HELICOPTER SIMULATION TECHNOLOGY: AN AMES RESEARCH CENTER PERSPECTIVE

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Abstract

Helicopter handling qualities have been the subject of many simulator programs at Ames Research Center over the past decade. The earlier experiences, in fixed-cockpit simulators, demonstrated the basic difficulties of simulating the inherently complex control tasks of helicopter flight to the level of subjective fidelity required for confident evaluation. It became recognized that deprivations in visual and motion cueing were probably major factors in the problem. More recent simulations have utilized large-amplitude cockpit motion systems, and efforts have been made to optimize the effectiveness of the visual simulations. This paper reviews the total experience for evidence regarding the levels of motion- and visual-cueing fidelity required for handling-qualities research in ground-based simulators. Positive contributions of cockpit motion were identified, but much remains to be learned regarding the sensitivities of individual control modes to cueing attenuation. A firmer understanding of the pilot's utilization of visual and motion cues is the key to more efficient use of simulation in helicopter control-systems research.

Introduction

Flight-simulation technology is especially challenged by the helicopter. Mathematical modeling and verification procedures are difficult. Flight modes include those often characterized by low stability and cross-axis control coupling, conditions that tend to produce unrealistically high workloads in simulation. A sense of realism, better termed subjective fidelity, in the simulated flight task is essential for its use in research; and, depending on the research objective, some moderate to high level of objective, or engineering, similarity to the flight task is required to create that realism. There is no basic obstacle to the attainment of objective fidelity in the simulation of an aircraft except in the areas of cockpit motion and the outside visual scene. At best, simulation can provide only part of the cues available in the aircraft. The effects of these deprivations, their individual contributions to the diminution of subjective fidelity, is not clearly understood; they have not been subjected to adequate study. In the absence of better information, research simulations are configured and used in the manner that experience indicates to be probably effective.

It is the objective of this paper to review recent helicopter simulation experience at Ames Research Center for evidence relating fidelity of motion and visual cueing to subjective fidelity and confidence in research results. The scope of this experience in terms of objectives, facilities, and simulated flight tasks is briefly described. Approaches to optimization of the utilization of unique cockpit motion- and visual-simulation capabilities are discussed, and several experiences that offer hints regarding the role of vertical acceleration in hovering tasks are described. Concluding remarks address the need for a firmer understanding of the effects of cueing deprivations and suggest a program of directed research on the subject.

Scope of Research Activities

Objectives and Tasks

Several papers presented at this meeting discuss recent helicopter research conducted in Ames simulators. A series of handling-qualities studies, in the context of a "nap-of-the-Earth" flight task, is discussed in Ref. 1. That paper touches on the relationships of simulation facilities and procedures to the interpretation of results. The results of tests to guide the development of helicopter IMC flight certification criteria are presented in Ref. 2. Control systems and guidance displays were evaluated in an ILS-like approach that included deceleration to hover on instruments. The study of Ref. 3 closely examined variations in engine and control-system response in critical height-control maneuvers. This simulation required optimized visual cues and, like the study of Ref. 2, anticipated benefits from the utilization of a simulator with a large-amplitude cockpit motion system. Motion- and visual-cueing considerations in that study will be expanded upon in a later section of this paper.

Although these are typical of helicopter simulation studies being conducted at Ames, others must be mentioned to indicate the broad scope of objectives pursued. The XV-15 Tilt Rotor aircraft has been the subject of simulation exercises for the 9 years since concept proposals were evaluated. This program, conducted in support of the vehicle development and flight tests, used a variety of Ames facilities; it is documented in Ref. 4. Another example of support of a research aircraft is the recent simulator studies defining optimum operating procedures for the winged, or "compound" version of the Rotor Systems Research Aircraft (RSRA). A dedicated simulator cab is being constructed for continued support of the two flight vehicles.

Individual simulator exercises in these flight-support programs might have one or several specific objectives, but collectively they involve tasks covering the operational envelope of the aircraft. They represent a specific challenge and opportunity. The requirements for fidelity are severe, but since the aircraft exists in a flight-test configuration, the opportunities for verification are excellent. Reference 4 reports several illuminating exercises comparing simulation responses with those of the Tilt Rotor aircraft, and relating them to the pilot's subjective impressions.

Another helicopter research effort in its early stages is one that joins VTOL studies in addressing the special guidance and control problems of approaching and landing on a destroyer in very adverse weather, perhaps among the most difficult tasks to simulate adequately. This task will also be the subject of further discussion.

A number of helicopter simulations have been used in terminal-area traffic control studies, and a current program is assessing airborne radar concepts of guidance to offshore oil platforms. These are IMC flight tasks with very modest maneuvering requirements.

This overview has not touched on all of the Ames helicopter simulation activity, but perhaps it has described those efforts in which the quality of visual or motion cueing, or the effects of their absence, should have been a consideration.

Facilities

Cockpit and Motion Systems. This discussion of facilities is limited to those factors defining the pilot's immediate environment: displays, controls, and, most importantly, cockpit motion- and visual-cueing systems. The simulator cab illustrated on Fig. 1, designated Chair 6, is popular with experimenters who are in the preliminary phases of a research program, or who are studying navigation or display questions unrelated to the higher frequency dynamics of the helicopter. It is a box on wheels that can be located handily in the computer laboratory, but like most Ames simulations, it is equipped with a collimated TV monitor for displaying a scene generated by a model-board system. It also has provisions for a collimated head-up display. To avoid the complications of hydraulics, control loaders are simple electromechanical devices. Another fixed-cockpit simulator, which utilizes a salvaged UH-1 cab and control hardware, is used primarily in the development of software for a helicopter avionics flight program.

The Flight Simulator for Advanced Aircraft (FSAA), illustrated in Fig. 2, features a lateral motion envelope of 30 m, together with 3 m of vertical travel and 2.5 m of fore-and-aft movement. Three independent drives provide generous amplitudes of angular motion. All drives are electric. Linear acceleration capabilities are modest, less than ±0.5 g, but are generally satisfactory for helicopter simulation. The large transport-type cockpit has two pilot stations, and is equipped with hydraulic control loaders, visual simulation TV monitors, and head-up display equipment. As in all simulators (except the several "dedicated cockpit" simulators), this cab is reconfigured for each new simulation. Over the past decade, this facility has been used in simulation of a wide range of aircraft. Currently, helicopter simulations make up about 25% of its operation.

The newest facility, the Vertical Motion Simulator (VMS), is shown in Fig. 3. The present cab is of the same specifications as the FSAA, but is driven in angular motion by a small, six-actuator hydraulic system. This is mounted on a laterally driven carriage with 13 m of travel atop a beam which can be moved vertically in a 19 m envelope. These latter two drives are electric, and are capable of nearly 1-g accelerations. A second horizontal motion component is not provided; however, the cab can be rotated to substitute fore-and-aft motion for lateral motion. A later section of this paper will discuss the capabilities of those large motion systems to reproduce the motion cues of maneuvering flight.

Visual Simulation Systems. Ames operates two Redifon TV model-board visual scene generators. These systems can provide a 34° by 48° visual field on a 525-line color televison raster format. The model-boards have accumulated a variety of features modeled at scales from 1:300 to 1:1200. Half of one of the model-boards is devoted to hilly terrain appropriate for helicopter NOE flight tasks. A variety of aviation ship models, mechanized to provide deck motion, are provided. An oil drilling platform is also available. A recent acquisition at Ames is a Singer-Link computer-generated-image (CGI) visual simulation system. This device can produce four independent 34° by 48° visual fields on 1024-line raster formats. The scenes, which are in color, can present simulations of day, dusk, and night conditions. Scenes presently available include an airfield and surrounds, a destroyer with helicopter landing facilities, and a small carrier. A new simulator cab, shown in Fig. 4, is configured for a helicopter pilot's station and is equipped with four collimated CRT "windows" for display of the CGI scenes. It has operated as a fixed-cockpit simulator. Within the year, this cab, which is the first of a series of "interchangeable" cabs, will be installed on the VMS motion system to combine the increased viewing area with the large-motion capability.

Cueing Effectiveness

The preceding descriptions of the motion and visual systems fall short of defining the extent to which those systems can reproduce the cues sensed by the pilot in flight. This definition can be obtained only through examination of the specific simulated flight task -- the accelerations of flight compared with the limited spectrum available in the simulator -- and the visual information vital to the task in flight compared with what is available in the simulator. The following paragraphs initiate this process by establishing generalized maneuver-cueing relationships for the VMS motion system and the visual simulation devices. The high-frequency dynamic response capabilities of these systems will not be addressed here. The general topic of allowable lags in motion and visual systems is well covered in the recent literature.

Motion-Cueing Capabilities

The motion commands to the VMS drives are composed of 1) the computed motions of the modeled aircraft subjected to second-order high-pass filtering and possibly attenuated; and 2) discrete limiting logic that arrests the motion at the excursion limits, if the primary mode of confinement is overpowered. The characteristic frequencies of these "washout" filters are directly related to the maximum amplitudes of the lower-frequency accelerations anticipated in the simulated maneuvers, the degree to which direct attenuation of the accelerations is acceptable or necessary, and the excursion envelope of the related motion-system mode. The roll and pitch modes are not usually constrained by their own angular excursion limits, but rather by the consequences of logic that attempts to minimize spurious longitudinal or lateral accelerations owing to cockpit tilting. Thus, roll excursions are limited by the capability of the lateral drive to retain the specific force vector in its proper orientation as the cab is rolled. Gains and washout frequencies typical of those used in the VMS in helicopter simulation are indicated in the Bode diagrams of Fig. 5. This diagram describes the "band-pass" of the system -- those portions of the maneuvering spectrum that can be reproduced accurately. It also illustrates that motions at frequencies near the washout frequency will be highly distorted in phase. The roll-off in dynamic response shown at the high frequencies is typical of the drive system, not the motion constraint logic.

Lateral Motion. The curves labeled "roll" in Fig. 5 represent the combined mode of cockpit roll and lateral motion mentioned earlier. The indicated gain of 0.5 and the washout frequency of 0.7 rad/sec are appropriate for the simulation of lateral maneuvers involving angles-of-bank seldom greater than 30°, which in this case would result in a lateral excursion of about 5 m. Accommodation of higher-amplitude lateral maneuvering would require more attenuation or an increase of the washout characteristic frequency. Experience has indicated that for active lateral maneuvering, the former is the preferred option. In simulated visual flight tasks, motion-vision phase disparities can be consciously disturbing, as washout frequencies are increased above 0.7 rad/sec. It is seen in this case that motions in the frequency range from 0.7 to 1.5 rad/sec are transmitted with large leading-phase distortions. Fortunately, many of the simulated helicopter tasks involve less lateral maneuvering than provided for in this case, although one series of experiments at Ames, conducted in a fixed-cockpit simulator, utilized a high-speed NOE task that included 60° to 60° roll reversals.

Body-axis lateral accelerations are produced essentially undistorted, the short-term components provided by the lateral drive system and the low-frequency components generated by easing a "tilt" component into the cockpit roll attitude.

Vertical Motion. Two response curves are shown for vertical motion. They describe the relative capabilities of the VMS and the FSAA to reproduce the vertical motions seen in a flight task involving maximum lower-frequency vertical accelerations of about ±0.3 g. Helicopter low-speed tasks and hovering tasks usually fall in this category. It can be seen that the VMS, with a washout frequency of 0.4 rad/sec, provides an unattenuated, effective (less than 30° phase error) band-pass between 1 and 6 rad/sec. The relatively limited excursion capability of the FSAA defines a washout frequency of 1.4 rad/sec and an effective band-pass between 3.0 and 6 rad/sec. Such increases in vertical washout frequency have not produced the strong conscious motion-visual disparity disturbance seen in roll.

Visual-Cueing Capabilities

The comparison of visual cues provided in simulation with those present in flight is not the straightforward process demonstrated for motion cues. A visual scene has many measures, and the significance of each to the pilot's perception of his position and velocity remains ill-defined. However, some of the obvious capabilities and limitations of the model-board and CGI systems can be noted.

Field-of-View. In Fig. 6, the extent of four visual fields, as might be generated by the CGI system, is compared with the pilot's outside visual field in a typical helicopter. The model-board systems are capable of supplying only the single forward scene. The fourfold increase in field offered by the CGI system still falls short of matching the flight condition, though it adds sideward and downward scenes that are assumed to be of prime importance for position and velocity cues in precision hovering. Also, the argument is made that the more generous lateral field improves the pilot's perception of rates-of-change of aircraft attitude.

Quality of the Scene. Visual systems are most severely tested in simulations of flight in proximity to the terrain or structures, exactly the tasks usually chosen for critical helicopter control-systems evaluations. There is no inherent limit to the extent that real-world textures and detail can be reproduced on the model-board; however, models are only seldom detailed to match the limited resolution capability of the camera optics and video system. Even without the deliberate detail, objects on the model-board usually possess some level of resolvable texture. By comparison, the CGI system, because of the limited number of lines it can draw, is severely limited in presentation of detail. The CGI scene, with its comparatively high resolution, is excellent at medium to large distances but tends to lose its realism as the terrain is approached. The concentration of the system's image-producing capacity on a limited scene feature, as in a ship model, offers at least a partial solution to the difficulty. More will be said about simulated scene content in discussions of several specific simulation applications.

Observations and Discussion

Validity of Simulation

The foregoing has considered a variety of research objectives, and the varying limitations of the facilities used in the investigations. From this experience, observations can be made relating objective, cueing capabilities, and validity of the simulation. As defined here, validity is the effectiveness of the simulation as a means of achieving the research objective, and thus does not imply a specified level of subjective or objective fidelity in the vehicle simulation itself.

Fixed-Cockpit Simulations. In the earlier experience at Ames, handling-qualities issues were addressed in fixed-base simulation, with limited results. The simulations of light, agile vehicles drew strong adverse comment from the pilots who experienced exaggerated, unrealistic workloads in conventional helicopter maneuvers. Pilots required considerable practice to reach a stable level of performance, and performance differences between pilots tended to be large. Subjectively, the pilots considered the aircraft model suspect, and judged the limitations of the model-board visual system to be another prime source of their difficulties. The experimenters, recognizing that motion-cue deprivation might be a major part of the problem, began to seek the use of the FSAA and the VMS for their stability and control studies. However, lack of motion did not appear to present serious problems to all experimenters. Simulations of larger stabilized vehicles, used in studies of navigation and display systems, were generally accepted by the pilots. The summary observation is made that if the character and workload of the vehicle control task is not severely distorted, and if the pilot is not asked to pass critical judgment on the vehicle's dynamic responses, the fixed-cockpit simulation appears to be adequate.

Adequacy of the Visual System. The single forward window provided by the model-board visual system places a limit on the fidelity of helicopter simulation in visual tasks. In turning flight near the terrain, the inability to see what lies ahead in the predicted path is disconcerting and unrealistic. Quick stops are almost prohibited because of the loss of virtually all visual information at large nose-up pitch attitudes. Precision hover is made difficult because of the lack of translational velocity cues that normally are obtained from sideward and downward views. The extent to which these factors limit the validity of the simulation varies with the maneuvers of the simulated flight task. Validity also depends to some degree on the pilot's sense of subjective fidelity. In the fixed-cockpit simulations, visual-scene limitations were often assessed as a major cause of performance difficulty. In the more recent programs using cockpit motion, these criticisms have been less strident. The visual constraints on the task are recognized, but performance difficulties within that constrained task are not so often attributed to a lack of visual cues. This latter assessment more closely agrees with the results of flight tests[5,6] in which limitations of the pilot's field of view affected performance to a lesser degree than anticipated in view of early simulator experiences.

Cueing Optimization

The experimenter has the opportunity, and the obligation, to shape the simulated flight tasks to take best advantage of motion- and visual-cueing capabilities in the pursuit of his research objective. A standardized procedure is not offered here; instead, the simulation of Ref. 3, which is considered a particularly effective example of cueing optimization, is discussed in detail. The objective of those experiments was the evaluation of variations in height-control parameters. The critical maneuvers were determined to be climbs over obstacles at low forward speeds while minimizing exposure time above the obstacles, deceleration to hover under cover of obstacles, and a "bob-up" to a momentary surveillance position above the obstacles before a return to hover. A particular arrangement of simulated obstacles, identifying a course on the model-board, minimized the significance of visual limitations while defining flight maneuvers that optimized the cueing potential of the VMS.

Visual Simulation. The pilot's view of the experimental course, as seen at the instant of passing over one of the obstacles, is shown in Fig. 7. Obstacles are laid out between two rows of trees that define the straight-line course. This avenue is terminated in the distance by a crossing row of trees. The obstacles were arbitrary in form, and made no contribution to a sense of realism in the scene. Rows of trees might have been more aesthetically pleasing. Models of ground vehicles were included to help establish a sense of scale, and the level surface between obstacles included scattered shrubbery to aid in the sense of proximity to the ground. The avenue of high trees did more than identify a course; it served to optimize visual perception of height and height-rate from the limited forward field-of-view. This cueing augmentation was vitally important during the deceleration to hover. The pilot's view during this maneuver is seen in Fig. 8. Even though the pitched-up attitude severely constrains the view of the surface, the trees offer an effective set of references for the perception of vehicle velocities. Some of this effectiveness is attributed to the fact that the trees did not completely obscure the more distant scene. It has been noted that in restricted viewing fields, in which close objects or surfaces completely predominate, the visual cues of angular and linear motions can become confused.

At several points in the task, field-of-view limitations were especially noted. It was difficult for the pilot to assess his clearance distance when passing over the obstacles; and during his bob-up maneuver, it was very important to retain sight of some tree tops over the nose in order to maintain position reference.

Cockpit Motion. Because no lateral maneuvers were required other than to maintain position between the rows of trees, the lateral motion constraints of the VMS were minimized. Altitudes in the task did not exceed 80 ft, a height that is only slightly greater than the vertical excursion capability of the VMS. Thus, vertical accelerations were reproduced with unusual fidelity for ground-based flight simulation. The vertical acceleration band-pass noted for the VMS in Fig. 5 was realized; and moreover, because the task was so limited in altitude, vertical accelerations to the limits of the machine could be utilized.

Another Optimization Opportunity. Recent limited experience with the four-window CGI display suggests that the radically increased field of view does not relieve the experimenter of the need to seek optimization of the visual information. If, for example, aircraft systems are to be evaluated for their adequacy in landing on a moving ship deck, the visual simulation must approach the real-world scene in the provision of attitude and position cues. As mentioned earlier, the four-window CGI system falls short of presenting the in-flight field-of-view. In Fig. 9 are shown the four scenes, as presently configured, representing the pilot's view near touchdown. His only significant view of the deck is in the lower right window, and this view is notably separated from the other visual information sources. What we see is a problem of limited (or perhaps non-optimally oriented) field of view compounded by the geometry of the deck and superstructure.

The argument is made that neither the window placement nor the simulated ship geometry should be constrained by real-world measures, if as a result of either constraint the task is made unrealistically difficult. Window placement should be optimized and the scene elements designed to provide attitude and position cues of maximum effectiveness. Unfortunately, there is little in the literature to guide the experimenter in this quest. Great effort is being expended on the development of more sophisticated computer-generated scenes, but little research is under way to address the question of how to use current capabilities most effectively.

Benefits of Improved Cueing

What benefits are seen as a result of such efforts to increase the cueing fidelity of simulation? Like the cues themselves, the benefits tend to be subtle, though, as will be seen shortly, startling effects can be demonstrated if the appropriate tests are made. Even with the motion cueing provided by the FSAA or the VMS, there remain many reminders to the pilot that he is operating a simulation. The motion system contributes its own reminders if the motion logic is improperly conditioned for the simulated flight task. The introduction of large-amplitude cockpit motion to helicopter simulations does lead to these general observations: 1) the pilot's initial assessment of subjective fidelity is somewhat improved; 2) his "transition time," or time to a performance plateau with an unfamiliar vehicle and task is shortened; 3) maneuver amplitudes and control "style" compare more favorably with those of flight; 4) less variation in performance and assessment is seen across a group of pilots; and 5) ratings and commentary regarding handling-qualities issues appear to be offered with greater ease and confidence.

Two peripheral observations are worth noting: there is noticeably less criticism of the visual system's limitations, and comments regarding motion are limited almost exclusively to those inspired by anomalies, such as limit encounters, or by audible noise from the motion drives. Again, the reader is reminded that even with excellent motion cues, the pilot is dealing with a simulated flight task; he will have reservations regarding the fidelity and validity of the simulation until he has accommodated to the remaining artificialities, especially those of the visual simulation.

Some effects of improving the visual cues are more obvious. In the example discussed earlier, a particular flight task was enabled by configuring model-board elements to optimize the information in the single forward field. The increased field of view offered by the CGI system enables a simulated landing on a ship or a drilling platform. These additions are consciously appreciated by the pilots; they see an increased validity of the simulated mission, but contributions to a sense of subjective vehicle fidelity are unclear.

Some Observations Regarding Vertical-Motion Cueing

The most unique aspect of the Ames simulation experience has been the availability of vertical motion in the VMS. Though this facility has been operational for nearly 2 years, no formalized investigation has been conducted in an attempt to identify the contribution of the vertical motion cues to the validity of simulation. Other than helicopter studies such as those discussed earlier, the use of the facilities has been limited to Space Shuttle control-systems verification studies. The pilots recognized the Shuttle simulations to be of unique quality, particularly in their examinations of the pitch-control modes for PIO tendencies, but perhaps their most significant specific comment relative to motion cues was, "This is the first time we have experienced realistic turbulence in a simulator." The turbulence model was conventional, the same as they had experienced in FSAA Shuttle simulations. For the first time, they were physically sensing the lower frequency vertical gusts.

Another limited, but striking, item of evidence of vertical-motion effects was obtained during the experiments of Ref. 3. The objectives and the task of that study were described earlier in this paper. The pilots were asked to evaluate a number of collective-control and engine-response configurations in terms of a formalized handling-qualities rating scale and subjective commentary. As in many experiments of this kind, the evaluations were "blind"; that is, the pilot was not made aware of the specific variations as his evaluations progressed from one configuration to another. During the latter part of his participation in the tests, one pilot, in several instances, was subjected to a variation in vertical motion instead of a variation in the vehicle model. He was not informed of this change during the tests, nor did he consciously sense that the simulator motion had been changed. He assumed he was evaluating modifications to aircraft parameters. The change effected was an increase of the vertical-motion washout frequency from 0.4 to 1.4 rad/sec, constraining the cockpit motion to that experienced in the FSAA (see Fig. 5). The effects of this change on the pilot's subjective ratings of two helicopter configurations is shown in Fig. 10. Subsequently, the pilot was informed of the experiment and asked to repeat the evaluations in the absence of cockpit motion. His commentary accompanying the ratings of those cases with attenuated motion cited insufficient vertical rate damping in the vehicle.

The two helicopter configurations differed only in their values of vertical damping. With the full VMS vertical motion, they were given the same rating. The descriptor associated with the 4.5 rating is "minor to moderate annoying deficiencies requiring pilot compensation." With reduced cockpit motion, one configuration displayed "very objectionable but tolerable deficiencies, requiring extensive pilot compensation," and the other was assessed as having "major deficiencies requiring improvement." In the fixed-cockpit evaluations, the ratings were further degraded.

It might be inferred from these results that if the research program had been conducted in the FSAA, the degraded evaluations would have prevailed, leading to quite erroneous experimental conclusions. It is likely that such an inference is somewhat pessimistic. In the brief "back-to-back" tests in the VMS, the pilot had no opportunity to accommodate to the altered visual-motion relationship. It is probable that if the entire program had been conducted with reduced vertical motion, ratings would have been degraded less than demonstrated here; however, it remains for some directed studies to consider this question in the detail it deserves.

Another example of evaluations differing with variations in vertical motion cues was seen in a fixed-base simulator investigation of the use of a multiaxis, integrated side-stick controller (SSC) in lieu of conventional helicopter controllers for nap-of-the-Earth flight. It was discovered that with sufficient levels of stability and control augmentation, up to three axes of control (pitch, roll, and yaw) on the SSC provided handling-qualities equivalent to those achieved with the conventional controller. However, the addition of the fourth controlled axis (vertical) to the SSC yielded significant degradation in pilot rating. In contrast, in a follow-on moving-base simulation on the Vertical Motion Simulator, the same four-axis SSC configuration was given pilot ratings equivalent to those achieved with conventional controllers.

The sensitivity of this height-control problem to cockpit motion brings to mind the difficulty of achieving subjective fidelity and flight-like performance in the simulated airplane landing maneuver. The hypothesis is offered that the visual cues of linear motion are often very weak, especially in the case of vertical motion; thus, vertical acceleration cues are heavily relied upon in the conduct of precise control of height rate. This dependency might extend to the lower ranges of maneuvering frequency (near 1 rad/sec). Visual cues of angular motions are much stronger. Sensitivities to angular-motion-cue deficiencies are usually manifested at the higher frequencies typically seen with high-response control systems (3-6 rad/sec).

Concluding Remarks

A review of helicopter simulation experience at Ames Research Center indicates that experimenters seeking sound pilot evaluation of vehicle handling qualities have developed an appreciation for, if not an understanding of, cockpit motion. It is observed that low-order, well-damped, uncoupled control modes, in the presence of strong visual cues, are not sensitive to motion-cue deprivation. As these descriptions -- order, damping, coupling -- move toward the other end of their scales, or if visual cues are weakened, sensitivity to motion-cue deprivation is increased. There are indications that helicopter height control, with its collective and cyclic contributions, benefits strongly from large-amplitude simulator motion.

All significant experience at Ames with simulation of visual flight tasks has been obtained with a limited forward field of view. The advantages of a fourfold increase of viewing area are anticipated, though they remain undefined. With optimization of scene elements, the single-window model-board view has demonstrated surprising adequacy in a number of simulator studies.

These are very generalized observations, and they do guide the utilization of simulation facilities at Ames; but still lacking are the well-documented demonstrations of effects of cue deprivation that are required in the development of an understanding of the motion- and visual-cueing processes. The experiences with the VMS vertical-motion capabilities suggest their use in carefully conditioned studies of the roles played by vertical acceleration in helicopter piloting tasks. To be "carefully conditioned," such experiments should employ the most promising human performance measurement and modeling techniques, and should be designed in recognition of the probably influences of learning and task complexity on the pilot's utilization of motion cues. The visual simulations used during these experiments, in combination with the piloting tasks, must be of the highest achievable fidelity to minimize contamination of the results as a result of visual deficiencies.

Another attractive objective is the further development and evaluation of substitute cueing mechanisms (variable geometry seats, torso/helmet pullers) in the context of helicopter flight tasks; the VMS offers the opportunity for direct comparison of the effectiveness of such devices with that of essentially unattenuated motion. Also, the VMS offers some opportunity to study visual fidelity factors in the presence of high-quality motion cues. The studies suggested here should produce results facilitating more graceful and intelligent accommodation to simulations with limited cueing capabilities, and providing a firmer basis than presently exists for further simulation technology development.

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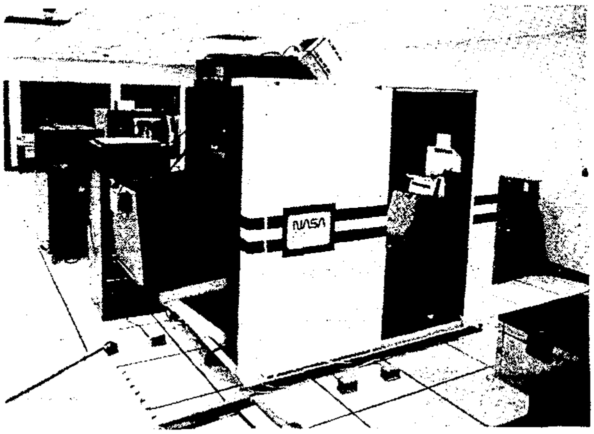


Fig. 1. Typical "fixed-base" simulation cab incorporating visual simulation and head-up display.

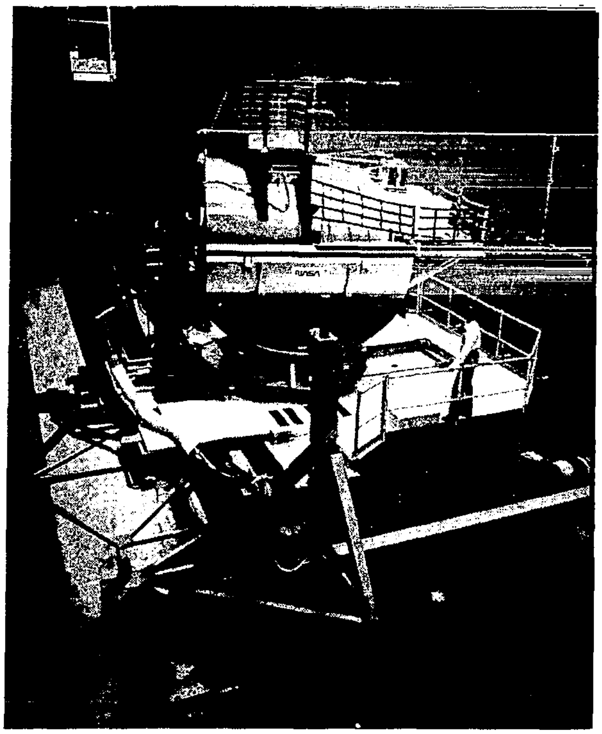
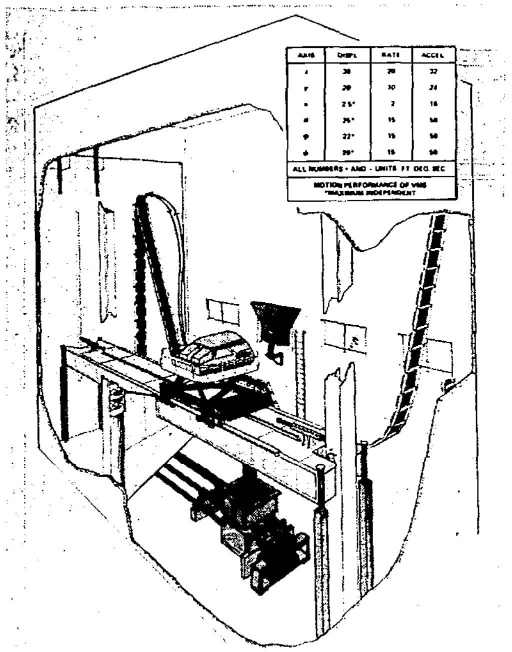


Fig. 2. The Ames Flight Simulator for Advanced Aircraft (FSAA).



AXIS	DISPL	RATE	ACCEL
z	30	20	32
y	20	10	24
x	2.5*	2	16
θ	25*	15	50
φ	22*	15	50
ψ	20*	15	50
ALL NUMBERS + AND - UNITS FT DEG SEC			
MOTION PERFORMANCE OF VMS *MAXIMUM INDEPENDENT			

Fig. 3. The Ames Vertical Motion Simulator (VMS).

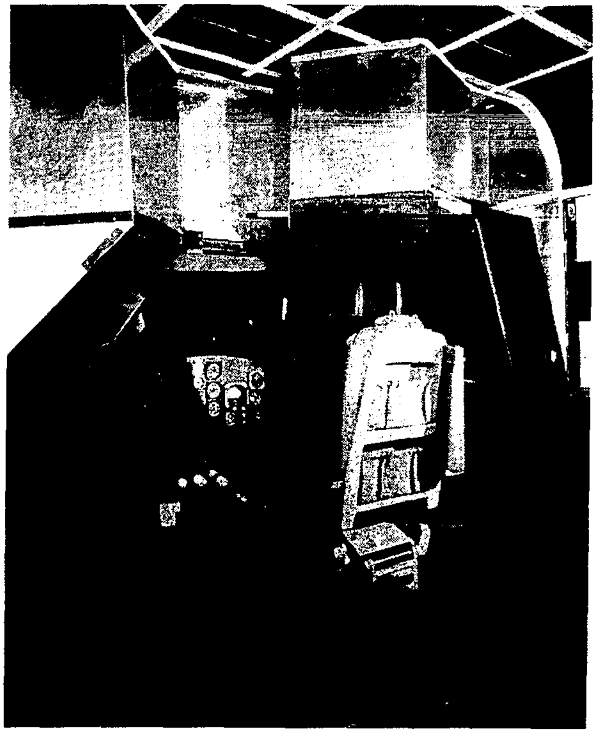


Fig. 4. "Interchangeable Cab," with four-window CGI visual simulation display.

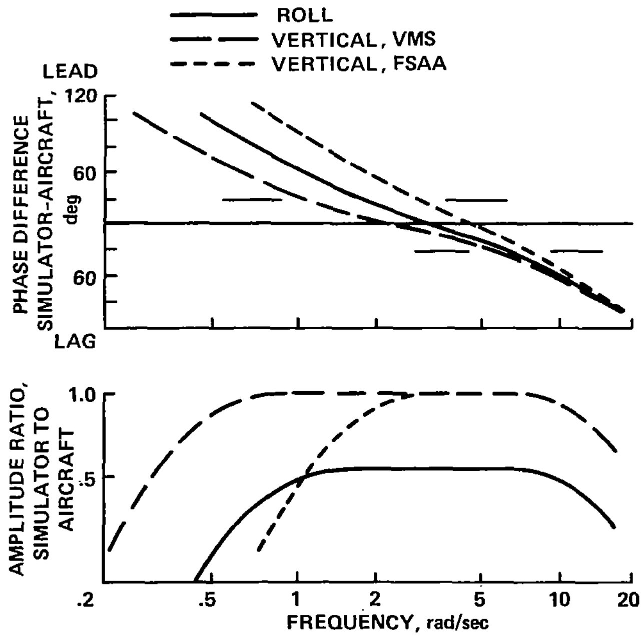


Fig. 5. Simulator motion response relative to that of the modeled aircraft.

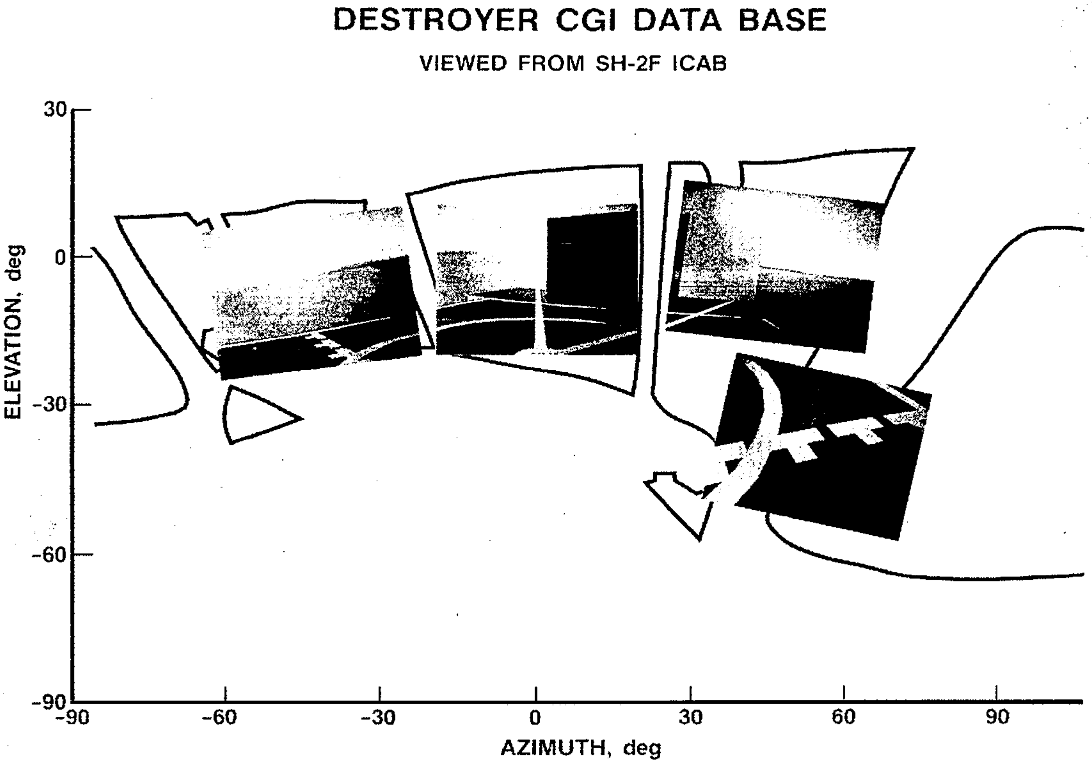


Fig. 6. Windows provided by visual simulation systems compared with typical helicopter fields of view.

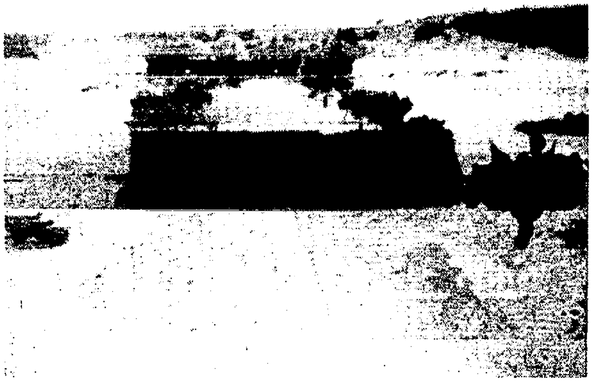


Fig. 7. View of helicopter longitudinal maneuvering course on visual simulation model-board.

Fig. 8. Pilot's view while decelerating to hover.

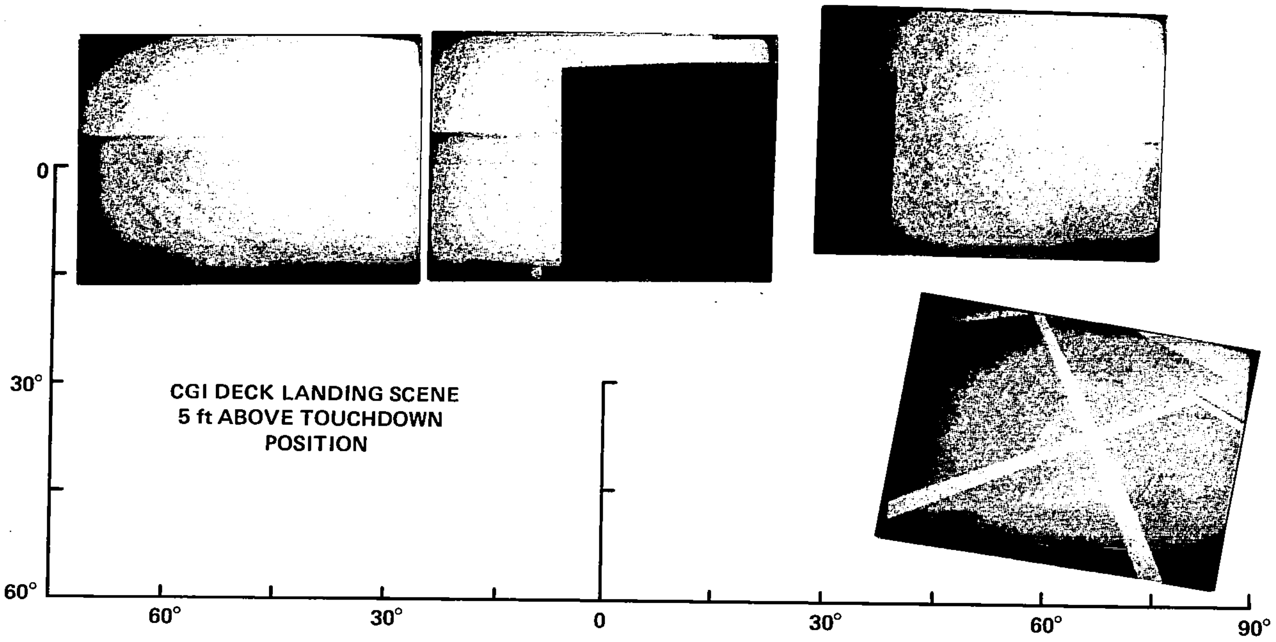


Fig. 9. Pilot's views just before touchdown on deck as provided by CGI visual system.

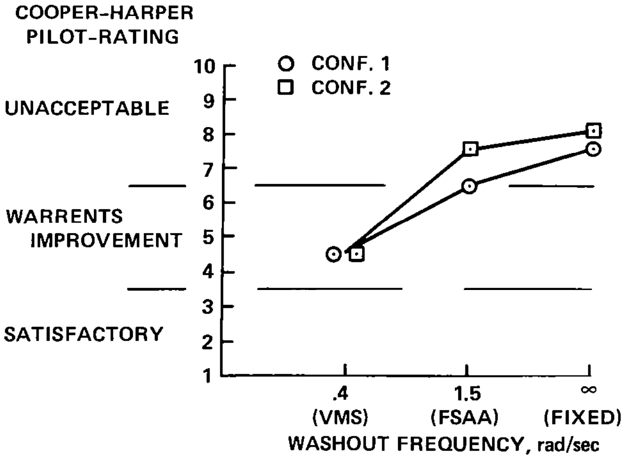


Fig. 10. The effects of changes in cockpit motion on pilot ratings of helicopter handling qualities.