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OPERATING AN UNMANNED AERIAL SYSTEM FROM A MOVING PLATFORM

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Abstract

While the Spatial Disorientation (SD) has long been recognized as an important causal factor in aviation incidents and accidents, it is only beginning to be recognized as a factor in Uninhabited Aerial Systems (UASs). Self, Ercoline, Olson and Tvaryanas (2006) predicted SD to be most likely for a manually controlled UAV when operated from a mobile platform.

As a first step towards better understanding the effects of control platform motion on manual UAV control Olson, DeLauer and Fale (2006) had 10 rated Air Force pilots fly a simulated UAV task (MS Flight Simulator) from a motion capable control platform (aircraft simulator). Participants performed two basic flight tasks – a vertical task (climb/descent) and a horizontal (turning task). The control platform motion was varied to provide either congruent, neutral, or conflicting motion cues. Congruent and incongruent motion cures were defined as motion in the same axis and either same/different direction as the primary task (i.e., simulator turned left/right and task was a constant left hand turn). Neutral motion was defined as motion in a different axis of motion relative to the primary task (i.e., simulator motion was climb/descent and task was a constant bank turn). There were three levels of visual and vestibular control platform motion cues (no motion/visual cues, motion with no outside visual display, motion with outside visual). The results indicate that there was little effect of control platform motion on roll axis performance, i.e., bank and heading error. However, pitch axis deviations (altitude and vertical velocity) showed an effect of both control platform motion and motion type. Presence of both visual and motion cues resulted in greater pitch deviations than motion only or baseline (no motion/no visual cue) conditions and the presence of motion in the off-axis of motion resulted in the greatest error. These results suggest that platform motion may

interfere with an operator's ability to manually control a UAV from a moving platform (a possible precursor to SD).

The current study replicates the simulator study using an aircraft (C-172) as the control platform. This will allow for a more complete examination of platform motion cues since simulators cannot adequately simulate sustained motion. This study also adds a landing task to examine glide path and azimuth error. The results of this study mirror those of the previous simulator study and show a general increase in error, particularly in the vertical axis during UAS control from a moving platform; there was no statistically significant effect on lateral error measures. For the landing task, there was no statistically significant effect on glide path error, however, control platform motion did result in higher runway alignment error. These results have implications for planned UAV operations from both fighter and transport aircraft.

Background

Operational needs are driving both military and civilian operators to consider operating UASs from moving platforms (ground, sea, and air vehicles) (DeLauer & Fale, 2006). Controlling a UAS from a moving platform introduces challenges that are different from a ground-based control station; namely Spatial Disorientation (SD) and conflicting visual cues and vestibular/proprioceptive inputs. It seems likely that motion cues (visual as well as vestibular/proprioceptive) resulting from control platform motion may interfere with UAS control.

A wealth of experience from manned aviation indicates that conflicting motion cues can lead to SD. In the case of UAS control from a moving platform these conflicting cues may be manifested by degraded UAS control. While little formal research has been conducted in UAS SD or control interference, work by Self, Ercoline, Olson and Tvaryanas (2006) suggests that these phenomena would be most likely to occur when UAS's are manually controlled from a moving platform. While the concept of spatial disorientation in a UAS may seem unlikely to those unfamiliar with UAS operations, Tvaryanas, Thompson and Constable (2005) report a number of UAS accidents in which SD was a causal factor. In order to better understand the linkage between conflicting visual and vestibular cues and UAS control performance, controlled studies must examine the impact of visual cues and control platform motion.

One of the few laboratory studies on the effects of control platform motion and UAS controllability was conducted by Reed (1977) at the Advanced Systems Division, Wright-Patterson Air Force Base, Ohio. This study concentrated on visual-proprioceptive cue conflicts in the control of remotely piloted vehicles (RPVs). In this study, a simulated RPV was controlled from a motion-based simulator. Control platform motion was limited to simulated turbulence. The results indicate that simulated turbulence did have a negative effect on RPV

control (control errors and response time), particularly when control platform motion conflicted with control inputs necessary for RPV control and in the presence of visual motion cues.

In order to better understand the impact of control platform motion cues and direction of platform motion, Olson, DeLauer and Fale (2005) conducted a preliminary study on UAS control from a moving platform. In this study, 10 rated military pilots flew a simulated UAS (Microsoft Flight Simulator) from a motion based simulator. The two UAS control tasks included a vertical task (constant rate climb and descent) and a horizontal task (constant bank turns) Independent variables included type of control platform motion cues (none, motion only, visual + motion) and direction of control platform motion relative to the UAS control task (same direction, opposite direction, motion in a different axis). The results indicated that control platform motion did interfere with UAS control, primarily in the vertical axis (climb/descent rate & altitude control). Performance was particularly degraded in the presence of both visual and motion cues and when control platform motion was in different axis than the UAS control task, e.g., control platform climbing or descending when UAS task was to maintain a constant bank turn.

These simulator studies provide important evidence that control platform motion may interfere with UAS control, however, generalizability to an actual aircraft is somewhat limited since simulators can only simulate the onset of control platform motion and cannot simulate sustained motion. Additionally, the Olson, DeLauer and Fale (2005) did not simulate the presence of turbulence.

The purpose of this study is to replicate Olson, DeLauer and Fale (2005) using a Cessna C-172 as the control platform. In addition to the vertical and horizontal tasks, participants in this study will also complete a simulated landing task. Based on previous research we expect that the presence of both motion and visual cues will create a larger error in vertical performance measures (altitude and vertical velocity), especially when the control platform motion is incompatible or in a different plane of motion. Additionally, it seems likely that UAS glide path error will be most affected in the landing task.

Method

Participants

A total of 15 military fixed-wing pilots will serve as participants in this study. These participants ranged in military rank from Captain to Brigadier General with an average 10 years of flying experience.

Apparatus

Control Platform. **A USAF T-41 (Cessna 172) served as the control platform. This aircraft seats 3 people (pilot, participant and facilitator) and was capable of making the 30 degree banks and 500 fpm climbs and descents with all personnel on board. The participants sat in the back seat of the T-41. In order to ensure adequate out-of-window views, all flights were conducted in visual meteorological conditions (VMC).**

Simulated UAS controls and displays. **Participants flew a simulated Mooney Bravo in Microsoft Flight Simulator 2004 in the full screen mode (See Figure 1). The simulated weather was clear with unrestricted visibility for all UAS tasks. Both wind and turbulence were set to zero. The simulation was run on a Dell Latitude computer with 17" display and was controlled using a Logitech Attack 3 Joystick. The laptop and joystick were mounted on a kneeboard situated on the participant's lap.**

Figure 1. **Simulated UAS display for horizontal and vertical tasks.**

Figure 2. **Simulated UAS display for landing task.**

UAS Control Tasks

Participants flew three different UAS control tasks - a horizontal task, a vertical task and a landing task. In the horizontal task, participants were instructed to maintain a 30 degree bank turn to the right or left while holding a constant altitude. This turn was held for approximately 90 degrees. In the vertical task, participants were instructed to perform a constant rate climb or descent (500 feet per minute) while maintaining a constant heading. The altitude gained or lost during this maneuver was approximately 500 feet. In the landing tasks, the simulated UAS was positioned approximately 3 miles from the landing runway on the desired glide path and aligned with the landing runway. The simulated landing environment included a standard four light Precision Approach Path Indicator (PAPI) system which was visible to the left of the touchdown zone (See figure 2). Participants were instructed to perform an approach to landing while maintaining a normal glide path and alignment with the runway centerline.

Independent Variables

This study employed two independent variables – type of control platform motion cues and direction of control platform motion. *Control platform motion cues.* There were three types of control platform motion cues – no-motion cues, motion-only cues and visual + motion cues. The baseline no-motion cue data was collected on the ground. Motion-only cues were created by having the participants wear a vision restriction device (foggles) so they could only see the

UAS display and had no ability to see motion cues out of the aircraft windows. In this case, vestibular and proprioceptive cues served as the only source of information regarding control platform motion. Motion + visual cues were present when the participant was in the air and not wearing vision restricting devices. In this case the participant received both visual (out the window) and vestibular/proprioceptive information regarding control platform motion.

Direction of control platform motion. **There were three levels of control platform motion – compatible, incompatible, and different plane of motion. For each type of motion, the control platform (T-41 aircraft) executed 30 degree bank turns or 500 fpm climbs and descents as appropriate. Compatible motion was defined as aircraft motion in the same magnitude and direction as the simulated UAS task, e.g., aircraft in a 30 degree left turn during a UAS horizontal task requiring a 30 degree left turn. Incompatible motion was defined as aircraft motion in the same magnitude but in the opposite direction of the simulated UAS task, e.g., aircraft climbing at 500 fpm during a UAS task requiring a 500 fpm descent. Different plane of motion was defined as aircraft motion in a different axis from that required by the UAS task, e.g., aircraft climbing at 500 fpm during a UAS task requiring a 30 degree bank turn.**

Dependent Variables

Horizontal and vertical measures of UAS control error were collected for each flight task. Error measures were collected using the FSUIPC flight recorder module and were sampled at approximately 2 Hz. For the horizontal (turning) task error measures were altitude error and bank angle error. For the vertical (climb/descent) task error measures were vertical velocity error and heading error. For the landing task error measures were angular deviation from optimum glide path and runway alignment as indicated by Horizontal Situation Indicator (HSI) deviation.

Procedure

Upon arrival, participants were given a brief introduction to the study describing the UAS simulated flight tasks, equipment and procedures. After this introduction, the participants were given 10 minutes of practice time on the flight simulator using the same simulated aircraft and view as required during actual trials. The first five minutes of practice was composed of 90 degree left and right turns at 30 degrees bank as well as wings level 500 feet per minute climbs and descents. After 5 minutes, participants were shown the landing task and allowed to land once. This familiarized them with the runway and PAPI lights used to assist in glide path control.

Following this introduction and practice session, participants were pseudo-randomly assigned to complete the baseline (no motion) condition either prior to or after the flight. Roughly half of the participants completed the tasks in the

baseline condition prior to the in-flight conditions and roughly half afterwards. Furthermore, within each motion cue condition, half the participants completed the horizontal and vertical tasks prior to the landing task and vice versa.

The baseline (no-motion) condition was completed on the ground. Both the motion-only and the motion+visual condition were completed in the aircraft. The participant was seated in the aft seat of the T-41 while the facilitator and the pilot sat in the front two seats (see Figure 3). Although sitting in the front seat would have given the participant a better view of the visual platform motion cues, safety considerations prevented the participant from sitting in the front seat.

Figure 3. Seating arrangement for participants.

For the baseline (no-motion) condition, each participant completed each of the three flight tasks one time. For the two in-flight conditions (motion-only and motion+visual cues), the horizontal and vertical tasks were repeated three times – once with each type of platform motion. The landing task was repeated twice – once while the control platform was turning from side to side using 30 degree bank turns, once while the control platform was climbing and descending at 500 fpm. The presentation of each task within each motion cue condition and type of platform motion was blocked to minimize order effects. The facilitator in the front seat coordinated maneuvers with the pilot and instructed the participant which task to complete and when to start and stop each maneuver.

Participants were debriefed after the experiment was finished. The length of the entire experiment was approximately 60 minutes.

Results

While 15 participants completed the study, 2 of those participants were eliminated from the study due to highly variable performance (frequently exceeding twice the standard deviation). The following set of figures depicts the mean square horizontal and vertical error measures collected, which contained

significant results. Recall that bank angle error and altitude error were collected during the horizontal (turning) task. Vertical velocity and heading error were collected during the vertical (climb/descent) task. Finally, glide path and runway alignment error were collected during the landing task. The figures that follow depict mean square error broken out by motion cue condition and type of platform motion. On each chart, the MSE of the baseline (no-motion) condition error is presented first followed by the motion + visual cue condition for each type of platform motion (compatible, incompatible, different plane), and finally the motion only cue condition for each type of platform motion.

Figure 4 presents the vertical (VVI) error measures for the vertical (climb/descent) task, while Figure 5 presents the altitude (ALT) error measures for the turning (right/left) task.

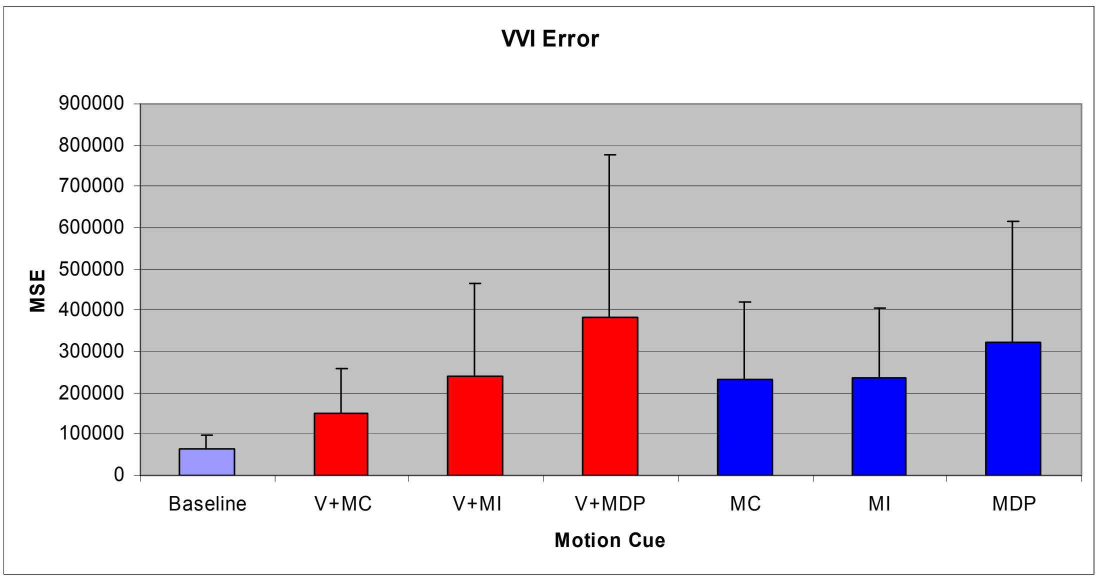

Figure 4. Mean Square Vertical Velocity error for the climb/descent task

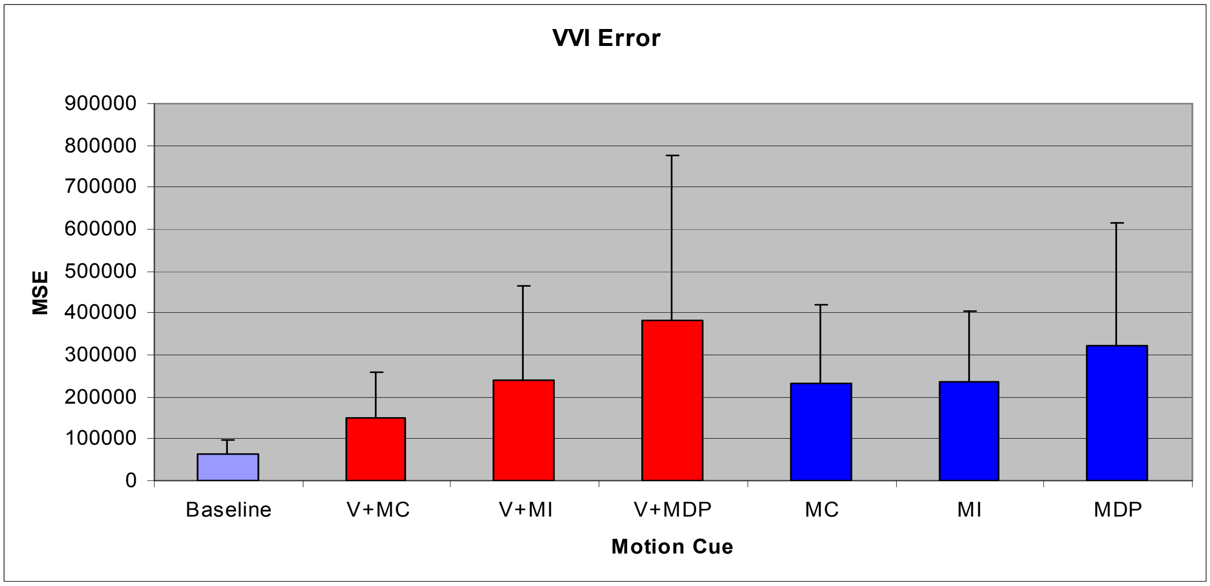

Figure 5. Mean Square Altitude error for the turning task

These error data were analyzed using a repeated measures ANOVA. VVI MSE for all conditions was significantly higher than the baseline ($p < .05$). While there was no statistically significant difference between the various motion conditions, the trend towards higher error for motion in a different plane mirrored the results of the previous simulator study (Olson, DeLauer and Fale, 2006). Figure 5 shows a general trend of higher error from a moving control platform, however, due to variable performance, only the visual +motion/ compatible was significantly worse than the baseline condition ($p=.038$). Both the visual+motion/incompatible and motion only/compatible had a marginally significant difference (higher error) than the baseline condition ($p<.12$).

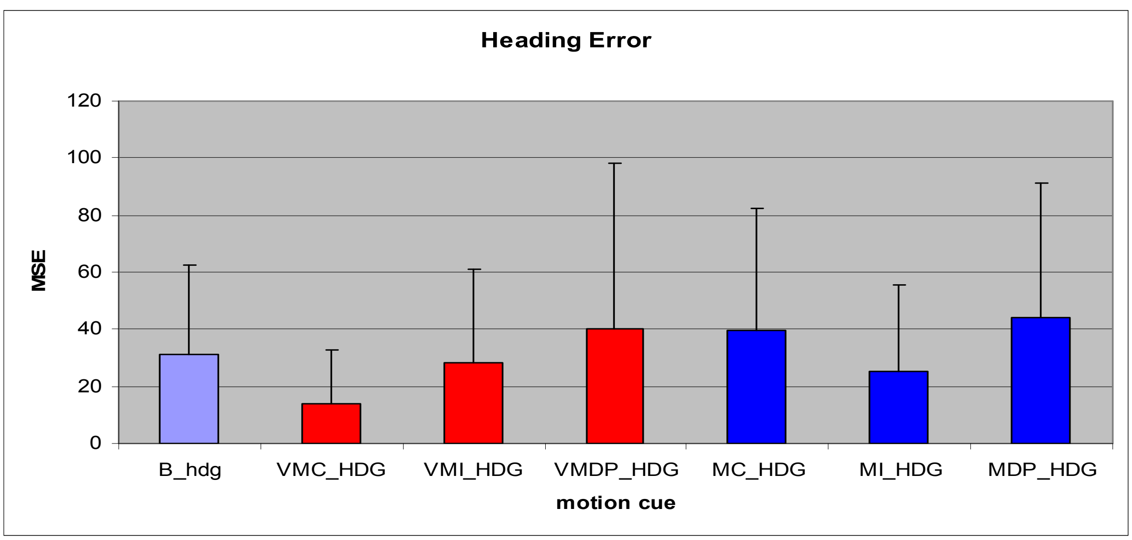

Figure 6. **Mean Square Heading error for the turning task.**

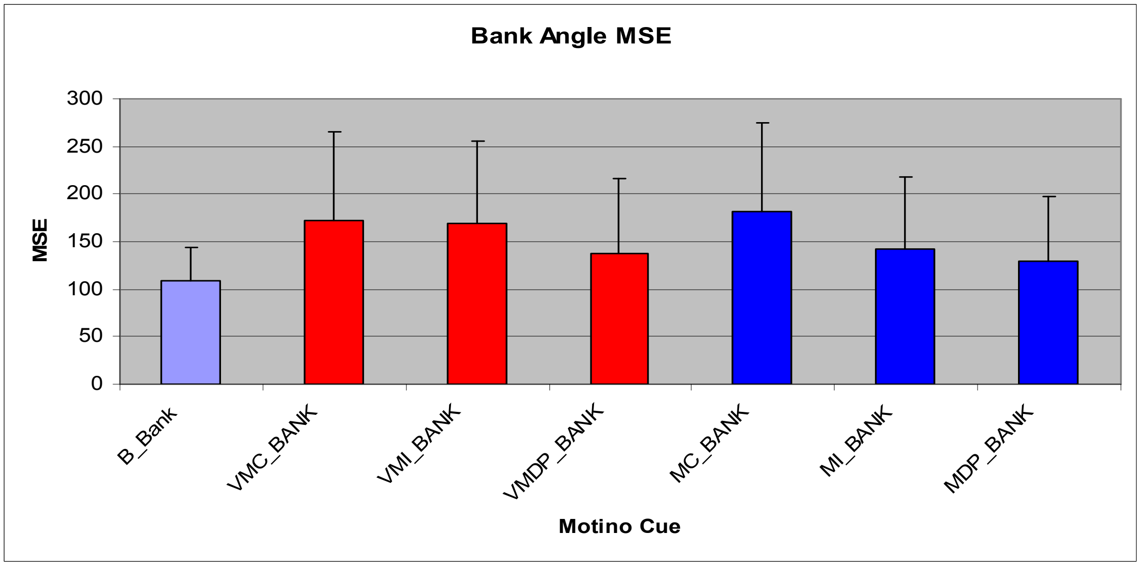

Figure 7. Mean Square Bank Angle error for the turning task

Figures 6 and 7 present the error for lateral flight performance with Figure 6 depicting heading MSE and Figure 7 presenting bank angle MSE. Although the trend was for higher error for the motion (non-baseline) conditions, these differences were not statistically significant. This finding mirrors the results of the Olson, DeLauer and Fale (2005) which also showed no significant effect of platform motion on lateral flight performance measures.

Figures 8 and 9 present the runway alignment and glide path mean square error for the landing task. The error data present here represents angular deviation from the desired runway alignment and glide path (localizer and glide slope) for the landing runway. Compared to the no-motion baseline conditions, runway alignment error was significantly higher for the visual + motion/compatible ($p=.014$), visual+ motion incompatible ($p=.075$) and motion only/compatible ($p=.014$). Runway alignment error was marginally significantly worse for the motion only/incompatible condition ($p=.184$). There was no statistically significant differences in glide path error ($p>.60$).

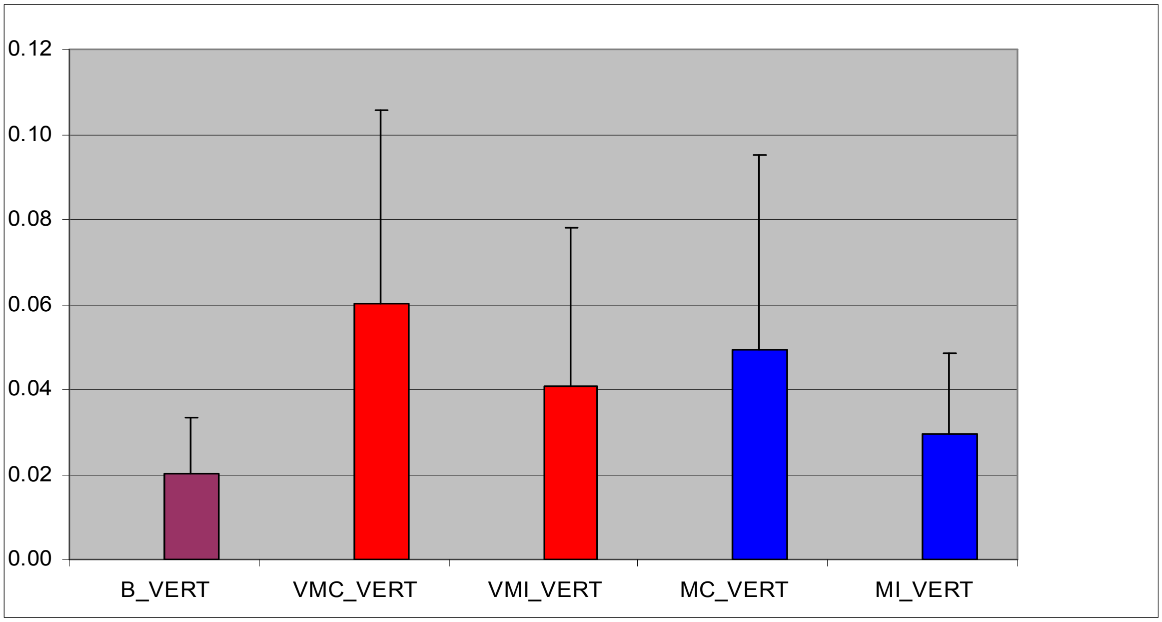

Figure 8. **Mean Square runway alignment error for the landing task.**

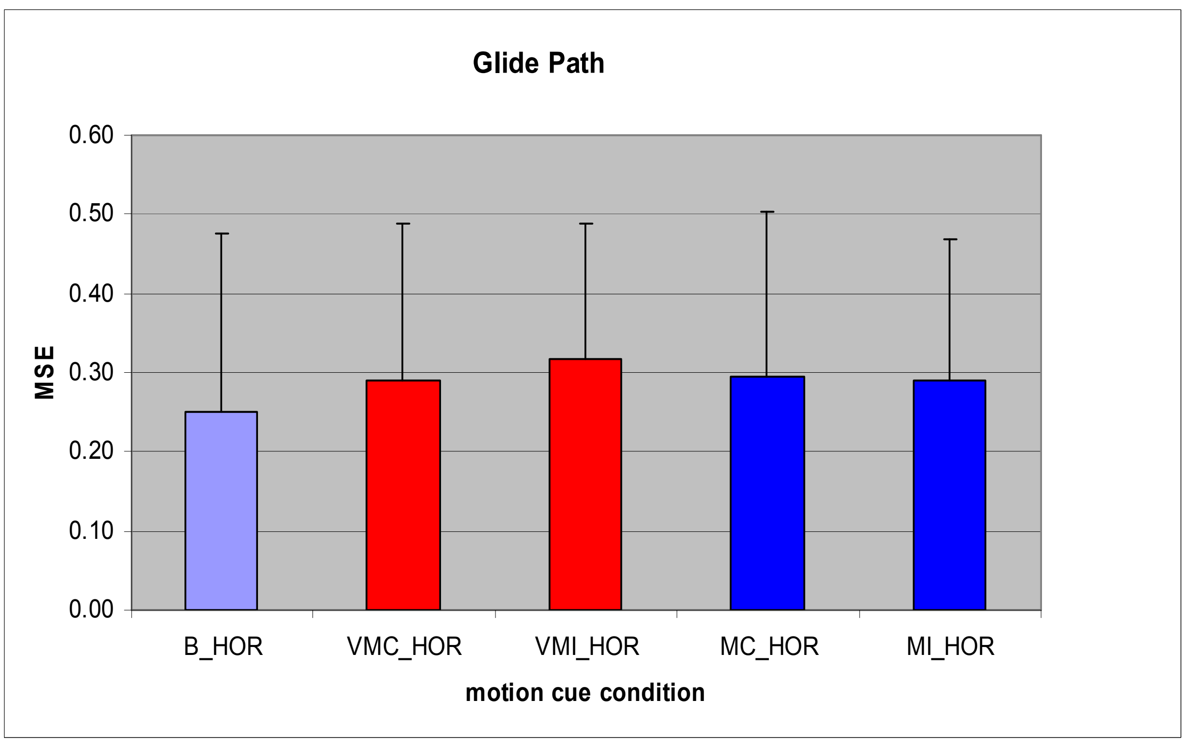

Figure 9. **Mean Square glide path error for the landing task**

Discussion

Caution must be exercised when interpreting the results from this study due to the low sample size and relatively high degree of performance variability, however, some general observations may be made. First, our data are in general agreement with the previous simulator study by Olson, DeLauer and Fale (2005) as well as Reed (1977), i.e., UAS control from a moving platform tended to result in greater error than when performed in a non-moving platform (the baseline condition). Furthermore, vertical error measures seemed most affected by type of motion cues as well as direction of motion. These data show a trend towards greater vertical error in the presence of both visual and vestibular/proprioceptive cues. Finally, it appears that incompatible motion produced the lowest vertical error, although strong statements cannot be made about the relative difference between incompatible motion and motion in a different plane. These findings support the theory that conflicts between the platform motion cues and the UAS control task do result in interference. The relatively greater error when both visual and vestibular/proprioceptive cues are present may be a result of the relative importance of visual information in spatial orientation (Previc, 2004). From a practical standpoint, this implies that use of a UAS pitch autopilot may be desired to minimize error in vertical performance.

Given these findings, the lack of effect on glide path error and presence of runway alignment effects in the landing task is somewhat surprising. Based on these results as well as Olson, DeLauer and Fale (2005) we expected to find glide path error effects during the landing task. These results may be explained, in part, by the presence of the PAPI lights in the visual scene for the landing task. The PAPI lights provided a salient and sensitive visual cue for the presence of vertical error. Just as display design can mitigate the effects of spatial disorientation, it may be that enhanced visual cues can also mitigate the effects of control interference when operating a UAS from a moving platform. These results suggest that guidance cues (e.g., a flight director) or enhanced error cues (e.g., highway in the sky) may mitigate errors during a landing task.

In addition to these error measures, participants also provided their subjective opinions during the post-experiment debrief. Participants reported the most difficulty in the presence of visual and motion cues when the control platform motion incompatible maneuvers with the UAS control task. Many of the subjects also mentioned that the outside visual cues created considerable difficulty in their performance whether it was a turning or a landing task. These verbal reports do not necessarily match the error data.

Additionally, and more importantly, most participants in this study did report experiencing motion sickness symptoms. While none of the participants became actively sick, all participants experiencing these symptoms reported they were at least a distraction if not a disruption to the UAS control task. Since none of the subjects in the simulator study reported any motion sickness symptoms,

we did not administer a motion sickness inventory in this study. The presence of motion sickness symptoms may explain the variable performance noted during this study and may be a serious concern during actual UAS control from a moving control platform.

Taken together, these findings have two major implications for UAS control from a moving platform. First, planned UAS operations from moving aircraft must take into account the likelihood of greater vehicle control error. In order to counter these errors UAS design may need to consider provisions for supervisory control (autopilot, etc.) as well as enhanced visual cues for control error. Second, it appears that the presence of visual cues may exacerbate control error, especially in the vertical axis. This finding suggests that operators may be able to better manually control a UAS if they do not have a view of the outside world. It is likely that UAS operators may also encounter motion sickness symptoms that may also degrade vehicle control. Motion sickness countermeasures may be necessary to mitigate control error as well as performance variability.

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