up an adequate (failure-mode) experience base in a real aircraft for use in an evaluation of the characteristics designed into a simulator.

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, before proceeding, it is useful to take a brief look at current procedures to establish a common point of departure.

Although 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 about the 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 agree, and such disagreements tend to bring the validity of the entire evaluation into question.

In short, the lack of a usable (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 flight simulators that involves pilot ratings.

There are many explanations for disagreements in pilot subjective ratings, and though some scatter in the data is normal, all evaluations should be conducted so as to minimize the scatter in the ratings. This presentation deals at great 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 method presented is based on the premise that if an engineer asks 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. That is, the proposed method introduces a discipline to the evaluation process.

Nevertheless, all scatter cannot 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. Alternatively, one pilot may have used a different piloting technique and effectively changed the task. There is almost always a reason for apparent scatter that is not eliminated by the discipline to be proposed.

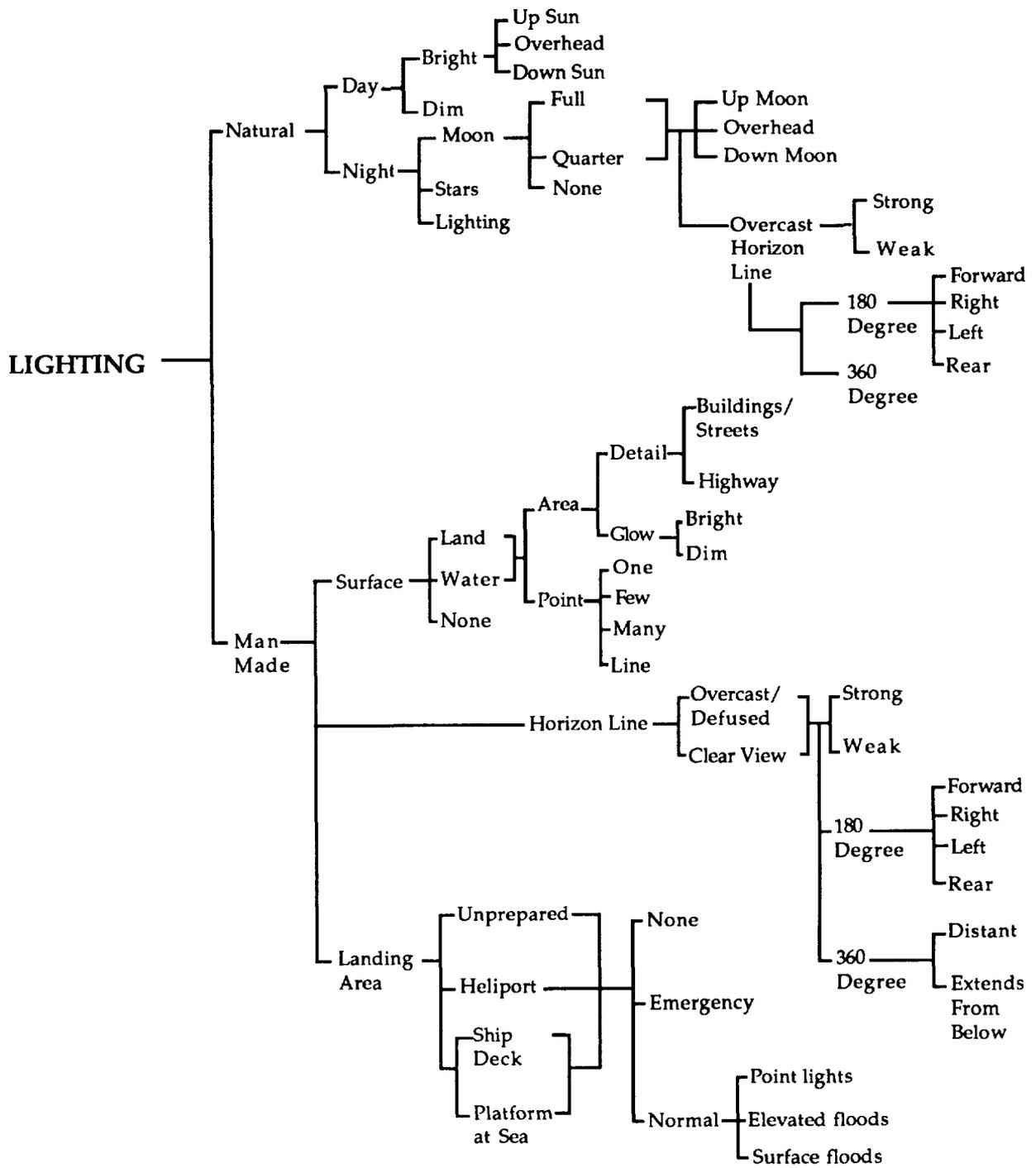
Pilots evaluate simulators by manipulating them as though they were flying a real aircraft in the conduct of a real mission task. Some operations are conducted single-pilot, some are two-pilot operations. Some flights are conducted with all systems operative, others are conducted with a variety of failures. Some tasks are very relaxed. Some relaxed flight tasks are 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.

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 simulator. Gusty winds will increase the workload. Decreasing visibility will also increase the workload. The introduction of factors that 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 a simulator's performance and related authenticity.

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 how to 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 simulation 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 learning process, aging the pilot to maturity in the least calendar time and at a minimum expense to the employer, and at the same time maintaining maximum safety by minimizing accident exposure in actual flight during abnormal and emergency operations.

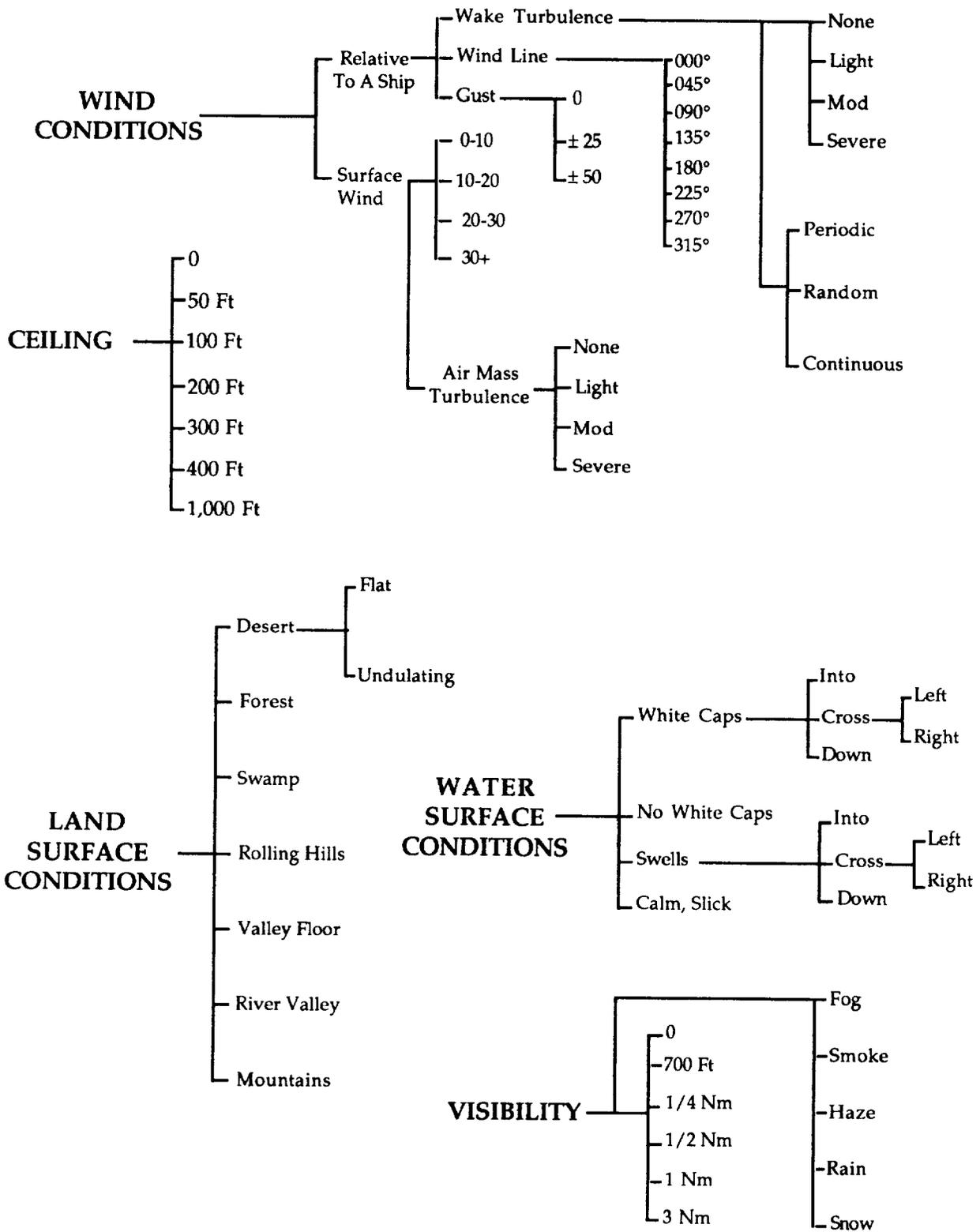
Figures 1(a) and 1(b) illustrate the variety of unique conditions which collectively define the environment within which a pilot can be expected to fly a rotorcraft. These environmental conditions can be used in a variety of visual conditions. The authentic duplication of these environments may dictate that a simulation device have a large repertoire of visual scenes. After some analysis, one might conclude that the availability of a large number of discrete visual scenes is not as important as the authenticity of the scenes available in the simulator. Repeatability of specific scenes in the simulator is also useful when analyzing the effect of variables such as pilot experience and training levels on the ability of crews to accomplish specific maneuvers. Waiting with a real aircraft for specific meteorological conditions (in the real world) to be repeated to derive similar data can be prohibitively expensive.

A moonless, starless flight over a dark sea is easy to simulate. The world is dark. Daylight scenes are more difficult. Images of trees, buildings, and runways as



(a) Lighting

Figure 1. Characteristics defining operational environment.



(b) Weather and terrain

Figure 1. Concluded.

observed through a haze may or may not be authentic; it is difficult to know. Maybe we don't even care if such scenes are authentic. The need for a sharp representation of microtexture during a low hover, on a bright day, is often very difficult to authentically simulate. This may be one of the most significant conditions to evaluate, for a failure to achieve the desired authenticity in the low-altitude, daylight environment may preclude the accomplishment of a precision hover training task.

The introduction of turbulence into this task (environment) can prevent a pilot from accomplishing a precision hover task in some real helicopters. Thus, the introduction of turbulence reduces the expectations of the pilot where he no longer expects to do well in the simulator either. Here the introduction of turbulence into a simulation event has the potential of masking some simulator problems because of decreased expectations. The point: one must be careful in the use of environmental variables. We will return to the environment later.

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 fig. 2). With ratings ranging from 1 to 10, it is the basic scale for most aircraft flying-qualities research work accomplished today. This an excellent scale, supported by 40 or more years of experience, but it lacks the detailed definition required for the evaluation of simulation devices. The range of this scale extends beyond the scope (or typical needs) of most FAA evaluations of simulation devices.

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

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

Figure 3 shows a scale that has been expanded to meet the needs of the FAA for the evaluation of civil rotorcraft operations. This rating scale is only a sugges-

tion; it has not been endorsed by the FAA and there is every reason to expect that it can and should be improved. Nevertheless, the added detail is intended to help a group of pilots produce more consistent results by minimizing the opportunity for scatter in the data caused by individual interpretation of the Cooper-Harper scale.

When you compare the scale in figure 2 with the scale in figure 3, be advised that they are the same scale. The words in figure 3 are meant to expand upon the words in figure 2. They are intended to provide pilots with a better understanding of the meaning of the very brief statements in figure 2. Also note that the expanded scale provides definitions for ratings of 1.5, 2.5, 3.5, etc., whereas figure 2 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 shorthand for pilots to communicate with engineers and other pilots. It is used to report the results of research that 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 effect 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 debriefing period following a flight evaluation. At that time, the pilot should rate the simulator experiences. This process will be developed in detail later.

Assume that a team of four pilots has been selected to evaluate a simulator. Their first step is to refresh their knowledge of the aircraft. If they are very familiar and current in that respect, this step is accomplished from memory. But for this example, assume that all of these pilots need to fly the aircraft. The first pilot, Green, conducts the hover-landing task described on the "Pilot Data Card" under the four conditions identified in figure 4 as A, B, C, and D.

Each time a pilot conducts the task, the factors that define the situation are recorded. Next, an assessment is entered for each situation. In this example, the assessments have ranged from a rating of 2 for a "clear day, calm air" to a 6 for an "overcast nighttime" situation. The

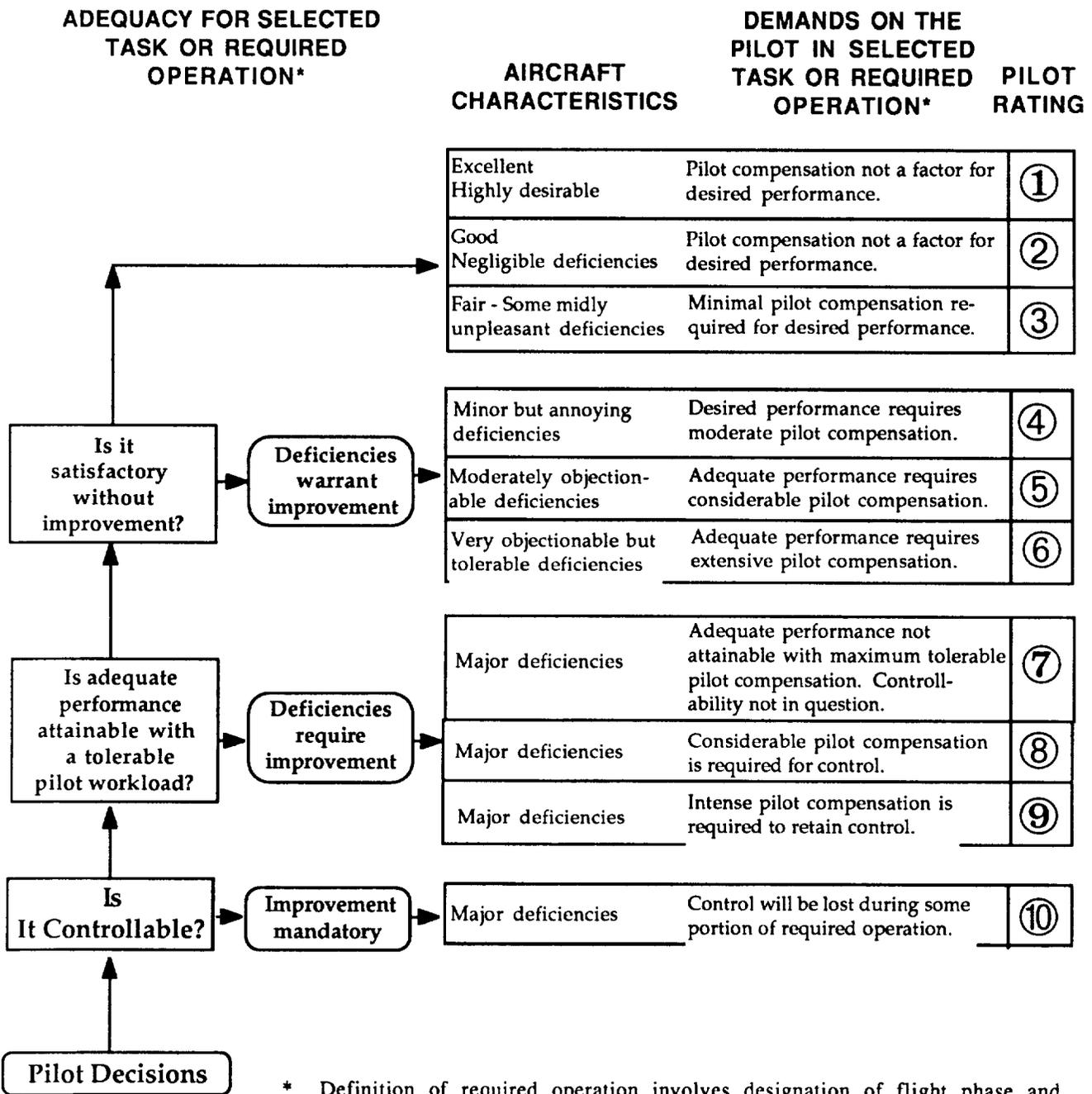


Figure 2. Cooper-Harper pilot rating scale.

1.0	<b>Excellent Highly Desirable</b>	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. Auto-matic mode shifting is provided (i.e., cruise to glideslope or glideslope to go around).
		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.
1.5	<b>Good</b>	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 continuous but relaxed. Pilot may be required to occasionally adjust one axis/parameter during the performance of precision maneuvers or during major flight path changes.
2.0		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.
2.5	<b>Fair, Some Mildly Unpleasant Characteristics</b>	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.
3.0		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.
3.5	<b>Minor, But Annoying Characteristics</b>	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.
4.0		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.
4.5		

Figure 3. Expanded evaluation scale for evaluation of civil rotorcraft.

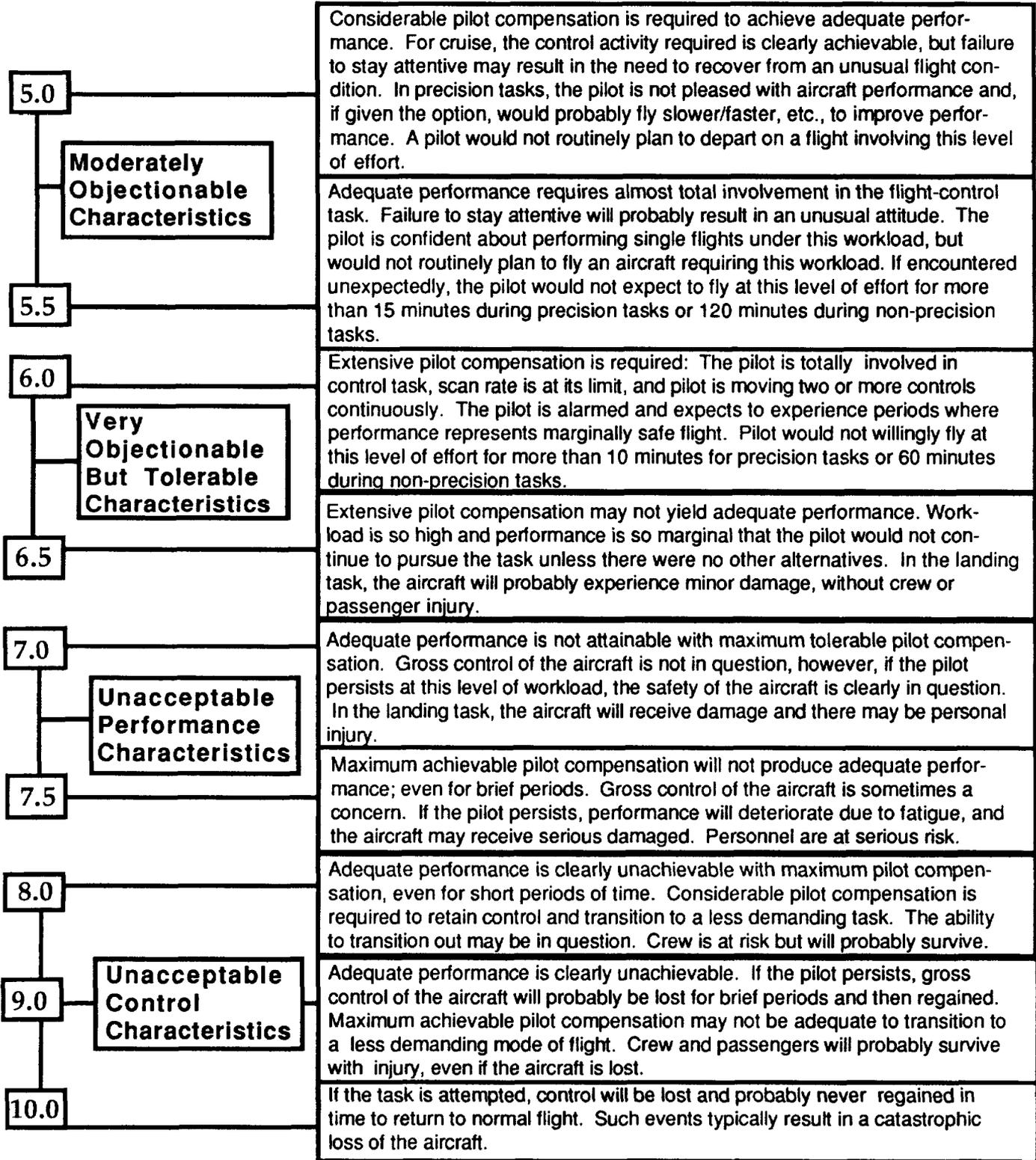


Figure 3. Concluded.

TASK SHORT TITLE		PILOT DATA CARD		SIM FLT <input type="checkbox"/>
PLATFORM HOVER-LANDING		Pilot Name: <u>GREEN</u>		A/C FLT <input checked="" type="checkbox"/>
<b>TASK:</b> <i>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.</i>				
SITUATION ID CODE	FACTORS DEFINING THE TASK ENVIRONMENT SITUATION			PILOT ASSESSMENT (RATING)
<b>A</b>	Clear Day, Calm Air.			2
<b>B</b>	Clear Day, 10 KT RT Cross Wind.			2.5
<b>C</b>	Clear Day, 10 KT RT Cross Wind, Gusting to 17 KT.			5
<b>D</b>	Night, Overcast, no surface lights, single landing LT, 10 KT RT Cross Wind, Gusting to 17 KT, (see Note 1)			6
<b>OPERATING STATE:</b> Normal				
<b>CONFIGURATION:</b> Mid wt, mid C.G., Doors closed				
<b>Note 1:</b> Tower obstruction lights, landing pad edge lights.				

Figure 4. Pilot rating data card for assessing one aircraft for the accomplishment of one task under four environmental conditions.

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.

To continue this example, assume that three more pilots fly the same task under the same conditions and that they individually complete a data card. Their findings are summarized in figure 5. It is obvious that these four pilots did not totally agree, but when we analyze the results, we find the data are 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 pilot 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 6 are then the sum results of four pilots evaluating their personal "pilot-machine" performance under four task-environment situations. It must be understood that the rating process is personal. It refers to the performance that the evaluation pilot has achieved in flight. This performance evaluation is then something of a

self-appraisal and is the product of the pilot's skill level at the time, as well as the personal experience accrued by the pilot prior to the flight event that produced the recorded pilot rating.

This is the way the process should work. 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 method to work, pilots must rate their personal performance.

The results summarized in figure 5 have been plotted in figure 6. This plot illustrates the preferred data presentation format for most comparative analyses. The format has been designed to be easily understood, and a shaded band has been added to figure 5 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 familiarity with the task or environment can produce scatter. This apparent uncertainty is both understandable and acceptable.

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

Figure 5. Summary of pilot assessment data.

Figure 7 illustrates the next step in the method. For this illustration, pilot 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 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 that 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 of the order of  $\pm 2$  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. The data developed by pilots who do not understand the

pilot rating process are normally in conflict with the group and can be easily identified as such, and discounted.

Figure 8 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 that allows the rating to ascend from left to right. This results in a situation where the sets of environmental factors are becoming more adverse left to right. This arrangement enhances data analysis and helps the evaluator insure that a complete spectrum of task complexity has been considered.

A simulator can be evaluated by one pilot or by a team of pilots. To simplify this next discussion, one pilot, Green, will be considered. Remember that the data in figure 8 represent the best characterization of the real aircraft that Green was able to establish. Assume for the moment that the data provided by the remaining pilots would have nominally agreed with Green's data. This confirms that Green's ratings of the seven different operating environments is sufficiently accurate to use in the evaluation of a simulator. In addition, an inspection of the seven operational environments used in flight confirms that they probably provide an adequate spectrum of situations to use as simulation environments for evaluating a simulator. That is, a simulator operator can be asked to electronically program the simulator to present the evaluation pilot with a set of winds, turbulence, and visual scene factors that collectively represent each of the environmental conditions relating to each of the situations defined in figure 8.

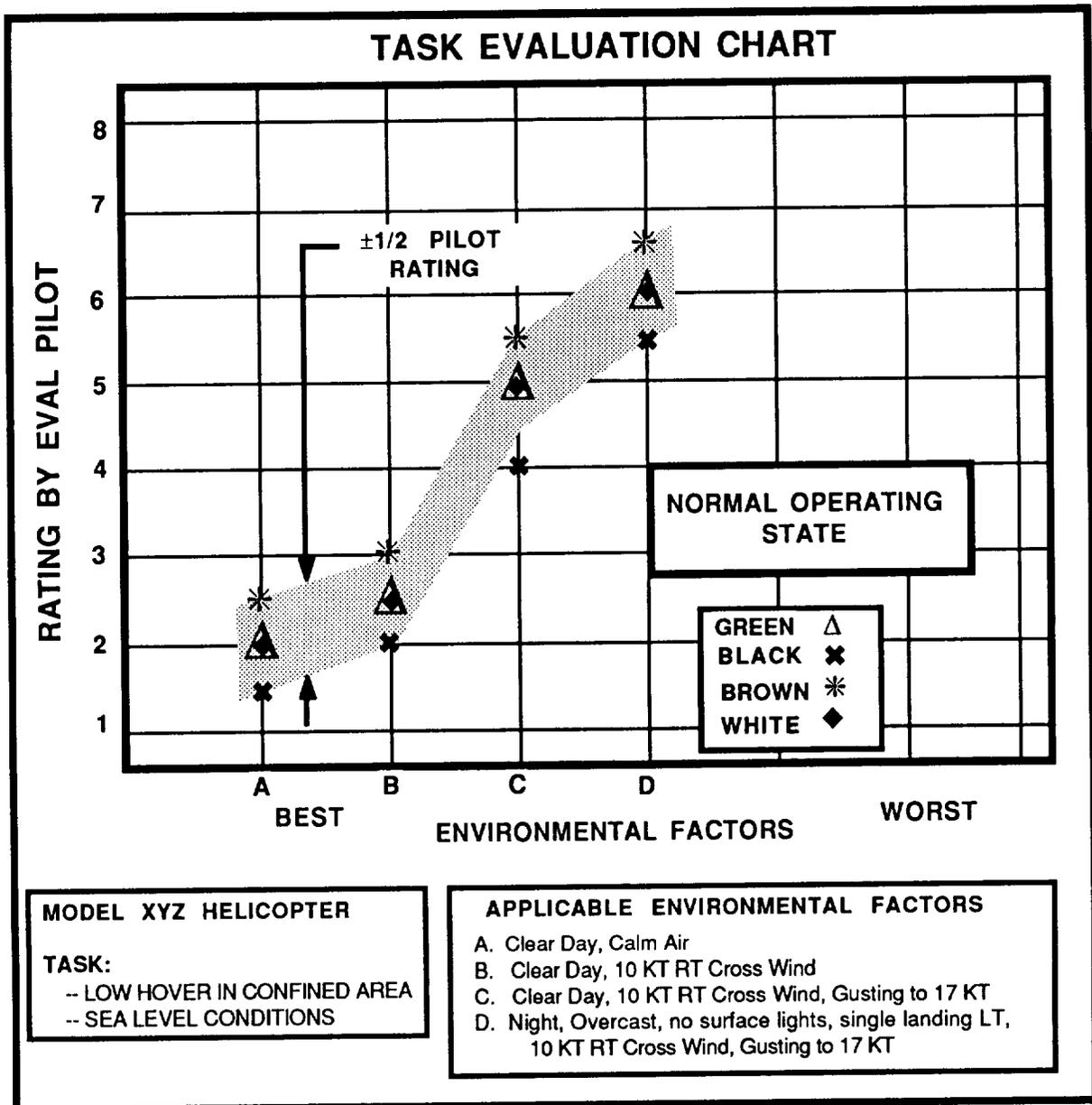


Figure 6. Charting pilot assessment data.

<b>TASK SHORT TITLE</b> PLATFORM HOVER-LANDING		<b>PILOT DATA CARD</b>		SIM FLT <input type="checkbox"/>	
		Pilot Name: <u>GREEN</u>		A/C FLT <input checked="" type="checkbox"/>	
<b>TASK:</b> <i>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.</i>					
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 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	6			
E	Night, Full Moon, Stars, Hover Lights, 10 KT RT Cross Wind, Gusting to 17 KT.		3.5		
F	Night, 1/4 Moon, Single Landing LT, 10 KT RT Cross Wind, Gusting to 17 KT.		5.5		
G	Night, Thunderstorm, 20 KT Wind, Gust to 30 KT.			7.5	
<b>OPERATING STATE:</b> Normal		CURRENT OBSERVED	PAST OBSERVED	PROJECTED	
<b>CONFIGURATION:</b> Mid wt, mid C.G., Doors closed					
<b>Note 1:</b> Tower obstruction lights, landing pad edge lights.					

Figure 7. Pilot rating card for flight evaluation of an aircraft.

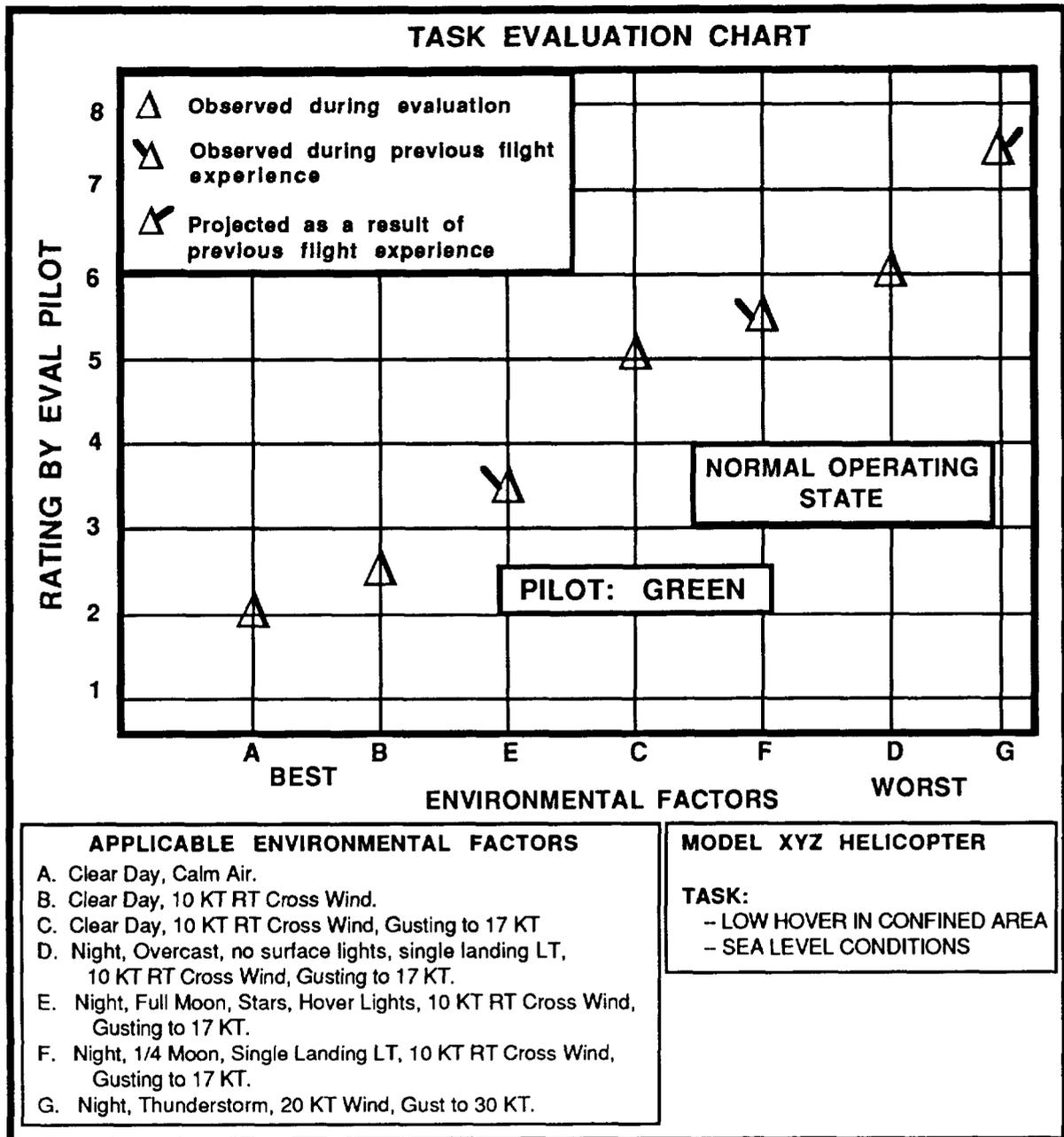


Figure 8. Building a more complete characterization.

Assume that these situations are simulated one by one and that the pilot establishes an assessment (rating) for each and enters this rating on a pilot data card as illustrated in figure 9. Now pilot Green has generated two sets of ratings trying to accomplish the very same task. One set responds to his experience in the real aircraft and one responds to his evaluation of the representation of the aircraft and visual scene provided by the flight simulator. The pilot has in fact rated his ability to achieve a given

task with a specific degree of precision (performance) at a given level of effort. It should therefore be possible to plot both sets of data on one chart to determine the degree to which the data agree or disagree.

This has been done and the results are presented here as figure 10. Figure 10 shows that the three pilot ratings established during "daylight" operations in the simulator are roughly two pilot ratings higher than the trend band which bounds the data defined for flight in the real aircraft

<b>TASK SHORT TITLE</b> PLATFORM HOVER-LANDING		<b>PILOT DATA CARD</b> Pilot Name: <u>GREEN</u>		SIM FLT <input checked="" type="checkbox"/>		A/C FLT <input type="checkbox"/>	
<b>TASK:</b> <i>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.</i>							
SITUATION ID CODE	FACTORS DEFINING THE TASK ENVIRONMENT SITUATION			PILOT ASSESSMENT (RATING)			
A	Clear Day, Calm Air.			4			
B	Clear Day, 10 KT RT Cross Wind.			4.5			
C	Clear Day, 10 KT RT Cross Wind, Gusting to 17 KT.			6.5			
D	Night, Overcast, no surface lights, single landing LT, 10 KT RT Cross Wind, Gusting to 17 KT			6.5			
E	Night, Full Moon, Stars, Hover Lights, 10 KT RT Cross Wind, Gusting to 17 KT.			4			
F	Night, 1/4 Moon, Single Landing LT, 10 KT RT Cross Wind, Gusting to 17 KT.			6			
G	Night, Thunderstorm, 20 KT Wind, Gust to 30 KT.			7			
<b>OPERATING STATE:</b> Normal				CURRENT OBSERVED	PAST OBSERVED	PROJECTED	
<b>CONFIGURATION:</b> Mid wt, mid C.G., Doors closed							

Figure 9. Pilot rating card for simulator evaluation.

during similar conditions. In contrast, pilot ratings assigned for simulated night operations are in reasonable agreement with the pilot's earlier characterization of the real aircraft.

On first analysis, these data suggest that the pilot found the simulated daylight-visual task to be substantially more difficult than he found the task of operating the real aircraft in the real world. Continuing with this line of thought, the increased difficulty is probably a result of some lack of authenticity in the visual scene. The agreement between aircraft and simulator experience at night suggests the pilots did not detect any shortcoming in the simulator when the simulated scene contained only a modest amount of microtexture. That is, the authenticity of the visual scene became less important during situations in which poor definition was involved.

The evaluation-charting process can be used to evaluate the authenticity of flying qualities as well. The data in

figure 11 provide such an example. The data plot indicates the real aircraft was much more difficult to fly than the simulator. This disagreement in ratings may have been caused by simulator control characteristics (being too good) or by the simulator model being less sensitive to turbulence than it should have been. It is also possible that the wind/turbulence model is in error. Regardless, the data trends are consistent and have meaning.

This process can be repeated for (1) failure modes, (2) tasks that require gross-aggressive maneuvering, and (3) instrument flight where all reference is to cockpit displays. The results should allow the evaluation team to accurately determine the utility of the simulator. Most important, the process will help everyone gain a better understanding of the subject aircraft and of the procedures and techniques pilots employ during its operation. If everyone agrees about the way the aircraft should be flown, and if they all evaluate the simulator using these

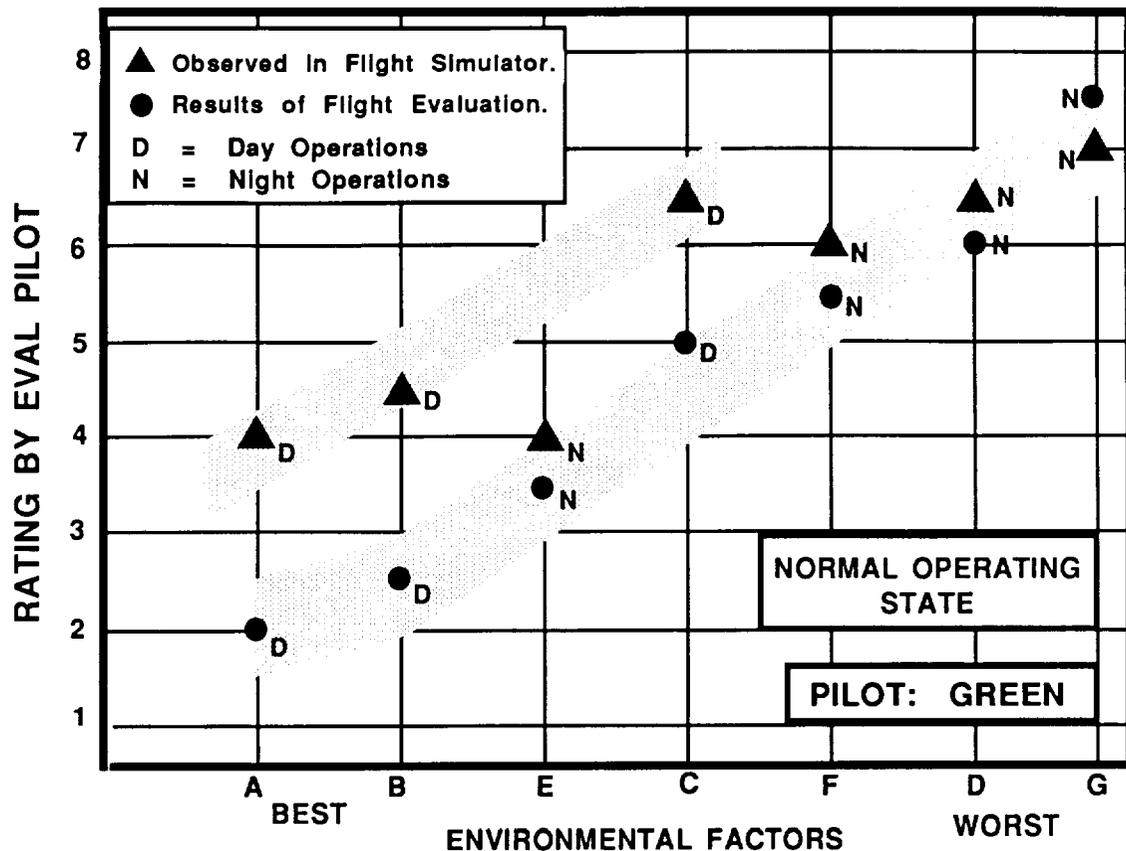


Figure 10. Comparing simulation assessments and real aircraft experience.

common methods, the evaluation will most likely produce results to which most pilot-evaluators will be able to ascribe. Agreement in these areas will help preclude misunderstandings regarding simulator value and applicability.

Finally, charts should be established for a family of flight phases. Failure modes should be examined for each flight phase considered to be critical to the crew training capability of the simulator.

A final set of graphics, figures 12(a) and 12(b) has 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 12(a) that the ratings dropped from 4.5 for C to 4 for D for the single-rotor helicopter, and that there was no change in the pilot's 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 crosswind was important to the single-rotor helicopter, but insignificant to the tandem-rotor helicopter. In fact, the loss of the crosswind was more impor-

tant 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 12(b) and the result is a more orderly plot, one which is easier to compare and analyze by the general public.

The scope of this presentation did not allow a complete treatment of the data collection-presentation methods that have been developed by Starmark. I encourage you to tailor and expand the concepts presented here to fit your individual needs.

There are many ways to achieve further reductions in scatter and ways to determine the importance of a given failure mode to the training experience. Many of these additional attributes became obvious to the evaluation engineer as experience is gained during application of the process discussed here.

Everyone who elects to use this material as a guide is encouraged to concentrate on the task of defining the combinations of environmental factors that (1) pilots have personally experienced and that can best define the

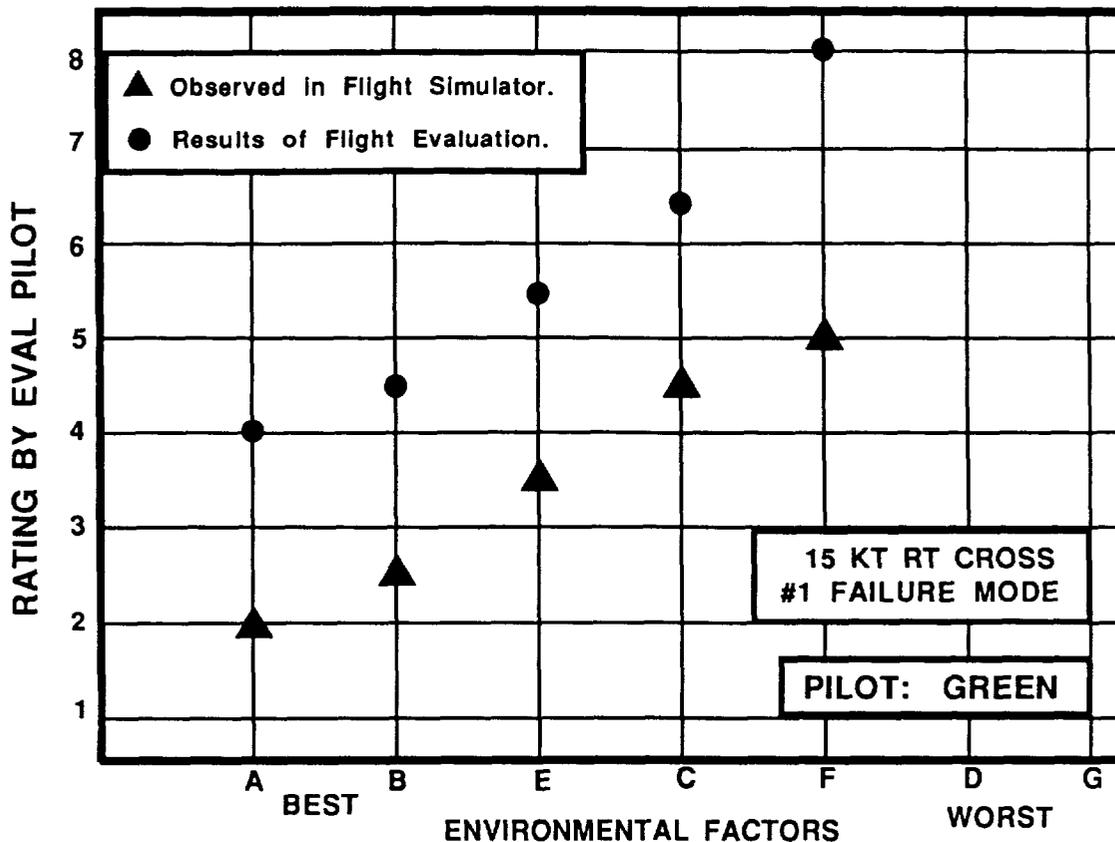


Figure 11. Data indicating that simulator is too easy to fly.

normal operating envelope, and (2) allows pilots to feel they can also best define the extremes of the operational envelope. If the simulation device can provide an adequate, authentic training experience under both situations, the usefulness of the simulator will have been validated in terms of handling qualities and visual scene representations.

MR. WARTH: It is good to see there is a life after flying. How close do the ratings have to be to be considered a good match in the Cooper-Harper figures?

MR. GREEN: I am saying when you write down a definition or expand the definition to meet your needs, just try to keep it in the perspective of Cooper-Harper. There are references that you can use. Did I answer your question?

MR. WARTH: How close do the numbers have to be?

MR. GREEN: You mean scattering of the data?

MR. WARTH: I mean between the simulator and the aircraft.

MR. GREEN: Well, see, that is a whole other discussion. I think just as a very quick answer, that if you could get within a pilot rating and a half, you would think you had died and gone to heaven, and you would want it to be a little more difficult in the real aircraft, I would guess. But what I would do is slip the whole scale to the right. In other words, my visual is wrong. I would say my visual is wrong or something else is wrong, just as long as we don't give the pilot a misimpression of the handling qualities of the aircraft, or misinform him somehow.

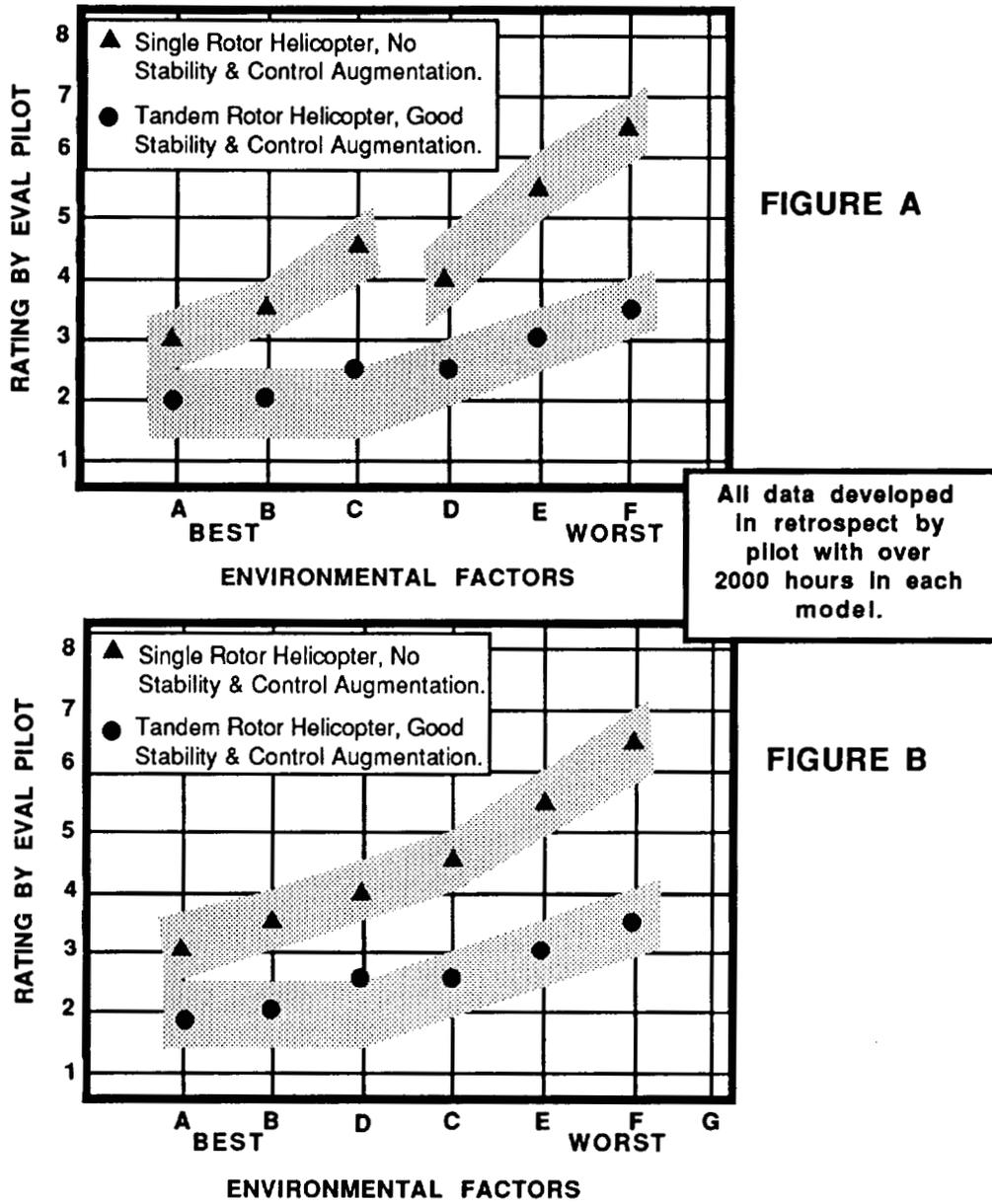


Figure 12. Pilot rating data for single- and tandem-rotor helicopter conducting precision hover. (a) Original sequence of environmental factors, (b) reorder sequence of environmental factors.



David L. Green is president of Starmark Corporation. He is widely recognized as an aviation safety expert and author. Mr. Green is a graduate of the U.S. Naval Academy and of the Navy Test Pilot School, and is the author of the first helicopter stability and control flight test manual. He managed rotorcraft flight tests for Fairchild-Hiller and was vice president of Pacer Systems, Inc., prior to his employment at Starmark. Mr. Green has been involved in FAA rotorcraft evaluation projects since 1968, and has flown 73 models of helicopters, V/STOL, and propeller and turbojet aircraft. He is now an adjunct associate professor of aviation systems at the University of Tennessee.

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## 12. PROGRESS THROUGH PRECEDENT: GOING WHERE NO HELICOPTER SIMULATOR HAS GONE BEFORE

RICHARD J. ADAMS

Since it is late in the day I would like to tell you a brief story about helicopter safety which was mentioned this morning by Dick Birnbach and a few others, how we have gotten to where we are.

I would like to discuss the last 5 years of training and how we have improved and how we have reduced accidents by doing cognitive training. And finally, I would like to suggest appropriate thoughts for our discussions tomorrow.

The following is a quote from Dwight Eisenhower. Like all political quotes, it can be taken in many ways. "Things are more like they are now than they ever have been before." It made me think that we haven't come very far since the workshop in 1985. But you can also look at it as an opportunity to accomplish some things in this workshop. I hope by the end of the presentation you will understand in what way I have contributed to it.

Let's talk about safety and the general definition of safety. There are a lot of parameters that helicopter people

use (accident/100,000 departures, risk of serious injury, etc.). There are a lot of parameters that fixed-wing people use (accidents/100,000 hours, accidents/100,000 passenger miles, etc.). I am limited by time to reviewing only one set of data, and I have accepted the following definition; I hope you will, too. "Safety is the identification and control of risk according to some preconceived parameters."

Historically, the FAA and NTSB supply data for accidents per 100,000 hours. The data set shown in figure 1 came from Jim McDaniel's office when we looked at safety parameters. Accidents per 100,000 departures, accidents within a mile of a heliport, and years between accidents in terms of a facility. As you can see, there is a quarter century of data shown in figure 1. It tells a very interesting story. At least in the United States you notice in 1965 we were running 55 or 60 accidents per 100,000 hours (total fatal and nonfatal).

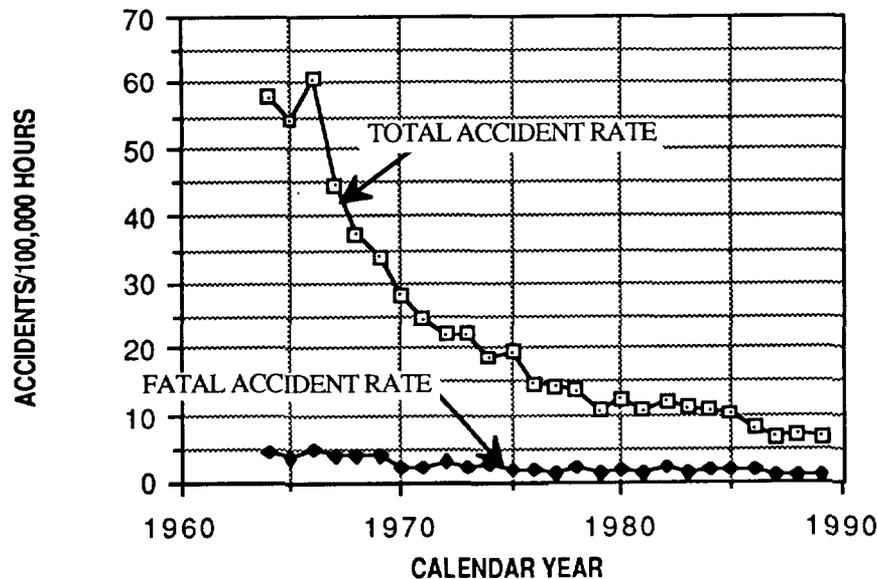


Figure 1. Safety needs.

And then over a period of about 10 years, 1965 to 1975, we dropped by almost two-thirds down to 20. Those of you in this country who have been in the industry that long realize that that was the time the turbine engine was introduced. About 1965 we were almost 100% pistons. Then the turbine was introduced, with its higher mechanical reliability, easier maintenance, and various safety improvements. I don't want to imply that the turbine was the only change, but it was one of the major changes that occurred during the 1965-1975 period.

During the middle of the time period covered in figure 1 (about 1975), we had a bunch of very experienced military pilots returning from Vietnam. Those pilots were military and human and they had good and bad habits; however, they did have a high degree of experience in risk management, which has been mentioned by several people today. They were able to work under high-workload, stressful conditions. Later, I will point out some areas where simulators may be used to provide more realistic risk-management training.

Then, about 1975 to 1980, in this country we began to realize that all of these accidents, at least a large percentage of them—65% in the entire helicopter community, if you looked at the more high-risk EMS it is nearer 80%—were all human-error related. The same thing was occurring in fixed wing; about 80% of fixed-wing accidents were also attributed to pilot error. The bottom line was to start stressing the human elements in studies. As a result, NASA developed a substantial effort in the area of cockpit resources management. And we were successful in bringing the accident rate down somewhat, although it

is leveling off as you can see. I think that is the challenge we face here. Getting back to the study that generated the curve shown in figure 1, we set a goal of trying to get the rate down to 4.5 accidents per 100,000 hours by 1995.

I would like to talk about a successful human-error reduction program and about conventional training and some ways we may begin to depart. Figure 2 depicts the basic novice pilot, or *ab initio*, coming in with a lot of knowledge. He knows systems, he knows aerodynamics, he knows the ATC system, he knows weather, he knows procedures on top of that, stall practice, autorotation, things like that. He builds skills in flying the aircraft. Until recently, 1985-1986, it was always thought he could only learn good judgement or decision-making through experience. We all know that led to a lot of bending of metal and unfortunate injuries and accidents.

So the FAA set out, between 1975 and 1985, on a program to see if we could train and actually teach better decision-making in the classroom. It has turned out to be very successful, as Pete Hwoschinsky mentioned this morning. We generated 15 different manuals, everything from students' private manuals up to manuals for administrators and Part 135 operators. These have been used throughout the industry and the military.

As an example, Petroleum Helicopter, Inc. (PHI) looked at their accident data from 1982 through 1986. Correct me if I am wrong, Jerry [Golden], but you fly about 2 million takeoffs and landings annually. Before 1986 PHI could not get the accident rate below two per 100,000 hours. And in 1987 they dropped it to 1.86 per

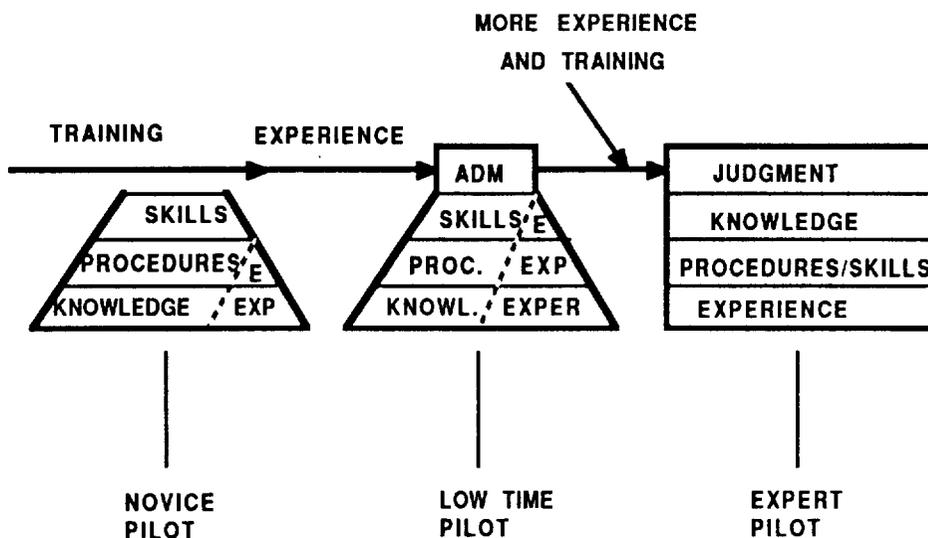


Figure 2. Training needs.

100,000 hours. The following years, after all the pilots were trained, they dropped it to 1.046.

The Navy did a similar thing and reduced the human-error factors in helicopter accidents by 51%. Bell has introduced advanced decision-making into their worldwide 206 safety seminars. They believe that even though they haven't reached all their operators, they have achieved a reduction of 31% in human-error accidents.

The bottom line is we can train decision-making, but there is a problem. The problem is that when we look closely at the procedures and the attitudinal training we developed, they work much better with the *ab initio* and less experienced (5-year-and-under) pilot.

The research I am working on now is aimed at how we get at the more experienced pilot, how does he think differently? At the same time, we were getting all the good results in the helicopter community. The air carriers were having some spectacular saves or, as Dick Birnbach said, some diabolical failures: failures of aircraft materials, the Sioux City accident, a lost engine, a lost hydraulic system. The two decompressions, Flight 811 United Honolulu, and the Flight 232 Maui accident Aloha—both aircraft incurred very large holes in the fuselages.

In the case of 232, I will just dwell on two of the successes for a minute. The captain had access to a training airman in the back who know how to control pitch and yaw with the throttles. The captain immediately accepted his volunteer and used him to control lateral movement and aircraft pitch attitude. While they were doing that and checking to make sure that passengers were prepared for an emergency, they were still fighting a tendency for a 38° right bank and severe pitch oscillations, or phugoids. Nevertheless, as you know, they successfully brought the aircraft down, at least in a partial save.

Both of these decompression accidents (UAL Honolulu and Aloha, Maui) are very interesting because the pilots and crew acted contrary to handbook training procedure, which would have had them dive to regain cabin pressure. The captain decided that would be a bad move, because it might enlarge the hole in the fuselage. As a result, he decided to slow the aircraft. However, he didn't know the speed at which the aircraft would stall, given the big hole in the fuselage and the extra drag it created.

The second important thing about all of the saves—all the time they were handling the emergencies while creating new procedures, if you will, in response to the cues they had. They were able to keep up the housekeeping chores, they communicated with ATC, they did engine

shutdown checklists, all the things they were trained to do. That is a lesson we will get back to in a minute.

During the past 30 months I have been looking at the accidents, looking at the difference between experts and *ab initios*, and it turns out there are 24 different characteristics that distinguish experts from novices. I have summarized the top five in table 1. Believe it or not, in an emergency pilots go back to what their instructors told them—they fly the airplane. That is evidenced in all the accidents studied. they have instantaneous recall of training; in some cases it takes on the characteristics of instinct. They maintain their composure, they come up with a reasonable plan, and they execute it with all their available resources. It is not surprising that this is exactly what we have been trying to train for with the cockpit resources management program. Finally, as we know, pilots are goal-oriented, self-assured individuals.

Table 1. Training needs: expert characteristics

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| 1. Reversion to basic airmanship skills  |
| 2. Instantaneous recall of training      |
| 3. Reasoned approach in emergencies      |
| 4. Positive in approach and expectations |
| 5. Self-assured and optimistic           |

I would like to look now at a few of what we call fatal fallacies (table 2). They are attributed to Dr. Walt Schneider at the University of Pittsburgh. He looked at both air-traffic control and aviation accidents and came up with these six fallacies. I don't know why he termed them fatal, but undoubtedly he has his reasons.

Basically, practice makes perfect is a fallacy because it is a bump and grind approach. It does work, but it does not have a lasting effect on most people. In some cases the procedure is never learned properly. Training a task in

Table 2. Training needs: fatal fallacies<sup>a</sup>

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| 1. Practice makes perfect                          |
| 2. Train in the form to be used                    |
| 3. Skill training is intrinsically motivating      |
| 4. Must include high accuracy standards            |
| 5. Initial performance predicts eventual outcome   |
| 6. Intellectual understanding produces proficiency |

<sup>a</sup>Dr. Walter Schneider, University of Pittsburgh Learning and Development Center.

exactly the form in which it is to be used is time-inefficient. We talked about autorotation earlier, sling loads, things like that. In the fixed-wing, we having holding patterns. All those things can be learned much better and retained better with quick reenforcement practicing, 10 or 20 an hour as opposed to 1 or 2 an hour. They are things that can best be done in a simulator.

Number 3—skill training is intrinsically motivating—is interesting because flying is fun in itself and people are motivated to learn how. But even though that might be true initially, after you have been at it for 5 years it seems that the basic thrill is usually gone and you are going through the hoops, going through the FAA-required checklist of maneuvers. But again, what they found at Pittsburgh was that if they had bells and interesting sounds and visual cues for training reenforcement, they had a 30% to 50% reduction in failure rate.

The fourth one—high accuracy standards—is particularly pertinent. That is, we all think about high accuracy standards—good steady needles, good heading and altitude control; these are very important, especially in the real world. But they are not necessarily the best way to train in a simulator. What happens when you become a very accurate, precise pilot? You may not be very good at other things, like high-workload tasks, emergencies, multiple-tasking, sharing your attention. These are best

taught in a loft scenario, in a simulator, in composite high stressful situations, as Dave Green said in his presentation earlier today.

The last two of the fallacies are self-explanatory.

Early this morning I heard some words from the FAA that got me very excited. The regulations are being changed to allow the inclusion of more simulators. What is appropriate training? What can we do? What should we do in simulator versus aircraft? I submit that the current standards for simulator uses (table 3), though limited, should be retained and should not be thrown out with the bath water, as someone said. Greg McGowan pointed out that he trained nearly 10,000 pilots with these; the evidence I pointed out earlier documents that it works, as well. My perception was that at least part of the reasons for the four required aircraft maneuvers was that the FAA needs to maintain control. I again need to suggest that we have to discover whether the hover and the current four maneuvers are the correct ones to retain.

Ed Boothe suggested an exemption if somebody wants to come up with that. I think in this group, with the expertise we have, we can come up with a better set of criteria.

As far as interim uses are concerned (table 3), I have been thoroughly brainwashed by Curt Treichel and others in this room to think that if a pilot has the experience,

Table 3. Appropriate training

1. Current simulator uses	
Biannual flight review	61.56
D/N currency, instrument competency	61.57c,d,e(2)
12/24 month PIC check	61.58b,c
ATP rotorcraft type check (90%)	61.163a
Initial/recurrency testing	135.293
PIC instrument proficiency	135.297
2. Quality control	
Hover requirement versus hover proficiency	
Emergency procedures (discussion vs experience)	
3. Desired near-term uses	
FAR approval versus exemption	
ATP rotorcraft add-on type rating	61.163a
Commercial add-on instrument	61.65g
ATP airplane add-on rotorcraft category	61.165
Instrument instructor	61.191
4. Alleviate training fallacies	
5. Support overall training and licensing system	

commercial rating, ATP fixed wing, there is no reason he can't get the helicopter ATP add-on in the simulator.

And at the top of that list, I think we all would like to see FAR approval of simulators as opposed to the timely, costly exemption process. I think again, that together we can come up with scenarios and lists of tasks that can alleviate training fallacies. I am not talking about turning things upside down that we have today, but about just looking at the real world.

Finally we need to come up with an integrated approach. I haven't heard anybody come up with a systems approach from the top down to designing a training program. Far-term or blue sky, more controversial might be total licensing and testing in the simulator (table 4). We would like recognition of helicopter simulators equal to that granted the fixed-wing simulators. There is no reason that if a 727 pilot can get his type rating in a simulator that we can't get type ratings in an S-76 simulator some day. I don't know how many of you have looked at the ATP program, which allows trading off simulator time. We ought to set our sights on the rotorcraft community the next time we are talking about that for helicopter simulators.

Table 4. New frontiers: far-term suggestions

1. Initial licensing and testing
2. Equal recognition with airplane standards
3. Advanced qualification program
4. Crew testing and licensing

Finally, there is crew testing. I went over fixed-wing accidents and how the interpersonal skills of the crews were involved. You can't test that in an S-76 or in any helicopter today. There is no place for the examiner to sit back and evaluate the crew. It can only be done in a simulator. Right now Curt Treichel tells me that crew evaluations are limited because the test pilot sits in the left seat.

They think pilot in command (PIC), so we need to work on that a little bit. Getting back to our expertise and my current efforts. I think there is also an opportunity to introduce some new concepts there. When we talk about the next generation of decision-making training, the question is when to do it.

The *ab initio* pilot knows all the facts; he has the facts he needs to know to fly the airplane and to survive (fig. 3). The low-time pilot knows how to survive, he has instantaneous recall of what to do if the engine quits. But

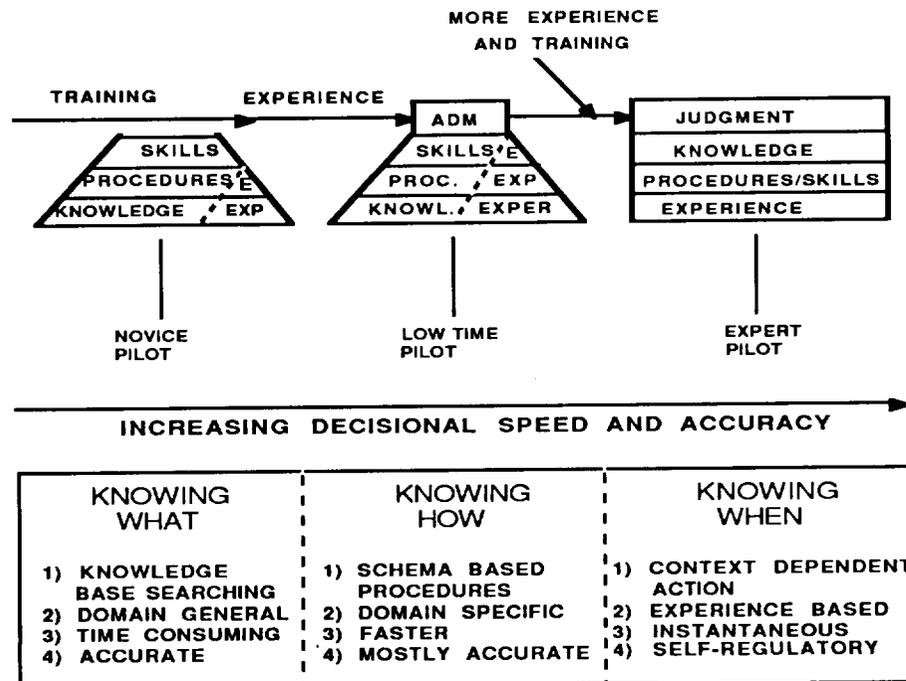


Figure 3. New frontiers.

he does not know when to alter those actions; he does not have the ability to react to novel things. Like the pilot in the cabin of Aloha 737, who looked back and saw blue sky. I don't think we can take a true *ab initio* pilot and bring him to that level; it is all in the procedural knowledge base and how we use the procedures we have learned in combination with the knowledge we have and facts that we have learned.

And finally, the expert pilot does all this in a self-regulatory mode. Self-regulatory means the next step in situational awareness. As I said, the expert can undergo an untrained-for emergency like those discussed and still maintain his housekeeping chores, carrying out his normal ATC communications and things like that. So they are not impossible tasks; it is just going to require some new training scenarios.

Finally, the most exciting new frontier I can think of is our being here at this workshop and that we have been invited to help the FAA generate new standards:

1. Joint industry-government simulator qualification standards development

2. Appropriate and sufficient training and testing criteria

3. Mission- and task-driven qualification standards

I think it is a great opportunity and I think from talking to the FAA people here, that it is going to be more pervasive than just in the simulator area. I welcome the chance to work with them. I think we should all think about the words "appropriate and sufficient training." I think we have a lot of components, we all know some of the weakness. I think I have an idea of some of the new ones based on research I have done. We need to think about missions and tasks to use for training concepts.

Thank you for your time and I look forward to working with you in the next couple of days.



Richard J. Adams, vice president of Advanced Aviation Concepts, has worked in civil aviation research and development for 26 years. He is the author of 69 technical reports, articles, and papers dealing with flight safety, decision-making training, pilot-error accident data analysis, air-space/route design, helicopter performance modeling, and helicopter pilot training deficiencies. Mr. Adams received a B.S. in aeronautical and astronautical engineering from the University of Illinois, and an M.S. in mechanical engineering from the University of Florida. Mr. Adams is a registered professional engineer in Florida and a private pilot.

### 13. TRANSFER OF TRAINING AND SIMULATOR QUALIFICATION OR MYTH AND FOLKLORE IN HELICOPTER SIMULATION

JACK DOHME

I noticed something yesterday—perhaps others in the audience did too. Have you seen any young kids come up here and address this body? It would be, perhaps, impolite to note that gathered here are the grand old men of the field, that is, considerable experience is represented. So...I got to wondering why Bill Larsen asked me to speak. I'm not a test pilot; I'm not a graduate engineer; I don't have 10,000 hours experience beating the air into submission. However, it occurred to me that I wear trifocals so I'm certainly not a kid. I carry an AARP (American Association of Retired Persons—minimum age 50) card in my pocket so I guess I'm old enough. And we do have a perspective at "Mother Rucker" (The Army Aviation Center at Fort Rucker, Alabama) that may be worth sharing. So, I changed the title of my presentation this morning to "Myth and Folklore in Helicopter Simulation." This presentation has a second author, my boss, Chuck Gainer, and I should note that he contributed ideas but did not suggest the mode of this presentation. In

summary, I suspect the real reason that Bill Larsen asked me to address this august body is for comic relief.

Table 1 is intended to present some political stuff, to stir up trouble and to get people to think about the issues in that X-rated document we've been asked to read, the "AC 120-XX." I thought I would begin by listing three of what I'm calling "myths" in the field of helicopter simulation. In discussing these myths, the "straw man" that I'm attacking wears green and I think that's fairly safe in this audience.

Let's look at myth 1: "A Simulator Should Look, Taste, and Smell Like a Helicopter." An IP (Army Instructor Pilot) once kidded me that, "If it don't smell like JP-4 (jet fuel), it couldn't be no good." Well, what is the objective of simulation? Is it to look, taste, smell, and feel like a helicopter? Let me answer that question with three examples: The Crew Station Research and Development Facility (CSRDF) at NASA Ames is an engineering simulator, right? Could you train somebody

Table 1. Myths in helicopter simulation: myth 1

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Simulator should look, taste, and smell like a helicopter
Must determine the objective of the simulation
Crew station design/man-machine interface; CSRDF
Combat training technology/user requirements: SCTB
Primary training technology/train neophytes: UH-1TRS
Must define fidelity to meet the objective
AGARD Working Group (Key 1980)
1. "Objective fidelity" – simulator reproduces measurable aircraft states or conditions
2. "Perceptual fidelity" – degree to which Ss perceive the simulator to duplicate aircraft states or conditions
STI definition (Heffley et al. 1981)
"Simulator fidelity is the degree to which characteristics of perceivable states induce correct psychomotor and cognitive control strategy for a given task and environment"

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in it? Sure you could, but that's not its purpose. It was created to address questions in crew station design. The Simulator Complexity Test Bed (SCTB at ARI, Fort Rucker) is a \$24 million toy that is coming to Fort Rucker this year. Initially configured as an Apache, it has red-station/blue-station training capability beyond any helicopter simulator in existence. It is an ideal device for developing advanced combat training. It is a trainer, but it is more of a training research tool. It is not an engineering simulator, not directly.

Moving from the sublime to the ridiculous, how about "Cheap Charlie," the UH-1TRS? It is a trainer, pure and simple. You cannot start it, you cannot fly an ILS with it, it does not use fuel, that is, we don't currently drive the fuel gauge. But, it trains "hands and feet," neophytes, kids off the street. In other words, it has evidenced significant positive TOT (transfer of training) to the UH-1 aircraft using neophyte pilots as research subjects. I think we should keep the objective of a given simulation in mind as we review our ideas today.

Once we have decided on the objective of a given simulator, an associated issue is the question of simulator fidelity. I brought some of my favorite definitions that I think are worth reviewing (table 1). Dave Key, who was in the audience yesterday, was the key player, no pun intended, in the AGARD working group in 1980, when they distinguished between "perceptual versus objective fidelity." The issue here is, do you want to measure what the simulator does and compare it with the aircraft, or do you want to measure what the "bus driver" does and compare pilot responses from the simulator to the aircraft? I think the latter is more appropriate, at least from a trainer's perspective.

The definition we most commonly use at ARI is that set forth by Heffley and a cast of thousands at Systems Technology Incorporated (STI). STI did a report for us that defined fidelity as "the degree to which characteristics of perceivable states induce correct psychomotor and cognitive control strategy for a given task and environment." Although I worry about the word "correct," I think this definition is worth considering; it focuses on the bus driver and not on the bus.

While we are reviewing the issues involved in simulator fidelity, I think it is worthwhile to reconsider Vernon Carter and Clarence Semple (table 2). When I first read their definition of "error fidelity," I thought, what kind of nonsense is that? Any good psychologist knows about error-free learning. But then, I thought the definition and saw that it has several important advantages. Looking at the error distribution that students make in a simulator and in the aircraft places the focus on the behavior of trainees, with the ultimate goal being "good" performance in the aircraft. Although this definition is specific to training simulators and not engineering simulators, it does suggest a metric for simulator evaluation...training errors.

At the bottom of table 2, I've included a reminder from Ed Eddowes and Wayne Waag: "There is no compelling relationship between training effectiveness and fidelity/realism." That's the kind of statement I'd like to use as a final examination question. We could ask the students to react to it as either true or false and then write a short essay to support their choice. The students could get 100% credit for agreeing or disagreeing, depending on the strength of their arguments. I think I would disagree because training effectiveness is a practical definition of fidelity. If a simulator trains, it has fidelity...who cares what it looks like?

Table 2. Myths in helicopter simulation: more myth 1

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Carter and Semple (1976)
"Error fidelity" – assumes objective is training
1. Trainees make same errors in simulator and aircraft
2. Relative frequency distribution of errors same in both simulator and aircraft
3. Effect of trainee errors on system performance is same in both simulator and aircraft
Advantages of concept
1. Focus on behavior of trainees
2. Recognizes ultimate goal – performance in aircraft
3. Suggests a metric – training errors
A reminder (Eddowes and Waag 1980)
"–There is no compelling relationship between training effectiveness and fidelity/realism"

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Table 3 suggests a second myth: “The engineering test pilot knows best.” In this myth, the bad guys are not people like Roger Hoh, they are the green-suited simulator test pilots. We all know how the Army goes about accepting a helicopter simulator for training. There’s a procedure called Operational Test-2 (OT-2) in which a would-be expert, usually a senior warrant officer with a lot of time in the airframe, is assigned to make subjective judgments regarding the simulator’s handling qualities. I don’t necessarily mean Cooper-Harper ratings but something more subjective than that. Then the software is “tweaked” to satisfy the judgment of the “expert pilot.” This is the way simulators are accepted into the Army inventory.

Is there anything wrong with this approach? Yes there is! The smart folks at STI, Hogue, Jex, and Magdelano evaluated the Army’s UH-60 simulator. The UH-60 simulator has a six degree of freedom (DOF) synergistic motion base, but the STI report noted that as a result of the OT-2, two of the degrees of freedom were “tweaked” entirely out of existence! Specifically, the simulator has only pitch, roll, yaw, and heave. It has no measurable sway or surge. The Army owns 18 UH-60 simulators, 17 in the field and one at the factory in Binghamton. And none of them exhibits more than four DOF. Is that what improving simulator fidelity is all about? It doesn’t make sense to me. But, if we’re going to attack this green straw man, let me offer an alternative.

Yesterday, Ken Cross (Anacapa Sciences) offered “backward transfer” as an empirical yardstick with which

to evaluate existing simulators. Senior aviators performed emergency touchdown maneuvers in the AH-1 Cobra aircraft until they met published criteria. Then they flew the same maneuvers in the AH-1 flight simulator: 58% failed one or more maneuvers. The backward transfer ratios were relatively low, ranging from 0.16 to 0.43. Since the aviators had been qualified in the aircraft within the past few days, it is unlikely that they “forget” how to accomplish the maneuvers. It is more likely that the skill requirements in the simulator and the aircraft are not the same. As Ken Cross noted, the existence of positive TOT data does not necessarily mean that the simulator is effective. The OT-2 report on the AH-1 simulator (by Bridgers, Bickley, and Maxwell) cited some evidence of positive transfer to the aircraft and yet look at the results of the backward transfer study. Positive TOT alone may simply reflect some procedural transfer to the aircraft while obscuring a substantial aerodynamic deficit that will limit the overall training efficacy of the simulator.

Can we improve on the subjective pilot opinion method of evaluating a simulator’s effectiveness? I think so. Let’s look at Stan Roscoe’s transfer effectiveness ratio (TER) (table 4). As an example from our Cheap Charlie research, we took a random sample of 10 Army officer trainees and dragged them kicking and screaming into the UH-1TRS where we substituted 9 hours of simulator time for 9 hours of aircraft time. We trained them to published criteria in the simulator (three successive maneuver iterations that met the Flight Training Guide standard) and then we employed the same criteria on the flight line in

Table 3. Myths in helicopter simulation: myth 2

<p>“The engineering test pilot (or SIP or Eagle Scout) knows best”</p> <p>Army acceptance test procedure</p> <ol style="list-style-type: none"> <li>1. Assign an “expert”</li> <li>2. Subjective judgment of handling-qualities/training features</li> <li>3. “Tweak” the software</li> </ol> <p>Outcome (Hogue, Jex, and Magdaleno 1982)</p> <ol style="list-style-type: none"> <li>1. UH-60FS has six DOF synergistic motion base</li> <li>2. Only four DOF (no sway or surge)</li> <li>3. Army has 17 fielded UH-60FSs with four DOF motion bases</li> </ol> <p>Alternative approach: empirical yardstick to evaluate existing device – backward transfer</p> <p>Example (Kaempf and Blackwell 1990)</p> <ol style="list-style-type: none"> <li>1. Trained to criterion in AH-1 Cobra (ETMs)</li> <li>2. Flew AH-1FWS: 58% failed one or more maneuvers</li> <li>3. Backward transfer ranged from 0.16 to 0.43</li> <li>4. Demonstrates skill requirements different in aircraft and simulator</li> </ol>
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the aircraft. We compared them with a control group of students who did not have simulator training. I've included a kind of "middling" example, traffic pattern flight. We found that the control group required about 21 maneuver iterations to meet the standard whereas the experimental (simulator-trained) students required about 13. That savings of about eight maneuvers on the flight line can be divided by the "cost" of producing the savings: about 13 iterations in the simulator. Thus, the TER for that maneuver is 0.60. This could be interpreted as meaning that the simulator was about 60% as effective as the aircraft, using the aircraft as the criterion measure. This metric has the advantage of measuring "in vivo" training effectiveness of actual flight students embedded in the Initial Entry Rotary Wing (IERW) training program.

Let's look at the final myth: "The more features the better" (table 5). Here, we tread on some hallowed ground. My favorite example, after 14 years at Fort Rucker, is in the area of motion-base requirements. I recall the Singer-Link folks telling the Army that the cost of a simulator motion base adds only 2% to the total

device cost. To evaluate that assertion, I'd like to develop ROC (Required Operational Characteristics) requirements for the LHX simulator specifying no motion base and then, on the day of the best and final offer, add 2% to the contract and say we changed our minds!

Anyway, the draft Advisory Circular 120-XX that Dean Resch and I talked about requires a motion system for acceptance, even for level A. Is there any evidence that motion even contributes to training, let alone is required for training? We've done two small-number empirical evaluations at ARI using neophyte trainees, one in 1984 using five students on motion and five without motion, and one in 1990, with six on motion and six off. All students were strapped in the simulator; we erected the motion base in every case and students were not informed (nor did they guess) that we were evaluating the effects of motion on training. In both experiments, the nonmotion students outperformed the motion students. Now that evidence only pertains to Army *ab initio* (that's a Latin phrase for "kids off the street") trainees learning basic hovering and traffic pattern skills. However, our

Table 4. Myths in helicopter simulation: more myth 2

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To evaluate developing technology: transfer effectiveness ratio (TER)
Measure transfer of training "in vivo" – embedded in training program
Random sample of trainees
"Blind" evaluation of flight line – same criterion
Calculate TER:
$TER = (C_a - E_a)/E_s$
Example from UH-1TRS – traffic pattern:
$TER = (20.7 - 13.2)/12.6 = 0.60$

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Table 5. Myths in helicopter simulation: myth 3

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"The more features the better the simulator"
Motion base – the 2% myth
Draft AC-120-XX requires a motion system, even for level A
Small N research suggest motion may inhibit training
Instructional support features – unused/unusable
Auto co-pilot
Auto check ride
Recorded demonstrations
AAA reviews (1982, 1985)
Insufficient training data to justify acquisitions
Recommended training requirements – empirical basis
Identified no "blade hour" savings

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research agrees with the literature in finding no significant training advantage for a motion base.

Another example would be Instructional Support Features (ISFs). I'm short on time and won't discuss these but table 5 lists three examples from the 2B24 Huey instrument flight simulator that either don't work, are virtually never used, or have been recently taken off-line by the Army. Couldn't we have based the simulator features on a research evaluation of the requirements instead of just buying all the bells and whistles the manufacturer could offer?

My third example of simulator features requires that I bend logic a bit. In 1981, the Army Audit Agency (AAA) came to Fort Rucker and evaluated simulator utilization. Their 1982 report noted that the written premise for procuring flight simulators had been "blade hour savings." The folks from the AAA looked around Rucker and couldn't find the money! The Command Group's answer was that there was no intent to reduce flight hours but that simulators were training multipliers. There's nothing essentially wrong with viewing simulators as adjuncts to "blade hour" training, except perhaps the inherent dishonesty. The AAA made two recommendations: first, that Fort Rucker needs more training data to justify further simulator acquisitions and second, that something as expensive as Army aviation training should have an empirical basis. Actually, the AAA said that Fort Rucker can have simulators to experiment with in "the school-house" but that procurements of simulators for the field would be carefully scrutinized for appropriate training requirements analyses and for empirical means of establishing simulator effectiveness. I think it's embarrassing to have a bunch of auditors come around and tell the trainers how to do their business. But it makes the point

that simulators should be designed, evaluated, and procured for effectiveness and not for a bunch of "gee whiz" features.

So, what would we propose as an alternative? Again, if you want to stir up a hornet's nest, you'd better have a bug bomb. The philosophy behind our suggested approach is to do a thorough, boring, tedious front-end analysis to determine the training requirements based on the ultimate criterion of mission readiness in the field (table 6). At an initial level, that's not all that difficult to accomplish since the Army's Directorate of Evaluation and Standardization (DES) sends flight-skill evaluators worldwide for no-notice evaluations. Thus, it should be relatively easy to determine where the basic mission-readiness training deficits are. Then, a cost-of-training-effectiveness-analysis (CTEA) could be used to compare the training cost of simulation, blade time, or a combination. In summary, if you don't have a problem training the maneuver or mission in the aircraft, don't design a simulator to train it.

We can also try to design our simulators to be more flexible...to anticipate future requirements. We don't want to perpetuate the Army way: procure by publishing requirements, discover that the requirements won't get the training job done before the device is even fielded, initiate a Product Improvement Program (PIP) to modify the device to do what you originally intended (but didn't ask for). The PIP system makes the Army look dumb and the contractors look wealthy. We should be able to do better. Can't we develop requirements with an eye to the future? Can we design part-task trainers and modular simulator designs in place of plenary simulators that are designed as aircraft replacements? Can we do CTEAs to estimate the effectiveness of simulators before we buy them?

Table 6. Myths in helicopter simulation: more myth 3

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Alternative philosophy

1. Perform a front-end analysis  
Training requirements: assess mission readiness in field  
CTEA: Compare aircraft and simulator efficiency
  2. Design/construct modular simulations – flexibility to meet changing requirements  
Design for spare capacity – hardware/software  
Use TOT evaluations of training effectiveness; iterate design
  3. Design/construct part-task trainers instead of plenary simulators  
Design to meet training requirements  
Iterate design
- 
-

So let me go to my last point. In our shop, we call our simulator Cheap Charlie because we don't want to be taken too seriously, but also because we want to emphasize that it's a low cost training tool and not a surrogate aircraft. In a similar vein, I'll call our approach the ACME "Fly by Night" Simworks to try to keep our attention directed to doing useful and meaningful research related to our charter; low-cost entry level helicopter flight training (table 7). I apologize for the pedestrian acronym, ACME, but it may serve to keep our attention focused on our research goals. Perhaps it has value to other simulator designers, researchers, and users as well.

Table 7. Myths in helicopter simulation: still more myth 3

ACME "Fly-by-Night" Simworks and Oyster Bar
Analyze – does it meet requirements? (CTEA)
Combat – does it address Army mission?
Modular – is the design flexible?
Evaluate – does it train? (TOT)

My wife and I don't watch much television but we have come aficionados of the network show, Twin Peaks. My hero, Special Agent Cooper, has a new enamorade... a woman recently released from a convent, that is, an ex-nun. Given her status, he decided to woo her with a joke about penguins. There were two penguins on an ice flow in Antarctica and one turned to the other and said, "You look like you're wearing formal evening wear." The other penguin said, "Maybe I am." The connection to fidelity in simulation is obvious, right?

MR. DAVE GREEN: Just a quick observation with which you can agree or disagree regarding your comments about motion. I think what we say is that bad motion is worse than no motion. When somebody tweaks a machine to make motion, it was probably pretty bad motion. When you get the kind of training you get by taking motion out, it is because motion was a negative training feature. Would you agree or disagree?

MR. DOHME: Well, I would pass the baton. The question is, regarding our getting worse training with motion than with no-motion, Mr. Green is saying that the issue is probably that bad motion is worse than no motion. I would agree that perhaps bad motion is worse than no motion at all. However, we probably had a most thorough evaluation of the motion system on the UH-1TRS by the University of Alabama Flight Dynamics Laboratory (FDL). The FDL engineers analyzed and tweaked our

motion system and wrote a thorough report on their efforts and I would refer you to that report since I'm not an engineer.

The FDL engineers were convinced that our motion base was doing as well as it could, given the limitations inherent in simulating the motions of flight. For example, the issue of washout. Is it subliminal or not? It wasn't that we were naive regarding the issue of motion base fidelity, and we did have simulator-experienced engineers develop and tweak our motion-base equations as best they could. I would be happy to provide a copy of the report; I think it was done right.

MR. FRANK CARDULLO: I would like to follow up on that comment a little bit further. Virtually every transfer-of-training study that has been done about motion has indicated that there has been no transfer. Unfortunately, though, just about every transfer study on training of motion has been done on bad motion systems. You admitted yourself there were two degrees of freedom missing.

MR. DOHME: No, not on the motion system we used with the UH-1TRS. All five were working; as a matter of fact, we had sway, which, it turns out, the original 2B24 doesn't have.

MR. CARDULLO: But, nevertheless, that one is a fairly archaic motion system and the performance is poor, and the cueing-out rhythms are poor. That has been virtually true of all the motion-transfer-of-training studies. I think good motion-transfer-of-training studies should be done, and I wish the impetus would come from the Army or from your organization in particular to do a good transfer-of-training study on a good motion system.

MR. KATZ: Good suggestion, Frank. I am not here to comment on the work that the laboratory did previously, but again, along this same vein, because obviously your talking invites these comments, let me first of all note that you did not say anything about the effect of motion on backward transfer. And you see you had the problem of backward transfer, I assume, with motion.

DR. DOHME: Yes.

MR. KATZ: And then you had a problem with forward transfer with the motion so it invites the hypothesis that the bad motion as a matter of fact caused this. And the thing that I think ought to be studied is to see if the backward transfer would also improve by eliminating this motion. And then I would make the hypothesis that if you get your engineering work up to the level where the backward transfer would be good with the motion that in

this case also the forward transfer would be good with that motion.

MR. DOHME: Interesting hypothesis. Those, of course, are different vehicle we used for those two studies. The backward-transfer work was done in Germany. It's difficult to do that kind of in vivo testing in an active military unit, but it is a good idea: A motion versus no-motion backward transfer study.

MR. GERDES: My background is about 25 years of simulation at Ames, ever since we had first fixed-base and then motion-based simulators. And I have extensive experience on our five, six and three degree-of-freedom simulators. I'm only saying this to give you some qualifications for what I am about to say.

First of all, I agree very, very highly that no motion is better than bad motion. That is what we have been saying for years. Second, motion comes into play or is useful in an engineering simulator, perhaps more so than in a training simulator, where you are looking for, say, the six and one half boundary, the boundary where controllability or emergency control of the aircraft or helicopter is important. Then motion feedback to the pilot is extremely important for the engineering pilot to assess what the control problem might be. Third, about five years ago, I participated in a simulation on our VMS, which has plus or minus 30 feet of vertical travel. It is a six degree-of-freedom and we did an autorotation simulation. I think it was for this particular theme we are looking at, but for the

Army; in other words, are simulators useful for training? And the autorotation maneuver was critical, extremely hard to perform and learn and so forth. That one simulation was probably the one that stands out most in my mind as to where motion, and it was good motion, played a very, very important part in this training business.

I was able, with practice, to make a whole series of autorotations down to a fairly reasonable area and this is a vertical motion simulator. So you have this stress that others here have talked about. There is a simulator you can break, so you try very hard. With the sound system we had, we were able to give the pilot cueing for the rotor sounds. When we pitched up to flare, we got the motion travel to give us the deceleration and we had to doctor up the visuals a little bit. We had to put in a couple of vertical towers for visual height perception.

We did have a fourth window, a chin bubble, we could see through as you could on a Huey. We could do some fantastic things as far as accurate touchdowns are concerned. This was not training, this was an engineering simulation in which we varied disk loading, weights, winds, all of these things. We did a whole matrix of autorotations under difficult conditions, and all of them turned out really well and defined boundaries and so forth.

I am saying all this because motion, when properly used, is very good for training, as well as for engineering simulations.



Jack A. Dohme has a B.A. degree in psychology from Baldwin-Wallace College, and M.S. and Ph.D. degrees in experimental psychology from the University of Arizona. He has taught undergraduate psychology at the universities of Arizona and Maryland and at Concordia College and Grinnell College, and has worked as a senior research consultant at Stanford Research International. His primary research interests are aviator training, flight simulation, and human performance measurement. Dr. Dohme is a licensed fixed-wing and helicopter pilot.



## 14. VALIDATION AND UPGRADING OF PHYSICALLY BASED MATHEMATICAL MODELS

RONALD DU VAL

I appreciate this opportunity to talk to this select group about these issues. The subject is validation and upgrading of physically based mathematical models. There are a lot of terms that are going to have to be defined.

The previous speaker discussed validation from a totally different standpoint from the one I am going to address. He was looking at total validation of the simulation complex, which involves the motion-based system, the visual system, the transport delays—everything that affects the way a pilot perceives what is going on in the simulator. The starting point for all of these issues, however, is the mathematical model that drives all of these systems. And it is very difficult to determine what constitutes validity in terms of visual display or what constitutes validity in terms of motion-based display.

On the other hand, the determination of what constitutes validity in terms of a mathematical model is very straightforward: model validation is a systematic procedure for testing and modifying a simulation mathematical model to achieve the required level of fidelity in matching experimental data. So as a starting point in determining validation of an entire simulation complex, it makes sense to at least make sure the mathematical model on a stand-alone basis can be validated and then to go on and use the more subjective criteria he recommended for validation of the entire complex. So I am defining validation strictly from a standpoint of making sure the mathematical model that drives these systems has acceptable fidelity.

The steps in validating a mathematical model are as follows:

1. Establish acceptance criteria
2. Conduct flight tests and collect data
3. Conduct simulation tests and compare results
4. Analyzes discrepancies that exceed acceptance limits
5. Modify the mathematical model to reduce discrepancies so they are within acceptance criteria limits

I will go through each of these in more detail. The first step—the previous speaker made this point as well—is to establish the acceptance criteria. And that is very critical. It drives everything else from there on down. Once you have determined what is important to the missions you are trying to accomplish, then you can establish criteria to validate the model against those missions and then you can perform the rest of these activities: to conduct the necessary flight tests, and collect the data as a basis of comparison; to perform simulation tests in an appropriate fashion to run comparisons with the experimental data; to analyze any discrepancies between the simulation results and the flight-test results; and, when those discrepancies exceed the acceptance criteria limits, to modify the mathematical model to bring those discrepancies within acceptable limits. The latter is, of course, the most difficult task.

Let's start with acceptance criteria, the first part of the procedure (table 1). I am going to define validation in two different ways: functional validation and physical validation. To begin with, functional validation, or acceptance criteria to determine functional fidelity, basically requires fidelity of pilot cues. What you are trying to do is to make sure that what the pilot sees is an accurate representation of the input/out relationships of the aircraft. You don't care what is going on inside the mathematical model. It is a black box. All you are really interested in is that given the right input you are getting the right output. That is functional fidelity. And this, of course, is the primary way in which current training simulators are evaluated, on a functional basis.

The kinds of criteria that are used for functional validation are based on the effect, not on the cause. The response is being validated, not what is producing the response. The three classic criteria are trim, stability, and dynamic response. Regarding trim, you usually characterize the control settings required to trim the aircraft at different flight conditions. Often, stability is not specifically

Table 1. Acceptance criteria: functional fidelity

1.	Requires fidelity of pilot cues
2.	Functional criteria (validate effect)
	Trim
	Stability
	Response
3.	Tuning factors: empirical coefficients
4.	Scope of validation: validation at system level
5.	Bandwidth of validation: limited to handling-qualities range
6.	Amplitude of validation: limited to linear range

used as a criterion in the training industry. It is somewhat inherent in the response measurements, but stability characteristics could be prescribed either in the frequency domain or in the time domain. For the frequency domain, the phase or gain margins can be specified; for the time domain, the eigenvalues or eigenvectors can be specified. The dynamic response of the actual test vehicle can be compared both in the time and the frequency domains with similar responses for the simulation to determine whether the response is correct. This is often used in the training industry, at least in terms of time-domain responses. There is very little in the way of frequency-domain criteria that is being used right now for validation.

As far as the training industry is concerned, one of the major problems with the current acceptance criteria that have been established is that there is no attempt to specify how the manufacturer can tune the mathematical model to meet the acceptance criteria. The manufacturer basically has carte blanche to do whatever he needs to in order to meet those acceptance criteria. And typically what happens is the manufacturer will add empirical coefficients at appropriate places in the simulation that make it very easy to tune in order to satisfy the acceptance criteria.

I have seen a number of cases in which scale factors and biases have been added to aerodynamic forces and moments. It is nonphysical, but it accomplishes the job of satisfying the specific test criteria. The problem with this kind of manipulation is that because it is done totally empirically, it satisfies the criteria at the test points but there is no guarantee that it is going to give a realistic response outside the test points or between test points. Basically, the test curve that the government gives you to satisfy is being fitted, and you can't be assured that it is going to really represent the correct aircraft response. The other issues associated with the acceptance criteria are the

scope of the validation. By this I mean is it end-to-end validation of the total aircraft that is of concern or is it the subsystems and their independent validation.

Typically, right now validation is performed at the system level only, and it is based strictly on the six-degree-of-freedom aircraft rigid-body motion. If that is accomplished, the basic idea is that that is what the pilot sees, that is what the pilot perceives; there is no reason to carry validation into any more depth than that. The problem with that, as we will shall see, is that it allows the manufacturer to tweak a subsystem, the tweaking of which may be totally inappropriate, in order to get the total response correct. If the rotor model isn't right, he may alter the control system in order to give the net response that is desired. By allowing validation at the global level, the manufacturer is given a lot of leeway in adjusting individual components, which in turn eliminates interchangeability and modularity of the resulting simulation.

Another major issue is the bandwidth of the validation, that is, the frequency to which the simulation must be accurate (table 1). And typically there have not been a lot of frequency-response criteria associated with training simulators. This is a major problem. The way in which it is evaluated, though, does predominantly limit the bandwidth to the handling-qualities range, which again assumes that that is all the pilot is going to see and all he cares about.

The last acceptance criterion, which is a really important issue, is the amplitude of the validation (table 1). Typically, people will limit the perturbations in the linear range. Validating the model when it is driven into its nonlinear range is a much more difficult job. There are virtually no acceptance test criteria that enforce driving the model into the nonlinear range to see if it is accurately represented. What you end up with is a training simulator

that has been validated only in the middle of the envelope for mild maneuvering. If a pilot maneuvers it aggressively or flies to the edge of the envelope, the simulation and that environment based on these validation criteria have not been validated. And that is precisely where simulation should be particularly valuable, in conditions in which a pilot would not want to fly a real aircraft. That is typically not addressed in the validation criteria.

Let's take the other alternative, which is physical fidelity (table 2). By this I mean we are requiring that the mathematical representations of the physical phenomena in the simulation be correct. Instead of looking at the simulation as a black box where all you are interested in is proper end-to-end response, you are going to look at the way in which the phenomena are modeled and try to validate it to that level. This is typically done in engineering simulators. The main reason it has not been used in training simulators is because it is a much more difficult process, much more costly to do and to validate, and, ultimately, because it is very difficult to perform in real time, which is required for training in real-time simulations. What is happening right now, however, is that with the advent of parallel processing technology and modern high-speed computers, we can take physically based models and perform real-time simulation with them.

Computer technology has been developed to the point where we can start using physically based models for real-time training applications. As a result, we need to look at what the advantages are of this kind of modeling to the training industry. Again, the acceptance criteria in a physically based model are to validate the cause rather than the effect. Here what you are going to try is to compare applied loads for accelerations of the vehicle for given flight conditions. The way in which the model is tuned is much more restrictive than it is in a functional model. The only way the contractor is allowed to modify the system is to modify the structure of the mathematical model, in a

physically meaningful manner, or to change physically meaningful parameters, not empirical coefficients. So it tremendously complicates the process of tuning the simulation to match the acceptance criteria.

The scope of the validation is another important issue. Now we are talking about validating the system at the subsystem level. It is not acceptable to think of this as just a black box—that as long as the right response is obtained, we don't care what goes on inside. You are now going to break the total model down to a main-rotor module, a tail-rotor module, horizontal stabilizers, and engines. Each of the components is going to be separately validated against independent test criteria so the control system can no longer be altered to make up for problems in the rotor model. The bandwidth of the validation now has to be significantly increased. And it has to be expanded to include the bandwidth of all modeled degrees of freedom in the system. If the subsystems are going to be validated with physically based models, it is necessary that the degrees of freedom of all the physically based models in the system be exercised. Of course, it is necessary to be able to excite it throughout the range, to be able to go into the nonlinear region and validate it there.

One of the benefits of going to physically based models is that it should make it possible to achieve global fidelity of the mathematical model; that is, you should be able to drive it to the edge of the envelope, fly it with aggressive maneuvering, and really use it as it should be used, as a tool for training a pilot in dangerous flying activities, those he could never achieve or even come close to, safely, in an aircraft.

The third item on the list was flight test and data acquisition (table 3). These have to be geared to the acceptance criteria. Once the acceptance criteria are established, data must be collected to support the performance of this acceptance test. What is done is to collect data associated with functional validation, trim data, stability

Table 2. Acceptance criteria: physical fidelity

1.	Requires fidelity of mathematical representation of physical phenomena
2.	Physical criteria (validate cause): applied loads/acceleration
3.	Tuning factors
	Model structure
	Physically meaningful parameters
4.	Scope of validation: validation at subsystem level
5.	Bandwidth of validation: includes bandwidth of all modeled degrees of freedom
6.	Amplitude of validation: excites nonlinear range

data, response data; typically this is limited to the airframe rigid-body motion.

Physical validation is a much more difficult problem. In order to isolate subsystems for independent validation, it must be possible to collect boundary data at each of the subsystems. For example, the reaction loads between the rotor and the fuselage must be measured so that the rotor can be isolated from the fuselage motion and validated as an independent subsystem. Typically, therefore, it must be possible to collect load data at the subsystem interface and to be able to collect acceleration rate and displacement data at subsystems. As a result, it is a much more difficult data-collection task.

The way in which this is commonly performed, or can be performed, is to use redundant sensors and kinematic constraints to eliminate the instrument, calibration, and procedure errors that are encountered. Too often raw test data with no cross-checking are used for acceptance test criteria. Our experience has been that such data are fraught with calibration errors and procedure errors. There are too many good ways available for doing consistency

testing, kinematic cross-testing, for this to be the case. This should be used to ensure that you have the right experimental data to form the basis of the acceptance criteria.

The mass properties and the sensor geometry must be documented. It must be possible to perform maneuvers that span the bandwidth and amplitude of the validation criteria. For the closed-loop simulation, here for the simulation tests, there are two approaches. The purpose of the closed-loop simulation is basically to initialize the simulation to the starting test conditions, drive it with test control inputs, and then compare its response with the dynamic response of the test (table 4).

This is the way in which it is ordinarily done. The advantage is that it is simple to implement and requires minimal sensor data. The disadvantage is that you have a cumulative buildup of error and you cannot isolate subsystems because of the coupling between them. The open-loop approach to testing the simulation is to disable the airframe rigid-body motion and drive the simulation with the control inputs and the rigid-body motion that has been

Table 3. Flight test and data collection

1. Functional validation
Collect trim, stability, and response data for airframe rigid body degrees of freedom
2. Physical validation
Collect loads data at subsystem interfaces and acceleration, rate, and displacement data at subsystems
3. Perform data consistency tests with redundant sensors and kinematic constraints to eliminate instrument calibration errors and procedural errors
4. Document mass properties, sensor geometry, and atmospheric conditions during tests
5. Perform maneuvers that span the bandwidth and amplitude of the validation criteria

Table 4. Conduct simulation tests and compare results

Closed-loop simulation	
1. Method	<ul style="list-style-type: none"> <li>Initialize simulation to starting test condition</li> <li>Drive simulation with test control inputs</li> <li>Compare dynamic response of simulation to dynamic response of test</li> </ul>
2. Advantages	<ul style="list-style-type: none"> <li>Simple to implement</li> <li>Requires minimal sensor data</li> </ul>
3. Disadvantages	<ul style="list-style-type: none"> <li>Cumulative error build up due to closed-loop integration limits validity of comparison</li> <li>Coupling between dynamic subsystems limits ability to isolate discrepancies</li> </ul>

determined from the test data (table 5). So what you are really doing now is driving the simulation on in a dynamic wind-tunnel mode and looking at the loads that are produced along the same flight trajectory that the aircraft produced. You compare these loads with those obtained from the flight to validate the model. The advantage is that it eliminates cumulative error buildup and it allows the subsystems to be validated independently. The disadvantage is that it is much more difficult to implement, and more expensive data are required to isolate the loads at the subsystems.

For the analysis and modification methods there are two primary objectives: model structure has to be established and the parameters have to be modified (table 6). And the kinds of modifications you will typically have to make are to add coupling, higher-order dynamics, and nonlinearities.

The parameter identification method used for linear-parameter dependency can be regression. The more difficult problem of nonlinear dependencies would require an

output-error approach. The point I have been making all along is that training simulators are functionally validated. The validation is performed at the system level with the rigid-body airframe response as the validation criterion. Satisfaction of this criterion is achieved by tuning empirical coefficients. The result is a model tuned for specific conditions that has been validated only for bandwidth low-amplitude maneuvers (table 7).

The bottom line is that validation requirements drive the modeling sophistication (table 8). You get what you ask for. And the simulation manufacturers will not produce the physically based simulation if the validation requirements are functionally based. For example, rotor-map models are functional approximations to the blade-elements model; they satisfy acceptance test criteria as currently specified. However, you could specify criteria in a form such that contractors would have to go to a blade-elements model in order to achieve your requirements. In conclusion, what I think is really needed is a standard for rotorcraft validation that in a sense is like the standard that

Table 5. Conduct simulation tests and compare results

Open-Loop simulation	
1. Method	<ul style="list-style-type: none"> <li>Disable integration of airframe rigid-body motion in simulation</li> <li>Drive simulation with control inputs and rigid-body motion from test data</li> <li>Compare loads/accelerations of simulation with test data</li> </ul>
2. Advantages	<ul style="list-style-type: none"> <li>Eliminates cumulative error build up due to integration of airframe states</li> <li>Allows subsystems to be isolated and validated independently</li> </ul>
3. Disadvantages	<ul style="list-style-type: none"> <li>Implementation of simulation run is more difficult</li> <li>More extensive test data are required to isolated loads at subsystems</li> </ul>

Table 6. Analysis/modification methods

Model structure determination	
1. Correlate errors to states and controls for nominal parameter values	<ul style="list-style-type: none"> <li>Statistical correlation of error</li> <li>Frequency response of error</li> </ul>
2. Postulate modification to model structure	<ul style="list-style-type: none"> <li>Additional coupling</li> <li>Higher-order dynamics</li> <li>Nonlinearities</li> </ul>
3. Repeat comparison step and iterate until error can be sufficiently limited by reasonable parameter changes	

Table 7. Problems with current validation approach

<ol style="list-style-type: none"> <li>1. Validation is only guaranteed in vicinity of test points</li> <li>2. Low-bandwidth validation does not support aggressive maneuvering, high-speed flight, or high-gain controllers</li> <li>3. Low-amplitude (linear) validation does not support aggressive or edge-of-the-envelope maneuvers</li> <li>4. Lack of subsystem validation eliminates modularity and interchangeability in subsystem models</li> </ol>
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Table 8. Validation requirements drive modeling sophistication

<p>You get what you ask for</p>
<p>Simulation manufacturers will not produce physically based simulations if the validation requirements are functional</p> <p>Example:</p> <p>Rotormap models are functional approximations to the physically based blade-element model</p> <p>They satisfy trim and stability requirements and low-bandwidth response requirements for function validation</p> <p>They will not satisfy a validation criteria that specifies rotor impedance (rotor load frequency response to hub acceleration)</p>

Table 9. Rotorcraft validation standard

<p>A standard for rotorcraft validation is required that will address the following:</p> <ol style="list-style-type: none"> <li>1. Acceptance criteria versus simulator mission requirements</li> <li>2. Flight-test procedures and instrumentation versus acceptance test criteria</li> <li>3. Generation of simulation data and comparison with flight data</li> <li>4. Model structure determination and parameter identification methods for reducing errors to specified limits</li> <li>5. Acceptable physically based parameters for tuning and their allowable range of variation</li> </ol>
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we are addressing here this week for simulation qualifications (table 9). It could be either a part of the simulation qualifications or be detailed enough to require a separate specification.

We have to define the acceptance criteria as a function of the mission requirements. We have to determine flight-test procedures and instrumentations in order to be able to implement acceptance criteria. We have to be able to generate the simulation data and compare them with flight data in a systematic manner, apply modern tools for model structure determination, and parameter identification for achieving the criteria. Then we have to determine what physically based parameters are acceptable for tuning the simulation and what is their allowable range of validation. These are all terms that should be defined in a specification so that validation can be standardized.

MR. WALKER: Since the interface between the subjective evaluator and the mathematical models is really the simulator that is provided by visual systems, motion

bases, audio systems, and so on, how do you resolve the errors that may be introduced by these systems in the development of your validation?

MR. DU VAL: I am referring strictly to the validation of the mathematical model; my contention is that you should not compensate for errors in these other systems by modifying the mathematical model; you should put in compensations for the systems, where they belong, that is, within the systems.

MR. HAMPSON: I agree entirely with you. I do have some difficulty, though, with some of the comments you made with respect to tweaking the model. I don't know if this is particularly a helicopter problem you are addressing, but certainly with fixed-wing and also with the helicopter models that are provided by the aircraft manufacturer, we, as a simulator manufacturer, do not tweak the models. We identify the deficiencies and go back to the aircraft manufacturer and tell him there is something wrong with his model or have him explain to us why we

have a problem. And I think that is the proper way to do things, rather than expecting the simulator manufacturer to tweak a model.

It goes back to something I said yesterday, but in the helicopter world we rarely get a model from the manufacturer of the aircraft. That is a significant issue, I think.

MR. DU VAL: That is true. I haven't really made the distinction of whether the mathematical model was generated by the simulator manufacturer or the aircraft manufacturer. The point is if the physically based mathematical model does not match the acceptance criteria, to add empirical parameters to make it match the criteria is not an appropriate solution, that it must be physically modified.

MR. GALLOWAY: You mentioned that you get what you ask for. I would like to add the comment that you get what you pay for or are willing to pay for. How

do I convince my Navy program managers to pay for the efforts you advocate for getting the data?

Mr. DU VAL: The answer is modularity. You are going to pay for it in the short term, but you are going to get your money back in the long term. If you validate the subsystem models at the subsystem level, then you have interchangeability of mathematical models. You can plug in rotor models, you can build on them, because you validated each of these components separately. It provides for the kind of modular interchangeable mathematical modeling for simulation that we have been striving for. Once you have validated the basic component it is only a matter of changing the physical attributes to validate it with a different aircraft. So even though it is more costly to do this up front, it is going to reduce the cost of validation on future simulation activities because you have building blocks you can work from.



Ronald W. Du Val is president of Advanced Rotorcraft Technology, where he has developed a team with a reputation for excellence in the fields of rotorcraft simulation and analysis. He received a B.S. in mechanical engineering from the University of California, Berkeley, an M.S. in systems engineering from the University of Houston, and a Ph.D. in aerospace engineering from Stanford University. Dr. Du Val worked for NASA at the Johnson Space Center, where he assisted in the development of simulations in support of the Apollo missions, and where he participated in the initial design of the space shuttle's reentry and terminal-area guidance and control systems. He later transferred to NASA Ames Research Center where he applied methods of state space control to the problems of rotorcraft. Dr. Du Val left NASA in 1982 to set up Advanced Rotorcraft Technology.



## 15. FREQUENCY-RESPONSE TECHNIQUES FOR DOCUMENTATION AND IMPROVEMENT OF ROTORCRAFT SIMULATORS

MARK B. TISCHLER

I would like to pick up on a number of points that Ron Du Val made. It was a good introduction for some more of the detailed aspects, and I think it follows well with what Dave Key is going to talk about afterward. I am going to talk specifically about analytical techniques, some of which Ron introduced for documenting and improving rotorcraft simulation. This includes mathematical modeling, which Ron was addressing, and visual and motion systems, how we do that documentation, and how we tweak the model, as was discussed.

I would like to cover the background of the general topic, which is system identification, a class of techniques for documenting both the mathematical model and the implementation in the simulator. The specific approach that I have been working on and what we use at Ames extensively is the frequency-response approach. It is an input/output validation technique, but can be used to document and to validate physical models. Specifically, we are going to look at the application of system identification to a variety of validation problems. The core of my presentation is going to be a series of illustrations of how we used the technique for a number of simulators, including the UH-60, AH-64, and STOVL.

I will show you a potpourri of illustrations, how these techniques are used, how you interpret them, and finish off with a summary.

As I mentioned, the overall class of techniques is included in the category of system identification. And for those who are not familiar with system identification, it is a procedure by which a mathematical description of an aircraft, in this case a rotorcraft, is extracted from flight-test data. In this respect it is the inverse of simulation. In simulation we make such assumptions about the characteristics of the aircraft, its aerodynamics, how many degrees of freedom it has, etc., and based on those assumptions we formulate a physical model, and generate a simulation that is intended to predict aircraft motion. When all that works and the predicted aircraft motion

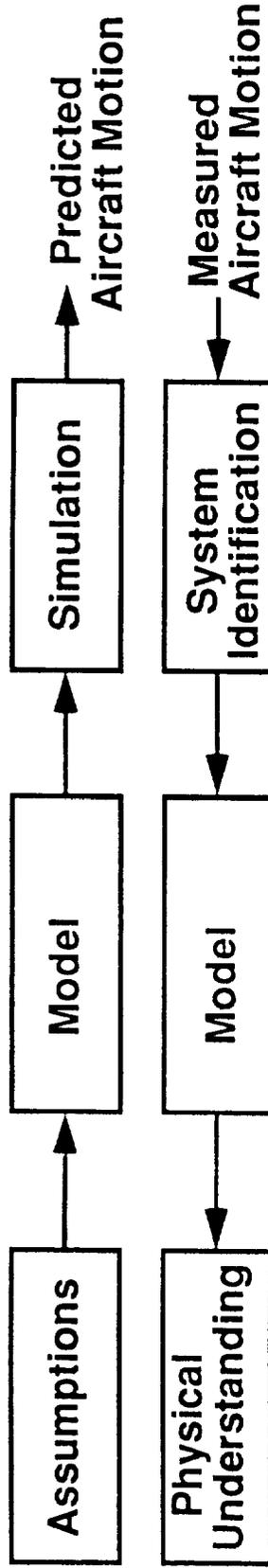
equals measured aircraft motion, we have a good simulation.

Unfortunately, as has been pointed out a number of times, that is often not the case. It is very difficult to figure out how to change the mathematical model on this end to update the simulation and make these two things match. One of the most sophisticated ways of making that happen is to work the problem in reverse. That is, take aircraft data, go out and do special flight tests for system identification; system identification becomes an inverse procedure by which one extracts a mathematical model from the flight tests. These can be physical models, transfer-function models, or state-space models. Once these models are extracted they represent the exact characteristics of the aircraft. Then they can be compared back to back with the simulation, the simulation models can be updated, and a comprehensive method is produced, by which both the mathematical models and our physical understanding can be updated. We may want to go back and change some assumptions; maybe, for example, some of our mathematical assumptions were not good.

Typical examples of the uses of system identification are given in figure 1. System identification has been around a long time, but only recently has it been adopted in a broad way in the rotorcraft community—in the last 5 to 10 years. The reason is, there are special problems associated with it that make it more difficult in some ways than a standard fixed-wing problem.

In rotorcraft there is a high-level rotor noise. The helicopter is inherently a very high-order system, so the system cannot be decoupled, unlike in fixed-wing work where only a small subset of transfers is identified. Generally, instead of having to identify 10 or 20, as many as 40 or 50 might have to be identified. There is a great degree of high-axis coupling. You have to go at least six- or nine-degrees-of-freedom, and helicopters are generally unstable machines. I am not going to go through in detail the engineering aspects of system identification (shown in

- What is rotorcraft system identification?
- Determination of a mathematical description of rotorcraft dynamic behavior from measured aircraft motion



- What are system identification results used for?
- Wind tunnel vs. flight test measured characteristics
- Simulation model validation
- HQ specification compliance
- Optimization of automatic flight control systems
- What are the special problems in applying system identification to rotorcraft?
- High level of measurement noise
- High degree of inter-axis coupling
- High order of helicopter dynamical system
- Unstable vehicle dynamics

Figure 1. System identification background.

fig. 2). There are a lot of papers about it, papers by Ron, me, and others in the audience here. Frequency-sweep testing of the aircraft is conducted to generate a data base. Then, data compatibility is used to make sure the data are good, state-estimation is used to reconstruct poorly measured states, and advanced FFTs are used to convert the time-domain data to frequency-response data.

The frequency response is a complete description of the aircraft. It is a linearized description, but it is a linearized function of a nonlinear function. In that respect it does fully characterize the aircraft. For a lot of what we want to do, this is sufficient, because we can characterize the aircraft behavior by its frequency response and compare that with the simulation frequency response. I am going to show you an illustration of that.

In handling qualities we work with frequency responses of the system to check bandwidth. You can use advanced techniques for extracting from the frequency-response stability-control derivative models. This is important. I will show you an example in which we used such a model and actually flew it in a piloted simulation. In a number of simulations we implement a stability and control derivative look-up table as a function of flight condition. This is one way of actually generating a simulation model for piloted simulation. Finally, we want to verify that these identified models are correct by checking in the time-domain.

This is sort of the overall road map and I will not go into any more detail. Let me just point out a couple of reasons why we like the frequency-response approach for rotorcraft. First, the frequency-response technique has the advantage in that when you form the frequency-response ratio, the uncorrelated effects of process and measurements noise drop out. That is, any noise source that is not correlated to the input drops out of the calculation. And that makes identification easier. You do not have to make an assumption about the noise or you don't have to identify it. So from a technical standpoint it has some advantages, especially for a helicopter in which the data are often quite highly contaminated by noise, by turbines, or by measurement noise.

Second, you can extract parametric models in the frequency range where the data are valid. We have access to the function called the coherence function, which gives you direct measurements of the accuracy of the data. If the coherence drops in a particular frequency range, you may go out and rerun the data and go for it again.

Third, you can estimate time-delays directly, because the phase shift is a linear function of time-delay. It is very

important in simulators where you want to identify time-delay. Then there is integration in the time and frequency domains. There are methods for artificially stabilizing the system; they do not work very well for highly unstable rotorcraft. Frequency domain does work well for that. All the results I will show you are for unstable systems.

Finally, we have developed a comprehensive package for the frequency-domain approach, CIFFR, for Comprehensive Identification From Frequency Responses. Application of system identification to the simulation environment in sort of a broad sense is depicted in figure 3. The pilot is going to make inputs into a mathematical model, which produces estimates of what the aircraft is doing. That may drive the visual system through its compensation, and the motion system through wash-outs and motion drives. The pilot is subjected to these cues, and they may be matched or mismatched and produce an overall percept. The frequency approach that I'm going to talk about is applicable to all aspects of the validation process.

You can calculate frequency responses between pilot inputs and aircraft states and validate the mathematical model alone. You can look at aircraft states, to the visual system, and characterize the motion-system response, or go end-to-end and characterize the overall response. One example has been mentioned, the XV-15. We suppressed the actuator dynamics, because those delays were compensated by the visual systems dynamics, and because we knew that there were going to be extra delays in the visual system and that the end-to-end response would be okay. That is an example of where you might shift some of the delays and get the same end response. Some examples of what we have done in the past (and there are papers on all of these) are what I am going to highlight in the remainder of my discussion. I mentioned the XV-15; it was highly validated both in the time and frequency domains, and was a very good example.

I think most people involved in the XV-15 would agree that it was probably one of the best simulations ever run at Ames. The transfer of training was excellent, and most of the papers by Ron Gerdes and Dan Dugan indicate that the pilots were amazed when they got into the aircraft. The frequency-response studies that were done indicated that the validation was excellent across the whole pilot-handling-qualities range. We have done quite a few studies over the years on the UH-60. I will talk about some work on STOVL simulation. There has been considerable effort recently in characterizing the VMS

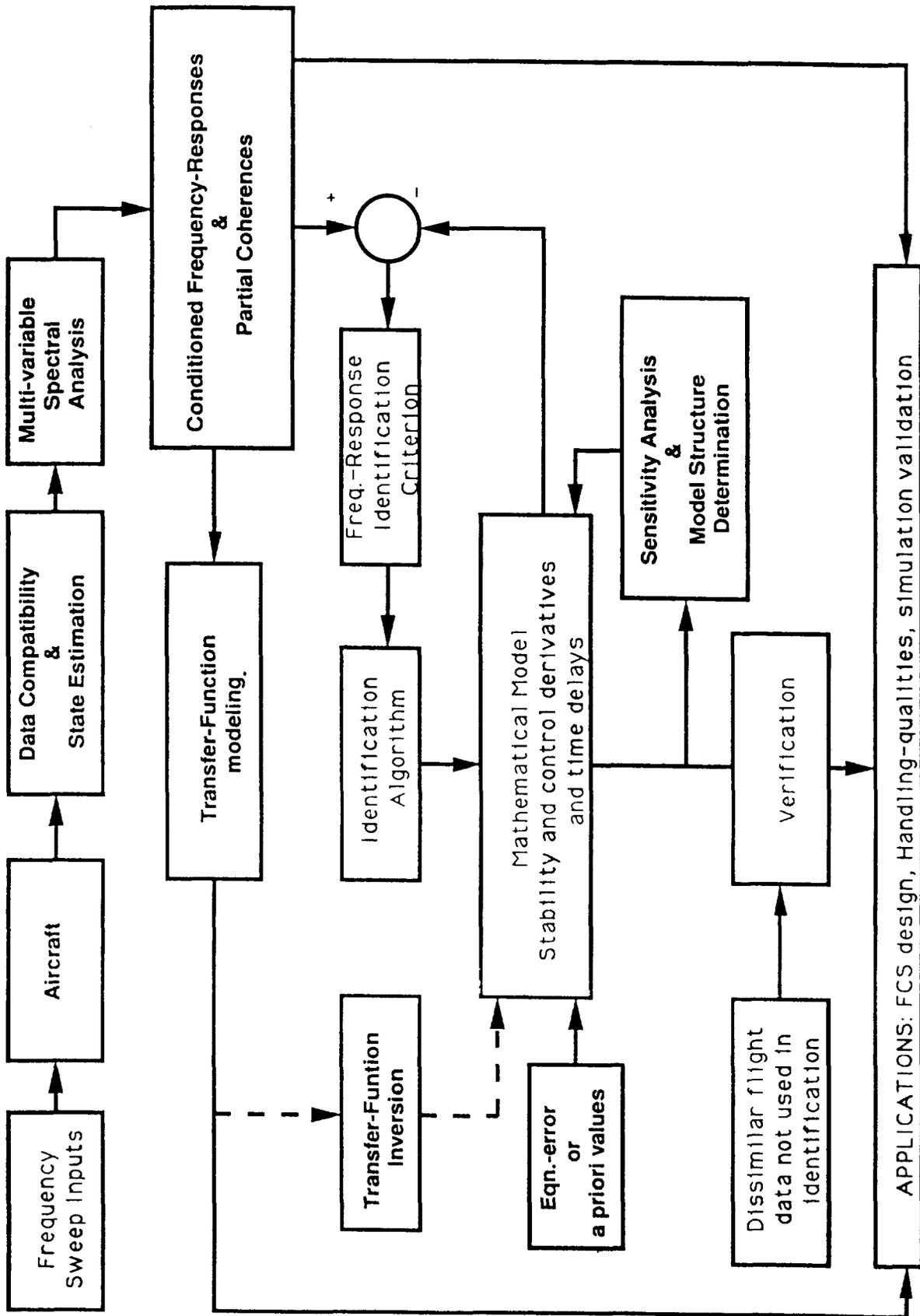
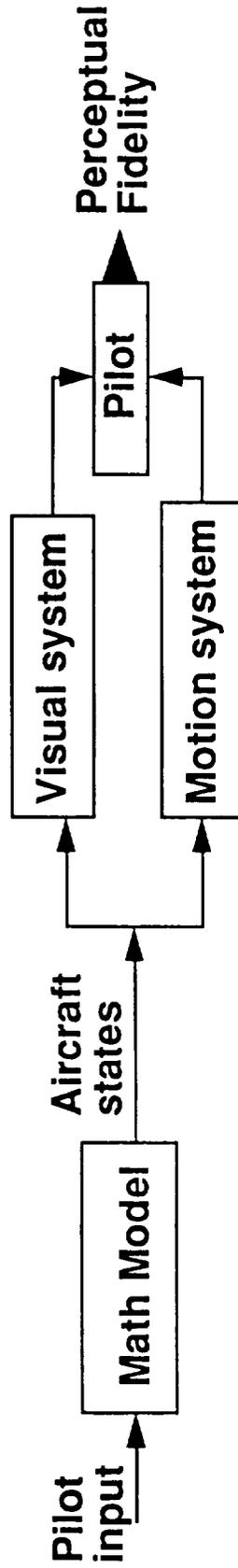


Figure 2. Frequency-response method for system identification.



- **XV-15 - math model validation and upgrades**
- **UH-60 - math model validation and upgrades**
- **STOVL - accurate linear model extraction from nonlinear-simulation**
- **SIMVAL - VMS motion and visual drive calibration**
- **LH - simulation / simulator evaluation**
- **AH-64 - hover model extraction for use in simulator**

Figure 3. Application of frequency-response procedures to simulation/simulator validation.

motion base and visual systems, and I will present some results from that.

Frequency-response testing was used heavily in validating the LH simulation, both in terms of characterizing its response and of validating the handling qualities. The Army Test Directorate (AQTD) had our software in a portable suitcase and actually characterized the frequency responses in the lab. And then we have recently made, as I mentioned, an Apache mathematical model extracted from flight-test data.

The Blackhawk study that was reported by Mark Ballin at the last AHS meeting is shown in figure 4. We did frequency sweeps; here is an example. The pilot generates the inputs; we are not in favor of computer-

generated input. The pilot supplies a good input. In this case we are interested in validating the simulation mathematical model. It is a physical based mathematical model—it is a blade-element-type model, very sophisticated. This is our input into the system. We use frequency-response techniques to identify input to output frequency response of the model itself, and of the aircraft. Figure 4 shows the pilot's input to the aircraft.

In figure 5, the solid lines are magnitude, phase, and the coherence function. When the coherence function is high, it indicates the data are accurate. In this case they are accurate, and include the rotor dynamics. In fact, the notch shown in the coherence-function curve is an effect of the lead-lag motion of the blades.

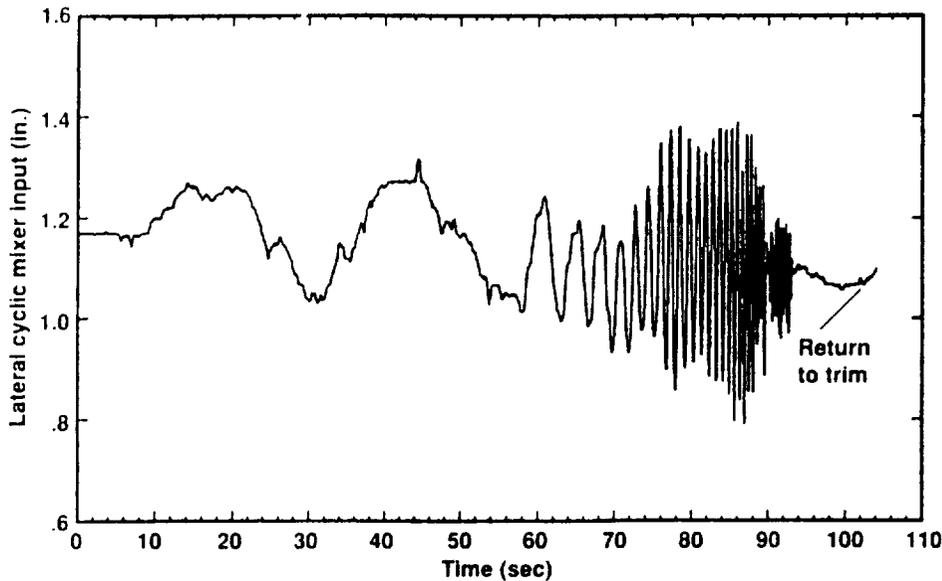


Figure 4. UH-60 Black Hawk Frequency-Sweep Flight Tests in Hover (from Ballin, 1990 AHS forum).

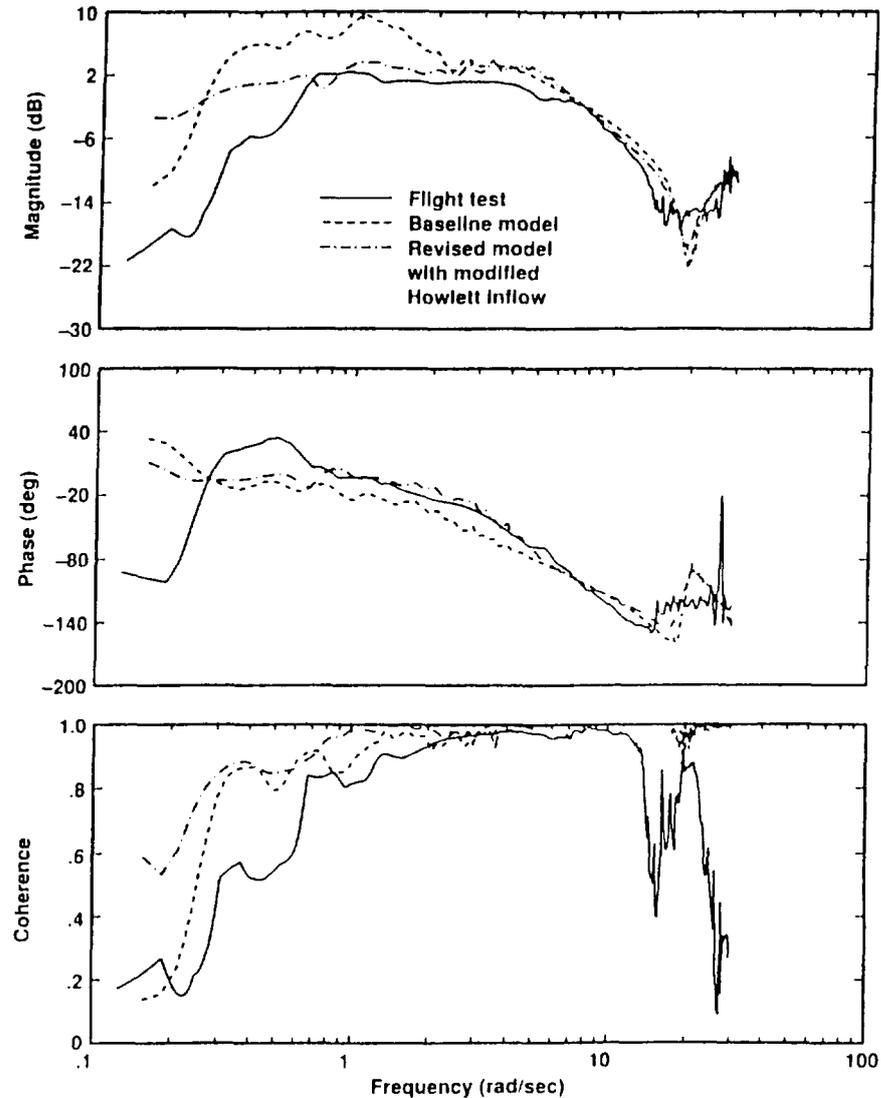


Figure 5. Tuning Howlett inflow model for improved roll correlation.

You can see that the baseline model, the dashed lines in figure 5, is pretty good at high frequency. The rotor dynamics are pretty well approximated and things look good beyond 1 rad/sec. Below that, there is quite a bit of error between the baseline model; it turns out the problems were associated with inflow dynamics. There is a first-order inflow model, referred to as the Howlett model. When the model was developed there was no way of tuning the coefficient; there were no flight-test data at that time, and this provided opportunity to collect some. By adjusting a couple of the aerodynamic constants in the inflow equations we were able to bring the model into very close agreement with the flight-test data; this response is very close to the more sophisticated, so-called Pitt Peters model; it is an example of how this tuning,

which was discussed before, is done. You can get a very detailed characteristic of how the model changes by tuning the aerodynamic parameters. In this case the pilots reported a great improvement in their perceptual opinion of the characteristics of the simulator.

The next program I want to talk about is the Apache. We ran a series of frequency steps, in late August 1990. It was a very comprehensive program, with a variety of goals, one of which was to validate the AH-64 mathematical model. We have a couple of mathematical models from one of the manufacturers and one of them was developed in house. We did frequency sweeps in hover and in forward flight with the SAS off, and gathered quite a data base from that. One of the goals of the program was to extract a linear model, which was then used in the

simulator to do handling qualities. In this case, the study was done to evaluate the displacement dynamics and to determine how they affect pilot handling qualities. The point is, we extracted a mathematical model and actually flew it. That was one of the first times that had been done. The hover response, SAS off, is shown in figure 6; the figure also shows the on-axis pitch response, the on-axis roll response, magnitude, and phase. The flight data are represented by a solid line, the dashed line is the model.

We identify a model that, as you can see (fig. 7a), characterizes response very well. This particular model has basic rigid bodies of freedom. It also has in it the inflow degree of freedom, and you can see that the characterization is quite good. In the time-domain (fig. 7b), the model is very characteristic of the on-axis response to pedal input, yaw rate, and acceleration, which is very good. And the dominant coupling response, which is a roll response, is excellent. So this is an example of where we took the model and drove it with these similar flight-test data; as you can see, the predictions are really excellent. The pilots reported very good fidelity (fig. 7b) of the simulation, that the coupling responses are very good, and that they are actually flying this model.

Another example is the STOVL program (fig. 8). In this case we wanted to extract a linear model. You have the possibility of generating a linear model, but you can also use system-identification techniques to do the same thing. And when you use system-identification techniques to do that, you can characterize some of the nonlinear behaviors much better.

The step input into the elevator, which is the dominant longitudinal response, is shown in figure 9. The dashed line is the numerical perturbation model. In fact, for the very beginning of the response the numerical perturbation technique is much better because it is a very small perturbation. And as you can see, it is unstable.

Our last example is a vertical motion simulator, which is a lead-in to Dave Key's presentation. Here we were interested in documenting the vertical motion simulator response, both the visual system and the model response, as well as the motion system (fig. 10). The model response—and it is an ideal, simple model—is the solid line; it is a very simple attitude system. Our visual system drive uses an algorithm developed by McFarland to buck out the inherent delay, and the resulting response is exactly on top of the model (fig. 10). He did a very nice job in coming up with an algorithm that allows the system to follow the mathematical model.

The motion command has a great deal of wash-out at low frequency, and tracks with some gain error at high frequency the motion follow-up which the pilot feels, lag at high frequency (fig. 10). The system-identification approach provides a way to characterize independently all these various effects; Dave Key will talk about how you interpret that. The point is, you go into the simulator and split out the various effects. You can see that at low frequency the motion wash-out is quite significant. The last result (fig. 11) shows a comparison of pilot workload in the UH-60 in a hover/bob-up task. Here we are looking at the frequency contents, and what I have plotted is frequency range versus the rms of the pilot stick input over the total rms.

What figure 11 shows is that most of the pilot's input—say up to about 80% of it, which is reflective of the crossover frequency—is at 2.5 rad/sec. That indicates the pilot is operating at a crossover frequency of 2.5 rad/sec. The flight data are indicated by the open circles; you can see the characteristics are almost on top of each other. In fact, the pilot ratings are essentially the same. I think they were off by one pilot rating. It is another way of using the frequency-response method to calibrate workload and to get transfer-of-training issues, because a pilot from 1 to 10 rad/sec is operating the same.

Summarizing, I think you can see that system-identification techniques are comprehensive and allow you to look at the whole range of problems. They are very well suited to rotorcraft and provide a great deal of physical insight. Finally, there are a number of computational tools out there for doing this analysis: Mathematical Lab, Control C, and CIFFR.

Are there any any questions?

MR. BRICZINSKI: I think that your implication of using this frequency-response technique primarily can be used to complement, to help analyze, simulation models as opposed to generating them. I think your techniques of system identification will generate a linear small-perturbation model. We find it necessary in your field to use a full force and moment type model. Did you suggest perhaps generating maps of stability derivative-type models that could be interpolated and then serve in a simulation technique?

DR. TISCHLER: Some of the best simulation models of helicopters in fact have been done by easily programming table look-ups at every 20 knots of perturbation derivatives. You can put in the aerodynamics and then the gravity and kinematics in a nonlinear way.

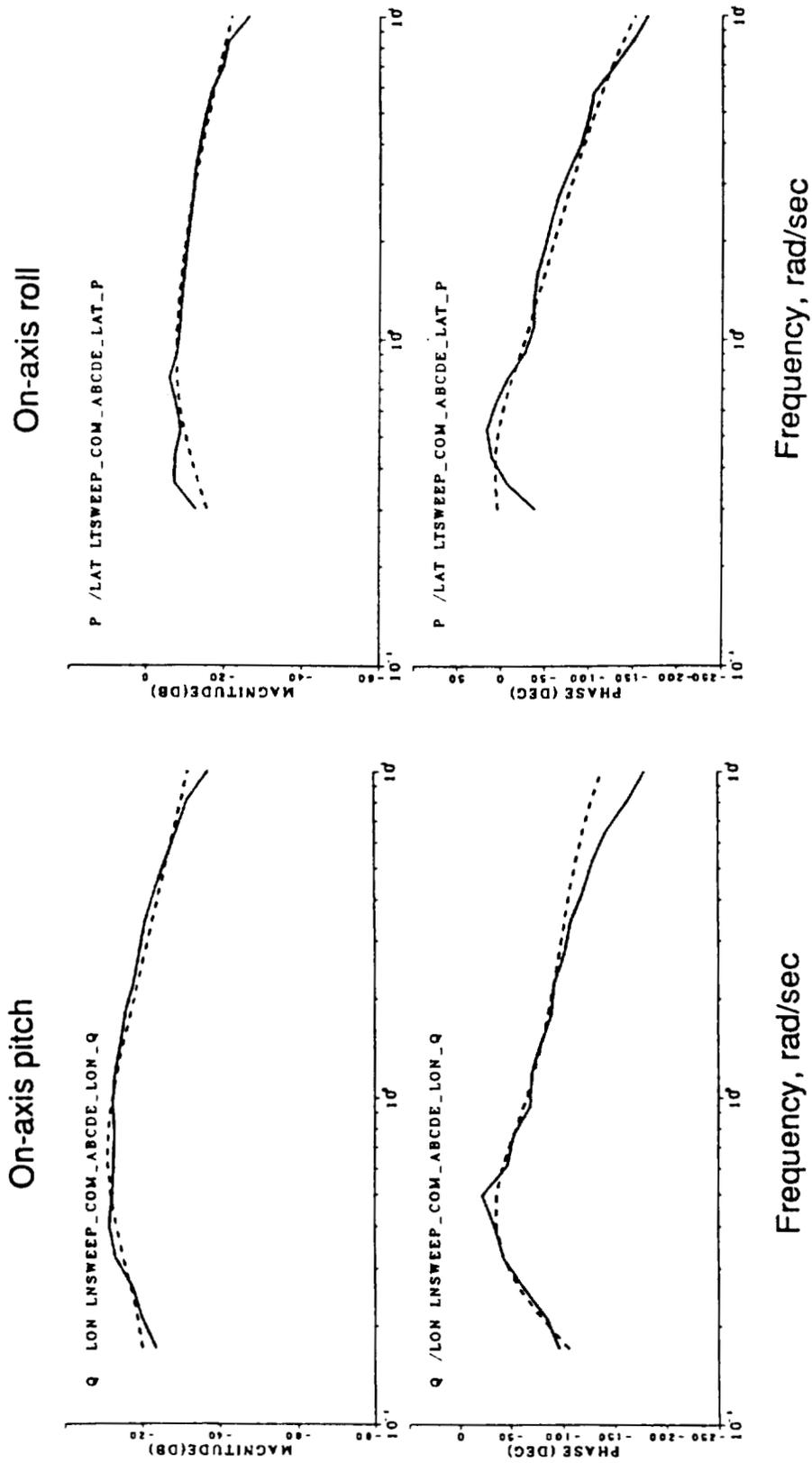
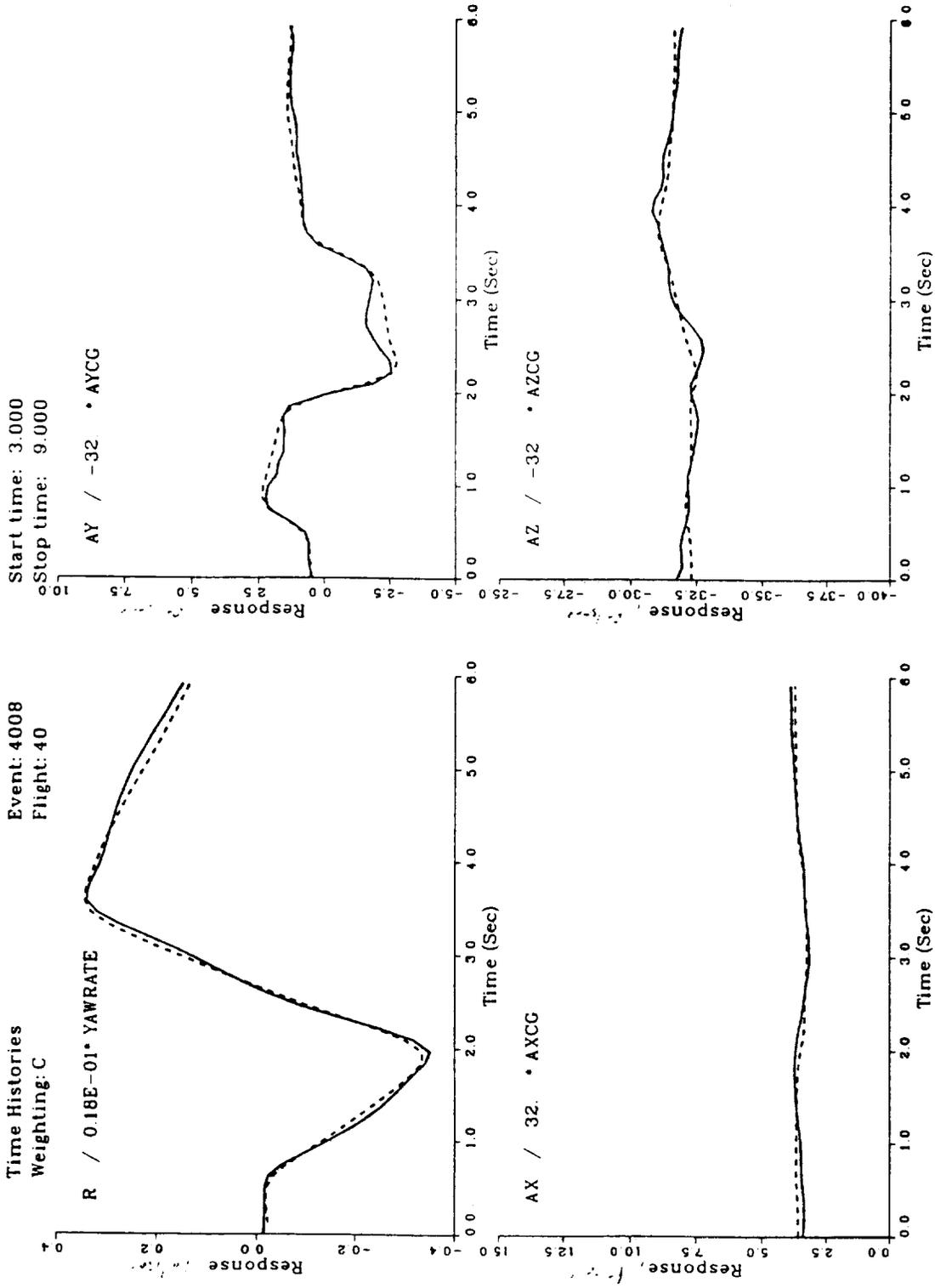
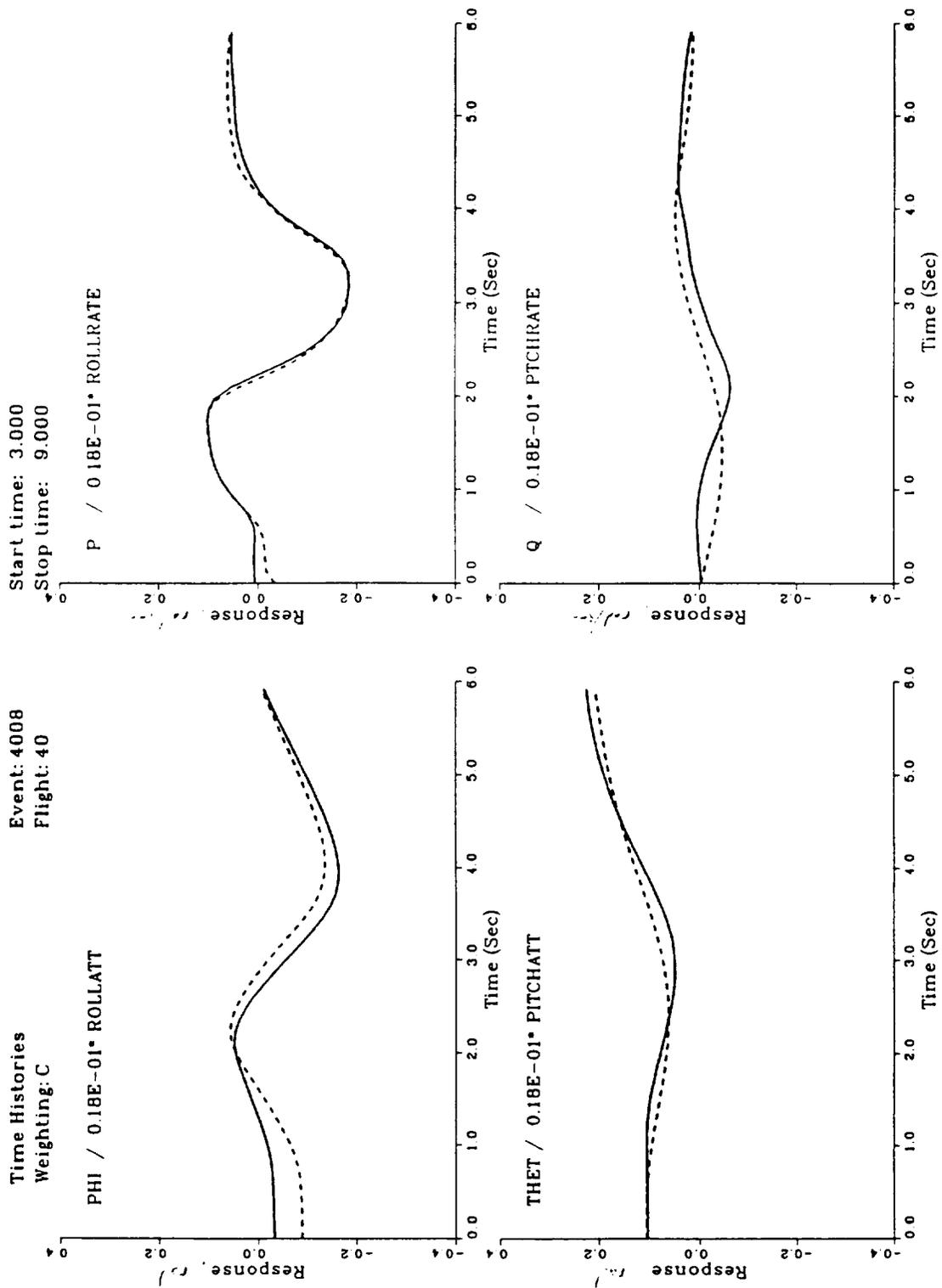


Figure 6. Identification of AH-64 hover model for piloted simulation.



(a) Yaw rate

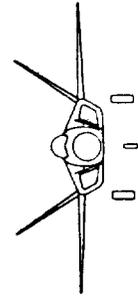
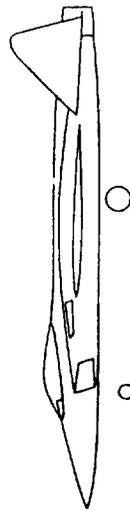
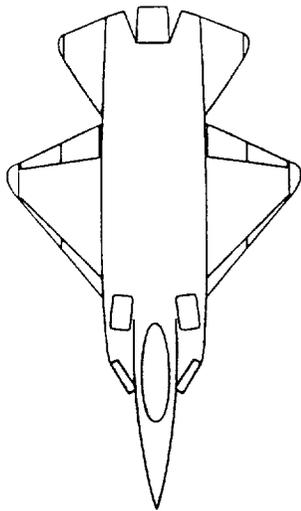
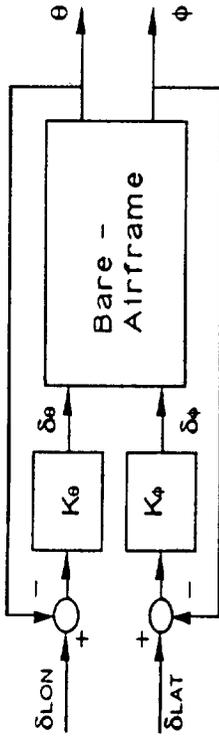
Figure 7. Model verification for pedal doublet.



(b) Roll attitude

Figure 7. Concluded.

Identification of bare-airframe responses to  $\delta_\theta$



Derivative	Initial Value	Final Value	C.R. (%)
$X_u$	-0.03471	-0.03602	-5.662
$X_w$	0.03958	0.02852	6.910
$X_{\dot{w}}$	6.764E-04	6.764E-04	.....
$X_q$	0.2451	0.2451	.....
$X_{PCD}$	-7.690E-03	-8.303E-03	-7.504
$X_{PLA}$	0.02270	0.02229	3.731
$X_{\theta N}$	-0.5150	-0.5586	-2.353
$Z_u$	-0.04596	-0.03312	-13.62
$Z_w$	-0.3704	-0.2817	-4.386
$Z_{\dot{w}}$	-0.01023	-0.01023	.....
$Z_q$	-3.754	-3.754	.....
$Z_{PCD}$	0.1389	0.1551	5.571
$Z_{PLA}$	-0.3800	-0.3305	-2.254
$Z_{\theta N}$	-0.01724	-0.03055	-4.646
$M_u$	1.661E-04	-1.059E-03	-6.016
$M_w$	1.222E-03	3.715E-03	5.263
$M_{\dot{w}}$	-1.286E-03	-1.286E-03	.....
$M_q$	-0.4971	-0.6852	-5.561
$M_{PCD}$	0.02494	0.02818	2.517
$M_{PLA}$	4.993E-04	4.993E-04	.....
$M_{\theta N}$	2.502E-04	4.953E-04	10.16

Figure 8. STOVL linear model extraction from nonlinear RT sim (Engelland).

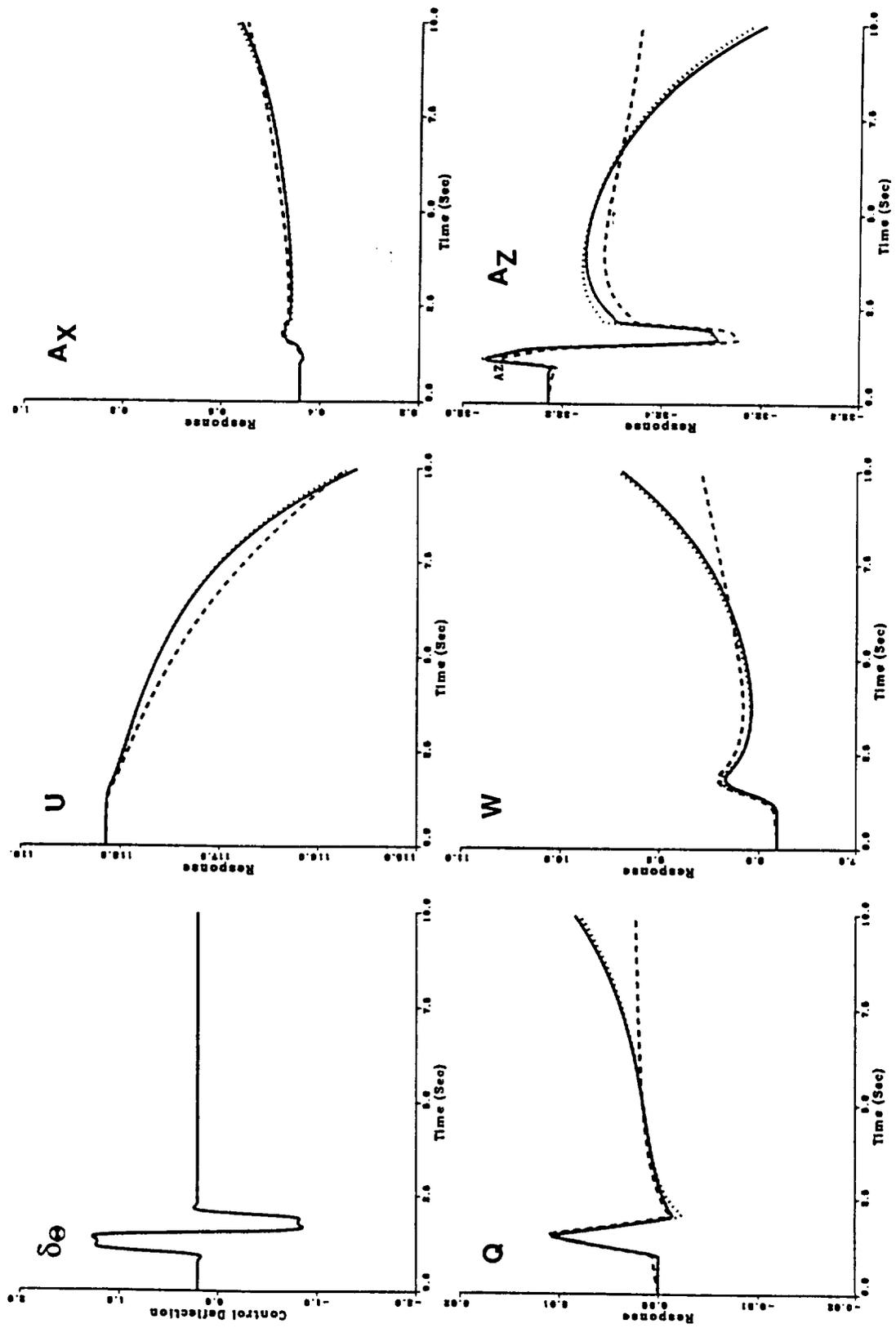


Figure 9. Comparison of time-domain predictions: numerical perturbation versus identification.

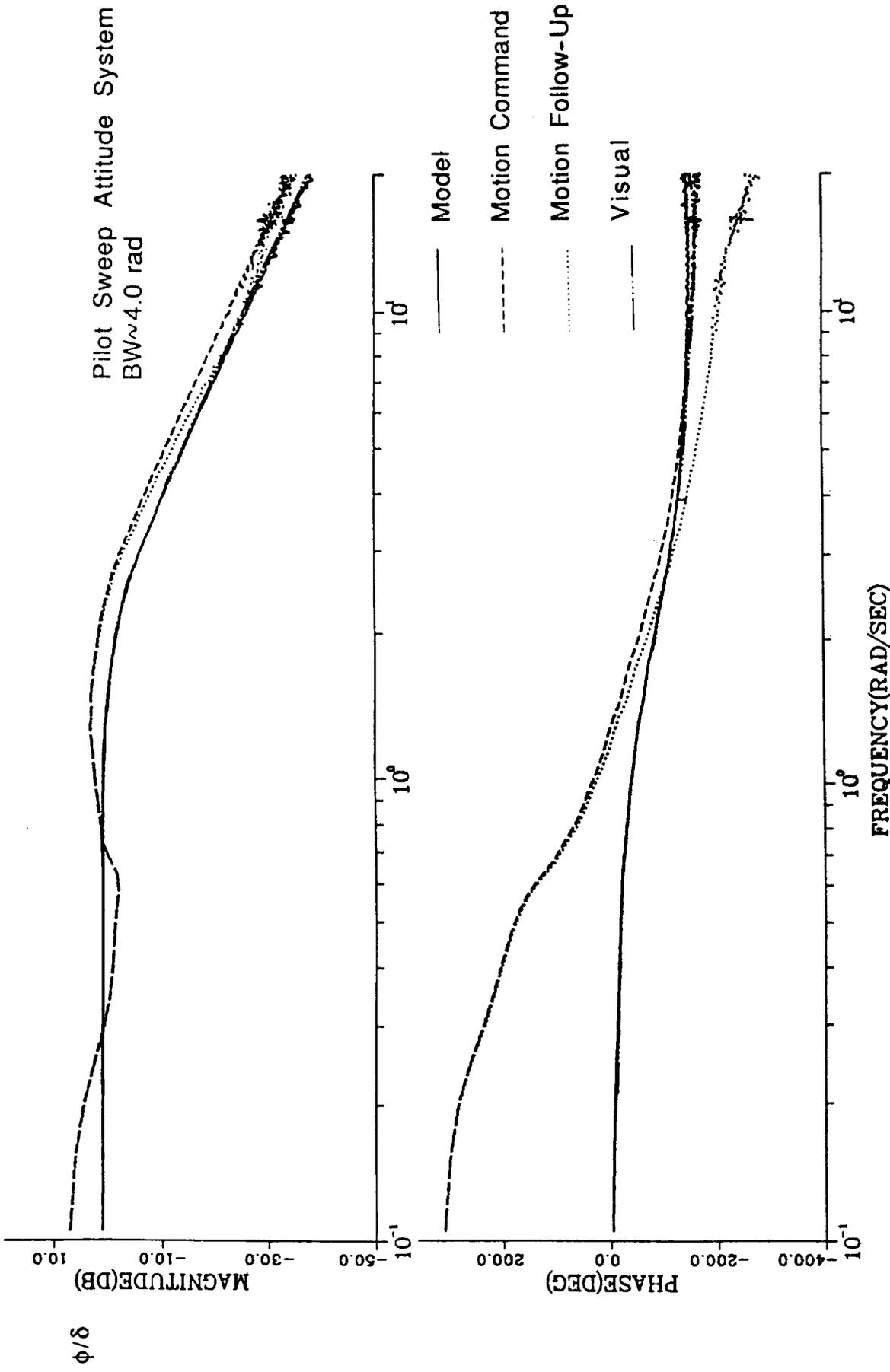


Figure 10. Documentation of vms: motion and visual systems (Atencio).

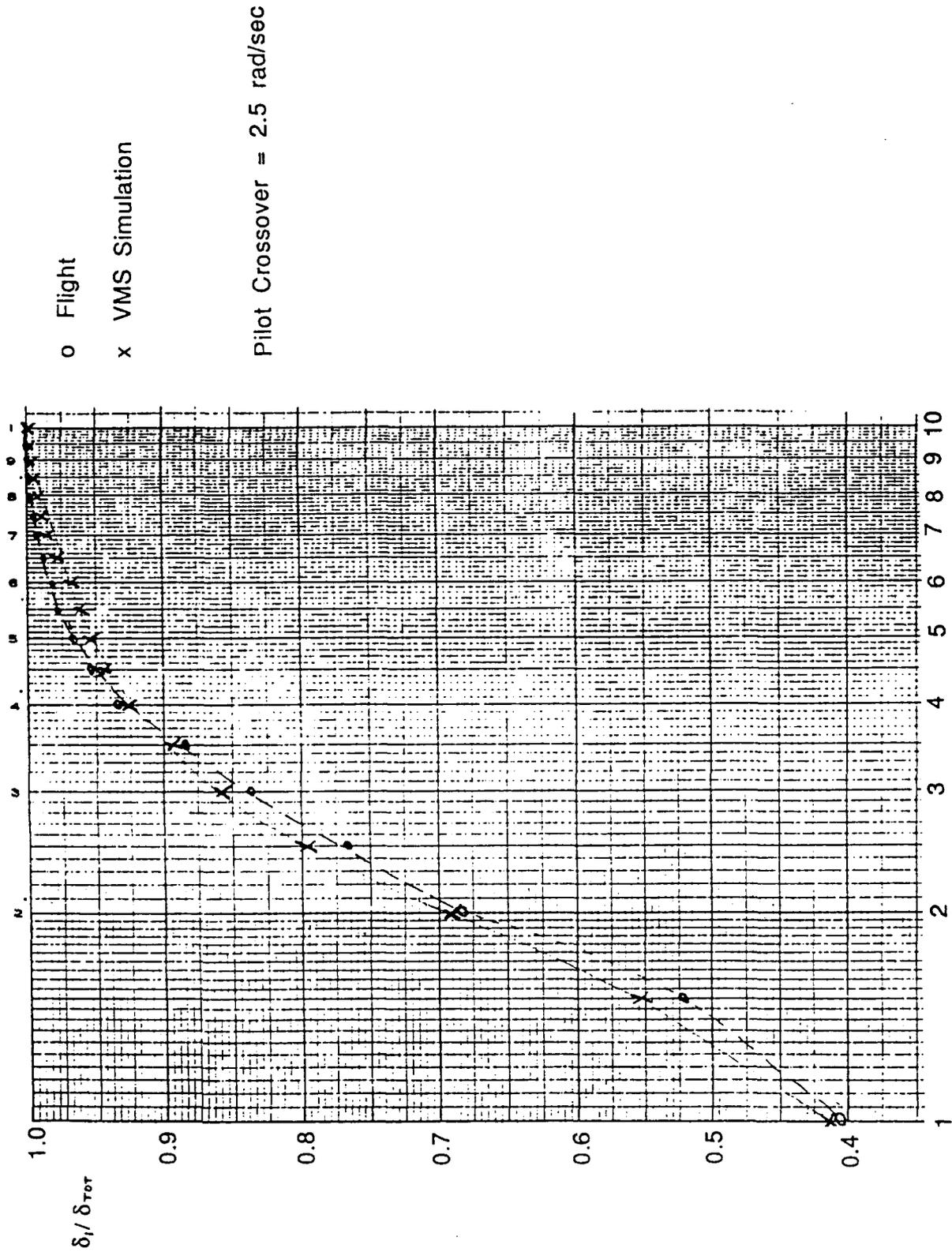


Figure 11. Comparison of pilot workload: UH-60 bob-up task (Atencio).

Of course if you are going to try to get the edges of the envelope, you are not going to make it. If you are talking about in and around the reference points, they are quite accurate. In fact the frequency sweeps, if you look at some of the papers, show pretty extreme responses. The aircraft was at the edges of its envelope and yet the linear approximations were pretty good.

**MR. BRICZINSKI:** We are progressing in the rotor modeling from quasi-map methods to a more rigorous blade-element method to say we are going to go where it might go for coefficient map models and take our entire aircraft as opposed to the rotor and go to quasified mapping models.

**DR. TISCHLER:** I am suggesting that there are some applications, for example, in this Apache case, in which we were interested in looking at the hover characteristics. We have no outside visual cues so that you are not going to be maneuvering off the edges of the envelope. You are flying on one eye and operating your hover. Clearly, it is appropriate there. The computers are now such that you can run these very sophisticated mathematical models without always making those approximations. What I am saying is it provides a mechanism for validating those, and there may be some situations in which that sort of characterization is enough. I would not say that that is generally true. Just as an example, an illustration of how you would use it.

**MR. McFADDEN:** My question is, do you find that small discontinuities in nonlinearities at neutral are a problem, or can you ignore them?

**DR. TISCHLER:** It depends on what kind they are. We did a characterization, for example, of the ADOCs system and it has nonlinear stick sensitivity, which is very common. If you have a small dead band and if you are

operating through the dead band, that has a linear describing function. But it has a phase effect and that's a mess. So it depends on how severe they are. If they are simple nonlinearities they can be accurate.

**MR. CARDULLO:** There have been considerable attempts to use parameter identification techniques to identify full force and moment nonlinear models for fixed-wing airplanes and they have been quite successful. Do you have any plans to try to develop this technique for rotary-wing nonlinear models?

**DR. TISCHLER:** I think there is some work going on in that field. I think Ron Du Val has worked to some extent in that field. It is a very tough one because the parameters that you are talking about in a full-force model combine in a very nonlinear way and in a highly correlated way. If you look at the sensitivity of some of these parameters, there isn't any. In terms of the input/output characteristics, you need a lot of detailed inflow in the component sense. You need accurate measurements. The problem with rotorcraft is that the measurements have not been made. If you look, for example, at longitudinal response, how are you going to do a correlation based on validating the X-force when there isn't any in a helicopter?

**MR. CARDULLO:** SCT has been doing some work with the V-22, I think.

**DR. TISCHLER:** Yes. And they have done a lot of work on the Harrier. They have encountered a high level of correlation. If you start introducing a lot of effects, they found things dependent on squares and cubes of whole inputs; everything was correlated. It is difficult. You need measurements of the individual components. It can be done but it is difficult.



Mark B. Tischler is rotorcraft group leader for the Army Aeroflightdynamics Directorate at NASA Ames Research Center, in which position he is in charge of research activities in rotorcraft system identification and high-bandwidth flight control. Before joining the Aeroflightdynamics Directorate in 1983, Dr. Tischler worked at Systems Technology, Inc., where he conducted analyses of a variety of fixed- and rotary-wing vehicles. He received B.S. and M.S. degrees in aerospace engineering from the University of Maryland, and a Ph.D. from Stanford University's Department of Aeronautics and Astronautics. Dr. Tischler is a U.S. member of the AGARD Flight Mechanics Panel.

## 16. BANDWIDTH AND SIMDUCE AS SIMULATOR FIDELITY CRITERIA

DAVID KEY

Many characteristics define a visual system's quality: the field of view, the resolution, the detail, and, what I will talk about, the delays in response. In addition, I will talk about how to make an overview of the total visual cuing quality.

Bandwidth has been mentioned several times today. I will define it in the context of handling qualities. I will show how the visual delays affect the bandwidth and the handling qualities, and how we could use that to assess the simulation fidelity. The first paper this morning raised many questions about how much fidelity you need for transfer of training. The report the author referred to then (ref. 1) was one I worked on back in 1980. We asked the same questions 11 years ago. My field is handling qualities, not training, so I still do not have the answers. But I will give some hint of how I think you can interpret fidelity.

Figure 1 shows a page out of the handling-quality specification ADS-33 (ref. 2), and defines bandwidth. For a rate-response type, the bandwidth is the lower of the gain margin or the phase margin. For an attitude-command/attitude-hold system, you use the phase margin.

Figure 2 shows the bandwidth boundaries in the handling quality specification. Target acquisition and tracking requirements are not appropriate for many civil aircraft. More appropriate would be the boundaries for "all other MTEs in Usable Cue Environment  $UCE \approx 1$ ." UCE is defined in reference 2. Essentially, a UCE greater than 1 implies degraded visibility, and I will limit this discussion to the context of day visual requirements.

Figure 3 shows the UH-60 Black Hawk helicopter's frequency response, gain, and phase. If we put 100 msec of pure delay into the system, it does not affect the gain, but it does affect the phase. Reading the bandwidth (it turns out that the Black Hawk is gain-margin limited), the result can be plotted on the roll bandwidth requirement (fig. 4). With 100 msec of delay, the response moves much closer to the Level 2 boundary. Thus, with an extra 100 msec of delay, the Black Hawk would have changed

from a really good (Level 1) almost into the region of degraded handling qualities (Level 2). The levels of flying-qualities concept (ref. 2) is based on the Cooper-Harper Pilot Rating Scale (ref. 3). The Cooper-Harper pilot rating scale provides a measure of subjective evaluations of handling qualities. Ratings from 1 to 3.5 imply that the aircraft is good, has desirable performance, and an acceptable workload. At ratings between 3.5 and 6.5, the aircraft is not so good (Level 2). The pilot can still do the job, but with only adequate performance and the workload is increasing. Above 6.5, the aircraft is so bad that the pilot can no longer do the task, but should not lose control (Level 3).

So, we can see that with an added 100-msec delay the Black Hawk response goes from very good to marginal, that is, almost into the Level 2 region. Now what does that mean in the simulation world? Figure 5 is a timing diagram for the VMS at Ames Research Center. Starting at the pilot's controls, there are some delays or dynamics in the artificial feel system, then there are some measurement delays, then signals go into the main host computer, which has a 20-msec cycle time. Finally, the computed aircraft response comes out to drive the CGI and the motion base. Nominally, the CGI operates at 60 Hz and effectively takes 2.5 cycles, so it adds an 83-msec delay. The motion base can add an equivalent delay of 70 msec in pitch and roll and up to 160 msec in heave. The motion dynamics are not truly a pure delay, but can be represented as such for the frequency range of interest ( $<3$  Hz).

When the pilot moves the control, he can only tell how the helicopter responds by the response of the visual and motion system. As far as he is concerned, this is the airplane. He cannot distinguish delays in the visual and motion cuing from delays in the mathematical model—that is, from the aircraft being simulated. This hypothesis sounds obvious, but we have performed an experiment to demonstrate the fact (ref. 4). The configurations tested are shown in figure 6. The fastest configuration had a roll damping  $L_p = 4$ . This would have a bandwidth = 4 with

Phase Delay:

$$\tau_p = \frac{\Delta\Phi_{2\omega_{180}}}{57.3(2\omega_{180})}$$

Note: if phase is nonlinear between  $\omega_{180}$  and  $2\omega_{180}$ ,  $\tau_p$  shall be determined from a linear least squares fit to phase curve between  $\omega_{180}$  and  $2\omega_{180}$

**CAUTION:**

For ACAH, if  $\omega_{BW_{gain}} < \omega_{BW_{phase}}$ , or if  $\omega_{BW_{gain}}$  is indeterminate, the rotorcraft may be PIO prone for super-precision tasks or aggressive pilot technique.

Rate Response-Types:

$\omega_{BW}$  is lesser of  $\omega_{BW_{gain}}$  and  $\omega_{BW_{phase}}$

Attitude Command/Attitude Hold Response-Types (ACAH):

$$\omega_{BW} = \omega_{BW_{phase}}$$

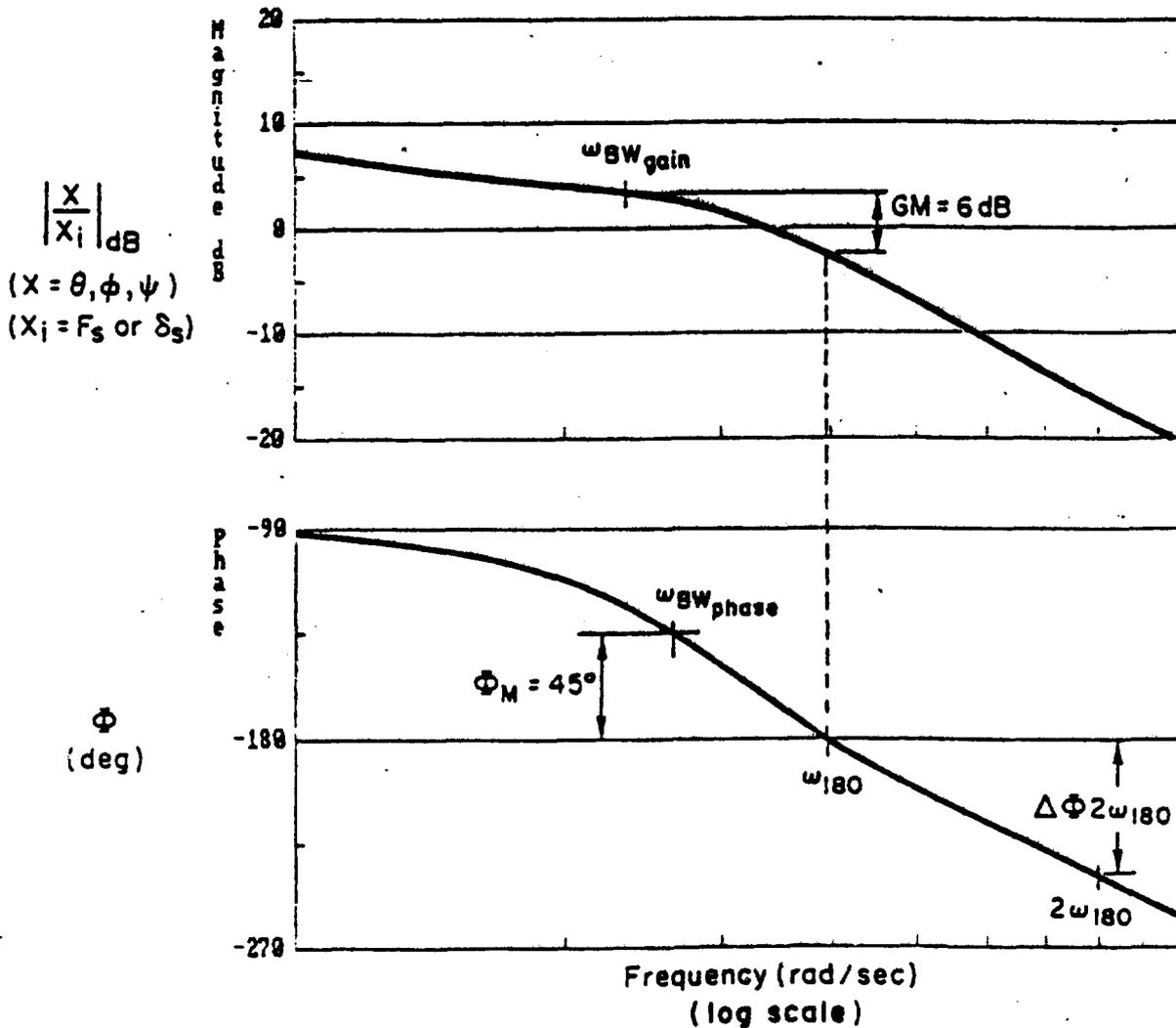


Figure 1. Definition of bandwidth and phase delay.

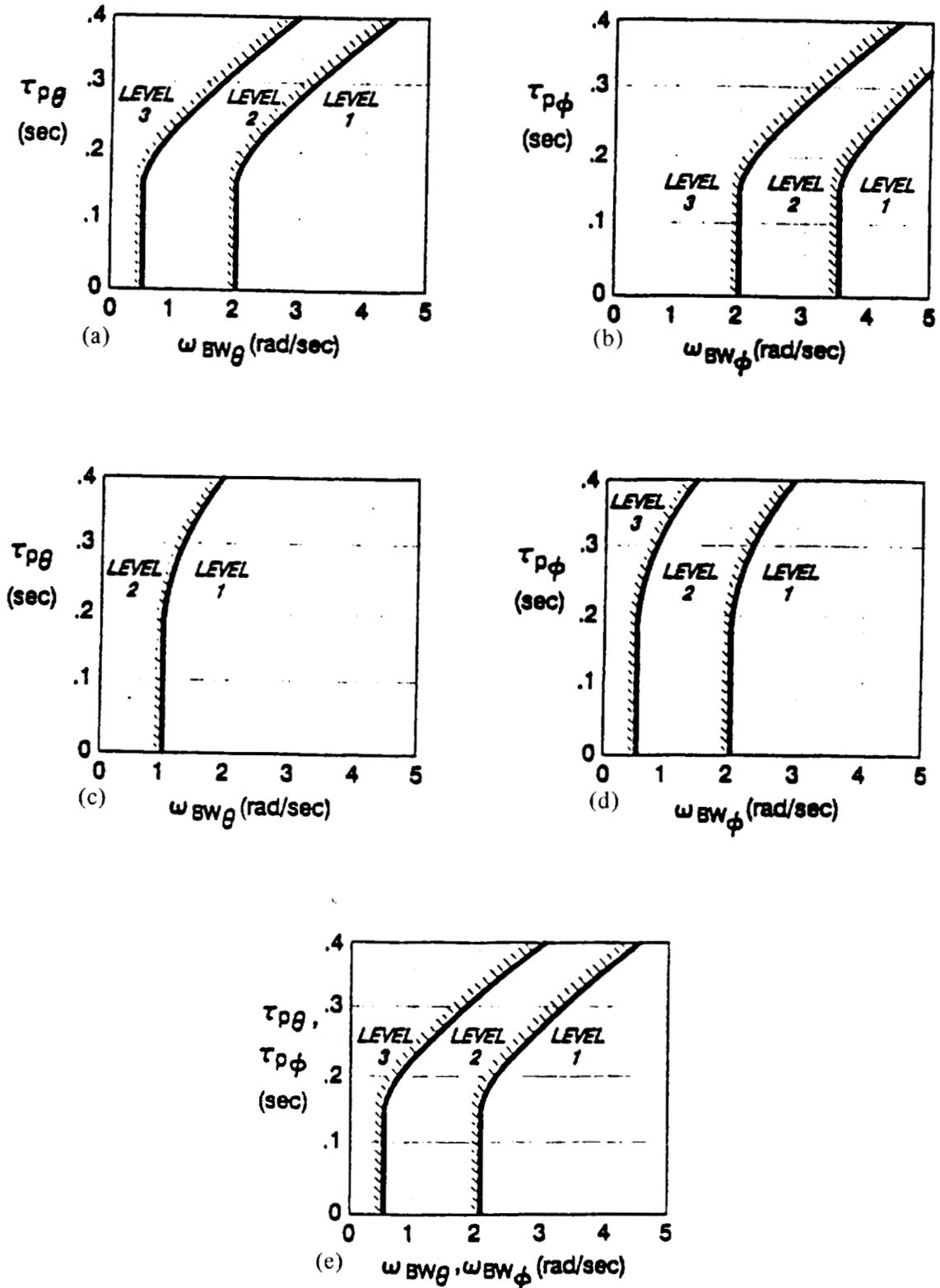


Figure 2. Handling-qualities boundaries for pitch and roll (hover). (a) Target acquisition and tracking (pitch), (b) target acquisition and tracking (roll), (c) all other MTEs - UCE = 1 and fully attended operations (pitch), (d) all other MTEs - UCE = 1 and fully attended operations (roll), (e) all other MTEs - UCE > 1 and/or divided attention operations (pitch and roll).

ROLL ATTITUDE DUE TO LATERAL CYCLIC, UH60, HOVER, SAS ON

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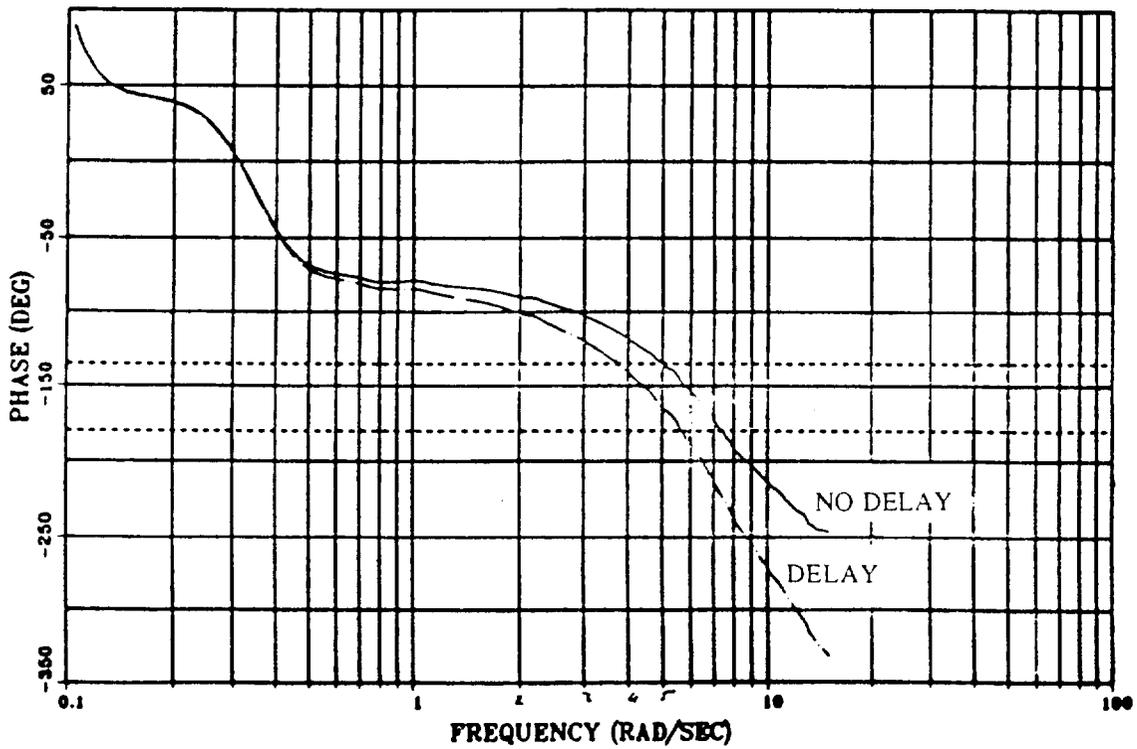
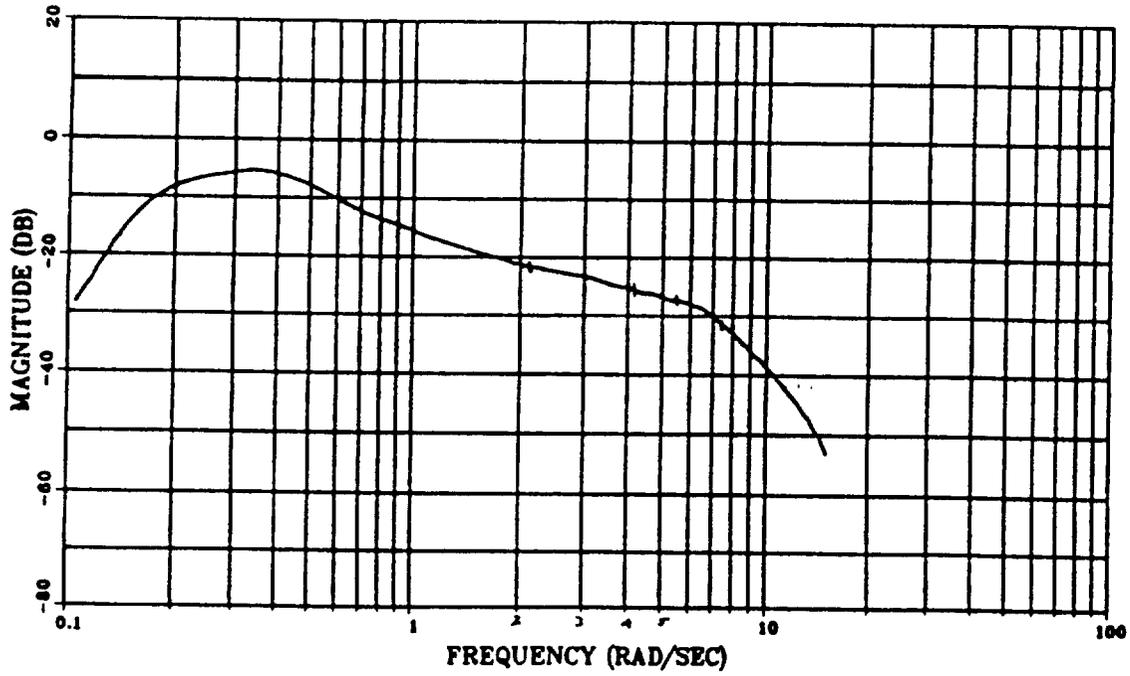


Figure 3. Effect of 100 msec delay on frequency response.

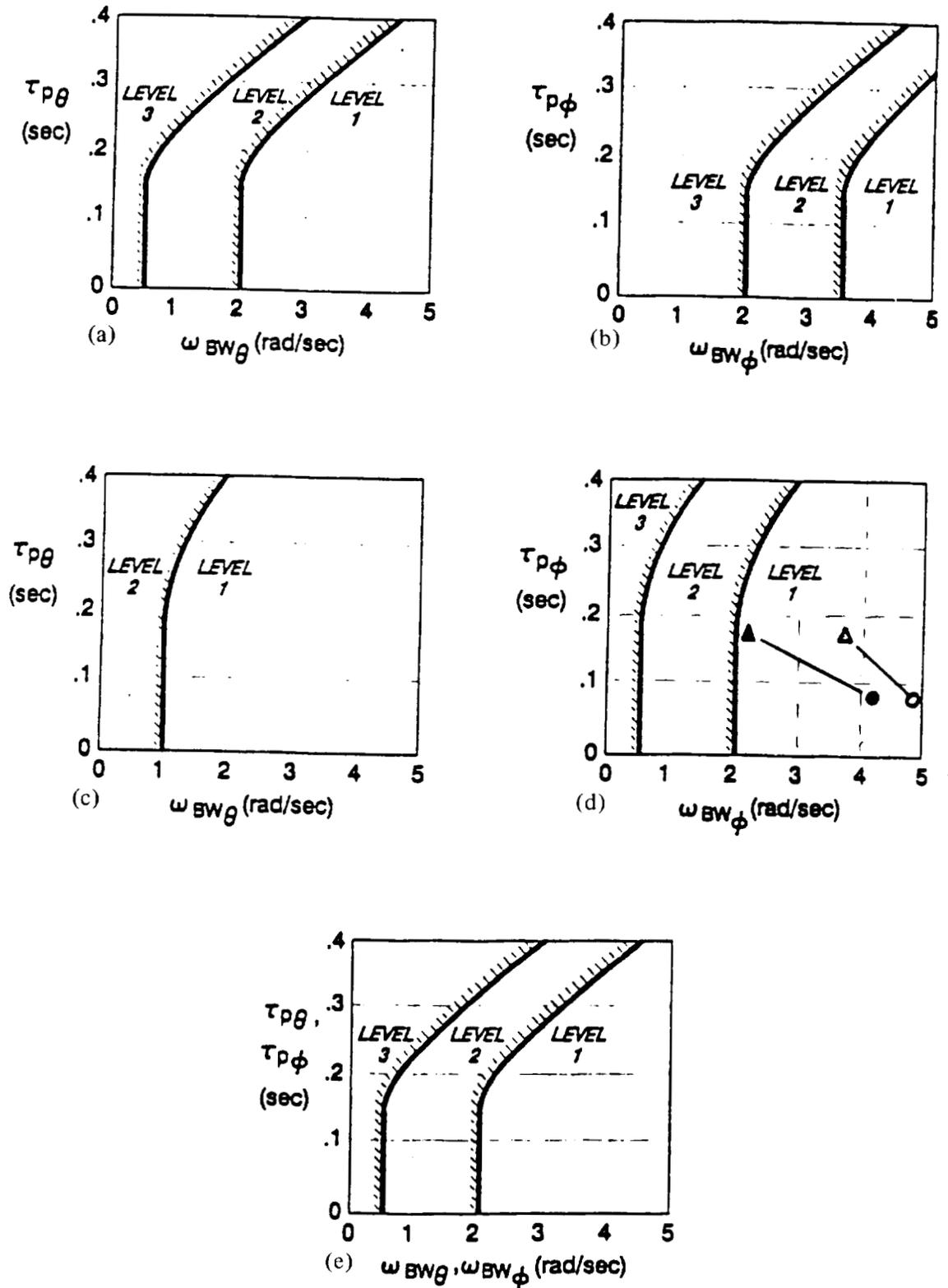


Figure 4. Effect of delay on bandwidth and phase delay. (a) Target acquisition and tracking (pitch), (b) target acquisition and tracking (roll), (c) all other MTEs - UCE = 1 and fully attended operations (pitch), (d) all other MTEs - UCE = 1 and fully attended operations (roll), (e) all other MTEs - UCE > 1 and/or divided attention operations (pitch and roll).

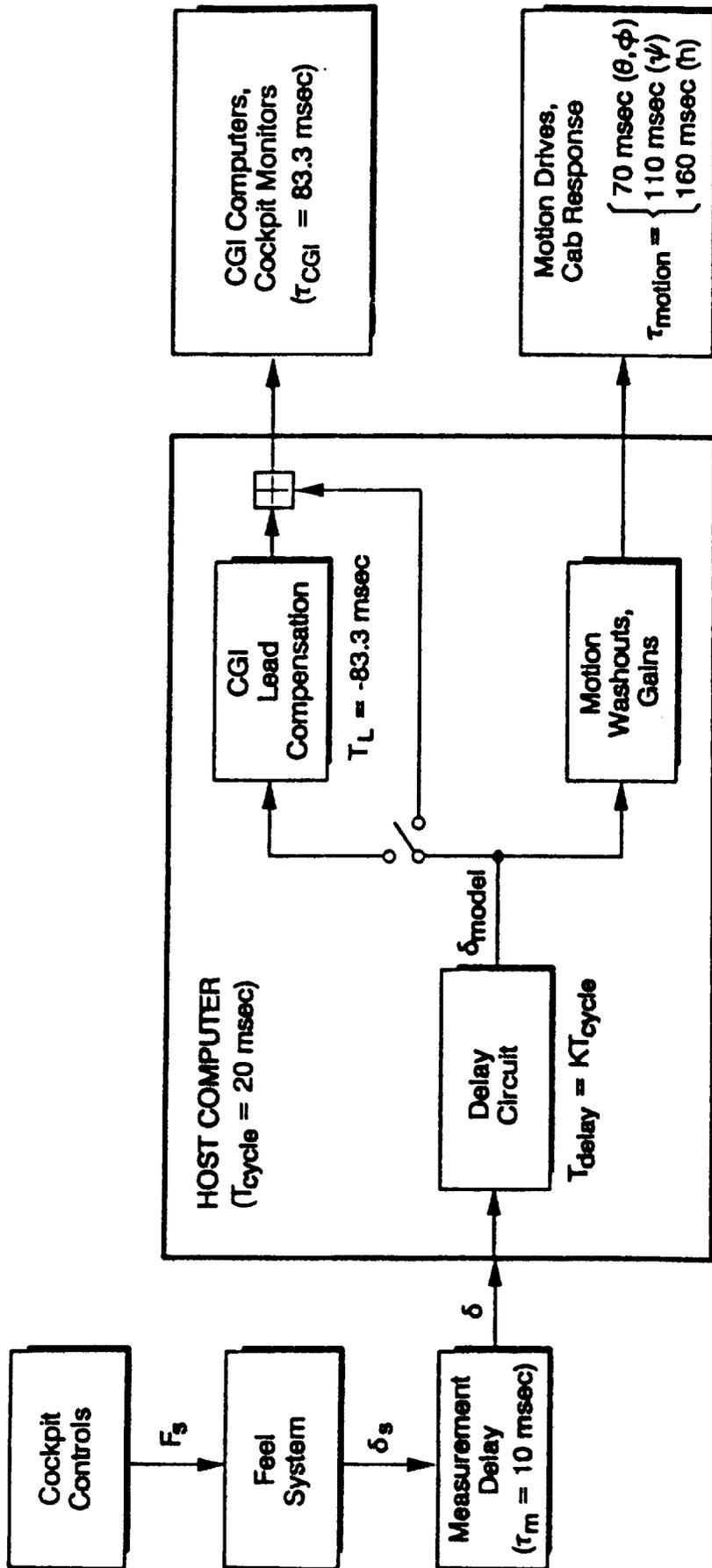


Figure 5. Simulator timing diagram.

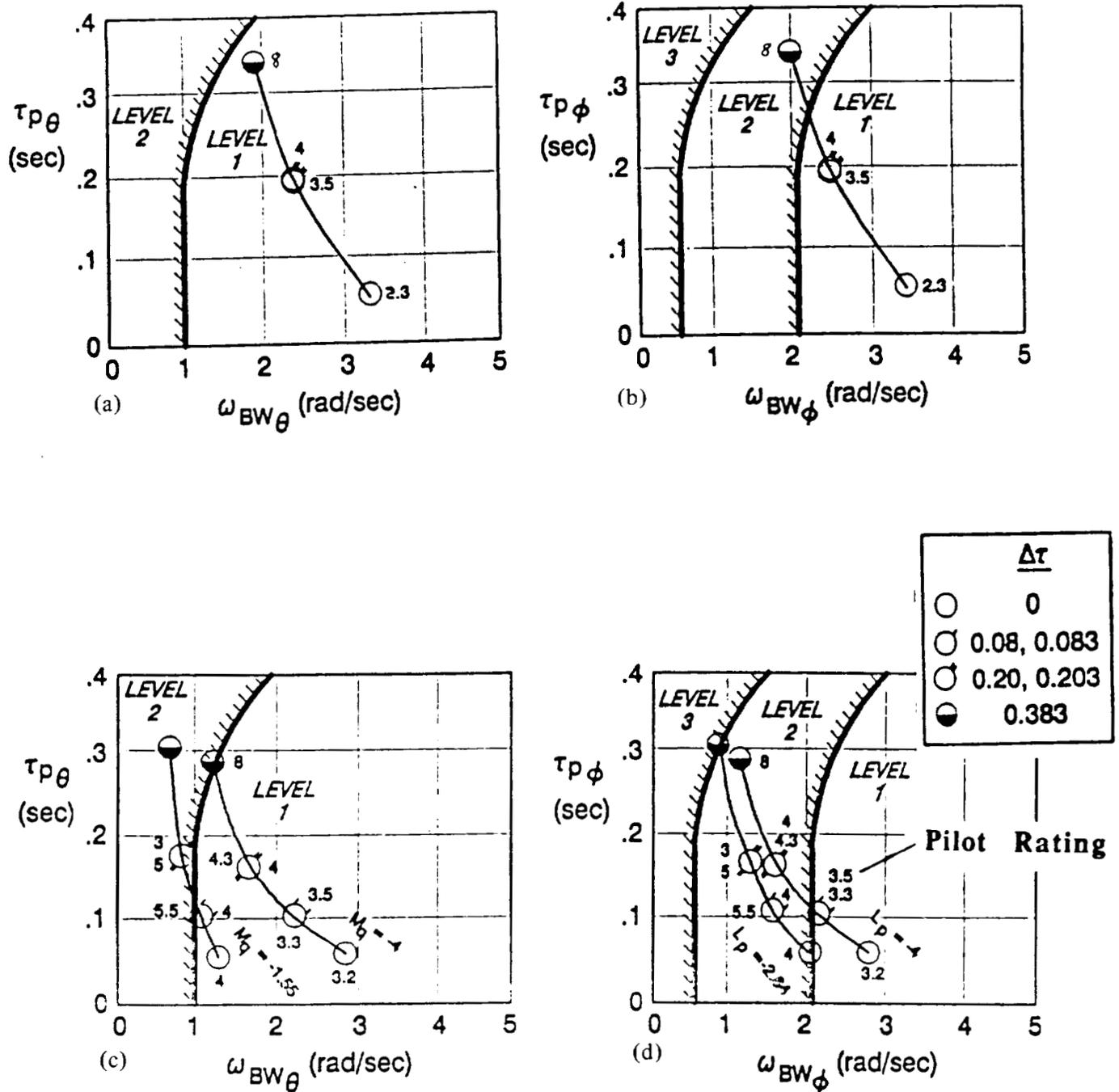


Figure 6. Handling-qualities variations with visual delays. (a) All other MTEs - UCE = 1 and fully attended operations (pitch), (b) all other MTEs - UCE = 1 and fully attended operations (roll). Attitude command response types. (c) All other MTEs - UCE = 1 and fully attended operations (pitch), (d) all other MTEs - UCE = 1 and fully attended operations (roll). Rate response types.

no delay. However, there were some delays from the computation times, so actually it has a bandwidth of about 2.8.

Dick McFarland of Ames has generated a scheme for compensating for the CGI delay (ref. 5) in such a way that

the visual delay can be made zero. To investigate the effects of delay in the visual system compared with the mathematical model (aircraft response), the basic visual delay was compensated or, alternatively, a delay was added further downstream as though it was part of the

mathematical model. Those two points lie on top of each other on the bandwidth plot (fig. 6). Similar combinations of delays up to 0.383 msec were investigated. The handling-qualities pilot rating was 3.2 (Level 1) with no delay, and with 0.383 delay the pilot rating was 8. So it is clear that the pilot ratings do indeed degrade as delays are increased, and the ratings correlate well with the ADS-33 bandwidth boundaries. Also, as hypothesized, the pilot cannot tell the difference between delays in the visual and delays in the mathematical model.

When we consider motion cues, the situation is a bit more complicated. The helicopter model was a very sim-

ple first-order one. Figure 7 shows the Bode plot for the motion. If we add the stick dynamics, the phase and gain are changed as shown. But the motion cue not only has a delay, it has to have washout to limit excursions; this changes the response even more. Consider the cab response between 1 rad/sec and the bandwidth (5 rad/sec), the region that is really of interest. The gain is about 8 dB down (a factor of about 6). Roll would be down by a factor of about 2. Phase matches the model exactly at about 2 rad/sec. At 1.0 rad/sec, there is about 45° of phase lead, and at 5 rad/sec there is about 45° of lag.

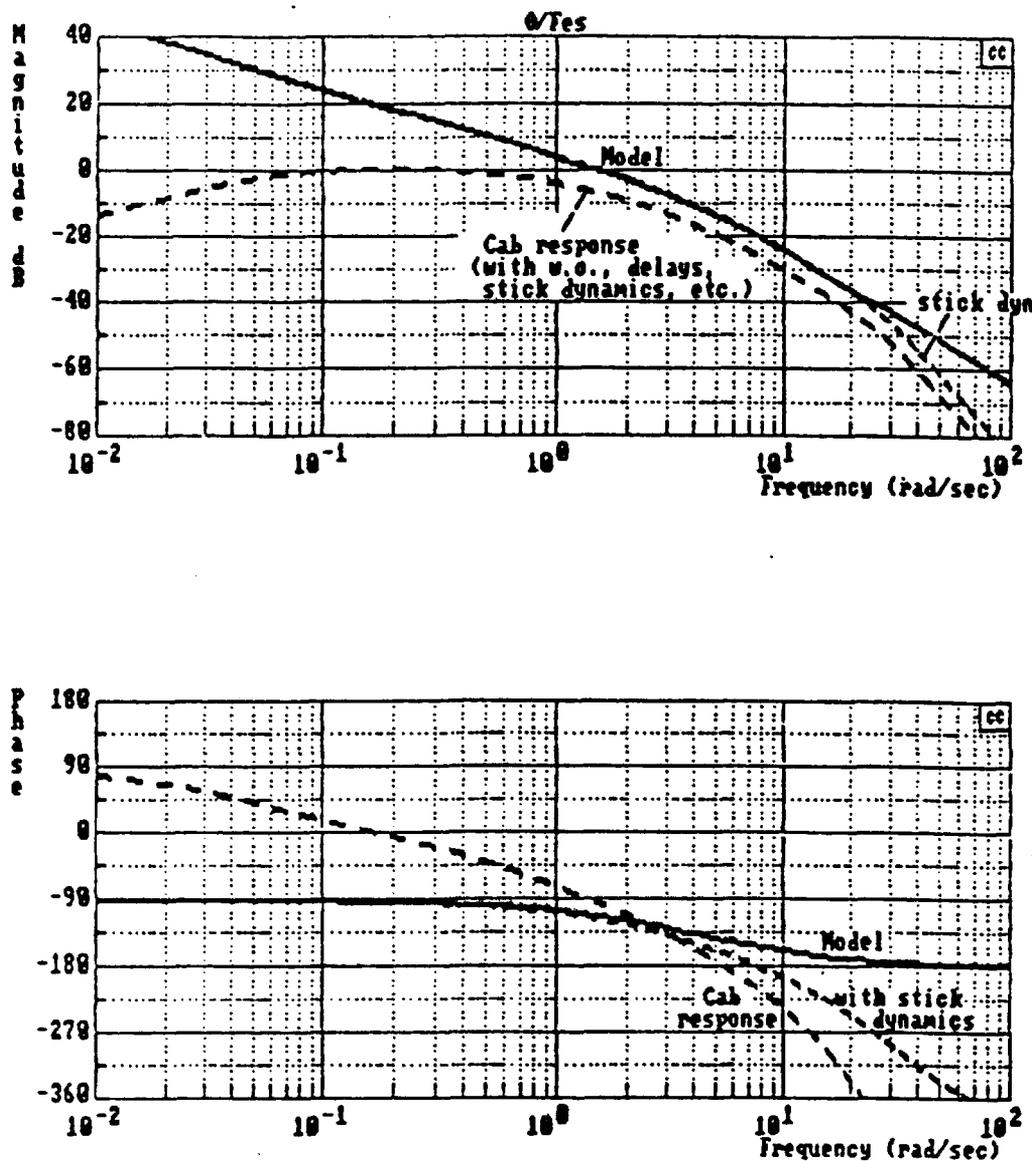


Figure 7. Motion base frequency response (pitch angle response to stick force).

Figure 8 shows pilot ratings obtained with and without 83 msec of delay, with and without motion. The first point to make is that for each of these tasks motion is better than no motion. The next point is a question: How do you combine the visual and motion dynamics? Should the visual and motion be matched or should we try to compensate for the visual time delay? We do not have an answer to this, but do plan an experiment to investigate it later in 1991. In the meantime, it would seem reasonable to set the visual delay to match the fastest axis of motion.

Back to the question of how much delay should be allowed in the visual system? My suggestion is to allow the stick-to-visual bandwidth to degrade to Level 2 (figs. 3(c) and 3(d)), but do not go out of the Level 2 region. Level 3 means the pilot cannot do the task. Presumably, if the handling qualities are so bad a test pilot cannot fly the task, then it is unlikely to give a very good transfer of training. If the helicopter itself is Level 3, you can match the helicopter, but if you are training to fly a Level 3 helicopter, there are other problems that need fixing before routine training starts! These points are summarized in table 1. Note that a fixed value of delay such as 100 ms may or may not cause these boundaries to be violated, depending on the bandwidth of the helicopter being simulated.

Now consider the question of how to assess overall visual cue fidelity. In developing the handling quality specifications (ref. 2) we had to address flying qualities in a degraded visual environment, such as when flying at night with night-vision goggles. Many parameters such as field of view, resolution, scene detail, and response dynamics influence the cue fidelity so that it is currently impossible to compute a cue fidelity. As an alternative we invented a subjective scheme for evaluating how well the pilot could see and called it the usable cue environment (UCE). The procedure is essentially as follows: Take a helicopter with good Level 1 rate response in day visual conditions and assess its capabilities in the degraded visual environment. Thus, on an appropriate dark night with clouds, rain, etc., with the vision aids to be used, perform precisely defined tasks and ask the pilot to rate how precise and aggressive he can be. The process is summarized in figure 9. To get an assessment of the simulator visual cues, we can apply the same procedure (table 2). We call this SIMulator Day UCE; that is where "SIMDUCE" comes from. If the cues are as good as they would be during the daytime,  $SIMDUCE = 1$ . If the  $SIMDUCE = 2$  or 3, it is roughly equivalent to having

Level 2 or Level 3 handling qualities, so the SIMDUCE number could be treated the same way as the degradation caused by delays. That is,  $SIMDUCE = 2$  is probably satisfactory for training. If  $SIMDUCE = 3$ , it is not satisfactory. We applied this routine to the NASA VMS simulator and obtained the data shown in figure 10. This shows the average and standard deviations and an overall UCE of 3. The VMS visual is not inherently that bad; we were trying to get degraded UCE so had put in "fog." For the FAA to incorporate the SIMDUCE concept into an advisory circular, they will have to define a Level 1 rate-response type helicopter mathematical model. This should be a standardized model, and it could be made very simple—I do not expect manufacturers would mind too much.

My conclusions can be summarized as follows:

1. For simulator delays, the visual and motion delays should be set approximately equal. Then the bandwidth from the stick, all the way through to the visual response, should be no worse than ADS-33C Level 2. A single value of delay such as 100 msec will not achieve this and should not be used.
2. Use the SIMDUCE procedure to get an overall calibration of the cue fidelity and it should be 1 or 2, not 3.

Are there any questions?

## Questions

MR. McFADDEN: I won't leave you without a question, David. What frequency response was the VMS when you used it there? You showed a frequency response. Do you recall?

MR. KEY: I am not sure I understand your question.

MR. McFADDEN: Where was your 45° phase margin?

MR. KEY: Okay. The 45° phase on the cab response to stick was around 2 rad/sec.

MR. McFADDEN: Thank you.

MR. KEY: That is not the response of the VMS to a pure input to the VMS motion. That response is through the washout. This is the way we had it set up with the washout.

MR. McFADDEN: I understand. You could have made it better.

DR. TISCHLER: Right.

MR. GREEN: The question I have is how do you treat saturation or the limited throw relative to the cab? In other words, of the motion base.

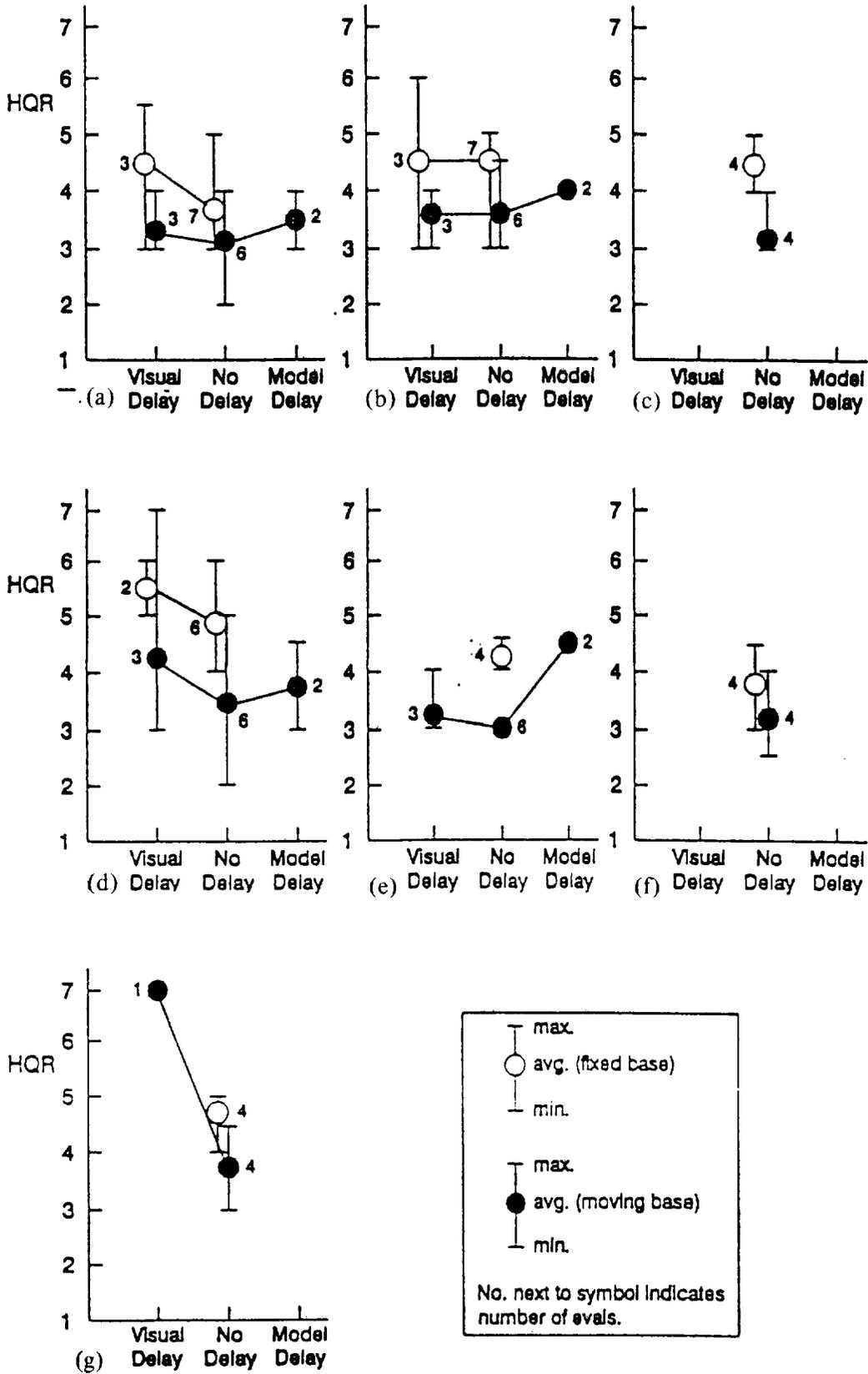


Figure 8. Comparison of handling qualities with and without motion. (a) Hover, (b) vertical translation, (c) pirouette, (d) slalom, (e) bobup, (f) dash/quickstop, (g) sidestep.

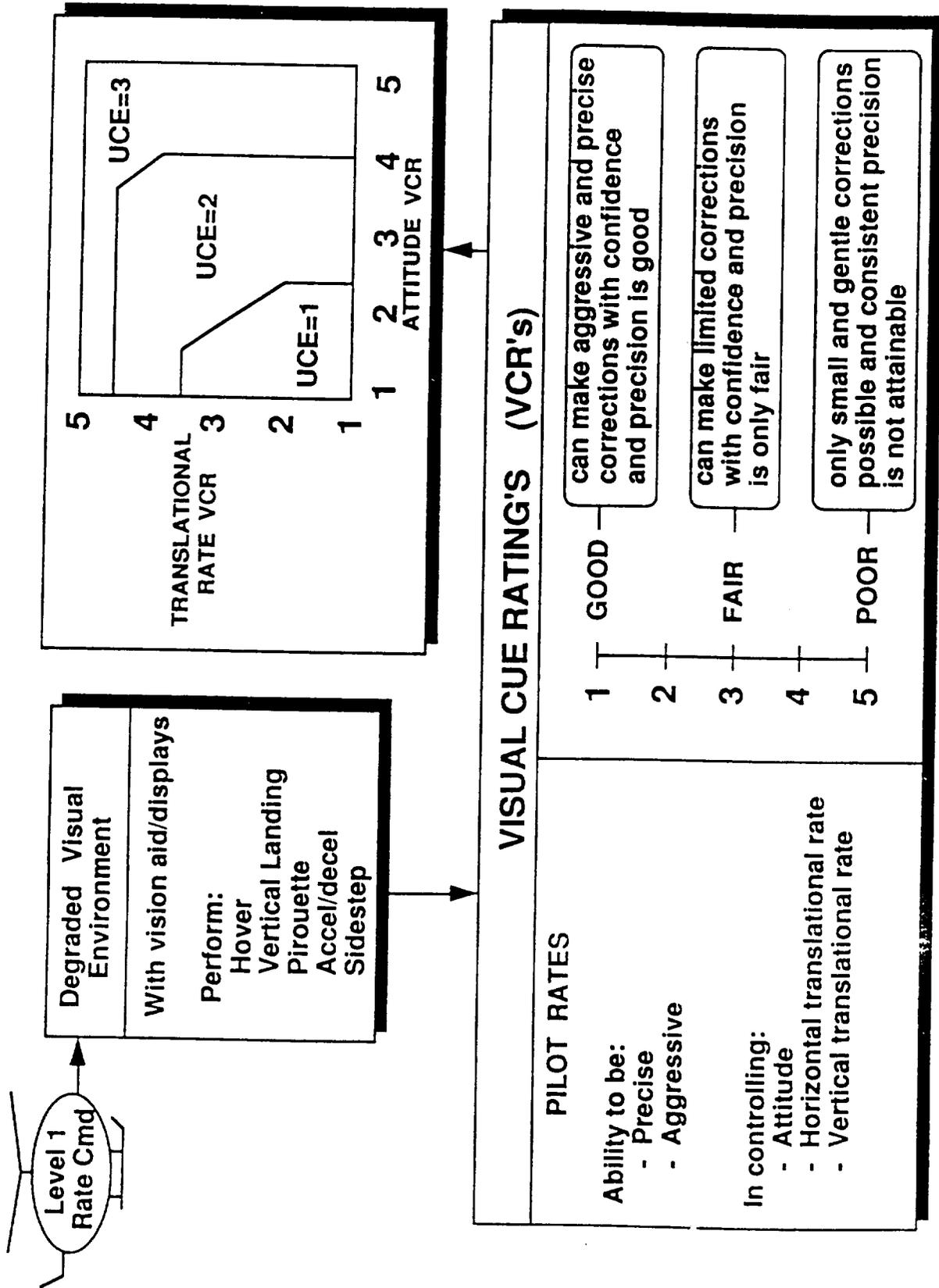


Figure 9. Determination of UCE.

Task	VCR Type	Worst VCR (each pilot)					Average VCR (each task)	Standard Deviation
		A	B	C	D	E		
Hover	Attitude	3.75	3	5	4.5	4.5	4.15	.70
	Translational	4	5	5	4.5	4.5	4.60	.37
Landing	Attitude	3.5	3	5	NR	4.5	4.00	.79
	Translational	4	5	5	NR	4.5	4.63	.41
Pirouette	Attitude	4	3	5	3	4	3.80	.75
	Translational	4.5	5	5	3	4	4.30	.75
Acceleration	Attitude	4	3	5	NR	3	3.75	.83
	Translational	4.5	5	5	NR	4	4.63	.41
Sidestep	Attitude	4.5	3	5	4.5	4.5	4.30	.68
	Translational	4	5	5	5	4	4.60	.49

**Average Attitude VCR = 4.0**

**Average Translational VCR = 4.55**

**UCE = 3**

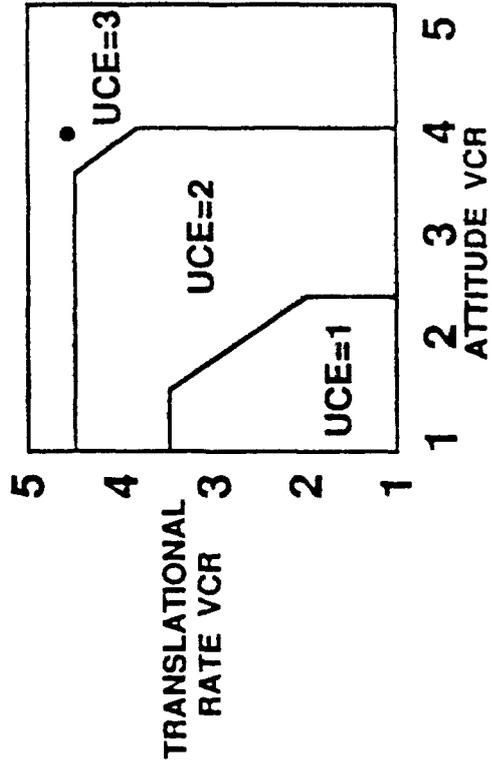


Figure 10. VCR/UCE results.

Table 1. Application of bandwidth to simulation fidelity

Criteria for simulator delay limits:
How to combine visual and motion cues?
Match visual and motion (rather than each as fast as possible)
How much handling-qualities fidelity for transfer of training?
Do not allow stick to visual BW worse than Level 2 (or match the helicopter)

Table 2. SIMDUCE: calibration of visual cue fidelity

Obtain VCR as for UCE except:
Simulator, not flight
Day, not degraded visual environment (DVE)
Task performance standards for day, not DVE
Rating is <i>SIMulatorDayUCE</i> (SIMDUCE)
Should be 1 if cues are as good as flight
If 2 or 3:
Fidelity is equivalent to Level 2 (or 3)
Treat same as degradation due to delays
Disadvantages for FAA application:
Requires a Level 1 rate response model for evaluation
Method requires subjective pilot ratings

MR. KEY: What will happen is if you saturate you will have to drive this gain down, otherwise you will be bumping into the stops all the time when you do maneuvers.

MR. GREEN: Is that self-adaptive, though?

MR. KEY: No, it is not. How do we set these things? Well, until Dick Bray retired, he did it. Now we ask him to do it even though he has retired. One of the motivations for getting these data and doing this experiment is to come up with a more systematic way of setting these washout parameters. I don't think we have good answers yet.

MR. HUTCHINSON: Would you like to suggest a time difference for the approximate cuing between the motion and visual? We all know that motion should precede the visual, but do you have any specific time element?

MR. KEY: You say you know the motion should precede the visual? Well, on the VMS we could make the visual faster than the motion, but would have to slow the visual response to make the motion faster. In terms of pure delay, I do not think visual should be slower than any motion axis. Overall, it would be nice if we could get the phase line to lie along the aircraft model through this

region (1 to 3 rad/sec) and increase the gain somewhat. I think we are trying to minimize the phase and gain distortions, that is, to minimize the gain reduction and to minimize the phase lead or lag. So whatever you can do to make the gain and phase of the motion and visual match the model is desirable.

MR. CARDULLO: I was confused by something you said—that the motion was always slower than the visual, yet according to the numbers that you gave, in two degrees of freedom, the motion has actually got less delay than the visual. You quoted 80 msec for the visual, and in pitch and roll I think you quoted 70 msec for the motion.

MR. KEY: That is true. What I thought I said was that we can compensate for the visual. There is a neat scheme for generating lead to drive the CGI. So we can compensate the visual down to zero.

MR. CARDULLO: But the delay is still there; you just compensate the phase, essentially. You could use that in motion too.

MR. KEY: No you can't. You can't do it to the motion.

DR. TISCHLER: Delay compensation will produce side bands at high frequency. Visual electronics is one

thing; in fact, in some cases even it will shudder. If we try to put similar lead through a motion system, I think it would go unstable.

MR. CARDULLO: Is that because of the high-frequency anomaly that McFarland predicts?

MR. KEY: Yes. If you take McFarland's prediction and get into very high frequency inputs or turbulence, then things do break up. So there is a limit to the frequency range that you can use it over. And like Mark [Tischler] was saying, when you try to push it through a motion base, that frequency comes down into the usable range. So it can't be done to the motion.

MR. MITCHELL: There is lead compensation already on the VMS, even for those numbers. They compensated what they could to make up for delays to begin with. The numbers are a lot worse without lead compensation.

MR. KEY: At 1 rad/sec we already have 45° of phase lead.

MR. DUVAL: We experimented with a visual lead technique when we tied Flight Lab into the Fort Ord trainer last year. And what we found was that it really did a good job, as long as the pilot's motion was continuous. But you still sense the transport delay at the onset when you had the first discontinuity of something abrupt. The lead certainly could not deal with that. Does that initial discontinuity affect the pilot's perception of what's going on?

MR. KEY: Well, it sure would if it was there. But you were driving a different system through different sets of equations with the different algorithm. A lot of people have used this without noticing too much effect. In the last simulation having a high bandwidth requirement, we only compensated the visual down to match that motion, that is, 70-msec delay on the motion; we did not go all the way to zero. So it is much smoother. But yes, if you push it to far, it will get noisy.

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David L. Key is Chief of the Flight Control Branch, Aeroflightdynamics Directorate of the Army Aviation Systems Command, Ames Research Center, Moffett Field, California. He leads 12 engineers, scientists, and pilots in a research program of flight dynamics, stability and control, flying qualities, and simulation technology. His most notable endeavor has been management of the effort to revise the helicopter handling qualities specification, MIL-H-8501A. To date, this effort has resulted in a specification adopted by the Army as AVSCOM Aeronautical Design Standard ADS-33, which has already been applied to the Light Helicopter (LH) procurement. Formal tri-service coordination for the purpose of securing ADS-33's adoption as a new MIL standard is under way.

## 17. METHODOLOGY DEVELOPMENT FOR EVALUATION OF SELECTIVE-FIDELITY ROTORCRAFT SIMULATION\*

MAJOR WILLIAM D. LEWIS, D. P. SCHRAGE, J. V. R. PRASAD, AND MAJOR DANIEL WOLFE

The value of rotorcraft simulators in providing increased safety, reduced operating/training cost, and enhanced mission training has been well documented in the past 20 years. Because of the increased emphasis on rotorcraft simulation, the FAA has launched a program to establish certification standards for rotorcraft simulators. This program is aimed at updating both rotorcraft simulator standards and the methods of simulator validation through objective and subjective tests. No methodological and acceptance criteria currently exist for the performance and handling-qualities assessment of rotorcraft simulators. In order to establish certification criteria, a planned research effort to quantify the system capabilities of "selective fidelity" simulators is required. This paper addresses the initial step toward that goal: the establishment of a method for defining the performance and handling-qualities acceptance criteria for selective-fidelity, real-time rotorcraft simulators. Within this framework, the simulator is then classified based on the required task. The simulator is evaluated by separating the various subsystems (visual, motion, etc.) and applying corresponding fidelity constants based on the specific task. This method not only provides an assessment technique, but also provides a technique for determining the required levels of subsystem fidelity for a specific task. This provides a helpful tool for use in eliminating system suboptimization.

In developing a method, our task becomes twofold: define rotorcraft simulators in terms of fidelity and then apply data-collection techniques to evaluate performance and handling qualities. With respect to fidelity, the current thrust of minimizing training costs focuses attention on the question, What is the required level of fidelity? As a general rule, procurement of new simulation devices or the updating of existing models consisted of fulfilling a wish list. If a state-of-the-art system was desired, state-of-

the-art subsystems were procured and integrated. It would not be inconceivable to have a high-fidelity visual and motion system coupled with a somewhat simplistic mathematical model. After investing millions of dollars in the system, the pilot comments were still unfavorable, for example, "A very nice procedural trainer, but it just doesn't fly like the aircraft." In this case the system integrator has suboptimized the system. Unfortunately, there is no quantitative method for defining a required level of fidelity for a given simulation task. A method for assessing selective-fidelity simulators would provide the systems integrator with acceptance criteria and would aid in preventing system suboptimization by defining required subsystem fidelity for a specific task. This paper proposes to approach this problem by defining a task-specific simulator classification system based on fidelity. With respect to applying data-collection techniques for evaluating handling qualities, ADS33, the emerging standard in helicopter handling qualities, coupled with the U.S. Army Light Helicopter (LH) Demonstration/Validation Phase test results are used to define the following:

1. Quantitative evaluation criteria. In general, data collection focuses on quantifiable items such as bandwidth, minimum and peak rates, and damping ratios that are useful in defining acceptable tolerances between actual flight data and simulation data.
2. Qualitative evaluation criteria. In general, a rating scale system for a specified set of tasks is outlined for pilot acceptance of the simulation.

As depicted in figure 1, the fidelity requirement for any simulation device is inherently dependent on the given simulation task.

The requirements for simulators in the civil and military fields have expanded greatly throughout the past decade. Along with that growth, the variety of simulation tasks has also increased. Tasks can be categorized as follows:

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\*Paper presented by Cliff McKeithan.

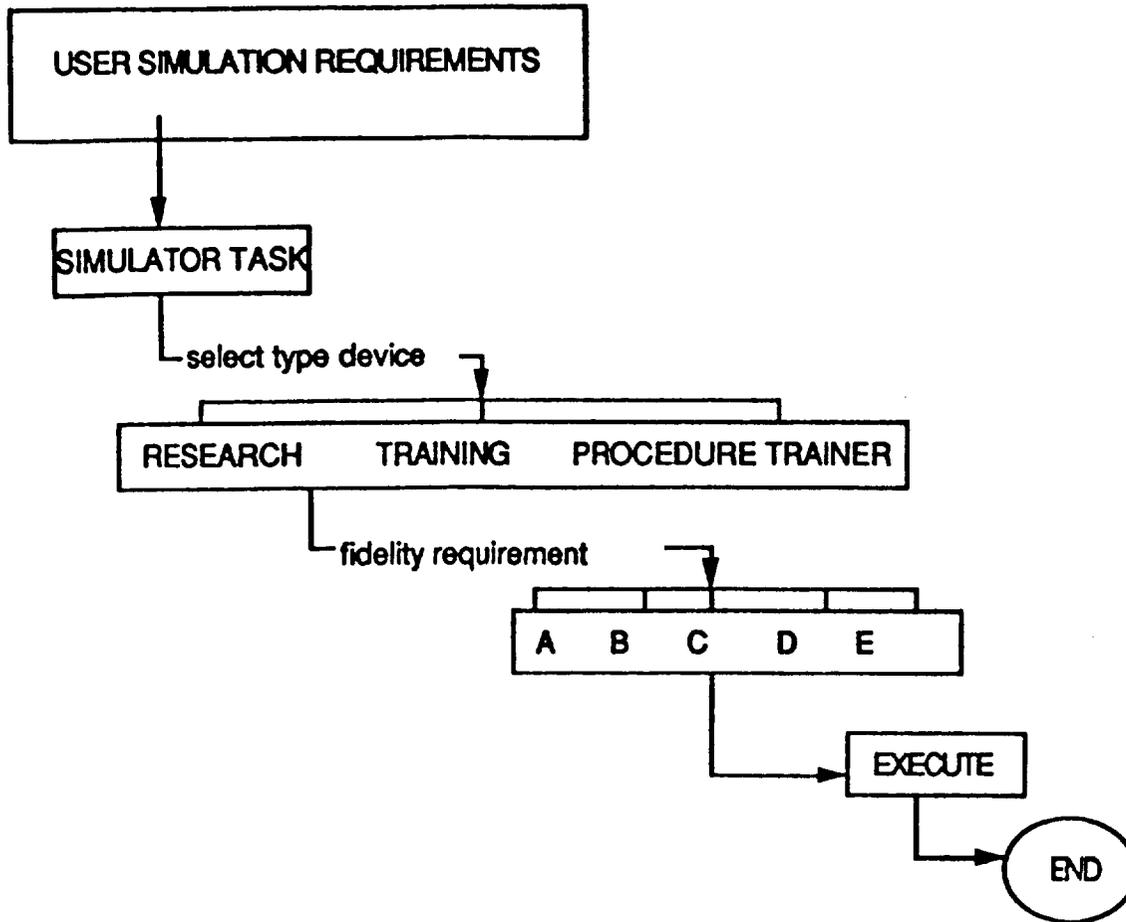


Figure 1. Fidelity dependence on type task.

1. Non-real-time research analysis
2. Part-task simulation
3. Part-mission
4. Full-mission
5. Interactive mission scenario (networked, multiple nodes)

Encompassing these tasks, simulation devices can be broadly categorized into three types: research, training, and procedural trainers. Within these broad simulation types, the levels of fidelity for a given type of device can vary greatly. For example, using cockpit crew coordination as our simulation task, a work station can be defined as a relatively low-fidelity research simulator. Yet, another simulator of the same type, such as the Crew Station Research and Development Facility (CSRDF) located at Ames Research Center, certainly has a higher level of fidelity for the same task. Thus, for a specified task, the user must be able to determine fidelity requirements. Failure to properly determine these requirements can result in (1) unsatisfactory results owing to a lack of

fidelity, and (2) satisfactory results but at a premium cost (suboptimization).

Consequently, it is desirable to classify a simulation device in terms of its fidelity. This allows a user with defined, task-specific fidelity requirements to select a simulator of appropriate fidelity and eliminate the above problems. The Federal Aviation Administration (FAA), for example, qualifies airplane training simulators in terms of objective fidelity. Simulator classification by fidelity sets a basis from which the user community can identify the specific simulation device that optimizes their needs.

The current FAA approach to the qualification of airplane simulators is embodied in FAA AC-120-40B. A similar approach is being planned by the FAA for qualification of rotorcraft simulators. The FAA approach designates simulators in four categories, levels A through D, based on increasing levels of objective fidelity. Simulator standards, objective validation tests, and functional and subjective tests are then defined for each category. For

airplanes, the standards, validation tests, and functional and subjective tests have been fairly well accepted by industry through a series of workshops. Rotorcraft simulators do not have such well-defined standards owing to the unique capabilities and complexities of the air vehicle and existing simulation technology. Development of the rotorcraft criteria will require extensive research and development.

Unlike the FAA approach to simulator classification, this method quantitatively classifies a given type of simulation device in terms of objective fidelity and a simulation-task-dependent weighting vector (TDWV). Each TDWV consists of a weighting parameter per fidelity characteristic, that is,

$$\text{SIMRATING}_{\text{task}(i)} = [\text{FIDELITY CONSTANTS}] * [\text{TDWV}]$$

where

$$[\text{FIDELITY CONSTANTS}] = [C_{\text{Cockpit}} \ C_{\text{audio}} \ C_{\text{motion}} \ \dots \ C_{\text{visual}}]$$

$$[\text{TDWV}] = [K_{\text{cockpit}} \ K_{\text{audio}} \ K_{\text{motion}} \ \dots \ K_{\text{visual}}]^T$$

For example, an air-to-air combat task requires a significant weighting parameter for the visual characteristic, whereas, the instrument training task would not require as large a weighting parameter for the visual characteristic.

Clearly, in general terms, the weighting vector will always be dependent on the simulation task to be performed. The fidelity of the simulation device is assessed by rating each component of the system. For the purposes of this method, a simulation device is described in terms of 10 subsystems, with each subsystem having varying degrees of sophistication.

In surveying current simulation designs and existing technologies, there are generally 10 subsystems which adequately describe a given simulation device:

Cockpit	Audio
Motion	Control system
Mathematical model	Environment
Ground handling	Mission equipment
System latency	Visual

In each subsystem, it is possible to associate a level of fidelity with the degree of equipment/software sophistication. For example, a motion system that employs six degrees of freedom can be associated with high fidelity, whereas a fixed-base system can be associated with low fidelity. This association between fidelity and the subsystems defines *fidelity characteristics*. Subsequently, listed below are the fidelity characteristics (rank order; low to high) of the simulator subsystems that span the spectrum of fidelity. The fidelity characteristics are assigned respective values from 1 to 4.

- |  |   |
|--|---|
| <ol style="list-style-type: none"> <li>1. Cockpit/crew station                     <ul style="list-style-type: none"> <li>Simulated instruments</li> <li>Basic, generic-type instruments</li> <li>Partially simulated cockpit</li> <li>Full-up crew station</li> </ul> </li> <li>3. Motion                     <ul style="list-style-type: none"> <li>None</li> <li>2DOF (pitch and roll)</li> <li>3DOF (pitch, roll, and yaw)</li> <li>6DOF</li> </ul> </li> <li>5. Mathematical model                     <ul style="list-style-type: none"> <li>3 DOF</li> <li>6 DOF</li> <li>6 DOF w/simple rotor</li> <li>6 DOF w/complex rotor</li> </ul> </li> <li>7. Ground handling                     <ul style="list-style-type: none"> <li>No gear</li> <li>Rigid gear</li> <li>Simplified gear model</li> <li>Comprehensive</li> </ul> </li> </ol> | <ol style="list-style-type: none"> <li>2. Audio                     <ul style="list-style-type: none"> <li>None</li> <li>Significant cockpit sounds</li> <li>Incidental sounds (precip., etc.)</li> <li>Realistic</li> </ul> </li> <li>4. Control system                     <ul style="list-style-type: none"> <li>No force feel</li> <li>Constant force (spring/damper)</li> <li>Partial duplication of actual force</li> <li>Complete duplication</li> </ul> </li> <li>6. Environmental                     <ul style="list-style-type: none"> <li>Clean air</li> <li>Discrete gusts</li> <li>First-order filtered turbulence</li> <li>Rotationally sampled turbulence</li> </ul> </li> <li>8. Mission equipment                     <ul style="list-style-type: none"> <li>None</li> <li>Communication only</li> <li>Communication/navigation only</li> <li>Complete</li> </ul> </li> </ol> |
|--|---|

9. System latency

- Non-real-time (off line)
- Significant delay
- Minimal delays
- Real time

10. Visual

None		
<u>Field of view</u>	<u>Dynamic range</u>	<u>Detail</u>
Workstation	Day	Low
75° horiz./30° vert.	Dusk	Medium
90° horiz./40° vert.	Haze/fog	High
Wider	Night	Very high

Assigning a value to each fidelity characteristic of the simulation device allows us to quantify fidelity by forming the fidelity constants matrix. For example, the U.S. Army 2B38 UH-60 simulator has the following characteristics:

1. Cockpit: full up crew station
2. Audio: incidental sounds
3. Motion: 6DOF
4. Control system: complete duplication
5. Math model: 6DOF w/simple rotor
6. Environment: discrete gusts
7. Ground handling: simple gear model
8. Mission equipment: complete
9. System latency: real time
10. Visual: 90° horiz./40° vert. full dynamic range medium detail

With the above characteristics, the UH60 training simulator's fidelity constants matrix is

$$[FIDCONST] = [C_{cockpit}, C_{aud}, C_{mot}, C_{feel}, C_{math}, C_{env}, C_{gmd}, C_{mep}, C_{lat}, C_{vis}] = [4 \ 3 \ 4 \ 4 \ 3 \ 2 \ 3 \ 4 \ 4 \ 3.25]$$

For a given simulation task, minimum acceptable fidelity characteristics must be established in order to constrain the number of simulation devices eligible to perform the task. For example, to conduct aircrew contact training, some form of visual system is a minimum requirement for the visual fidelity characteristic. Without a visual system, the device would be unable to adequately provide task training. Consequently, a  $FIDCONST_{min}$  matrix:

$$[FIDCONST_{min}] = \{ \min[C_{cockpit}, C_{audio}, C_{motion}, \dots, C_{visual}] \}$$

is utilized to establish the minimum acceptable fidelity characteristics for a given task. Exemplifying this concept, the U.S. Army 2B24 instrument training simulator, although it has many high-fidelity characteristics, such as a 6DOF motion system, full-up cockpit, and a complete

mission package, is not eligible for consideration as a simulator for contact training because it lacks a visual system

The function

$$SIMRATING_{task(i)} = [FIDCONST] * [TDWV_{task(i)}]$$

constrained by

$$[FIDCONST_{min}] = \{ \min[C_{cockpit}, C_{audio}, C_{motion}, \dots, C_{visual}] \}$$

permits classification of a type-simulation device with respect to fidelity. Given a simulation task, a  $FIDCONST_{min}$  matrix and a TDWV are determined, either subjectively or through extensive research. Once the weighting vector is known, a minimum and maximum  $SIMRATING_{task(i)}$  is calculated. Given this range of values, the simulation devices can be classified in terms of fidelity for a specified task. The range of values is partitioned into five subranges, the lowest corresponding to poor fidelity and the highest corresponding to high fidelity.

As an example, suppose the given task is instrument training and the hypothetical  $FIDCONST_{min}$  and TDWV have been determined to be

$$[FIDCONST_{min}] = [4 \ 2 \ 4 \ 4 \ 3 \ 2 \ 1 \ 3 \ 4 \ 1]$$

$$[TDWV] = [1 \ 0.5 \ 1 \ 1 \ 0.75 \ 0.5 \ 0.25 \ 0.75 \ 1 \ 0.25]$$

Multiplying  $[FIDCONST_{min}] * [TDWV]$  we find the minimum  $SIMRATING_{task(i)}$  to be 23. For the maximum  $SIMRATING_{task(i)}$ , we must multiply

$$[FIDCONST_{max}] * [TDWV]$$

where the maximum fidelity constant matrix  $[FIDCONST_{max}]$  is defined as

$$[FIDCONST_{max}] = [4 \ 4 \ \dots \ 4]$$

Thus, the maximum  $SIMRATING_{task(i)}$  is calculated to be 112. Partitioning this range of values, we can now form a task specific (instrument training) classification for simulation devices based on fidelity. For this example:

Fidelity	Classification	SIMRATING
Excellent	A	94 - 112
High	B	76 - 93
Medium	C	58 - 75
Low	D	41 - 57
Lowest	E	23 - 40

Within the scope of this method, the fidelity characteristics were limited to a range of 1 to 4 in order to provide an equivalent weighting between characteristics. This general approach obviously cannot handle specifics of any single characteristic. An alternative approach to provide equivalent weighting between characteristics is to employ normalized matrices for each characteristic. This approach would allow a greater degree of flexibility in assessing each characteristic. For example, while assessing the visual system the user could include the use of texture, infinity collimation, display types, etc. over a wider range of values. This enables the visual system characteristic to be well defined in terms of its specific attributes.

The approach has assumed fidelity constants. This implies that no coupling exists between the various fidelity characteristics. Anyone who has flown in a simulator with a high-fidelity visual system employing infinity collimation knows this to be untrue. With a fixed-base motion system, the aforementioned visual system will cause a perceived motion. The strength of the perceived motion will vary, depending on the fidelity of the visual system. This example would indicate some degree of coupling between the visual and motion characteristics. This interdependence may be better represented by use of a matrix. The terms of the matrix could be constants or variables. The exact form of the coupling would need to be determined through research.

The method at this point allows categorization of rotorcraft simulators in terms of fidelity for a specific task, but leaves unanswered the means of evaluating the performance and handling qualities of the rotorcraft simulator.

A simulator must be assessed in the areas critical to the accomplishment of the assigned mission task. These areas typically include longitudinal- and lateral-directional responses, performance in takeoff, climb, cruise, descent, etc. Objective tests are used to quantita-

tively compare simulator and aircraft data to ensure that they agree within some specified tolerance. ADS33 specifies an absolute standard for actual rotorcraft stability behavior. Requirements for handling-qualities standards are quantitatively specified, often in terms of frequency responses. Subsequently, characteristics of frequency response, such as bandwidth, damping ratios, overshoot, and time-to-peak become the tools of quantitative evaluation criteria. The method of ADS33 is applicable to simulation as well, except now these quantitative tools define tolerances between flight-test data and simulation data.

Historically, simulator performance has been evaluated in terms of the simulator's original design specification. This specification normally requires the simulator designer to meet the aircraft's flight-test data within specified tolerances. Paralleling the FAA's approach, performance testing will include the following flight regimes: hover, vertical and forward flight climb, level flight, and autorotational descent. The method of performance testing will consist of classic test techniques as outlined in USNTPS-FTM-106, Rotary Wing Performance, reference x. Tolerances between actual and simulated flight data are then established for each phase of flight based on simulator category. The tolerance for a category A simulator is thus the most restrictive and the tolerance for a category E simulator is the most relaxed. Figure 2 illustrates the relation between the level of tolerance and the simulator category. The level of tolerance, represented by the expanding circles, reflects an increasing  $\pm$  tolerance range with decreasing simulator fidelity classification.

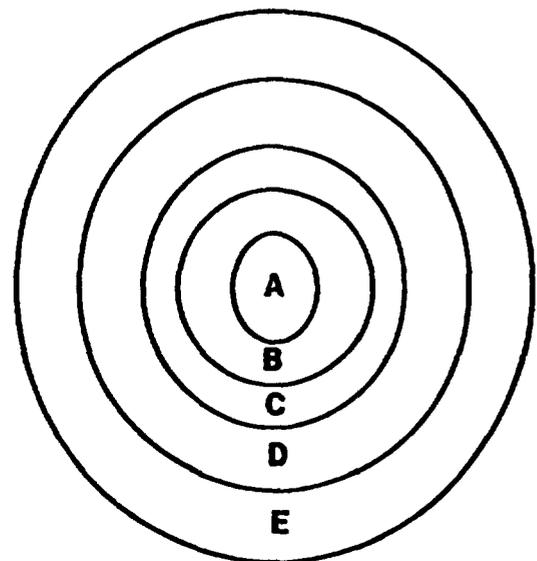


Figure 2. Tolerance level and simulator category.

Although classic performance testing techniques were adequate for evaluation purposes, classic handling-qualities testing techniques do not provide adequate information for assessing comparative simulator response. For the past 8 years, the U.S. Army, with participation from the other military services, the FAA, and industry, has been developing a new approach to specifying flight-handling qualities for rotorcraft. The existing military specification, MIL-H-8501A, was first published in the early 1950s and was revised once in the early 1960s. The new specification will eventually be designated MIL-H-8501B; however, for application to the U.S. Army LH procurement, the designation ADS33 has been issued. The approach in this new specification is based on defining mission task elements (MTE's) and relating the visual cue environment (VCE) experienced in the aircraft to the level of stabilization required. Although the approach is currently being applied to qualifying rotorcraft, it will have substantial applicability to rotorcraft simulators. ADS33 provides clear quantitative requirements for classifying rotorcraft in terms of their handling qualities. A designation of levels (I, II, III) is utilized. These requirements are divided into three main categories; control-system characteristics, hover and low speed, and forward flight. Applying this same standard to simulation, these categories now define evaluation criteria for simulation devices. Subsequently, a set of tolerance levels between flight and simulation data must be established for each simulator category as described in figure 2. A set of flight-test maneuvers based on mission-task elements is simulated to obtain quantitative and qualitative data. These quantitative data are then analyzed, and a comparison with actual flight-test data is conducted. The deviation between actual and simulated flight data then becomes the measure of acceptabil-

ity. The proximity to the specified tolerance then validates the simulation device classification.

Pilot acceptance is a subjective evaluation. Subjective tests are designed to provide a basis for evaluating simulator capability to perform over a typical training period and to verify correct operation of the simulator instruments and systems. With respect to ADS33, the flight maneuvers outlined in the previous paragraph serve as the vehicle for a subjective, qualitative evaluation. Based on mission-task elements and the visual-cue environment, this set of flight maneuvers allows the pilot to assess the perceived performance and handling-quality characteristics of the simulator. These are then compared with the pilot's assessment of identical maneuvers in the aircraft. This set of flight maneuvers allows the pilot to explore the perceptual fidelity of the system so that a fair assessment can be made. A Cooper-Harper rating scale system is used for the evaluation.

## Conclusion

The method discussed here offers the rotorcraft simulation community a unique tool for analyzing and tailoring simulation devices for specific requirements. By tying fidelity directly to the simulation task, linkage is achieved through the simulator classification model. Concurrently, methods for evaluating quantitatively and qualitatively the performance and handling qualities of a rotorcraft simulation device are presented. These methods are consistent with current evaluation criteria. Additionally, this approach permits melding of the FAA certification method with the emerging rotorcraft handling-qualities specification, ADS-33.

**APPENDIX A**

**PANEL DISCUSSION SUMMARIES**

**NASA/FAA HELICOPTER SIMULATOR WORKSHOP**



## FOREWORD

These summaries were developed from transcriptions of stenographic recordings of the session presentations and discussions. Although care has been taken to identify and eliminate the errors of interpretation to which this technique is prone, undoubtedly others remain. They are the responsibility of the editor; the discussion moderators and panelists are blameless, at least in this regard.

1. Session A: Training: Limits, Allowances, and Future  
*Ronald J. Adams*
2. Session B: Scene Content and Simulator Training Effectiveness  
*Walter W. Johnson*
3. Session C: Low-Cost Training Alternatives: Part- and Full-Task Trainers  
*David A. Lombardo*
4. Session D: Dynamic Response and Engineering Fidelity in Simulation  
*Edward D. Cook*
5. Session E: Current Training: Where Are We?  
*Greg J. McGowan*
6. Session F: Aero Modeling  
*Ronald W. Du Val*



## 1. SESSION A

### TRAINING: LIMITS, ALLOWANCES, AND THE FUTURE

RICHARD J. ADAMS,\* MODERATOR

**Panelists.** Edward Boothe, FAA National Simulation Program Office; Martin Flax, Northrop Corporation; Edward Stark, Research Consultant; Curt Treichel, United Technologies, Inc.

**Principal Topics.** Improved training and safety using simulators; regulatory limitations on testing helicopter emergencies; reduced training and cost; recommended aeronautical experience flight proficiency regulatory changes; certification credit for improved simulator training; and working-group proposed revisions to airman certification regulations.

Historically, the qualification, approval, and use of helicopter simulators have been constrained by the state of the art of visual-system fidelity and phase lag or motion-system performance. The effects of these technological limitations on the low-speed performance and hover characteristics of simulators have been to curtail the use of simulators for airman certification purposes. The intent of this session was to develop a statement of user needs for simulators, to analyze the skills pilots need to do their jobs, and to examine the suitability of presently available simulators and motion and visual systems.

Rather than dealing specifically with the principal topics originally suggested for Session A, the panelists encouraged a wide-ranging, open discussion as a means of getting ideas presented and discussed and eliciting comments and criticisms.

Warren Robbins (FAA Flight Standards) reviewed the proposed Title 14, Code of Federal Regulations, Part 142. The proposed Part 142 provides for a much more extensive use of helicopter simulators and of other, various-level training devices. Given this new regulatory sanction, it will remain for each affected school to develop an appropriate training program and associated syllabi. Once the programs and syllabi are approved, the schools will be free to market their products. Ed Boothe also pointed out that the new Part 142 certified training school would afford much greater flexibility in the ways in which helicopter simulators could be used.

The Session A group agreed upon four recommendations. **First**, it agreed to support Ed Boothe in his efforts to bring out the advisory circular. This support would extend beyond the workshop to provide support for the philosophy underlying the circular.

**Second**, it was agreed to support changes in the proposed MPRM for Part 142 when that document is made available for public comment. Warren Robbins is making every effort to produce a good and useful document, and the timely submission of panel comments will facilitate his work.

The **third** recommendation had to do with exemptions, in particular with supporting and encouraging Greg McGowan in his pursuit of additional exemptions that would enable the further utilization of the FlightSafety simulators. Special emphasis was placed on his attempts to gain approval of the simulator for use in granting add-on ratings. Some of those present agreed to work with Greg in producing another letter requesting this latter exemption. Greg said that FlightSafety is presently seeking an addendum or change to 4609 that would allow them to do some of the things discussed at the workshop. Other efforts along this line are more or less on hold, pending the outcome of this request.

The near-term plan in this regard is to request as many exemptions as practical while supporting longer-term objectives. The issue of treating the simulator as a training tool, just as the aircraft is, generated extensive discussion. It is recognized that both these training devices have limitations, but it is important to recognize

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\*Advanced Aviation Concepts.

that **both** have real and useful capabilities that should be appropriately exploited.

It would be desirable if the regulations would permit rating approval, testing, and licensing approval for simulators, if that is what the student has access to, or for the aircraft, if that is available to him. If he fails in the simulator, however, he fails just as certainly and to the same extent as if he had failed in the aircraft.

**Fourth**, it was recommended that the simulator be used as a crew training and evaluation tool. Because

industry is moving more and more toward the use of simulators and because interpersonal skills and resource management are key safety factors, it was agreed that these skills could best be evaluated in a simulator.

Although Session A discussions did touch on the issue of levels of sophistication that simulators would have to possess before flight-hour credits could be given, this matter was not considered in detail and was left for future meetings.

## 2. SESSION B

### SCENE CONTENT AND SIMULATOR TRAINING EFFECTIVENESS

WALTER W. JOHNSON,\* MODERATOR

**Panelists.** Robert Hennessy, Monterey Technology, Inc.; Robert J. Randle, NASA Ames Research Center.

**Principal Topics.** Scene display technology; scene image content; simulator utilization; and compliance evaluation.

The single most important feature of modern flight-training simulators is their visual systems, but relatively little work has been done to determine precisely what scene content best supports the training functions they perform.

The emphasis has been on how well scenes are drawn (resolution) and on how fast they are drawn (update rate). The principal purpose of Session B was to promote a discussion of how the physical scene presented by the simulator—for example, terrain, clouds, and objects—can influence the effectiveness of simulator training.

The panel addressed two main issues related to **scene display technology** in helicopter simulators: the important ways in which this technology can affect depth perception, and minimal field-of-view (FOV) requirements in simulators.

For performing low-level, close-in missions, as helicopters are often required to do, appropriate depth cues are viewed as being of major importance. In this regard, both collimated displays and the absence of binocular displays were discussed. Collimated optics, which cause all displayed objects to appear at a great distance, generate a compelling feeling of depth in the displayed scene. However, this is optically correct only for simulating objects that are far way from the observer, and thereby conflicts with scene content information—for example, perspective and absolute size—in which the objects are shown at shorter ranges. Consequently, there were recommendations by panel members that (1) a thorough analysis of image collimation be conducted to determine how it affects or distorts the appropriate optics for near-objects, with particular attention to different eye positions

(pilot/co-pilot) or observer head movements; and (2) human performance studies be undertaken to evaluate the importance of these depth cues and their accompanying distortions.

The need for good binocular cues was considered, with many panel members saying these cues are essential in low-level, close-in tasks. It was pointed out that we are capable of testing the importance of binocular cues in many head-slaved systems, but have not yet done so. Because providing binocular cues will, of necessity, require head-mounted displays, a significant cost will be incurred. Nonetheless, some of the researchers involved in this work consider the provision of binocular cues a potentially critical factor in close-in work capability for helicopters.

Field-of-view (FOV) requirements are considered to be an essential issue by industry and research workers. Because displays are the major cost items in simulation systems, industry needs to know what the requirements are. The panel did not find a consensus on this matter, but several related points were brought up during the discussions.

It was agreed, for example, that FOV requirements are largely maneuver-dependent, and that the horizontal FOV must exceed 140°, although the need for FOVs greater than 180° was questioned. It was also noted that although many pilots want a vertical FOV, such a capability is often unavailable in the actual aircraft. Moreover, vertical field of view is most often a function of cockpit design, but is also dependent on the rolling and pitching that are often encountered during maneuvers. For example, during decelerating landings, the helicopter often pitches up, thus eliminating any forward views looking downward, even though the cockpit design allows such a

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\*NASA Ames Research Center.

view in other orientations. Consequently, the important thing is to make the FOV in the helicopter simulator appropriate to the helicopter and to the maneuvers being simulated.

The panel discussion of **scene image content** was concerned principally with the issues of realism and generalization. The FAA representative wants the scene to be as realistic as possible, the reason being to make the simulator capable of doing final check rides, especially for approaches into urban vertiports, and of allowing the pilot to fly as well in the simulator as he would in the helicopter. In this regard, there were discussions about scenes depicting specific areas (e.g., a vertiport in a given city) or if the effort should be, instead, to present general characteristics from a range of possibilities.

Unfortunately, the desire for maximum realism is in conflict with training uses of the simulator, in which the ability to use both generic visual cues (horizon ratios, texture density, known size scaling) and special cue training paradigms was considered of utmost importance. Again, the panel concluded that the lack of essential research into some of these topics made it difficult to establish a visual data base that would at once be optimum for training and for efficient pilot certification testing.

In the panel's discussion of the **utilization of simulators** it was noted that training (initial, transitional, and recurrent) and certification applications of helicopter simulators may well require significant differences in the visual scenes used. For example, training effectiveness is

often improved by selective manipulations of the visual scene, whereas certification testing requires highly standardized formats.

The panel members acknowledged that **certification of compliance** is a difficult issue. Some thought that the introduction of compliance requirements for the visual scene data-base design would result in prohibitive cost increases. As a result, it was proposed that consulting groups of experts should be the recommended approach.

It was also proposed that methods should be developed for evaluating compliance; expert opinion is an example of this approach, but performance-based criteria were also suggested. The point was made that it is difficult to have principled compliance criteria without measurements of in-flight pilot performance as a basic reference.

FAA representatives involved in TERPS development want simulators to permit performance as good as that that can be achieved in flight, thereby ensuring that TERPS criteria can be met during certification flights. However, others cautioned that this performance must not be achieved by making the simulation unrealistic.

In general, the panel members agreed that the technology exists to provide the visual scene content that is required in simulations, but that we do not yet know what we should put in the visual data bases. Similarly, the display technology required for close-in helicopter missions has not been explored. Both of these deficiencies must be addressed in a more direct manner.

### 3. SESSION C

## LOW-COST TRAINING ALTERNATIVES; PART- AND FULL-TASK TRAINERS

DAVID A. LOMBARDO,\* MODERATOR

**Panelists.** Graham Beasley, Silicon Graphics; Jack Dohme, U.S. Army Research Institute; Steve Hampton, Embry-Riddle Aeronautical University; Alfred Lee, Integrated Systems Engineering.

**Principal Topics.** Personal computers and training software; computer-based flight-training devices; building the modular simulator; and designing for training device effectiveness.

The purpose of Session C was to review the background of and current research efforts in the general area of low-cost, computer-based simulation alternatives, as well as to provide recommendations for directing future, related work. Low-cost simulation alternatives are defined to include computer-based flight simulation, and both generic and type-specific non-motion flight-training devices. These alternatives have been used by many fixed-wing operators with great success, but have been otherwise ignored because they do not meet FAA guidelines for flight-training devices and simulators. Nonetheless, technological advances in the microprocessor industry ensure that the training capabilities of these and similar devices will be moved forward in directions and ways that are as of now unimaginable.

Session C panel members from Silicon Graphics, the U.S. Army Research Institute at Fort Rucker, the Embry-Riddle Aeronautical University, Integrated Systems Engineering, and Bowling Green University presented a series of wide-ranging papers. There were discussions, among others, of what constitutes a "low-cost" alternative, and what can be expected of them in terms of capability.

Research concluded earlier this year—in which computer-based training and computer-based flight simulation and their applications to teaching instrument procedures and, primarily, navigation procedures (e.g., VOR, ADF)—was reviewed. Overviews of low-cost training devices and a summary of a project in which computer-

based training was specifically applied to attitude-instrument flying were presented. In the latter, emphasis was on ab initio students and the extent to which they could be effectively trained in attitude instrument flying through use of a computer-based training program.

Regarding **personal computers and training software**, there was a consensus that they are worthy of additional support. Panel members viewed them as a developing technology, a way of the future. Virtual reality was discussed, and what is viewed as its major implications for simulation was summarized.

The panel's discussion of **computer-based flight-training devices** was never developed owing to time constraints. In discussions of the **modular simulator**, there was general agreement about a generic type of data base and that a reasonable amount of vertical information would have to be presented for effective helicopter training. The discussion here dealt principally with the data base itself, with only limited consideration given to such items as the number of channels required and the ones used the most.

The fourth topic for the panel's consideration was **designing for training device effectiveness**. In brief, the discussion of this topic reduced itself to a question: Are the data available that would permit a reliable prediction of the training effectiveness of a given simulator without the need of evaluating the simulator? The panel concluded that the answer is no—the data do not exist.

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\*Bowling Green State University.

## 4. SESSION D

### DYNAMIC RESPONSE AND ENGINEERING FIDELITY IN SIMULATION

EDWARD D. COOK,\* MODERATOR

**Panelists.** Richard Bray, NASA Ames Research Center; Roger Hoh, HOH Aeronautics, Inc.; Al Sodergren, FAA.

**Principal Topics.** Maximum tolerable transport delay; handling-qualities parameters; other matching parameters; motion parameters; and visual system parameters.

Simulator responses to control inputs must duplicate, within specified tolerances, the responses that the same inputs would effect in the actual aircraft. It is these tolerances that constitute the main subject matter in the development of simulator standards. The responses that are usually measured are of three general kinds: (1) aircraft responses of the kind frequently used to measure handling qualities; (2) limiting transport delays; and (3) correct motion responses. These responses have long been used to ensure adequate simulator fidelity so that pilot skills learned in the simulator transfer to aircraft. The application of these methods to helicopters re-opens the issues discussed in Session D.

Regarding transport delay, the panelists first dealt with the question of what constitutes an acceptable delay. The consensus seems to be for a transport delay of about 100 msec. There are commonly used methods for reducing the effects of transport delay by adding lead to the system. Which brings up the question of how to check the efficiency of such methods. Should it be done in the frequency domain? For example, should it be done using a sine wave or with a step input? The problem is that delay can be compensated for with a lead circuit in the frequency domain only so long as there is a fairly smooth and continuous input.

Given a sudden step, however, there will still be a temporary delay in the transport delay. One panel member recommended that the phase delay parameters used in handling-qualities analyses are potential metrics for determining whether the simulator properly represents its stability characteristics to the pilot as a whole. And this

leads to the question of defining appropriate handling-qualities parameters and selecting the correct ones to use.

The panel agreed that the frequency-response data of the total end-to-end system are probably as good a criterion as any for determining whether the system is working together as a unit and whether it represents itself to the pilot as the real system it simulates.

Do the Cooper-Harper ratings serve as a good basis for comparisons? In terms of validating a simulation, is the practice of having a pilot rate both the simulation and the flight vehicle a reasonable one? The panel decided that the answer is probably no. Comparisons of that kind are seen as being too time-consuming and too costly.

Concerning which motion parameters should be specified, the panelists agreed that the bandwidth of the motion hardware, which is a limiting factor, has to be increased. If it is not possible to do a good, all-around job, the yaw axis, vibration, and on-ground contact were selected as being the most important motion cues and the ones that should be emphasized. As for latency in the visual system, it can, to a great extent, be corrected by prediction techniques. The sudden step will still cause delay, but when the motion is continuous, the delay can be led and tracked.

It was agreed that the actual latency that must be categorized should be task-dependent and driven by the stipulated level of certification. That is, there should be no one generalized number. And a final comment—there were suggestions that a 30° field of view downward through the chin window should be provided.

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\*FAA National Simulator Program.

The panel discussion also touched on the problem of the relative difficulty of flight in the simulator and in the aircraft. For example, hovering is probably more difficult in the simulator than in the aircraft, and there was some

talk about providing subtle augmentation in the simulation as a means of making the workloads in the simulator and aircraft more equivalent.

## 5. SESSION E

### CURRENT TRAINING: WHERE ARE WE?

GREG J. MCGOWAN,\* MODERATOR

**Panelists.** Kenneth Cross, Anacapa Sciences; Gerald Golden, Petroleum Helicopters, Inc.; Douglas Schwartz, FlightSafety International.

**Principal Topics.** Areas of simulation improvement; simulation utilization; and economics and accessibility.

The use of commercial helicopter simulators for training and checking is controlled by FAA regulations (FARs). In some cases, exemptions to the FARs are granted for the use of an approved simulator; in others, the FARs themselves permit use of the simulator for specified training and checking procedures. However, many procedures—especially emergency procedures—that are routinely practiced in simulators, are not required by the FARs. As a result, the simulator's capacity for training that goes beyond the scope of the FARs is being underutilized.

The Session E panel convened to discuss, in general, the three principal topics mentioned above—areas of simulation improvement, simulation utilization, and the economics and accessibility of helicopter simulators. In the event, however, the discussion centered on the third of those topics, the economics and availability issue, modified, however, to couple the "helicopter simulator" term with "training devices."

Most of this panel's discussion pertained to training devices and to what can be done, especially for devices that rank in capability (and thus in complexity and cost) below the approved simulator level, to enhance their availability and to make them more economical to use and maintain.

The panel agreed that the benefits of helicopter simulation training can be made economically available to a larger segment of the helicopter-user community only through use of training devices that offer a range of training capabilities. Two prerequisites to ensure that such an expansion in training-device availability occurs were

identified: (1) definition of the training objectives and tasks that these devices would or should address, and (2) the development of an advisory circular, or of an appendix to an existing advisory circular, that would set forth the criteria with which the various levels of training devices would have to comply.

A third step, an outgrowth of item (2) above, identifies the need to establish the training and checking requirements that will be allowed for each level of training device. That is, a determination must be made about how these devices will be certified and about the training uses for which they will be approved.

These are essential considerations for the training-device manufacturers. If these devices are going to be made available to the operators, the manufacturers must have assurance that the devices they propose to produce are going to meet preestablished criteria of acceptability. If such criteria are not set forth, the risk of manufacturing the devices is too great to be entertained.

In the panel's discussion of the above, another question surfaced: Would the envisioned proliferation of lower-level training devices act to stifle the development of the more elaborate and technologically superior simulators—the Level C and D simulators? The panel's answer was no—the widespread use of limited-capability but effective training devices will not cut into the market for the highly capable machines. On the contrary, the panel finds it likely that the lower-level training devices, by introducing operators to the possibilities of simulation training in general, will act as a market stimulant for the more advanced (and expensive) simulators. As more and more operators use the lower-level devices, their interest in the higher-level ones will be heightened and they will,

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\*FlightSafety International.

perhaps, come to constitute a new market segment for the full-fledged simulator.

Although not an agenda item for this session, the panel discussed the issue of transfer of training. As a result, it recommended a thoroughgoing review of all studies pertaining to the transfer of training from simulator (or training device) to the actual flight vehicle. That is, does a skill mastered on the training device transfer positively and directly to operation of the aircraft? All sources of such information should be exploited—government, military, commercial, domestic or foreign.

If the review discloses that the information on transfer of training is inadequate for purposes of making reliable conclusions, the panel recommended that an appropriately designed study, one of adequate scope to ensure comprehensive data production, be conducted. It is a

given that transfer-of-training studies are difficult and expensive. Consequently, it is the panel's suggestion that such an effort be undertaken with the full cooperation of the government, industry, operators, and users.

In conjunction with any transfer-of-training study, there is a need for a well-defined helicopter job-task analysis. A previously conducted job-task analysis identified 56 jobs that are now being done with helicopters. The panel's recommendation is that these helicopter jobs be analyzed and broken down into their component tasks. Then, given the results of a comprehensive transfer-of-training study, the most effective training devices or simulators can be matched with the training needs at hand to produce the most effective and economical training. Task-designated priorities would ensure that tasks having the most direct bearing on safety would be addressed first.

## 6. SESSION F

### AERO MODELING

RONALD DU VAL,\* MODERATOR

**Panelists.** Frank Cardullo, State University of New York; R. Thomas Galloway, Naval Systems Training Center; Robert Toller, Quintron; Gary Hill, NASA Ames Research Center.

**Principal Topics.** Physically based simulation models; validation of physically based models; and achieving a higher level of physical modeling simulation.

Trainer manufacturers typically rely heavily on empirical models as a means of reducing computation time and maximizing tunability. Unfortunately, these models may provide poor fidelity away from the test points, and this is particularly true of rotorcraft simulators, in which empiricism may mask additional degrees of freedom as well as severe nonlinearities. This panel's purpose was to consider the need for an increased level of physically based modeling in rotorcraft simulators.

The panel's discussion centered on the trade-offs between physical and functional modeling for training simulations. It became clear during the discussion that terms had to be better defined, and from that evolved a better understanding of what is meant by an acceptable form of functional simulation: one traceable to first principles through a physical simulation.

For example, there are instances in which a rotor-map model may be an appropriate simulation model. And as long as the rotor-map model is traceable to a blade-element model from which it was derived, the functionality can be traced. That is to say, if at first a physical model of the system is created, and if the necessary approximations and reductions are made to bring it down to an appropriate level for the task to be undertaken, it should then be possible to track it back to the higher-level engineering model; in that way, control can be maintained over the procedures used to provide the modeling.

The other level of traceability is through experimental data; for example, modeling an airfoil in terms of lift and

drag data that are traceable to a wind-tunnel test. The point is that the level of functionality or analytical modeling present at any point in the simulation has to be dependent on the tasks performed on the simulator and on the level of certification that the simulation is intended to support. But for comparative purposes, it should be possible to trace any functional representation to a higher physical level so that the assumptions involved and the conditions under which the functionality is valid can be known.

The trade-offs concerning rotor-map and blade-element models were considered in this session, and it was concluded that the magnitude of the computational task associated with the blade-element model is no longer a significant limitation in its application to training simulation. Although in the past the computation costs of the blade-element model were prohibitive, fast parallel-processing computers are available and are up to the computational tasks involved. As a result, decisions concerning the use of one or the other of these models should no longer be based on computation costs.

Choosing between rotor-map and blade-element models means considering model tunability. The rotor-map model is easier to tune as a means of complying with acceptance criteria, but whether that is desirable or not has not been resolved. If model performance is force-fitted to comply with acceptance criteria, it is no longer a physically based model, and its validity between test points is unknown. Tuning the blade-element model, on the other hand, requires validation from physically meaningful parameters or from model structure changes, which is a much more costly process.

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\* Advanced Rotorcraft Technology.

Interactional aerodynamic and inflow models were viewed as comprising an important problem area, but one that is commonly neglected in training simulations. The empirical models that are used to cover these problems are often inadequate. It was noted that there is a requirement for shipboard landing simulations that can properly account for the aerodynamic interactions of the rotor wake during approaches to rolling ship decks and for the interference of the ship superstructure with the aircraft. Even engineering-level simulations lack adequate modeling to properly assess these issues. The solutions to some of these problems await technological developments.

Other issues involve solution and integration techniques. Although not usually set out in the acceptance test criteria, these factors nonetheless significantly affect simulator performance. The questions here are whether degrees of freedom are to be solved simultaneously or sequentially, how large an integration step size to use, and what kind of integration algorithms to use. The alternatives are many, perhaps to such an extent that they contribute to the problem—there are so many different approaches that can be pursued.

The panel's discussions emphasized the advantage of subsystem-by-subsystem validation over complete end-to-end validation of the entire system. With the former, what is required and how it is required can be stated more specifically. Instead of looking at the aircraft response to stick movement, for example, one looks at the way the rotor responds. Isolating the various components of the simulation model and validating them individually, improves the flexibility with which simulation models can be interchanged in future machines. As a result, one would not have to start anew with each simulation. Moreover, there would be greater confidence that the model was correct off test points.

The way models are validated also affects the physical model. A simulation may begin with a lot of physical content but then have a whole structure of tuning coefficients superimposed on it when it comes to meeting the acceptance test criteria. At present, procurement specifications do not prohibit the manufacturer from using this means of passing the acceptance test. So perhaps consideration should be given to specifying which parameters can be tuned, thus making certain that it is done in a physically meaningful manner.

How can contractors be required to use a higher level of engineering analysis and fidelity in their training models? One way would be to specify that each subsystem be validated separately and to specify the acceptance tests in terms of frequency-domain criteria. For example, specifying the frequency response of the rotor with respect to motions of the hub would mandate a blade-element model; accurate frequency-response data for the rotor could not be achieved with a rotor-map model.

A final and valid question that came out in the panel's discussion: Why create fine physically based models when the control system completely overwhelms the physical aspects of the system? It is true that the pilot cannot appreciate what is going on because of the heavy suppression of the control system. This leads to another question: Should a simulation be validated only for the nominal flight condition—control system on in the middle of the envelope with mild maneuvering—or should training systems be validated to properly model extreme conditions? If the latter is the goal, that is, if control-system failures, edge-of-the-envelope maneuvering, and other aggressive maneuvers are to be modeled, the mathematical basis for the simulation has to be far more sophisticated.



**APPENDIX B**

**LIST OF ATTENDEES**



**HELICOPTER SIMULATOR WORKSHOP ATTENDEE LIST  
FOR APRIL 23-26, 1991**

Cathy Adams  
Advanced Aviation Concepts  
10356 Sandy Run Road  
Jupiter, FL 33478  
(407)747-3414 FAX (407)747-3439

Richard J. Adams  
Advanced Aviation Concepts  
10356 Sandy Run Road  
Jupiter, FL 33478  
(407)747-3414 FAX (407)747-3439

Major Ken Adkins  
PM TRADE ATTN: AMCPM ACTS  
12350 Research Parkway  
Orlando, FL 32826

Tom Aldrete  
NASA Ames Research Center, Code FSE  
M/S 243-5  
Moffett Field, CA 94035-1000  
(415)604-3271

Graham Beasley  
Silicon Graphics  
2011 North Shoreline Blvd.  
M/S 7L552  
Mountain View, CA 94039-7311  
(415)335-7420

Holly Berry  
U.S. Army  
Aeromedical Research Laboratory  
P.O. Box 577  
Ft. Rucker, AL 36362-5292  
(205)255-6834

Richard Birnbach  
FAA Headquarters, AFS 210  
800 Independence Ave, S.W.  
Washington, D.C. 20591  
(202)267-3718

Steve Bone  
Royal New Zealand Air Force  
No 3 Squadron  
RNZAF Base Hobsonville  
Private Bag  
Auckland, New Zealand  
(64)4-4960518

Edward Boothe  
FAA Southern Region, ASO-205  
P.O. Box 20636  
Atlanta, GA 30320  
(404)763-7773

Dick Bray  
Sverdrup Technology  
NASA Ames Research Center  
M/S 211-2  
Moffett Field, CA 94035-1000  
(415)604-6002

Stan Briczinski  
CAE-Link Corp  
Link Flight Simulation Division  
M/S 622  
P.O. Box 1237  
Binghamton, NY 13902  
(607)721-4270

C. David Buchanan  
FlightSafety International  
2700 North Hemlock Circle  
Broken Arrow, OK 74012  
(918)251-0500 FAX(918)251-5597

Frank Cardullo  
Watson School of Engineering  
SUNY Binghamton  
P.O. Box 6000  
Binghamton, NY 13902-6000  
(607)777-6728 FAX(607)777-4000

T. Carver  
Civil Aviation Authority  
FOD 6  
Aviation House  
Gatwick Airport, Gatwick  
W. Sussex, RH6 OYR, England  
44-29-3573488

Bob Chen  
NASA Ames Research Center, Code FSD  
M/S 211-2  
Moffett Field, CA 94035-1000  
(415)604-5008

Bill Chung  
NASA Ames Research Center, Code FSD  
M/S 211-2  
Moffett Field, CA 94035-1000  
(415)604-6002

Gary Churchill  
NASA Ames Research Center, Code FAR  
M/S 237-5  
Moffett Field, CA 94035-1000  
(415)604-6091

Ronald Clenney  
FAA, AVN-540  
6500 S. MacArthur  
P.O. Box 25080  
Oklahoma City, OK 73125  
(405)680-4164

Edward D. Cook  
FAA Southern Region, ASO-205  
P.O. Box 20636  
Atlanta, GA 30320  
(404)763-7773

Kenneth Cross  
Anacapa Sciences, Inc  
P.O. Drawer Q  
Santa Barbara, CA 93102  
(805)966-6157

James Davis  
IVEX Corp  
4355 International Blvd  
Norcross, GA 30093  
(404)564-1148

Dr. James W. Dees  
U.S. Army  
ATZQ-TDS-ST  
Ft. Rucker, AL 36362  
(205)255-3148 FAX(205)255-2904

Dr. Jack Dohme  
U.S. Army  
Army Research Institute  
Aviation R&D Activity  
Ft. Rucker, AL 36362-5364  
(205)255-2873

Ronald Du Val  
Advanced Rotorcraft Technology, Inc  
1685 Plymouth St, Suite 250  
Mountain View, CA 94043  
(415)968-1464

James Erickson  
FAA Southwest Region  
4400 Blue Mound Road  
Fort Worth, TX 76193  
(817)624-5100 FTS 734-5100

Paul Faidley  
FAA Southwest Region, ASW-270  
4400 Blue Mound Road  
Fort Worth, TX 76193  
(817)624-5272 FTS 734-5272

Joseph Fernandez  
Aero Simulation Inc  
P.O. Box 290357  
Tampa, FL 33687  
(813)985-2072

Martin Flax  
Northrop Corp  
3521/64  
1 Northrop Ave  
Hawthorne, CA 90250  
(213)332-2201

Umberto Fontanella  
Agusta S.p.A.  
21049 Tradate (VA)  
Via Isonzo, 33  
39-331-815111 FAX-39(331)843910

Thomas Galloway  
U.S. Navy  
Naval Training Systems Center, Code 211  
12350 Research Parkway  
Orlando, FL 32826  
(407)380-4648 FAX(407)380-4257

Vickie Gardner  
Sverdrup Technology  
NASA Ames Research Center  
M/S 237-11  
Moffett Field, CA 94035-1000  
(415)604-5673

Ronald M. Gerdes  
Syre  
NASA Ames Research Center  
P.O. Box 96  
Mt. Hermon, CA 95041  
(408)335-2384

Antonio Gervasi  
Agusta S.p.A.  
C.A.S.V. Polizia Di Stato  
00010 Pratica Di Mare  
Roma, Italy  
39-331-229195

Gerald Golden  
Petroleum Helicopters Inc  
P.O. Box 90308  
Lafayette, LA 70502  
(318)235-2452 (318)235-3424

David Green  
Starmark Co  
1745 S. Jefferson Davis Hwy  
Arlington, VA 22202-3402  
(703)685-4250

Dave Graham  
Ferranti International  
Flight Simulation & Training  
2238 Grey Fox Ct.  
Orange Park, FL 32073  
(904)264-0700 FAX(904)264-0058

David Gupton  
IVEX Corp  
4355 International Blvd  
Norcross, GA 30093  
(404)564-1148

Brian Hampson  
CAE Electronics  
8585 Cote De Liesse  
Montreal, Quebec, Canada  
(514)340-5531

Steve Hampton  
Embry-Riddle Aeronautical University  
D Building  
Daytona Airport  
Daytona Beach, FL 32114  
(904)239-6800

Dan Hart  
NASA Ames Research Center, Code YBC  
M/S 210-7  
Moffett Field, CA 94035-1000  
(415)604-3505

Jake Hart  
Aerospatiale Helicopter Co  
2701 Forum Drive  
Grand Prairie, TX 75051  
(214)641-3566

Sandy Hart  
NASA Ames Research Center, Code FLR  
M/S 262-3  
Moffett Field, CA 94035-1000  
(415)604-6072

Gary Hassett  
Burtek, Inc  
P.O. Box 1677  
7041 East 15th St  
Tulsa, OK 74101  
(918)836-4621

Robert Hennessy  
Monterey Technologies  
NASA Ames Research Center  
M/S 243-4  
Moffett Field, CA 94035-1000  
(415)604-5004  
William Herberger  
Star Technologies, Inc  
515 Shaw Road  
Sterling, VA 22170  
(703)689-4400

Gary Hill  
NASA Ames Research Center, Code FAS  
M/S 237-11  
Moffett Field, CA 94035-1000  
(415)604-6577

Roger Hoh  
HOH Aeronautics, Inc  
2075 Palos Verdes Drive, North  
Suite 217  
Lomita, CA 90717  
(213)325-7255

Jacob A. Houck  
NASA Langley Research Center  
Analysis & Simulation Branch  
M/S 125B  
Hampton, VA 23665-5225  
(804)864-6412 FAX(804)864-7635

John Hutchinson  
Link-Miles  
Churchill Industrial Estate  
Lancing, Sussex, United Kingdom

Pete Hwoschinsky  
FAA Headquarters, ARD-30  
800 Independence Ave, S.W.  
Washington, D.C. 20591  
(202)267-8531

Donald Irving  
Civil Aviation Authority  
FOD 6  
Aviation House  
Gatwick Airport, Gatwick  
W. Sussex, RH6 OYR, England  
44-293-573715 FAX 44-293-573999

Walter Johnson  
NASA Ames Research Center, Code FLR  
M/S 262-2  
Moffett Field, CA 94035-1000  
(415)604-3667

Amnon Katz  
University of Alabama, Tuscaloosa  
P.O. Box 870280  
Tuscaloosa, AL 35487-0280  
(205)348-7303 FAX(205)348-8573

David Key  
U.S. Army AVSCOM  
Aeroflightdynamics Directorate  
M/S 210-7  
Moffett Field, CA 94035-1000  
(415)604-5839

Ronald Kruk  
CAE Electronics  
8585 Cote De Liesse  
St. Laurent, Quebec, Canada H4T1G6  
(514)341-6780 x2012

Bill Larsen  
FAA Field Office  
Ames Research Center  
M/S 210-2  
Moffett Field, CA 94035-1000  
(415)604-6380  
Nick Lappos  
Sikorsky Helicopter  
6900 Main St.  
Stratford, CT 06118  
(203)386-6705

Al Lee  
Decision Systems  
220 State Street  
Los Altos, CA 94022  
(415)949-1789

David Lombardo  
1113 S. Raven Road  
Shorewood, IL 60436  
(815)838-0500 x433

James I. McDaniel  
FAA Headquarters, ARD-30  
800 Independence Ave, S.W.  
Washington, D.C. 20591  
(202)267-8759 FAX(202)267-5117

Bert McFadden  
McFadden Systems, Inc  
11835 E. Smith Avenue  
Santa Fe Springs, CA 90670  
(213)948-4414 FAX (213)948-1291

Greg McGowen  
FlightSafety International  
887 Southern Blvd  
West Palm Beach, FL 33406-1431  
(407)686-7677

John McIntosh  
Hughes Simulation Systems, Inc  
Arlington Division  
Arlington, TX 76011  
(817)640-5000

Cliff McKeithan  
Georgia Institute of Technology  
Atlanta, GA 30332-0150  
(404)894-2995 FAX(404)894-2760

Scotty McMillan  
U.S. Army  
Simulator Flight Instructor  
Flight Simulation Branch  
Fritzsche Army Airfield  
Ft. Ord, CA 93941-5620  
(408)242-5836

Skip Mead  
FAA Headquarters, ARD-30  
800 Independence Ave, S.W.  
Washington, D.C. 20591  
(202)267-8263

David Mitchell  
Systems Technology, Inc  
13766 S. Hawthorne Blvd  
Hawthorne, CA 90250  
(213)679-2281

Peter J. Nalder  
New Zealand Ministry of Transport  
Air Transport Division  
Aviation House  
CNR Market Gr & Woburn Rd  
P.O. Box 31441 Lower Hutt, New Zealand  
64-4-600-415 FAX 64-4-692-024

Hubert Pate  
U. S. Army  
USAAVNC, Directorate of Training and  
Doctrine  
ATZQ-TDS-SM  
Fort Rucker, AL 36362-5000  
(205) 255-2482 or -5619

Barry Payne  
AVNET New Zealand  
P.O. Box 1287  
Auckland, New Zealand  
011-64-9-3032768

Anil Phatak  
Analytical Mechanics Associates, Inc  
Suite 76, 790 Lucerne Drive  
Sunnyvale, CA 94086  
(408)738-3650

Fred Piasecki  
Piasecki Aircraft Corp  
West Terminus of Second St.  
Essington, PA 19029  
(215)521-5700

Lloyd Popish  
Lloyd N. Popish Writing & Editorial Services  
525 Davenport Court  
Sunnyvale, CA 94087  
(408)720-8355

Bob Randle  
Sverdrup Technology  
NASA Ames Research Center  
M/S 210-2  
Moffett Field, CA 94035-1000  
(415)604-6380

L.D. Reid  
Institute for Aerospace Studies  
University of Toronto  
4925 Dufferin Street  
Downsview, Ontario, Canada M3H5T6  
(416)667-7705

Dean Resch  
FAA Headquarters, ARD-30  
800 Independence Ave, S.W.  
Washington, D.C. 20591  
(202)267-8514

Warren Robbins  
FAA Headquarters, AFS-850  
800 Independence Ave, S.W.  
Washington, D.C. 20591  
(202)267-3842

Bob Rutkowski  
McDonnell Douglas Training Systems  
Mail Code 288-2092  
12301 Missouri Bottom Road  
Hazelwood, MO 63042  
(314)895-9558

Brian Sawyer  
Systems Control Technology  
1611 N. Kent Street, Suite 910  
Arlington, VA 22209  
(703)243-3633 FAX(703)528-2392

Bill Schinstock  
Kohlman Systems Research  
319 Perry  
Lawrence, KS 66044  
(913)843-4099 FAX(913)843-6459

Steve Sedor  
Contraves  
P.O. Box 11478  
Pittsburgh, PA 15238-0478  
(412)967-7401 FAX(412)967-7836

Stephen M. Sekach  
HQ AVSCOM  
ATTN: AMCPM-TND-STL (PM TRADE)  
4300 Goodfellow Blvd.  
St Louis, MO 63120-1798  
(314)263-1194

Keith Shipman  
FlightSafety International  
2700 North Hemlock Circle  
Broken Arrow, OK 74012  
(918)251-0500 FAX(918)251-5597

Thomas Snyder  
NASA Ames Research Center, Code F  
M/S 200-3  
Moffett Field, CA 94035-1000  
(415)604-5066

Alan Sodergren  
FAA Southern Region, ASO-205  
P.O. Box 20636  
Atlanta, GA 30320  
(404)763-7773

Edward Stark  
13 Lincoln Avenue  
Montrose, PA 18801  
(717)278-1693

Colin Taylor  
Rediffusion Simulation  
2116 Arlington Downs Road  
P.O. Box RSIM  
Arlington, TX 76005

Major Terry Teeter  
U.S. Army  
Department of Tactics & Simulation  
Attack Scout Division  
Ft. Rucker, AL 36362-5000  
(205)255-6138 FAX(205)598-2191 (CAE)

Mark Tischler  
U.S. Army AVSCOM  
Aeroflightdynamics Directorate  
NASA Ames Research Center  
M/S 211-2  
Moffett Field, CA 94035-1000  
(415)604-5563

Joseph Traybar  
FAA Technical Center  
ACD-230 Bldg 201  
Atlantic City International Airport  
Atlantic City, NJ 08405  
(609)484-4286 or -4136

Curt Treichel  
United Technologies Corp  
Corporate Aircraft Department  
Rentschler Airport  
East Hartford, CT 06108  
(203)565-7060

Domencio Vaccari  
Agusta S.p.A.  
Cascina Costa (Varese)  
Italy  
39-331-229 195

Joe Walker  
McDonnell Douglas Helicopter Co  
B531/C240  
5000 E. McDowell Road  
Mesa, AZ 85205-9797  
(602)891-6189

Tom Walsh  
FAA Field Office  
Ames Research Center  
M/S 210-2  
Moffett Field, CA 94035-1000  
(415)604-5051

LCDR Gregory Warth  
U.S. Coast Guard  
Aviation Training Center  
Bates Field  
Mobile, AL 36608  
(205)639-6196 FTS 537-6201

Robert White  
McDonnell Douglas Training Systems  
1901 E. University, Suite 200  
Mesa, AZ 85203  
(602)891-2524 FAX(602)891-2501

John Zuk  
NASA Ames Research Center, Code FAC  
M/S 237-11  
Moffett Field, CA 94035-1000  
(415)604-6568

# REPORT DOCUMENTATION PAGE

*Form Approved*  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

<b>1. AGENCY USE ONLY (Leave blank)</b>	<b>2. REPORT DATE</b> April 1992	<b>3. REPORT TYPE AND DATES COVERED</b> Conference Publication	
<b>4. TITLE AND SUBTITLE</b>  NASA/FAA Helicopter Simulator Workshop		<b>5. FUNDING NUMBERS</b>  DTFA01-88-Z-02015	
<b>6. AUTHOR(S)</b>  William E. Larsen,* Robert J. Randle, Jr.,** Richard S. Bray,** and John Zuk			
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  Ames Research Center Moffett Field, CA 94035-1000		<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>  A-92020	
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>  National Aeronautics and Space Administration Washington, DC 20546-0001		<b>10. SPONSORING/MONITORING AGENCY REPORT NUMBER</b>  NASA CP-3156 DOT/FAA/RD-92/2	
<b>11. SUPPLEMENTARY NOTES</b> Point of Contact: William E. Larsen, Ames Research Center, MS 210-2, Moffett Field, CA 94035-1000; (415) 604-6380 or FTS 464-6380  *Federal Aviation Administration, Ames Research Center, Moffett Field, CA 94035-1000. **Sverdrup Technology, Inc., Ames Research Center, Moffett Field, CA 94035-1000.			
<b>12a. DISTRIBUTION/AVAILABILITY STATEMENT</b>  Unclassified — Unlimited Subject Category 01		<b>12b. DISTRIBUTION CODE</b>	
<b>13. ABSTRACT (Maximum 200 words)</b>  A workshop was convened by the FAA and NASA for the purpose of providing a forum at which leading designers, manufacturers, and users of helicopter simulators could initiate and participate in a development process that would facilitate the formulation of qualification standards by the regulatory agency. Formal papers were presented, special topics were discussed in breakout sessions, and a draft FAA advisory circular defining specifications for helicopter simulators was presented and discussed. A working group of volunteers was formed to work with the National Simulator Program Office to develop a final version of the circular. The workshop attracted 90 individuals from a constituency of simulator manufacturers, training organizations, the military, civil regulators, research scientists, and five foreign countries.			
<b>14. SUBJECT TERMS</b>  Simulation, Training, Evaluation		<b>15. NUMBER OF PAGES</b>  193	
		<b>16. PRICE CODE</b>  A09	
<b>17. SECURITY CLASSIFICATION OF REPORT</b>  Unclassified	<b>18. SECURITY CLASSIFICATION OF THIS PAGE</b>  Unclassified	<b>19. SECURITY CLASSIFICATION OF ABSTRACT</b>	<b>20. LIMITATION OF ABSTRACT</b>