



Human Factors Engineering Evaluation of the CH-47F Horizontal Situation Display Hover

**by Jared Sapp, Sage Jessee, Jonathan Crutcher, Mary Carolyn King, and
Anthony Morris**

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Human Research and Engineering Directorate, ARL

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14. ABSTRACT A crew station working group demonstration was conducted on the manual flight control effectiveness and usability of the simulated CH-47F Horizontal Situation Display Hover (HSDH) pilot visual interface. The study compared three HSDH display configurations: (1) the existing CH-47F baseline HSDH, (2) a proposed HSDH redesign, and (3) a default decluttered configuration of the proposed HSDH redesign. Eight career pilots evaluated the HSDH usability under simulated brownout visual conditions for six different hover and landing tasks. Usability was assessed along four dimensions, including cockpit visual gaze, aircraft control, pilot workload, and pilot vehicle interface preference for ease of use and effectiveness of information presentation. Crew gaze analyses converged to indicate that pilots had a collective reduction in the amount of visual workload for the proposed and decluttered HSDH compared to the baseline. Aircraft control analyses indicated that pilots had gains in the overall aviating effectiveness while flying with the proposed and decluttered HSDH. Crews reported that workload demands were at acceptable levels while using the new displays during all mission tasks included in the study. Pilot feedback indicated that the interface readability of the new displays was effectively designed and presented. Pilots highly recommended the overall design of the proposed HSDH and voted unanimously for its immediate implementation.					
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Executive Summary

A crew station working group demonstration was conducted on the manual flight control effectiveness and usability of the simulated CH-47F Horizontal Situation Display Hover (HSDH) pilot visual interface. The study compared three HSDH display configurations: (1) the existing CH-47F baseline HSDH, (2) a proposed HSDH redesign, and (3) a default decluttered configuration of the proposed HSDH redesign. Eight career pilots evaluated the HSDH usability under simulated brownout visual conditions for six different hover and landing tasks. Usability was assessed along four dimensions, including cockpit visual gaze, aircraft control, pilot workload, and pilot vehicle interface preference for ease of use and effectiveness of information presentation. Crew gaze analyses converged to indicate that pilots had a collective reduction in the amount of visual workload for the proposed and decluttered HSDH compared to the baseline. Aircraft control analyses indicated that pilots had gains in the overall aviating effectiveness while flying with the proposed and decluttered HSDH. Crews reported that workload demands were at acceptable levels while using the new displays during all mission tasks included in the study. Pilot feedback indicated that the interface readability of the new displays was effectively designed and presented. Pilots highly recommended the overall design of the proposed HSDH and voted unanimously for its immediate implementation.

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1. Introduction

1.1 Background

Between October 2001 and October 2009, the greatest causal factor for rotary wing combat non-hostile airframe losses (24% of losses) was aircraft operation in degraded visual environments (DVE), commonly referred to as brownout or whiteout (Aircraft Survivability, 2010).

Brownouts occur when the helicopter is within ground effect and particulates are entrapped and circulated in the rotor wash, obscuring the view of the surroundings. In light of this data, developing Pilot vehicle interfaces that support the safe and effective aviation of rotorcraft in poor visual conditions is a high priority.

The CH-47F Chinook Horizontal Situation Display Hover (HSDH) software crew station working group (CSWG) evaluated the design and usability of hover flight management software designed to enhance a pilot's manual control of horizontal (position, drift, and heading) and vertical (position and speed) flight parameters in a brownout DVE. The worst-case scenario of manual aircraft control without pilot access to position hold and translation rate command was studied. The study compared three HSDH display configurations: (1) the existing CH-47F baseline HSDH, (2) a proposed HSDH redesign and (3) a default, decluttered configuration of the proposed HSDH redesign.

1.2 Cargo Helicopter – Engineering Analysis Cockpit

The Cargo Helicopter Program Management Office supports the Cargo Helicopter – Engineering Analysis Cockpit (CH-EAC) for designing and rapid prototype development and of the Common Aviation Architecture System (CAAS). Pilot-based studies and demonstrations are conducted using a CSWG method. The CSWG method is used across multiple aircraft platforms to determine the best upgrades and modifications to the current aircraft (Havir et al., 2006; Kennedy and Durbin, 2005). This method incorporates input from working group members to determine possible modifications which are tested in a simulator using an engineering analysis cockpit. During this testing, performance is measured and pilots' observations and opinions are collected to determine changes for future design increments.

1.3 CH-47F Simulator

The CH-EAC is a CH-47 hull adapted to run AFS for rapid prototyping experiments with operational pilots in a simulated environment. The simulator is equipped with a Fokker Control Loader for realistic stick feedback. Simulated flight characteristics are managed by an integrated flight model from the Aviation Engineering Directorate (AED) for realistic flight performance. Pilot Vehicle Interface (PVI) inputs for the pilots are captured and time-stamped for human factors engineering (HFE) analysis. Audio is also recorded and used for extra-cockpit communication, such as simulated tower calls.

1.4 Degraded Visual Environment Simulation

A physics-based particle model was used to simulate the degraded visual conditions of brownout. This brownout model was incorporated into the out-the-window system in the Battlefield Highly Immersive Virtual Environment (BHIVE). The model uses flight dynamics from the flight model and helicopter physical characteristics to generate a dynamic visual model of brownout conditions.

1.5 Objectives

The primary objective of the CSWG demonstration was to determine whether the newly designed HSDH would increase pilot situational awareness, decrease demands on pilot workload, and decrease aviating behaviors associated with brownout accidents. Data were obtained on crews' evaluation and feedback for the pilot-vehicle interface, mission workload, crew gaze, and aircraft control measures.

2. Method

2.1 Participants

Participants included eight male CH-47 pilots ranging in age from 25 to 45, consisting of six U.S. Army active duty CH-47 pilots, one Department of the Army Civilian, and one Major in the Canadian Air Force. Participant demographics were collected using the demographic questionnaire included in appendix A. The participants represented a group of experienced pilots with a U.S. Army service duration range of 2–5 years minimum and 20–25 years maximum. Total flight hours ranged from 130 to 6311 h (mean = 3288 h, median = 3375). The majority (69%) of their total flight hours were in the CH-47 (mean = 2260 h, median = 1750), and all but one had served as an instructor pilot (IP) for the CH-47.

2.2 Design, Training, and Mission Description

Participants were assigned into pilot/co-pilot crews of comparable rank and the crew pairings were maintained for all flights according to table 1. One exception to the crew pairing was the final crew in the third mission set with a decluttered HSDH. Pilot P1 flew in the place of pilot P6 due to pilot P6 being reassigned to a different task. Each member of a crew flew each mission as pilot on controls and as co-pilot. As such, the co-pilot flew the next mission in a set as the pilot on controls. In all flights except the first crew of mission three (decluttered HSDH), the right-seated pilot flew as first pilot on controls and the left-seated pilot flew as second pilot on controls. This flight order resulted in three opportunities of measurement for each pilot and resulted in a repeated-measures or within-subjects design. Each crew flew a single simulated mission in the BHIVE. The BHIVE is developed and maintained by the System Simulation and Development Directorate (SSDD) of the U.S. Army Aviation and Missile Research, Development, and Engineering Command (AMRDEC) at Redstone Arsenal, AL.

Table 1. Crew responsibility and flight order.

Pilot	Baseline	Proposed	Decluttered
1st	P7, P2, P5, P6	P7, P2, P5, P6	P8, P2, P5, P3
2nd	P8, P4, P1, P3	P8, P4, P1, P3	P7, P4, P6, P1

Training on the CH-EAC simulator for the CH-47F was conducted for all pilots on the first day of test and before the simulated flights of record. In addition, specific training for the current HSDH and its proposed modifications was conducted prior to flights of record on the simulated mission. Before entering the simulation, crews were provided a mission brief and their flight plan.

The flight mission was flown in and around simulated terrain from Fort Irwin and National Training Center (NTC). The mission was executed under visual flight rules (VFR) conditions. The flight plan included six evaluation maneuvers that punctuated the en-route flight legs of the mission. The evaluation maneuvers were constructed using guidance from the Aircrew Training Manual (ATM) Cargo Helicopter, CH-47D/F tasks 1039 Perform Hovering Flight Utilizing Symbology, 1058 Perform Visual Meteorological Conditions Approach, and 1063 Perform External Load Operations. The mission was designed to have multiple types of landing and hover events. Each of the six maneuvers was designed so as to exercise pilots' manual control of the aircraft during brownout DVE. Manual control of the aircraft was implemented in the simulator by turning off the position hold (P-Hold) and translation rate command (TRC) capability. The DVE condition existed at 40 ft and below. The DVE conditions reinforced the situational demand for pilots to rely on the HSDH during the maneuvers. The mission background events included standard personnel/equipment air transport. The missions were developed by subject matter experts (SMEs) within SSDD at the AMRDEC.

The conditions of these landing zones were designed to require different levels of control and enforce different types of evaluation maneuvers. Landing Zone 1 (LZ1) was in an open area with a smoke plume marking the desired landing site. No hover was required, and an alpha approach landing was used. Landing Zone 2 (LZ2) was located in a courtyard next to a mosque. The approach to LZ2 was relatively open with a few obstacles and vehicles located in the landing area. There was a 20-ft hover reference point defined directly above the landing zone. During landing Zone 3 (LZ3), a sling load operation was performed. There was a 50-ft hover reference point horizontally offset from a 15-ft hover reference point above the load. The aircraft was not to land at this location. Landing Zone 4 (LZ4) was located next to a tall building and trees. The configuration of this location required a high hover with a vertical descent. There was a hover reference point located 80 ft above the landing zone. Bicycle Lake Army Airfield (KBYS) was the last location in the flight plan. This landing zone was in an open area. No hover was required, and an alpha approach landing was used. A final reposition was requested after the initial landing at KBYS. This was not a planned location, but the crew was simply told to

reposition the aircraft a certain distance away in a cardinal direction. The pilot was free to choose to land the aircraft in a variety of manners. The full list of mission tasks for each landing zone is presented in table 2.

Table 2. Mission tasks per evaluation maneuver.

LZ1 Alpha Landing	LZ2 Hover to Landing	LZ3 Sling Load	LZ4 Hover to Landing	LZ5 Alpha Landing Bike Lake	LZ6 Reposition
1. LZ1 overall 2. Maintain approach to desired landing point 3. Maintain rate of closure 4. Maintain ground track alignment 5. Perform a controlled termination to touchdown	6. LZ2 overall 7. Perform a controlled termination to initial hover 8. Perform a controlled descent with minimal drift	9. LZ3 overall 10. Perform a controlled termination to initial hover 11. Perform a controlled termination to hookup point	12. LZ4 overall 13. Perform a controlled termination to initial hover 14. Perform a controlled descent with minimal drift	1. Maintain approach to desired landing point 2. Maintain rate of closure 3. Maintain ground track alignment 4. Perform a controlled termination to touch-down	15. Perform a controlled termination to initial hover

2.3 Displays: Horizontal Situation Display Hover

2.3.1 Current HSDH Display

The CH-47 HSDH baseline symbology shown in figure 1 includes multiple indicators which are used in concert to control the vertical position and velocity of the aircraft. Of particular interest to the CSWG Demonstration were the vertical speed indicator (VSI), the radar altitude (RAD ALT) indicator, and the hover box. The VSI displays vertical speed from –1000 ft/min (fpm) to 1000 fpm. The RAD ALT indicator displays the altitude above the terrain presently beneath the aircraft from 0 to 525 ft. The hover box provides visual reference of error between the reference altitude and the radar altitude by increasing in size as the aircraft descends, and decreasing in size when the aircraft ascends. The scaling of the hover box can be seen in figure 2 and can be used by the pilot for control around the desired altitude that has been entered into the control display unit (CDU).

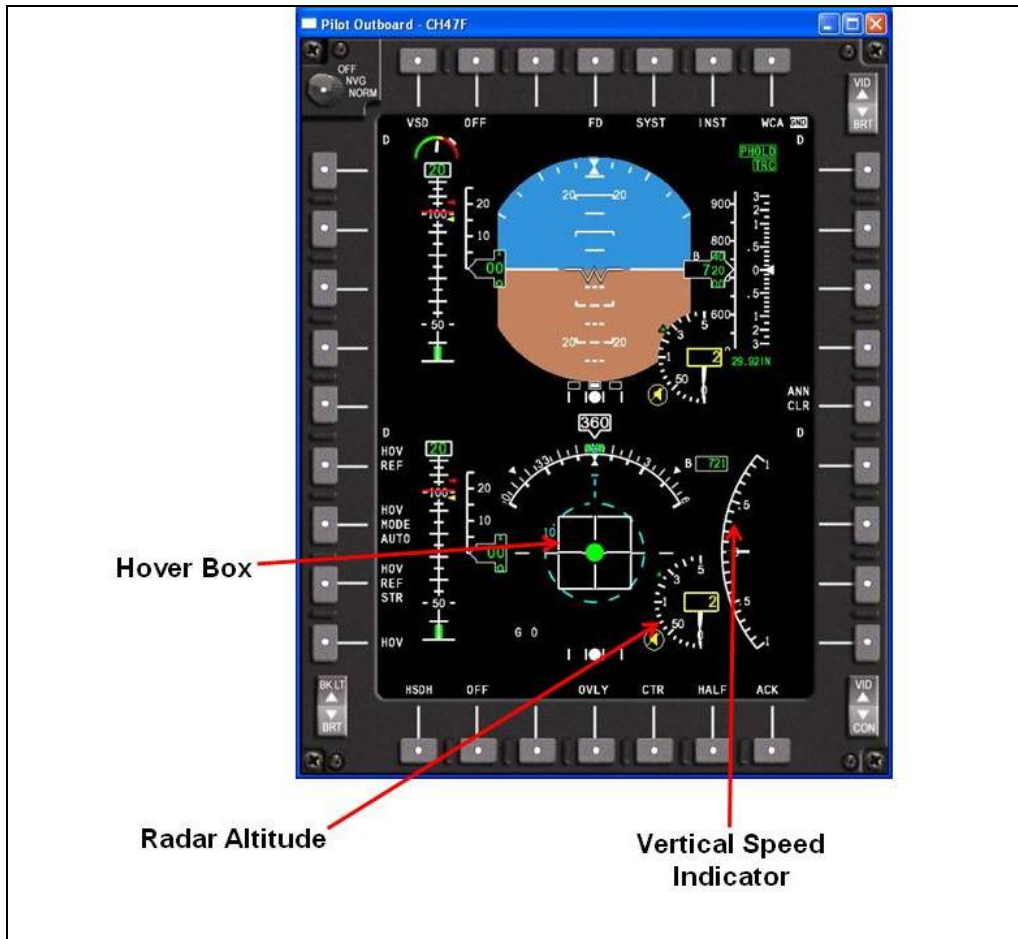


Figure 1. Baseline HSDH.

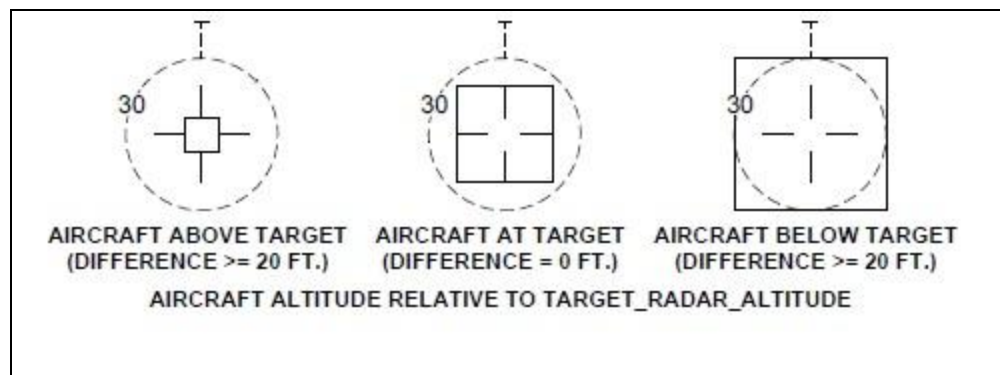


Figure 2. Baseline HSDH hover box.

2.3.2 Proposed HSDH Display

The proposed HSDH, shown in figure 3, incorporates changes to the baseline symbology to be used during hover and landing. The vertical speed tape, which is used to control the vertical speed and position of the aircraft, was added. This tape has markings on a dual-purpose scale

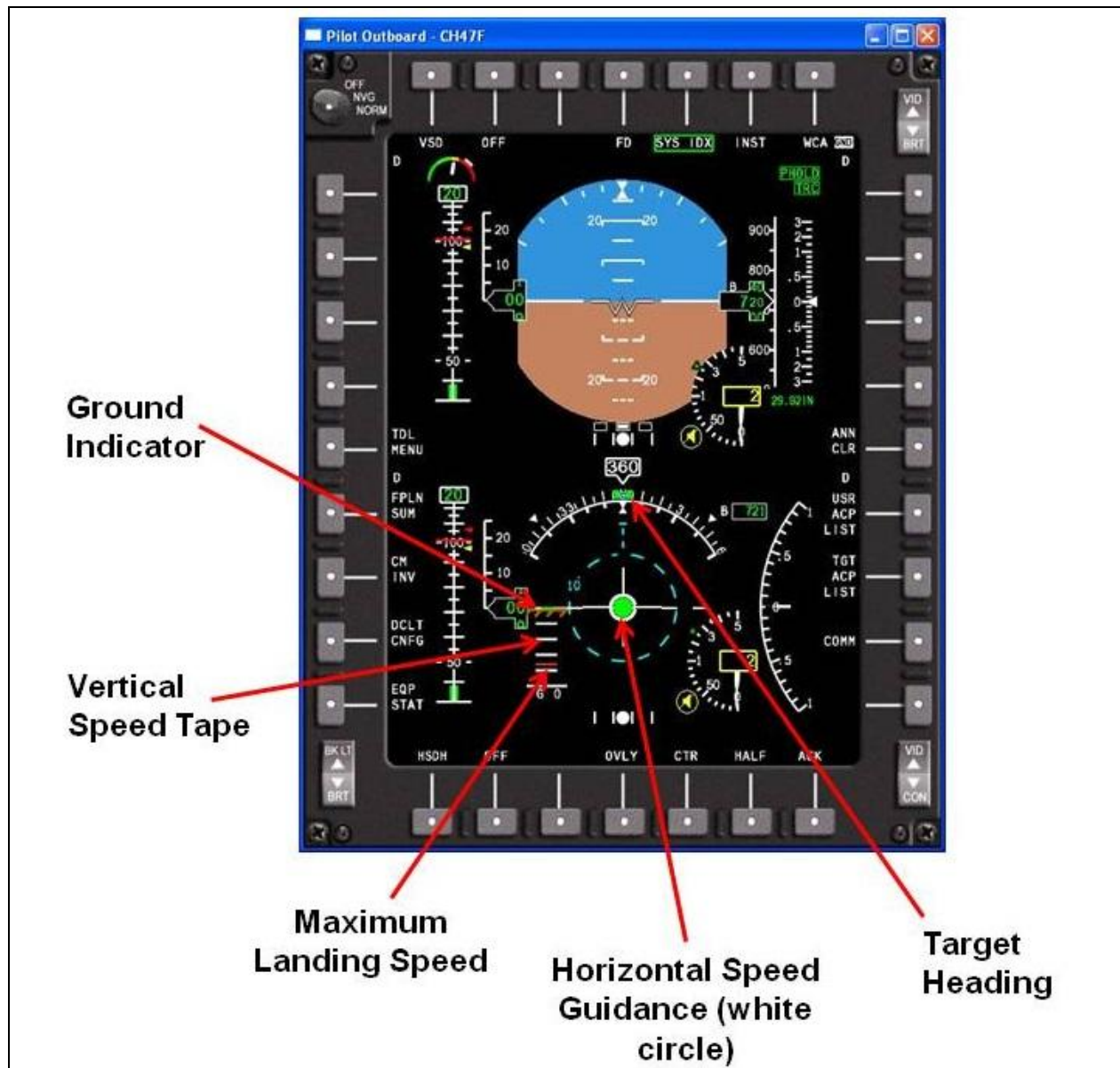


Figure 3. Proposed HSDH display.

with marks at 100 fpm, per tick mark, for indicating vertical speed, and 20 ft per tick mark for indicating radar altitude. The dual-purpose scale makes available to the pilot the relative information between the rate of descent and the location of the ground plane. This proposed design makes available two pieces of information for one detection effort. The vertical speed tape has a bar that extends up or down from the center horizontal line based on the current vertical speed of the aircraft. The color of this bar changed based on various conditions, as shown in figure 4.

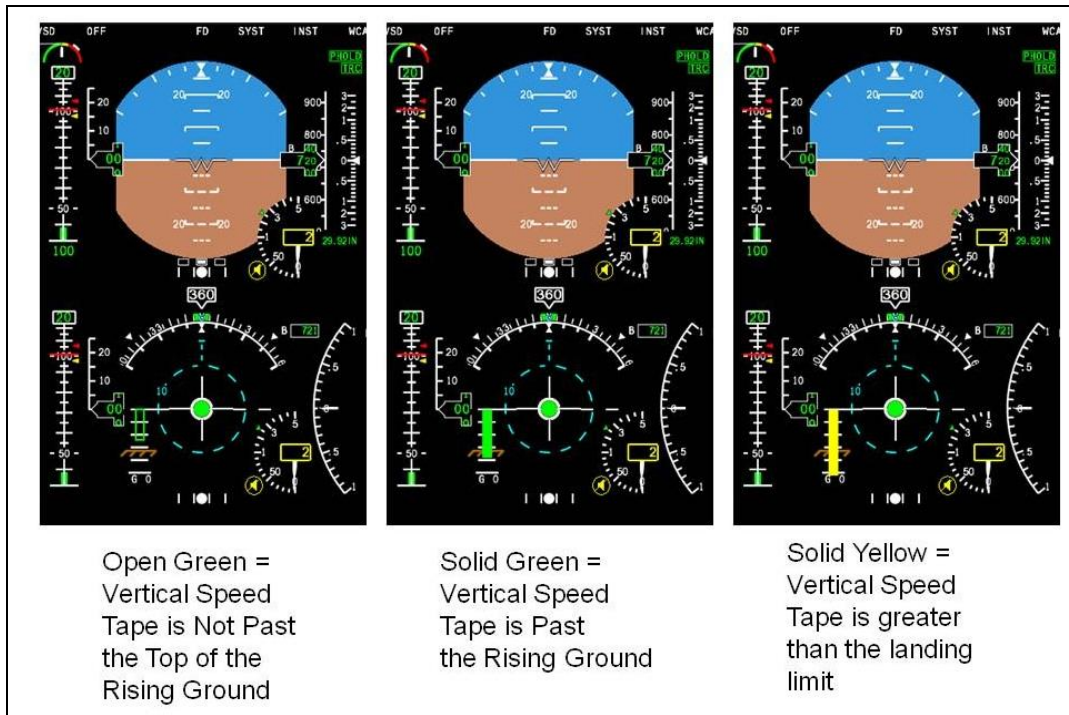


Figure 4. Proposed HSDH vertical speed tape.

The vertical speed tape also shows a representation of the distance to ground as measured by the radar altimeter. This ground indicator will first appear at 100 ft above the ground at the bottom of the tape and will move upward toward the center horizontal line as the aircraft approaches the ground, becoming even with the center horizontal line when the RAD ALT is at 0. This indicator can also be used to show a reference altitude if entered into the CDU or flight plan. The height of the reference altitude is represented by the top line of the hangman, as seen in figure 5.

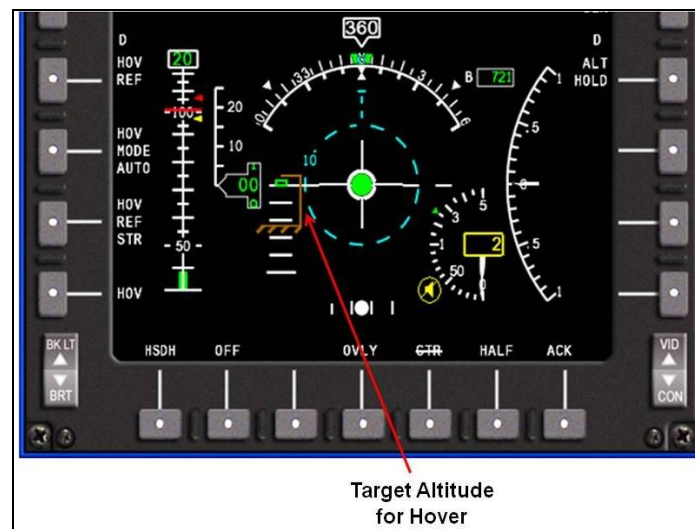


Figure 5. Proposed HSDH target altitude for hover hangman.

For controlling the aircraft in the horizontal direction, the HSDH has an acceleration cue, which is represented by the green circle (see figure 6) and shows the acceleration vector of the aircraft, and a velocity vector, which is represented by the green line extending from the center of the HSDH and shows the direction and speed of the aircraft. The proposed HSDH added a horizontal speed guidance cue, which gives the pilot an indication of where the acceleration cue should be placed in order to direct the aircraft to the desired hover or landing point. This is represented by the magenta horseshoe as shown in figure 6. This horseshoe changed into a white circle when the desired acceleration is zero, indicating that the aircraft is hovering at the desired point. Also, a target heading indicator was added to HSDH, as shown in figure 3.

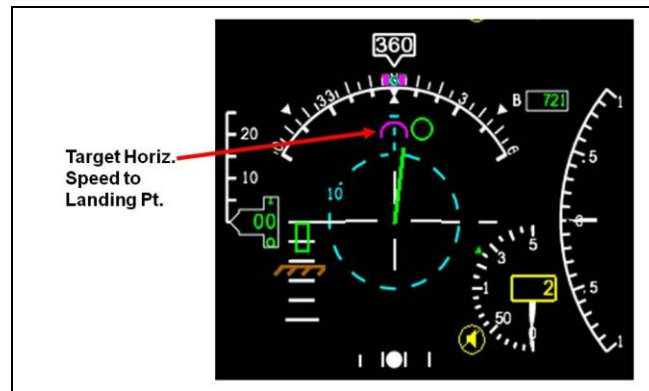


Figure 6. Proposed HSDH horizontal speed guidance.

2.3.3 Proposed Decluttered HSDH Display

The proposed HSDH default decluttered configuration consists of several changes to simplify the look of the HSDH and eliminate unnecessary information as seen in figure 7. The decluttered HSDH removes the torque tape and replaces it with simply the torque digital readout. The decluttered HSDH also removes the air speed tape. Both of these tapes are still available to the pilot on the vertical situation display (VSD), located on the upper half of the multi-function display (MFD). The ground speed is moved from the bottom of the vertical speed tape to the left side of the center horizontal line to bring it closer to the other important gauges used when hover or landing.

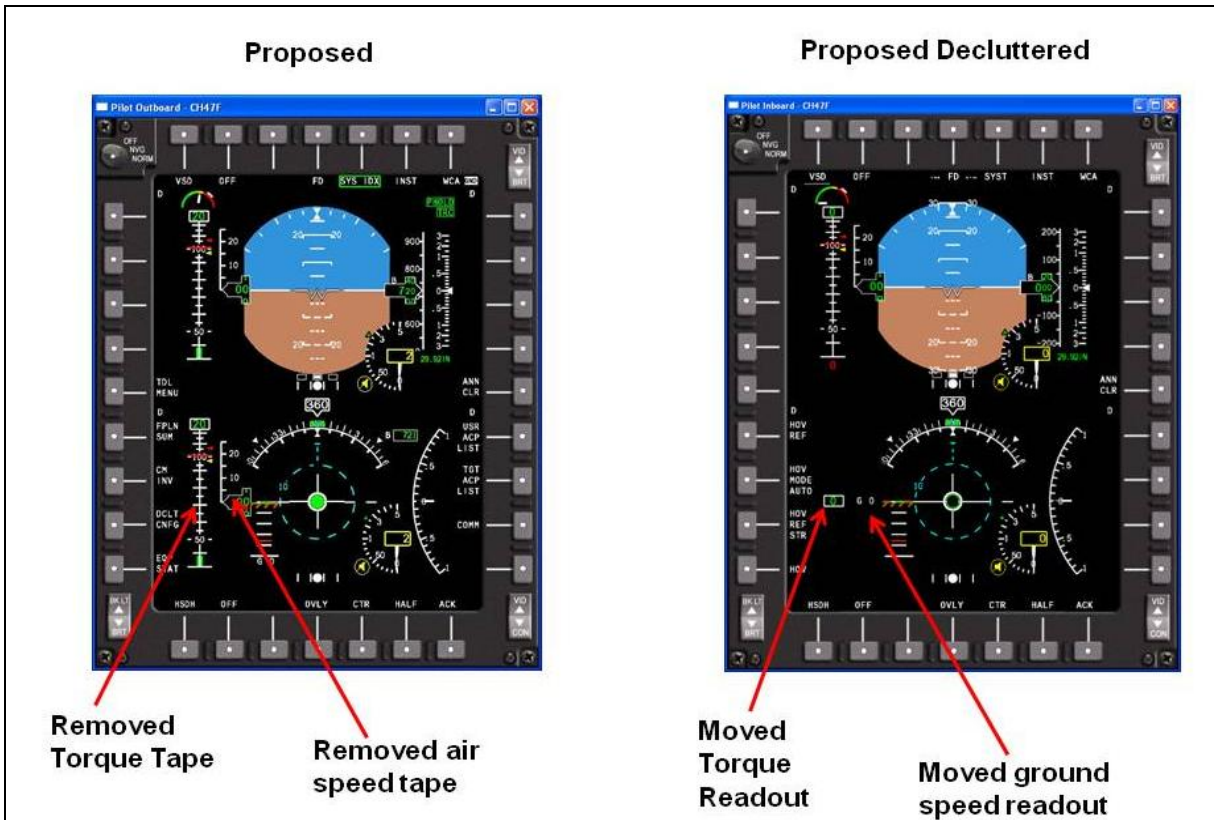


Figure 7. Proposed HSDH vs. proposed decluttered HSDH.

2.4 Apparatus

2.4.1 Eye Tracker System

Crew visual gaze and dwell times were collected with a head and eye tracking system from Applied Science Laboratories (ASL) depicted in figure 8. This system was selected because of its eye-head integration capability that allowed for unrestricted head movement. The ASL eye-head package included a Model H6 eye tracker and NDI Polaris optical head tracker. The ASL software allowed continuous monitoring and data collection of crew (pilot and co-pilot) eye positions. This technology allowed data collection for predefined functional areas of the CH-47 CHEAC cockpit.

Crew gaze analysis determined the total gaze time in each of the three different areas of interest (AOI) for the pilot, shown in figure 9. The three AOIs were defined for the outboard MFD at each crew station: RAD ALT, VSI, and horizontal situation display (HSD). The eye gaze analysis results are presented in section 3.1.



Figure 8. Eye tracker, pupil/camera monitors, and control-panel interface.



Figure 9. Pilot gaze analysis scene planes.

2.4.2 Audio-Video Collection

The BHIVE includes a Battlemaster, an exercise control station that has access to the currently running simulation. The Battlemaster station has access to data collection devices, headset communications, and video monitoring. Audio and video feeds were recorded for crew communications, as well as aircraft telemetry and pilot-vehicle interface displays. The Battlemaster station provided the SMEs with the information needed to coordinate the scenario-driven events and data collection devices required for the CSWG events.

2.5 Aircraft Control Measures

Information on the aircraft's position and velocity was recorded directly from the simulator throughout all runs. This data was then analyzed to determine the controllability of various aspects of the aircraft's flight. The various analyses conducted were transverse landing speed, vertical speed at landing, linearity of approach to LZ1, verticalness of approach to LZ4, accuracy of landing at LZ4, and vertical deviation during sling load operations. The transverse landing speed provides a measure of the danger of a rollover on landing, with higher values indicating a more dangerous landing. The vertical speed at landing was measured to indicate whether or not the various landings were at rates higher than the maximum rate of descent at landing, which could possibly cause damage to the aircraft. The linearity of approach to LZ1 and the verticalness of approach to LZ4 were intended to measure the horizontal controllability of the aircraft during these maneuvers. The vertical deviation during sling load operations was intended to measure the vertical controllability of the aircraft during hover maneuvers. The accuracy of landing at LZ4 was measured to indicate how close the aircraft was being landed to the desired landing location.

2.6 Questionnaires

2.6.1 Bedford Workload Rating Scale

To estimate the level of spare workload capacity needed to perform the landing and hover tasks under brownout DVE conditions, the participants completed the Bedford Workload Rating Scale (BWRS) (appendix B) immediately after each mission. Participants completed the BWRS to rate the workload needed to accomplish each major task in the mission (refer to table 2).

The BWRS has been used extensively by the military, civil, and commercial aviation communities for pilot workload estimation (Roscoe and Ellis, 1990). It requires pilots to rate the level of workload associated with a task based on the amount of spare workload capacity they estimate they have to perform additional tasks. Spare workload capacity is an important commodity for pilots because they are often required to perform several tasks concurrently. For example, co-pilots often perform navigational tasks, communicate via multiple radios, monitor aircraft systems, and assist the pilot with controls of flight tasks (e.g., maintain air space surveillance) within the same time interval. Mission performance is reduced if pilots are task

saturated and have little or no spare capacity to perform other tasks. Design elements of the CH-47F HSDH pages should ensure that pilots can maintain adequate spare workload capacity while performing flight and mission tasks. The BWRS results are presented in section 3.2.

2.6.2 Crew Station Pilot-Vehicle Interface

The design of a crew station PVI influences crew workload and situational awareness (SA) during a flight mission. A crew station that is designed to augment the cognitive and physical abilities of crews will minimize workload, enhance SA, and contribute to successful mission performance. To assess the PVI, the crews completed a comprehensive questionnaire (appendix C) at the end of each mission for the different HSDH implementations. The PVI questionnaire addressed usability and informational effectiveness of the different HSDH configurations: baseline, proposed, and proposed default decluttered.

All question items in the PVI questionnaire, except PV-5, were rated on a 4-point Likert-type scale. Questions in group PV-1 had anchors of very effective, somewhat effective, somewhat in-effective, and very in-effective (scored 1–4, respectively). Questions in the PVI-2 group had anchors of excellent, good, poor, and unsatisfactory (scored 1–4, respectively). Questions in the PVI-3 group had anchors of very easily, somewhat easily, somewhat difficult, and very difficult (scored 1–4, respectively). Questions in group PV-4 had anchors of very effective, somewhat effective, somewhat in-effective, and very in-effective (scored 1–4, respectively). Therefore, lower scores indicate positive crew station usability. Response options for questions in the PV-5 group were open-ended, written reports. Pilot reports are presented in appendix D, “Summary of PVI Comments.” Participants were also solicited to list in open response format any comment on the PVI dimensions queried on the design of the different HSDH configurations. The PVI results are presented in section 3.3.

The baseline HSDH PVI questionnaire consisted of 15 question items, in four main categories: eight questions addressed the effectiveness of HSDH vehicle interface cues for supporting the mission evaluation tasks (PV-1), four questions addressed the informational value of the HSDH symbols and cues (PV-2), one question assessed the ease of understanding the color schemes on the HSDH screen (PV-3), and two questions addressed the overall effectiveness of the HSDH to support the mission and pilot situational awareness (PV-4). The final question (PV-5) allowed pilots to write in comments about the likes and dislikes of the baseline HSDH.

The proposed HSDH PVI questionnaire consisted of 16 question items, in four main categories: eight questions addressed the effectiveness of HSDH vehicle interface cues for supporting the mission evaluation tasks (PV-1), five questions addressed the informational value of the HSDH symbols and cues (PV-2), one question assessed the ease of understanding the color schemes on the HSDH screen (PV-3), and two questions addressed the comparison of the baseline and the proposed HSDH displays for overall effectiveness in supporting the mission and pilot situational awareness (PV-4). The final question (PV-5) allowed pilots to write in comments about the likes and dislikes of the proposed HSDH.

The proposed decluttered HSDH PVI questionnaire consisted of 20 question items, in four main categories: eight questions addressed the effectiveness of HSDH vehicle interface cues for supporting the mission evaluation tasks (PV-1), seven questions addressed the informational value of the HSDH symbols and cues (PV-2), one question assessed the ease of understanding the color schemes on the HSDH screen (PV-3), and four questions addressed the comparisons among the baseline, proposed and decluttered HSDH displays for overall effectiveness in supporting the mission and pilot situational awareness (PV-4). The final question (PV-5) allowed pilots to write in comments about the likes and dislikes of the proposed decluttered HSDH.

2.6.3 Training Assessment

Participants completed a training assessment questionnaire (appendix E) after the simulator and HSDH display training. The training assessment questionnaire consisted of five question items, rated on a 4-point Likert-type scale with anchors of strongly disagree, disagree, agree, and strongly agree (scored 1–4, respectively). Therefore, higher scores indicate positive attitudes toward the training. Participants were also asked to list three positive aspects of the training and three improvements that could be made for training. The training assessment results are presented in section 3.5.

2.7 Procedure

Participants received one day of training on the CHEAC simulator and the three software implementations of the baseline, proposed, and decluttered HSDH displays. Flight procedures with relevant mission scenario problems were operationally reviewed, and software page sequences were trained in a series of increasing fidelity sessions which include classroom lecture format, desktop software trainer, and CHEAC simulation flights. All participants were allowed free discussion to ask questions throughout the day of training. At the end of the training day, participants completed the training assessment questionnaire. Also at the end of the training day, crew 1 flew the first mission. All crews consecutively flew the mission using the baseline HSDH, the proposed HSDH, and finally the decluttered HSDH. Before the start of each flight, the pilot and co-pilot were fitted with the ASL eye tracker and calibrated. After each pilot of a crew pair flew the mission to completion, participants immediately completed the BWRS and PVI questionnaires. An after-action review (AAR) was conducted for each crew individually. Upon completing flights utilizing the three HSDH designs, an overall AAR was conducted with all pilots present, except P6, who was reassigned to another location after the second flight mission.

2.8 Data Analysis

Descriptive statistics were calculated for responses to the training assessment, BWRS, and PVI questionnaires. Where shown in the figures, error bars indicate the 95% confidence interval (CI) of the mean. These error bars can be used to help make conclusions about statistically significant differences. If two 95% CI error bars do not overlap and the sample sizes are nearly

equal, the difference is statistically significant with a P value much less than 0.05 (Payton et al., 2003). To confirm statistically significant differences, analysis of variance (ANOVA) and/or t-tests was conducted.

2.9 Limitations

Some limitations should be considered when interpreting the data presented in the results section:

- There was a small sample size of crew members ($N = 8$) that may not be representative of the total pilot population.
- Pilot P6 left the study early missing his last flight.
- The small sample size limits the power of the statistical analyses to find true effects.
- The small sample size limits the confidence in generalizing results to a broader pilot population.
- Training scope and duration were short. This may have limited the pilot's mastery of the simulator and contributed to learning effects and order effects (i.e., display presentation was not counterbalanced) during the flights of record.
- Flights were conducted in a simulator. Although the simulator has a high degree of fidelity, some discrepancies between the simulator and actual aircraft performance may exist.

These limitations are not uncommon when replicating a complex aviation system in a simulator. However, the data and the information given in the Results and Summary sections of this report should be interpreted based on these limitations. Additional data should be collected during future simulations and tests to augment and expand the findings contained in this report.

3. Results

3.1 Visual Gaze

Visual gaze behavior was analyzed using four ocular activity metrics and localized areas of interest (AOI) analyses. Specifically, fixation duration, interfixation angle, fixation frequency, and blink frequency were analyzed as behavioral measures, and the HSD, VSI, and RAD ALT AOIs were taken as measures of visual attention. Statistical comparisons (one-way repeated measures ANOVA) were conducted for each of these measures with display type (baseline HSDH, proposed HSDH, and decluttered HSDH) as the independent variable.

3.1.1 Fixation Duration

In order to measure the cognitive cost of processing the proposed HSDH symbology compared to the baseline symbology, fixation duration data were analyzed and statistically compared across different display types while collapsing data across a variety of hover tasks. Fixation duration indicates the length of time a pilot's visual attention is captured by a given stimulus. Often, this is taken as a measure of mental workload (Tole et al., 1983), in which longer fixation durations indicate greater workload because of longer processing cycles.

Results can be viewed in figure 10, which indicate no statistical difference, $F(2, 6) = 1.536$, $p > 0.05$ across display conditions.

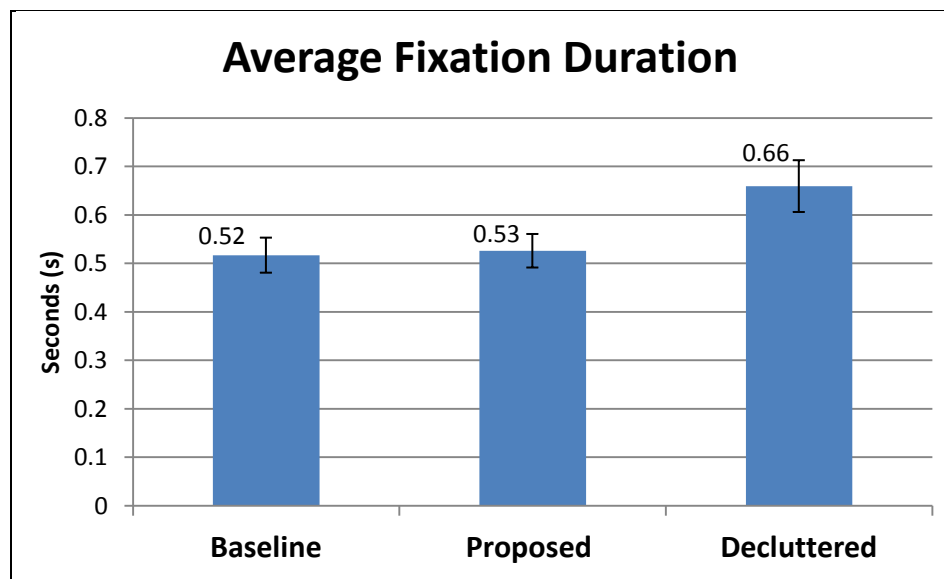


Figure 10. Average fixation duration across display types.

3.1.2 Interfixation Angle

In order to investigate the amount of effort exerted by the visual system as a result of changing the HSDH symbology, interfixation angle, a different measure of visual workload was compared across display types while collapsing data across all of the hover conditions. Interfixation angle, as measured in this analysis, is the angular distance between gaze fixations. A reduction in interfixation angle indicates that less effort was required by the visual system to obtain information related to the pilot's task.

A one-way repeated measures ANOVA indicated a strong trend towards significance, $F(2, 6) = 5.513$, $p = 0.057$, suggesting that the pilots' visual system effort requirements were sequentially reduced with the introduction of the proposed and decluttered HSDH symbology. These data are graphically represented in figure 11.

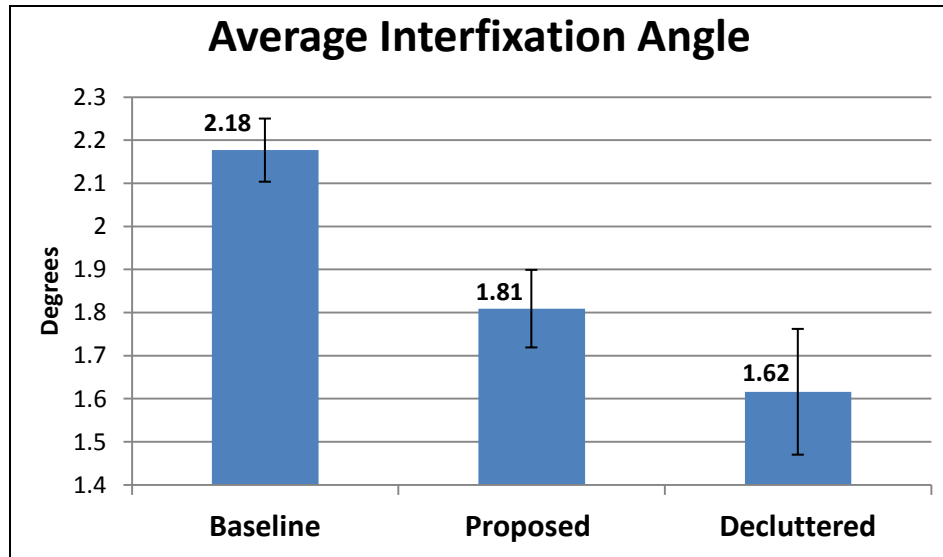


Figure 11. Average interfixation angle across display types.

3.1.3 Fixation Frequency

One purpose of the proposed HSDH symbology was to localize the pilot's visual attention to a more central position when monitoring information related to the pilot's hover position. If this were achieved, then the frequency of fixations required to gather this data should have decreased, indicating that pertinent information for the pilot was more readily available. Essentially, it means that the "units of information" per fixation would increase, thereby requiring fewer fixations to achieve the same job.

Data can be viewed in figure 12, which indicates that there were no significant differences in average fixation frequency across display conditions, $F(2, 6) = 0.226$, $p > 0.05$.

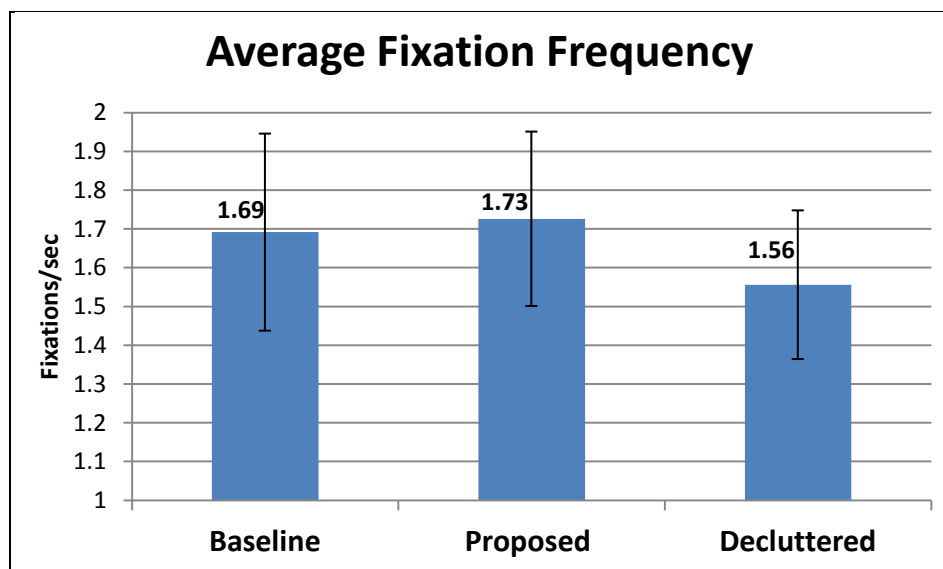


Figure 12. Average fixation frequency across display types.

3.1.4 Blink Frequency

Blink frequency is associated with both visual and mental workload, and some previous research has demonstrated a negative correlation between these variables (Veltman and Gaillard, 1998). As blinks increase workload tends to be reduced. The following analysis evaluates blink behavior as a function of display type.

A one-way repeated measures ANOVA indicates that blink behavior was significantly inhibited as a function of display type, $F(2, 6) = 9.753$, $p = 0.021$. Figure 13 graphically presents these data.

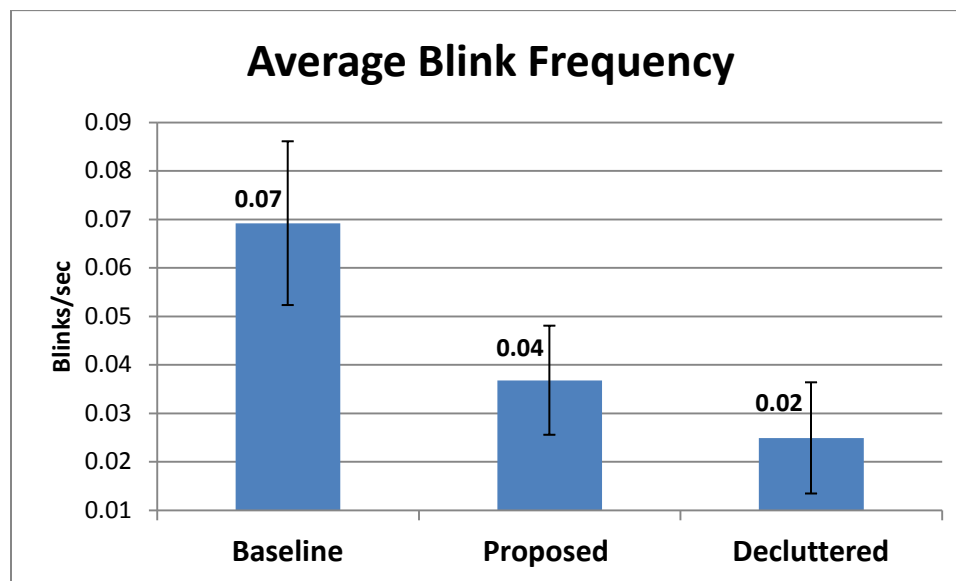


Figure 13. Average blink frequency across display types.

3.1.5 Horizontal Situation Display Visual Gaze Analysis

The following HSD analysis was conducted to investigate if the pilot's visual attention was more consistently allocated to the HSD symbology as a function of the display type. The purpose of the new symbology was to enhance, and consequently reposition, the same information displayed by the RAD ALT and VSI. The enhanced symbology was placed within the AOI of the HSD. Consequently, if the enhanced HSD symbology successfully provided the required RAD ALT and VSI information to the pilot, then the visual gaze percentages within the HSD symbology should be reduced from the RAD ALT and VSI and should increase within the HSD AOI. The following statistical analysis evaluates the varying gaze percentages of the HSD across display types.

Figure 14 presents a significant increase in the percentage of time spent visually gazing over the HSD AOI, $F(2, 6) = 6.782$, $p = 0.04$. This indicates that the pilots were able to continuously rely on the enhanced symbology for the required hover information.

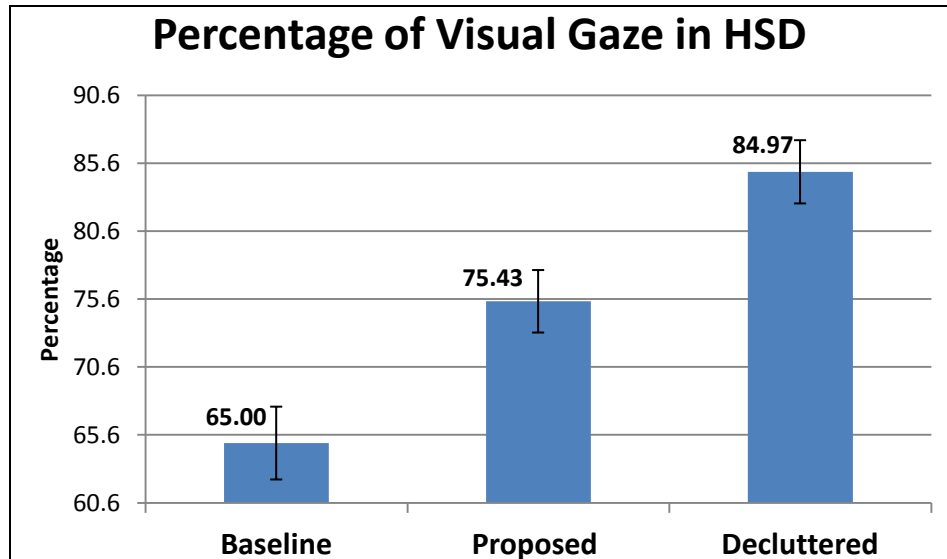


Figure 14. Percentage of visual gaze on HSD AOI.

3.1.6 Radar Altimeter Visual Gaze Analysis

Similar to the previous analysis, the percentage of visual gaze time spent over the RAD ALT was analyzed in order to determine whether pilots relied on the hangman symbology for information that is traditionally presented on the RAD ALT. This analysis determines an objective pilot preference for each information source.

Figure 15 illustrates that there is no significant difference in visual gaze on the RAD ALT exhibited across display type, $F(2, 6) = 0.222$, $p > 0.05$. These results indicate that, although there was a significant increase in the visual gaze of the HSD symbology, pilots still relied just as heavily on the RAD ALT in terms of total time spent visually dwelling on the RAD ALT symbology.

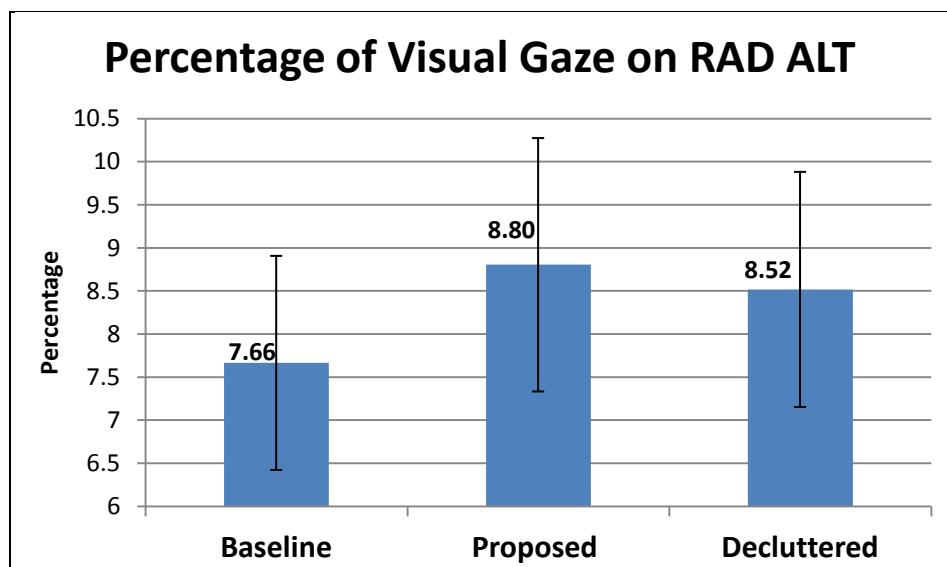


Figure 15. Percentage of visual gaze on the RAD ALT AOI.

3.1.7 Vertical Speed Indicator Visual Gaze Analysis

Similar to the previous analysis, the percentage of visual gaze time spent over the VSI was analyzed in order to determine if pilot's relied on the vertical speed tape symbology for information that is traditionally presented on the VSI. This analysis determines an objective distribution of a pilot's focus of attention.

Figure 16 illustrates a significant difference in visual gaze on the VSI was exhibited across display type, $F(2, 6) = 4.05$, $p = 0.045$. These results indicate that there was a significant decrease in the visual gaze on the VSI, indicating pilots used the vertical speed tape for information that is usually presented on the VSI in the baseline HSDH.

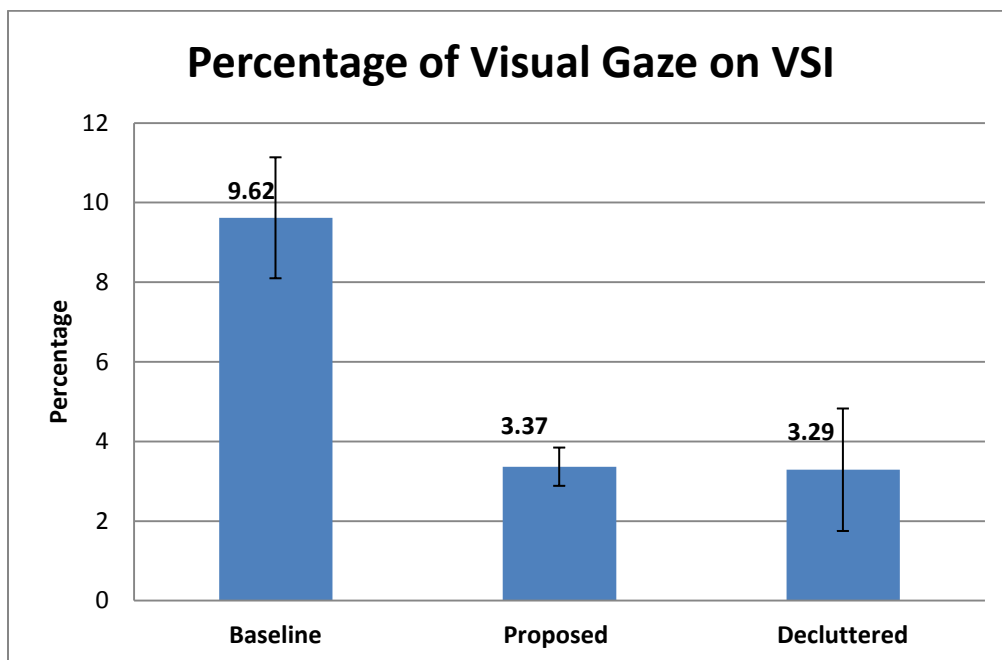


Figure 16. Percentage of visual gaze on the VSI.

3.2 Workload

The BWRS was constructed to assess a pilot's subjective perception of available spare mental workload during the evaluation maneuvers performed at each mission task site. BWRS scores were taken for each landing zone overall and for the ATM subtasks that constituted the mission at a particular flight plan waypoint. A workload rating between 2 and 3 indicates that the rater had "enough workload capacity for all desirable additional tasks." BWRS scores greater than 6 are not considered "tolerable for the task" and therefore are considered as high workload.

3.2.1 Overall Workload for HSDH Display Type

The overall pilot BWRS score for all mission task IDs (see table 2) were 3.58, 3.44, and 3.06 for baseline HSDH, proposed HSDH, and decluttered HSDH, respectively (see figure 17). Error bars represent the 95% confidence interval of the mean. The combined BWRS scores across

evaluation tasks graphically appear statistically similar, as indicated by overlap of the 95% confidence interval error bars. A one-way, repeated measures ANOVA also indicated no significant statistical difference among HSDH configurations $F(2, 14) = 0.64, p > 0.05$. Data indicate that pilots reported having adequate spare workload capacity while utilizing the three HSDH displays.

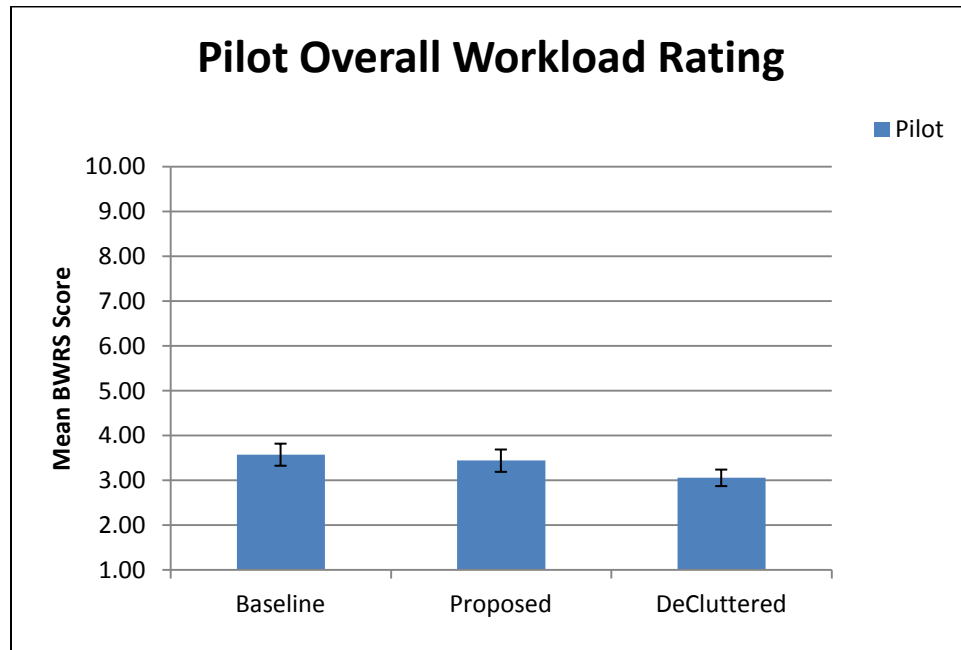


Figure 17. Crew overall workload ratings by HSDH configuration.

3.2.2 Workload for Evaluation Maneuvers per HSDH Display

The BWRS results for the mission task IDs (see table 2) performed with the baseline HSDH are presented in figure 18. Although the maximum mean BWRS score is 4.5 for Mission Task ID 6, LZ2 hover to landing, one pilot indicated a BWRS score of 7 on performing three tasks with the baseline HSDH. The tasks thus rated were: performing a controlled termination to touchdown at LZ1, performing a controlled descent with minimal drift at LZ2, and performing a controlled descent with minimal drift at LZ4. Even though some of the evaluation maneuvers were challenging, pilots reported overall having enough spare workload capacity for easy additional tasks.

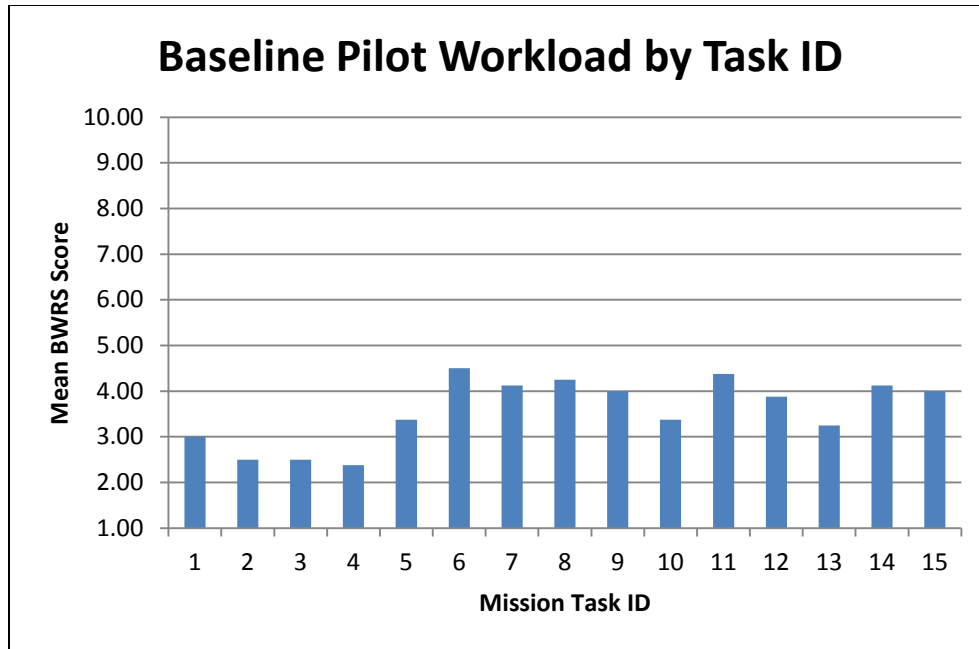


Figure 18. Baseline HSDH mean workload ratings for mission task IDs.

The BWRS results for the mission task IDs (see table 2) performed with the proposed HSDH are presented in figure 19. Although the maximum mean BWRS score is 4.13 for Mission Task ID 11, LZ3 Sling load, one pilot indicated a BWRS score of 7 while performing task ID eight with the proposed HSDH. The tasks rated greater than 6 on BWRS were: LZ2 overall hover to landing (ID 6), performing a controlled termination to touchdown at LZ2 (ID 8), LZ3 sling load overall (ID 9), performing a controlled termination to initial hover at LZ3 (ID 10), perform a controlled termination to hookup point at LZ3 (ID 11), LZ4 overall hover to landing (ID 12), performing a controlled termination to initial hover at LZ4 (ID 13), and performing a controlled descent with minimal drift at LZ4 (ID 14). Again, the hover maneuvers were challenging, but pilots reported having additional spare workload capacity for some attention to additional tasks.

The BWRS results for the mission task IDs (see table 2) performed with the proposed decluttered HSDH are presented in figure 20. The maximum mean value was 3.63 for task ID 14 performing a controlled termination to touchdown at LZ4. No pilot reported a workload value greater than 6 for the proposed decluttered HSDH.

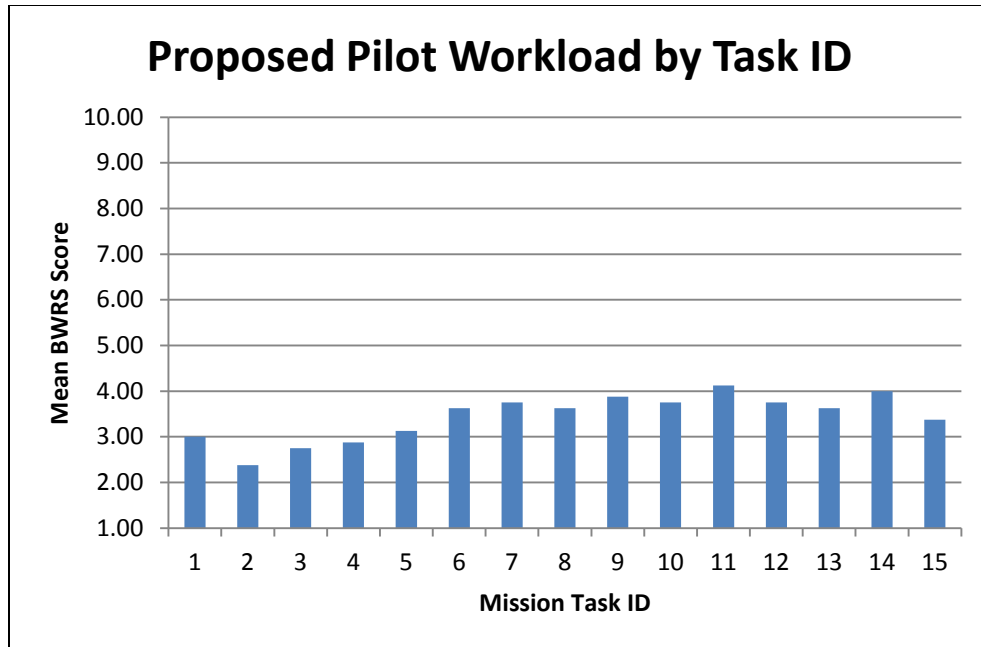


Figure 19. Proposed HSDH mean workload ratings for mission task IDs.

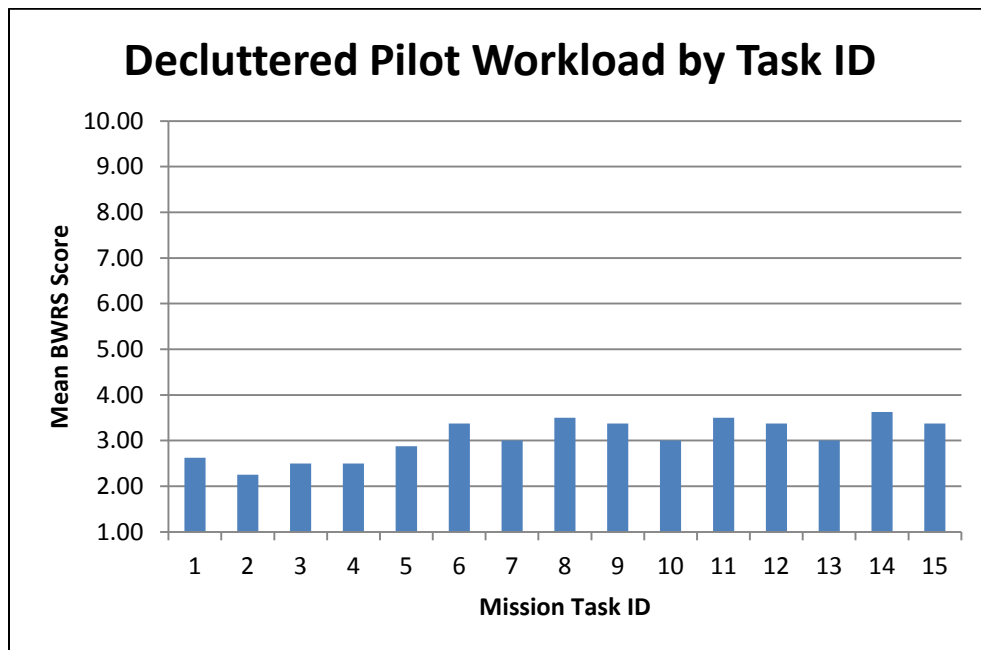


Figure 20. Proposed decluttered HSDH mean workload ratings for mission task IDs.

3.2.3 Workload for Each Overall Mission Task by HSDH Display

An analysis was also conducted between the pilots reported BWRS for overall mission ID and the three HSDH designs. This analysis investigated the reported pilot workload for the overall evaluation tasks. The analysis answers the question of how much workload did a mission task entail as compared across different displays. This analysis captures whether a particular HSDH design has an advantage or disadvantage in a given mission context.

The overall pilot BWRS scores for mission task LZ1 alpha landing (see table 2) were 2.75, 2.82, and 2.55 for baseline HSDH, proposed HSDH, and decluttered HSDH, respectively (see figure 21). Error bars represent the 95% confidence interval of the mean. The combined BWRS scores for LZ1 graphically appear statistically similar, as indicated by overlap of the 95% confidence interval error bars. A one-way, repeated measures ANOVA indicated no significant statistical difference among HSDH configurations $F(2, 14) = 0.16, p > 0.05$.

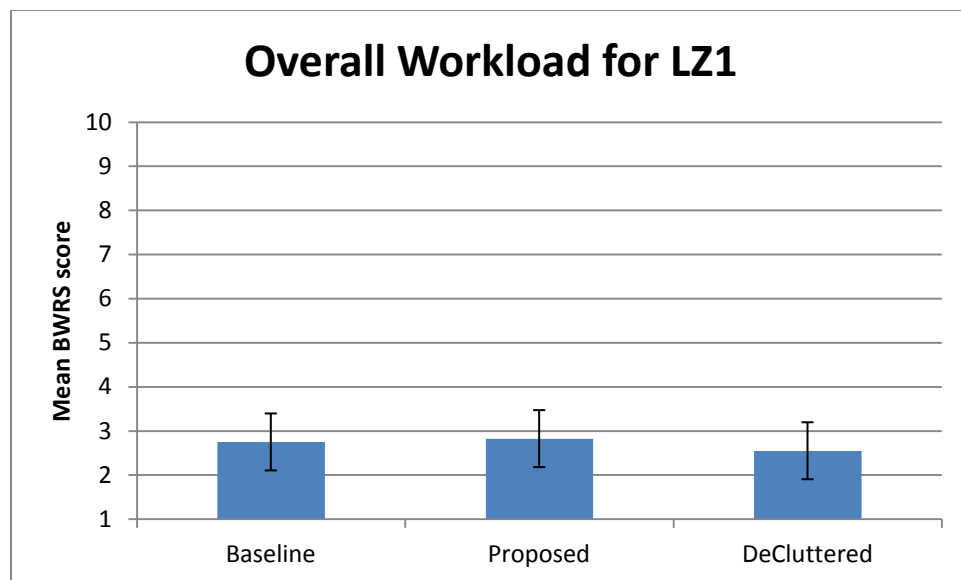


Figure 21. Workload ratings for overall mission task LZ1 approach landing.

The overall pilot BWRS scores for mission task LZ2 hover to landing (see table 2) were 4.29, 3.67, and 3.29 for baseline HSDH, proposed HSDH, and decluttered HSDH, respectively (figure 22). Error bars represent the 95% confidence interval of the mean. The combined BWRS scores for LZ2 graphically appear statistically similar, as indicated by overlap of the 95% confidence interval error bars. A one-way, repeated measures ANOVA indicated no significant statistical difference among HSDH configurations $F(2, 14) = 1.40, p > 0.05$.

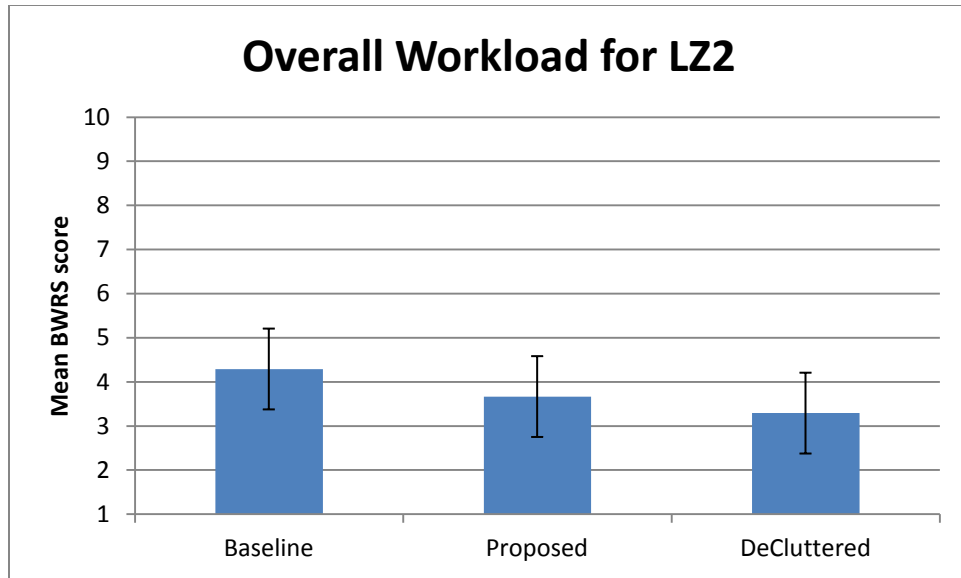


Figure 22. Workload ratings for overall mission task LZ2 hover to land.

The overall pilot BWRS scores for mission task LZ3 sling load (see table 2) were 3.92, 3.92, and 3.30 for baseline HSDH, proposed HSDH, and decluttered HSDH, respectively (figure 23). Error bars represent the 95% confidence interval of the mean. The combined BWRS scores for LZ3 graphically appear statistically similar, as indicated by overlap of the 95% confidence interval error bars. A one-way, repeated measures ANOVA indicated no significant statistical difference among HSDH configurations $F(2, 14) = 0.95, p > 0.05$.

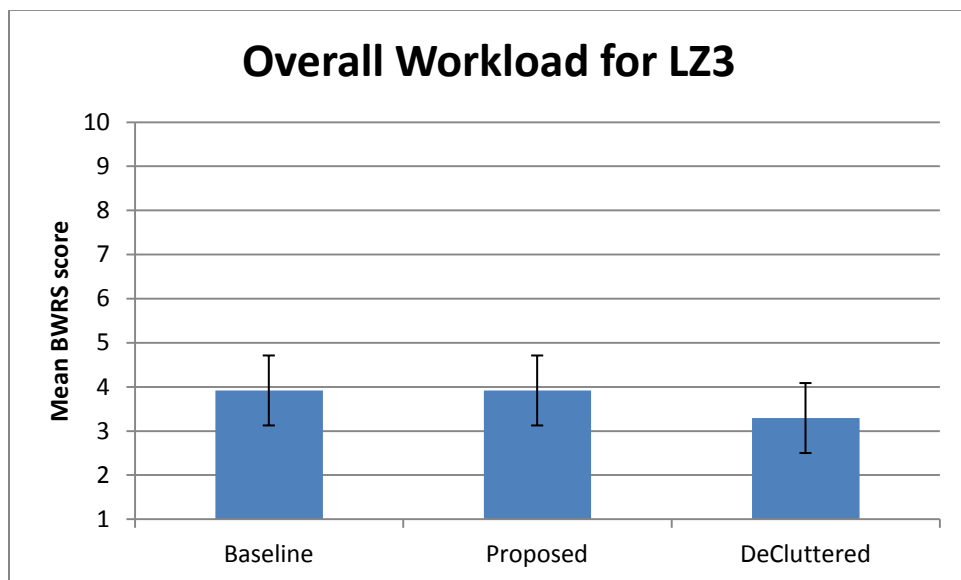


Figure 23. Workload ratings for overall mission task LZ3 sling load.

The overall pilot BWRS scores for mission task LZ4 hover to landing (see table 2) were 3.75, 3.79, and 3.33 for baseline HSDH, proposed HSDH, and decluttered HSDH, respectively (figure 24). Error bars represent the 95% confidence interval of the mean. The combined BWRS scores for LZ4 graphically appear statistically similar, as indicated by overlap of the 95% confidence interval error bars. A one-way, repeated measures ANOVA indicated no significant statistical difference among HSDH configurations $F(2, 14) = 0.44, p > 0.05$.

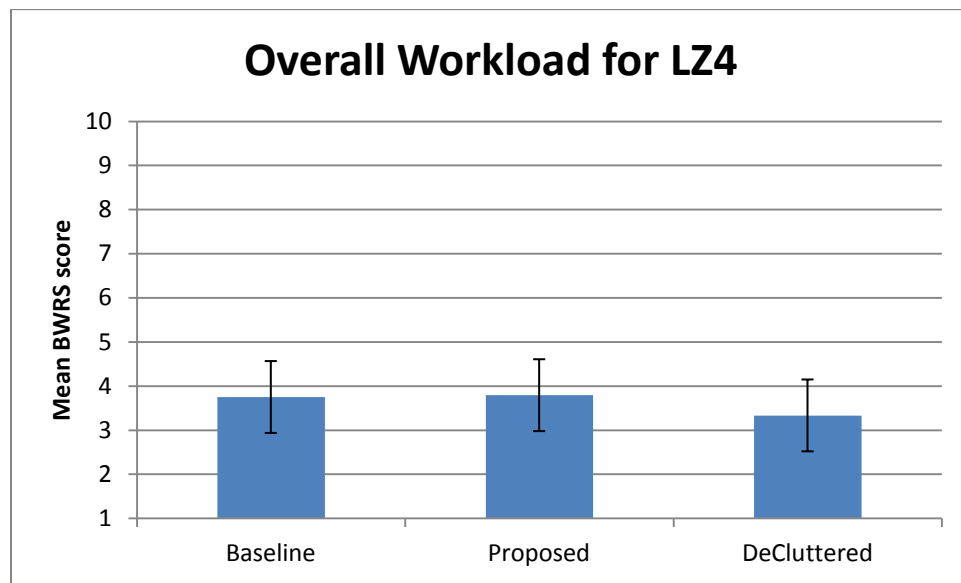


Figure 24. Workload ratings for overall mission task LZ4 high hover to land.

The overall pilot BWRS scores for mission task LZ6 reposition (see table 2) were 4.00, 3.375, and 3.375 for baseline HSDH, proposed HSDH, and decluttered HSDH, respectively (figure 25). Error bars represent the 95% confidence interval of the mean. The combined BWRS scores for LZ4 graphically appear statistically similar, as indicated by overlap of the 95% confidence interval error bars. A one-way, repeated measures ANOVA indicated no significant statistical difference among HSDH configurations $F(2, 14) = 0.54, p > 0.05$.

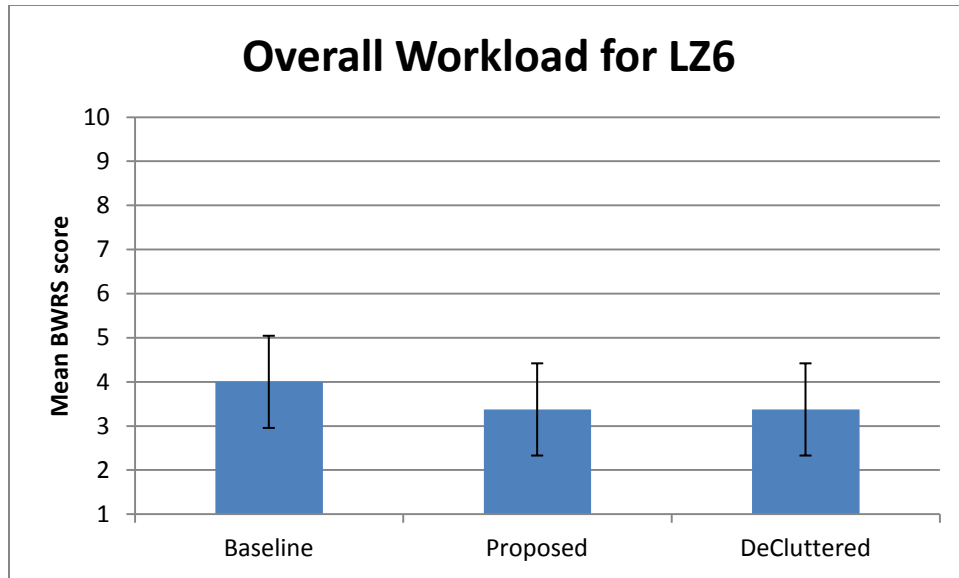


Figure 25. Workload ratings for overall mission task LZ6 reposition.

3.3 Crew Station Pilot-Vehicle Interface

The PVI questionnaire investigated pilots' perceptions and preferences of the different HSDH displays to inform them of the successful control of the aircraft. Pilots' comparisons of the overall usability of the baseline, proposed, and decluttered displays were collected.

3.3.1 Overall PVI Ratings

The overall crew station PVI questionnaire responses for all PVI dimensions were 1.97, 1.75, and 1.73 for baseline, proposed, and decluttered HSDHs, respectively (figure 26). Recall that a PVI score between 1 and 2 indicates that the rater selected between "very easy/very effective" and "somewhat easy/somewhat effective" on average. Error bars represent the 95% confidence interval of the mean. In addition, participant comments regarding general concerns about the HSDH designs and the three things they liked/disliked about the design of interface are presented in appendix F.

3.3.2 PVI Comparisons by HSDH Display

A breakdown of the PVI responses by category, PV-1, PV-2, PV-3, and PV-4 for each HSDH design is presented in figures 27–29. Smaller values represent greater pilot preference.

For the baseline HSDH, the overall mean pilot report for establishing and maintaining hover is 1.88, falling nearest to the somewhat effective category. The overall mean pilot rating for supporting landing is 1.63. For the baseline HSDH, the mean pilot report for overall mission effectiveness is 1.74, falling nearest to the somewhat effective category. For the baseline HSDH, the mean pilot report for maintaining situational awareness is 1.75, falling nearest to the somewhat effective category.

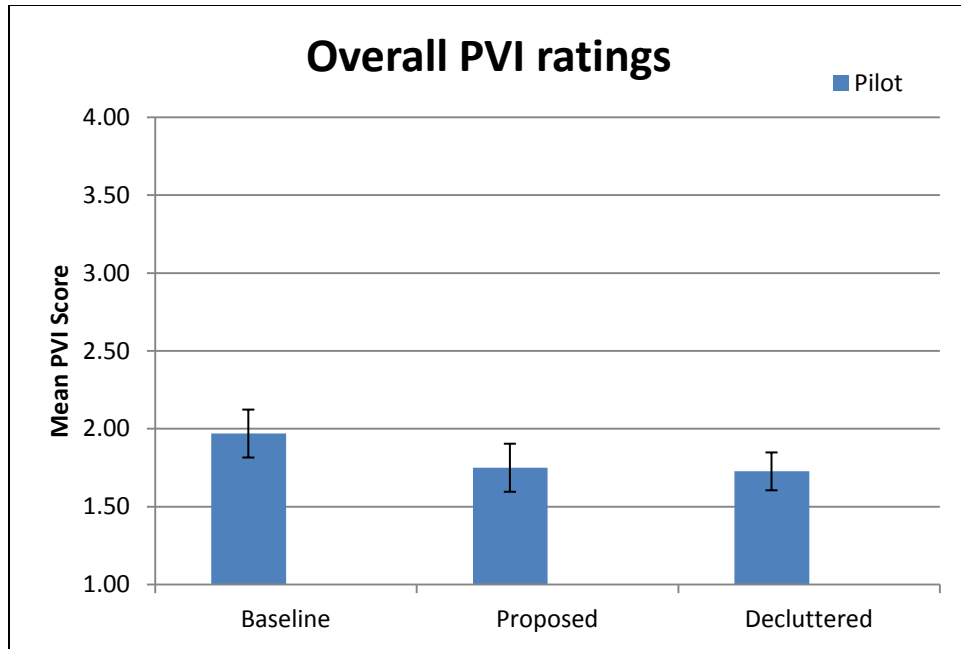


Figure 26. Crew overall PVI ratings by HSDH design.

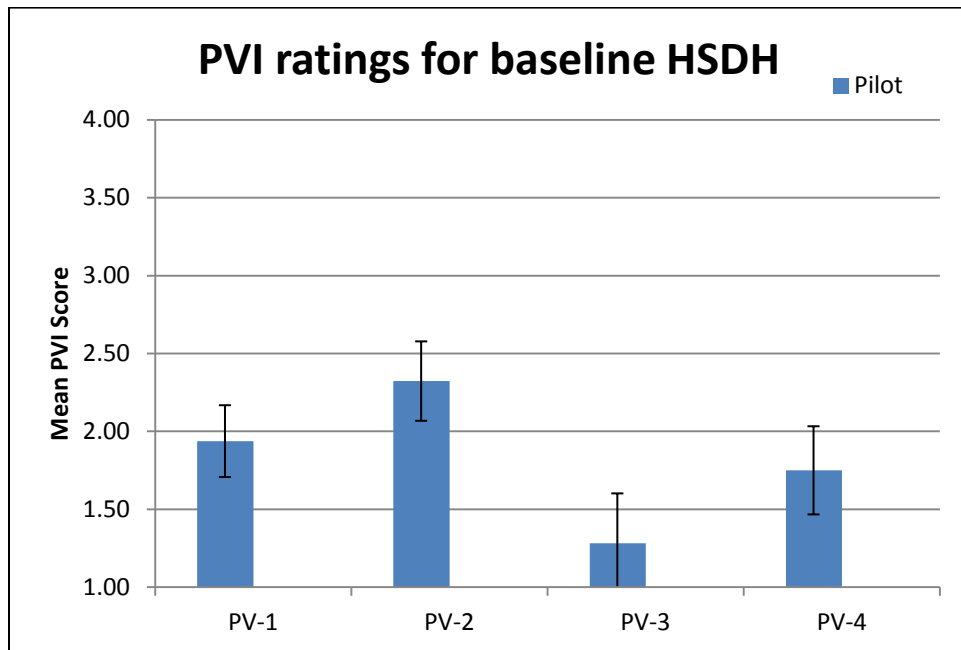


Figure 27. PVI ratings by dimension for baseline HSDH.

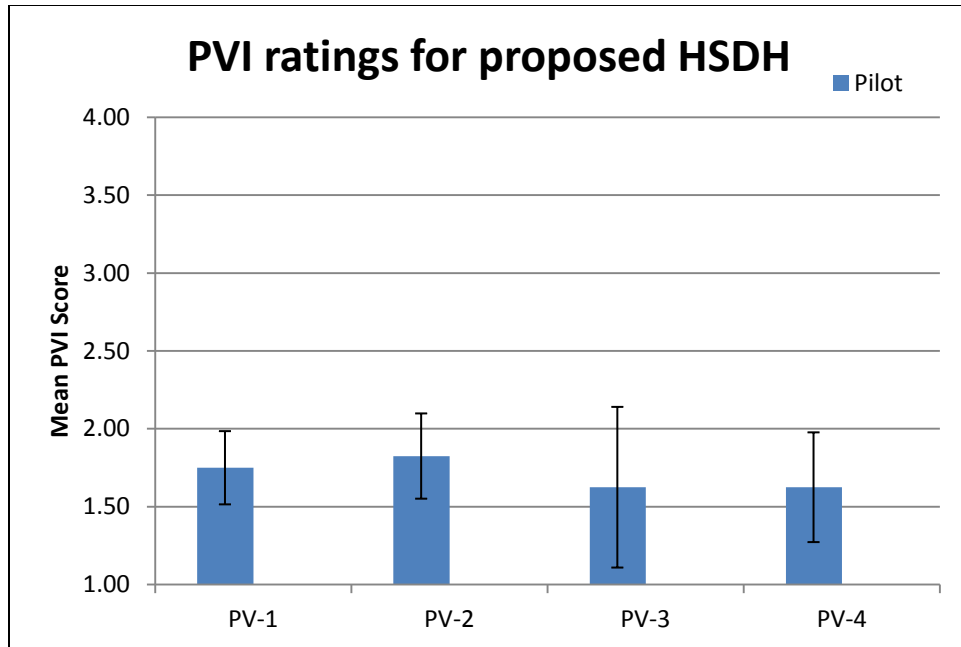


Figure 28. PVI ratings by dimension for proposed HSDH.

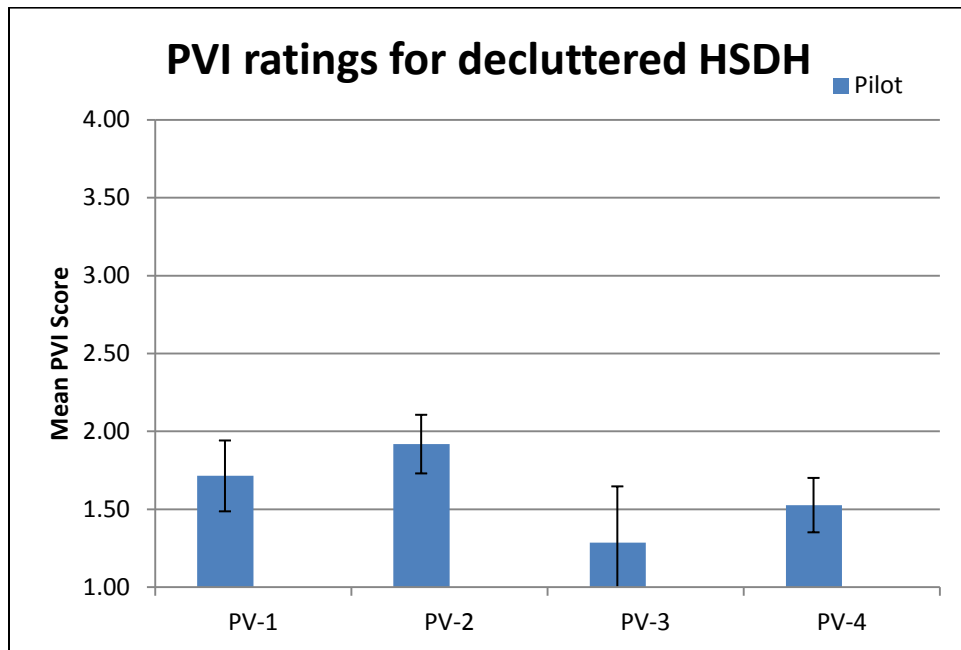


Figure 29. PVI ratings by dimension for proposed decluttered HSDH.

For the proposed HSDH, the overall mean pilot report for establishing and maintaining hover is 1.13, falling nearest to the very effective category. The overall mean pilot rating for supporting landing is 1.38, falling nearest the very effective category. For comparison ratings between the proposed HSDH and the baseline HSDH, the mean pilot report for overall mission effectiveness is 1.50 in favor of the proposed HSDH. For comparison ratings between the proposed HSDH and the baseline HSDH, the mean pilot report for maintaining situational awareness is 1.75 in favor of the proposed HSDH.

For the proposed decluttered HSDH, the overall mean pilot report for establishing and maintaining hover is 1.43, falling nearest to the very effective category. The overall mean pilot rating for supporting landing is 1.00, falling at the very effective category. For comparison ratings between the proposed decluttered HSDH and the proposed HSDH, the mean pilot report for overall mission effectiveness is 1.63 in favor of the proposed decluttered HSDH. For comparison ratings between the proposed decluttered HSDH and the baseline HSDH, the mean pilot report for maintaining situational awareness is 1.35 in favor of the proposed decluttered HSDH. For comparison ratings between the proposed decluttered HSDH and the baseline HSDH, the mean pilot report for overall situational awareness is 1.49 in favor of the proposed decluttered HSDH. For comparison ratings between the proposed decluttered HSDH and the proposed HSDH, the mean pilot report for maintaining situational awareness is 1.63 in favor of the proposed decluttered HSDH.

3.3.3 Pilot After Action Review Summary

An all-hands discussion was conducted with the seven remaining pilots on the final day of the CSWG demonstration. Notes were taken of the discussion by two independent observers. These two sets of notes were compared and compiled. A summary of the main points of the group discussion is presented as follows.

- All pilots reported favorable preferences for the proposed and decluttered HSDH.
- All pilots indicated that the proposed and decluttered displays improved hover performance.
- Pilots indicated that the VSI tape as simulated was too wide and obscured the VSI scale.
- Pilots reported that the yellow VSI tape worked well for attention capture for descent rates greater than the landing limit.
- Pilots reported that locating a digital readout of the RAD ALT on the left side of the HSD would decrease the required visual scan area.
- Pilots discussed that the VSI tape helped them visually confirm a positive rate of climb.
- Pilots reported a mixed vote for and against the hangman for hover altitude hold indication.

- Pilots generally liked the rising ground plane cue, though some reported that its brown color was lost in the yellow of the VSI tape.
- Pilots unanimously favored the horizontal guidance cue. “Put-the-ball-in-cup” became a commonly repeated theme of the demonstration. Some pilots did report that scale changes of the guidance cue was an aggressive approach compared to their approach practice.
- All pilots voted in favor of immediate implementation of the horizontal guidance cue.

3.4 Aircraft Control Measures

In order to determine the utility of the HSDH display designs to inform the pilots’ maneuvering of the aircraft, five different aircraft control measures were defined and analyzed for specific mission tasks. These analyses allow for the investigation of how the displayed cues influenced the aviating performance of the pilots. The aircraft control measures conducted are transverse landing speed, vertical speed at landing, horizontal deviation in landing, horizontal deviation in vertical descent, and vertical deviation during sling load operations. Due to one pilot being present for only two of the HSD types, all aircraft control measures were analyzed on only the seven remaining pilots.

3.4.1 Transverse Landing Speed

The speed of the aircraft perpendicular to the longitudinal axis of the aircraft was measured for all landings. Lower transverse landing speeds result in a lower risk of rollover on landing. The graph of transverse landing speed by pilot can be seen in figure 30, and the graph of transverse landing speed by landing site can be seen in figure 31.

A one-way repeated measures ANOVA indicated no significant change in transverse landing speed, $F(2, 6) = 1.30, p > 0.05$, suggesting that the new symbology did not result in lesser or greater transverse landing speeds. Transverse landing speeds tended to be greater during alpha approaches (LZ1, KBYS).

3.4.2 Vertical Speed at Landing

Although pilots were not instructed to land at any specific or minimum speed, it is desirable that the pilot land at a speed below the maximum rate of descent at touchdown (landing limit). Landings above this rate could result in damage to the aircraft. The number of landings for which the vertical speed was above the landing limit were tallied and can be seen by pilot in figure 32 and by landing site in figure 33. A one-way repeated measures ANOVA indicated no significant change in the number of landings above the maximum rate of descent at touchdown, $F(2, 6) = 2.67, p > 0.05$. Overall, there were 18 rough landings with the baseline symbology, 16 with the proposed symbology, and 12 with the decluttered symbology.

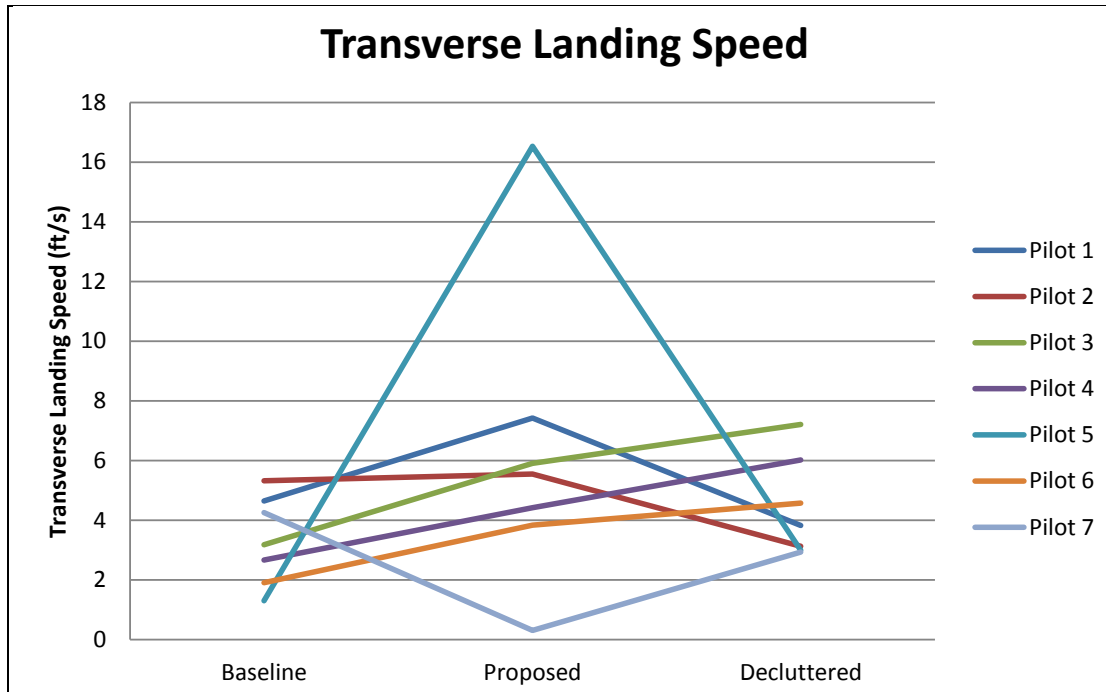


Figure 30. Transverse landing speed by pilot.

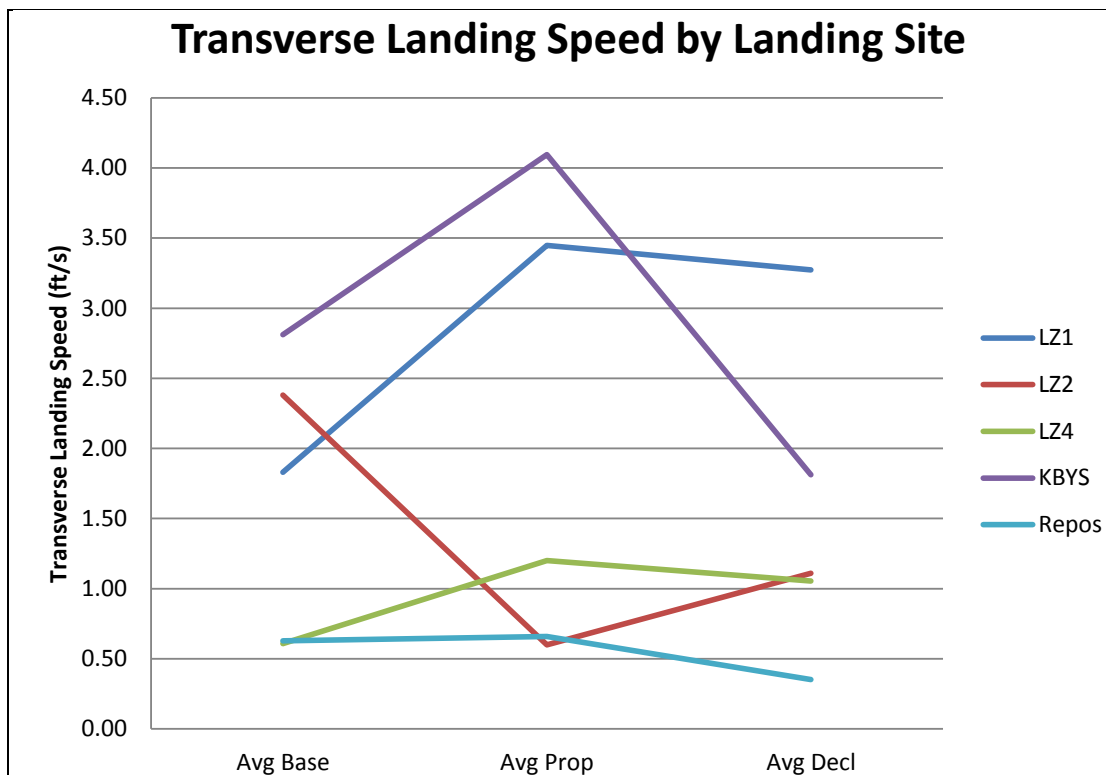


Figure 31. Transverse landing speed by landing site.

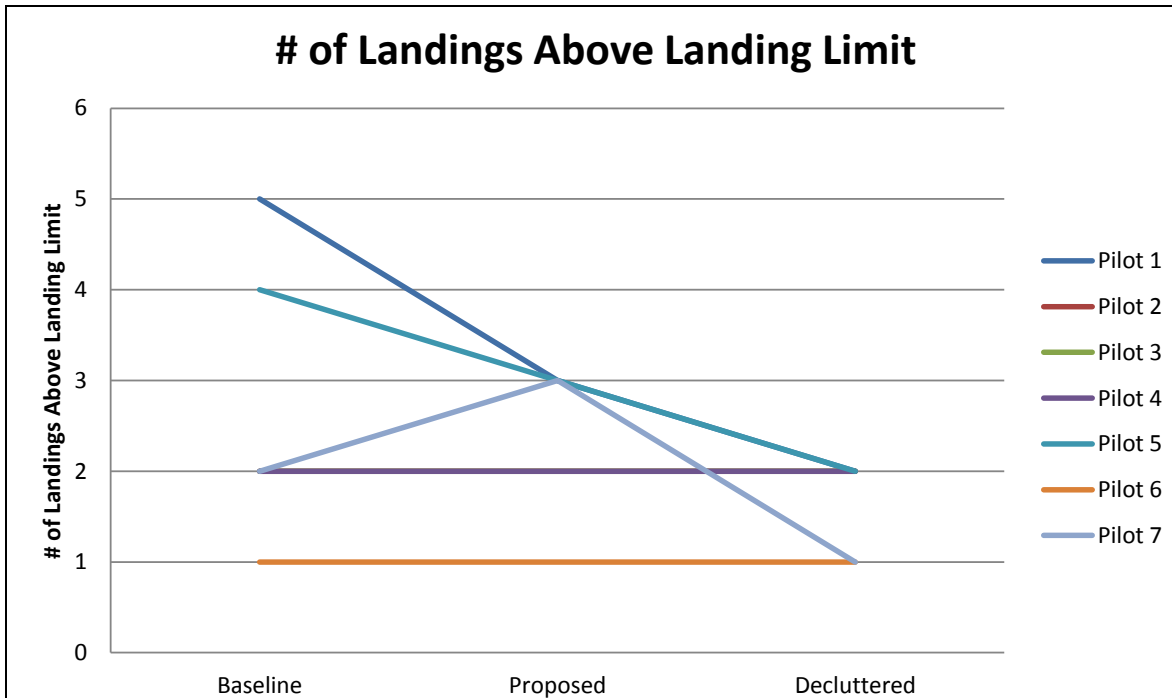


Figure 32. Vertical landing speed by pilot.

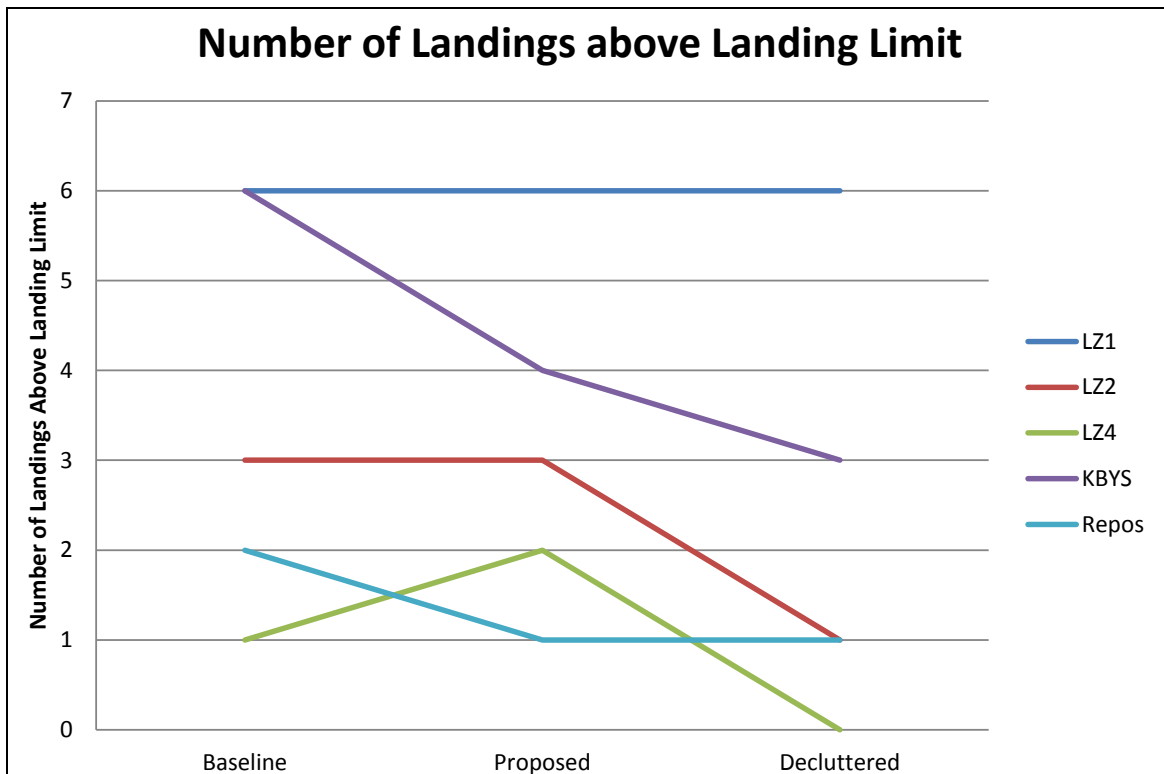


Figure 33. Vertical landing speed by landing site.

The number of rough landings was higher during alpha approaches (LZ1, KBYS) accounting for 31 of a total 45 rough landings. These 31 rough landings during alpha approaches were out of 42 possible alpha approach landings for an overall rough landing percentage of 73.8% as compared to 14 out of 63 non-alpha approach landings for an overall percentage of 22.2%.

3.4.3 Horizontal Deviation During LZ1 Approach

The (x, y) position of the aircraft during the approach to LZ1 while in brownout conditions was plotted, and a linear regression was performed. The coefficient of determination for this linear regression was calculated to give a measure of the linearity of the approach in the (x, y) plane. Larger coefficients of determination would indicate a more linear approach, indicating a more controlled approach. The coefficients of determination by pilot for LZ1 can be seen in figure 34. Two of the pilots had large oscillations when close to the ground during one of the runs which were not representative of an alpha approach. The graph of the remaining pilots data can be seen in figure 35.

A one-way repeated measures ANOVA indicated no significant change in coefficient of determination, $F(2, 6) = 0.72, p > 0.05$, suggesting that the new symbology did not result in a straighter path during alpha approach. The ANOVA for the reduced group of pilot data did not show a significant change either, $F(2,4) = 2.18, p > 0.05$.

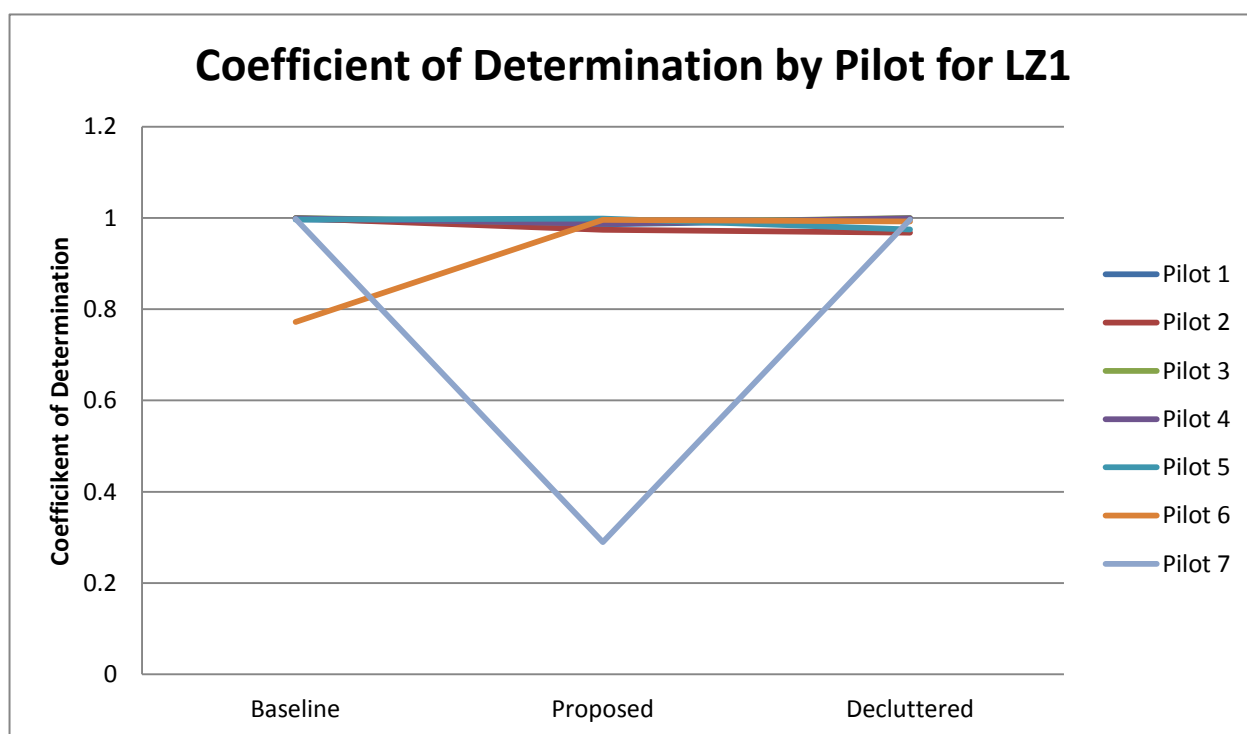


Figure 34. Coefficient of determination by pilot for LZ1.

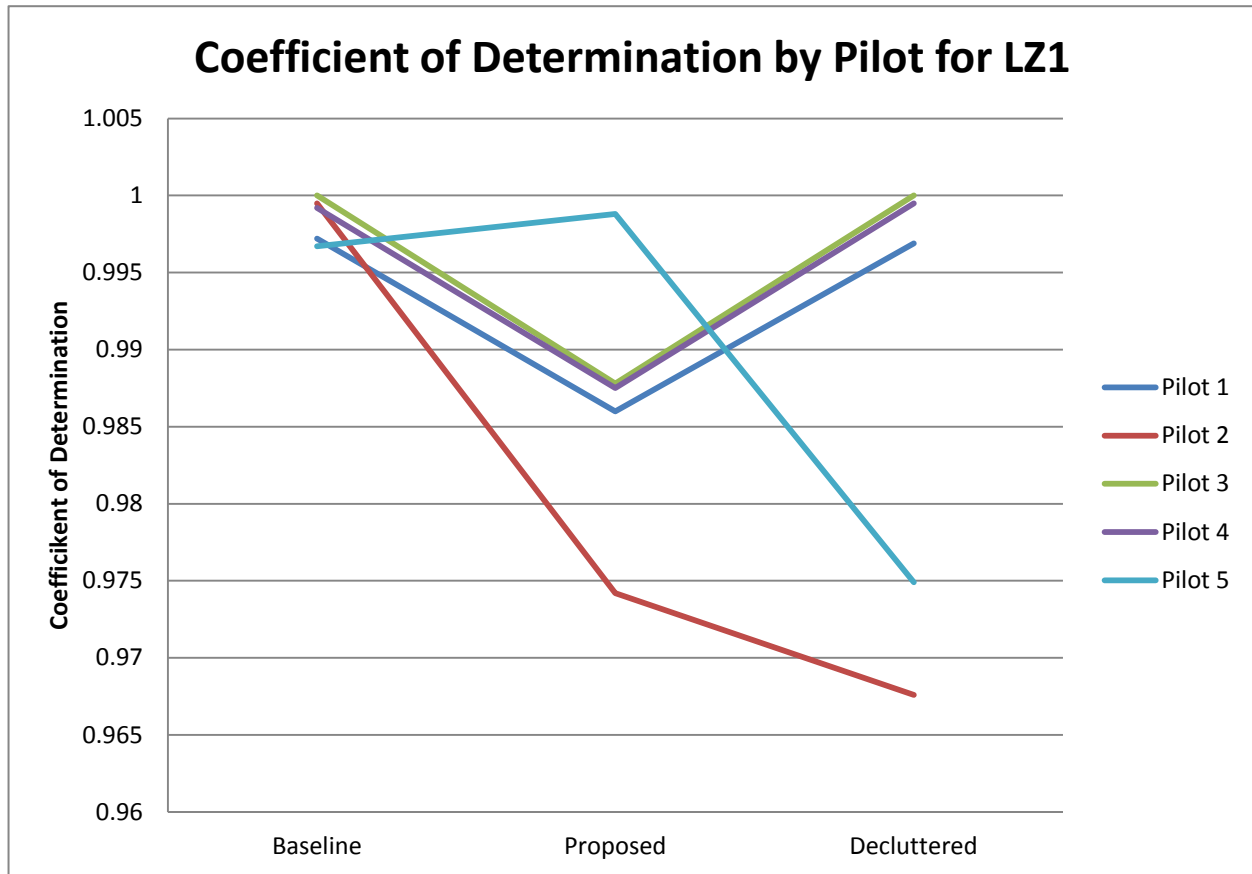


Figure 35. Coefficient of determination by pilot for LZ1 with outliers removed.

3.4.4 Horizontal Deviation During Vertical Descent

The (x, y) position of the aircraft during descent at LZ4 while in brownout conditions was recorded, and the mean position was calculated. From this, the average linear deviation in feet during the descent was calculated to provide a measure of how close the approach was to perfectly vertical. Lower values indicate that the approach was more vertical. A graph of the results by pilot can be seen in figure 36.

A one-way repeated measures ANOVA indicated no significant change in the coefficient of determination, $F(2, 6) = 2.36$, $p > 0.05$, suggesting that the new symbology did not result in a more vertical descent. Overall, deviation during vertical descent was not large in any condition.

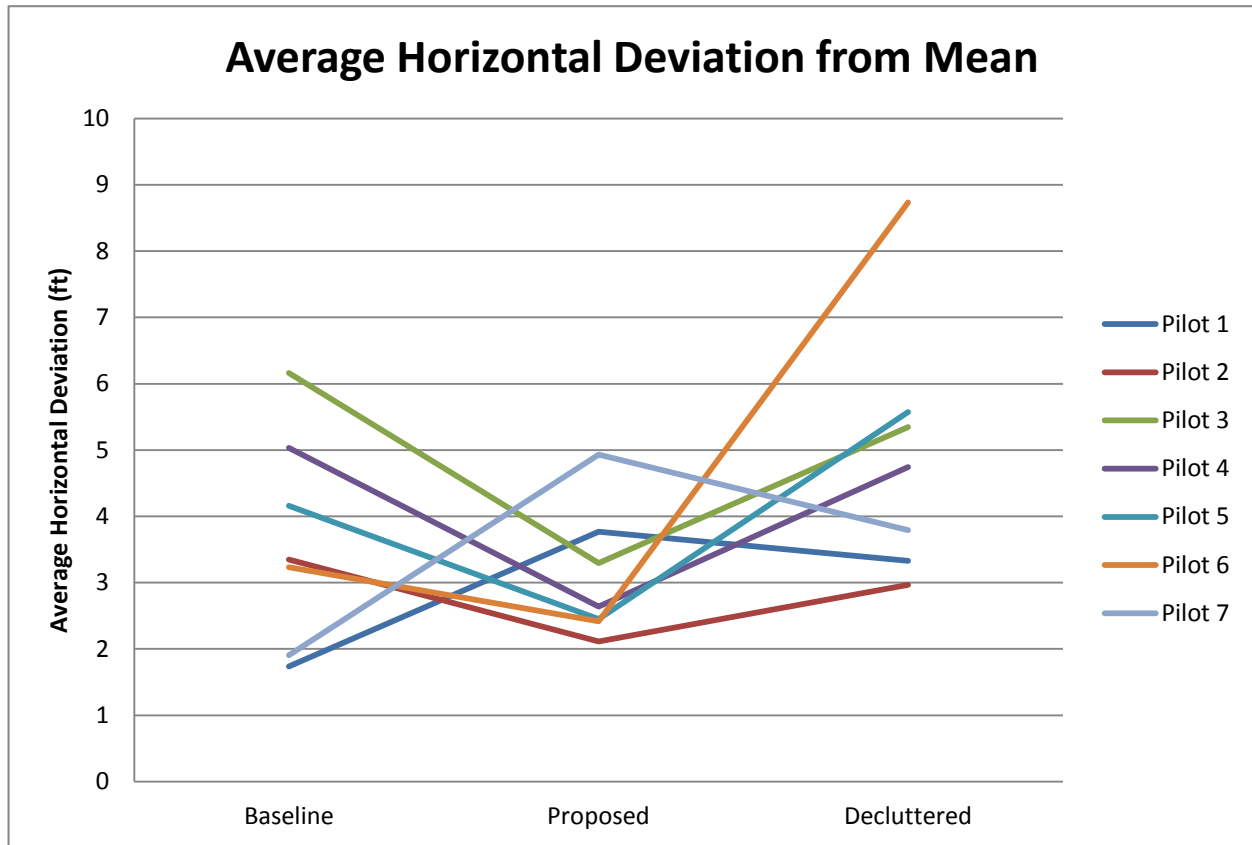


Figure 36. Horizontal deviation from mean during vertical descent at LZ4.

Additionally, the deviation in feet from the planned landing zone location and the actual location at which the aircraft was landed was calculated. Results can be seen in figure 37. A one-way repeated measures ANOVA indicated a significant change in coefficient of determination, $F(2, 6) = 4.30$, $p = 0.039$, indicating that the new symbology allowed the pilot to more accurately land the aircraft at the desired landing site.

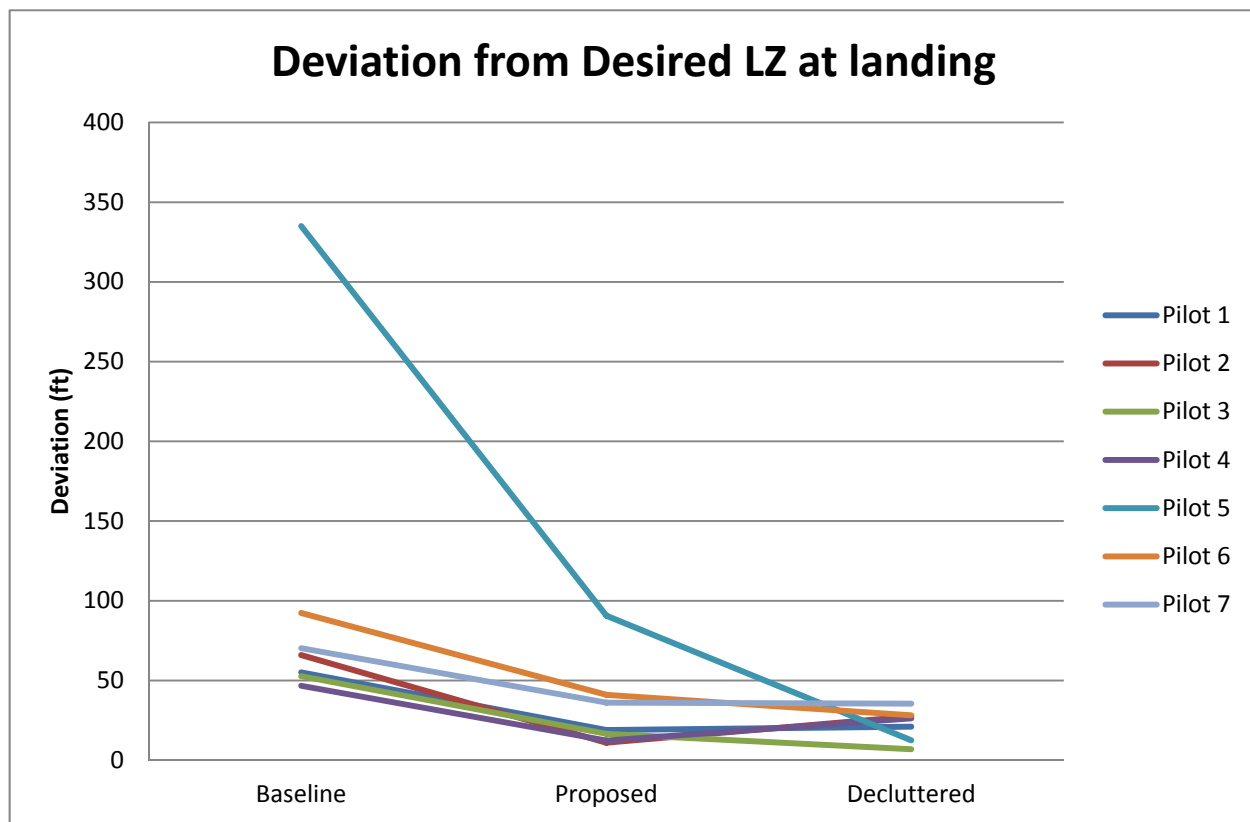


Figure 37. Horizontal deviation from desired LZ4 at landing.

3.4.5 Vertical Deviation During Sling Load Operations

The average deviation in feet around the desired 15-ft hover height for the sling load operation was calculated. The beginning and end of the 15-ft hover were determined by the analyst's judgment. Where possible, the inflection point in the altitude data, which indicated a controlled stop to the descent, was used as the start point, and the last point before ascent was used as the end point. Lower values indicate that the aircraft altitude was maintained closer to the desired 15-ft level during this section of the operation. The average error by pilot can be seen in figure 38.

A one-way repeated measures ANOVA indicated a significant change in coefficient of determination, $F(2, 6) = 5.71$, $p = 0.018$, indicating that the new symbology allowed the pilot to more accurately control the vertical position of the aircraft during a hover.

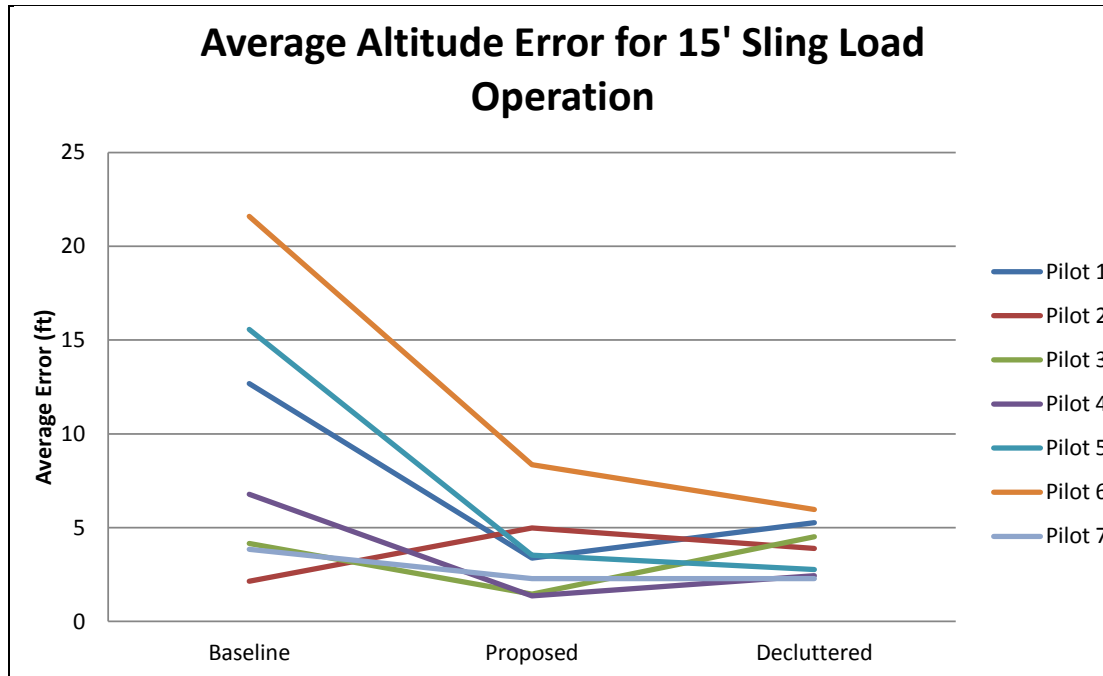


Figure 38. Average altitude error for 15-ft sling load operation.

3.5 Training Assessment

Pilots were surveyed on their perceptions of the effectiveness of the training session conducted on day one of the CSWG demonstration. The mean overall training assessment rating for all participants was 3.6, i.e., the mean response was between the “agree” and “strongly agree” responses. Higher scores are better. The training results are further detailed by each question in figure 39.

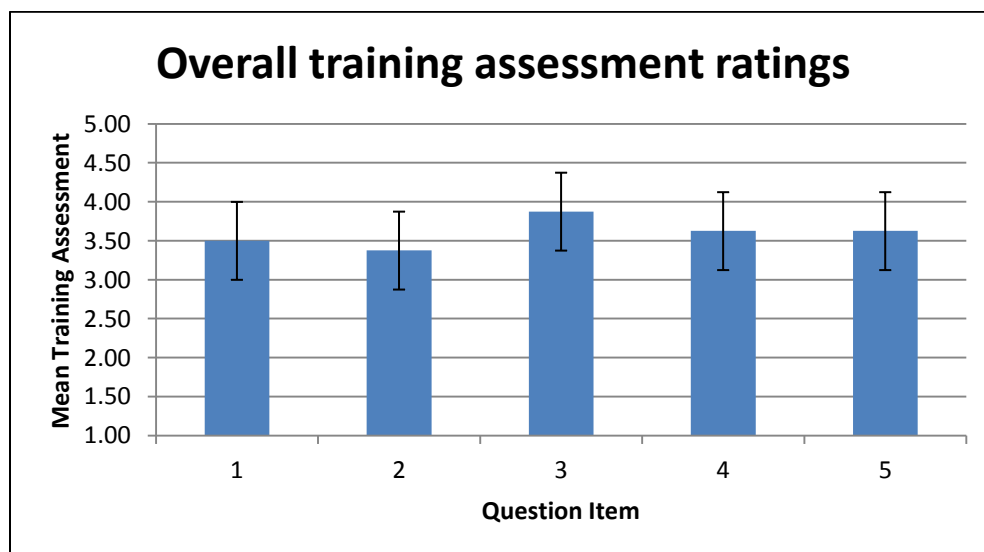


Figure 39. Overall training assessment ratings by question.

4. Discussion

4.1 Visual Gaze

Acknowledging the small sample size, the data pattern for fixation durations, which can be viewed as short processing cycles, indicate that, for the evaluation maneuvers considered as a whole, the display type had no consistent effect on pilots' fixations. As for the implications to workload, the two proposed displays did not increase workload as compared to the existing display. This is an important metric for "doing no harm" when designing new user interfaces. No reduction in workload for the fixation duration measure was found for the new display designs. This may be attributed to the lack of training with this particular simulator, or the small sample size.

The interfixation angle was reduced in the proposed and decluttered conditions compared to the baseline condition. This is most likely due to the smaller visual search areas needed to gather the required information to control the aircraft. These data indicate a pattern showing that pilots moved their eyes shorter distances for the new display designs. This effect, though not statistically significant in likelihood due to the small sample size, is most likely due to the reduced scan area of the new displays as compared to the baseline. Although the following figure is not a representation of the entire sample see figure 40, this illustrates the expected and exhibits in at least one instance, a scanning pattern that would be performed in a real aircraft in which pilots have more experience with the proposed HSDH symbology.

As can be seen in the error bars for fixation frequency (figure 12), pilots exhibited a high degree of individual differences for fixation frequency patterns. This participant variability is an obvious mitigating factor for identifying a decrease in fixation frequency and a concomitant increase in information gained per fixation.

The blink frequency was reduced in the proposed and decluttered conditions compared to the baseline condition. A tenuous inverse relationship has been shown to exist between blink frequency and workload measures. Blink frequency may indeed be associated with higher visual workload which, in the case of the proposed and decluttered HSDH, may be due to the higher information availability in a smaller scan area. Additionally, blinks are often conducted before saccades. With a significant reduction in interfixation angle, it is likely that the opportunity to perform efficient blinks was not presented as frequently with the proposed and decluttered HSDH displays.

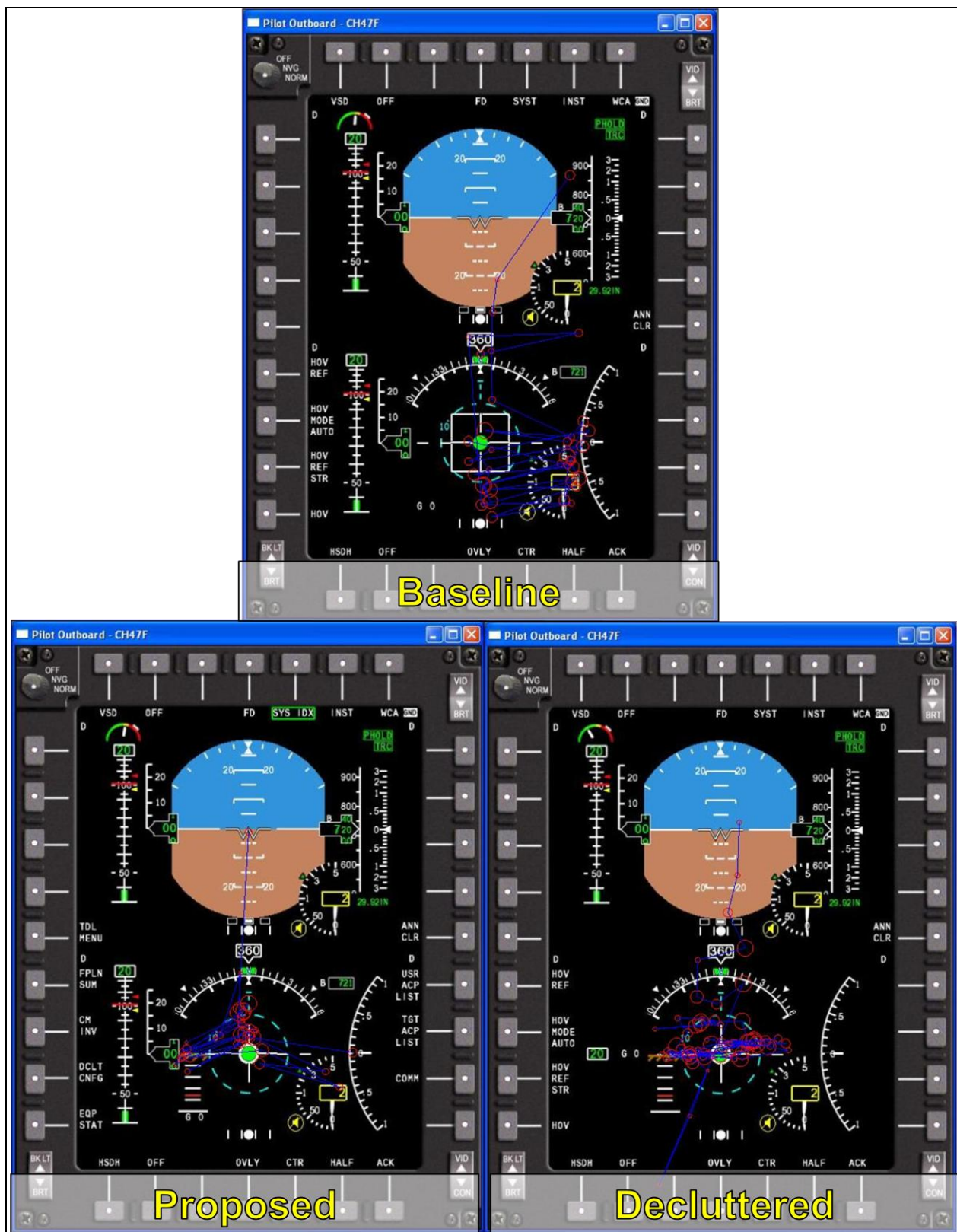


Figure 40. Comparison of common visual scanning patterns.

The percentage of visual gaze in the HSD AOI was increased in the proposed and decluttered conditions compared to the baseline condition, while the percentage of visual gaze in the VSI AOI was decreased. This is most likely caused by the relocation of vertical speed information to the vertical speed tape, which is located in the HSD AOI. The percentage of visual gaze in the RAD ALT AOI stayed relatively constant, which correlates well with pilots comments during After Action Review that they were often looking for the RAD ALT Digital Readout to get the exact height in feet. Pilots' visual gaze patterns were advantageously restructured with the two new HSDH displays. Ocular motion was concentrated in a smaller area of the HSD AOI. This means that a pilot's total visual attention was released from necessary gaze patterns over to the VSI.

The collective results from the HSD and RAD ALT gaze analyses favorably support the proposed HSDH design. During the collective after action review, pilots openly discussed the synergy between the proposed HSD and RAD ATL. Pilots recommended locating the digital RAD ALT value closer to the HSD horizontal acceleration cue. The concentrated gaze on the new HSD displays and continued reliance on RAD ALT indicate that new useful information for the controlling the horizontal disposition of the aircraft was available to pilots in the proposed and decluttered HSDH displays. Please see appendix F for overall percentages of time spent gazing at the RAD ALT, HSD, and VSI across each display condition.

The observed gaze patterns for the VSI AOI mean that a pilot significantly saves both time and ocular distance travelled on the proposed HSDH designs as compared to the baseline HSDH. For statistical significance, note that the error bars in figure 16, defined as confidence intervals, for the proposed and decluttered HSDH do not overlap with the baseline HSDH error bars.

4.2 Workload

From the perspective of pilot mental workload, the various HSDH displays performed similarly across different mission tasks. Overall average subjective workload scores ranged in the 3 to 4 range, well below the critical value of 6. The workload scores indicated that the evaluation maneuvers were challenging, but did not detrimentally overwhelm pilots' available spare workload capacity. Each of the HSDH displays supported the successful control of the aircraft and successful execution of the mission tasks. Furthermore, no single display showed an advantage toward reducing workload for any of the particular mission tasks or subtasks.

4.3 Crew Station Pilot-Vehicle Interface

The PVI questionnaire indicated a high degree of pilot acceptance for the proposed and decluttered HSDH displays. The overall crew station PVI questionnaire responses for all PVI dimensions indicated that the pilots selected between "very easy/very effective" and "somewhat easy/somewhat effective" on average. For the baseline HSDH, the overall mean pilot report for establishing and maintaining hover fell nearest to the somewhat effective category.

For the proposed HSDH, the overall mean pilot report for establishing and maintaining hover fell nearest to the very effective category. The overall mean pilot rating for supporting landing fell nearest the very effective category. For comparison ratings between the proposed HSDH and the baseline HSDH, the mean pilot report for overall mission effectiveness was in favor of the proposed HSDH. For comparison ratings between the proposed HSDH and the baseline HSDH, the mean pilot report for maintaining situational awareness was in favor of the proposed HSDH.

For the proposed decluttered HSDH, the overall mean pilot report for establishing and maintaining hover fell nearest to the very effective category. The overall mean pilot rating for supporting landing fell at the very effective category. For comparison ratings between the proposed decluttered HSDH and the proposed HSDH, the mean pilot report for overall mission effectiveness was in favor of the proposed decluttered HSDH. For comparison ratings between the proposed decluttered HSDH and the baseline HSDH, the mean pilot report for maintaining situational awareness was in favor of the proposed decluttered HSDH. For comparison ratings between the proposed decluttered HSDH and the baseline HSDH, the mean pilot report for overall situational awareness was in favor of the proposed decluttered HSDH. For comparison ratings between the proposed decluttered HSDH and the proposed HSDH, the mean pilot report for maintaining situational awareness was in favor of the proposed decluttered HSDH.

4.4 Aircraft Control Measures

The absolute error of the aircraft when landing at a particular LZ was greatly reduced due to the changes incorporated in the Proposed HSDH. The horizontal speed guidance encourages the pilot to bring the aircraft directly to the landing zone or hover reference point. The pilots in this study referred to the changing of the magenta horseshoe to a white circle as “the circle of confidence,” which indicated to them that they were at a controlled hover at the desired location. This resulted in pilots more accurately locating the aircraft over the desired LZ.

The altitude of the aircraft was more controlled during hover operations due to changes incorporated in the proposed HSDH. The hangman gives the pilot an easy to follow reference in order to adjust his torque to establish or maintain a specific altitude. The movement of this hangman provides immediate feedback to the pilot on any variation in altitude.

The transverse landing speed as a function of display type was not statistically significant. This may be partly due to the fact that the transverse landing speeds were not particularly great due to the nature of the various landings. Landings that were mostly vertical did not have much variance in any direction and were generally controllable. It may be more valuable to study the amount of landings that were over a certain safe transverse velocity value in a larger set of landings to determine if the new display types were helpful in landings that for one reason or another were not as smooth. The transverse landing speeds tended to be higher on the angled approaches than on the vertical approaches. This may be due to the fact that all horizontal velocities are generally higher on angled approaches.

The number of landings above the landing limit was not statistically significant. This may be due in part to the fact that the pilots were not trying to control for minimum or very slow landing speeds. Furthermore, the difficulty of controlling the torque of aircraft in the simulator may have resulted in overcompensation.

The coefficient of determination for the landing at LZ1 was not statistically significant. This was due to the fact that most of the landings at LZ1 had very little deviation from a straight line path. The consistency of performance indicates that there was not much room for improvement with the proposed displays. The few landings that deviated from a straight line path were large deviations unassociated with the display technology. For instance, the largest deviation came from one pilot when he tried to come to a hover near to the ground at the end of the angled approach even though this maneuver was not part of the mission requirements.

The average deviation from the mean horizontal position during the vertical approach to LZ4 was not statistically significant. The average deviation was relatively small in all attempts, indicating that this type of approach is well controlled in the baseline HSDH condition, leaving little room for improvement.

4.5 Training Assessment

Participants rated the overall training effectiveness with a mean of 3.6 on a 1–4 scale, where 4 represented “strongly agree” regarding the effectiveness of the training. The training was well received by participants. However, it could have been longer with more pre-test simulator time given to reduce learning and order effects during the demonstration.

5. Recommendations

Within the CSWG demonstration, four lines of evidence converge indicating a high degree of pilot acceptance for the overall design and implementation of the proposed and decluttered HSDH displays. Crew gaze analyses indicate pilots had reduced scanning extents for the VSI AOI in the proposed and decluttered HSDH as compared to the baseline HSDH. Thus, the new HSDH should reduce visual workload. The smaller footprint of the information required for hover and landing as presented in the new HSDH should aid the pilots when they perform these tasks. Mental workload measures verified the challenging nature of the simulated brownout DVE landing while also recommending the new HSDH displays for consuming slightly less spare workload capacity of the pilots than the baseline display. Aircraft control analyses also recommend the new HSDH designs for effectively supporting the aviating performances of the pilots. Open-ended pilot comments suggested making the horizontal speed cue less aggressive in order to alleviate the abrupt effect associated with the auto-scaling. The comments of pilots also recommend that the RAD ALT digital readout be located near to the vertical speed tape, to

give actual height when the altitude information is needed. Additionally, pilots recommended making vertical speed tape change color only on conditions such as over the landing limit. Unanimously, pilots voted in favor of the immediate implementation of the proposed HSDH display.

6. References

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Appendix A. Demographic Questionnaire

This appendix appears in its original form, without editorial change.

CH-47 Hover Symbolology CSWG Demographic Data Sheet

The information requested on this form will be used only for the purpose of obtaining a profile of those pilots who complete the training and demonstration missions. Your responses will remain anonymous. Names will be dissociated from the reported data. If you are uncomfortable answering any question, please omit it. Any information provided will be used solely as part of the Army Research Laboratory efforts to gather feedback on the CH-47 Hover Symbolology. Thank you in advance for completing the demographic data sheet.

Name: _____ (Please Print)

Confidentiality PIN: _____ Current Unit: _____

Rank: _____ Date of Rank: _____

Your MOS: _____

What is your primary aircraft? _____

Dominant Hand: Right / Left (circle one)

Sight correction while flying: Yes / No Correction type: _____

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Gender: Male or Female

Age Group (years; circle one):

Under 20	40-45
20-24	45 and over
25-29	
30-34	
35-40	

Education Level (circle one):

High School/GED
1-2 yrs college
Associates Degree
Bachelor's Degree
Masters Degree

Service Component (circle one):

Active Army
Reserve
National Guard
Other Service: _____

Military Service Duration (circle one):

2-5 years	15-20 years
6-9 years	20-25 years
10-15 years	Over 25 years

Airframe Experience:

Platform	Qualified	IP Hours	PI Hours	PIC Hours	NVD Hours
CH-47					
Other (name)					
Other (name)					

Appendix B. Bedford Workload Rating Scale (BWRS) Questionnaire

This appendix appears in its original form, without editorial change.

**For Official Use Only
CH-47 HSDH Workload**

Name: _____

Date: _____

1. Crew # _____

2. Which HSDH was used? Baseline Proposed Proposed Decluttered (Circle One)

Workload

3. Refer to the Bedford Workload Rating Scale included in this packet. The Bedford scale employs the concept of spare capacity to measure mental workload. Based on that scale and its descriptions, rate the workload for the flight and mission tasks you performed during the previous mission scenario.

For example, if when Operating the CH-47 you feel that “reduced workload capacity” is an accurate description for your spare capacity on that task, please indicate a ‘5’ in the Bedford Workload Rating Column.

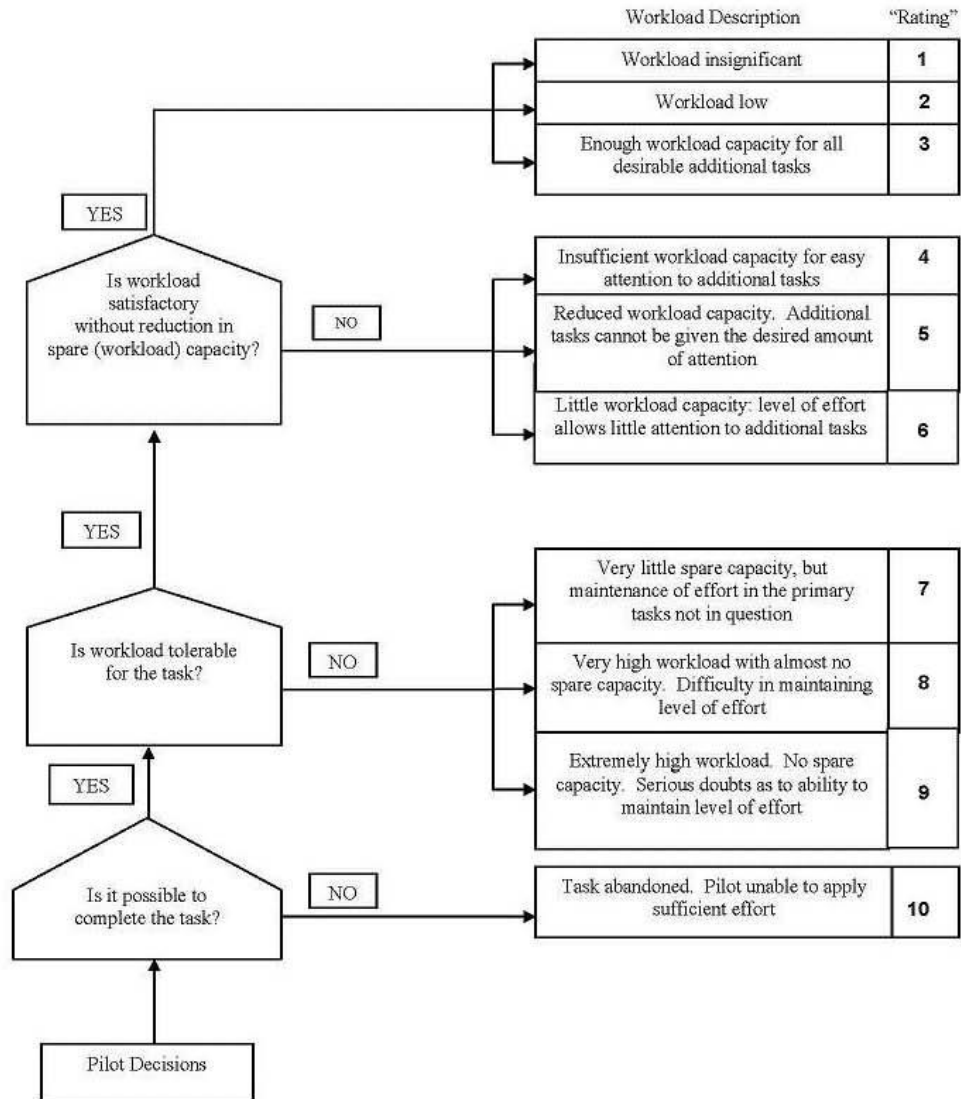
Flight and Mission Tasks	Bedford Workload 1 = Lowest to 10 = Highest
Land at smoke in field (overall)	
Maintain constant approach to desired landing point	
Maintain rate of closure	
Maintain ground track alignment	
Perform a controlled termination to touchdown	
Land at mosque (overall)	
Perform a controlled termination to initial hover	
Perform a controlled descent with minimal drift	
Perform sling load operations (overall)	
Perform a controlled termination to initial hover	
Perform a controlled termination to hookup point	
Land at confined area (overall)	
Perform a controlled termination to initial hover	
Perform a controlled descent with minimal drift	
Relocate landing point (overall)	

**For Official Use Only
CH-47 HSDH Workload**

If you gave a workload rating of '6' or higher for any task, explain why the workload was high for that task:

In the mission you just flew, list any flight and/or mission tasks that you had to ask your crewmember to accomplish because your workload was too high: (Use back for additional space).

**For Official Use Only
CH-47 HSDH Workload**



Appendix C. Pilot Vehicle Interface (PVI) Questionnaires

This appendix appears in its original form, without editorial change.

PILOT-VEHICLE INTERFACE (PVI) QUESTIONNAIRE
Baseline HSDH

1. PIN:

2. Date:

3. Crew # _____

The information provided will be used for the purpose of providing feedback related to the CH-47 Baseline HSDH. Your responses should be based only on symbology used during the mission that you just completed.

PV1. Rate the effectiveness of these Hover Symbology items for supporting the following mission objectives.

Hover Box for Establishing Desired Hover Altitude

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Hover Box for Maintaining Desired Altitude

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Radar Altitude Indicator for Landing

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Radar Altitude Indicator for Establishing Desired Altitude

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Radar Altitude Indicator for Maintaining Desired Altitude

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Hover Vertical Speed Scale for Controlling Vertical Speed

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Overall Baseline HSDH for Establishing/Maintaining Hover

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Overall Baseline HSDH for Landing

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

PV2. Please rate the following properties of the Baseline HSDH

Size/Location of the Hover Box

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Size/Location of the Torque Tape

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Size/Location of the Airspeed Tape

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Size/Location of the Barometric Altitude Tape

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

PV3. Please rate the ease of understanding the color schemes on the Baseline HSDH:

1	2	3	4	(Circle One)
Very Easy	Somewhat Easy	Somewhat Difficult	Very Difficult	

Was your mission task affected by the HSDH color scheme? Yes No (Circle One)

If yes, then please explain:

PV4. Please rate the Baseline HSDH with respect to **overall mission effectiveness**.

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Please rate the Baseline HSDH with respect to **maintaining situational awareness**.

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

PV5.

Please list two (2) things you liked about the Baseline HSDH:

- 1.
- 2.

Please list two (2) things you did not like about the Baseline HSDH:

- 1.
- 2.

Please provide other comments you have not covered elsewhere:

PILOT-VEHICLE INTERFACE (PVI) QUESTIONNAIRE
Proposed HSDH

1. PIN: _____ 2. Date: _____

3. Crew # _____

The information provided will be used for the purpose of providing feedback related to the CH-47 Proposed HSDH. Your responses should be based only on symbology used during the mission that you just completed.

PV1. Rate the effectiveness of these Hover Symbology items for supporting the following mission objectives.

Vertical Speed Indicator Tape for Establishing Desired Hover Altitude

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Vertical Speed Indicator Tape for Maintaining Desired Altitude

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Vertical Speed Indicator Tape for Landing

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Vertical Speed Indicator Tape for Controlling Vertical Speed

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Target Horizontal Speed Guidance Horseshoe for Control Guidance to Desired Hover/Landing Point

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

High Hover Indicator (Hangman) for Controlling Hover Altitude

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Overall Proposed HSDH for Establishing/Maintaining Hover

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Overall Proposed HSDH for Landing

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

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PV2. Please rate the following properties of the Proposed HSDH

Size/Location of the Vertical Speed Tape

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Size/Location of the Ground/High Hover Indicator (Hangman) on Vertical Speed Tape

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Size/Location of the Target Horizontal Speed Guidance Horseshoe

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Scale of the Vertical Speed Tape for Vertical Speed

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Scale of the Vertical Speed Tape for Altitude

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

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PV3. Please rate the ease of understanding the color schemes on the Proposed HSDH:

1	2	3	4	
Very Easy	Somewhat Easy	Somewhat Difficult	Very Difficult	(Circle One)

Was your mission task affected by the HSDH color scheme? Yes No (Circle One)

If yes, then please explain:

PV4.

Please rate the Proposed HSDH **compared to** the Baseline HSDH with respect to **overall mission effectiveness**.

1	2	3	4	
Much More Effective	Somewhat More Effective	Somewhat Less Effective	Much Less Effective	(Circle One)

Comments: _____

Please rate the Proposed HSDH **compared to** the Baseline HSDH with respect to **maintaining situational awareness**.

1	2	3	4	
Much More Effective	Somewhat More Effective	Somewhat Less Effective	Much Less Effective	(Circle One)

Comments: _____

PV5.

Please list two (2) things you liked about the Proposed HSDH:

- 1.
- 2.

Please list two (2) things you did not like about the Proposed HSDH:

- 1.
- 2.

Please provide other comments you have not covered elsewhere:

PILOT-VEHICLE INTERFACE (PVI) QUESTIONNAIRE
Proposed Decluttered HSDH

1. PIN: _____ 2. Date: _____
3. Crew # _____

The information provided will be used for the purpose of providing feedback related to the CH-47 Proposed Decluttered HSDH. Your responses should be based only on symbology used during the mission that you just completed.

PV1. Rate the effectiveness of these Hover Symbology items for supporting the following mission objectives.

Vertical Speed Indicator Tape for Establishing Desired Hover Altitude

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Vertical Speed Indicator Tape for Maintaining Desired Altitude

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Vertical Speed Indicator Tape for Landing

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Vertical Speed Indicator Tape for Controlling Vertical Speed

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Target Horizontal Speed Guidance Horseshoe for Control Guidance to Desired Hover/Landing Point

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

High Hover Indicator (Hangman) for Controlling Hover Altitude

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Overall Proposed Decluttered HSDH for Establishing/Maintaining Hover

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

Overall Proposed Decluttered HSDH for Landing

1	2	3	4	(Circle One)
Very Effective	Somewhat Effective	Somewhat In-Effective	Very In-Effective	

Comments: _____

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PV2. Please rate the following properties of the Proposed Decluttered HSDH

Size/Location of the Vertical Speed Tape

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Size/Location of the Ground/High Hover Indicator (Hangman) on Vertical Speed Tape

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Size/Location of the Target Horizontal Speed Guidance Horseshoe

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Size/Location of the Torque Readout

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Size/Location of the Airspeed Readout

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

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Scale of the Vertical Speed Tape for Vertical Speed

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

Scale of the Vertical Speed Tape for Altitude

1	2	3	4	(Circle One)
Excellent	Good	Poor	Unsatisfactory	

Comments: _____

PV3. Please rate the ease of understanding the color schemes on the Proposed Decluttered HSDH:

1	2	3	4	(Circle One)
Very Easy	Somewhat Easy	Somewhat Difficult	Very Difficult	

Was your mission task affected by the HSDH color scheme? Yes No (Circle One)

If yes, then please explain:

PV4.

Please rate the Proposed Decluttered HSDH **compared to** the Baseline HSDH with respect to **overall mission effectiveness.**

1	2	3	4	(Circle One)
Much More Effective	Somewhat More Effective	Somewhat Less Effective	Much Less Effective	

Comments: _____

Please rate the Proposed Decluttered HSDH **compared to** the Proposed HSDH with respect to **overall mission effectiveness.**

1	2	3	4	(Circle One)
Much More Effective	Somewhat More Effective	Somewhat Less Effective	Much Less Effective	

Comments: _____

Please rate the Proposed Decluttered HSDH **compared to** the Baseline HSDH with respect to **maintaining situational awareness.**

1	2	3	4	(Circle One)
Much More Effective	Somewhat More Effective	Somewhat Less Effective	Much Less Effective	

Comments: _____

Please rate the Proposed Decluttered HSDH **compared to** the Proposed HSDH with respect to **maintaining situational awareness.**

1	2	3	4	(Circle One)
Much More Effective	Somewhat More Effective	Somewhat Less Effective	Much Less Effective	

Comments: _____

PV5.

Please list two (2) things you liked about the Proposed Decluttered HSDH:

- 1.
- 2.

Please list two (2) things you did not like about the Proposed Decluttered HSDH:

- 1.
- 2.

Please provide other comments you have not covered elsewhere:

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Appendix D. Summary of Pilot Vehicle Interface (PVI) Comments

This appendix appears in its original form, without editorial change.

Baseline HSDH

PV-1 Comments

- Hover Box for Establishing Desired Hover Altitude
 - Quite honestly my brain doesn't even identify that it's there.
 - Will be cross checked with RAD ALT.
 - I don't use it because it gives no real idea of where the ground is.
 - Did not look at it for altitude reference, the hover pose was too cluttered when + or – 10 ft of the hover reference altitude the box looked the same.
 - Not analyzed
- Hover Box for Maintaining Desired Altitude
 - Will be crossed checked with RAD ALT
 - Not analyzed
- Radar Altitude Indicator for Landing
 - One of my primary cues
 - Graphic depiction would be better then reading numbers
- Radar Altitude Indicator for Establishing Desired Altitude
- Radar Altitude Indicator for Establishing Desired Altitude
 - Had to use the USI to maintain altitude
- Hover Vertical Speed Scale for Controlling Vertical Speed
 - Combined solution with RAD ALT indicator.
 - I still tend to look at the VSD on the upper half of the MFD, just because that's what is referenced most of the time in forward flight.
 - It's effective however: it creates to large of a scan area.
 - Found myself looking at the vertical speed next to the VSD.

- Overall Baseline HSDH for Establishing/Maintaining Hover
 - Used it for years with great success.
 - Works better with PHOLD
 - The symbology is spread out too far on the MFD, a lot information that wasn't needed.
 - I used the VSD for pitch indication.
- Overall Baseline HSDH for Landing
 - Once an established hover is attained, landing is less difficult than maintaining the hover.
 - VSD used for pitch.

PV-2 Comments

- Size and Location of the Hover Box
 - Hard to rate since I do not utilize.
 - I feel it could be smaller.
 - I don't like it, not as sensitive too. Give me accurate information.
 - Not Analyzed
- Size/Location of the Torque Tape
 - However I do not use tape; I only focus on digits.
 - Location creates too large of a scan area.
 - Didn't look at it for the hovering.
 - I don't look at the tape. Just the number.
- Size/Location of the Airspeed Tape
 - Primarily use ground speed.
 - G speed could be moved up to rod indicator line.
 - Ground speed is what needed when landing in brown-out.
 - Didn't look at it, used the GS lead-out during the transition to hover and for hovering.
- Size/Location of the Barometric Altitude Tape
 - Not used during brown-out.

- Didn't look at it.
- I primarily use RAD ALT.

PV-3 Comments

- Was mission affected by HSDH color scheme? (If yes, please explain)
 - Red is difficult to read at night.

PV-4 Comments

- Overall Mission Effectiveness
 - Scanning the large area can cause drift.
- Maintaining Situational Awareness
 - Would like to have a cue for next way point regardless of Flight Plan sequence.
 - The hover reference was useful because you can see your intended hover point and landing direction.

PV-5 Comments

- Liked
 - Ease of interpretation
 - Regardless of its change or not it is usable.
 - Familiarity of use
 - Drift Vectors
 - Symbol change when changing from PH/TRC
 - Hover reference home plate
 - Hover modes, Auto, Trans, etc.
 - Shows neutral stick position
 - Where hover reference is to you location
 - RAD ALT
 - Velocity vector
 - Auto-scanning was very useful/reduce workload
 - Good organization and density of provided data
 - 10 kt/30 kt ring

- Dislike
 - HUR Box
 - Dog house
 - Too much info when not decluttered
 - Hover dot and the reference about the same size
 - Hover box
 - Airspeed/Distance ring only changes number value when going to the next scale, needs to have color change of size of ring change.
 - Placement of VSI, and GS
 - Too much info not needed for hovering/dust landing
 - Needs more info due to fixation on instruments
 - Altitude Readout
 - Torque Readout
 - Altitude/RAD ALT was somewhat out of “field of view”
 - Found hover cues to be initially counter-intuitive
 - Torque Tape
 - Vertical situating horizon
- Comments not covered elsewhere
 - Adapting to HSDH was not difficult but required more than one practice session. (Subject has no 47F experience or Training)

Proposed HSDH

PV-1 Comments

- Vertical Speed Indicator Tape for Establishing desired Hover Altitude
 - If the tape could be a bit more narrow. It tends to cover up the altitude tick marks.
 - The only time I really devoted any attention to it was when it covered the G/S. Other than that, I was more apt to use the VSI that I am used to.
 - At first, a little hard to decipher rate of descent.

- When I looked at it!
- Vertical Speed Indicator Tape for Maintaining Desired Altitude
 - Went back to old scan once established to the altimeters on the right of MFD
 - Easily noticed change from climb and descent.
 - The color's changing cued me to check my rate of descent.
- Vertical Speed Indicator Tape for Landing
 - Very nice gives a wake-up call. However, may cause Pilots to start reaching for the ground. Power in, power out, in, out
 - When descent was enough to trigger yellow bar, it was difficult to determine rate of descent; yellow bar over-powered scale.
- Vertical Speed Indicator Tape for Controlling Vertical Speed
 - I liked the color change when the rate become excessive.
- Target Horizontal Speed Guidance To Desired Hover/Landing Point
 - Loved It! It forces Pilots to maintain that slow forward movement to target. This feature will also be very useful for pinnacles from an OGE hover with no ground references.
 - Very easy to decipher
 - Was effective if your hover page was active prior to 0.2 Nm, gave me time to react
 - Sometimes, I would remember that I would also have to slide left or right depending on my landing heading.
- High Hover Indicator (Hangman) for Controlling Hover Altitude
 - I don't know if I ever looked at it for landing. Too much info on one small area. Altitude lines hangman vertical speed indicator etc.
 - Hangman bleached out by yellow bar
 - It blended into the background; the V.S. tape overpowered the hangman and washed it out.
 - My eyes seem to just scan over it, but I was more interested in Rad Altitude

- Overall Proposed HSDH for Establishing/Maintaining Hover
 - Less hangman- can we make the brown line go all the way across the HSDH. The long Brown line would stay level, giving you good reference off the HSDH roll indicator, not having to reference USD up top.
- Overall Proposed HSDH for Landing
 - I like knowing where the ground is.

PV-2 Comments

- Size/Location of the Vertical Speed Tape
 - Size is too wide. Would like it narrow.
 - Wish scale was bigger.
- Size/Location of the Ground/High Hover Indicator (Hangman) on Vertical Speed Tape
 - To thick, didn't like it at all. Right handed look right. I want a hard number. Also brown may be hard to interpret under goggles with a dim cockpit. Too much clutter.
 - It blended into the background, needs to be a little larger or maybe not associated with the V.S. tape.
- Size/Location of the Target Horizontal Speed Guidance Horseshoe
 - Keep it.
- Scale of the Vertical Speed Tape for Vertical Speed
 - Again more narrow.
 - Shouldn't cover any other data at any time.
 - Scale hard to read with bar and hangman over top of scale.
- Scale of the Vertical Speed Tape for Altitude
 - Needs to be bigger.
 - Not used; the V.S. tape dominated that portion of my scan.

PV-3 Comments

- Was your mission task affected by the HSDH color scheme? If yes, then please explain.
 - Do not like anything brown in the cockpit color scheme.
 - Color of hangman does not stand out enough; yellow bar very distracting and too bright.

- The yellow color of the V.S. tape was too bright; captured a good portion of my scan.
- I would catch my rate of descent through the corner of my eye and was able to react to the color yellow.
- It informed me of excessive rates of descent.

PV-4 Comments

- Proposed HSDH compared to Baseline HSDH (Overall Mission Effectiveness)
 - I don't know if relearning new cues over and over again is actually counterproductive to building and improving on cues already in place; small additions (i.e., the horseshoes) are good but the need to completely change the VSI is just not needed.
 - Smaller scan.
- Proposed HSDH compared to Baseline HSDH (Maintaining Situational Awareness)
 - For two reasons, the Horseshoe and the vertical speed tape.
 - Nice to know where the ground is.

PV-5 Comments

- Likes
 - Horseshoe
 - Vertical Speed Tape
 - Horseshoe
 - Hover reference
 - Guidance cup
 - Heading bug
 - The horseshoe was very effective.
 - The vertical speed tape
 - VSI color—easy to know if your rate of descent was too high
 - Smaller scan
 - Vertical speed rate
 - Hangman
 - Improved situational awareness (ref: altitude and vertical speed)
 - Better direction to attain/maintain hover point

- VSI tape
- THSG (horseshoe)
- Dislikes
 - Hangman
 - Any brown colors of MFD
 - The “hangman” combined with the VSI/RALT is too much info in one spot to be really useful, that and with the fact that the RALT (proposed) has no hard number with it made it unusable to me. The interpretation of a scaled VSI in a DVE situation causes a lag in response where seeing a hard Gist number on the legacy VSI/RALT takes one less computation for my brain to make resulting in a faster response.
 - VSI tape scale
 - Hangman color
 - Hangman
 - The .2 Nm sequence to hover point was too close to hover point
 - Hangman
 - Ball cup when changing levels. It seemed that I needed to put in more cyclic since the cup changed scales. But the cup started to move much faster.
 - Cup movement when AUTO is selected (didn’t like it snapping into different scales).
 - Found that increased VSI/ground awareness may lead to overcontrolling thrust.
 - Found horizontal speed guidance cues a bit aggressive.
 - CHEAC thrust issues complicated the assessment (control model inaccurate).
 - Horizontal line on horizontal situation
 - Torque tape

Decluttered HSDH

PV-1 Comments

- Vertical Speed Indicator Tape for Establishing desired Hover Altitude
 - The color caught my attraction but I still reverted to legacy VSI for majority of time.
 - Good Location too wide when it’s solid

- Scale hard to read
- Vertical Speed Indicator Tape for Maintaining Desired Altitude
 - Couldn't keep myself from using legacy VSI.
 - I still find myself using altimeter on right.
- Vertical Speed Indicator Tape for Landing
 - Couldn't keep myself from using legacy VSI.
 - Still using Altimeter
 - Yellow bar too bright
 - Gave good visual reference of the rate of descent.
 - The more and more I use this, I am able to pick up on the information.
- Vertical Speed Indicator Tape for Controlling Vertical Speed
 - Great for a wake-call for descent when it turns yellow.
 - Color scheme was good indicator of vertical speed.
- Target Horizontal Speed Guidance To Desired Hover/Landing Point
 - Love it! Many different ways to use it.
- High Hover Indicator (Hangman) for Controlling Hover Altitude
 - Never used the legacy cues are so easy for me to use that I basically disregarded the hangman.
 - I just don't use it. I'm sure it works. I just don't use it.
 - Color needs to stand out more.
 - Used today seemed like it was more pronounced versus the proposed.
 - The scale seems like it would get you close to the height, but a solid number is better for a hover.
- Overall Proposed HSDH for Establishing/Maintaining Hover
 - Very clean picture. Not confusing.
 - Loved the GS location.
 - Could move up the radar alt. readout higher to line up the lateral scan.
 - Very simple.

- Overall Proposed HSDH for Landing
 - Less the hangman.
 - Decluttered had enough info to do the task.

PV-2 Comments

- Size/Location of the Vertical Speed Tape
 - Size and location are really not an issue.
 - Size of scale needs to be bigger.
- Size/Location of the Ground/High Hover Indicator (Hangman) on Vertical Speed Tape
 - Rising ground indicator may be more useful if stretched through the whole HSI.
 - Could be a little more pronounced larger scale or brighter color.
- Size/Location of the Target Horizontal Speed Guidance Horseshoe
- Size Location of the Torque Readout
 - Torque tape decluttered
- Size Location of the Ground Speed Readout
 - Would like to see maybe one or two fonts larger for clarity.
 - Really didn't use.
- Scale of the Vertical Speed Tape for Vertical Speed
 - Still like real numbers.
 - Too small.
- Scale of the Vertical Speed Tape for Altitude
 - Will take some getting use to, but it can be affective. I still prefer a hard number for the altimeter.
 - Too small.

PV-3 Comments

- Ease of understanding the color schemes. If yes, then please explain.
 - Color of hangman blends in—yellow bar bleaches out VSI scale.
 - The yellow arrow for rate of descent, I feel like as soon as it turned into the arrow I needed a lot more thrust than I actually needed.

PV-4 Comments

- Proposed Decluttered HSDH compared to Baseline HSDH (Overall Mission Effectiveness)
 - Simpler the better.
 - Less Hangman.
 - Ease of use not as busy looking.
 - It had enough information I needed for the task.
- Proposed Decluttered HSDH compared to Proposed HSDH (Overall Mission Effectiveness)
 - Because of location of GS.
 - All the info on the left side of HSDH, all easier to read and understand.
- Proposed Decluttered HSDH compared to Baseline HSDH (Maintaining Situational Awareness)
- Proposed Decluttered HSDH compared to Proposed HSDH (Maintaining Situational Awareness)
 - A lot less confusing.

PV-5 Comments

- Likes
 - Simplicity
 - Less confusion
 - GS location
 - Torque location
 - Ground Speed Readout
 - Unnecessary information was removed to ease the scan.
 - I like the TQ readout without the tape.
 - Liked having GS readout on the same side as the TQ and HS Tape
 - Plenty of information
 - Less confusing with too much going on with the page.
 - Less Busy

- Less Redundancy
- Dislikes
 - Hangman
 - Proposed VSI
 - Radar Altitude Readout was too low, for ease of lateral scan can be lined up on the same plane as GS readout.
 - It would be nice to have the RAD ALT on the same side as the TQ and GS.
 - I don't like having RAD ALT scale of VSI on the HSDH
 - Radar Alt scale. The number is all I look at.
 - Horizon line on horizontal situation.

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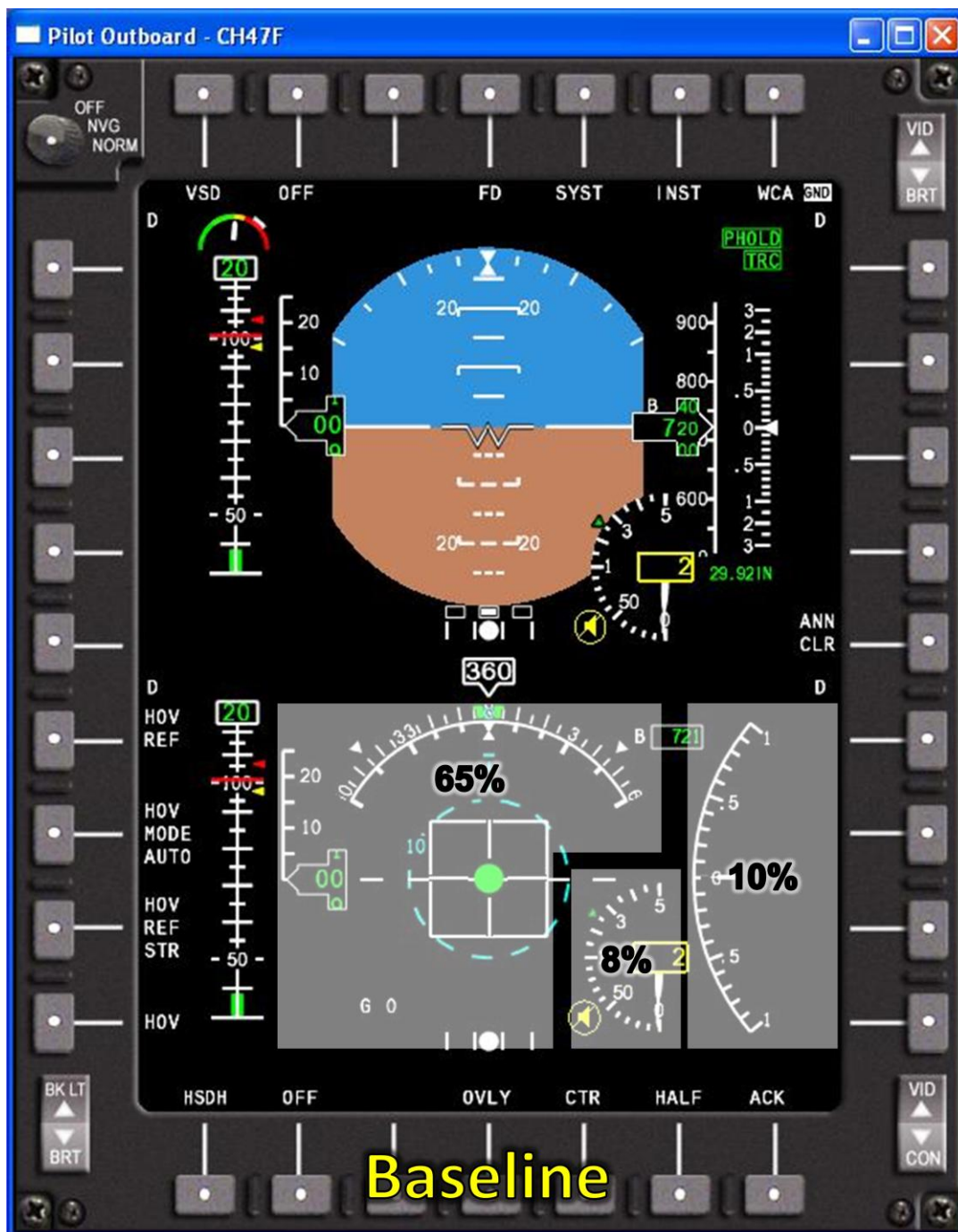
Appendix E. Pilot Training Assessment Questionnaire

This appendix appears in its original form, without editorial change.

The training I received...	Strongly Disagree	Disagree	Agree	Strongly Agree
1. The practice flights were helpful.	1	2	3	4
2. The duration of the training and practice flights was adequate.	1	2	3	4
3. The training covered the important aspects of the new Hover Symbology.	1	2	3	4
4. Overall, the training I received was adequate for the CSWG event.	1	2	3	4
5. I am confident I can fly the CSWG Missions with the information and training provided.	1	2	3	4

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Appendix F. Crew Gaze Analysis



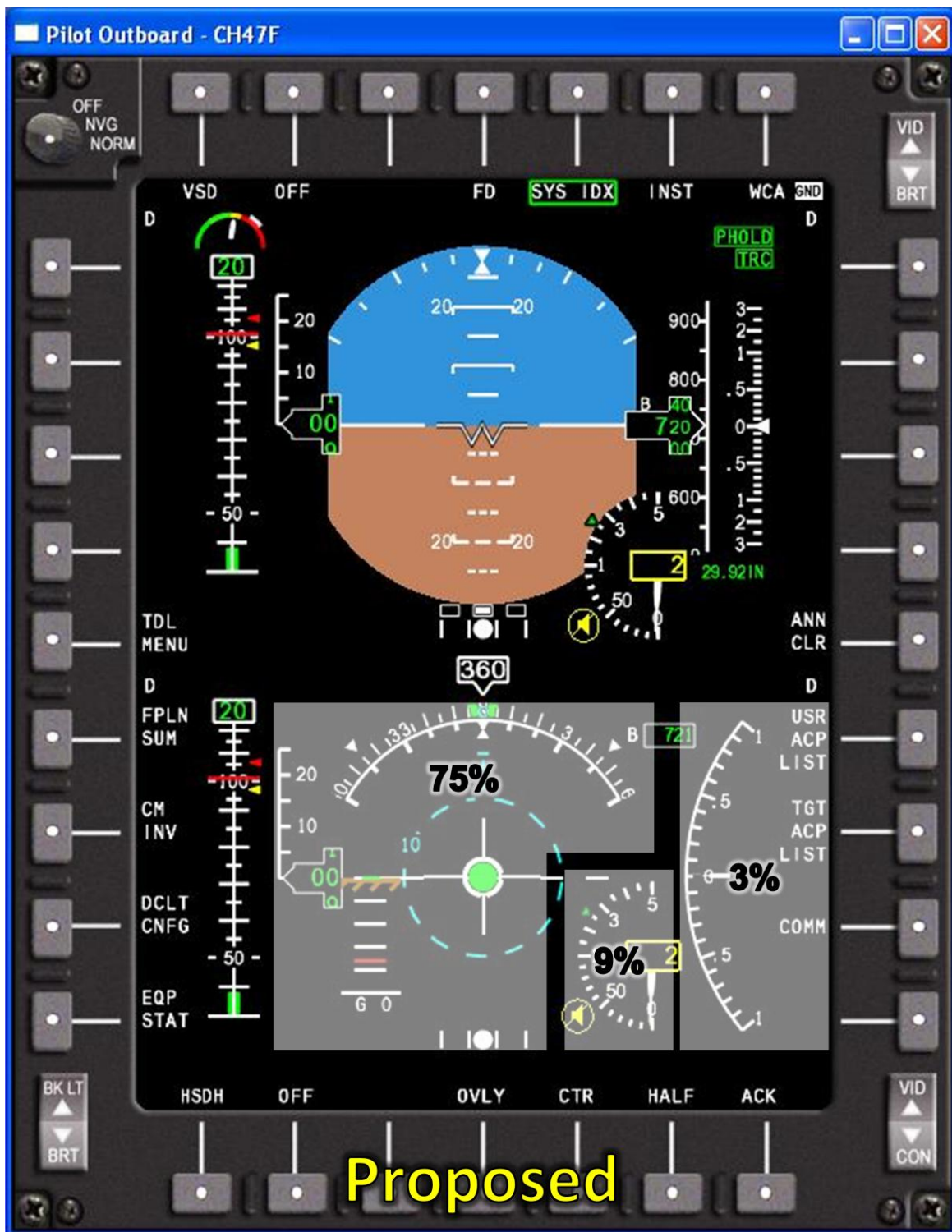


Figure F-2. Pilot visual gaze distribution for proposed HSDH.

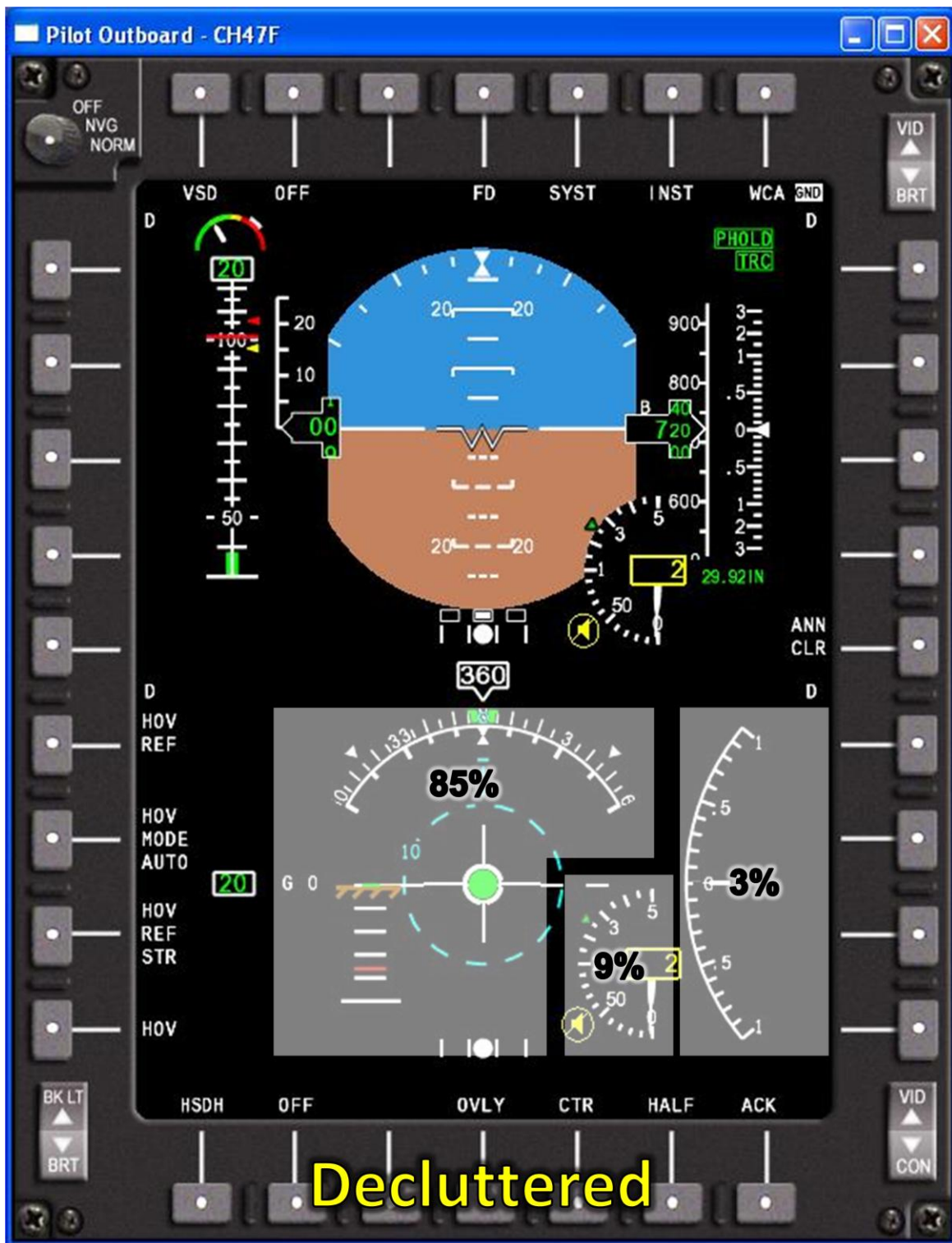


Figure F-3. Pilot visual gaze distribution for decluttered HSDH.

Appendix G. Summary of Training Survey Comments

Positive Comments:

- None Reported

Negative Comments:

- None Reported

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Appendix H. Summary of Bedford Workload Rating Scale Comments

This appendix appears in its original form, without editorial change.

Q: If you gave a workload rating of '6' or higher for any task, explain why the workload was high for that task:

A: Smoke field- That landing area best suits a running landing. No references at all make it more difficult. Mosque- obstacles require controlled drift. Sling loads- Trying to be precise not bang up equipment. Confined area- obstacles

A: Land at Mosque: It was difficult to determine vertical speed and maintain alt./position of hover part. As I looked at VSI I would lose my scan on the altitude and the hover reference.

A: Just know my surroundings. I noticed my right pedal and tried to convert it. But fixation on trim -ball oversaturated the maneuvers. Hover symbology was not in my mind.

A: Field- No references, Pilot knows he will hit dust making the anticipation higher for the landing. Confined Area- Tough with obstacles everywhere, no PHOLD

A: New scan: Reading and understanding the cues was difficult.

Q: In the mission you just flew, list any flight and/or mission tasks that you had to ask your crewmember to accomplish because your workload was too high: (Use back for additional space).

A: Co-Pilot called out Airspeed and Altitude as part of normal crew coordination.

A: Normal Crew interaction

A: Normal Crew Coordination per ATM (Aircrew Training Manual)

A: Normal Crew Coordination call-outs

A: Back me up on RAD ALT during hover operations. I found myself focusing on getting the ball in the cup.

A: Basic Crew Coordination IAW CH-47 Aircrew Training Manual

A: Normal Crew call-outs

A: Normal Crew Coordination IAW Aircrew Training Manual

List of Symbols, Abbreviations, and Acronyms

AAR	After Action Review
AED	Aviation Engineering Directorate
AMRDEC	Aviation and Missile Research, Development, and Engineering Command
ANOVA	Analysis of Variance
AOI	Area of Interest
ASL	Applied Science Laboratories
ATM	Aircrew Training Manual
BHIVE	Battlefield Highly Immersive Virtual Environment
BWRS	Bedford Workload Rating Scale
CAAS	Common Aviation Architecture System
CDU	Control Display Unit
CH-EAC	Cargo Helicopter – Engineering Analysis Cockpit
CI	Confidence Interval
CSWG	Crew Station Working Group
DVE	Degraded Visual Environments
fpm	Feet/Minute
GS	Ground Speed
HFE	Human Factors Engineering
HSD	Horizontal Situation Display
HSDH	Horizontal Situation Display Hover
HSI	Horizontal Speed Indicator
IAW	In Accordance With
IP	Instructor Pilot
KBYS	Bicycle Lake Army Airfield

LZ1	Landing Zone 1
MFD	Multi-Function Display
NTC	National Training Center
PH	Position Hold
PHOLD	Position Hold
PVI	Pilot Vehicle Interface
RAD ALT	Radar Altitude
RALT	Radar Altimeter
SA	Situational Awareness
SME	Subject Matter Expert
SSDD	System Simulation and Development Directorate
TQ	Torque
TRC	Translation Rate Command
TRC	Translation Rate Command
VFR	Visual Flight Rules
VS	Vertical Speed
VSD	Vertical Situation Display
VSI	Vertical Speed Indicator

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