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SIMULATOR CERTIFICATION METHODS AND THE VERTICAL MOTION SIMULATOR

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INTRODUCTION

The development of the Vertical Motion Simulator (VMS) has been progressing steadily and will soon be complete. A desire to gauge the success of the VMS development effort has lead to questions about how to measure and evaluate VMS performance capabilities and what those performance capabilities should be. As a response to those questions, the following document has been created.

The VMS is an aircraft simulator designed to simulate a variety of experimental helicopter and STOL/VTOL aircraft and can be adapted to simulate other kinds of aircraft with special pitch and Z axis characteristics. The VMS will include a large motion base with extensive vertical and lateral travel capabilities, a computer generated image (CGI) visual system, and a high speed CDC 7600 computer system, which will perform aero model calculations.

Developing guidelines on how to measure and evaluate VMS performance has been complicated. No clear cut approach was obvious and few relevant documents were available. As a first step, a survey of simulation users was conducted. Appropriate personnel in the airlines, the FAA, and the military were questioned concerning how they evaluated and certified simulators for use (reference Appendix A for a list of contacts). The results of that survey can be found in the sections: "Simulator Certification, Federal Aviation Administration and the Commercial Airlines " and "Simulator Certification, U.S. Air Force, Army, and Navy." The general outcome of the survey was that simulator certification primarily involves assessing simulator fidelity and that what fidelity really means can (and should) vary according to user needs. That outcome and its implications are discussed in the section: "Summary and Implications."

It was becoming quite obvious that VMS user needs would be relevant to how VMS performance should be measured and evaluated. In order to clarify and define what those user needs really were, a survey of VMS users was conducted. The results are discussed in the section: "Survey Methods and Summary." The effects of VMS user needs upon the VMS certification are further discussed in sections: "VMS Certification, Suggested Objective Tests" and "VMS Certification, Suggested Functional Evaluations."

SIMULATOR CERTIFICATION

FEDERAL AVIATION ADMINISTRATION

AND

THE COMMERCIAL AIRLINES

Confronted with increasing airport traffic, rising fuel costs, and new aircraft systems, the FAA and airlines have been expanding the role of aircraft simulation in the training of pilots. Recent advances in simulation technology, especially in the areas of visual systems and aero modelling, have enabled the airlines to accomplish all of their transition and upgrade training objectives using simulation. Now, a pilot training to hold his same crew status (e.g., co-pilot) on a new aircraft system (i.e., transition train) or one training to upgrade his crew status (i.e., upgrade train) can receive all of his training, including his check-ride in some cases, in an aircraft simulator.

While optimistic about the training effectiveness of total simulator training programs, both the FAA and the airlines are facing the difficult task of evaluating and certifying specific aircraft simulators for use in such programs. The FAA has published two documents (reference 1 and 2) which describe and comment upon the new FAA simulator certification process.

The new FAA simulator certification process emphasizes determining and evaluating simulator performance. What is the visual scene content?

What is the visual system response lag? What are the control system forces and dynamics? What are the aero model parameters? How may axes of motion are simulated? These are typical simulator performance issues. The scope and number of the performance issues that are reviewed vary based upon the type of training the airline is proposing to use the simulator to do.

The FAA certification process has been organized into the following three categories:

Phase 1. Phase 1 approval certifies a simulator for use in the current landing maneuver training for transition training. Phase 1 is designed to encourage upgrading of simulator equipment.

Phase 2. Phase 2 certification will provide enhanced training capability by expanding the ability of simulators to portray more realistic visual scenes and flight characteristics and by improving simulator response dynamics. Phase 2 certification will allow both transition and upgrade training.

Phase 3. Phase 3 approval will allow all but the static aircraft training and the line check to be conducted in the simulator. Due to the scope of the training and the possible low experience level of the training candidates, a high degree of simulator fidelity and realism is mandatory.

The underlying rationale of the preceding is that increases in simulator training effectiveness can be had only through corresponding increases in simulator fidelity. It has been common within the aviation community for simulator training effectiveness to be equated with simulator fidelity. This has occurred even though data does exist (reference 3) which reveals that substantial amounts of training can be accomplished using relatively low fidelity aircraft simulators. The assumption that high fidelity is required for high quality training is so strong, however, that those who design, certify, and use simulators adhere very closely to fidelity concepts and criteria in whatever they do.

The term fidelity is quite vague and overused. Unfortunately, this document will do little to refine the term or to refrain from its use. Fidelity, as defined by the FAA and airlines, relates to many issues almost too numerous to mention. Embedded in the term "fidelity" is some concept that the cues provided by the simulator are approximate representations of those presented to the pilot during actual flight. The more that simulator cues duplicate those of the actual aircraft, the more "fidelity" the simulator is purported to have. The scope of the definition is alarmingly broad and is showing no signs of being refined. To date no one has been able to decide which of the many possible flight cues are really relevant to the training of pilots and which are not.

Result? In one way or another, any sort of motion, visual scene, instrument, aircraft dynamic, aircraft system, or weather cue has been argued persuasively as relevant to creating a high quality aircraft simulator for pilot training. The outcome is that the utmost "fidelity" is sought in just about every aspect of aircraft simulator design. Accordingly, the FAA certification process attempts to determine the "fidelity" of all those various aspects of the simulator.

In the FAA certification process the fidelity requirements increase in number and scope as the training role of the simulator is expanded. For instance, phase 1 requires only a three axis motion presentation, whereas phase 2 and beyond requires the equivalent of a six axis motion simulation.

The FAA fidelity certification tests and criteria are organized into three separate sets which also vary according to phase. Those sets are: general requirements, objective performance tests, and functional evaluations.

General requirements include such criteria as the number of axes of motion simulation, visual scene content, and weather simulation capabilities. Most general requirements are certified by inspection.

Objective performance tests are more sophisticated and engineering oriented and are based upon objective criteria, such as frequency response. Visual system, motion system, and control response dynamics are tested in this set of tests. One significant and typical specification is that the maximum acceptable visual system delay is 300ms (phase 1). Another is that the visual, motion, and instrument systems shall respond to pilot inputs within 150ms, but not before the time when the airplane would have responded under the same conditions (phase 2 and beyond). How adequate simulator performance is can be readily determined using these type of tests.

Another area of objective performance testing involves aero model analysis. Aero model performance is tested by flying given maneuvers in the simulator. The aero model output obtained from the simulator computer is then compared with actual aircraft performance data collected previously during airborne test sessions. A parameter by parameter comparison of aero model and actual aircraft data trends is done subjectively and simulator aero model changes are made accordingly. A special FAA national test team, composed of experienced engineers and pilots, assists the airlines in performing all objective performance tests and all general requirements testing.

At the outset of the drive to expand simulator use in airline pilot training the FAA heavily emphasized objective criteria and tests in evaluating and certifying a simulator. For instance, at one time changes to the aero model based upon pilot opinion data were forbidden if any actual aircraft flight data could be found to substantiate the aero model parameters. According to airline officials, the FAA encountered numerous problems with user acceptance because of this policy. Pilots continually complained that a simulator lacked fidelity in one aspect or another and should be changed. However, because such a change would have caused a loss of simulator certification, the required adjustments were not made and the complaints continued.

Eventually, however, functional evaluations gained in importance. These tests, which are designed to further explore and evaluate simulator fidelity, rely upon the perceptions and opinions of select pilots on the FAA national team and within the airline community. A functional specification would be, for example, after roll-out onto final approach, the runway should appear as it would in the actual aircraft at the distance. The criteria for compliance with such a specification is completely subjectively defined by the simulator test pilot. This is unlike objective tests where compliance is more observable. Simulator performance can be measured outwardly and compared with discernable criteria when performing objective tests. To perform functional evaluations, pilots are required to perform a given set of maneuvers and subjectively evaluate simulator performance. Pilot opinion data is then aggregated and interpreted and the appropriate changes are made to the simulator hardware and software.

Without the functional evaluation process, there would be no way for the FAA to certify that the simulator performs perceptually as required. Objective performance tests are isolated and insufficient and cannot relate directly to the perception issue. They cannot provide sufficient cause for accepting a simulator, but can provide a basis for rejecting one or a means of directing the use of functional evaluations. For instance, once the visual system frequency response has been measured objectively and accepted, attention can be focused on visual scene content, which would be evaluated subjectively using functional procedures.

SIMULATOR CERTIFICATION

U.S. AIR FORCE, ARMY, AND NAVY

The military has also been increasing its use of simulation and has been deeply involved with developing simulator certification procedures. The certification processes for the Army, Navy, and Air Force are similar to those of the FAA. All involve some set of general requirements and objective tests. And, all rely heavily on a pilot-in-the-loop type of functional evaluation.

Again, as it was with the FAA certification tests, the military tests are aimed at determining and evaluating simulator fidelity. The military also feels that in order to achieve high levels of training in a simulator, the simulator must be of exceptionally high fidelity. The military defines fidelity even more broadly than do the FAA and the airlines. The military is not only concerned with the fidelity of the simulated aircraft, but it is also requiring that a variety of high fidelity combat environments be presented through visual simulation. For instance, fighter-attack aircraft simulator visual system specifications have called for the simulation of enemy missiles and a variety of terrain. Although the airlines are interested in presenting a quality visual image of a runway and surrounding terrain, the military's requirements for terrain and scene detail simulation far exceed those of the airlines.

As a result, the military simulator specifications contain numerous functional specifications. For example, a fighter-attach aircraft simulator visual system specification might require that the pilot be provided with sufficient high fidelity visual cues to perform a low altitude, high speed penetration maneuver. Such a specification requires a pilot-in-the-loop evaluation to determine compliance. No objective test exists. To be sure, however, military specification also contain objective type specifications, such as visual or motion system response criteria. In either case, whether functional or objective criteria are employed, the ultimate goal is to specify the fidelity of the simulator.

However, at times the military has questioned its reliance upon the specification and determination of simulator fidelity as the primary indicator of simulator training potential. The Tactical Air Command (TAC) is about to perform a series of tests under the guidance of the Air Force Technical Evaluation Center (AFTEC) to evaluate how well pilot evaluations of simulator fidelity correlate with empirical measures of simulator training effectiveness.

Further, the military has also attempted to take another approach to defining simulator performance requirements other than by simply attempting to specify the highest fidelity simulator possible. That approach, called Instructional Systems Development (ISD), is based upon a breakdown of a aircraft's operational missions into a set of discrete pilot tasks. Each task is then analyzed and assigned a set of pilot skill requirements, which are then reviewed to determine what kinds of training media would be necessary to develop the required skills.

The ISD process seems to be a theoretically appropriate approach to the design of simulators as pilot training devices. The process, however, has been plagued by problems. The ISD process requires high level management support to succeed and that appears to have been lacking. In the Air Force, for example, ISD teams are appointed within each operational command where, due to excessive workload and limited expertise, those teams have been unable to contribute much to the specification process. Their major task and most significant contribution has been to devise the training syllabus and other instructional procedures to use in integrating a given simulator into an ongoing pilot training program.

The ISD process is, however, hindered by more fundamental problems. For those of you who have either performed or reviewed a task analysis, certain things be me obvious. Performing a high quality task analysis · very, very hard. Often the definition of tasks is vague and arbitrary and the subsequent skills analysis is compromised from the start. Even if the task analysis were exact and accurate, deducing which skills are pertinent to the performance of which tasks is also quite difficult. It should be of no surprise that determining training media specifications using such a set of pilot skill requirements can often result in a product of poor quality. The ISD process lacks support for good reason. THe process, or any process like it, can take years, cost millions, and lead to a product of questionable quality.

Only through the use of expert personnel and the increased availability of improved techniques and data can improvements in the quality of ISD type products be attained.

It is not without warrant then that the aviation community has relied upon the determination of simulator fidelity as the primary (and perhaps only) a priori indicator of a simulator's training potential. Previously, military and airline pilots were trained successfully using the aircraft as the primary training media. The extensive use of simulation as a training media is recent and the reliance on simulator fidelity as a certification yardstick seems warranted in light of the success of pre-simulation pilot training programs.

The military has not published any documents which discuss and define all the phases and procedures involved in how it specifies and certifies a simulator. Further, the specification and certification process within each service involves many distinct organizations, so a review of the whole process would have to encompass the viewpoints of all the participating organizations.

However, personnel within certain participating organizations have written documents which are relevant (references 4, 5, 6, 7, and 8). One (reference 4) discusses how to use flight test procedures in a functional evaluation of the fidelity of the simulator aero model. Another article (reference 5) discusses the use of pilot-in-the-loop analyses and objective tests in the determination of helicopter simulator fidelity. A third (reference 6) presents sets of objective criteria for simulator visual and motion systems, but does not present evidence or a strong rationale to support the criteria. A fourth (reference 7) discusses in general terms how to collect and use pilot opinion data. And, a fifth (reference 8) describes a device which can monitor real-time simulator performance.

SUMMARY AND IMPLICATIONS

Any discussion of simulator certification soon leads to an examination of the simulator design specifications. It is also true that questions about the validity of the certification invariably raise questions about the validity of the specifications, whether they be objective or functional. And, where functional specifications are involved, additional questions are raised concerning whether or not the functional specifications have been met.

In both the military and the FAA simulator specifications have been selected to create the highest fidelity simulator possible. Both objective and functional specifications and tests have been geared toward this goal.

Meeting a given objective criteria, such as one for visual system frequency response, can create a certain satisfaction. But, that satisfaction can be short-lived. The workings of human perceptual processes are quite complex and not yet well understood. Too little is known about how a pilot sees, hears, and feels to allow simulator design engineers to write a set of objective engineering specifications that will satisfy human perceptual requirements and create a high fidelity simulation. Objective performance tests, then, in turn, cannot totally describe the quality of the simulation. Functional specifications and evaluations are needed as well.

However, functional tests and criteria have not resolved the simulator certification issue. Functional evaluations rely upon the collection and interpretation of pilot opinion data. Since the quality of pilot opinion data can vary greatly as a function of the data collection procedures, the value of any functional evaluation cannot be judged until the circumstances surrounding how the data was collected have been described and evaluated. It is questionable if those who certify simulators have given the pilot opinion data collection procedures sufficient attention.

One reason for the sparse attention pilot opinion data collection procedures have received may be due to the way functional specifications are written. The authors of functional specifications rarely define how the pilot opinion data should be collected or what kind and amount of variability in pilot opinion data should be tolerated. However, a warning should be sounded. Not any set of pilot opinion data collection procedures will do. Great care must be taken in creating such procedures, for opinion data can be easily mishandled.

Different approaches to specification and certification are needed depending upon how the simulator will be used. For example, one F-16 simulator could be used for pilot training, another one could be employed as a research tool for investigating F-16 handling qualities, and a third could be used to research the effects of different pilot training methods. Even though each of these simulators would be an F-16 simulator, they would probably perform differently. For example, although the basic aerodynamic model should be the same for all, certain portions of the model might be modeled in greater detail for use in handling qualities research than for use in pilot training or pilot training research. Other differences across these three simulators would probably also exist. In turn, different sets of specifications and certification procedures should be in effect for each.

Now then; what does the proceding have to do with certifying a research simulator like the VMS? The role of a research simulator is a varied one. Not only do the general performance requirements of the research simulator usually differ from those of a training simulator, but a research simulator's performance requirements change regularly as new research tasks are proposed. In fact, the change can be so great that, for example, a research simulator configured as an F-16 could be reconfigured as a A-10 for a new research project.

The constant change in performance requirements of a research simulator such as the VMS will make its certification an ongoing, evolutionary process shaped almost entirely by the demands of the research task. Given that the research tasks dictate the performance requirements of a research simulator, any discussion of simulator certification must first involve an examination of the research issues facing the simulator user community. Once these issues are defined, one can determine which aspects of the simulation must be of the highest fidelity and which aspects are not that critical. With this determination made, then more attention can be paid to how the certification process should be conducted and what kinds of certification procedures, both objective and functional, should be performed.

SURVEY METHODS AND SUMMARY

During the months of July and August 1981 a survey was conducted of potential Vertical Motion Simulator (VMS) users within the NASA/Ames community. The potential users were NASA, Navy or Army affiliated engineers and scientists who were involved with STOL, VTOL and/or helicopter technology development. All users were interviewed in person and each interview included, but was not limited to, discussion of the following topics:

1. General program description and reasons for using simulation,
2. Program goals,
3. Reasons for those goals,
4. Tasks to be performed in the simulator (e.g., landing),
5. Performance measures,
6. Visual system requirements (including a discussion of computer generated image (CGI) technology),
7. Motion requirements (special emphasis on discussing the value of the vertical motion capabilities of the VMS),
8. Potential problem areas, and
9. Future programs.

After collecting the user comments (reference Appendix B for interview data), the comments were organized and reviewed and a survey synopsis table was prepared (reference Table 1). As shown in Table 1, the VMS user community is very homogeneous, with the predominant research interest being in handling qualities research. Such interests require

Table 1
Survey Synopsis*

Program	Goal	Aircraft	Task	Equipment Requirements			
				High Speed Computer	Wide Angle Visual	High Scene Detail	Vertical Motion
NAVTOLAN C.Paulk	Determine display & control sys design requirements for landing on a ship	Helicopter	Landing on small ship	4 **	1	4	3
ARMCOP L. Corliss D. Carico	Determine effects of engine and fuel system dynamics on handling qualities.	Helicopter	Nap-of-the Earth(NOE) flight	3	2	1	2
698-VTOL B. Lampkin S. Wilson	Determine effects of vehicle design and operating procedures upon handling qualities.	VTOL	Cruise, hover, transition	4	1	4	2
HELI IFR R. Forrest V. Lebacqz	Determine effects of IFR and VOR approach & control sys design on handling qualities.	Helicopter	IFR & VOR approach	5	5	5	2

Table 1 cont'd

Program	Goal	Aircraft	Task	Equipment Requirements			
				High Speed Computer	Wide Angle Visual	High Scene Detail	Vertical Motion
RSRA J.Jinkerson	Determine effects of new rotor design on vehicle performance & handling qualities.	Helicopter	All typical helicopter maneuvers	1	1	4	1
ADOCS E. Aiken	Determine effects of new control system & display concepts on handling qualities & pilot procedures.	Helicopter	NOE flight	4	1	1	2
SSV R. Bray	Validate performance of specific control systems on the Orbiter	Space Shuttle	Approach & landing	5	4	3	1
NOTAR G. Churchil	Evaluate control laws & control system augmentation concepts for NOTAR aircraft.	NOTAR (no tail rotor) helicopter	Low altitude low speed precision control;e.g hover	4	2	4	1

Table 1 cont'd

* All comments and ratings were based upon the author's interpretation of user comments.

** Rating Scale:

1. Definitely required
2. Often required
3. Most likely required
4. Maybe required
5. Will not be required

that the research simulator dynamics be of the highest quality. Other research concerns, such as the need to perform high energy, low altitude maneuvers, will create a need for a visual system with good dynamics and high detail scene content. These issues and others have been reviewed and the following four areas of concern are proposed for further discussion:

1. Computer systems (CDC 7600) performance.
2. Motion system software performance.
3. CGI system performance and use.
4. Simulator system dynamics response characteristics.

Computer System Performance

One user professed a distinct need for a high speed computer capability, while several researchers indicated that their future programs would profit from and may even require such computer capability. This, in concert with the fanfare surrounding the acquisitions of the CDC 7600, may have created high expectations. Disappointment, perhaps even disillusionment, would ensue, should the CDC 7600 not perform as expected.

Motion Systems Software Performance

Nearly all VMS users felt that the motion system vertical travel capability was an asset. However, those users whose research tasks involved high energy maneuvers, such as nap-of-the-earth (NOE flight), had reservations about the motion systems software. In particular, these users expressed doubts about whether or not the wash-out scheme was optimized for NOE flight.

It was thought that facilities engineers might have different motion system performance goals than researchers. Facilities personnel, it was postulated, may be more oriented toward equipment performance characteristics and limitations, while users are more concerned with creating an environment condusive to performing their research tasks. This difference in orientation may be producing motion system software optimized to exploit hardware capabilities rather than to complement research tasks, such as NOE flight.

CGI System Performance and Use:

Concern was raised about whether or not the present CGI data base would allow pilots to perform NOE flight. Specifically, users wondered if the visual scene would present sufficient detail to enable pilots to perform NOE flight as though they were flying an actual aircraft. Should the CGI data base provide insufficient detail, on-line operational changes to the visual scene would be required in order for the researchers to create the desired test environment and to collect data within their assigned simulator time.

The changes to the visual scene that are envisioned are of the "quick and dirty" variety. A complete remake of the data base in order to create a scene perfect in every detail is not under consideration. What is under consideration is how to change the texture-less scene presented by the CGI so that sufficient cues are available to perceptually define a ground plane at low altitudes.

For example, while the author was with the Air Force Human Resources Laboratory, researchers attempted to use the Advanced Simulator for Pilot Training (ASPT) in conducting an A-10 low altitude penetration study. In that study pilots were required to fly at 200 feet above-ground-level and at speeds of 400 knots through hostile enemy territory. Unfortunately, initial attempts at performing this study were unsuccessful because pilots could not maintain the 200 foot altitude requirement without crashing. The flat, texture-less valley floor over which they flew provided no depth or altitude cues. Only after the valley floor was peppered with numerous pyramids were pilots able to perform the low altitude penetration task. The idea of using objects such as pyramids to generate the required cues occurred as a result of trial and error. Further, the spacing and size of the pyramids were determined only after numerous attempts.

NASA researchers, faced with similar tasks and hardware, may have to mimic Air Force researchers and resort to creative trial-and-error methods to adapt their CGI visual scene to low altitude tasks. Assuming that CGI scene modifications will be needed, users questioned how those changes would be made and which organization and which personnel would make them.

All users professed a lack of expertise in CGI technology, which will make them very dependent upon facility personnel to perform and sort of

CGI scene change. Should it be required that users conduct their research within the allotted time, users and facilities CGI people will probably have to be in close and continuous contact at the start of a user's simulator time. Otherwise, the required CGI scene changes will take overly long to implement and evaluate, leading to substantial delays and wasted simulator time.

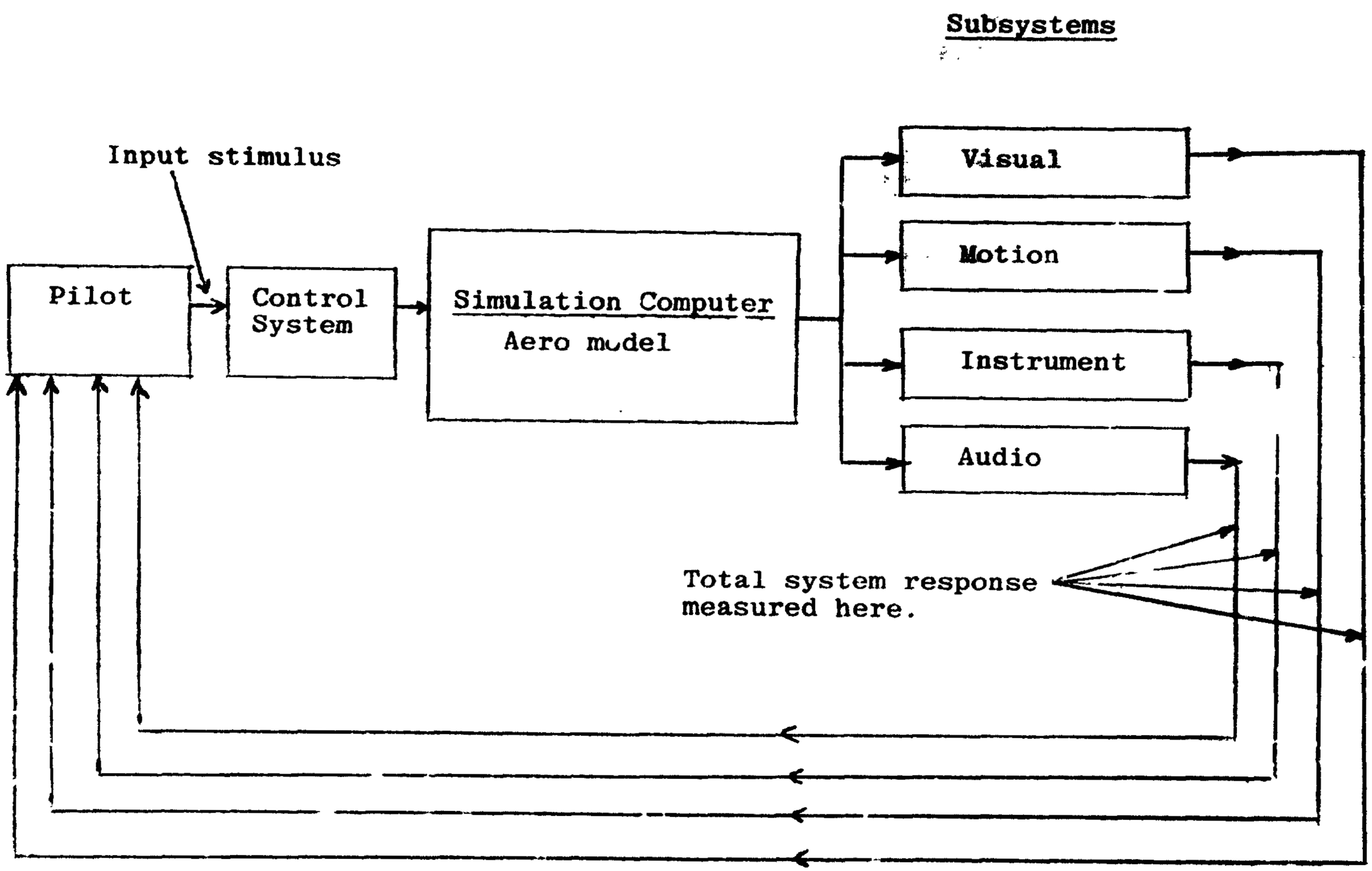
A second CGI issue was raised. The CGI dynamics were of concern to almost all researchers. Their research involved handlir ntities evaluation, which would rely heavily upon visual scene dy. cs. Without high quality dynamics, pilots would not be able to properly control the aircraft nor accurately rate its handling qualities.

Simulator System Dynamic Response Characteristics

As one reads the following it will become obvious that the preceding three concerns, computer systems performance, motion system software performance, and CGI system performance and use, can in part be considered subsets of the fourth concern, simulator system dynamics. Simulator system dynamics, as shown in Figure 1, is depicted as the time required for the simulator subsystems, the visual, motion, instrument, and audiotory subsystems to respond to a given pilot input. Actually, simulator system dynamics should be described not just in simple time lag terms, but also in such terms as bandwidth, phase lag, and amplitude ratios. In any case, these and other similar measures serve to describe a system's dynamics and the dynamics of the VMS are of concern to VMS users.

Figure 1

Total Simulator System



The users often questioned how well the total simulator system would perform dynamically, which raised such issues as: Would the simulator faithfully reproduce the aircraft dynamics as provided in the aircraft math model? If not, what kinds of dynamic performance deficiencies would be occuring? Which simulator subsystems (e.g., visual systems) would contribute the most to the simulator system dynamic performance deficiencies? Could the performance deficiencies be eliminated or substantially reduced? If not, what would be the effect of simulator performance deficiencies on pilot perception and performance and hence upon the validity of handling qualities data?

Of the four major concerns raised here, the issue of total simulator system dynamics is, as judged by the interviewer, the most critical one. In handling qualities research, the simulator is the aircraft and the performance of the simulator is evaluated as though it were the aircraft. Should the issues of total system and subsystem dynamics be ignored, the aircraft dynamics so carefully constructed and calculated in the aero model computations may be seriously distorted by dynamic deficiencies of downstream simulator subsystems. The issue of simulator dynamics needs attention if the quality of simulator handling qualities data is to be assured.

VMS CERTIFICATION

SUGGESTED OBJECTIVE TESTS

Throughout the preceding discussions the cameleon-like term, fidelity, has been a fundamental concept, either implicitly or explicitly. Yet, its meaning was changing subtly from discussion to discussion. To the FAA the term had one set of connotations, to the military another, and to the research community, fidelity appears to have had yet a third. The changes in the meaning of the term fidelity can be directly traced to the simulator user community and to the role it assigned simulation. Through the interaction of the user and the role simulator fidelity requirements took shape, and, in some user environments, continued to evolve and change to suit changing user-role relationships. A heterogeneous user community and/or a complex, multi-dimensional role for simulation could make the meaning of fidelity alarmingly broad and the task of providing an adequate simulation environment terribly difficult. Or, at the other end of the spectrum, a homogeneous user and a narrowly defined role could refine the meaning of fidelity and make creating, evaluating, and certifying the simulation easier (but not necessarily easy).

As discussed, the VMS user community is homogeneous and is concentrating on simulating and evaluating the handling qualities of some type of experimental aircraft. Naturally, to them the dynamic fidelity of the total simulator system is crucial. Without dynamic fidelity, the validity of their research data could be challenged easily.

What appears to be needed as a first step toward certifying the VMS is to develop an objective, engineering oriented technique for measuring the dynamics of the total simulator system. That technique should emphasize measuring the responses of the visual and motion systems, since those systems provide the bulk of the relevant cues and are probably the source of most of the system dynamic deficiencies.

Measurements taken at the output of the simulation computer would be insufficient because they ignore the dynamic effects (and possible distortion) introduced by downstream simulator subsystems. Measurements of the dynamics of a given piece of subsystem hardware, such as the motion hardware, would also be insufficient because the dynamic effects of the software that controls that hardware would be absent, as would be the effects of that software-hardware interaction upon the total simulator system dynamics.

However, it is also realized that measuring the total simulator system response may be difficult and lead to ambiguous results. For example, non-linearities in the aero model may corrupt attempts to measure total system dynamics. Should that be expected to occur often, it may be more productive to concentrate upon measuring and modelling the visual and motion subsystems and include in such models all relevent issues that affect total system dynamics.

In any case, whether total system or just subsystem dynamics are being examined, it is crucial that the subsystem response, such as the movement of the cab itself or the visual scene, be accurately measured. The technology for measuring the simulator cab motion is available. Through the use of the appropriate accelerometers and motion system position sensors, the responses of the motion system could be accurately measured.

The technology for measuring the movement of images on a CRT screen is less developed, however. What would apparently be needed would be a means of converting light level changes into voltage changes, which then could be reduced to numerical trends. A possible technique might employ a stylized visual image such as a white/black bar graph and panel of sensitive photoelectric cells that would be strapped on to the CRT optics and connected to a computer system. A given pilot control input, when played through the simulator system would cause the bar graph to move accordingly. The bar graph movement would, hopefully, cause changes in the photoelectric cell voltage output. The fluctuation in voltage output could then be organized and interpreted by the computer system and its software.

Other means of measuring visual response could also be used. Matching visual scene response with that of a preprogrammed superimposed visual image has also been suggested. In any case, the issue is to determine and measure the dynamics of the visual system and relate that to the dynamic performance of the whole simulator system. Any objective accurate, reliable, easy-to-use technique will do.

Ease-of-use is quite important. Given the varied role the VMS will be required to play (reference Table 1), certifying the VMS will be an on-going issue. Each new research task will change VMS performance and require that simulator performance be re-validated. Thus, any certification technique will be used regularly and often and must, therefore, be easy to use.

Other issues warrant discussion as well. NASA has encountered difficulties in adapting the CDC 7600 to perform real-time simulation. Appropriate personnel have been assigned to deal with these difficulties and their progress is being monitored by NASA management. Once the system software is developed and approved, the dynamic performance of the simulation computer (reference Figure 1) should be documented and re-examined regularly, especially after system software changes or large, complex aero models have been introduced. Measurement of simulation computer dynamics could be accomplished using a variety of hardware based objective techniques.

Besides the dynamic performance characteristics of the motion subsystem, certain more qualitative concerns exist. Those surround the issue of adapting the motion software to the peculiarity of a task, rather than to equipment nuances. Although motion system frequency bandwidth definitely affects how well the motion cues of a given task can be simulated, bandwidth is not the only relevant issue. Users need to know more about how motion system cues differ qualitatively from those commanded by a valid aero model. For instance, in a pure pitch maneuver, does the motion system introduce any lateral or roll accelerations? Such issues could be evaluated by comparing two time histories: one describing cab accelerations and another defining the accelerations commanded by a valid aero model. Even though the comparison would involve subjective evaluation, the two observable time histories would provide the basis for comparison and lend considerable objectivity to the evaluation.

As an aside, one cause for the concern over motion subsystem performance is a lack of rapport between users and facilities engineers. Neither has had time to more throughly understand the other's area.

Perhaps a useful tool to use to bridge the gap between users and facilities engineers would be a short VMS motion system seminar. A small group of facilities engineers would be made responsible for presenting an in depth overview of the VMS motion system software and hardware characteristics at the seminar. The engineers could complement that presentation with a discussion of how to develop and implement motion curing in a real-time simulation. The seminar might also include a presentation by interested users on the motion characteristics of motion sensitive tasks. The goal of the seminar would be to determine how to adapt the VMS motion system to high energy motion sensitive tasks like NOE flight.

In essence, the creation and use of objective tests such as those described above would solve numerous problems associated with certifying the VMS. Remember, however, these techniques will not resolve the whole certification issue. Other issues do still require attention and other types of tests will be relevant. It is only because of the heavy emphasis placed on dynamic fidelity by the user community that objective tests such as those described could solve such a large portion of the problems surrounding VMS certification.

ORIGINAL PAGE IS
OF POOR QUALITY

VMS CERTIFICATION

SUGGESTED FUNCTIONAL EVALUATIONS

Once objective tests such as those suggested previously are developed and used, data that defines VMS system dynamics should be available. That data will most likely reveal that the VMS lacks complete dynamic fidelity and that the fidelity deficiencies are due to subsystem dynamic performance limitations. What will also probably be determined is that some VMS dynamic performance deficiencies are irrepairable, leaving the following issue to be resolved: What effects do VMS dynamic deficiencies have upon pilot perception and performance?

Answering such a question is important if the value of handling qualities data is to be determined. To answer the question will require the collection and interpretation of pilot opinion and pilot performance data. Deciding how to collect that kind of data and how to interpret it can cause one to encounter many complex and subtle issues.

One issue is under what conditions can a pilot evaluate the phenomena in question. What kinds of circumstances or perceptual inadequacies are liable to undermine his ability to consistently render a valid judgement? How can those things be controlled so that the validity and reliability of the pilot's judgement is preserved? (Validity is the ability of a subject to focus upon the pertinent phenomena and accurately evaluate them. Reliability is the ability of a subject to consistently give the same response to the same situation.)

For instance, the typical functional evaluation might ask a pilot to evaluate simulator roll response and determine whether it is representative of the roll response of the aircraft. In rendering the evaluation a pilot must compare the simulator roll response with his memory of the aircraft roll response. The evaluation process is iterative and somewhat haphazard. Rarely are the pilots completely satisfied initially, so numerous adjustments to simulator roll response are made and evaluated. The process continues until some sort of consensus is reached.

Usually insufficient attention is given to organizing the sequence of changes or to evaluating whether the pilots were changing their evaluation methods or criteria during the evaluation. Devising pertinent performance measures and a valid means to interpret and resolve differences in opinion across pilots are difficult problems also awaiting attention and resolution. The basic problem with this mode of evaluation is not that pilot opinion was solicited, but how it was solicited. This mode of evaluation often employs faulty procedures that cause data reliability and validity problems.

Data validity and reliability problems plague the use of pilot performance data, as well. For example, if a pilot can accurately track a glide path using a dynamically deficient simulation, what does that mean? Also, what does an accurate track look like? How inaccurate is it? How many "accurate" profiles must a pilot be able to fly in order for a researcher to certify that simulation? Further, must all pilots perform to the same level? If not, how many should in order for a meaningful evaluation to be made?

Despite the soundest data collection procedures and the most insightful experimental design, one aspect of human opinion and performance is never altered. That is change. From trial to trial or from person to person, even though the situation is outwardly the same, opinion or performance data will almost always vary, sometimes subtly, sometimes drastically. Accurately interpreting that data variance is one of the most fundamental issues in behavioral research. Sometimes variance indicates that reliability and validity problems and sometimes it does not. Using a valid means of organizing data variance for further examination will help to make data more meaningful and to reduce data reliability and validity problems.

The discipline of inferential statistics was developed to help researchers organize and accurately interpret data variance. Inferential statistics tests are designed to determine when reliable differences in performance or opinion has occurred across a set of alternate situations. How the alternate situations are structured and presented and how performance is measured in each are crucial to determining if inferential statistics tests can be used effectively. Often, functional evaluations are conducted with such little attention to data collection procedures and performance measures that inferential statistics tests cannot be used meaningfully.

Through the use of appropriate empirical procedures, a researcher could employ statistical tests. By using improved empirical procedures and statistical tests, a researcher could make a more informed evaluation of the VMS. Since the main issue is to determine how VMS dynamic deficiencies may affect pilot perception and performance, any functional evaluation must deal with a range of simulator dynamics and attempt to measure how sensitive pilots are to changes in simulator dynamics.

This type of evaluation, sometimes called a sensitivity analysis, might proceed as follows: As first step, on an apriori basis select a set of frequency bandwidths that would be expected to affect the pilot's perception of simulator dynamic fidelity. For example, the appriori rational may be that pilots would perceive narrow bandwidth systems as low in dynamic fidelity and wide bandwidth systems as high. Next, program the visual and motion subsystems to represent each member of the set and expand the paradigm with another variable, aero model stability. Select and include a variety of aero models ranging from unstable to stable. Then, create a series of tasks and select a group of pilots. Finally, collect the appropriate opinion and performance data, including dynamic fidelity ratings and handling qualities evaluations, using acceptable empirical procedures.

By using a more conceptually organized approach and more acceptable empirical procedures, this type of sensitivity analysis should provide much more information than would a typical functional evaluation. One virtue of this approach is that data comparisons can be done statistically and are now more meaningful. Comparison of the data within a given condition and across conditions should suggest how reliably the pilots responded and how sensitive they were to a change in conditions. Changes in pilot opinion and performance across conditions should suggest, specifically, how dynamic deficiencies affected the perception of dynamic fidelity and the rating of handling qualities. Thus, a researcher would know more about how much dynamic fidelity could be attained and how degradations in dynamic fidelity could affect handling qualities evaluations.

Actually, the preceding example needs further development before meaningful sensitivity analysis could be performed. But, the concept is valid. This type of analysis could provide a researcher with a much richer context in which to evaluate the quality of a simulation. And, although the analysis is not a complete cure for all data validity and reliability problems, the richness of the empirical context should provide a researcher with more cues about the quality of his data.

To further develop the preceding, a number of issues must be explored in more detail. For instance, regarding pilot selection, what kind of pilots should be selected and how many? The selection of pilots has a great deal of influence upon the kind, quality, and reliability of opinion data. Further, if performance data is to be collected, what tasks are to be performed and how will performance be measured? For collecting pilot opinion data, how will the questions be asked and what type of responses will be appropriate? Will the questions be open ended or structured with a rating scale? And, if a rating scale is appropriate, what kind of scale? Should the scale be unidime onal or multi-dimensional? Should the scale be a simple bar graph or a well defined interval scale? Finally, will the questionnaire data be classified as ordinal, interval, or ratio? The scaling of data has a great influence upon the type of statistical tests that can be applied. Generally, interval and ratio data can be used in a larger number of statistical tests than can ordinal data.

The overall experimental paradiagm is important also. Should the pilots be organized into independent groups, each receiving only one research condition, or should all pilots be exposed to all conditions (i.e., repeated measures)? Further, if all pilots receive all conditions, should the sequence of conditions be counterbalanced or randomized? Within a given research condition, how should the effects of repeated trials be interpreted and how will the issues of accommodation to the simulator be handled? (Accommodation is a phenomena in which experience with the simulation masks memories of aircraft experience, making it very difficult for a pilot to validly interpret, evaluate, and use simulator cues.) Further, what range of bandwidths and aero models should be selected and how many intervals within each range should be tested? Also, are other kinds of parameters besides bandwidth relevant to dynamic fidelity and if so, which ones and how should they be tested? These questions are just a subset of those that may prove to be relevant, so other questions may need to be asked and answered before a valid sensitivity analysis can be conducted.

A sensitivity analysis could also be done to evaluate CGI scene fidelity. Using apriori assumptions about what variables affect scene quality, alternate situations could be explored. The outcome of a scene functional evaluation, as with many kinds of functional evaluations, is particularly sensitive to the pilot tasks used during the evaluation. For one thing, that means that the answers to many of the questions in the two preceding paragraphs may vary from one task to another. For another, it means that the applicability of the results will be limited.

For instance, if the task were hover, one set of questions and performance measures would be relevant and if the task were approach and landing, another set would be appropriate. The results from the hover tests would be most relevant only to similar kinds of tasks and the same would be true of the results from the approach and landing tests. It is important, then, that any functional evaluation of the CGI scene incorporate the pilot tasks of interest to the VMS user community (reference Table 1). Further, scene functional evaluations may be aircraft sensitive as well. Fortunately, since the typical VMS user is simulating some type of helicopter (reference Table 1), scene functional evaluations should relate primarily to helicopter aircraft.

APPENDIX A

PERSONS CONTACTED

Lt Col R. MacArgel
TAC
Eglin AFB, Fl.

Maj Robert Whelton
AFTEC
Kirkland AFB, N.M.

Lt Col John Rizinski
AFTEC
Kirkland AFB, N.M.

Lt Col R. Rogers
SAC
Offutt AFB, Ne

Lt Col J. Mueller
AFTEC
Kirkland AFB, N.M.

Lt Col R. Hartog
MAC
Scott AFB, Ill.

Lt Col A. Meacham
ATC
Randolph AFB, Tx.

Capt Dalros
ATC
Randolph AFB, Tx.

Dr. Ken Boff
AMRL
Wright-Patterson AFB, Oh

Mr. Ken Potempa
AFHRL
Brooks AFB, Tx.

Dr. Thomas Gray
AFHRL
Williams AFB, Az.

Dr. Thomas Longridge
AFHRL
Williams AFB, Az.

Mr. Ronald Ewart
ASD
Wright-Patterson AFB, Oh.

Mr. George Dickison
ASD
Wright-Patterson AFB, Oh.

Mr. James Bassinger
ASD
Wright-Patterson AFB, Oh.

Mr. Thomas Galloway
NTEC
Orlando, Fla.

Mr. James Burns
NTEC
Orlando, Fla.

Mr. Walter Chambers
VTRS facility
Orlando, Fla.

Dr. Ronald Hofer
PM TRADE
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Col Deel
Aeromechanics Laboratory
Moffett Field, Ca.

Mr. David Key
Aeromechanics Laboratory
Moffett Field, Ca.

Mr. Richard Dunn
Aeromechanics Laboratory
Moffett Field, Ca.

Mr. Gary McCullough
United Airlines
Denver, Co.

Mr. Charles Huettner
FAA
Washington, D.C.

Mr. Edward Fell
FAA
Washington, D.C.

Mr. Robert Trainer
CSC
Moffett Field, Ca.

Mr. Walter Boeck
CSC
Moffett Field, Ca.

Mr. A. M. Cook
NASA Ames
Moffett Field, Ca.

Mr. Donald Dust
NASA Ames
Moffett Field, Ca.

Mr. David Brocker
NASA Ames
Moffett Field, Ca.

Mr. Herbert Hoy
NASA Ames
Moffett Field, Ca.

Mr. Richard Bray
NASA Ames
Moffett Field, Ca.

Mr. William Cleveland
NASA Ames
Moffett Field, Ca.

Mr. David Key
Aeromechanics Laboratory
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Dr. John Lauber
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Moffett Field, Ca.

Dr. Richard Dunn
Army Research and Technology Laboratory
Moffett Field, Ca.

Dr. H. C. Foushee
NASA Ames
Moffett Field, Ca.

APPENDIX B

SCHEDULED VMS USERS

Jul 81-Dec 82

	User	Program	Interview Dates
1.	Clyde Paulk, FSN	NAVTOLAND	6 Jul 81 18 Aug 81
2.	Lloyd Corliss, FSD	ARMCOP	17 Jul 81 19 Aug 81
3.	Bertram Lampkin, FHS Sam Wilson, FHS	698 VTOL	22 Jun 81 19 Aug 81
4.	Raymond Forrest, T Vic Lebacqz, FSD	HELI IFR	23 Jul 81
5.	John Jinkerson, FHI	RSRA	28 Jul 81
6.	Edward Aiken, FSDC	ADOCS	18 Aug 81
7.	Richard Bray, FSD	SSV	1 Sep 81
8.	Gary Churchill, FHTC	NOTAR	3 Sep 81

REASONS

1. C. Paulk

   - Interchangeable cab fits VMS
   - VMS designed for VTOL concepts (motion travel)
   - Needs wide angle visual to simulate hover
   - CDC 7600 capabilities play a minor role (for now)

2. L. Corliss

   - Evaluate value of vertical motion on VMS; Army urges use of VMS. Corliss cooperated.
   - Need for high speed computational capability. 50 msec cycle time too slow - marginal. Aiming for 25 msec frame time. High cycle (i.e. 50 msec) may corrupt value of data.
   - Future need for wide angle visual anticipated.

3. B. Lamplin, S. Wilson

   - 698 - VTOL/STOL aircraft program; tilting nacelles design by Grumman.
   - Thought simulation would be a good idea to use in evaluating advanced modeling work now under contract to Grumman.
   - High speed computational capability will not be needed until testing of STOL/VTOL landing (and landing gear) is performed.
   - High speed computer will also be needed eventually when high fidelity engine model is available.

4. R. Forrest, V. Lebacqz

   - Helicopter handling qualities during IFR flights; primarily approach.
   - Chose VMS because of frequency and travel characteristics of the motion system.

5. J. Jinkerson

- Rotor Systems Research Aircraft test advanced rotors.
- Test handling qualities of advanced rotors that will be on RSRA.
- Develop and test flight techniques for advanced rotors.
- Do failure modes and effects analysis.
- Validate stability augmentation system.
- Evaluate flight computer system, advanced control algorithms and advanced control systems.
- * Need high speed computational capability for multi-element rotor blade simulation. Multi-element blade model necessary: Standard Bailey models based upon actual aircraft data. Since rotor concepts tested here have not yet been developed into hardware form, multi-element blade model is only (best) way to translate wind tunnel aero data into a usable math model.

6. E. Aiken

- Advanced Digital Optical Control System.
- Evaluate controller and display configurations from a handling quality and human factor (i.e., workload perspective).
- Chose VMS because of motion and wide angle vision capabilities (4 axis controller).

7. R. Bray

- JSC limited in terms of engineering simulation. JSC emphasizes training simulation.
- Combination of visual and motion capabilities at Ames VMS thought appropriate for Orbiter engineering simulation research.

8. G. Churchill

- Frequency response of VMS simulator systems, including motion.
- Not much initial interest in CDC 7600 high speed computational capability.
- NOTAR (no tail rotor) concept evaluation dependent upon dynamic qualities of the simulation.

GOALS

1. C. Paulk

   - Develop technologies of flight control and display system (landing guidance systems) necessary to land a VTOL aircraft on board a ship (not necessary to impact a given vehicle design).

2. L. Corliss

   - Impact design of future helicopters .
   - Emphasis on control system design, especially engine control systems.
   - Primarily for high maneuver tasks (NOE).
   - Determine outer limits for frequency response, damping, time delays, available torque.

3. B. Lampkin, S. Wilson

   - Impact design of VTOL aircraft.
   - Demonstrate the usefulness of the aircraft configuration; especially the use of vanes to control aircraft moments at low speed.
   - To examine flying characteristics and handling qualities of aircraft concept.

4. G. Forrest, V. Lebacqz

   - Establish control system boundaries to use in the design of safe control systems.
   - Determine flight control and flight instrument requirements for optimum or near optimum IFR approach performance.
   - Need to determine level of control system augmentation required.

5. J. Jinkerson

- Impact rotor design technology
- Evaluate new rotor concepts
- Create rotors that are:
  - Quiet
  - Powerful
  - Vibration limited
- Simulation used to weed out unpromising rotor concepts

6. E. Aiken

- Evaluate and demonstrate "flight by light" controller concept including new and unique controller concept--4 axis.
- Develop controller and control laws optimized for aircraft (Black Hawk).
- Examination of a given control configuration just as important as the selection of a certain concept for optimization.
- Impact vehicle design.
- Need to compare and determine control requirements for day vs night NOE flight.

7. R. Bray

- Validate specific control systems configuration; e.g., verify auto land system capabilities in a variety of conditions: wind, nav. system failure, etc.
- Evaluate shuttle display concepts, especially with regard to HUD technology.

8. G. Churchill

- Investigate flight test anomalies associated with NOTAR (no tail rotor) concept.
- Evaluate control laws and control augmentation systems.
- Develop technology to impact tail rotor design on actual vehicle.

REASON FOR GOALS

1. C. Paulk

- Get minimum down to soft zero--zero condition.
- NASA

  Facilities

  Expertise
- "Fix the fleet" vs. radical change in fleet aviation concept.
- Long term Navy interest in landing on board small ship.

2. L. Corliss

- Army mission: need to perform maneuvers quickly (time/distance) in order to avoid detection and to effectively use terrain to mask radar signature.

3. B. Lampkin/A. Wilson

- Future Navy mission will involve STOL/VTOL aircraft.
- Need to evaluate contractor progress. Grumman boasting loudly. Need to review - evaluate.

4. G. Forrest/V. Lebacqz

- Use of helicopters increasing.
- More IFR flight will occur.
- There may be changes in helicopter design that will require dramatic changes in control system design.

5. J. Jinkerson

- Reason for goals is to keep U.S.A. helicopter manufacturers on the forefront of technology.
- No new rotor concepts in over 20 years.

6. E. Aiken

- Army mission
  Flight-by-light less susceptible to electro-magnetic influence than fly-by-wire.
- Other benefits of ADOCS:
  reduced workload (?)
  improved flying quality for NOE (better vision)

7. R. Bray

- Assure appropriateness of vihicle design.
- Increase confidence in use of equipment.
- Impact vehicle design, but only when system performance problems are discovered.

8. G. Churchill

- Tail rotor very vulnerable
  military operations
  excessive flare
- Other problems:
  hard to maintain
  noisy
- Elimination of tail rotor would be beneficial provided no degradation in vehicle handling qualities occurred.
- DARPA funded program.

TASKS

1. C. Paulk
   - Land VTOL or helicopter on the back of a small ship in a variety of weather conditiors.

2. L. Corlisss
   - NOE flight (and other high maneuver tasks, e.g. pop-up, high speed stop to a hover)

3. B. Lampkin/S. Wilson
   - Cruise: moderate altitude and airspeed
   - Transition corridor
     Cruise- low speed flight
     Examine thruse control and aircraft stability
   - Hover
   - Translation in low speed flight
     Fore/aft
     Lateral
     Vertical
   - Simulate system failure
   - Simulate engine failure
   - VTOL approach (landing in the future)

4. R. Forrest/V. Lebacqz
   - Non-precision VOR approach (IFR)
   - Presicison ILS approach using 6 glide path (IFR)

5. J. Jinkerson
   - Any/all types of tasks
   -

Task	Emphasis
Landing	Heavy
Takeoff	Heavy
Hover	Moderate
Noe	Light

Task	Emphasis
Cruise	Moderate
Lateral movement	Moderate
Pop-up	Moderate
Yaw	Moderate

- Note, this research is not a task oriented program. A typical command to the pilot would be, "Exercise the pitch axis."
- Searching for control stability and authority problems.

6. E. Aiken
   - NOF flight, both Day and Night

7. R. Bray
   - Approach and landing

8. G. Churchill
   - Low altitude task, low speed
   - Hover

PERFORMANCE MEASURES

1. C. Paulk
   - Measure A.C. performance: altitude rate, roll rate, etc.
   - Measure pilot performance: stick movement
   - Pilot comments
   - Cooper/Harper ratings
   - Integration with optimal pilot model
   - Above must be integrated and evaluated using expert opinion

2. L. Corless
   - Time between bob-ups
   - Error off intended flight path
   - Cooper/Harper ratings
   - Attempted to correlate pilot ratings with error scores (a problem)

3. B. Lampkin/S. Wilson
   - System performance measures (e.g. roll rate)
   - Pilot opinion
     - Navy pilots
     - Grumman pilots
     - NASA

4. R. Forrest/V. Lebacqz
   - Need to measure events surrounding basic longitiudinal stability
   - Mostly pilot opinion data

5. J. Jinkerson
   - Primary data source: pilot opinion
     - Open ended
     - Little use of structured questionnaires

6. **Ed Aiken**

- System performance

  Error scores (flight pattern error)

  Time required to perform a task

  Distance required

- Pilot opinion

  Test pilot- engineering evaluation

  Line pilot- human factors evaluation

- Workload measure

  Pilot rating

  Use of secondary tasks such as the Steinberg tasks

7. R. Bray

- Pilot opinion

8. G. Churchill

- Strip chart data
- Pilot opinion data
- Need to corroborate pilot opinion data with engineering data in order to ascertain if the pilot is responding to a characteristic of the aircraft or to some anomaly introduced by the simulation.

VALUE OF CGI

1. C. Paulk
   - Require wide field of view visual system
   - High detail may not be required
   - Simulation of ship dynamics critical, enen though level of detail requirements is low

2. L. Corliss
   - Not planning to use CGI presently (will let his colleagues find out how to use CGI)
   - In future wide angle capability will be required
   - Level of detail in CGI scene content may be in-adequate. Need scene as testured as it would be for NOE flight.
   - Perhaps a gybrid system

     Camera/model- forward field

     CGI- peripheral
   - May need to change CGI data base frequently

3. B. Lampkin/S. Wilson
   - Definitely require wide angle system
   - Need high detail for ship environment, depth perception
   - VTOL, lower right- high detail required
   - System dynamics critical, expecially visual/motion interaction. Would sacrifice motion dynamics for better visual
   - Hover and transition maneuvers especially sensitive to visual and motion dynamics.
   - Has used HUD to supplement wide angle visual.

4. R. Forrest/V. Lebacqz
   - Irrelevant to IFR flight
   - May use, though, for simulating new electronic instrument displays

5. J. Jinkerson
   - Quality of the scene will determine quality of the data
   - Need wide angle visual
   - Low need for high detail (?)
   - Critical vision sensitive tasks (all from precision hover)
     Hover
     Backward
     Lateral
     Forward

6. E. Aiken
   - Wide field of view required for daytime
   - NOE flight should be a problem. Lack of scene detail. Lacks knowledge of how to modify data base.
   - Needs to create an environment in which the pilot will exhibit "appropriate" behavior (i.e. behave as though he were performaing that task in actual aircraft).

7. R. Bray
   - Wide angle visual of little relevance
   - System dynamics critical
   - Detail requirements uncertain. Model board display used previously with success.
   - Expensive CGI may not buy much for landing maneuver performance.

8. G. Churchill
   - Present dynamics of camera model board system can be determined and satisfactorily modified.
   - Camera model board field-of-view a problem that can be tolerated, usually.
   - CGI wide field of view would be an advantage
   - Scene content?
   - CGI dynamics critical to research goals.

VALUE OF VMS MOTION

1. C. Paulk

   - Enhance value of experimental situation, especially flight control work and handling quality.
   - Frugal with the use of motion, use only when needed; value of interchangeable cab.
   - Favors 1-1 motion (no washout)
     vertical
     longitudinal

2. L. Corliss

   - Not sure
     Motion washout a critical problem (past experience).
     Large travel capability of VMS may allow 1-1 motion software. Use of 1-1 (i.e., the elimination of washout) would be very helpful.

3. B. Lampkin/S. Wilson

   - Intuitively, motion appears to be a strong cue.
   - Use of motion should aid in acquiring better data.

4. G. Forrest/V. Lebacqz

   - Motion an asset when evaluating minimally safe control systems.
   - Vertical travel capabilities an asset, given emphasis on longitudinal and vertical stability/control.

5. J. Jinkerson

   - Tasks sensitive to vertical motion and operation of the collective.
   - Pilot needs to perceive and use vertical motion to operate vehicle.

- Sure data will be of better quality due to enchanced VMS motion capability (esp. vertical motion).

6. E. Aiken

- Questions value of motion. Reports comments like: fixed base/single window and HUD system "better" than VMS/single window--no HUD.
- Motion system software may be a problem.
- * - Need to optimize software for NOE flight (or any task). Different points of view:
  1. Researcher: task; cues to pilot
  2. Facilities: hardware characteristics, software potential
  3. Result: different motion software would result.

7. R. Bray

- Helped a great deal. VMS travel capabilities helped especially in PIO work. Orbiter has unusual pitch and Z axis characteristics that can induce PIO. VMS motion helped pilots gain confidence about their ability to pilot the Orbiter.
- VMS motion also valuable for turbulence simulation. Lower frequency simulation capability of VMS provided better turbulence cues than FSAA type motion.
- Overall higher confidence in the data.

8. G. Churchill

- Vertical travel and frequency band width of VMS helpful. (Good data has been obtained using FSAA, however.)
- Need to model motion system (software and hardware) transfer function. Need simulator cab acceleration data. Must be able to modify motion system dynamics to fit the needs of the aircraft aero model in order to assure user of high fidelity simulation.

FUTURE USES

1. C. Paulk

   - Navtoland program should continue
   - Evolvement will occur, especially when the specification and procurement process begins to check out proposed hardware and specifications. May not use VMS, use simulation for control law development and solving real operational problems.

2. L. Corliss

   - Will be much like the present. (Effects of engine dynamics or handling qualities.)

3. B. Lampkin/S. Wilson

   - Research of this sort should continue. VTOL work an essential part of the long term Navy mission.
   - Navy specifically requested the use of simulation facilities for VTOL.

4. G. Forrest/V. Lebacqz

   - "slung load" simulation
   - Autorotation
     - advanced rotor models
     - ground effects

5. J. Jinkerson

   - Much like the past

6. E. Aiken

   - ADOCS will continue for a while

7. R. Bray

- Other SSV simulations planned
- Other research topics in simulation technique planned as well.

8. G. Churchill

- Limited flight test and/or simulation test results may limit future funding.

PROBLEM AREAS

1. C. Paulk

   - Will equipment integration occur <u>in time</u> on VMS system?
   - Coping with CGI may be a problem. Is the scene appropriate? How can we change it? How can the sim. task be made more realistic? Can the scene be changed? Is organization prepared to do so? (Should CSC be more involved? Is staff being created to do so?)
   - Anyone involved in examining CGI per se? (No)

2. L. Corliss

   - Motion washout. Use bob-up as a test task; washout vs. no washout.
   - Post flight data processing a problem. Tape conversion a problem. Could tape format be made compatible: RUNDUM tapes don't play on in-house computer.
   - CGI problem: detail and data base modification.
   - Cycle time a problem (CDC 7600)
   - Two shift availability would be desirable.
   - How do I know if everything is right? Does the motion, visual and instrument response correlate with the model and pilot input?

3. B. Lampkin/S. Wilson

   - Reached optimum blend of complexity and fidelity. More fidelity, more complexity→ too much→ more fidelity might compromise operating capability due to increased complexity. (Expense increases as well).
   - More thought required on products of use of simulation. High fidelity, full mission simulation not always required.
   - More emphasis on engine modeling (more than thrust or throttle position). (Need to examine critical engineering

parameters real-time during simulation) (CDC 7600 will have that capacity.)

4. R. Forrest/V. Lebacqz

   - Lack expertise in simulation technology. Need to demonstrate and understand simulation capability in order to evaluate its affect on research.
   - Need also to translate simulation response characteristics (e.g., Bode plots) into statements concerning the impact of simulator cues on the pilot.

5. E. Aiken
   - Motion system software
   - CGI detail
   - People problems: Too much direction from Sim Sci.
   - Need to solicit more research opinion prior to purchase or modification of hardware.

6. R. Bray

   - Random, insignificant.
   - VMS dynamic performance characteristics questioned by JSC people. No easy means available to demonstrate dynamic capabilities of VMS.

7. G. Churchill

   - Need to know simulator system (end-to-end) dynamics
     Motion (see motion)
     Visual (see CGI) effects
     Control system
   - Control system (loaders)
     Need independence of loader natural frequency and damping gradient.
     Need acceleration compensation system to compensate loader for simulator cab accelerations.

REFERENCES

1. "Aircraft Simulator and Visual System Evaluation and Approval," Advisory Circular, 121-14C, 8/29/80, Department of Transportation, Federal Aviation Administration, Washington, D.C.

2. "Advanced Simulation," Federal Register, Vol. 45, No. 127, 6/30/80, Department of Transportation, Federal Aviation Administration, Washington, D.C.

3. Semple, Clarence A., et. al., Simulator Training Requirements and Effectiveness Study (STRES), Aircrew Training Devices: Fidelity Features, AFHRL-TR-80-36, January 1981, Air Force Systems Command, Air Force Human Resources Laboratory, Brooks AFB, Texas.

4. Hewett, CDR. M. D. and Galloway, R. T., Improving the Flight Fidelity of Operational Flight/Weapon System Trainers, TM 75-1 SA, Strike Aircraft Test Directorate, Naval Air Test Center, Pautuxent River, Maryland, October 1975.

5. Woomer, Lt. C. and Carico, D., A Program for Increased Flight Fidelity in Helicopter Simulation, TM-77-1 RW, Rotary Wing Test Directorate, Naval Air Test Center, Pautuxent River, Maryland, April 1977.

6. Harris, Wm. T., Acceptance Testing of Flying Qualities and Performance, Cockpit Motion, and Visual Display Simulation for Flight Simulators, NAVTRAEQUIPCEN IH-251, Instrumentation and Controls, Naval Air Systems Command, Washington, D.C., May 1977.

7. Ragland, Fred A. and Richmond, Maj. J. A., "Planning and Conducting Subjective Evaluations of Flight Simulators", Aeronautical Systems Division, Wright-Patterson AFB, Ohio.

8. Curtice, Wm. L., The Simulator Data Test Instrumentation System: A New Concept in Training Device Fidelity Measurement, Aeronautical Systems Division, Wright-Patterson AFB, Ohio.