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A Method to Assess the Human Factors Characteristics of Army Aviation Helicopter Crewstations

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14. ABSTRACT

The U.S. Army Research Laboratory, Human Research and Engineering Directorate (ARL HRED) assesses Army Aviation helicopter crewstation design for new and modified aircraft. This report describes the methodologies used to assess crewstation design including: anthropometric modeling; simulation and operational testing to evaluate pilot workload, situational awareness (SA), crew coordination, and pilot-crewstation interface (PCI); anthropometric accommodation; and use of a head and eye tracker to assess visual gaze and dwell times. The methods that ARL HRED uses to assess the human factors characteristics of Army Aviation helicopter crewstations have been successful in identifying and eliminating human factors design problems. To date, over 300 crewstation design issues have been identified and resolved for Army Aviation aircraft. ARL HRED will continue to ensure that Army Aviation crewstations are designed to help pilots perform their flight and mission tasks by using crewstation assessment methods to drive design changes.

15. SUBJECT TERMS

Workload, situation awareness, aviation, human figure modeling, anthropometry, crewstation, Army aviation

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Contents

List of Figures

List of Tables

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1. Purpose

1.1 Background and Purpose

Effective aircrew performance is critical to mission success. Crewstations that are designed to augment the cognitive and physical abilities of aircrews will help minimize pilot workload, enhance situational awareness (SA), enable effective crew coordination, and contribute to successful mission performance. It is vital that crewstations be assessed early and often during development to ensure optimal design.

The U.S. Army Research Laboratory, Human Research and Engineering Directorate (ARL HRED) assesses crewstation design for new and upgraded Army Aviation aircraft. The assessments are conducted to identify and eliminate human factors design problems. The methodology used to assess crewstation design includes: anthropometric modeling; simulation and operational testing, to evaluate pilot workload, SA, crew coordination, and pilot-crewstation interface (PCI); anthropometric accommodation; and use of a head and eye tracker to assess visual gaze and dwell times. This methodology has been used by ARL HRED to help develop all modernized Army Aviation systems, including the AH-64D/E Apache Longbow, UH-60M Blackhawk, CH-47F Chinook, OH-58F Kiowa, and UH-72A Lakota. This report provides an overview of the assessment methodology used to ensure that Army Aviation crewstations are designed to help pilots perform their flight and mission tasks, and summarizes results that were used to drive crewstation design changes.

2. Method

2.1 Anthropometric Modeling and Measurement

ARL HRED developed and maintains a digital model library of Army Aviation aircraft, associated equipment, and newer aircraft designs that are in the conceptual phases. Human factors analysts use the digital model information to compare Army Aviation aircraft and equipment design to current human factors engineering standards. The analysts use the modeling results to assess anthropometric requirements, improve the ergonomic design and functionality of the systems, and reduce analysis timelines. When a physical prototype or first article hardware system is available for evaluation, anthropometric analyses of 10–15 critical human dimension metrics—stature, bideltoid breadth, chest depth, butt-knee length, interpupillary breadth, functional leg length, hand length, hand breadth, thumb tip reach, and sitting eye height (Donelson and Gordon, 1991)—are used to ensure that the participants represent a broad range of the intended user population with respect to human dimensions. For example, sitting eye height would be used to determine if a small female (5^{th} percentile of the target population) could attain the appropriate sitting height for field of view, and still manipulate all required controls and equipment in each reach zone of a newly designed cockpit. In this case, human figure modeling (HFM) and physical measurement would be used to determine whether there are any early limitations with respect to human accommodation.

2.2 Anthropometric Modeling Software

As part of the anthropometric modeling process, ARL HRED uses the Jack[1] HFM software to assess the ergonomic design of aircraft systems. Jack is an interactive tool for modeling, manipulating, and analyzing human and other 3-dimensional (3-D) articulated geometric figures (Badler, Phillips, and Webber, 1993). The software also contains a utility for importing anthropometric data that can be used to build and size the human figure models. This allows the human factors analyst to develop the models to represent a specific user population for whom the equipment is targeted.

Computer-based graphical human figure models have been used to perform ergonomic analyses of workplace designs since the late 1960s (Das and Sengupta, 1995). This method has gained widespread acceptance over the past two decades, as designers have migrated from traditional paper drafting methods to the use of computer-aided design (CAD) software. These HFM programs have proven to be an effective tool for evaluating the physical interaction between the human and the equipment. Figure 1 shows a model of the digitized aviation life support equipment worn by pilots and used to assess crewstation design, along with a small female pilot seated in a UH-60M crewstation and her projected line-of-sight.

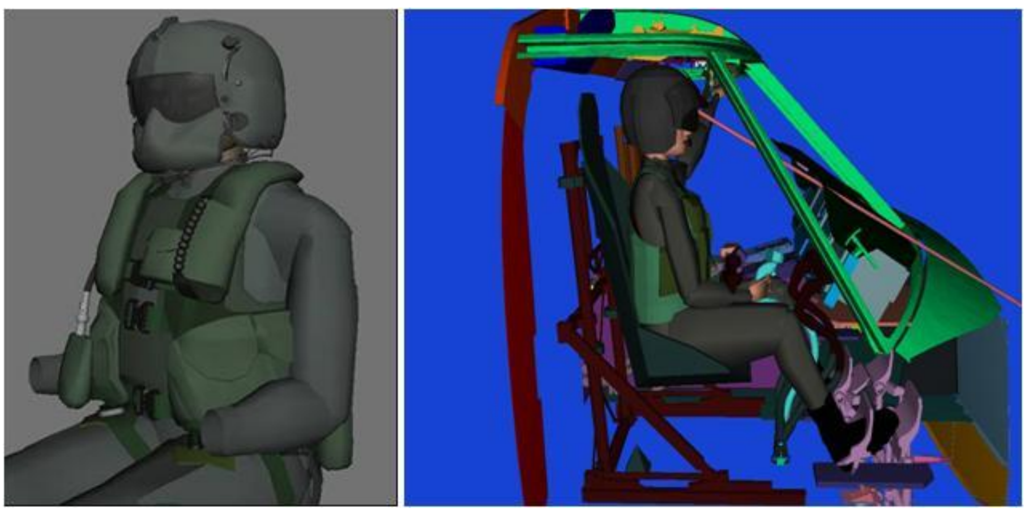

Figure 1. Model of aviation life support equipment and female pilot line-of-sight.

ARL HRED has used HFM to assess anthropometric requirements, visual obstructions, physical reach, flight control envelopes, Air Warrior life support equipment integration, and

[1] Jack is a registered trademark of Siemens.

pilot/equipment space restrictions. We authored a previous report describing past modeling efforts and results (Hicks, Durbin, and Kozycki, 2010).

2.3 Simulation

The simulators used by ARL HRED for crewstation design assessments are engineering simulators. The engineering simulators represent the intended production design and provide a platform for developing and assessing crewstation design, evaluating pilot performance, and assessing crew workload, SA, and crew coordination. Ten pilots with various levels of experience (e.g., 500–4000 flight hours) typically participate in the simulation events. This wide range of experience provides ARL HRED researchers a broad perspective on the design of each crewstation. Pilots use the simulators to perform tasks and fly representative missions (e.g., zone reconnaissance, call-for-fire, troop transport). The simulators are also used to help pilots develop tactics, techniques, and procedures (TTP) and provide limited training for pilots prior to operational testing in the aircraft. Results of the assessments are provided by ARL HRED to the aircraft program managers, Training and Doctrine Command (TRADOC) Capabilities Managers (TCM), Army Test and Evaluation Command (ATEC), Aviation and Missile Research, Development and Engineering Center (AMRDEC), and defense contractors.

Simulators previously employed by ARL HRED include the OH-58F, AH-64D Apache Longbow Risk and Cost Reduction Simulator (RACRS); UH-60M Blackhawk Helicopter Engineering and Analysis Cockpit (BHEAC) and Systems Integration Laboratory (SIL) simulators; CH-47F Chinook Helicopter Engineering and Analysis Cockpit (CHEAC); Armed Reconnaissance Helicopter (ARH) simulator; and the RAH-66 Comanche Engineering Development Simulator (EDS) and Comanche Portable Cockpit (CPC). The simulators contained the hardware and software that emulated the controls, flight characteristics, and functionality of the aircraft. The simulator crewstations replicated the corresponding crewstation in the actual aircraft, allowing each pilot to perform realistic flight and mission tasks. The OH-58F, BHEAC, CHEAC, and ARH simulators were housed in the Battlefield Highly Immersive Virtual Environment (BHIVE). The BHIVE is an immersive environment in which the simulation events are conducted, that provides a high fidelity out the window display. Table 1 lists the aircraft, associated simulator, virtual environment, and assessment/test for which the simulation was conducted.

Table 1. Army aircraft, associated simulator and assessment/test.

Aircraft	Simulator	Assessment/Test
OH-58F	OH-58F - BHIVE	Human Factors Engineering (HFE) #1, 2, 3 Design Assessment
AH-64D	RACRS	Unmanned Aircraft System (UAS) Teaming
ARH	ARH - BHIVE	Common Aviation Architecture System (CAAS) Assessment
CH-47F	CHEAC	Common Aviation Architecture System (CAAS) Assessment
RAH-66	CPC, EDS	Force Development Test and Experimentation (FDT&E) 1
UH-60M	BHEAC, SIL	Early User Demonstration (EUD) Limited User Test (LUT) Limited Early User Evaluation (LEUE)

As examples, figure 2 shows the OH-58F crewstation simulator and figure 3 shows the AH-64D Apache Longbow crewstation simulator.

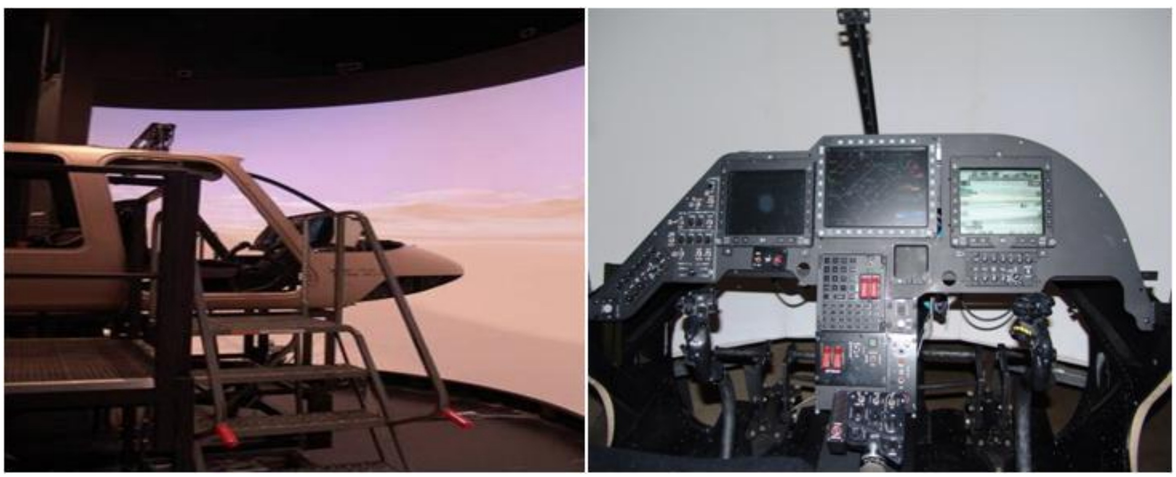

Figure 2. OH-58F crewstation simulator.

Figure 3. AH-64D Apache Longbow crewstation simulator.

2.4 Simulator Sickness Questionnaire

During the simulations, ARL HRED collects and analyzes pilot Simulator Sickness Questionnaire (SSQ) ratings. The ratings are used to identify whether the simulators induced simulator sickness symptoms (e.g., nausea, headache), if the symptoms caused significant discomfort that distracted the pilots during missions, and whether the symptoms contributed to an increase in perceived workload. The ratings were augmented with observations by ARL HRED personnel during the assessments, pilot feedback during post mission interviews, and comparison of SSQ ratings with ratings from other helicopter simulators (table 2). We wrote a previous report describing past simulator sickness data collection efforts and results (Hicks and Durbin, 2011).

Table 2. SSQ scores for simulators.

Simulator	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
ARH (BHIVE)	18.02	21.48	9.28	20.15
OH-58F (BHIVE)	8.86	21.32	18.91	19.23
CH-47F (CHEAC)	12.52	18.48	10.15	16.75
RAH-66 (EDS)	11.84	14.98	4.54	13.25
RAH-66 (CPC)	6.73	15.40	4.32	11.40
UH-60M – LEUE (BHIVE)	6.36	11.81	3.09	9.15
AH-64D – Integrated (UAS) (RACRS)	9.01	7.58	4.64	8.51
UH-60M – EUD (BHIVE)	13.88	6.89	0	8.5
UH-60M – LUT (SIL)	6.36	8.64	2.71	7.49
AH-64D – Non-Integrated (UAS) (RACRS)	3.18	5.05	4.64	4.98

The SSQ (appendix A) was developed by Kennedy, Lane, Berbaum, & Lilienthal (1993) and is a self-reported checklist of 16 symptoms. The 16 symptoms are categorized into three subscales. The subscales are Oculomotor (e.g., eyestrain, difficulty focusing, blurred vision), Disorientation (e.g., dizziness, vertigo), and Nausea (e.g., nausea, increased salivation, burping). The three subscales are combined to produce a Total Severity (TS) score. The TS score is an indicator of the overall discomfort that the pilots experienced during the mission (Johnson 2005).

To analyze the SSQ data, the symptom severity scores are calculated. The first step is to sum the values for each symptom (e.g., eyestrain, nausea). The values are coded by a specific number corresponding to symptom severity. A value of 0 equals “no symptom”, a value of 1 corresponds to “slight”, a value of 2 is “moderate”, and a value of 3 equals “severe”. Each symptom severity subscale score is calculated by summing the values of each subscale and then multiplying each individual sum by a conversion factor. The TS score is calculated by summing each subscale and multiplying by a total severity factor. A higher score indicates more severe symptoms and an increased likelihood of simulator induced sickness. Table 3 categorizes the TS scores as proposed by Kennedy (2002). Table 2 gives the SSQ scores for the engineering simulators used by ARL HRED.

Table 3. Categorization of SSQ Total Scores.

SSQ Total Score	Categorization
0	No symptoms
<5	Negligible symptoms
5–10	Minimal symptoms
10–15	Significant symptoms
15–20	Symptoms are a concern
>20	A problem simulator

2.5 Head and Eye Tracker

To help assess crewstation design, pilots wear a head and eye tracker to record visual gaze and dwell times during missions conducted in the simulators. Recording visual gaze and dwell times can help identify improvements that need to be made to crewstation design. For example, if pilots spend an excessive amount of time viewing the crewstation displays, this can indicate that the displays contain information that requires too many steps (e.g., button pushes, interpretation) to retrieve. The data are augmented with observations by ARL HRED personnel during the assessments, pilot feedback during post-mission interviews, and comparisons of eye tracker data with findings from other helicopter simulators. Figure 4 shows the eye tracker mounted onto a pilot's helmet. Table 4 shows outside/inside cockpit visual gaze times for the AH-64D, OH-58F and ARH, and UH-60M simulators during visual flight rules (VFR) conditions. We authored a previous report describing head and eye tracker data collection efforts and results (Hicks, Jessee, and Durbin, 2012).

Figure 4. Mounted eye tracker.

Table 4. Simulator comparison data.

Simulator (Attack/Recon)	Seat	Outside Cockpit	Inside Cockpit
AH-64D – Integrated UAS (RACRS)	Co-Pilot	6%	94%
	Pilot	75%	25%
AH-64D – Non-Integrated UAS (RACRS)	Co-Pilot	3%	97%
	Pilot	75%	25%
AH-64D – non-UAS (RACRS)	Co-Pilot	3%	97%
	Pilot	75%	25%
ARH (BHIVE)	Co-Pilot	7%	93%
	Pilot	61%	39%
OH-58F (BHIVE)	Co-Pilot	7%	93%
	Pilot	63%	37%
Simulator (Cargo/Lift)	**Seat**	**Outside Cockpit**	**Inside Cockpit**
UH-60M – EUD (BHEAC)	Co-Pilot	---	---
	Pilot	72%	28%
UH-60M – LEUE (BHEAC)	Co-Pilot	26%	74%
	Pilot	61%	39%
UH-60M – LUT (SIL)	Co-Pilot	28%	72%
	Pilot	86%	14%

2.6 Assessment of Pilot Workload, Situation Awareness, and Crewstation Design

ARL HRED uses a battery of rating scales and techniques to assess pilot workload and SA during missions. A common definition of pilot workload is “the integrated mental and physical effort required to satisfy the perceived demands of a specified flight task” (Roscoe, 1985). Assessing pilot workload is important because mission accomplishment is related to the mental and physical ability of the crew to effectively perform their flight and mission tasks. If one or both pilots experience excessively high workload while performing flight and mission tasks, the tasks may be performed ineffectively or even abandoned. In order to assess whether the pilots are task-overloaded during the missions, the level of workload for each pilot must be evaluated.

SA can be defined as the pilot’s mental model of the current state of the flight and mission environment. A more formal definition is, “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley, 1988). It is important to assess SA because of its potential to directly impact pilot and system performance. Good SA should increase the probability of good decision making and performance by aircrews when conducting flight and mission tasks.

2.6.1 Bedford Workload Rating Scale

The Bedford Workload Rating Scale (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 capacity they feel 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. They perform navigation tasks, communicate via multiple radios, monitor aircraft systems, and assist the pilot on the controls with flight tasks (e.g., maintain airspace surveillance), all 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. The pilots complete the BWRS (appendix B) immediately after each mission to rate the level of workload that they experience when performing flight and mission tasks. The rated tasks are selected because they are estimated to have the most impact on aircrew workload during the missions. The ratings are compared against the workload ratings requirements for the aircraft (as applicable) to determine if the crewstation design is imposing excessive workload on the pilots. Table 5 shows a summary of overall workload averages collected during a sample of simulations and operational tests. The ratings indicate that the pilots typically experienced moderate overall workload.

Table 5. Overall workload averages.

Bedford Workload Ratings - Overall Workload Averages		
System/Test	**Co-Pilot**	**Pilot**
AH-64D – Integrated (UAS)	2.60	2.90
AH-64D – Non-Integrated (UAS)	3.30	2.60
RAH-66 – FDTE 1	3.08	2.90
ARH – CAAS	3.71	3.94
UH-60M – LEUE	3.33	2.98
UH-60M – LUT	2.80	2.58
CH-47F – CAAS	2.66	2.70
OH-58F – HFE #2	3.17	3.00

2.6.2 Situation Awareness Rating Technique

The Situation Awareness Rating Technique (SART) (appendix C) is a multi-dimensional rating scale for pilots to report their perceived SA. The SART was developed as an evaluation tool for the design of aircrew systems (Taylor, 1989) and assesses three components of SA: understanding, supply, and demand. Taylor proposed that SA is dependent on the pilot's Understanding (U) (e.g., quality of information they receive), and the difference between the Demand (D) on the pilot's resources (e.g., complexity of mission) and the pilot's Supply (S) (e.g., ability to concentrate). When D exceeds S, there is a negative effect on U and an overall reduction of SA. The formula SA = U – D – S) is used to derive the overall SART score. The SART is one of the most thoroughly tested rating scales for estimating SA (Endsley, 2000). The pilots complete the SART immediately after each mission to rate the level of SA that they perceived while performing the mission. Additionally, pilots rate their perceived level (high-low) of SA of battlefield elements (e.g., location of enemy units or other aircraft). These data provide ARL researchers information on how well the pilots perceive the simulation environment and potential threats. The battlefield elements situation awareness questionnaire is completed in conjunction with the SART questionnaire after each mission. Table 6 shows a summary of overall SART score averages collected during a sample of simulations and operational tests. The data indicate that the pilots typically experienced moderate levels of SA.

Table 6. Overall SART averages.

Situation Awareness Rating Technique - Overall Averages		
System/Test	**Co-Pilot**	**Pilot**
AH-64D – Integrated (UAS)	18.40	23.20
AH-64D – Non-Integrated (UAS)	19.00	21.30
RAH-66 – FDTE	21.86	22.40
ARH – CAAS	17.67	17.22
UH-60M – LEUE	26.42	25.25
UH-60M – LUT	28.28	28.22
CH-47F – CAAS	23.83	20.13

2.6.3 Pilot-crewstation Interface Evaluation

PCI evaluations are used to examine the interaction between the pilots and the crewstation interface. The PCI impacts crew workload and SA during a mission. A PCI 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 PCI, the pilots report any problems that contributed to high workload and low SA at the end of each mission. They also complete a lengthy questionnaire (appendix D) at the end of their final mission. The questionnaire addresses usability characteristics of the PCI (e.g., software interface, control reach, and button presses).

2.6.4 Subject Matter Experts

Subject matter experts (SME) observe the missions independently to rate pilot workload and SA, mission success, and levels of crew coordination (appendix E) that they observe during the missions. An SME is typically an experienced pilot that has in-depth knowledge of the aircraft and crewstation being assessed. The ratings provided by the SME are compared to the corresponding test pilot ratings to identify any significant anomalies in perceived levels of workload or SA while interacting with the crewstation.

2.6.5 Pilot Interviews

Pilots are formally interviewed about their performance during after-action reviews (AAR), where the mission events and goal outcomes are discussed. Pilots are also interviewed by ARL HRED researchers informally throughout the test process to gain insights into procedures and to capture any additional comments or perceptions of the test process and general crewstation design. Additionally, pilots complete forms providing recommendations for improvements to the crewstation; their recommendations are addressed in future design iterations.

2.6.6 Data Analysis

Pilot responses to the BWRS, SART, SSQ, and PCI questionnaires are typically analyzed with descriptive statistics to examine means and percentages. Further analysis is conducted using non-parametric statistical tests, such as the Wilcoxon Signed Ranks Test (WSRT), to compare pilot ratings between seating positions (e.g., left vs. right) and aircraft models (e.g., Block II vs. Block III). The WSRT is used to calculate probability values for data comparisons and statistical significance. Eye tracker data is usually summarized into areas of interest (AOI) segments to determine the amount of heads-down time pilots have while operating the system. Finally, SME and pilot interview feedback are analyzed to provide additional information about trends or anomalies.

2.6.7 Operational Testing

In the final stages of crewstation development, operational tests are conducted to verify design requirements and ensure the crewstation is ready for fielding. ARL HRED participates in operational tests and typically collects the same data as was collected during the simulations. This provides a historical assessment of pilot performance and crewstation design. Results from the operational test are compared to the simulations to ensure improvements have been made to the crewstation design and to identify new issues.

3. Summary

The methods that ARL HRED uses to assess the human factors characteristics of Army Aviation helicopter crewstations have been successful in identifying and eliminating human factors design problems. To date, over 300 crewstation design issues have been identified and resolved for Army Aviation aircraft. Workload, PCI, and SA data collected during testing have been used to improve the crewstation interface. Examples include software improvements to crewstation displays, such as enhanced functionality and presentation of display pages to pilots, improved color-coding of battlefield graphics, reduced number of button presses to display information, enhanced readability of display map pages, and improved presentation of aircraft operational limits (figure 5). Anthropometric measurements, eye tracker data, and human figure modeling have resulted in crewstation hardware improvements that include modifications to crewstation seats, consoles, and glareshields. These modifications are designed to improve visual access and physical reach to displays and controls, provide improved functionality of flight helmets and helmet-mounted displays, and optimize crewstation switch location and function.

In summary, the benefits to using the crewstation assessment method are (a) iterative crewstation assessments drive continuous incremental improvements, (b) improvements are identified in near real-time which aids rapid modification, (c) identifies crewstation design that needs further improvement, (d) issues documented for one aircraft often apply to new or updated aircraft—helps with early identification of issues for new and updated aircraft, and (e) results feed the assessments used by acquisition officials to determine whether to manufacture and field Army Aviation aircraft.

ARL HRED will continue to use and improve the crewstation assessment methodology to meet the demands of the next-generation aircraft for the Army.

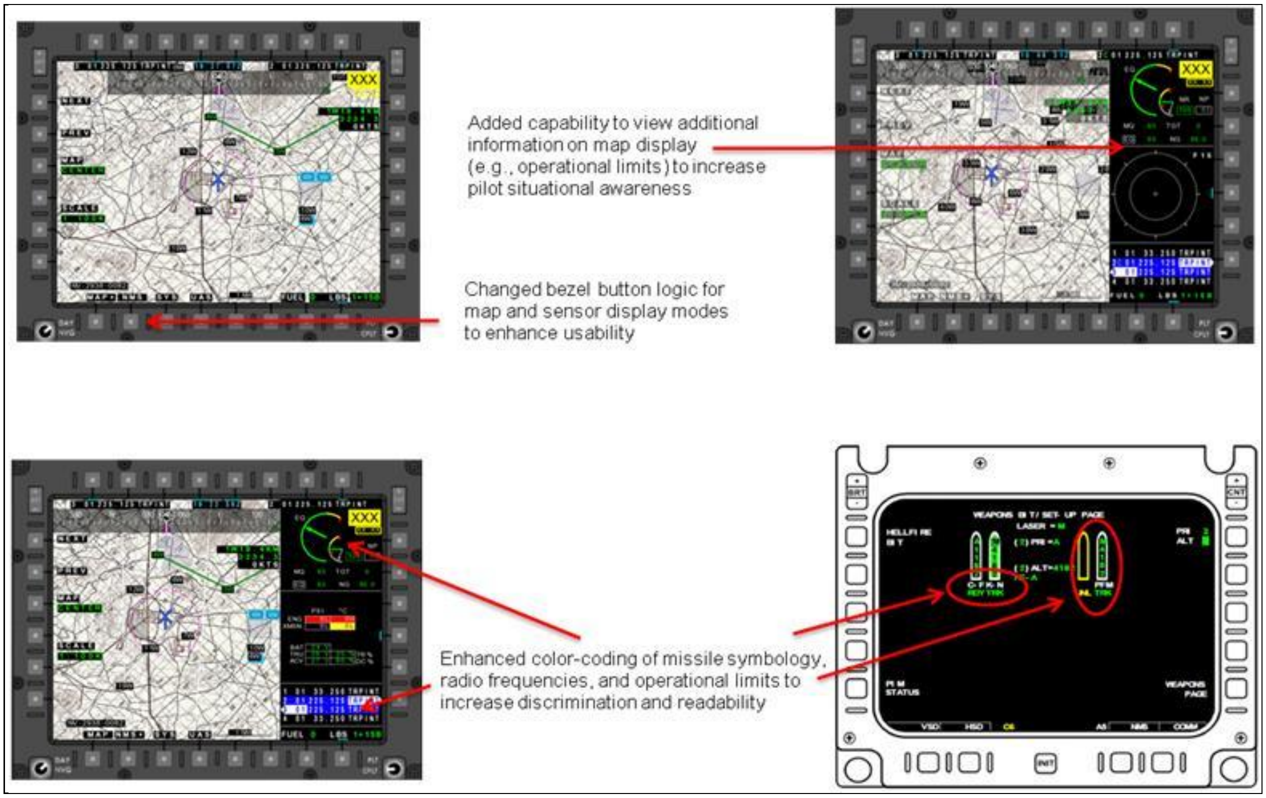

Figure 5. Software improvements to crewstation displays.

4. References

Badler, N.; Phillips, C.; Webber B. *Simulating Humans, Computer Graphics Animation Control*; Oxford University Press: New York, NY, 1993.

Das, B.; Sengupta, A. Computer-Aided Human Modeling Programs for Workplace Design. *Ergonomics* **1995**, *38* (9), 1958–1972.

Donelson, S. M.; Gordon, C. C. *1988 Anthropometric Survey of U.S. Army Personnel: Pilot Summary Statistics*; NATICK/TR-91/040; Natick, MA: U.S. Army Natick RD&E Center. AD A241 952, 1991.

Durbin, D. B.; Havir, T. J.; Kennedy, J. S.; Pomranky, R. A. *Assessment of the RAH-66 Comanche Pilot-Crew Station Interface for the Force Development Test and Experimentation I (FDTE I)*; ARL-TR-3027; U.S. Army Research Laboratory: Fort Rucker, AL, 2003.

Durbin, D. B.; Hicks, J. S. *Human Factors Evaluation of the Armed Reconnaissance Helicopter (ARH) Common Avionics Architecture System (CAAS) Crewstation*; Unpublished report; U.S. Army Research Laboratory: Fort Rucker, AL, 2006.

Durbin, D. B.; Hicks, J. S. *AH-64D Apache Longbow Workload Assessment for Unmanned Aerial System (UAS) Employment*; ARL-TR-4707; U.S. Army Research Laboratory: Fort Rucker, AL, 2009.

Endsley, M. R. *Situation Awareness Analysis and Measurement*; Mahwah, NJ: Lawrence Erlbaum Associates, 2000.

Endsley, M. R. Design and Evaluation for Situation Awareness Enhancement. *Proceedings of the Human Factors Society 32nd Annual Meeting* **1988**, *1*, 92–101.

Gower, D. W.; Lilienthal, M. G.; Kennedy, R. S.; Fowlkes, J. E.; Baltzley, D. R. *Simulator Sickness in the AH-64 Apache Combat Mission Simulator*; USAARL Report No. 88-1; U.S. Army Research Laboratory: Fort Rucker, AL, 1987.

Havir, T. J.; Durbin, D. B.; Frederick, L. J. *Human Factors Assessment of the UH-60M Common Avionics Architecture System (CAAS) Crew Station During the Limited Early User Evaluation (LEUE)*; ARL-MR-0634; U.S. Army Research Laboratory: Fort Rucker, AL, 2005.

Havir, T. J.; Durbin, D. B.; Frederick, L. J.; Hicks, J. S. *Human Factors Assessment of the UH-60M Crew Station During the Limited User Test (LUT)*; ARL-TR-3730; U.S. Army Research Laboratory: Fort Rucker, AL, 2006.

Hicks, J. S.; Jessee, M. S.; Durbin, D. B. *A Summary of Visual Gaze and Dwell Times for Army Pilots During Mission Simulations*; ARL-TR-5900; U.S. Army Research Laboratory: Fort Rucker, AL, 2012.

Hicks, J. S.; Durbin, D. B. *A Summary of Simulator Sickness Ratings for U.S. Army Aviation Engineering Simulators*; ARL-TR-5573; U.S. Army Research Laboratory: Fort Rucker, AL, 2011.

Hicks, J. S.; Durbin, D. *AH-64D Apache Longbow/Video from UAS for Interoperability Teaming Level II*; ARL-TR-4724; U.S. Army Research Laboratory: Fort Rucker, AL, 2011.

Hicks, J. S.; Durbin, D. B.; Kozycki, R. W. *An Overview of Human Figure Modeling for Army Aviation Systems*; ARL-TR-5154; U.S. Army Research Laboratory: Fort Rucker, AL, 2010.

Johnson, D. M. *Introduction to and Review of Simulator Sickness Research*; Research Report 1832; U.S. Army Research Institute for the Behavioral and Social Sciences: Arlington, VA, 2005.

Kennedy, R. S.; Lane, N. E.; Berbaum, K. S.; Lilienthal, M. G. Simulator Sickness Questionnaire: An Enhanced Method For Quantifying Simulator Sickness. *The International Journal of Aviation Psychology* **1993**, *3* (3), 203–220.

Kennedy, R. S.; Drexler, J. M.; Compton, D. E.; Stanney, K. M.; Lanham, D. S.; Harm, D. L. Configural Scoring of Simulator Sickness, Cybersickness, and Space Adaptation Syndrome: Similarities and Differences. In *Virtual and Adaptive Environments: Applications, Implications, and Human Performance*; Hettinger, L. J., Haas, M. W., Eds., Mahwah, NJ: Erlbaum, 2002, pp. 247–278.

Minninger, J. E.; Schiller, E. W.; Frederick, L. J. *Assessment of the Pilot-Vehicle Interface for the CH-47F Chinook Common Avionics Architecture (CAAS) Cockpit*; Unpublished report; U.S. Army Research Laboratory: Redstone Arsenal, AL, 2004.

Roscoe, A. H.; Ellis, G. A. *A Subjective Rating Scale For Assessing Pilot Workload In Flight: A Decade Of Practical Use*; Royal Aerospace Establishment, Bedford, UK, 1990.

Roscoe, A. H. *The airline pilots view of flight deck workload: A preliminary study using a questionnaire;* Technical Memorandum No. FS (B) 465; Bedford, UK: Royal Aircraft Establishment. ADA116314, 1985.

Taylor, R. M. Situational Awareness Rating Technique (SART): The Development of a Tool for Aircrew Systems Design. *Proceedings of the NATO Advisory Group on Aerospace Research and Development (AGARD) Symposium on Situational Awareness in Aerospace Operations*. AGARD-CP-478, 3/1 - 3/17). Neuilly Sur Seine, France: NATO – AGARD, 1989.

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Appendix A. Simulator Sickness Questionnaire

SSQ Questionnaire

Please indicate the severity of symptoms that apply to you right now by circling the appropriate word.

Symptom	0	1	2	3
a. General discomfort	None	Slight	Moderate	Severe
b. Fatigue	None	Slight	Moderate	Severe
c. Headache	None	Slight	Moderate	Severe
d. Eyestrain	None	Slight	Moderate	Severe
e. Difficulty focusing	None	Slight	Moderate	Severe
f. Increased salivation	None	Slight	Moderate	Severe
g. Sweating	None	Slight	Moderate	Severe
h. Nausea	None	Slight	Moderate	Severe
i. Difficulty concentrating	None	Slight	Moderate	Severe
j. Fullness of head	None	Slight	Moderate	Severe
k. Blurred vision	None	Slight	Moderate	Severe
l. Dizzy (eyes open)	None	Slight	Moderate	Severe
m. Dizzy (eyes closed)	None	Slight	Moderate	Severe
n. Vertigo*	None	Slight	Moderate	Severe
o. Stomach awareness**	None	Slight	Moderate	Severe
p. Burping	None	Slight	Moderate	Severe

* Vertigo is a loss of orientation with respect to vertical upright.

** Stomach awareness is a feeling of discomfort just short of nausea.

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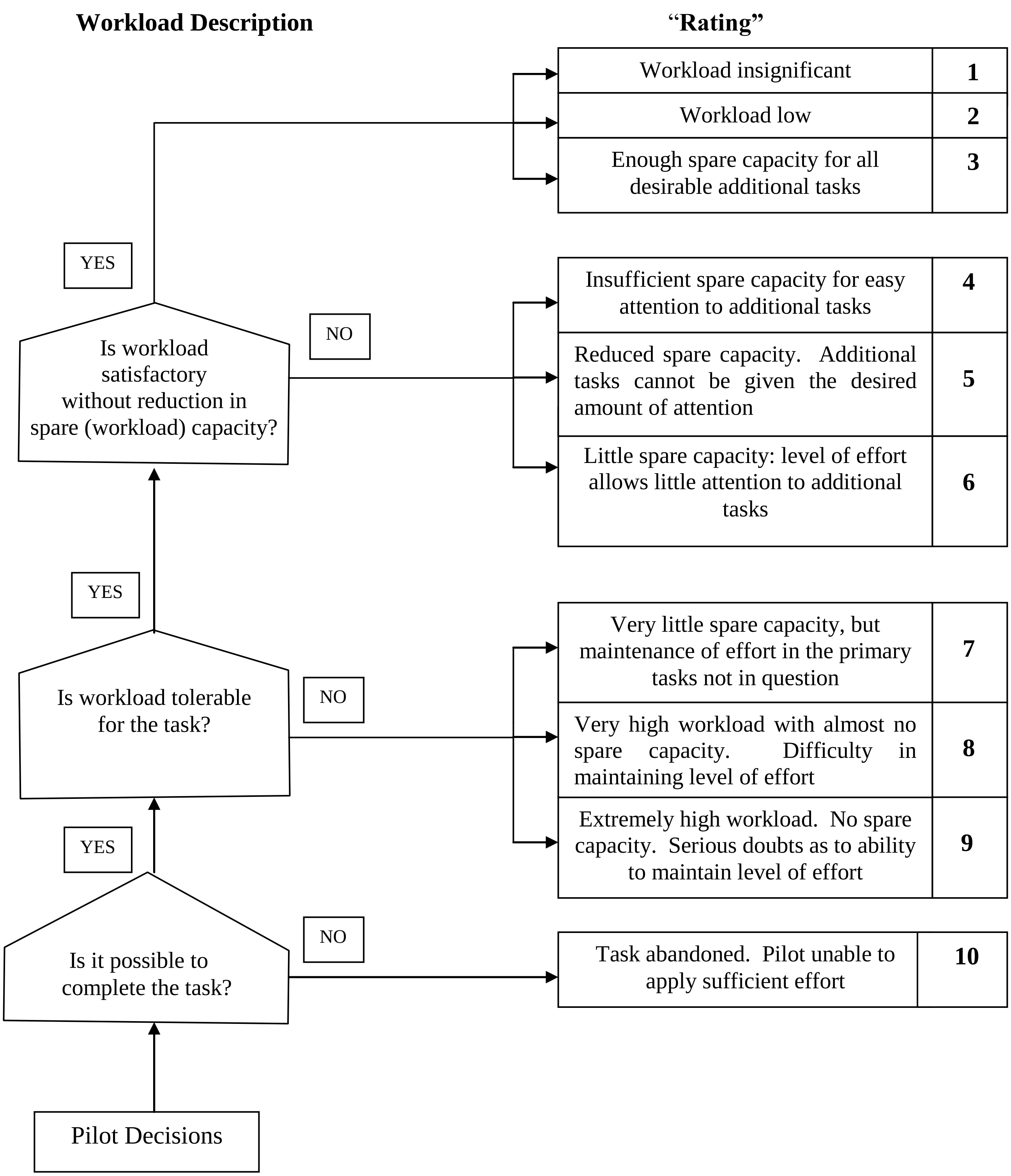
Appendix B. Bedford Workload Rating Scale and Questionnaire

Workload

Rate the workload for the Flight and Mission Tasks you performed (on the 2nd page) using the workload scale below. Place the workload rating in the blank next to each Flight and Mission Task.



Pilot Workload

Rate the workload for the Flight and Mission Tasks you performed during the mission that you just completed. Use the scale provided on the last page of this questionnaire. Place the workload rating in the blank next to each Flight and Mission Task. If you did not perform a task during the mission that you just completed, place an X in the non-applicable (N/A) column.

Task No.	Flight and Mission Tasks	Workload Rating	NA
1026	Maintain Airspace Surveillance		
1028	Perform Hover Power Check		
1030	Perform Hover Out-Of-Ground-Effect (OGE) Check		
1032	Perform Radio Communication Procedures		
1038	Perform Hovering Flight		
1040	Perform Visual Meteorological Conditions (VMC) Takeoff		
1044	Navigate by Pilotage and Dead Reckoning		
1046	Perform Electronically Aided Navigation		
1048	Perform Fuel Management Procedures		
1052	Perform VMC Flight Maneuvers		
1058	Perform VMC Approach		
----	Level of Interoperability (LOI) 2 with UAS		
1066	Perform A Running Landing		
1070	Respond to Emergencies		
1074	Respond to Engine Failure in Cruise Flight		
1140	Perform Nose Mounted Sensor (NMS) Operations		
1142	Perform Digital Communications		
1155	Negotiate Wire Obstacles		
1170	Perform Instrument Takeoff		
1176	Perform Non Precision Approach (GCA)		
1178	Perform Precision Approach (GCA)		
1180	Perform Emergency GPS Recovery Procedure		
1082	Perform an Autorotation		

1182	Perform Unusual Attitude Recovery		
1188	Operate ASE/transponder		
1184	Respond to IMC Conditions		
1194	Perform Refueling / Rearming Operations		
1404	Perform Electronic Countermeasures / Electronic Counter-Countermeasures		
1405	Transmit Tactical Reports		
1407	Perform Terrain Flight Takeoff		
1408	Perform Terrain Flight		
1409	Perform Terrain Flight Approach		
1410	Perform Masking and Unmasking		
1411	Perform Terrain Flight Deceleration		
1413	Perform Actions on Contact		
1416	Perform Weapons Initialization Procedures		
1422	Perform Firing Techniques		
1456	Engage Target with .50 Cal		
1458	Engage Target with Hellfire		
1462	Engage Target with Rockets		
1472	Perform Aerial Observation		
1471	Perform Target Handover		
1472	Aerial Observation		
1473	Call for Indirect Fire		
2010	Perform Multi-Aircraft Operations		
2127	Perform Combat Maneuvering Flight		
2128	Perform Close Combat Attack		
2129	Perform Combat Position Operations		
2164	Call for Tactical Air Strike		
-----	Zone Reconnaissance		
-----	Route Reconnaissance		
-----	Area Reconnaissance		
-----	Aerial Surveillance		
-----	Overall Workload for the Mission		

If you gave a workload rating of ‘5’ or higher for any task, explain why the workload was high for the task.

____

____

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Appendix C. SART Questionnaire

Situation Awareness

Situation Awareness is defined as “timely knowledge of what is happening as you perform your right or left seat tasks during the mission.”

Situation Awareness Rating Technique (SART)	
DEMAND	
Instability of Situation	Likeliness of situation to change suddenly
Variability of Situation	Number of variables which require your attention
Complexity of Situation	Degree of complication (number of closely connected parts) of the situation
SUPPLY	
Arousal	Degree to which you are ready for activity
Spare Mental Capacity	Amount of mental ability available to apply to new tasks
Concentration	Degree to which your thoughts are brought to bear on the situation
Division of Attention	Amount of division of your attention in the situation
UNDERSTANDING	
Information Quantity	Amount of knowledge received and understood
Information Quality	Degree of goodness or value of knowledge communicated
Familiarity	Degree of acquaintance with the situation

Rate the level of each component of situation awareness that you had when you performed 'flying pilot' tasks in the right seat **–or–** 'non-flying' pilot tasks in the left seat during the mission that you just completed. Circle the appropriate number for each component of situation awareness (e.g., complexity of situation).

DEMAND

Instability of situation: Low 1---------2---------3---------4---------5---------6---------7 High

Variability of situation: Low 1---------2---------3---------4---------5---------6---------7 High

Complexity of situation: Low 1---------2---------3---------4---------5---------6---------7 High

SUPPLY

Arousal: Low 1---------2---------3---------4---------5---------6---------7 High

Spare mental capacity: Low 1---------2---------3---------4---------5---------6---------7 High

Concentration: Low 1---------2---------3---------4---------5---------6---------7 High

Division of attention: Low 1---------2---------3---------4---------5---------6---------7 High

UNDERSTANDING

Information quantity: Low 1---------2---------3---------4---------5---------6---------7 High

Information quality: Low 1---------2---------3---------4---------5---------6---------7 High

Familiarity: Low 1---------2---------3---------4---------5---------6---------7 High

Battlefield Elements

Rate the level of situation awareness you had for each battlefield element during the mission? (Place an X in the appropriate column for each battlefield element).

Battlefield Elements	Very High Level of Situation Awareness	Fairly High Level of Situation Awareness	Borderline	Fairly Low Level of Situation Awareness	Very Low Level of Situation Awareness
Location of Enemy Units					
Location of Friendly Units					
Location of Non-Combatants (e.g., Civilians)					
Location of My Aircraft During Missions					
Location of Other Aircraft In My Flight					
Location of Cultural Features (e.g., bridges)					
Route Information (ACPs, BPs, EAs, RPs, etc.)					
Status of My Aircraft Systems (e.g., fuel consumption)					

Describe any instances when you had low situation awareness during the mission:

____

____

Appendix D. PCI Questionnaire

PV1. The following table lists the components of a CAAS crewstation. For each component, indicate whether or not you experienced a problem using the component in a quick and efficient manner during the mission you just completed. Check 'Yes' if you experienced one or more problems. Check 'No' if you did not experience any problems. Check 'Not Used' if you did not use the component during the mission you just completed.

- Multifunction Displays (MFD)
  - Vertical Situation Display (VSD) Yes _____ No _____ Not Used___
  - VSD Hover (VSDH) Yes _____ No _____ Not Used___
  - Horizontal Situation Display (HSD)Yes _____ No _____ Not Used___
  - HSD Hover (HSDH) Yes _____ No _____ Not Used___
  - EOS Yes _____ No _____ Not Used___
  - Digital Map Display (DMS) Yes _____ No _____ Not Used___
  - Warning, Caution, Advisory Display (WCA) Yes _____ No _____ Not Used___
  - Engine Instrument Caution Advisory System (EICAS) Yes _____ No _____ Not Used___
- Control Display Unit (CDU)
  - Initializing CDU Yes _____ No _____ Not Used___
  - Managing GPS / Flight Plan Yes _____ No _____ Not Used___
  - Managing COM, NAV, IFF (CNI) Yes _____ No _____ Not Used___

If you answered "Yes" to any of the questions, describe a) the problems you experienced, b) how much the problems degraded your performance, and c) any recommendation you have for improving the design of the various functional components.

____

____

____

PV3. Please answer the following questions regarding the Multifunction Control Unit (MFCU):

PV3-1. Did the functionality of the directional control and switches on the MFCU perform the actions you expected?

Yes _____ No _____ Not Used ______

PV3-2. Was the sensitivity of the directional control appropriate?

Yes _____ No _____ Not Used ______

PV3-3. Did you experience abnormal hand discomfort while using the MFCU?

Yes _____ No _____ Not Used ______

PV3-4. Did you have adequate space in the cockpit to use the MFCU?

Yes _____ No _____ Not Used ______

If you experienced any problems with the MFCU, please describe the problems in as much detail as you can and make recommendations to correct the problems.

____
____

PV4. Did you have difficulty using any of the switches on the collective or cyclic grips?

Collective Grip	Yes _______	No ________
Cyclic Grip	Yes _______	No ________

If you answered "Yes" for either flight control, please list which flight control and switch(es), and the problems you experienced (e.g., confused two switches due to similar shape, switch too hard to reach).

____
____

PV5. Was there any symbology depicted on the following displays/pages that was difficult to quickly and easily understand, cluttered, or otherwise difficult to use?

Vertical Situation Display (VSD)	Yes ______	No ______
VSD Hover (VSDH)	Yes ______	No ______
Horizontal Situation Display (HSD)	Yes ______	No ______
HSD Hover (HSDH)	Yes ______	No ______
EICAS	Yes ______	No ______
Digital Map System (DMS)	Yes ______	No ______

If you answered "Yes" to any of the questions, please describe a) the display/page, b) the symbology that was difficult to understand, c) how the symbology may have degraded your performance, and d) any recommendations you have for improving the design of the various functional components.

PV6. How would you rate your ability to detect the following occurrences based on the characteristics of the flight displays?

Caution / Advisory (MFD)

1	2	3	4	5
Very Easy	Somewhat Easy	Borderline	Somewhat Difficult	Very Difficult

Warning (Master Warning Panel)

1	2	3	4	5
Very Easy	Somewhat Easy	Borderline	Somewhat Difficult	Very Difficult

Entry into Operational Limits

1	2	3	4	5
Very Easy	Somewhat Easy	Borderline	Somewhat Difficult	Very Difficult

Low Fuel (MFD)

1	2	3	4	5
Very Easy	Somewhat Easy	Borderline	Somewhat Difficult	Very Difficult

If you answered "Somewhat Difficult", or "Very Difficult", please indicate which annunciation you had difficulty detecting, why you may have had difficulty detecting it, and any recommendations to make the annunciation more easily detectable.

PV7. Based on the missions you've conducted this week, what are the top enhancements that should be made to the crewstation to improve pilot performance?

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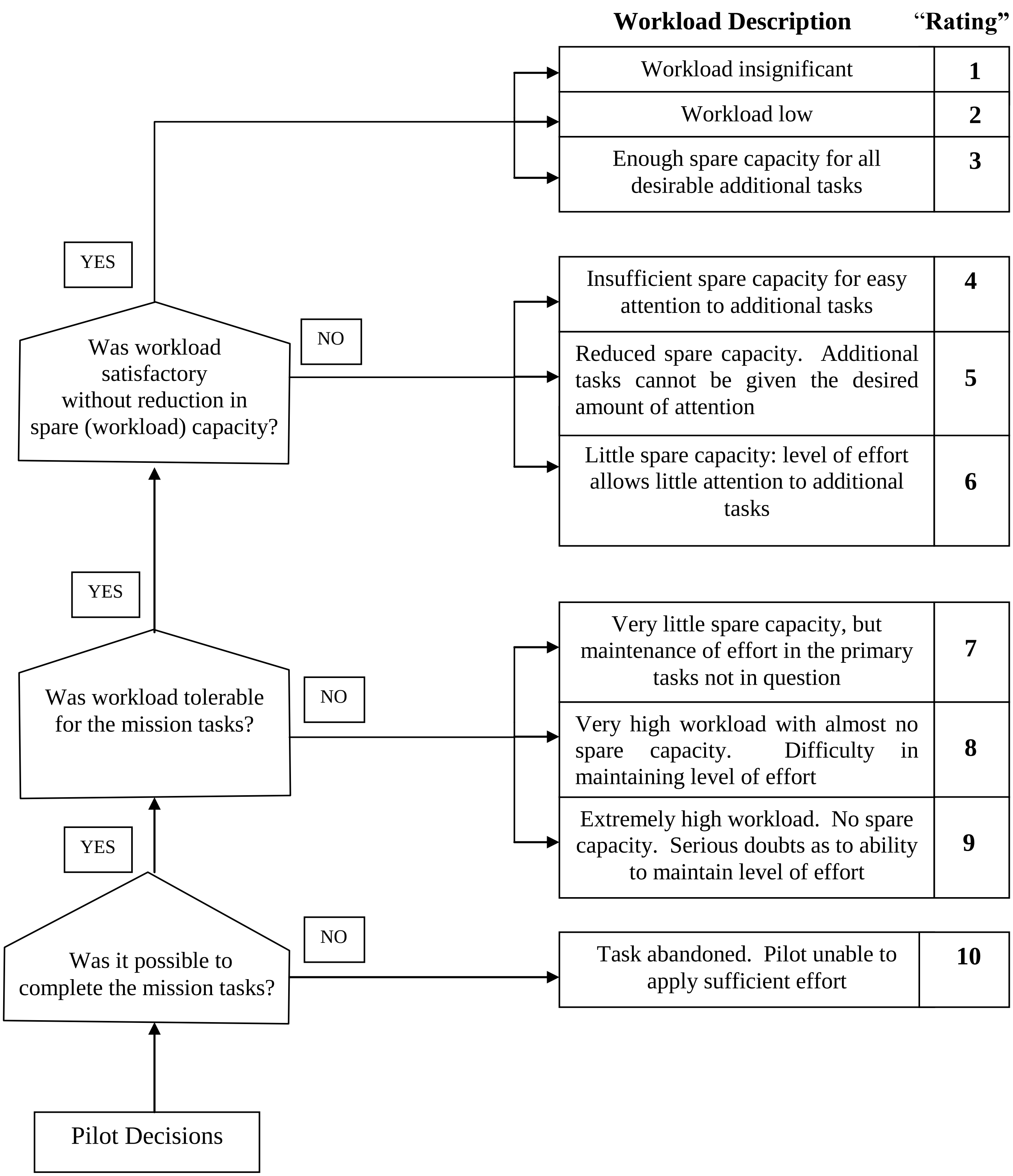
Appendix E. SME Questionnaire

Workload

TSCWL1. Using the workload scale below, rate the overall workload for the crewmembers that you observed (during this mission) on the following page.



TSCWL1. (con't) Place the workload rating in the blank next to each crewmember using the rating scale on the previous page.

Crewmembers	Overall Workload Rating For This Mission
Left Seat	
Right Seat	

If you assigned a workload rating of '6' or higher for either crewmember, explain why:

____

____

TSCWL2. Which crewmember was the 'flying pilot' for most of the mission?

Left seat _____ Right seat _____

TSCWL3. What percentage of the time was the crewmember (left seat or right seat in question above) the 'flying pilot' during the mission?

_______%

TSCWL4. Rate the effectiveness of aircrew coordination as defined by the USAAVNC Aircrew Coordination ETP and TC 1-210.

1	2	3	4	5
Excellent	Good	Average	Needs Improvement	Unacceptable

Situation Awareness

Rating	Check one
Crew was consistently aware of all entities on the battlefield	
Crew was aware of the battlefield with minor or insignificant variation between perception and reality.	
Crew was aware of the battlefield. Variation between reality and perception did not significantly impact mission success.	
SA needs improvement. Lack of SA had some negative effect on the success of the mission.	
Lack of SA caused mission failure.	

Describe any problems that aircrews had with situation awareness.

____

____

List of Symbols, Abbreviations, and Acronyms

3-D	3-Dimensional
AAR	After-Action Review
AMRDEC	Aviation and Missile Research, Development and Engineering Center
AOI	Area of Interest
ARH	Armed Reconnaissance Helicopter
ARL	Army Research Laboratory
ATEC	Army Test and Evaluation Command
BHEAC	Blackhawk Helicopter Engineering and Analysis Cockpit
BHIVE	Battlefield Highly Immersive Virtual Environment
BWRS	Bedford Workload Rating Scale
CAAS	Common Aviation Architecture System
CAD	Computer Aided Design
CHEAC	Cargo Helicopter – Engineering Analysis Cockpit
CPC	Comanche Portable Cockpit
EDS	Engineering Development Simulator
EUD	Early User Demonstration
FDT&E	Force Development Test and Evaluation
HFM	Human Figure Modeling
HRED	Human Research and Engineering Directorate
LEUE	Limited Early User Evaluation
LUT	Limited User Test
PCI	Pilot-Crewstation Interface
RACRS	Risk and Cost Reduction System
SA	Situation Awareness
SART	Situation Awareness Rating Technique
SIL	System Integration Laboratory
SME	Subject-matter Expert
SSQ	Simulator Sickness Questionnaire

TCM	TRADOC Capabilities Manager
TRADOC	U.S. Army Training and Doctrine Command
TS	Total Severity
TTP	Tactics, Techniques, and Procedures
UAS	Unmanned Aircraft System
VFR	Visual Flight Rules
WSRT	Wilcoxon Signed Rank Test

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1 PDF	ARMY G1 DAPE MR BEV KNAPP

ABERDEEN PROVING GROUND

	DIR USARL RDRL HR LAUREL ALLENDER RDRL HRM PAM SAVAGE-KNEPSHIELD RDRL HRS D BRUCE AMREIN

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