

ESTIMATING THE IMPACT OF RESTRICTING SIMULATED MOTION ON TRANSFER OF TRAINING IN ROTARY WING AIRCRAFT

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ABSTRACT

Training effectiveness studies have not conclusively established the need for motion as a training enhancement or to reduce the incidence of simulator sickness. Yet many rotary and fixed wing training systems continue to use motion base trainers for initial and sustainment skill training. This paper introduces an approach for estimating the impact of motion system restrictions on training effectiveness in rotary wing aircraft.

A study which forecasts the impact on training effectiveness of restricting motion system capability in Device 2F120, the operational flight trainer for the CH-53E helicopter, was conducted. The impacts of restricted motion on system cuing, pilot training performance and transfer of training were estimated. In Phase 1, restricted motion cuing was analyzed with respect to performance of four different maneuvers. Restricted cuing equivalent to 50 percent system capability was predicted to impact Tail Rotor failure/separation maneuvers only.

In Phase 2, all four maneuvers were flown in three trials under three different motion system configurations. Simulator performance of restricted and no motion groups was equal to or exceeded that of a full motion group for each of the maneuvers. No difference in simulator sickness between motion groups was found.

In Phase 3, relevant literature on transfer of training in helicopters was consulted. No negative impacts were forecast for the devices given improved visual systems and comparable training syllabi.

ABOUT THE AUTHOR

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INTRODUCTION

The debate over the impact of simulated motion on the acquisition of flight skills continues. The potential impacts of simulated motion on flight skill training can be divided into two major categories. First, simulated motion can improve the efficiency of training, reducing the time or effort required for a pilot to acquire a particular skill. Second, the inclusion of simulated motion can reduce the incidence or degree of simulator sickness experienced by pilots in the simulator. This paper addresses each of these issues for restricting simulated motion in a rotary wing training context.

Perhaps the most critical issue in simulator training is the degree of skill transfer from training to the operational equipment/environment. While much of the flight simulation research fails to support a differential transfer effect for simulated motion over no motion (Jacobs, Prince, Hays and Salas, 1990), only a few studies which experimentally manipulated motion in rotary wing training have been reported (Browning, McDaniel, Scott, & Smode, 1982; McDaniel, Scott, & Browning, 1983; Evans, Scott, & Pfeiffer, 1984; Pfeiffer and Scott, 1985). Within simulator studies have often failed to include those tasks most likely affected by motion cuing, i.e., emergency procedures. Given this lack of knowledge regarding the effects of simulated motion on helicopter training, any system decisions regarding simulated motion should be accompanied by estimates of their impact.

The gravitational forces imposed on pilots during simulated flight training are determined by a number of variables, including:

- 1) The degrees of freedom of the motion system.

- 2) The physical limits of the system (ram/leg extension).
- 3) The algorithm for providing cuing.
- 4) The reliability of the system.

Each of these factors influences the fidelity of motion that will be delivered and ultimately the impact cuing has on skill acquisition.

The influence of motion on pilot performance is dependent on the training context, which includes:

- 1) The type of aircraft involved.
- 2) The tasks/maneuvers being trained.
- 3) The individual differences in pilots' reaction to motion.
- 4) The type of training (initial, mastery, time/trial dependent, etc.).
- 5) The type of measure(s) used to determine an effect.

Therefore, any experimenter who attempts to determine the impact of motion on flight skill acquisition or simulator sickness must necessarily recognize the joint influence of these factors and design the study methodology appropriately.

It is little wonder that the effects of simulated motion on general piloting skills have been difficult to demonstrate. Most of the roadblocks to definitive findings are a result of the lack of control over tasks and experimental variables (training hops, motion system reliability, performance measurement, etc.) when conducting transfer-of-training experiments. Still, there is a practical need to evaluate the

contribution of motion in both fixed and rotary wing training systems.

Some pilots undergoing training in flight simulators experience a form of motion sickness referred to as simulator sickness. Simulator sickness is a term used to describe a number of aspects of pilot discomfort or disorientation which are exhibited in a trainer but do not occur in the aircraft. A great deal of research is ongoing in the Navy to determine the origin and nature of this phenomenon (Kennedy, Lillenthal, Berbaum, Baltzley, & McCauley, 1989). It is possible that the degree of simulated motion during training impacts simulator sickness. While the primary objective of the current study was training effectiveness, simulator sickness issues were also considered.

This effort was undertaken in order to determine the possible training impacts of reducing motion system capability in the operational flight trainer for the CH-53E helicopter (Device 2F120). As a result of a proposed increase in the visual system capability, the motion system for this trainer may be restricted to accommodate operation in the current facilities.

While the necessary resources for conducting a transfer-of-training or extensive simulator sickness experiment were not available, a rational approach for determining the impact of motion system modifications on training effectiveness and simulator sickness was attempted. This approach addresses training effectiveness implications in terms of 1) the actual impact of excursion reduction on cuing and cue sustainment within the simulator; 2) differences in the learning curves of full motion, restricted motion and no motion training groups; and 3) related literature findings on transfer of skill to helicopters. A methodology and results section for the two empirical approaches are presented and a discussion related to transfer of training comprises a third section. A limited analysis of simulator sickness data was also included in the second section.

Visual system upgrades to Device 2F120 were estimated to require motion system restrictions of approximately 50 percent of current platform displacement. Two modifications of the motion system were considered for research purposes. First, all platform cuing as a result of stick inputs and external conditions would be reduced by 50 percent.

This would reduce all cue amplitudes by one-half and possibly change some to below perceptual threshold. Second, the overall distance of the individual leg extensions could be reduced by 50 percent. This would keep those onset cues and accelerations within 50 percent of the total leg lengths intact, but curtail those when leg extensions exceed this 50 percent range. The latter method was pursued given its retention of the majority of cues and accelerations thought to be necessary for the training syllabi in question.

Information on which to base recommendations was collected using experimental data collection and current literature findings. Each methodology and results section is covered separately. Phase 1 of this report presents an analysis of the differential cuing issue. Phase 2 addresses pilot performance in the simulator under restricted cuing conditions and pilot discomfort and Phase 3 addresses transfer of training.

PHASE 1 - RESTRICTED MOTION CUING

Methodology

If proposed motion system modifications for Device 2F120 trainers are to affect skill acquisition, differential cuing or differential sustainment of cuing in the simulator should be demonstrable. That is, if students in the simulator are receiving the same onset, acceleration and sustainment cues with a modified system that they would normally receive, there is no reason to believe training would be affected. Training would, theoretically, have the same impact and motion would be as effective as the original system's cue model.

The approach for assessing differential cuing was to estimate where the position limits for the individual legs of the motion system would be and to collect data on student performance during a variety of maneuvers to determine if these limits were exceeded. If a great majority of the training hops result in performance within the limits set on these leg positions, little or no negative impact on training is forecast.

Instructors were asked to determine those maneuvers that would most likely be influenced by motion cuing and four such maneuvers were selected for study. The selected maneuvers were Automatic

Flight Control System/Servos Off Flight, Tail Rotor Failure/Separation, Shipboard Landings, and External Loads. Leg position data on each of the four maneuvers were collected using introductory pilots during training maneuvers.

Frequency of cues outside modification limits was recorded for each maneuver. Since there is currently no practical method for testing the importance of a given cue or overall cuing for skill acquisition, this analysis is exploratory in nature.

A continuous strip chart recorder measuring the output amplitude to each leg of the motion system was used for data collection. This amplitude is directly convertible to an excursion distance. Instructors were advised of the data collection and conducted training according to the standard flight syllabus. No automated pilot performance measurement was available in this simulator. Type of maneuver was recorded to allow separation of data. Pilots were initial students undergoing Replacement Aircrew Training at Marine Corps Air Station Tustin, CA.

Results

Data were collected during eight simulator hops during a single week of testing. These hops resulted in eight Tail Rotor Failure maneuvers, ten Shipboard Landings, four AFCS/Servo Off Flights and three External Load maneuvers. For each maneuver, the frequency of cues outside parameter limits was recorded.

Only the Tail Rotor Failure maneuver resulted in any platform leg excursions beyond the 50 percent of full range limits. Therefore, the analysis will focus on this maneuver. Table 1 indicates the frequency of cues outside restricted motion parameters for each of the eight trials for each leg of motion platform for the Tail Rotor Failure/Separation Maneuver.

According to these findings, cuing would be curtailed for a Tail Rotor Failure many times during the maneuver. Again, due to the nature of this data collection, the impact of this curtailment on onset, acceleration, or sustainment cuing cannot be determined. There also are no real data to confirm that the Tail Rotor Failure as modeled in the

simulator is an accurate training aid for an actual Tail Rotor Failure in the aircraft.

Table 1

Frequency of Cues Outside Excursion
Limitations by Leg for Tail Failure/Separation Maneuver

Attempt Number	Leg					
	1	2	3	4	5	6
1	2	3	4	3	3	3
2	0	1	5	2	3	5
3	5	3	5	1	8	7
4	1	1	3	3	4	5
5	0	1	0	1	1	0
6	2	2	4	1	5	6
7	3	3	6	4	5	6
8	0	0	2	2	3	3
Total	13	14	29	17	32	35

From this analysis one must conclude that the Tail Rotor Failure training has the potential for being adversely impacted by restrictions in the motion excursion. The AFCS/Servos Off Flight, Shipboard Landing and External Load maneuvers are not expected to be impacted negatively in any way since 50 percent excursion limits would not typically be reached. However, due to the low number of trials for each maneuver, all four maneuvers will be included in Phase 2.

PHASE 2 - PERFORMANCE IN THE SIMULATOR

Methodology

Forecasting the impact of a reduction in motion system capability should be made in terms of transfer of simulator-taught skill to the aircraft. That is, how is a pilot's performance in the aircraft affected by conditions under which learning occurs in the training system? Unfortunately, performance variation is often difficult to isolate and even more difficult to measure in the aircraft. Reliable measures of performance are best collected via automated systems, and no such systems exist on the CH53E helicopter.

Since the resources to support a transfer-of-training experiment were not available, a within-simulator study was designed to determine the possible effects of motion condition on pilot performance over a number of different maneuvers. Tail Rotor Failures, Automatic Flight Control System/Servos Off Flight, Shipboard Landings and External Load maneuvers were used to determine if the amount of motion cuing (none, restricted or full) differentially impacts pilot performance.

Twenty-four fleet pilots from the Marine Corps Air Station New River, NC, were randomly assigned to the three motion groups. Each maneuver was executed three consecutive times before a different maneuver was attempted. Maneuver sequence was counterbalanced within each motion condition such that eight different combinations of maneuver sequence were given in each group.

The three treatment groups consisted of pilots receiving either no motion cuing, full cuing or restricted cuing in which leg excursions were curtailed by 50 percent of full length. Full visual systems consisting of CRT displays were used for all conditions. Pilots were unaware of the purpose of the study and were not told under which condition they were flying. Each pilot also completed the Simulator Sickness Questionnaire (SSQ) (Lane & Kennedy, 1988) immediately upon completing the hop. This questionnaire measures simulator sickness using nausea, visual, and disorientation subscales, as well as a total score.

This design allows for an investigation of the hypothesis that increasing motion fidelity contributes to training effectiveness in the simulator. If motion is a significant contributor, then one would expect a significant interaction between the training effect and the motion conditions established in this experiment. In other words, one expects learning to be positively correlated with the degree of motion in a system. Generally, only when a differential training effect can be demonstrated would one expect differential transfer to the aircraft.

Several different measures of performance were taken for each maneuver. These measures were identified by instructor pilots as critical indicators of performance. Data were collected using a continuous strip chart recorder to provide the relevant measure. While this recorder provided continuous time

information which may be analyzed using root mean square methods, no automated package was available for analyzing these data. Therefore, data were hand coded into the following measures.

For the Tail Rotor Failure maneuver, vertical speed at impact, maximum pitch, pitch at impact, maximum roll, roll at impact and airspeed at impact were used for analysis. For the Automatic Flight Control System/Servo Off Flight maneuver, maximum airspeed error, maximum vertical speed error, maximum pitch, maximum roll and maximum heading error were used. For the Shipboard Landing maneuver, time to landing, maximum pitch, maximum roll and vertical speed at impact were used. And finally, for the External Load maneuver, time to hook up, maximum pitch, maximum roll, maximum vertical speed and heading error were used.

This study was designed to test for differences in pilot performance under different motion conditions and also to determine any learning that may occur through the use of repeated trials on each maneuver. The effect of maneuver sequence cannot be analyzed in conjunction with the other variables as there was only one case per motion condition. Counterbalancing was included in this design in order to neutralize any maneuver sequence effects.

Results

Motion condition and trial effects were analyzed for each measure using the Statistical Package for the Social Sciences (SPSS) Multiple Analysis of Variance for repeated measures. A summary of the analyses of the most critical measures for each maneuver is presented in Table 2.

For the Tail Rotor Failure maneuver, the trial effect for vertical speed at impact was significant but the trial cell means (Figure 1) reveal a decrease in performance (higher vertical speed) across the three trials. This indicates pilots performed worse in terms of impact speed with successive trials. The other significant effect for this maneuver was a motion effect for roll at impact. In this case the cell means (Figure 2) indicate greater roll at impact for the full motion condition. This would be contrary to a hypothesis that greater fidelity produces better performance. The Tail Rotor Failure maneuver is the most complex of the four maneuvers selected and

may require many more trials than allowed to show a training effect. This maneuver also produces rather violent simulator excursions and these movements may affect performance in and of themselves. More on this subject will be presented in the discussion section.

Table 2

Summary of the Effects of Trials and Motion Condition on Maneuvers (Select Performance Measures)

	Trial Effect	Motion Effect	Interaction Effect
<u>Tail Rotor Failure</u>			
Vertical speed at impact	(.02)	NS	NS
Pitch at impact	NS	NS	NS
Roll at impact	NS	(.03)	NS
<u>AFCS/Servos Off</u>			
Airspeed error	(.001)	NS	NS
Heading error	(.001)	NS	NS
Vertical Speed error	(.001)	NS	NS
<u>External Load</u>			
Time to hookup	NS	NS	NS
Heading error	NS	NS	NS
<u>Shipboard Landing</u>			
Time to landing	(.001)	NS	(.001)
Maximum pitch	NS	NS	NS
Maximum roll	NS	NS	NS

NOTE: NS - Not Significant. Numbers in parentheses indicate significance level.

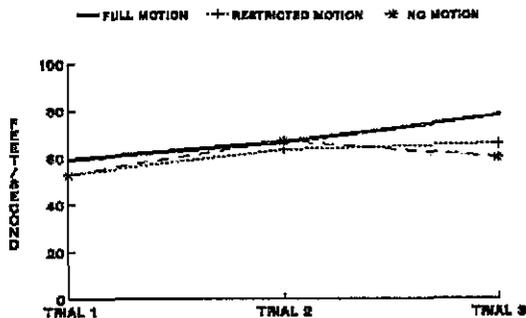


Figure 1. Mean Vertical Speed at Impact (in feet/second) for Tail Rotor Failure).

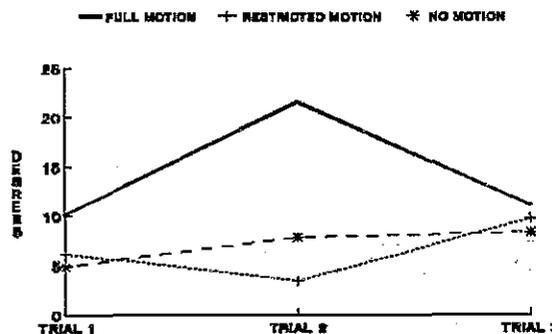


Figure 2. Mean Roll at Impact (in degrees) for Tail Rotor Failure.

For the AFCS/Servo Off Flight Maneuver, air speed (Figure 3), heading (Figure 4), and vertical speed (Figure 5) errors declined significantly across the trials. These data appear to follow a typical learning curve. None of the measures of External Load performance indicate a significant improvement from trial to trial (Table 2). This may be due to the relative simplicity of the maneuver or a failure to select a measure which reliably reflects improvement in performance.

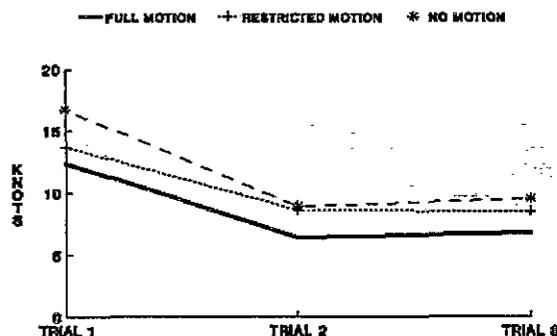


Figure 3. Mean Airspeed Error (in knots) for the AFCS/Servos Off Flight Maneuver.

For the Shipboard Landing maneuver, trials have a significant interaction with motion condition for the time to landing measures. Cell means are presented in Figure 6 and indicate that improvement occurs in both the restricted and no motion groups but not in the full motion group. It appears the full motion group has reached asymptote level with the

first trial, while the other groups demonstrate a typical learning curve across all three trials. This is

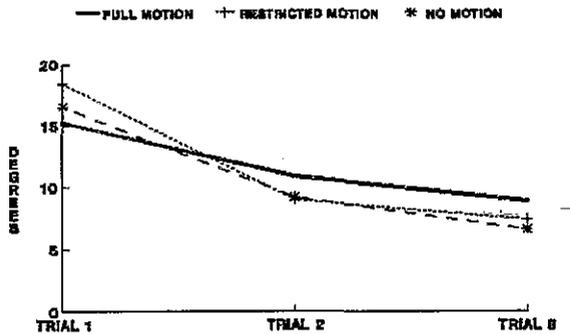


Figure 4. Mean Heading Error (in degrees) for the AFCS/Servos Off Flight Maneuver.

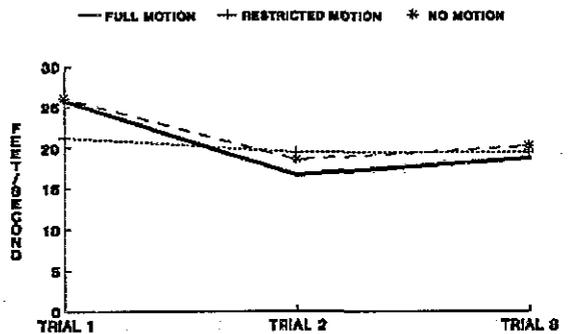


Figure 5. Mean Vertical Speed error (in degrees) for the AFCS/Off Flight Maneuver.

a tentative interpretation, however, since there were no significant performance differences between conditions. A significant trial main effect was evident from this measure as well.

The individual measures of performance may not adequately reflect how overall pilot proficiency is being impacted by motion condition and repeated trials. Since there are many different aspects of aircraft control occurring simultaneously, there may be a trade-off between what a pilot is able to control (or concentrating on) during a given trial. With multiple measures of performance available for each maneuver, some combination of these measures could reflect total pilot proficiency more validly than the individual measures.

Composite scores for each maneuver during each trial were generated by using standard score

transformations of the individual measures. This entailed standardizing each individual score (using

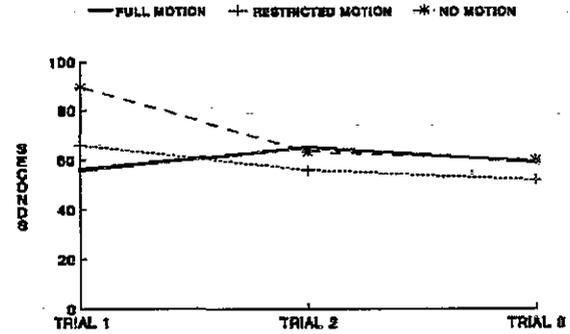


Figure 6. Mean Time to Landing (in seconds) for the Shipboard Landing.

means and standard deviations), adding the individual standard scores and dividing by the number of scores in the composite.

No significant interaction or main effects were evident for trial or condition for any of the composites generated. Again, this indicates there was no significant improvement with successive trials and there were no reliable performance differences between the motion conditions. Somewhat surprising is the failure of the AFCS composite to reflect a training effect since three of the five measures used in the composite did demonstrate an effect individually.

An attempt to measure the accuracy of the motion system should be made in any simulator experiment. Data were collected on the motion system for the device used in this phase but the results of this analysis were not available at the time this paper was prepared. This is an important consideration in evaluating the effectiveness of the motion condition and may have influenced the results.

Although the number of subjects available for conducting a simulator sickness experiment was well below that recommended, statistical tests were conducted to check for differences in the perceived discomfort of the three groups. Motion condition had no significant effect on total sickness score ($F_{(2,28)} = .5, p < .95$), nor on the nausea subscale ($F_{(2,28)} = .15, p < .76$). No significant effects of motion were detected for the other subscales.

PHASE 3 - TRANSFER TO THE AIRCRAFT

Since there was no opportunity to carry out a transfer-of-training experiment on the CH-53E simulator, the results of relevant studies were reviewed for applicability. Pfeiffer and Horey (1987) and Jacobs, et al. (1990) provide recent reviews of transfer of training studies which experimentally manipulated motion. A longitudinal effort to examine the effects of simulator device features on transfer of training was conducted by the Navy, (Browning et al., 1982; McDaniel et al., 1983; Pfeiffer and Scott, 1985; and Evans, Scott and Pfeiffer, 1984).

Findings from these efforts are summarized below. These experiments compared the performance of pilots on different types of tasks trained in several different simulator configurations (motion only, visual only, motion plus visual, no motion/no visual). Relevant findings include:

- 1) All simulator configurations resulted in significant time savings (transfer) compared with an aircraft-only trained group.
- 2) A simulator with motion and visual capability produced little more (non-significant) transfer than visual only training.
- 3) There were interactions between device features (motion, visual) and types of tasks (procedural, complexity, etc.).
- 4) Device features not required for certain tasks may actually provide a degree of distraction from training tasks not requiring those cues.
- 5) For the autorotation task particularly, visual and motion simulation (compared to the other configurations of the simulator) required the fewest training trials, but this task required the greatest amount of trials compared to other tasks.
- 6) Significant transfer resulted despite motion and visual system tests which indicate high quality motion was limited to cues in the 1.5 to 2.0 G range only.

Overall, these findings imply that the training of certain tasks is impacted by the simulator device features. However, visual cuing was found to be more important than motion cuing and in some cases (instrument training) neither was necessary for learning simple tasks.

A number of issues remain unresolved when interpreting the results of these studies. One critical concern is the inaccuracy of the motion system for cuing below 1.5 Gs. This may confound the findings regarding the performance of the groups trained under simulated motion.

There are studies using within simulator designs that have demonstrated a significant effect of accurate motion cuing on pilot performance (Ricard & Parrish, 1984; Ricard, Parrish, Ashworth and Wells, 1981). These studies lend support to the view that simulated motion contributes to the efficiency of training. However, until adequate transfer studies are conducted, the contribution of this efficiency cannot be assessed.

CONCLUSIONS

The results of pilot performance in the simulator for the four maneuvers examined in the present study fail to demonstrate a decrement in performance due to reduced motion cuing. Findings may be confounded somewhat by the study context. Performance in the simulator of the restricted and full motion groups may have actually been reduced to, or degraded below the performance level of the no motion group because of the motion itself. That is, pilots may have a harder time performing maneuvers because of the cockpit movements that result from motion cuing. Ideally, all pilots would be tested in the full motion condition to determine if differences that may occur in learning are due to the learning condition as opposed to the testing condition. Again, resources were not available for this design.

It is also possible that motion does not contribute to learning of certain tasks and in some cases may inhibit learning. This would be entirely consistent with the major findings from transfer of training motion studies in the literature when quality visual systems are included in the simulator. In the present study, motion had a deleterious impact on learning for two measures of performance (Figures 2 and 6).

It has been speculated in the literature that emergency procedure training benefits the most from full motion cuing. It has been difficult to test this belief however, due to the safety considerations in reproducing emergencies in the transfer aircraft. Within-simulator impact studies offer the only viable tests of the effect of motion on this training. Unless transfer is also demonstrated, however, these studies will be open to some criticism.

Additional difficulties in isolating the impact of simulator motion on piloting skills include the extent of training necessary to show an impact, the degree of sensitivity of the measures of proficiency, the individual differences in pilot reaction to training and the reliability of the motion cuing device. Each of these is difficult to control experimentally, and is a barrier to more specific findings related to the impact of motion on skill acquisition.

The Tail Rotor Failure maneuver was the most sensitive to motion cuing and therefore requires special attention in simulator modification. This maneuver was identified as the only one requiring motion cues outside of the restricted parameters. Coincidentally, it is also the maneuver most likely to show a training effect since it is not currently trained to mastery in any training syllabus. Maneuvers such as these likely require extensive training in the simulator regardless of the motion and visual characteristics of that simulator.

The above notwithstanding, some conclusions can be drawn from the present effort. It appears that any of the three simulator motion conditions allow for the same degree of performance accuracy (with the exception of roll at impact for the tail rotor failure). That is, having restricted or full motion cuing produces no better performance in the simulator than no motion. Also, given that the maneuvers included in this analysis were chosen by instructors as being most impacted by motion cuing, one would not expect the balance of the training syllabus to be impacted adversely by restricted motion.

One significant and consistent training effect of repeated trials was found for the Automatic Flight Control System/Servo Off flight maneuver. However, no differential effect of the motion condition variable was found. This finding offers additional support for the notion that restricted motion cuing does not adversely impact training.

The failure to demonstrate a consistent training effect across the other three maneuvers may have resulted from the use of trained pilots as subjects in the experiment, the relatively few trials given, the insensitivity of the measures, and/or the small sample size or other confounding variables.

RECOMMENDATIONS

Based on the findings of the cuing analysis, the within simulator performance tests, and the available literature related to differential impacts of motion on helicopter transfer of training, it is concluded that the training impact for the proposed simulators with reduced motion cuing would be negligible. Therefore, it is recommended that the motion system can be reduced to the estimated parameters (50 percent of current) used in this study. This recommendation assumes the upgraded visual systems will not produce negative transfer, but most likely increase the visual capability for improving training quality, in essence compensating for loss in the motion capability. This recommendation also assumes the training context studied here (maneuvers, students, simulator characteristics) will remain essentially the same in the future. A more extensive simulator sickness study is recommended.

One interesting implication of the transfer studies is the possibility that some tasks are best trained without motion. This is an area of research which should be pursued. The issue of when and where to use motion is not moot, but does require more in-depth and sensitive analysis before systemic decisions are warranted.

Some final comments on motion system algorithms, system reliability, and efficiency are warranted. As mentioned in the introduction, there are several different motion models available and most are modified somewhat following pilot comment on the system. Additionally, they are very difficult to maintain at their initial algorithm values due to wear and tear on the system. These characteristics, when considered along with effectiveness, simulator sickness, and cost factors should ultimately determine whether or not motion should be included in simulation.

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