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17. METHODOLOGY DEVELOPMENT FOR EVALUATION OF SELECTIVE-FIDELITY ROTORCRAFT SIMULATION*

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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:

*Paper presented by Cliff McKeithan.

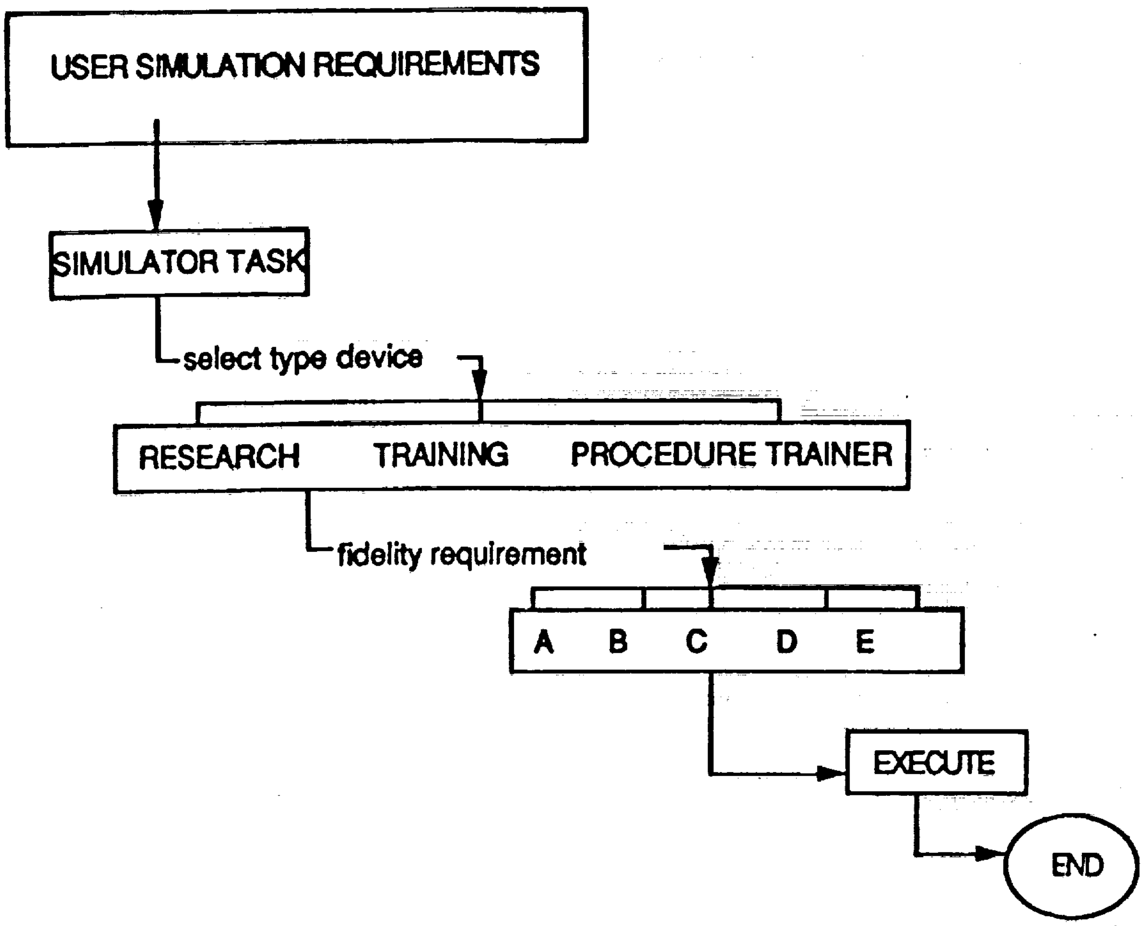

Figure 1. Fidelity dependence on type task.

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

$$[\text{FIDELITY CONSTANTS}] = [C_{\text{Cockpit}}\ C_{\text{audio}}\ C_{\text{motion}} \cdots C_{\text{visual}}]$$

$$[\text{TDWV}] = [K_{\text{cockpit}}\ K_{\text{audio}}\ K_{\text{motion}} \cdots K_{\text{visual}}]^T$$

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.

1. Cockpit/crew station
   - Simulated instruments
   - Basic, generic-type instruments
   - Partially simulated cockpit
   - Full-up crew station
2. Audio
   - None
   - Significant cockpit sounds
   - Incidental sounds (precip., etc.)
   - Realistic
3. Motion
   - None
   - 2DOF (pitch and roll)
   - 3DOF (pitch, roll, and yaw)
   - 6DOF
4. Control system
   - No force feel
   - Constant force (spring/damper)
   - Partial duplication of actual force
   - Complete duplication
5. Mathematical model
   - 3 DOF
   - 6 DOF
   - 6 DOF w/simple rotor
   - 6 DOF w/complex rotor
6. Environmental
   - Clean air
   - Discrete gusts
   - First-order filtered turbulence
   - Rotationally sampled turbulence
7. Ground handling
   - No gear
   - Rigid gear
   - Simplified gear model
   - Comprehensive
8. Mission equipment
   - None
   - Communication only
   - Communication/navigation only
   - Complete

9. System latency
   - Non-real-time (off line)
   - Significant delay
   - Minimal delays
   - Real time

10. Visual
    - None

Field of view	Dynamic range	Detail
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

$$[FIDCONST] = [C_{cockpit}, C_{aud}, C_{mot}, C_{feel}, C_{math}, C_{env}, C_{grnd}, C_{mep}, C_{lat}, C_{vis}] = [4\ 3\ 4\ 4\ 3\ 2\ 3\ 4\ 4\ 3.25]$$

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:

$$[FIDCONSTmin] = \{\min[C_{cockpit}\ C_{audio}\ C_{motion} \ldots C_{visual}]\}$$

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

$$[FIDCONST_{min}] = \{\min[C_{cockpit}\ C_{audio}\ C_{motion} \ldots C_{visual}]\}$$

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

$$[FIDCONST_{max}] = [4\ 4 \ldots 4]$$

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 interdependance 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 quantitatively 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 ± tolerance range with decreasing simulator fidelity classification.

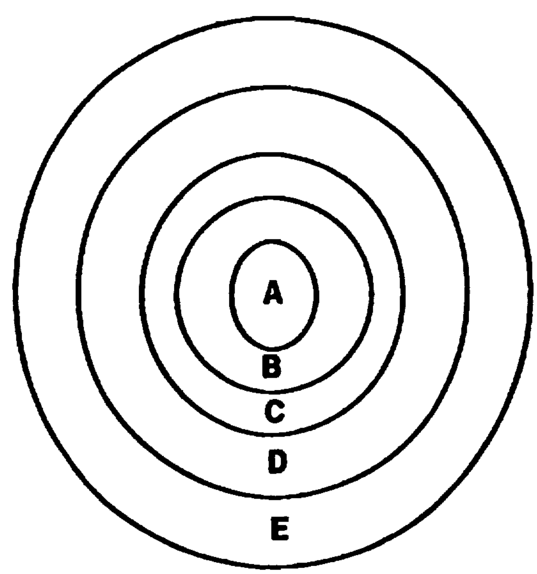

Figure 2. Tolerance level and simulator category.

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 acceptability. 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

*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

*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. Nonthеless, 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.

*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.

*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,

*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.

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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 relay 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.

*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

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13. ABSTRACT *(Maximum 200 words)*

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.

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