Army Research Laboratory

A Summary of Simulator Sickness Ratings for U.S. Army Aviation Engineering Simulators

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14. ABSTRACT

The U.S. Army Research Laboratory Human Research and Engineering Directorate (ARL HRED) uses U.S. Army Aviation engineering helicopter simulators to assess crewstation design for new or modified aircraft. This report summarizes pilot Simulator Sickness Questionnaire (SSQ) ratings for seven engineering simulators. The ratings were obtained from pilots during the assessments and used to identify if the simulators induced simulator sickness (SS) symptoms, if the symptoms caused significant discomfort which distracted the pilots during missions, and contributed to an increase in perceived workload. To assess whether the SSQ ratings provided by the pilots during the assessments were similar or different to ratings obtained in other helicopter simulators, the mean SSQ scores for the evaluated simulators were compared to the mean SSQ scores for several other helicopter simulators. Data collection and analysis of SSQ ratings will continue to play a meaningful role in the assessment and future development of U.S Army Aviation engineering simulators.

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1. Introduction and Background

1.1 Purpose

The U.S. Army Research Laboratory Human Research and Engineering Directorate (ARL HRED) uses U.S. Army Aviation engineering helicopter simulators to assess crewstation design for new or modified aircraft. This report summarizes pilot Simulator Sickness Questionnaire (SSQ) ratings for seven engineering simulators. The ratings were obtained from pilots during the assessments and used to identify if the simulators induced simulator sickness (SS) symptoms, if the symptoms caused significant discomfort which distracted the pilots during missions, and 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.

1.2 Simulator Sickness

SS has been defined as a condition where pilots suffer physiological discomfort in the simulator, but not while flying the actual aircraft (Kennedy et al., 1989). SS symptoms are similar to motion sickness symptoms, but usually result in less gastrointestinal disturbances and less vomiting (Kennedy and Fowlkes, 1992). The characteristics of simulator sickness include nausea, dizziness, drowsiness, and several other symptoms (Kennedy et al., 1989). Researchers agree that SS is likely caused by a mismatch either between the visual and vestibular sources of information about self-motion, or between the sensory information (e.g., acceleration cues) presented by the simulator and the sensory information presented by the primary aircraft that the pilot operates. When the sensory information presented by the simulator does not match the aircraft, the pilot’s nervous system reacts adversely to the sensory mismatch and the pilot begins to experience discomfort. It is important to assess simulator sickness because the discomfort felt by pilots can be distracting. Pilot distraction is one of the operational consequences of simulator sickness listed by Crowley (1987). If pilots are distracted by the discomfort they feel during missions, their performance is likely to suffer. Additionally, the discomfort could influence the perceived levels of workload that the pilots experienced during a mission.

1.3 Simulator Sickness Questionnaire

The SSQ (the appendix) was developed by Kennedy et al. (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).

1.4 Limitations of the SSQ

SS effects can linger for several hours (Johnson, 2007). Having pilots complete the SSQ immediately after a simulation event may fail to capture the after effects that were not immediately obvious. Also, participants may perceive that the appropriate response on the post-mission questionnaire is to report some difference in ratings as compared to the pre-mission questionnaires (Young et al., 2006).

1.5 U.S. Army Aviation Engineering Helicopter Simulators

There are many different types of U.S. Army Aviation simulators being used today. The most basic of these simulators is the Cockpit Procedure Trainer (CPT). The CPT is used to familiarize pilots with standard operational checks and procedures. The most advanced of these simulators is the Full Flight Simulator (FFS). Full flight simulators replicate as much of the aircraft environment as possible and simulate flight motion. There are also many combinations of simulators with varying degrees of fidelity. These simulators include: computer desktop trainers with only joysticks or touch screens and no surrounding cockpits; flight simulators that include a basic monitor, seat, controls, and limited functionality of aircraft control panels; and non-motion flight simulators that include the cockpit, visual displays, and control panels, but provide no motion feedback to the pilots.

The simulators that were used by ARL HRED personnel for the crewstation design assessments were engineering simulators. The engineering simulators were designed to provide a platform for developing and assessing crewstation design, evaluating pilot performance, and assessing crew workload, situational awareness and crew coordination. The simulators were also used to help pilots develop tactics, techniques and procedures and provide limited training for pilots prior to operational testing in the aircraft. The results of the assessments were used to support analyses by the U.S. Army Test and Evaluation Command (ATEC), Training and Doctrine Command (TRADOC) Capabilities Managers (TCM), Aviation and Missile Research, Development and Engineering Center (AMRDEC), ARL HRED, and industry.

The Army Aviation engineering simulators evaluated by ARL HRED were the AH-64D Apache Longbow Risk and Cost Reduction Simulator (RACRS), UH-60M Blackhawk Helicopter Engineering and Analysis Cockpit (BHEAC) - Battlefield Highly Immersive Virtual Environment 1 (BHIVE 1) and Systems Integration Laboratory (SIL) simulators, CH-47F Chinook Helicopter Engineering and Analysis Cockpit (CHEAC) - BHIVE 2 simulator, Armed Reconnaissance Helicopter (ARH) simulator - BHIVE 2, and the RAH-66 Comanche Engineering Development Simulator (EDS) and Comanche Portable Cockpit (CPC). The BHIVE's provide the out-the-window display, sound, and lighting environment for the hardware simulators that are housed inside. 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 appropriate flight and mission tasks. Table 1 lists the aircraft, associated simulator, virtual environment, and assessment/test for which the simulation was conducted

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

Aircraft	Simulator	Assessment/Test
AH-64D	RACRS	Unmanned Aircraft System Teaming
ARH	BHIVE 2	Common Aviation Architecture System Assessment
CH-47F	BHIVE 2	Common Aviation Architecture System Assessment
RAH-66	CPC, EDS	Force Development Test and Experimentation 1
UH-60M	BHIVE 1, SIL	Early User Demonstration Limited User Test Limited Early User Evaluation

1.6 AH-64D Apache Longbow Aircraft Description

The AH-64D Apache Longbow is a twin-engine, tandem-seat attack helicopter. Aircraft armament includes a belly-mounted slewable 30-mm chain gun, Hellfire missiles, and 2.75-in aerial rockets. The aircraft integrated sensor suite includes mast-mounted Longbow fire control radar (FCR) and a nose-mounted modernized target acquisition designation sight/pilot night vision sensor (MTADS/PNVS). The aircraft displays (figure 1) include two multipurpose displays (MPD) in each cockpit, the MTADS electronic display and control in the co-pilot/gunner (CPG) crewstation, and the integrated helmet and display sight system. The pilot (PI) flies the aircraft from the rear crewstation. The aircraft has a flight control system with a fully articulated, four-bladed main rotor system. The flight control system consists of conventional cockpit controls: cyclic, collective, and pedals connected mechanically to hydromechanical actuators for the main and tail rotors; a limited authority automatic stabilization system; and an electrically actuated stabilator.

Figure 1. AH-64D Apache Longbow cockpit and displays.

ARL HRED conducted two pilot workload assessments for unmanned aerial system (UAS) teaming using the RACRS. The assessments evaluated the video from UAS for Interoperability Teaming Level II (VUIT-2) system (Hicks et al., 2009) and the integrated UAS (IUAS) system (Durbin and Hicks, 2009) that were being incorporated into the aircraft. VUIT-2 provided the ability to conduct level II UAS interoperability (receive video from the UAS). The IUAS system provided the aircrew with the capability to conduct level II, level III, and level IV UAS interoperability (receive video from the UAS and control of the UAS sensor and air vehicle).

1.6.1 AH-64D RACRS Simulator Description

The RACRS cockpits used during the VUIT-2 and IUAS simulations consisted of high fidelity aircraft flight controls and displays (figure 2). The CPG used Target Acquisition and Designation System (TADS) Electronic Display and Control (TEDAC) grips to select and control the sensor’s field of view, azimuth, elevation, gain, and level. These controls were also selectable for adjustment of the UAS sensor. The TEDAC and MPD displays were used to monitor the sensor view from the Apache and/or the UAS.

Figure 2. RACRS cockpit simulator.

The simulator visual system was configured to fly the existing Bagram, Afghanistan, visual database (figure 3). This is a geo-specific large gaming area built from satellite acquired high-resolution imagery and detailed terrain relief. It also contained appropriate cultural features to increase realism for the pilots.

Figure 3. Bagram, Afghanistan visual database.

1.7 RAH-66 Comanche Aircraft Description

The RAH-66 Comanche was designed to be a fully integrated, lightweight, twin-engine, two-pilot, advanced-technology helicopter weapons system designed to gain information dominance; shape the battle space; and to conduct decisive operations. System features included lightweight composite airframe structures; protected anti-torque systems; low-vibration, high-reliability rotor systems; reduced radar cross section (RCS) and infrared (IR) signatures; built-in diagnostics and-or prognostics; second generation target acquisition; night vision sensors; and a radar system. The Comanche mission equipment package (MEP) consisted of a turret-mounted cannon, night-vision pilotage system, helmet-mounted display, electro-optical target acquisition and designation system, aided target recognition, and an integrated communication-navigation-identification avionics system. Targeting included a second generation forward-looking infrared (FLIR) sensor, a low-light-level television, a laser range finder and designator, and the Apache Longbow millimeter wave radar system.

1.7.1 RAH-66 CPC and EDS Simulator Description

The CPC (figure 4) and EDS (figure 5) each consisted of two Comanche crewstations arranged in a tandem seating configuration. The front and rear crewstation configurations were identical (figure 4), enabling each pilot to perform all aircrew navigation, communication and weapons employment tasks. The simulators contained the hardware and software that emulated the controls, flight characteristics, and most of the functionality of the proposed Comanche production aircraft. The EDS was a full motion simulator and the CPC was a fixed-base simulator. The EDS motion was the only significant difference between the simulators. The EDS and CPC were used by ARL HRED to assess the crewstation design during the RAH-66 Force Development Test and Experiment 1 (Durbin et al., 2003).

Figure 4. CPC simulator.

Figure 5. EDS simulator.

The Kaiser ProView 50* (figure 6) was the helmet mounted display (HMD) used by all of the pilots in the EDS and CPC. It had two liquid crystal displays with 28° (V) × 49° (H) field-of-view (25% binocular overlap), 1024 × 768 resolution, inter-pupillary distance adjustment, eye relief adjustment, adjustable headband and strap, an electronic control unit, and a Polhemus head-tracking sensor. The weight of the HMD was 1.3 lb. The HMD provided the out-the-window display to the pilots via a synthetic visual scene overlaid with monochrome symbology. When used in the night vision pilotage system (NVPS) mode, the HMD displayed the forward-looking infrared (FLIR) scene overlaid by the monochrome symbology. A headset was placed over the HMD to provide the pilots with the capability for radio and inter-cockpit communication.

* ProView 50 is a registered trademark of Rockwell Collins Kaiser Electro-Optics, Carlsbad, CA.

Figure 6. Kaiser ProView 50.

1.8 UH-60M Aircraft Description

The UH-60M Blackhawk is an upgrade to the UH-60A/L model and includes several multi-functional digital displays that present flight, navigation, and communication information to the aircrew to enhance battlefield situational awareness and decrease pilot workload. It is a twin-turbine engine, single rotor helicopter capable of transporting cargo, 11 combat troops, and weapons during day and night, instrument meteorological conditions (IMC), visual meteorological conditions (VMC), and degraded visual environment conditions. The UH-60M Blackhawk helicopter provides air assault, general support, and medical evacuation (MEDEVAC) capabilities for the U.S. Army.

1.8.1 UH-60M BHIVE 1 Simulator Description

The BHIVE 1 simulator (figure 7) consists of a projection system, three-dimensional surround sound audio, and a plug-and-play interface for the integration of the UH-60M reconfigurable crewstation. Each crewstation replicated the corresponding crewstation in the actual aircraft, allowing each pilot to perform position appropriate flight and mission tasks. The simulator contained the hardware and software that emulated the controls, flight characteristics, and functionality of the UH-60M aircraft. The projection system was a fixed-base bi-directional curved screen with three soft-edge blended projectors and an image generation system. The screen provides a field of view (FOV) of 40° vertical (111.61 in) and 150° horizontal (229 in). The distance from the screen to the pilot and co-pilot was ~152 in. The BHIVE 1 was used by ARL HRED to assess the UH-60M crewstation design during the Early User Demonstration 2 (Kennedy and Durbin, 2005) and the Limited Early User Evaluation (Havir et al., 2005).

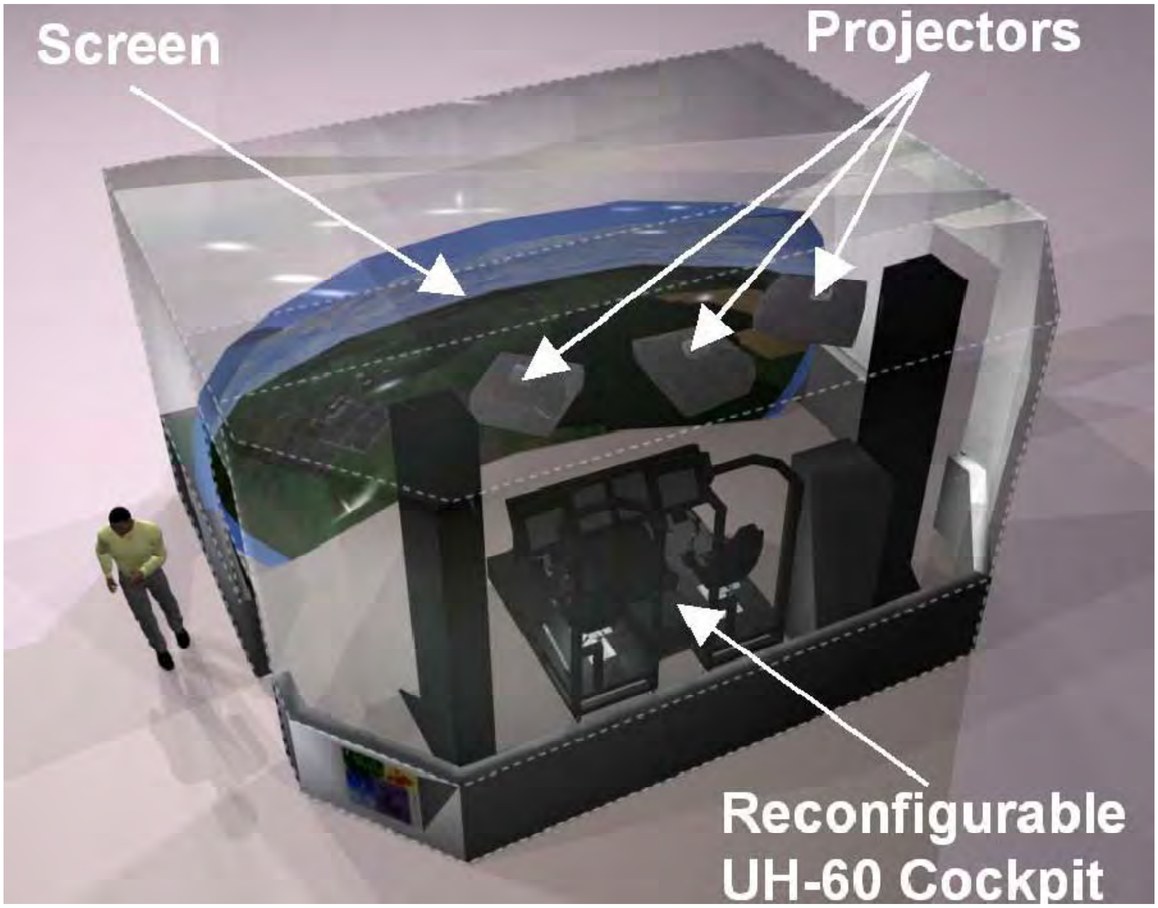

Figure 7. UH-60M BHIVE 1 configuration.

1.8.2 UH-60M System Integration Laboratory (SIL) Simulator Description

The UH-60M SIL included the forward section of a UH-60L aircraft (figure 8). Using the forward section of the actual aircraft provided a realistic crewstation environment by using production-representative hardware. The simulator emulated the controls, flight characteristics, and functionality of the UH-60M aircraft. The external visual scene was displayed on three rear projection monitors. The SIL was used by ARL HRED to assess the UH-60M crewstation design during the Limited User Test (Havir et al., 2006).

Figure 8. UH-60M SIL cockpit view.

1.9 ARH Aircraft Description

The ARH was a reconnaissance/scout helicopter designed to replace the OH-58D Kiowa Warrior. It was a militarized version of the Bell 407 single-engine commercial helicopter and designed to provide the U.S. Army with an enhanced capability in the areas of deployment, reconnaissance and light attack. The ARH crewstation consisted of multifunction displays and advanced avionics. The aircraft was designed to operate during day and night in limited weather environments.

1.9.1 ARH BHIVE 2 Simulator Description

The ARH BHIVE 2 simulator consisted of the forward section of an ARH fuselage and crewstation hardware and software (figure 9). Each crewstation replicated the corresponding crewstation in the actual aircraft, allowing each pilot to perform position appropriate flight and mission tasks. The simulator contained the hardware and software that emulated the controls, flight characteristics, and functionality of the ARH aircraft. The projection system was six SEOS[*] image generators which projected the OTW view onto an $180^{o} \times 60^{o}$ directional curved dome. The BHIVE 2 was used by ARL HRED to assess the ARH crewstation design during the Common Aviation Architecture System (CAAS) assessment (Durbin and Hicks, 2006).

[*] SEOS is a registered trademark of Rockwell Collins, Orlando, FL.

Figure 9. ARH BHIVE 2 cockpit and simulator.

1.10 CH-47F Aircraft Description

The CH-47F Chinook is a twin engine, tandem rotor heavy-lift cargo helicopter used for troop, artillery, and supply transportation. The CH-47F was an upgrade program to the CH-47D that incorporated multifunction displays in the crewstation and improvements to airframe reliability, maintainability, and avionics architecture.

1.10.1 CH-47F CH-Engineering Analysis Cockpit (EAC) Simulator Description

The CH-47F CH-EAC is a reconfigurable cockpit that utilizes computer monitors to emulate actual aircraft displays, control panels, and standby instrumentation (figure 10). The cockpit has two crewstations arranged in a side-by-side configuration. Each crewstation replicated the corresponding crewstation in the actual aircraft, allowing each pilot to perform the appropriate flight and mission tasks. The simulator contained the hardware and software that emulated the controls, flight characteristics, and functionality of the CH-47F aircraft. The projection system was six SEOS image generators which projected the OTW view onto an $180^{o} \times 60^{o}$ directional curved dome. The CH-EAC was used by ARL HRED to assess the CH-47F crewstation design during the CH-47F Limited Objectives User Demonstration #1 (Minninger et al., 2004).

Figure 10. CH-EAC cockpit and displays.

2. Method

2.1 Administering the SSQ

ARL HRED personnel administered the SSQ to pilots just prior to the start of each mission. The pilots then conducted missions that were based on a battlefield environment simulating southwest Asia. They performed missions that were appropriate for their aircraft. The missions included route, area, and zone reconnaissance, landing zone/pick-up zone reconnaissance, armed security, and close combat. The missions were typically 1.5–2 hr in length. The temperature in the simulators ranged from the upper 60's to mid 70's Fahrenheit. Pilots usually flew one mission per day.

ARL HRED personnel observed the missions and recorded any pilot behaviors (e.g., burping) and comments relating to SS symptoms. Immediately upon completion of the mission, the SSQ was again administered to the pilots. Pilots were asked to explain any elevated SS severity score ratings. This enabled researchers to identify early SS trends and monitor the overall health of participants. SS was also addressed during mission after-action reviews and any significant simulator issues (e.g., visual lag) were discussed and action taken to mitigate the issues. If a pilot was not in his usual state of health and fitness (e.g., been sick in the past several days), his ratings were not used.

2.2 SSQ Analysis

To analyze the SSQ data, the symptom severity scores were calculated. The first step was to sum the values for each symptom (e.g., eyestrain, nausea). The values were 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 was calculated by summing the values of each subscale and then multiplying each individual sum by a conversion factor. The TS score was calculated by summing each subscale and multiplying by a total severity factor. A higher score indicated more severe symptoms and in an increased likelihood of simulator induced sickness. Table 2 categorizes the TS scores as proposed by Kennedy et al. (2002).

Table 2. 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

3. Results

3.1 AH-64D VUIT-2 SSQ Results

The overall mean TS score (post mission) for both pilots was 4.98 (table 3). The mean TS score for the CPG was 7.79 and the mean TS score for the PI was 2.18. The TS scores were analyzed for each simulation using the Wilcoxon Signed Rank Test (WSRT) to determine statistical significance. The difference between the pre-flight SSQ and the post-flight SSQ scores for the CPG was not statistically significant (WSRT, $Z = -0.768$, $p = 0.461$). The difference between the pre-flight SSQ and the post-flight SSQ scores for the PI was also not statistically significant (WSRT, $Z = 0.000$, $p = 1.000$). A WSRT was not performed to identify statistical significance between the PI and CPG. Based on the categorization of simulator sickness symptoms (table 4), the PIs experienced "negligible" simulator sickness symptoms during the missions, while the CPGs experienced "minimal" simulator sickness symptoms.

Table 3. AH-64D VUIT-2 SSQ ratings.

Condition	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
Pre-Mission	2.78	4.73	2.32	4.05
Back seat (pilot)	1.59	3.15	0	2.18
Front seat (copilot/gunner)	3.97	6.31	4.64	5.92
Post-Mission	3.18	5.05	4.64	4.98
Back seat (pilot)	2.38	2.52	0	2.18
front seat (copilot/gunner)	3.97	7.58	9.28	7.79

Table 4. Categorization of AH-64D VUIT-2 SS symptoms.

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

3.2 AH-64D IUAS SSQ Results

The overall mean TS score (post mission) for both pilots was 8.51 (table 5). The mean TS score for the CPGs was 9.72 and the mean TS score for the PIs was 7.01. The difference between the TS scores for the CPG vs. the PIs was not statistically significant (WSRT, Z = –0.210, p = 0.875). A WSRT was not performed to identify statistical significance between the pilot and CPG. Based on the categorization of simulator sickness symptoms (table 6), the pilots and CPGs experienced “minimal” simulator sickness symptoms.

Table 5. AH-64D IUAS SSQ ratings.

Condition	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
Pre-Mission	1.06	2.94	3.09	2.70
Back seat (pilot)	1.19	0.94	3.48	1.87
Front seat (copilot/gunner)	.095	4.54	2.78	3.36
Post-Mission	9.01	7.58	4.64	8.51
Back seat (pilot)	9.54	5.68	1.74	7.01
Front seat (copilot/gunner)	8.58	9.09	6.96	9.72

Table 6. Categorization of AH-64D IUAS SS symptoms.

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

3.2.1 Comparison of RACRS Simulator SSQ Scores to Other Helicopter Simulators

To assess whether the SSQ ratings provided by the pilots during the assessments were similar or different to ratings obtained in other helicopter simulators, the mean SSQ scores for the RACRS simulator were compared to the mean SSQ scores for several other helicopter simulators (table 7). In comparison, the RACRS induced fewer simulator sickness symptoms during the VUIT-2 and IUAS missions than most of the other helicopter simulators listed in table 7.

Table 7. Comparison of RACRS simulator SSQ scores with other helicopter simulators.

Simulator	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
AH-64A[a]	—	—	—	25.81
ARH (BHIVE 2)	18.02	21.48	9.28	20.15
SH-3H	14.70	20.00	12.40	18.80
CH-47F (BHIVE 2)	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
CH-53F	7.50	10.50	7.40	10.00
UH-60M – LEUE (BHIVE 1)	6.36	11.81	3.09	9.15
AH-64D – IUAS (RACRS)	**9.01**	**7.58**	**4.64**	**8.51**
UH-60M – EUD (BHIVE 1)	13.88	6.89	0	8.5
CH-53D	7.20	7.20	4.00	7.50
UH-60M – LUT (SIL)	6.36	8.64	2.71	7.49
CH-46E	5.40	7.80	4.50	7.00
AH-64D - VUIT-2 (RACRS)	**3.18**	**5.05**	**4.64**	**4.98**

[a]SSQ subscale data not available.

The SSQ scores for the S-3H, CH-46E, CH-53D, and CH-53F helicopter simulators were obtained from a report by Kennedy et al. (1993). The SSQ scores for the AH-64A simulator were obtained from a report written by Johnson (1997). The S-3H, CH-46E, CH-53D, and CH-53F helicopter simulators were motion (six degrees of freedom) base simulators with cathode ray tube (CRT) displays that presented the out-the-window (OTW) scene to pilots. The AH-64A simulator used hydraulically actuated pneumatic seats to simulate motion. These simulators induced low-to-potentially problematic levels of simulator sickness symptoms in pilots.

3.3 RAH-66 CPC and EDS SSQ Results

The overall mean TS score (post mission) for both pilots was 12.62 (table 8). The range of TS scores was 2.13–32.41. One pilot consistently reported higher SSQ scores than the other pilots. A WSRT was not performed to analyze statistical significance between the pilot and copilot. The difference in overall TS scores (pre- vs. post-mission) was statistically significant (WSRT, $z = -2.52$, $p < 0.01$). While listening to the pilot's conversation during the missions, ARL HRED personnel heard only one discomfort problem occasionally mentioned by the pilots during the 39 missions that they conducted. The discomfort problem was a hot spot on the top of their head from the weight and friction of the communication headset and cable. Based on the categorization of simulator sickness symptoms (table 9), the pilots and copilots experienced "significant" SS symptoms during the missions. Wearing the HMD during missions may have been a contributing factor to the elevated TS scores based on the elevated oculomotor scores reported by the pilots.

Table 8. RAH-66 SSQ ratings.

Condition	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
Pre-Mission[a]	2.29	5.83	.90	4.02
Post-Mission	9.54	15.49	4.61	12.62
Back seat (copilot)	8.79	15.94	6.38	13.03
Front seat (pilot)	10.49	15.13	3.20	12.44
EDS	11.84	14.98	4.54	13.25
CPC	6.73	15.40	4.32	11.40

[a]Data was combined for both pilots.

Table 9. Categorization of RAH-66 SS symptoms.

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

3.3.1 Comparison of SSQ Scores for the RAH-66 CPC vs. EDS Simulators

The difference in TS scores for pilots when conducting missions in the EDS vs. the CPC was not statistically significant (WSRT, $z = -0.701$, $p > 0.10$, ns). However, the mean nausea subscale score was notably higher for pilots in the EDS vs. CPC. This may have been due to the motion of the EDS simulator during missions vs. no motion in the CPC simulator. The difference in TS scores for pilots vs. copilots was not statistically significant (WSRT, $z = -0.140$, $p > 0.10$, ns).

3.3.2 Comparison of RAH-66 CPC and EDS SSQ Scores to Other Helicopter Simulators

To assess whether the SSQ ratings provided by the pilots during the Comanche simulations were similar or different to ratings obtained in other helicopter simulators, the mean TS scores for the EDS and CPC were compared to the mean TS scores for the other helicopter simulators (table 10). The EDS and CPC simulators induced more than average SS symptoms in pilots compared to the other helicopter simulators.

Table 10. Comparison of CPC and EDS SSQ scores with other helicopter simulators.

Simulator	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
AH-64A[a]	—	—	—	25.81
ARH (BHIVE 2)	18.02	21.48	9.28	20.15
SH-3H	14.70	20.00	12.40	18.80
CH-47F (BHIVE 2)	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**
CH-53F	7.50	10.50	7.40	10.00
UH-60M – LEUE (BHIVE 1)	6.36	11.81	3.09	9.15
AH-64D - IUAS (RACRS)	9.01	7.58	4.64	8.51
UH-60M – EUD (BHIVE 1)	13.88	6.89	0	8.5
CH-53D	7.20	7.20	4.00	7.50
UH-60M – LUT (SIL)	6.36	8.64	2.71	7.49
CH-46E	5.40	7.80	4.50	7.00
AH-64D - VUIT-2 (RACRS)	3.18	5.05	4.64	4.98

[a]SSQ subscale data not available.

3.4 UH-60M EUD BHIVE 1 SSQ Results

The overall mean TS score (post mission) for both pilots was 8.10 (table 11). The range of TS scores for all of the pilots was 0 to 29.92. The difference in TS scores between the pilots vs. copilots was not statistically significant (WSRT, $z = 0.02$, $p = 1.00$). A WSRT was not performed to compare pre-mission SSQ results to post-mission SSQ results.

Table 11. UH-60M EUD BHIVE 1 SSQ ratings.

Condition	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
Pre-Mission [a]	6.36	3.16	0	3.74
Post-Mission	13.88	6.89	0	8.10
Right seat (pilot)	12.72	8.84	0	8.73
Left seat (copilot)	14.31	3.79	0	7.48

[a]Data was combined for both pilots.

3.4.1 UH-60M LEUE BHIVE 1 SSQ Results

The overall mean TS score (post mission) for both pilots was 9.15 (table 12). Individual pilot SSQ data and statistical analysis were not contained in the LEUE report.

Table 12. UH-60M LEUE BHIVE 1 SSQ ratings.

Condition	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
Pre-Mission [a]	2.64	3.35	3.87	3.73
Post-Mission	6.36	11.81	3.09	9.15

[a]Data was combined for both pilots.

3.4.2 UH-60M LUT SIL SSQ Results

The mean TS score (post-mission) for both pilots was 7.49 (table 13). The TS scores for left and right seats were 5.58 and 9.33, respectively. The difference between the TS scores was not statistically significant (WSRT, $z = -0.944$, $p = 0.345$). A WSRT was not performed to compare pre-mission SSQ results to post-mission SSQ results. Based on the categorization of simulator sickness symptoms (table 14), the pilots and copilots experienced “minimal” SS symptoms while conducting missions in the BHIVE 1 and SIL simulators.

Table 13. UH-60M LUT SIL SSQ ratings.

Condition	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
Pre-Mission[a]	1.59	1.06	1.95	1.67
Post-Mission	6.36	8.64	2.71	7.49
Right seat (pilot)	4.75	5.86	3.09	5.58
Left seat (copilot)	7.93	11.36	2.32	9.33

[a]Data was combined for both pilots.

Table 14. Categorization of UH-60M SS symptoms for the BHIVE 1 and SIL.

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

3.4.3 Comparison of BHIVE 1 and SIL SSQ Scores to Other Helicopter Simulators

To assess whether the SSQ ratings provided by the pilots during the EUD, LEUE, and LUT were similar or different to ratings obtained in other helicopter simulators, the mean TS scores for the BHIVE 1 were compared to the mean TS scores for several other helicopter simulators (table 15). The BHIVE 1 simulator induced average levels of SS symptoms in pilots compared to the other helicopter simulators. The SIL simulator induced fewer than average SS symptoms in pilots compared to the other helicopter simulators.

Table 15. Comparison of BHIVE 1 and SIL SSQ scores with other helicopter simulators.

Simulator	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
AH-64A[a]	—	—	—	25.81
ARH (BHIVE 2)	18.02	21.48	9.28	20.15
SH-3H	14.70	20.00	12.40	18.80
CH-47F (BHIVE 2)	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
CH-53F	7.50	10.50	7.40	10.00
UH-60M – LEUE (BHIVE 1)	**6.36**	**11.81**	**3.09**	**9.15**
AH-64D - IUAS (RACRS)	9.01	7.58	4.64	8.51
UH-60M – EUD (BHIVE 1)	**13.88**	**6.89**	**0**	**8.5**
CH-53D	7.20	7.20	4.00	7.50
UH-60M – LUT (SIL)	**6.36**	**8.64**	**2.71**	**7.49**
CH-46E	5.40	7.80	4.50	7.00
AH-64D - VUIT-2 (RACRS)	3.18	5.05	4.64	4.98

[a]SSQ subscale data not available.

3.5 ARH SSQ Results

The overall mean TS score (post-mission) for both pilots was 20.15 (table 16). The mean TS score for the pilot was 26.18 and the mean TS score for the copilot was 14.12. The TS score range was reported as 0 to 59.84. The difference between the TS scores for the pilot vs. copilot was statistically significant (WSRT, $z = –2.410$, $p = 0.016$). A WSRT was not performed to compare pre-mission SSQ results to post-mission SSQ results. It was noted that there was a short but perceptible lag in the update of the external visual scene (out-the-window) presented to the pilot and copilot. The pilots likely experienced more simulator sickness symptoms when flying the aircraft because they were consistently exposed to the visual lag. The copilots primarily maintained their visual gaze inside the aircraft to monitor and input data into their crewstation displays and were not consistently exposed to the visual lag. Based on the categorization of simulator sickness symptoms (table 17), the copilots experienced “significant” SS symptoms and the pilots experienced SS symptoms that are “a concern.”

Table 16. ARH SSQ ratings.

Condition	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
Pre-Mission[a]	3.71	7.58	3.09	6.03
Post-Mission	18.02	21.48	9.28	20.15
Right seat (pilot)	24.38	26.12	13.92	26.18
Left seat (copilot)	11.66	16.84	4.64	14.12

[a]Data was combined for both pilots.

Table 17. Categorization of ARH SS symptoms.

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

3.5.1 Comparison of ARH SSQ Scores to Other Helicopter Simulators

To assess whether the SSQ ratings provided by the pilots during the ARH assessment were similar or different to ratings obtained in other helicopter simulators, the mean TS scores for the ARH simulator were compared to the mean TS scores for several other helicopter simulators (table 18). The ARH simulator induced more than average levels of SS symptoms in pilots compared to the other helicopter simulators.

Table 18. Comparison of ARH SSQ scores with other helicopter simulators.

Simulator	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
AH-64A[a]	—	—	—	25.81
ARH (BHIVE 2)	**18.02**	**21.48**	**9.28**	**20.15**
SH-3H	14.70	20.00	12.40	18.80
CH-47F (BHIVE 2)	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
CH-53F	7.50	10.50	7.40	10.00
UH-60M – LEUE (BHIVE 1)	6.36	11.81	3.09	9.15
AH-64D - IUAS (RACRS)	9.01	7.58	4.64	8.51
UH-60M – EUD (BHIVE 1)	13.88	6.89	0	8.5
CH-53D	7.20	7.20	4.00	7.50
UH-60M – LUT (SIL)	6.36	8.64	2.71	7.49
CH-46E	5.40	7.80	4.50	7.00
AH-64D - VUIT-2 (RACRS)	3.18	5.05	4.64	4.98

[a]SSQ subscale data not available.

3.6 CH-47F SSQ Results

The mean pre-mission TS score for the left seat pilots was 11.84 with a post-mission TS score of 21.81. Right seat pre-mission TS score was 8.10 with a post-mission TS score of 11.68 (table 19). The difference in overall TS scores (post-mission) between the pilots vs. copilots was statistically significant (the WSRT analysis results were not reported). The average TS score for both seats was 16.75. A WSRT was not performed to compare pre-mission SSQ results to post-mission SSQ results. Based on the categorization of simulator sickness symptoms (table 20), the pilots experienced “significant” SS symptoms and the copilots experienced SS symptoms that categorize the simulator as a “problem simulator.”

Table 19. CH-47F SSQ ratings.

Condition	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
Pre-Mission	4.77	11.99	8.12	9.97
Right seat (pilot)	3.18	10.10	6.96	8.10
Left seat (copilot)	6.36	13.89	9.28	11.84
Post-Mission	12.52	18.48	10.15	16.75
Right seat (pilot)	10.73	10.42	8.70	11.68
Left seat (copilot)	14.31	26.53	11.59	21.81

Table 20. Categorization of CH-47F SS symptoms.

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

3.6.1 Comparison of CH-47F SSQ Scores to Other Helicopter Simulators

To assess whether the SSQ ratings provided by the pilots during CH-47F simulations were similar or different to ratings obtained in other helicopter simulators, the mean TS scores for the CH-EAC were compared to the mean TS scores for other U.S. Army Aviation helicopter simulators (table 21). The mean TS scores indicate that the CH-EAC induced more than average simulator sickness symptoms than the other simulators listed in table 21.

Table 21. Comparison of CH-47F SSQ scores to other helicopter simulators.

Simulator	Nausea Subscale	Oculomotor Subscale	Disorientation Subscale	Total Severity Score (Mean)
AH-64A[a]	—	—	—	25.81
ARH (BHIVE 2)	18.02	21.48	9.28	20.15
SH-3H	14.70	20.00	12.40	18.80
CH-47F (BHIVE 2)	**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
CH-53F	7.50	10.50	7.40	10.00
UH-60M – LEUE (BHIVE 1)	6.36	11.81	3.09	9.15
AH-64D - IUAS (RACRS)	9.01	7.58	4.64	8.51
UH-60M – EUD (BHIVE 1)	13.88	6.89	0	8.5
CH-53D	7.20	7.20	4.00	7.50
UH-60M – LUT (SIL)	6.36	8.64	2.71	7.49
CH-46E	5.40	7.80	4.50	7.00
AH-64D - VUIT-2 (RACRS)	3.18	5.05	4.64	4.98

[a]SSQ subscale data not available.

4. Conclusions

The AH-64D and UH-60M engineering simulators induced minimal SS symptoms for pilots. The RAH-66, ARH, and CH-47F simulators induced greater SS symptoms. The higher SS ratings reported by the RAH-66 pilots may have been caused by wearing a HMD during missions. The higher SS ratings reported by the ARH pilots were likely caused by a visual lag in the OTW scene. It is uncertain what caused the higher SS ratings reported by the CH-47F pilots. It is interesting to note that the pre-mission SS scores were fairly high for CH-47F pilots.

This indicates that they were experiencing physical discomfort prior to performing missions in the simulator.

Based on observations and recordings by ARL HRED personnel (during missions) and extensive post-mission pilot interviews, the SS symptoms induced by the RAH-66, ARH, and CH-47F simulators did not appear to cause significant discomfort for pilots, distract them during missions, or contribute to an increase in perceived workload. Further, the RAH-66, ARH, and CH-47F pilots reported low to moderate workload ratings for the flight and mission tasks they performed and successfully completed their missions. Therefore, it appears that the AH-64D and UH-60M, RAH-66, ARH and CH-47F engineering simulators do not induce debilitating SS and are suitable for continued assessment of the design of U.S. Army Aviation crewstations. ARL HRED will continue to assess SS during future simulations to identify whether SS symptoms negatively affect pilot performance.

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Appendix. Simulator Sickness Questionnaires

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

Pre-Mission SSQ Survey

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.

6. Are you in your usual state of health and fitness? **YES** **NO**

7a. Have you been ill in the past week? **YES** **NO**
b. If yes, are you fully recovered? **YES** **NO** **N/A**

Post-Mission SSQ Survey

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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List of Symbols, Abbreviations, and Acronyms

AAR	After-Action Review
AB3	AH-64D Apache Longbow Block III
AMRDEC	Aviation and Missile Research, Development and Engineering Center
ARH	Armed Reconnaissance Helicopter
ARL	U.S. Army Research Laboratory
ATEC	U.S. Army Test and Evaluation Command
ATM	Aircrew Training Manual
BHIVE	Battlefield Highly Immersive Virtual Environment
CH-EAC	Cargo Helicopter – Engineering Analysis Cockpit
CDU	Cockpit Display Unit
CPC	Comanche Portable Cockpit
CPG	Co-Pilot/Gunner
CPT	Cockpit Procedures Trainer
CRT	Cathode Ray Tube
EDS	Engineering Development Simulator
EUD	Early User Demonstration
FCR	Fire Control radar
FFS	Full Flight Simulator
FLIR	Forward Looking Infrared
FOV	Field of View
HFE	Human Factors Engineering
HRED	Human Research and Engineering Directorate
IMC	Instrument Meteorological Conditions
IR	Infrared

IUAS	Integrated UAS
LEUE	Limited Early User Evaluation
MEDEVAC	Medical Evacuation
MEP	Mission Equipment Package
MFD	Multifunction Display
MPD	Multipurpose Display
MTADS	Modernized Target Acquisition Designation Sight
MTCDL	Mini-Tactical Common Data Link
OSRVT	One System-Remote Video Terminal
OTW	Out-the-Window
PI	Pilot
PNVS	Pilot Night Vision System
RACRS	Risk and Cost Reduction System
RCS	Radar Cross Section
SA	Situational Awareness
SED	Software Engineering Directorate
SIL	System Integration Laboratory
SME	Subject-Matter Expert
SS	Simulator Sickness
SSQ	Simulator Sickness Questionnaire
TADS	Target Acquisition Designation Sight
TEDAC	TADS Electronic Display and Control
TCM	TRADOC Capabilities Manager
TRADOC	U.S. Army Training and Doctrine Command
TS	Total Severity
UAS	Unmanned Aerial System
UHF	Ultra High Frequency

VMC	Visual Meteorological Conditions
VUIT-2	Video from Unmanned Aircraft Systems for Interoperability Teaming
WSRT	Wilcoxon Signed Rank Test

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