PROCEDURES FOR EVALUATING FORCE CUEING IN TACTICAL TRAINING SIMULATORS

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ABSTRACT

The pilot in the aircraft constantly experiences various forces on the body that shape the pilot's "control behavior". These forces provide cues, consciously and unconsciously, about the accelerations of the aircraft resulting from pilot control input, aircraft operation, and the environment. In a static simulator, these cues are not present. As the use of training devices increases for distributed mission training and combat rehearsal, the contribution of force cueing needs to be established to ensure that the combat pilot's behavior and performance in the simulator will be as close as possible to that in the aircraft.

A study conducted for the US Air Force by SIMTEC, Inc., Manassas VA, concluded that the effectiveness of potential force cueing devices could be best determined by conducting operational evaluations in a mission context using experienced instructor pilots. The Air Force has successfully performed similar operational evaluations of visual combat simulators, under the "Vis-Eval" program. The study recognized that force cueing effects are much more subtle and harder to isolate than visual cues and, therefore, would be more difficult to evaluate. Because of this difficulty, and the fact that pilots may be unaware of changes in their control strategy in the simulator, it was essential that the force cueing evaluation be based largely on objective measures.

This concept was tested and refined at the Flight Control Simulation Facility of the Air Force Research Laboratory at Wright Patterson AFB. The evaluation system included an F-15 cockpit, visual simulation, a dynamic seat, an anti-g suit, and COMBAT EDGE. A trial evaluation using operational pilots was conducted. This paper will describe the evaluation procedures and the results of the trial evaluation as well as future force cueing evaluation concepts.

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Richard Heintzman has been involved in the development of Training Flight Simulators for 35 years, 27 of them with the U.S. Air Force in various capacities including Visual and Avionics Systems Branch Chief, Training Systems Division Chief and Air Force Technical Expert for Training Systems. More recently he has acted as a technical consultant to various US Companies and the Swedish Defense Materiel Administration. He is currently an Engineering Manager for SIMTEC, Incorporated working on various studies and analysis efforts. He has authored numerous technical papers and reports on various flight simulation topics. He was the 1982 winner of the American Institute of Aeronautics and Astronautics (AIAA) DeFlorez Training Award for unique development work in the area of aerial combat simulation.

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INTRODUCTION

The United States Air Force fighter aircraft community is starting a period of transition from normal and emergency procedures training to distributed mission training in networked ground based trainers. Many of the current fighter aircraft trainers have no or limited visual simulation capabilities and no force cueing or motion simulation capability. In preparation for future distributed mission training, the Training System Product Group (TPSG) developed and performed several operational visual simulation evaluations, better known as "Vis-Eval". These evaluations established the contribution of different visual simulation technologies to mission training. One of the observations from the Vis-Evals was that as the visual simulation increases in fidelity, the pilots' expectation for higher fidelity in the remainder of the simulator increased. One of these expectations was force cueing.

Force cues are defined as the forces experienced by the pilot in a fighter aircraft. These forces vary in frequency from the high-g sustained forces associated with high performance maneuvering to audio frequency range vibrations. This definition includes platform motion simulation.

To better understand the role of force cueing, the TSPG undertook a contract effort to study the role of force cueing in tactical training. This study was documented in the technical report "Determination of Force Cueing Requirements for Tactical Combat Flight Training Devices", ASC-TR-97-5001. This report may be downloaded from the Internet at http://www.tspg.wpafb.af.mil/YW/ywe.htm. This study concluded that force cueing needed to be evaluated in a manner similar to Vis-Eval but with more objective data collection. The study pointed out that the pilot might not be aware that control behavior changes with the cues presented in the simulator. Thus, pilot subjective evaluation, as in Vis-Eval, was not sufficient and a more comprehensive evaluation method was needed.

The Commander of Air Combat Command, during a Distributed Mission Training conference in July 1997, expressed concern that without force cueing, pilots would pull ten or twelve g's in a simulator without being aware that they were doing so.

The goal of a training simulator is to provide an environment for the pilot to develop, experience, and reinforce the techniques and habit patterns that will transfer to correct performance in the aircraft. For any task in the aircraft, there is a unique set of critical cues to which a pilot responds in order to accomplish the task. Pilots are very adaptable. If the proper cues are not provided in a simulator that would normally be used in the aircraft, the pilot will find other cues in order to accomplish the task. This generally does not result in optimal performance and may even lead to different control strategies than used in the aircraft. Obviously, this is not optimal for training since the pilot is simply learning to fly the simulator rather than the aircraft and may have to relearn to fly the aircraft.

The effect on training of force cueing in simulators is not well understood nor documented. The evaluation of force cueing is difficult. Pilots do not understand how or which force cues they use while flying the aircraft. The pilots cannot always articulate the impact of incorrect or missing force cues on their performance or control strategy. Thus, an analytical evaluation method is required to determine the contributions of various force cueing devices in a tactical training simulator. This paper describes an overall approach to the development of an evaluation method and a trial evaluation that examines a subset of the overall evaluation approach.

APPROACH

Studies that isolate the effects of different simulation device capabilities on training are difficult to develop and implement. Ideally, the determination of the need for training device capability should be based upon of transfer of training studies. However, transfer of training studies is difficult to design and conduct. An alternative to transfer of training studies is to evaluate force cueing effectiveness subjectively, similar to the USAF Vis-Eval program. Vis-Eval uses highly experienced instructor pilots to fly tactical missions in candidate visual simulators. These pilots rate the potential of the visual system to support student training of each task within representative combat missions (Brown, 1994). To apply this technique, it must be recognized that the effects of force cueing are often subtle and, in many cases, may not be outwardly recognized by the pilot. Another method to evaluate force cueing effectiveness is to measure differences in pilot performance with different force cueing. However, this technique by itself may not be sufficient since pilots may compensate for the lack of certain cues by altering their control strategy.

What appears to be an optimum approach to evaluating force cueing devices is to conduct a comparative data analysis of a combination of pilot performance, physiology, behavior and subjective opinion while flying a simulator with and without different force cue inputs during typical tactical missions.

TRIAL EVALUATION SYSTEM

Aircraft Model

For the trial evaluation system, an experimental F-15C was fabricated from existing and available equipment. The aerodynamics for this F-15C were implemented on an Encore RSX Computer. Stick inputs were accomplished using a side mounted force stick. The stick inputs were passed through a dead band and scaled using a dual slope gradient. Because the F-15 uses a center stick, the side stick had to be subjectively scaled using experienced pilots. The thrust of the simulated aircraft was controlled using two throttles for the left and right engines. Rudder inputs were not implemented. Turbulence was generated using a Dryden model.

Visual Scene

The out-the-window imagery was generated by an Evans and Sutherland ESIG 4530 Image Generator. The image was rear projected on a six feet by eight feet flat screen using a General Electric Light Valve Projector. The corresponding field of view was 64 degrees horizontally by 50 degrees vertically. A heads up display was electronically added to the image.

Force Cueing

Three force cueing devices used in the trial evaluation. They were a dynamic seat, the Combined Advanced Technology Enhanced Design “G” Ensemble Equipment (Combat Edge), and an anti-g suit.

Dynamic Seat The dynamic seat was both hydraulic and pneumatic activated. The hydraulic subsystems provided angular information through the seat pan and backrest and the pneumatic subsystem provided g-loading information via bladders. The seat pan is capable of rolling plus or minus twelve degrees. The same excursion is possible in pitch, but it was limited to match the pitch excursion of the backrest, which is 3.8 degrees (six degrees if midpoint rotation is used). The seat pan and backrest included pneumatic bladders that can be driven to a maximum pressure of three PSI. See Table 1 for characteristics.

Anti-g Suit A standard anti-g suit was used to provide z-axis g-cueing. The dynamic pressure range of the suit was set to one half (6.5 PSI at 9 g) of the range used in the aircraft. The pressure was scaled down due to the lack counter pressure provided by the pooling of blood in the lower extremities that occurs during actual flight. An electrically controlled g-valve was driven by software so that the g-suit inflation on-set would occur as in the aircraft at 2 g.

Combat Edge The Combat Edge system consisted of an inflatable vest, helmet with bladder, and the CRU-93 breathing regulator (Department of Defense, 1990). The inflatable vest applies pressure to the pilot’s chest. The breathing regulator provides positive pressure breathing. The inflatable bladder in the helmet holds the pilot’s oxygen mask to the face during high-g maneuvering. The combat edge system is normally controlled by the anti-g suit pressure. However, since the g-suit pressure is scaled down, a separate electrically controlled g-valve was required to drive Combat Edge. This ensured that its activation on-set would occur at 4 g as in the aircraft. Similar to the anti-g suit, the dynamic range of Combat Edge pressure was rescaled to one half (30 mm Hg at 9 g) of the range used in the aircraft.

Drive Algorithms The pitch angle of the seat pan and backrest were driven with a combination of aircraft pitch velocity and pitch acceleration. The roll angle of the seat was driven with a combination of aircraft roll velocity and roll acceleration. The yaw angle of the backrest was driven with a combination of side slip angle and side slip angle rate.

The drive laws were implemented in such a manner that allowed scaling to be specified as maximum seat movement. For example, the seat pan can roll as much as twelve degrees, but the scaling parameter for roll could be set to only five degrees. The coefficient for the basic drive law was then back calculated using vehicle performance information. This allows the magnitude of seat motion to be normalized across a wide range of flight conditions, specifically, Mach number. Due to high frequency effects, pitch acceleration had to be ramped out near mach one.

The seat pan bladder was driven with z-axis acceleration for simulating positive g. The original software for this dynamic seat was written so that the bladder pressure was decreased for positive g. This lowered the pilot onto hard blocks to simulate increased pressure on the buttocks. This also lowered the pilot with respect to the rest of the cockpit. For the trial evaluation, the drive law was written so that the bladder pressure increased with positive g, which increased the hardness of the seat and the perceived force. Although this approach is somewhat counter intuitive, it received consistent approval from pilots during the trial evaluation.

Since there is a tendency for the pilot to sink in the seat during high g maneuvering, it would be expected that there would be a need to lower the pilot's eye height in the simulator. This could have been done with the hydraulic actuators in the seat. However, the trial evaluation pilots did not feel this was necessary. A similar approach was used for the backrest bladder. It was driven with x-axis acceleration. When the simulated aircraft accelerated, the bladder pressure increased.

Task Scenarios

Five task scenarios were used in the evaluation. These tasks ranged from medium to high gain. In some cases the task was made more difficult by the introduction of turbulence. Not all three cueing devices were used for all tasks, i.e. only the dynamic seat was used for the landing task due to the lack of any high-g maneuvering during the execution of this task.

Landing A landing task was used to evaluate the effectiveness of angular seat cueing on the pilot's performance during approach and touchdown. A moderate to severe turbulence was present on one-half of the trials. Landings were made with and without force cueing. The only active cueing device during landing was the dynamic seat due to the low g nature of this task. Initial conditions were: altitude 1500 feet AGL, aircraft 8 miles out, on centerline, airspeed 193 knots, speed brake out, and gear down. The waypoint marker was overlaid on the runway to indicate the approach point, which is 1000 feet down the runway.

Table 1 Dynamic Seat Characteristics

Component	Axis	Excursion	Response
Seat Pan	Pitch, Roll, Heave Fore-Aft	+/- 12 degrees +/- 1.25 inches +/- 1.0 inches	36 ms, 7.3 Hz
Backrest	Pitch Yaw Surge	+/- 6 degrees +/- 9 degrees +/- 1.0 inches	36 ms, 7.3 Hz
Seat, Backrest Bladders	Heave, Surge	0-3 PSI	N/A
Seat Shaker	Heave	+/- 0.25 inches	34 Hz
Lap Belt	Fore-Aft	+/- 1.5 inches	30 ms, 10 Hz

The pilots were instructed to decrease airspeed to 155 knots, begin descent at five miles, and maintain a three-degree glideslope. Pilots were told to attempt a minimal sink rate landing. The actual touchdown point could be further down the runway than the 1000 feet approach point. The pilots were also instructed to maintain a wings-level approach while on centerline, specifically in the presence of turbulence. Pilots were given two practice trials, one with and one without turbulence. Two sessions of eight landing each were performed. The order of the independent variables (cueing and turbulence) was counter balanced.

Low Level Flight With Weapon Delivery This scenario was used to evaluate the usefulness of force cueing during low-level flight and weapon delivery. This mission was flown with and without force cueing. The force cueing included the dynamic seat, with bladders, Combat Edge and anti g-suit. The initial conditions were: altitude 1000 feet, airspeed 475 knots, speed brake in, gear up, heading 074 degrees, and the aircraft 25 miles from waypoint one. The pilots were instructed to fly at the lowest comfortable altitude and maneuver for optimal ridge crossing until they reach waypoint two. This delineates the terrain following segment of the mission. After waypoint two, the pilots performed an offset pop-up weapon delivery task using a CCIP pipper (continuously computed impact point). The pilots were instructed to perform all four-g turns. Pilots were given one practice trial. Two data collection sessions of four missions each were performed. The order of the independent variable (cueing) was counter balanced.

Air-to-Air Guns The air-to-air guns task was a medium g-level task that employed a tracking requirement. This scenario was flown with and without force cueing. The force cueing included the dynamic seat, with bladders, Combat Edge, and anti g-suit. The initial conditions were: altitude 10,000 feet, airspeed 448 knots, speed brake in, gear up, and target aircraft 1000 feet ahead. The avionics included a lead-computing optical sight system (LCOSS). The pilots were instructed to keep the LCOSS pipper on the target and maintain a distance of 1000 feet. Distance to the target and closure rate was indicated on the LCOSS reticule. Pilots were given one practice trial. Two data collection sessions of four missions each were performed. The order of the independent variable (cueing) was counter balanced.

Pylon Course The pylon course task consisted of a "highway in the sky" which was indicated by sets of pylons spaced five seconds apart. (See Figure 1.) The location of the pylons was based on a pre-recorded flight by an experienced pilot performing a box maneuver. The g-loading necessary to accurately fly the course increased with time. Specifically, the end of the course was much harder to fly than the beginning. The orientation of the pylons indicated the roll attitude from the pre-recorded flight. A lead aircraft flew the course just ahead of the pilot's simulated aircraft. The force cueing included the dynamic seat, with bladders, Combat Edge, and anti g-suit. The initial conditions were: altitude 10,000 feet, airspeed 333 knots, speed brake in, gear up, and lead aircraft is 1500 feet ahead and accelerating. The pilots were instructed to follow the lead aircraft through the pylon course and match the roll attitude of the pylons. Pilots were given one practice trial. Two data collection sessions of four missions each were performed. The order of the independent variable (cueing) was counter balanced.

Formation Flight The formation flight task was a high-gain task that required continual pilot input.

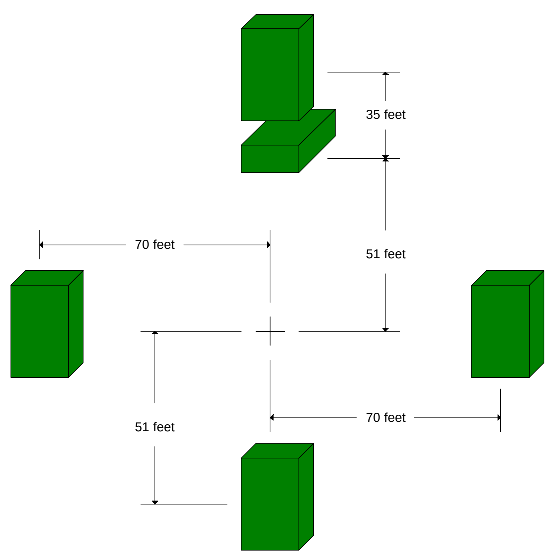

Figure 1. A graphical view of pylons placed five seconds apart to indicate the nominal fight path.

The limited field-of-view visual simulation display increased the task difficulty. The flight path of the lead aircraft was based on a pre-recorded flight. Similar to the pylon course, the g-loading increased with time. Force cueing included the dynamic seat, with bladders, Combat Edge, and anti g-suit. The initial conditions were: altitude 10,000 feet, airspeed 333 knots, speed brake in, gear up, and the trailing aircraft was 13 feet down and 60 feet behind the lead aircraft.

The pilots were told to maintain the initial relative position throughout the flight. The pilots were given specific references on the display to aid them in maintaining the relative position. These references used the burner cans of the lead aircraft and the HUD symbology on the pilot's display. Pilots were given one practice trial. Two data collection sessions of four missions each were performed. The order of the independent variable (cueing) was counter balanced.

Data Analysis

Performance data, control behavior, and subjective data were recorded and analyzed to identify differences between the cueing and no-cueing conditions. Some trials had to be eliminated to remove outliers. These resulted from system failure, pilot error, and operator error. Pilot error included mistakes such as loosing the pylon course and not relocating it. In another case, the pilot increased the following distance in the formation flight task to make the task easier. Two trials were lost due to hardware failure on the visual system. Three trials were lost due to operator error.

Some tasks were divided into segments and the data were analyzed separately. The Low Level Flight with Weapon Delivery task was divided into a terrain following segment and a weapon delivery segment. The pylon course data were divided into two segments where the difficulty level increased. The first three miles on the landing approach where the vehicle was in level fight were not included in the analysis.

Descriptive statistics (mean, standard deviation, and RMS) were computed for several aircraft state variables to investigate differences between cueing and no-cueing. Power spectral analysis was performed on stick activity to identify differences in control behavior with and without cueing. Subjective debriefing questionnaires were reviewed and summarized.

Evaluation Pilots

Four pilots were used for the trial evaluation. All have at least 2000 hours in modern fighter aircraft. Additionally, all four have served as instructor pilots and three of the four were still actively flying at the time of the trial evaluation. All the pilots had experience in the five flight scenarios used in the study. They were given written instructions before performing each scenario to ensure consistency. A checklist was used prior to each test session to make sure all switches and cueing hardware were in the correct configuration.

Trial Evaluation Results

Landing Task

The pilots were instructed to maintain a wings-level approach when on centerline. Previous drive law research (McMillan, Cress, etc., 1990) shows that the dynamic seat is very effective for improving this type of attitude maintenance in the presence of turbulence. It was evident from the data that the four pilots did benefit from the presence of force cueing. However, the benefit was much smaller than expected. The pilots were also told to land on centerline. There was an improvement in this measure with force cueing present. This was most likely the result of the instructions noted above.

There was an interesting, and unwanted, effect discovered in the stick data. With the turbulence turned off, there was higher stick activity when force cueing was present (figure 2). This effect was consistent for all four pilots. This suggests some degree of biomechanical coupling, which could slightly degrade the performance benefit of the seat. The coupling was most likely caused by the fact that the stick was rigidly mounted (i.e., it did not move in synchrony with the seat). It was observed that the dynamic seat moved forward and aft approximately one inch from neutral position at the pilot's shoulder. This movement was translated to the arm and hand and then to the control stick. A force stick, such as used in the F-16, may be especially vulnerable to such coupling. Other types of control sticks may also be affected. Therefore, seat motion resulted in body motion that was then transmitted to the stick.

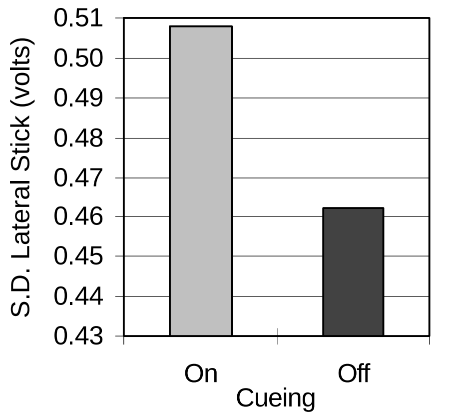

Figure 2. With no atmospheric turbulence there was higher stick activity when cueing was on. Although this biomechanical coupling is small, it could be problematic if the seat gains were increased. This effect was consistent for all four pilots.

Pylon Course Task

There were substantial benefits of force cueing in the pylon course task. When cueing was present, the pilots flew the course more accurately (figure 3), with less stick activity (figure 4) and more realistic stick activity. Specifically, the z-axis g-loading had considerably less variance when

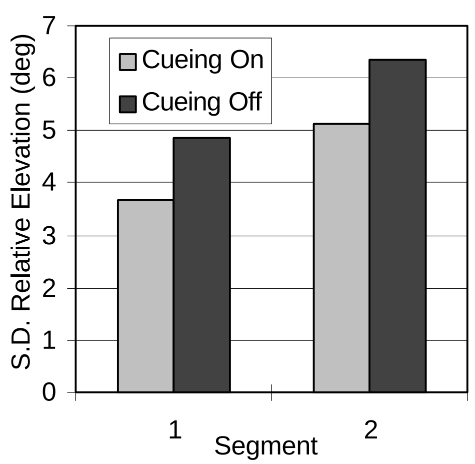

Figure 3. Pilots followed the lead aircraft through the pylon course more accurately when force cueing was turned on. A similar trend was present in relative azimuth. Standard deviation is used because of a large mean due to the following distance.

cueing was turned on. Examination of g-profile plots indicated that the pilots were putting in more erratic g-commands when cueing was off. With cueing present, the pilots commanded more deliberate, and consistent, z-axis loading. It is reasonable to suggest that the more consistent g-loading is attributable to the anti g-suit and Combat Edge activation. The presence of seat motion also seems to be helping the pilots in the pylon course task. The variance in the vehicle's angular rates is much lower when cueing is present. This enabled the pilots to fly the course more accurately, which is indicated in the relative geometry measures (relative azimuth and elevation between the lead aircraft and the trailing aircraft).

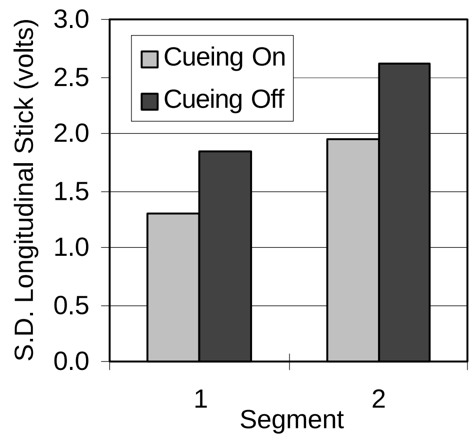

Figure 4. When force cueing was present the pilots used less stick activity to fly through the pylon course.

Air-to-Air Guns Task

Results similar to the pylon course task were found in the air-to-air guns tracking task, although the differences between cueing and no cueing are not as pronounced. This is most likely due to the fact that the air-to-air guns task requires less g-loading than the pylon course task. On average, the pilots did a better job on keeping the pipper on the target when cueing was present.

Low Level Flight Task

Other than a reduction in stick activity, the waypoint task showed little difference between the cueing conditions during the terrain following segment. There are two reasons for this. First, the task was not demanding in terms of g-loading. Three of the four pilots rarely pulled more than two g's for this segment. Second, the instructions to the pilots led to different control strategies. The pilots were told to fly at their lowest comfortable altitude. While one pilot was extremely aggressive in following the terrain, another simply skimmed over the valleys.

Formation Flight Task

The main effect of cueing on the formation flight task was seen in the tracking-type measures.

These measures include the relative azimuth position off the nose, relative elevation position off the nose, and the relative range (figure 5). The pilots did a much better job of maintaining the relative position between the two aircraft when the cueing was present. The improvement in relative range may be a result of the thrust feedback provided by the backrest bladder. Additional tests are required to confirm this suggestion.

Power Spectral Analysis of Stick Activity

In the no-cueing condition, there was consistent increased power in the one hertz region on both lateral and longitudinal stick activities. This effect was consistent across the five tasks, but was most pronounced in the formation flight task (figure 6). This is not surprising given the high gain nature of this task. As reported earlier, the pilots performed this task better (relative geometry) when force cueing was turned on. Therefore, the extra power in the one hertz region was not needed to perform the task, and consequently represents remnant and/or artifact. The most likely cause of this unneeded stick activity is due to pilots correcting for over shoot. The dynamic seat provided lead information which reduced the likelihood of over shoot.

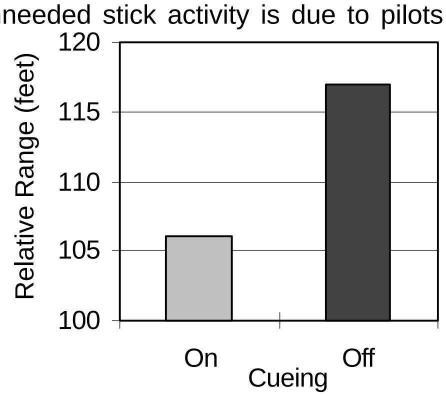

Figure 5. The pilots maintained a closer relative range when force cueing was active. Thrust feedback was provided by the backrest bladder.

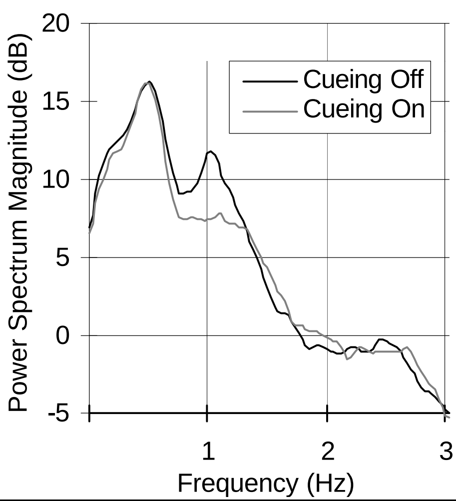

Figure 6. The average power spectrum for the four pilots in the formation flight task shows increased power in the one-hertz region when force cueing is turned off.

Debriefing Summary

The pilots commented that the cueing provided better/earlier feedback on the effects of flight control inputs. When asked "How did the presence of force cueing effect your ability to perform the task?", the pilots agreed that the cueing allowed them to perform the task in a manner closer to how they would perform it in the aircraft. The cueing allowed the pilots to make finer corrections.

The pilots were asked "Did the force cues enhance the operational realism of the simulator?". They responded with a strong consensus to the affirmative. One pilot stated it was the closest simulator that he has flown that "feels" like real flying. When asked if there is a force cueing subsystem that could be added that might improve the operational realism of the simulator; the pilots' comments varied from no, to maybe, but the increase in "feel" would not be worth the extra cost and complexity. Limb loading, aural cueing and more longitudinal acceleration were mentioned as possibilities.

The pilots' comments included that this technology could get more pilots to agree that simulators are Comments included that this technology could get more pilots to agree that simulators are getting very close to simulating actual flight conditions. Some stated that if this technology is cost effective, it should be added to all training simulators.

Trial Evaluation Discussion

A follow up study is needed to improve several aspects of the initial force cueing trial evaluation. These improvements range from simple things, such as instructions given to the pilots, to more complex issues, such as adaptive drive algorithms. For example, the instructions for the low level flight task need to be changed so that the pilots will fly in a similar manner. In the landing task, the differences between the cueing conditions were much smaller than anticipated based on previous drive law research. This is most likely due to minimal dynamic seat cueing, which was a result of the drive algorithms that were normalized across tasks and mach numbers. A follow-on study is needed to evaluate the utility of drive laws that are adaptive to the task.

Some of the tasks would benefit from a larger field of view (FOV) visual display. The limited FOV used in this study caused some trials to be missed in the pylon course and air-to-air guns tasks because the pylons (or target) would go off the screen and the pilots could not recover. The limited FOV also imposed constraints on the formation flight task. The lead aircraft had to be set up in a position similar to aerial refueling rather than the typical wingman arrangement.

Other implications for a follow up study include removal of the biomechanical coupling, elimination of the no-turbulence condition in landing, selection of a different low level flight course, and the addition of other force cueing devices. It may also be useful to make workload and physiological recordings.

CONCLUSIONS

Evaluating force cueing must be performed in a mission context. Evaluating cueing at the subtask level may prove to be invalid when the full context of the task is added. As an example, a tracking task developed as a one g-task that may be performed during high g pursuit.

The trial evaluation demonstrates a documented method for future force-cue evaluations. The combination of measured pilot behavior and performance while performing specific tactical mission tasks together with subjective pilot feedback provides an effective means of evaluating the contribution of force cueing to mission performance.

This evaluation method does not address how transfer of training may be affected by force cueing. Transfer of training may not be the real issue. Rather the issue may be whether force cueing will cause the pilot to perform and behave in the simulator similar to the aircraft. Behavior in a simulator, which is far different than the aircraft, may require relearning in the aircraft.

The intent of this program was to develop a method for performing simulator force cueing evaluation. The trial evaluation reported in this paper does not, in itself, fully define the method. However, based on the trial evaluation, the following questions should be asked about a force cueing system under evaluation:

1) Does the system reduce unneeded stick activity in high gain tasks?

2) Without force cueing in a simulator, pilots tend to pull an unrealistic level of positive g forces and in some case even negative g's. Do force cueing devices encourage more realistic g-profiles?

3) Does the system provide pitch-axis lead information for high gain pursuit-type tasks? (air-to-air guns).

4) A dynamic seat can provide a longitudinal acceleration cues through the back of the seat. Does the system under evaluation provide thrust feedback (i.e. -formation flight)?

The drive algorithms for a dynamic seat are more important in determining seat effectiveness than seat hardware performance. Without effective algorithms, the seat has limited effect on pilot behavior and performance or, as an extreme, may degrade performance. Drive algorithms need to be adaptive to the task, flight conditions, performance envelop of the vehicle, and the control behavior of the pilot.

In future applications of dynamic seats, caution should be taken in order to avoid such biomechanical coupling.

RECOMMENDATIONS

1. The work accomplished under this effort provides a method for conducting force evaluations for tactical combat flight simulation. Although this effort did demonstrate the positive effects of a dynamic seat on pilot behavior and performance, it did not address the impact of other force inputs such as vestibular. It is, therefore, recommended that a force cueing evaluation be conducted on a simulator which includes a full spectrum of force cueing devices, such as a high performance platform motion, a dynamic seat, g-suit, etc., a complete fighter cockpit and a full field of regard visual system. This force cueing evaluation would determine the contribution of the various force cueing technologies on pilot performance.

2. The drive laws need to be reviewed to improve cueing effectiveness. Because pilots can have very different control strategies, the gain of the algorithms may need to be adaptive. Additionally, the magnitude of seat and/or platform motion may need to adapt to the task.

3. The only veritable method for validating pilot behavior in the simulator is to compare the behavior in the simulator with behavior in the aircraft while performing the same set of maneuvers. It is, therefore, recommended that that a limited flight test program be initiated to collect pilot behavioral data.

4. The Clark Transducer offers a relatively inexpensive method of providing cueing in the frequency range greater than five hertz. Originally, this cueing device was to be included in the trial evaluation. However, it was found that to effectively use this device, aircraft data in the five-hertz and higher frequency range are required. Also, a linear high power amplifier capable of responding to the low frequencies which may provide tactile cues to the pilot. This data were unavailable. This would best be obtained by digital recording in a fighter aircraft. It is recommended that an evaluation of the transducer be conducted in a simulator using suitable amplification and aircraft data.

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