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Simulator Sickness in the AH-64 Apache Combat Mission Simulator

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As technology has been developed to provide improved visual and motion systems in operational flight trainers and weapons tactics trainers, there have been increasing reports of the occurrence of simulator sickness. Simulator sickness here refers to one or more symptoms which can occur while in a simulator, immediately postexposure, or at some later time following exposure. Some pilots have reported while driving following postexposure, they have had to pull off the road and wait for symptoms to subside. Instructor-operators have reported experiencing "the room spinning" when they went to bed. More critical is the potential for in-flight problems due to prolonged physiological effects. The U.S. Army Aeromedical Research Laboratory at Fort Rucker, Alabama, conducted a field survey to document the extent of the simulator sickness problems at operational AH-64 simulator sites. The simulator sickness incidence rates and the relative frequency of specific symptoms are presented and correlational factors such as flight experience, simulator experience, and flight mode also are presented. The study reinforces the need for continued research related to system design, training methods, and crew rest guidelines between simulator and actual flight.

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Introduction

U.S. Army's involvement with simulator sickness

Prior to the actual fielding of the newest rotary-wing simulator (the AH-64 Apache combat mission simulator (CMS)) at U.S. Army installations, training of Apache pilots was conducted at the Singer Link facility in Binghamton, New York. At that time, anecdotal information indicated some of the pilots and instructor operators (IO) were experiencing symptoms of simulator sickness resembling those reported in U.S. Navy and U.S. Coast Guard systems. The training flights were 2 hours in duration and most of the students completed the course of instruction in a week's time. This included 15 hours of instruction alternating between the pilot and copilot-gunner stations. IOs were complaining of the onset of a "spinning room" sensation while lying in bed by the middle of a training week. Indeed, some students took Dramamine to alleviate the effects of their symptoms. In May 1986, documentation of the problem reached the U.S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, Alabama. In July 1986, the Aviation Training Brigade at Fort Rucker formed a study group to examine the Apache training program. One of the issues was that of simulator sickness.

A brief survey of existing records and a literature search were conducted in August 1986. Training records of 115 students from the CMS showed that 7 percent of the students had sufficient symptoms to warrant a comment on their grade slips. While this incidence is low compared with Navy simulator sites (Kennedy et al., 1987b, in preparation), rates were derived from training records not designed to document simulator sickness, recording only those cases severe enough to interfere with training or to cancel a flight. The Navy has reported an incidence rate of 12 to 60 percent from the same simulator (Kennedy et al., 1984), depending on whether the data were collected by the squadron, the squadron flight surgeon, or by an independent source with guarantee of anonymity.

Comparatively, the seven percent incidence rate appeared to underestimate the magnitude of the Army's problem. The literature search led USAARL investigators to visit the Naval Training Systems Center (NTSC) in Orlando, Florida. From that association has grown a working relationship geared to capitalize on lessons learned from past research and expand the database of simulator sickness studies. As part of that search, it also was discovered that an independent survey in Europe by a U.S. Army flight surgeon had employed the NTSC methodologies to survey the incidence of simulator sickness in the AH-1 Cobra flight weapons simulator (Crowley, 1987).

In the report to the Army study group, it was recommended a problem definition study be conducted to ascertain more accurately the scope and nature of the problem of simulator sickness in the CMS. The request for that study was received in February 1987. The protocol for the study was approved by the USAARL Scientific Review Committee on 4 May 1987, and data collection began on 8 May 1987. This report documents the results of that study.

The nature of simulator sickness

Simulator sickness is considered to be a form of motion sickness. Motion sickness is a general term for the constellation of symptoms which result from exposure to motion or certain aspects of a moving environment (Casali, 1986), although changing visual motions (Crampton and Young, 1953; Teixeira and Lackner, 1979) may induce the malady. Pathognomonic signs are vomiting and retching; overt signs are pallor, sweating, and salivation; symptoms are drowsiness and nausea (Kennedy and Frank, 1986). Postural changes occur during and after exposure. Other signs (cf., Colehour and Graybiel, 1966; McClure and Fregly, 1972; Money, 1970; Stern et al., 1987) include changes in cardiovascular, respiratory, gastrointestinal, biomedical, and temperature regulation functions. Other symptoms include general discomfort, apathy, dejection, headache, stomach awareness, disorientation, lack of appetite, desire for fresh air, weakness, fatigue, confusion, and incapacitation. Other behavioral manifestations influencing operational efficiency include carelessness and incoordination, particularly in manual control. Differences between the symptoms of simulator sickness and more common forms of motion sickness are that in simulator sickness visual symptoms tend to predominate and vomiting is rare.

Advancing engineering technologies permit a range of capabilities to simulate the real world through very compelling kinematics and computer-generated visual scenes. Aviators demand realistic simulators. However, this synthetic environment can, on occasion, be so compelling that conflict is established between visual and vestibular information specifying orientation (Kennedy, 1975; Oman, 1980; Reason and Brand, 1975). It has been hypothesized that in simulators, this discrepancy occasions discomfort and the cue conflict theory has been offered as a working model for the phenomenon labeled "simulator sickness" (Kennedy, Berbaum, and Frank, 1984). In brief, the model postulates the referencing of motion information signaled by the retina, vestibular apparatus, or sources of somatosensory information to "expected" values based on a neural store which reflects past experience. A conflict between expected and experienced flight dynamics of sufficient magnitude can exceed a pilot's ability to adapt, inducing in some cases simulator sickness.

The U.S. Navy also has conducted a survey in 10 flight trainers where motion sickness experience questionnaires and performance tests were administered to pilots before and after some 1200 separate exposures. From these measures on pilots, several findings emerged: (a) specific histories of motion sickness were predictive of simulator sickness symptomatology; (b) postural equilibrium was degraded after flights in some simulators; (c) self-reports of motion sickness symptomatology revealed three major symptom clusters: gastrointestinal, visual, and vestibular; (d) certain pilot experiences in simulators and aircraft were related to severity of symptoms experienced; (e) simulator sickness incidence varied from 10 to 60 percent; (f) substantial perceptual adaptation occurs over a series of flights; and (g) there was almost no vomiting or retching, but some severe nausea and drowsiness.

In addition, a recent study examined the effects on sickness rates of differing energy spectra in moving base simulators (Allgood et al., 1987). The results showed the incidence of sickness was greater in a simulator with energy spectra in the region described as nauseogenic by the 1981 Military Standard 1472C (MILSTD-1472C) and high sickness rates were experienced as a function of time exceeding these very low frequency (VLF) limits. Therefore, the U.S. Navy has recommended, for any moving-base simulator which is reported to have high incidences of sickness, frequency times acceleration recordings of pilot/simulator interactions should be made and compared with VLF guidelines from MILSTD-1472C. However, in those cases where illness has occurred in a fixed-base simulator, other explanations and fixes are being sought.

Method

Description of the Army system

The newest generation of U.S. Army attack helicopters is the AH-64 advanced attack helicopter, commonly known as the Apache. This attack helicopter is the replacement for the AH-1 attack helicopter, known as the Cobra. The Apache helicopter provides the commander with a means of rapidly concentrating antitank and suppressive firepower on targets during all environmental conditions: day, night, and adverse weather.

The Apache*, built by McDonnell Douglas Helicopter Company, is a twin-engine, four-bladed attack helicopter operated by a tandem-seated crew of two (Figure 1). Planned operations are below 15,000 ft, and generally at tree-top level. The rear seat is occupied by the pilot who is responsible for flying the aircraft. The front seat is occupied by the copilot-gunner (CPG) who is responsible for detecting, engaging, and destroying enemy targets. Both stations have controls for flying the aircraft and instrumentation for flying in instrument meteorological conditions (IMC). However, the CPG often will fly the entire flight and never touch the controls. In general, the CPG will spend the majority (more than 80 percent) of his time looking at the video display unit (VDU) or through his helmet mounted display unit (HDU) for target acquisition, designation, and engagement. The remainder of the time is spent programming his navigation and weapons systems' computers in the cockpit. On the other hand, the pilot's task is to guide the aircraft's flight path and most of his time is spent controlling the aircraft and looking outside the cockpit inspecting for obstacles and enemy aircraft.

Armament for the Apache is of three types (Figure 2). The primary weapon on the Apache is the Hellfire antitank missile, a laser-guided missile capable of defeating all currently known armored vehicles at a significant standoff range. The 30mm chain gun automatic cannon is the primary area weapon subsystem, providing suppressive firepower and the capability to destroy lightly armored vehicles. Another option is the 70mm folding fin aerial rockets which have been a standard U.S. Army and NATO munition for many years. The pilot night vision sensor* (PNVS) developed by the Martin Marietta Orlando Aerospace Corporation enables pilots to fly at night and in periods of reduced visibility. Coupled with this system is the target acquisition

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* See Appendix B

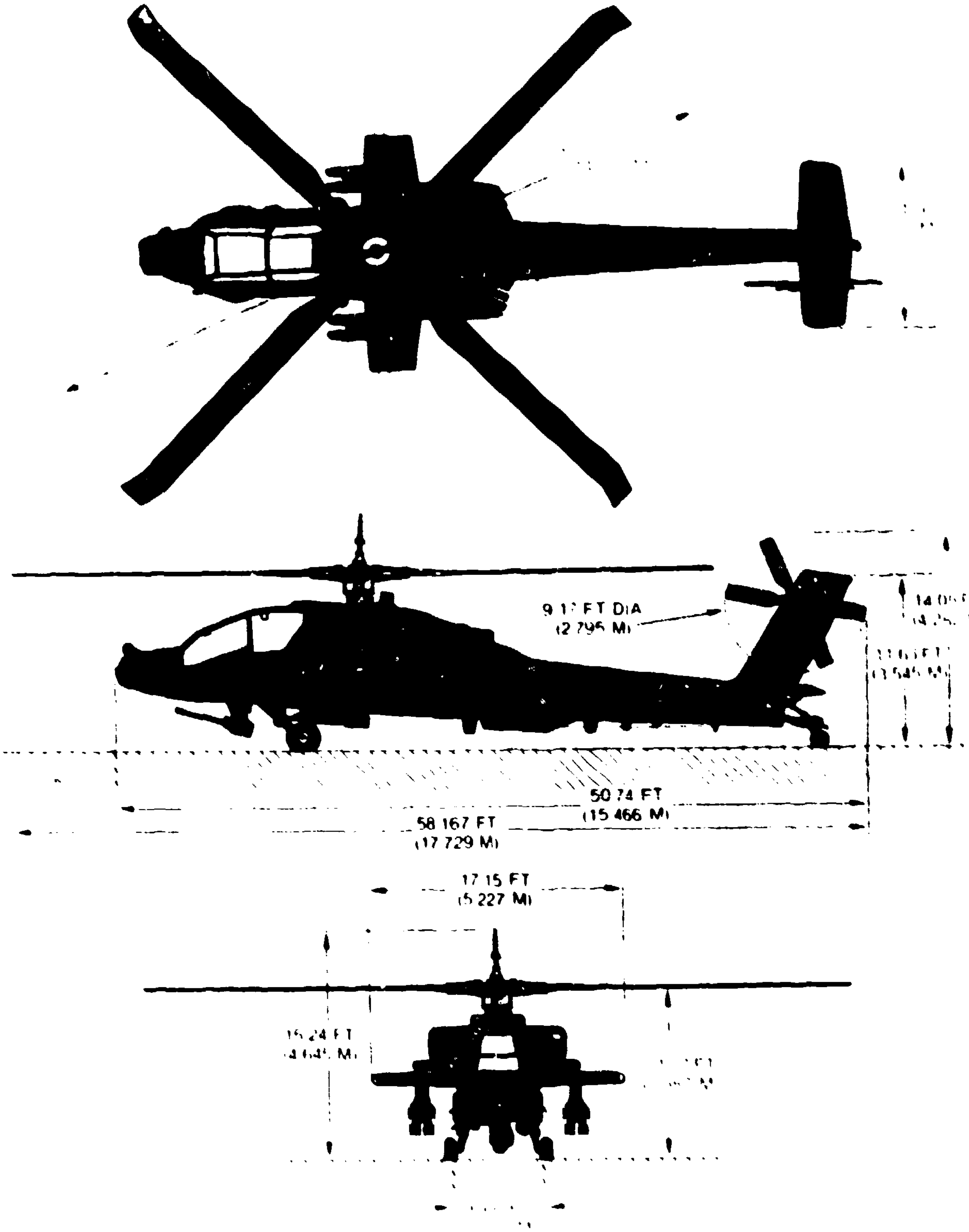

Figure 1. AH-64 advanced attack helicopter.

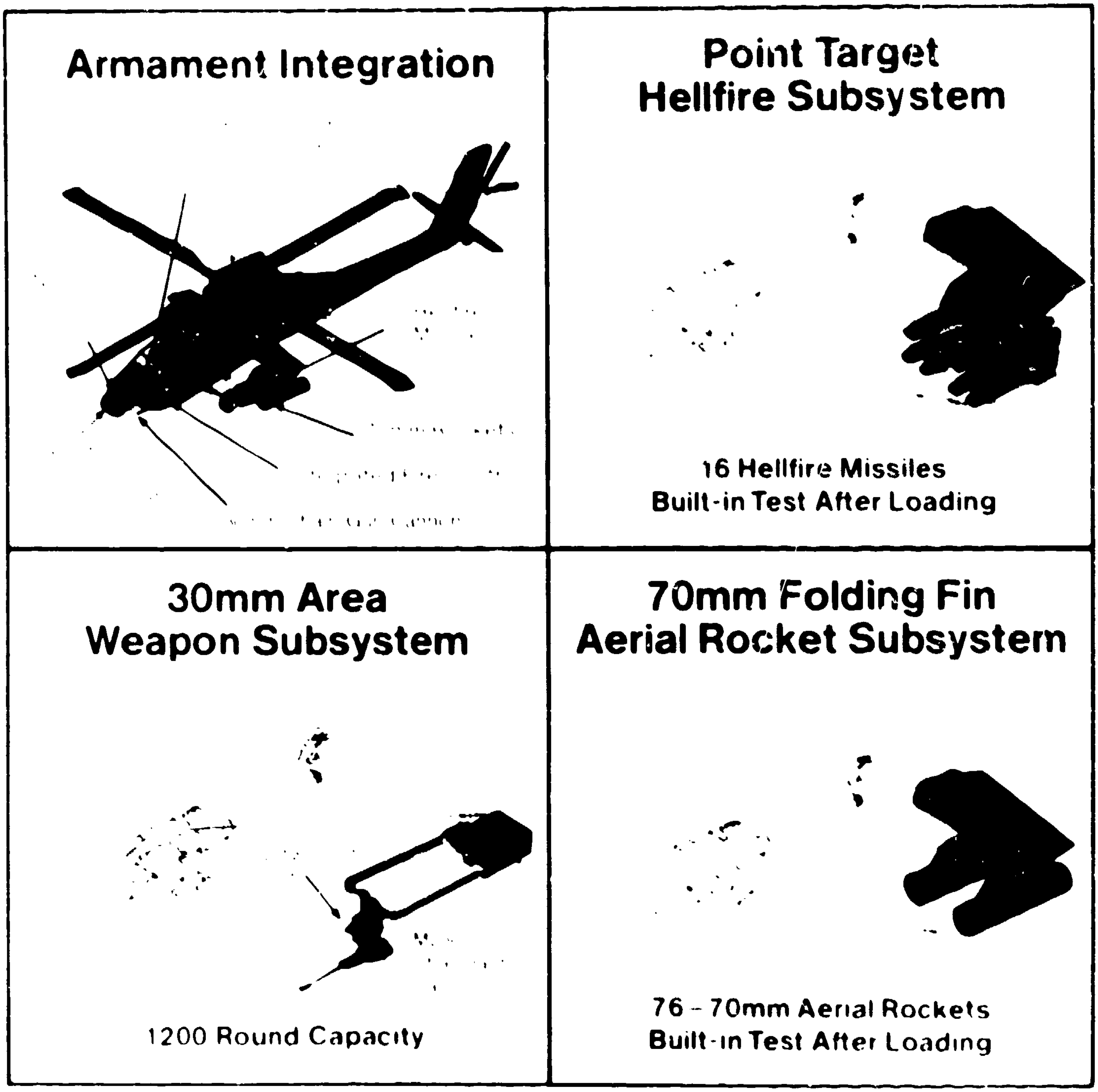

Figure 2. AH-64 armament integration and subsystems.

and designation sight (TADS) which combines high-power direct view optics, a forward looking infrared (FLIR) sensor for night operations, and a high-resolution day TV system with a laser designator and a laser spot tracker. The PNVS FLIR sensor provides real-time imagery of the terrain for nap-of-the-earth (NOE) flight and penetration of obscurants such as rain, fog, dust, and smoke. Sensors for these systems are located on the nose of the aircraft in a rotating turret which is slaved to the pilot's and copilot's head movements.

The TADS is operated by the CPG; however, both pilots may view the video. Normally, the PNVS is operated by the pilot, but it also can be used as a backup for the CPG as well. The wide field-of-view (FOV) of the TADS FLIR optics also is used as a backup for the PNVS. The pilots view the imagery produced by these systems in one of two ways. The first is by selecting the desired system and viewing it on the VDU mounted on the instrument panel of the pilot's console or through the displays of the optical relay tube (ORT) assembly and its associated VDU mounted at the CPG's console. The second mode is to select the display and view it through the HDU attached to the integrated helmet unit (IHU) of the Integrated Helmet and Display Sighting System (IHADSS). The IHADSS was developed under subcontract by Minneapolis Honeywell.

Each pilot can observe what his turret is looking at through the HDU. The HDU is an electro-optical monocular display device designed to provide the pilot with a selected video signal magnified to a 30- by 40-degree FOV, collimated to infinity, and projected at unity-magnification; that is, a one-to-one size relationship between the FLIR image of an object and the actual object. The HDU consists of a cathode ray tube (CRT) and combiner glass mounted on a barrel-type assembly with adjustments for focus and image orientation. The CRT uses a coarse-grained phosphor known as P43 which, when excited, emits visible light in the blue, green, and red wavelengths. (The red and blue wavelengths are filtered out in this application.) The P43 was chosen because its rapid decay rate allows the pilots to slew their heads at normal rates of movement and not have the problem of image smearing (afterimage).

Superimposed on the FLIR image is flight symbology to enhance the pilot's NOE flying capabilities. This provides the pilot with needed aircraft and flight performance information independent of his viewing direction. This symbology includes a magnetic heading tape, power readings in percentage of power available, sensor location, Doppler steering information, radar altimeter information, thrust vector and cyclic input information, as well as weapon system status and selection information.

Description of simulation system

The CMS faithfully reproduces all aircraft systems with great fidelity and realism using 29 high speed 32-bit microprocessors arranged to provide parallel processing. Virtually the only difference is that all of the images are produced by a digital image generator. Trees look like cones, the terrain is not textured, and the houses and manmade structures appear to be "cartoonish" (Figure 3). Considerable and compelling realism is present in the simulator and pilots report becoming so engrossed in the unfolding battle scenario that the exercise takes on the sights, sounds, and intensity of a real conflict. The CMS* produced by the Singer Link Company is a full motion-based simulator with 6 degrees of freedom, with 60 inches of travel. One unique feature is each of the pilots is located on an individual motion platform with a colocated instructor-operator (Figure 4). The two motion platforms are linked by the computer so visual and motion information are the same for each. One pilot at a time is designated to "have the controls." Each cockpit has three windows for out-the-window (OTW) viewing in addition to VDU and HDU visuals of the actual aircraft. The CMS incorporates whole cockpit vibration supplemented by a seat shaker for each pilot. (When the aircraft fires its chain gun, the pilots' seat shakers add increased vibration to simulate that activity. However, the added vibration is not felt by the IO.) CMS now does not have G-suit, G-seat, or lap and shoulder belt tightening features. When air-to-air combat features are added to the database, these features are felt to be needed to accurately simulate the envisioned flight scenarios. Even at its present stage of development, the CMS is on the cutting edge of technology and has yet to reach its full potential.

The database now covers a 16- by 16-km area of generic European terrain. Efforts are underway to expand the database to a 32- by 40-km area. Almost all of the flight scenarios are NOE and, therefore, require detail of terrain, vegetation, and trees, etc., not required by other simulators. As a result, only 20 percent of the database is provided with the detail in which to conduct NOE flight.

Figure 3. Combat mission simulator (CMS) visuals.

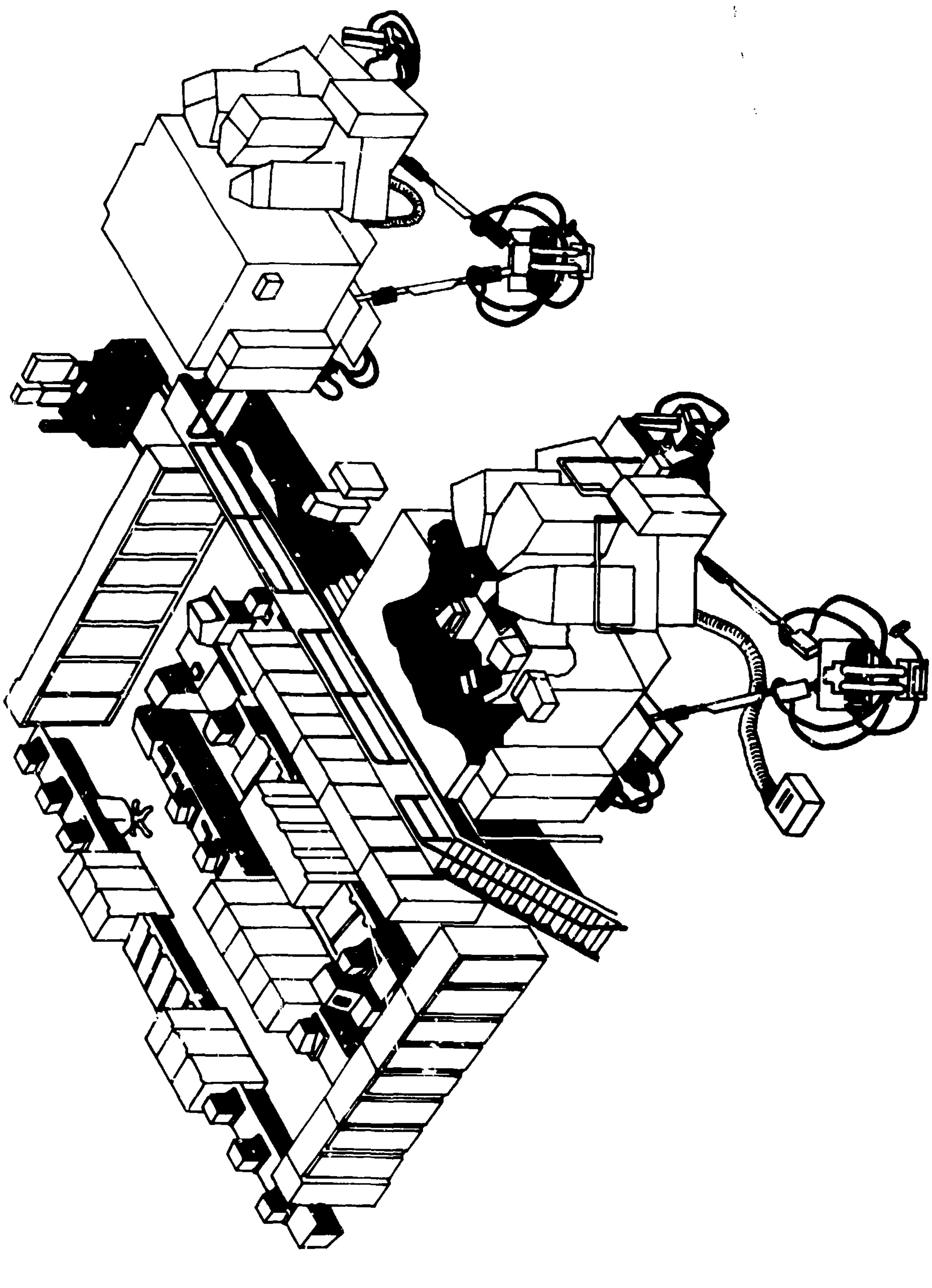

Figure 4. The AH-64 combat mission simulator (CMS) facility.

The CMS is an interactive simulator in the sense it shoots back. The IO can set the hostility level from a low of 1 to a maximum of 10 depending on the crew's skill and proficiency level. The IO also can set the lethality level from a low of 1 to a maximum of 10. Basically, these levels initially determine how rapidly the Apache can be acquired on radar by the enemy, and secondly, how deadly will be the resultant fire he receives. Each of the enemy armor and antiaircraft systems in the database are capable of acquiring, tracking, and engaging the Apache aircraft with the same capabilities as the real pieces of equipment. The pilots also receive information in the form of radar warning and lock-on data in the same manner they would in the aircraft. Should the crew expose themselves to detection and not seek cover, the enemy can, and effectively will, engage them and the result is a very violent engagement. Noise, impact, and system malfunctions are simulated with alarming accuracy.

Method

The Army's initial study into simulator sickness was a field study designed to complement and expand the Navy's database of 10 simulators (Kennedy et al., 1987b, in preparation; Van Hoy et al., 1987), and the Coast Guard data (Ungs, 1987). As employed in previous surveys, this study consisted of an on-site survey of pilots and IOs using a motion history questionnaire (MHQ), a motion sickness questionnaire (MSQ), and a postural equilibrium test (PET).

The MHQ is a self-report form designed to evaluate the subject's past experience with different modes of motion and the subject's history of susceptibility to motion sickness. The MHQ is administered once. The MSQ is designed to assess the symptomatology experienced from the simulator. It has a pre- and postflight component. Additional information about this instrument is in Kennedy et al., (1987c).

The MSQ is divided into four sections. The first section is preflight background information which gives a better description of the pilot subject and allows placing that subject in the proper category according to flight position, duties, total flight time in the aircraft and in the simulator, and a history of recent flight time in both the aircraft and the simulator. Additional descriptive information concerning scoring methods and validity data is in Lenel et al., (1987).

The second section is the preflight physiological status section. This section is administered at the simulator site, and gathers benchmark data as to the subject's recent exposure to prescription medications, illness, and use of alcohol and/or tobacco products. The second part of this section is the preflight symptom checklist which documents how the subject felt before entering the simulator.

The third section is the postflight symptom checklist and is exactly the same as the preflight symptom checklist. This section is administered immediately after the simulator flight, and provides data regarding any increase or decrease in severity of the symptoms that the subject is experiencing. If the subject was experiencing an increase in any of the symptoms, an attempt was made to monitor him or to interview him the following day in order to provide some information regarding recovery from the experienced symptoms. This was easier at the Fort Rucker site than at the Fort Hood site.

The fourth section is the postflight information section which provides data on the flight conditions the pilot experienced while in the simulator and information concerning the status of the various systems within the simulator. Postural equilibrium tests (Thomley, Kennedy, and Bittner, 1986) were administered concurrently with the MHQ and MSQ. These tests consist of three subtests, each designed to measure an aspect of postural equilibrium, as follows:

a. Walk-on-floor-with-eyes-closed (WOFEC). The subject is instructed to walk 12 heel-to-toe steps with his eyes closed and arms folded across his chest. The subject is given a score (0-12) based on the number of steps he is able to complete without sidestepping or falling. The subject is tested five times, both pre- and postflight. Subjects are scored on the average number of steps taken using the best three of the five tests.

b. Standing-on-preferred-leg-with-eyes-closed (SOPLEC). The subject designates his preferred leg (the leg he'd use to kick a football) and this is annotated on the form. The subject then is asked to stand on his preferred leg for 30 seconds with his eyes closed and arms folded across his chest. The experimenter records the number of seconds the subject is able to stand without losing balance. The subject is scored on the number of seconds he is able to stand. The test is administered five times with the best three of the five being used for analysis.

c. Standing-on-nonpreferred-leg-with-eyes-closed (SONLEC). The SONLEC is administered and scored in the same manner as the SOPLEC. The SONLEC will use the opposite leg from the SOPLEC and is administered five times. The subject's score is the average number of seconds he is able to stand, using the best three of the five tests for the analysis.

In order to gather the most comprehensive data in the least intrusive manner, the surveys were administered to all aviators who presented themselves at the simulator sites for flight periods. No attempt was made to randomize the population, but rather to study the problem in the operational setting in which it is found and using flight scenarios normally found during training.

Participants

The survey sample was obtained from three target populations. The first were student aviators. These individuals are rated Army aviators who were at Fort Rucker for the AH-64 transition course. They were either recent initial entry rotary-wing graduates with 150 hours, or more senior aviators with several thousand hours of flight time. Of importance for this survey was that they were essentially naive with respect to both the simulator and the AH-64 helicopter prior to this course. During the final 2 weeks of their course, after all of their time allocated in the actual aircraft had been accomplished (normally 40 hours of flight time), they spent 15 hours of flight time in the simulator. This consisted of five flights in each crew station, each flight consisting of 1.5 flight hours. Because Uliano, Kennedy, and Lambert (1986) reported illnesses associated with simulator sickness quickly dissipate with time when a pilot who is unfamiliar with a simulator is exposed repeatedly, it was expected similar adaptations would occur here. The opportunity to monitor the students in the transition course afforded USAARL an opportunity to compare its experience with adaptation to these findings. Approximately 40 students were surveyed over an average of 9 flights each.

The second target population was the rated Army AH-64 pilots who return to the simulator site at their duty station for continuation and mission training on an irregular basis. All these individuals currently are located at Fort Hood, Texas, which is the Army's single station for the fielding of the Apache helicopter and its advanced attack helicopter battalions. It also is the only other operational CMS facility now used by the Army.

The third and final population was the IOs or instructor pilots (IPs) for the CMS. At Fort Rucker, they all are members of the Aviation Training Brigade and are warrant officer aviators charged with training the students attending the AH-64 transition course. Conversely, at Fort Hood, the IOs are Department of the Army civilians who work at the simulator site as IPs. However, each is a retired Army aviator and most are former AH-1 Cobra pilots with combat experience in Vietnam. They are restricted from flying in the aircraft by regulation and job description. Unit IPs from the units which are located at Fort Hood provide very limited duty as IOs. It should be noted due to the scheduling of IOs at the Fort Rucker site and the resulting small number of subjects available, and the fact that all of the Fort Hood IOs do not fly the aircraft, most of the data concerning the IOs were considered unusable. Consequently, no data of any substance for this population are available for this report.

In order to capture the data necessary from the mentioned populations, the sites used were Fort Rucker and Fort Hood. A target sample size of 200-250 was the objective, but due to time constraints and the nuances of operational usage of the simulator, only 127 subjects were obtained. They performed the normal program of instruction at the Fort Rucker site and one of several operations orders (OPORD) designed to maintain proficiency at the Fort Hood site. As a matter of explanation, each flight in the CMS at both sites was based upon a tactical situation as presented in an OPORD and proceeds as rapidly or as slowly from target to target as the crew's skill permits. Hostility levels and lethality levels are set by the IO depending on skill level of the crew and the desired teaching goal for that particular flight. The investigator did not perform any intervention or exercise any control over the flights in the conduct of this survey. Due to suspense dates placed on the study by the Assistant Secretary of the Army/Research, Development and Acquisition, only the CMS could be surveyed. There are three other Army simulators (for the AH-1, CH-47, and UH-60) that must still be surveyed.

All aviators scheduled for flight were surveyed. Each was guaranteed anonymity and each was permitted nonparticipation. Data obtained from the questionnaires and the PET were entered into a generic database using the programs in use at the NTSC, and data reduction and analyses were performed as in previous studies. The data in this report now are incorporated into the Navy's simulator sickness database, which also includes Coast Guard data in order to determine commonality of symptoms and simulator usage and design (Gower et al., 1987). Unique to the present study is that the student population was evaluated over a 2-week period and 9-10 flights. An initial look at adaptation to the simulator and postsimulator symptoms recovery time is presented.

The 127 Army aviators surveyed ranged from 20 to 47 years (mean 30.6, SD 5.77). Their ranks ranged from warrant officer 1 to chief warrant officer 4 and first lieutenant to colonel. Flight experience was in the range 150 to 8400 flight hours (mean 1583.48).

Results

Overall incidence

Based on previous experiences in monitoring motion sickness in Navy simulators, we have adopted as our index of discomfort the percent of persons who were sick enough upon exiting to report at least one minor symptom which ordinarily is associated with motion sickness. These overall incidence data, based on 434 separate simulator pilot exposures, appear as Table 1. Presented in the table is the overall incidence as well as the grand incidence for two symptom categories --- those related to asthenopia and those related to motion sickness.

In Table 2, the information presented in Table 1 is presented separately for student and rated aviators. Student aviators were surveyed over 9 to 10 flights during the transition course. The data for rated aviators represents only the first observation for each subject, even though some were surveyed two or three times during the course of the study. In addition, for each pilot group, the data are presented by seat (whether the pilot occupied the pilot or copilot-gunner position). For rated aviators, the data indicate pilots generally are more likely than copilots to experience symptoms of greater severity. Previous studies (Kennedy et al., 1987b, in preparation; McGuinness, Bouwman, and Forbes, 1981; Havron and Butler, 1957) have found aviators with greater experience in the actual aircraft reported more difficulties with simulators, particularly when they have 'recent high time.' In this survey, it is our understanding individuals selected to fly in the pilot seat from the "rated aviator" category would be expected to have considerably more Apache flight time than those selected for the copilot seats and it is our speculation this is the probable genesis for this difference in incidence.

Ataxia

The PET means and standard deviations, along with minimum and maximum scores, are reported in Table 3. Paired t-tests were used to assess changes from prescores to postscores for each of the three PET dependent variables, where pre- and postscores were based on the average of the best three out of five pre- and posttrials, respectively. Comparison of pre- and post-WOFEC scores ($t = 4.74$, $df = 408$, $p < .001$), pre- and post-SONLEC scores ($t = 5.20$, $df = 405$, $p < .001$), and pre- and post-SOPLEC scores ($t = 6.19$, $df = 406$, $p < .001$) revealed statistically significant decreases in postural stability occurred for each measure.

Table 1

Incidence of postflight (15-30 minutes) symptoms recorded following 434 simulator flights (127 subjects)

Overall incidence*: 44%

Asthenopia	Percentage	Motion sickness	Percentage
Eye strain	29%	Drowsiness/fatigue	43%
Blurred vision	3%	Sweating	30%
Difficulty focusing	9%	Nausea	7%
Difficulty concentrating	11%	Dizziness/vertigo	5%
Headache	20%	Stomach awareness	6%
		Fullness of head	7%

* At least one minor symptom checked off on the postflight symptom checklist

Table 2

Comparative incidence of key postflight (15-30 minutes) symptoms* for student aviators and rated aviators by seat where N = number of observations for students and N$1 = number of subjects for rated aviators

	Student aviators		Rated aviators	
	(N=171)	(N=168)	(N1=44)	(N1=42)
Overall incidence	41%	44%	44%	57%
<u>Symptoms of asthenopia:</u>				
Eye strain	29%	30%	18%	36%
Blurred vision	1%	4%	2%	5%
Difficulty focusing	9%	8%	9%	17%
Difficulty concentrating	6%	13%	14%	17%
Headache	21%	24%	9%	14%
<u>Symptoms of motion sickness:</u>				
Drowsiness/fatigue	39%	47%	43%	38%
Sweating	29%	35%	16%	36%
Nausea	7%	7%	0%	10%
Dizziness/vertigo	1%	2%	2%	7%
Stomach awareness	4%	7%	2%	19%
Fullness of head	4%	8%	16%	7%

* At least one minor symptom checked off on the postflight symptom checklist

Table 3

Means, standard deviations, minimum/maximum scores and Ns* for pre- and post-WOLFEC, SONLEC, and SOPLEC measures

	WOFEC		SONLEC		SOPLEC	
	Pre	Post	Pre	Post	Pre	Post
Mean	11.38	11.02	23.17	21.81	23.06	21.54
SD	1.42	1.79	7.89	8.07	7.81	8.16
Min-max	3.3-12.0	3.3-12.0	5.0-30.0	2.3-30.0	5.6-30.0	3.3-30.0
N	410	409	410	406	410	407

* N = Number of observations

In Table 4, the PET data are presented according to pilot group and seat occupied. For the student aviators, only the SOPLEC measure revealed a significant decrease for both pilots and copilots from the pre- to posttesting. Analysis of WOFEC and SONLEC measures revealed statistically significant decreases for the pilots only. Analyses for the rated aviators revealed statistically significant decreases for both pilots and copilots on the WOFEC and SOPLEC measures. However, on the SONLEC measure, a significant decrease was found only for the pilots.

Simulator sickness symptoms

Table 5 shows overall pre- and postexposure mean scores for the MSQ. The MSQ is a composite score summarizing many symptoms. A paired t-test, used to assess changes across pre- and postmeasures of symptomatology, revealed a statistically significant increase in symptomatology ($t = 11.29$, $df = 432$, $p < .001$). The results show that aviators who train in the CMS experience a marked change in motion sickness symptomatology over the course of a training session. These data are presented according to aviator group and seat in Table 6. For both aviator groups, there was a statistically significant increase in symptomatology from the pre- to postsimulator training.

Characteristic symptoms of sickness and asthenopia

Table 7 shows the self-reported incidence of the characteristic symptoms of motion sickness (drowsiness, sweating, nausea, dizziness with eyes open, vertigo, stomach awareness, and fullness of the head) and for the characteristic symptoms of asthenopia (eye strain, blurred vision, difficulty focusing, difficulty concentrating, and headache). The samples for each symptom exclude individuals reporting the symptoms prior to simulator exposure so that the proportions and frequencies are limited to those individuals who did not have the symptoms upon entering the simulator, but did have them when exiting. This particular method of presenting the data may underestimate the extent of the problem because different aviators may experience different symptoms, and others may experience an increase in a preexisting symptom--it is suggested this is one reason why the incidence rates in Table 1 generally are higher than those in Table 7.

In addition, for our survey, measures of characteristic motion sickness symptoms generally result in conservative values that may underestimate the magnitude of the problem. Aviators train in the simulator from 1 to 10 times during the qualification course and some individuals seemingly adapted or habituated to the simulator. It was not possible to correct these data by using an aviator's report of syllabus number

Table 4

Pre- and postexposure PET scores for student aviators and rated aviators by seat

	N*	Premean	Postmean	Difference mean	t	p
Test: WOFEC:						
Student aviators:						
Copilot	163	11.29	11.29	0.00	0.03	.980
Pilot	158	11.35	11.07	0.28	2.70	.008
Rated aviators:						
Copilot	43	11.65	10.70	0.95	3.61	.001
Pilot	41	11.73	10.46	1.27	3.97	.000
Test: SONLEC:						
Student aviators:						
Copilot	163	22.70	22.33	0.37	0.91	.370
Pilot	158	23.83	21.81	2.02	5.56	.000
Rated aviators:						
Copilot	41	23.68	22.76	0.92	1.13	.270
Pilot	40	22.57	20.48	2.09	2.43	.020
Test: SOPLEC:						
Student aviators:						
Copilot	163	22.99	22.27	0.73	2.06	.041
Pilot	158	23.45	22.00	1.45	4.14	.000
Rated aviators:						
Copilot	41	23.21	20.81	2.39	2.29	.030
Pilot	41	22.03	18.79	3.23	3.63	.001

* N = Number of observations

Table 5

MSQ mean, minimum/maximum scores, and Ns*

	Pre	Post
Mean	0.85	1.66
SD	1.30	1.59
Min-max	0.0-4.0	0.0-6.0
N	434	433

* N = Number of observations

Table 6

Pre- and postexposure diagnostic MSQ means for student aviators and rated aviators by seat

	N*	Premean	Postmean	Difference mean	t	p
Student aviators:						
Copilot	171	.73	1.54	.81	7.45	.000
Pilot	168	.98	1.74	.76	6.74	.000
Rated aviators:						
Copilot	43	.58	1.58	1.00	3.91	.000
Pilot	42	.93	1.95	1.02	3.86	.000

* N = Total number of observations for student aviators and number of cases for rated aviators

Table 7

Characteristic symptoms of motion sickness and asthenopia*

Primary motion sickness symptoms**	Percentage/Ratio
Drowsiness	9.1 (34/375)
Sweating	24.6 (97/394)
Nausea	5.8 (25/429)
Dizziness (eyes open)	1.4 (6/434)
Vertigo	1.2 (5/434)
Stomach awareness	5.2 (22/424)
Fullness of head	3.8 (16/419)
Eye strain related symptoms**	
Eye strain	24.3 (98/403)
Blurred vision	3.0 (13/434)
Difficulty focusing	9.3 (40/431)
Difficulty concentrating	8.4 (34/406)
Headache	14.0 (53/388)

* Percentages of those not reporting a symptom before exposure that report the symptom after exposure

** Total possible observations = 434

because of the multiplicity of other variables which occur during regular training (e.g., there were different time intervals between flights and different kinematics are known to occur in the same syllabus number). We propose this is an additional reason why the data reported here may be expected to be conservative estimates of the incidence.

The data in Table 7 are separated in Table 8 according to aviator group and seat. Data for student aviators suggest the severity of symptoms experienced largely is independent of seat occupied. However, for rated aviators, there is a general tendency for pilots to experience symptoms of greater severity than those experienced by the copilot-gunners.

Table 9 presents correlations obtained between selected pilot and simulator variables and indices of simulator sickness (i.e., post-MSQ scores, difference between pre- and post-WOFEC scores). Only correlations that were significantly different from zero at the .05 level have been included in the table. Correlations between scores obtained on Day 1 have been presented along with correlations between scores obtained for all days combined. Day 1 correlations were calculated because they may represent relationships between variables that exist before pilots have adapted to the nauseogenic aspects of the simulator. In general, though, the correlations obtained by either criterion revealed the same relationships.

Pilot variables: Although previous research (e.g., McGuinness, Bouwman, and Forbes, 1981) has found that pilots with greater flight experience have a greater likelihood of experiencing simulator sickness, this was not borne out in the present data. The number of flight hours in the last 2 months was not related to symptomatology and was inversely related to postural stability. That is, more flight hours were associated with greater postural stability. There was a trend for greater recent simulator experience to be associated with less symptomatology, as expected, since adaptation occurs. However, it was surprising that greater recent simulator experience was also associated with increased ataxia.

Not surprisingly, the number of hours of sleep was correlated negatively with pre-MSQ scores. That it was also associated with post-MSQ scores is in keeping with the view that pilots who are not in their usual state of fitness may be more susceptible to nauseogenic simulator stimuli (Kennedy et al., 1987a). Finally, MHQ scores were positively related to post-MSQ scores, indicating that pilots with more history of motion sickness are more likely to experience simulator sickness.

Simulator variables: A consistent finding in the simulator sickness literature (e.g., Crosby and Kennedy, 1982), and confirmed by the present research, is that longer simulator hops

Table 8

Characteristic symptoms* of motion sickness and asthenopia for student aviators** and rated aviators*** by seat

	Student aviators		Rated aviators	
	Copilot	Pilot	Copilot	Pilot
Primary motion sickness symptoms:				
Drowsiness	6.5%(10/155)	5.0%(7/141)	26.3%(10/38)	14.3%(5/35)
Sweating	24.4%(38/156)	29.1%(44/151)	14.3%(6/42)	27.8%(10/36)
Nausea	5.8%(10/170)	6.0%(10/166)	0.0%(0/44)	9.5%(4/42)
Dizziness (eyes open)	1.2%(2/171)	1.2%(2/168)	2.3%(1/44)	2.4%(1/42)
Vertigo	0.0%(0/171)	1.8%(3/168)	0.0%(0/44)	4.8%(2/42)
Stomach awareness	3.0%(5/166)	6.0%(10/166)	2.3%(1/43)	19.5%(8/41)
Fullness of head	0.0%(0/165)	3.8%(6/159)	15.9%(7/44)	7.1%(3/42)
Eye strain related symptoms:				
Eye strain	26.0%(42/162)	24.2(37/153)	14.3(6/42)	31.6%(12/38)
Blurred vision	1.2%(2/171)	3.6%(6/168)	2.3%(1/44)	4.8%(2/42)
Difficulty focusing	8.8%(15/170)	7.7%(13/168)	9.1%(4/44)	15.0%(6/40)
Difficulty concentrating	3.7%(6/162)	9.6%(15/156)	12.5%(5/40)	15.4%(6/39)
Headache	13.7(21/153)	17.7%(26/147)	9.1%(4/44)	7.7(3/39)

* Percentage of those not reporting symptoms before exposure that report the symptom after the exposure

**Total possible observations = 171 for copilots; 168 for pilots

***Total possible cases = 44 for copilots; 42 for pilots

Table 9

Correlations* of selected pilot and simulator variables with indices of simulator sickness (day 1/all days)

	PreMSQ	PostMSQ	WOFEC Diff. score
Pilot variables:			
Flight hrs last 2 months			-.21/-.19
Simulator hrs last 3 months		-.27/-.13	--/.11
Simulator hrs last 3 days			.17/--
Sleep	-.41/-.23	-.19/-.13	
Motion history questionnaire		.24/--	
Simulator variables:			
Time in simulator		.16/--	.17/--
Number of freezes		--/.11	.17/.14
Wait		--/.11	.19/--
Time waiting		--/-.24	-.61/-.32
Number of landings			.16/.11
Visual system disruption		.31/.17	.17/.18

* All correlation coefficients presented in the table are statistically significant at least at the .05 level.

are associated with greater ataxia and incidence of symptomatology. Also associated with simulator sickness was poor instrument control (i.e., collective, cyclic pitch, cyclic roll, and antitorque control) and freezing. Freezes, especially when turning and/or in the early stages of training, have been implicated as nauseogenic (Kennedy et al., 1987a). Possibly related to freezing is waiting in the simulator. Pilots who had to wait in the simulator for any reason were more likely to experience greater ataxia and report more symptomatology. Interestingly, for those pilots who had to wait, longer wait times were associated with less simulator sickness suggesting that time-outs may reduce simulator induced discomfort. The use of time-outs as a way to reduce simulator sickness has been mentioned previously (Kennedy et al., 1987a). Landings involve close ground interaction which has been implicated as contributing to sickness. The significant positive correlations between number of landings and ataxia supports the view that low level flight may be disruptive. Finally, disruptions in the visual system were associated with simulator sickness.

Figure 5 presents the postflight MSQ severity scores for aviators who completed their qualification course phase in the CMS according to the training syllabus. As might be expected, the figure indicates during the 10 flights there is adaptation as the aviators gain simulator experience in the CMS. Aviators generally report fewer symptoms as they fly the simulator more often. There is a general trend downward even though there are slight deviations from a decreasing function. It was expected this downward trend might be sharper than actually experienced.

Figures 6, 7, and 8 present the postflight ataxia test difference scores for the same student aviators. This preflight score minus the postflight score for the three tests, WOFEC, SOPLEC, and SONLEC, is used as an indicator of gain and loss of function, in this case, equilibrium. It should be noted there is an apparent loss of equilibrium that progresses over the course of flights. Following session four, the three tests indicate a general trend of a sustained level of a loss of equilibrium. In the earlier flights it would be expected that whatever effect was present would be masked by the learning that would be taking place, as seen in Thomley et al., (1986). This appears to be what has happened in these cases.

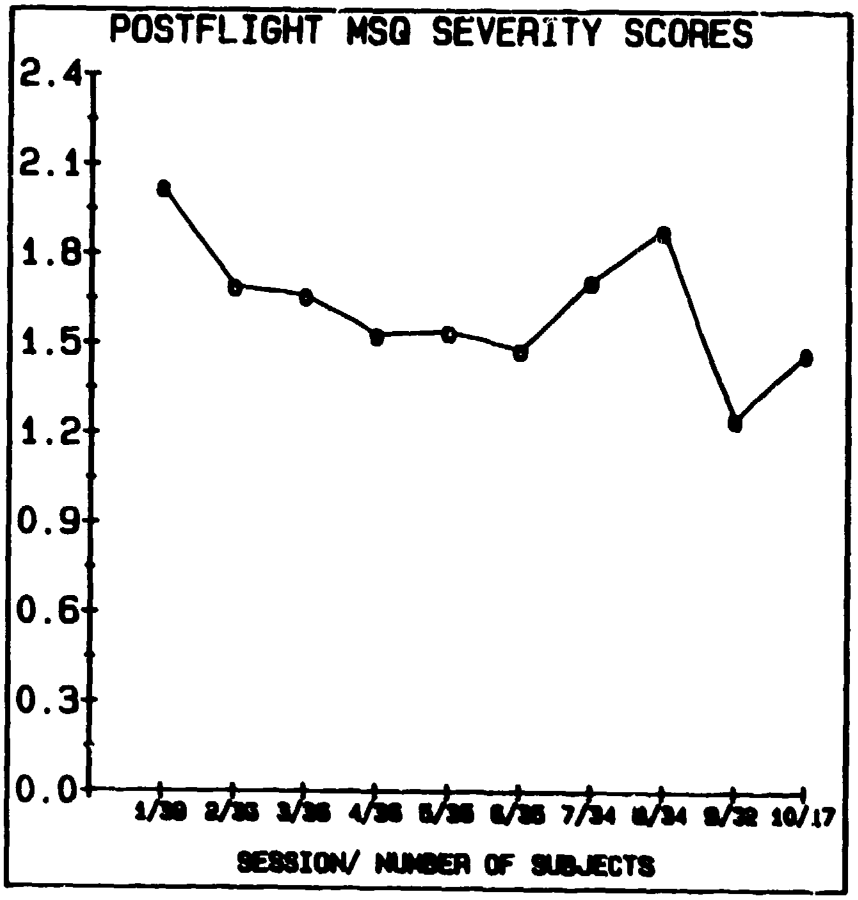

Figure 5. Postflight-MSQ severity scores for student aviators over 10 sessions in the CMS.

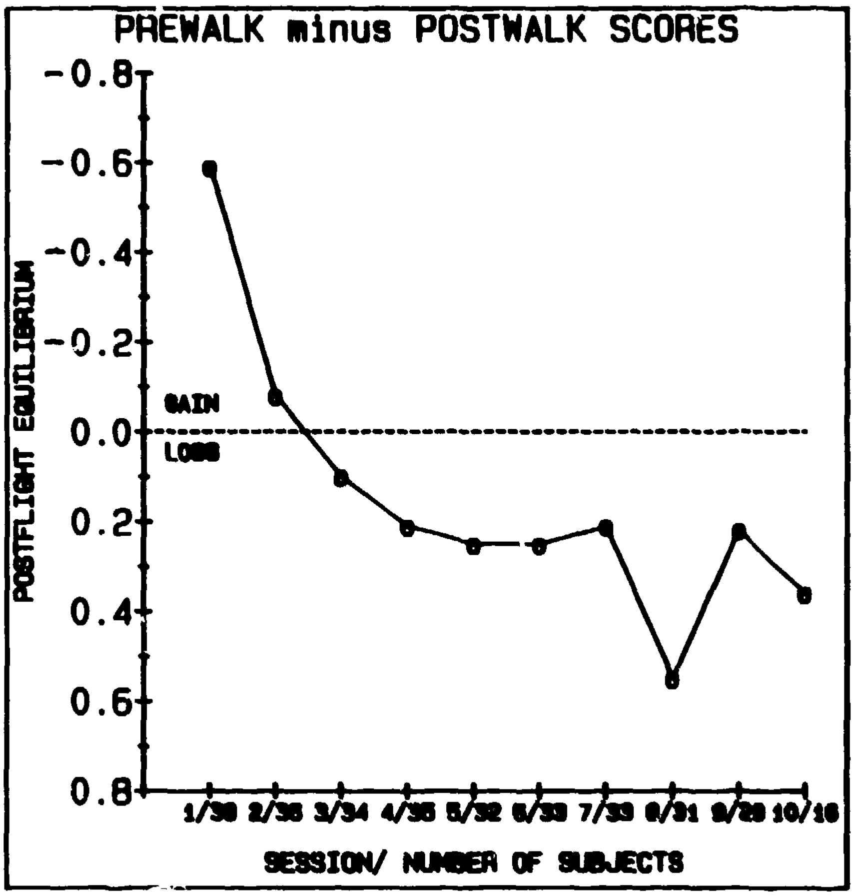

Figure 6. Preflight minus postscores (WOFEC) for student aviators over 10 sessions in the CMS.

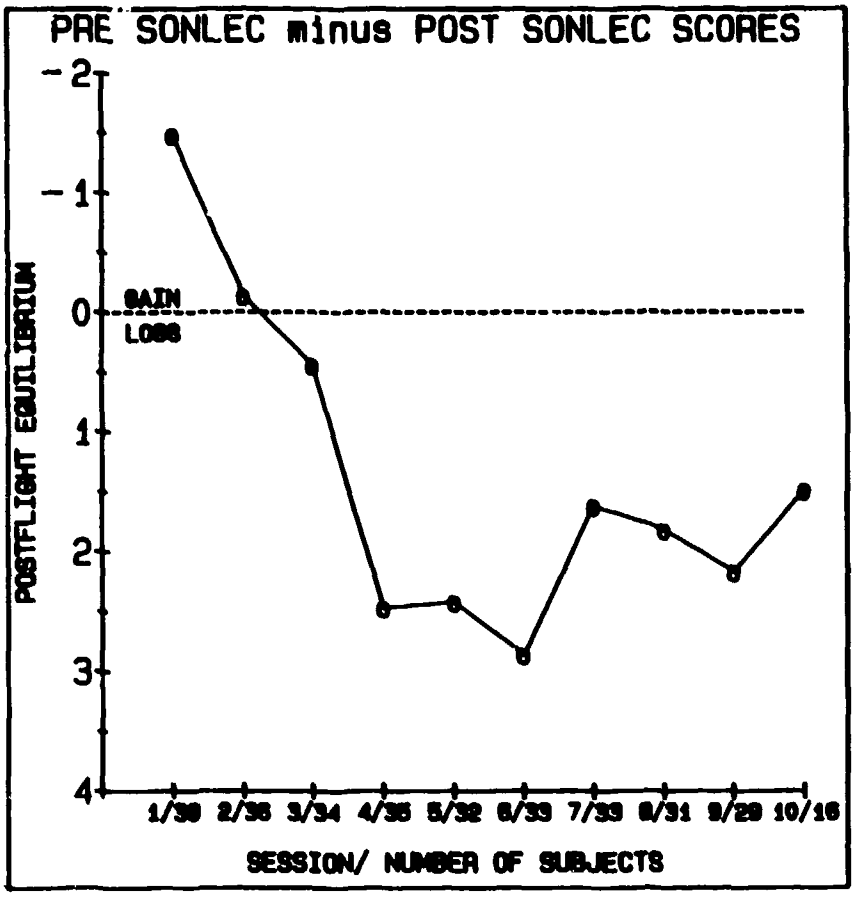

Figure 7. Preflight minus postflight scores (SONLEC) for student aviators over 10 sessions in the CMS.

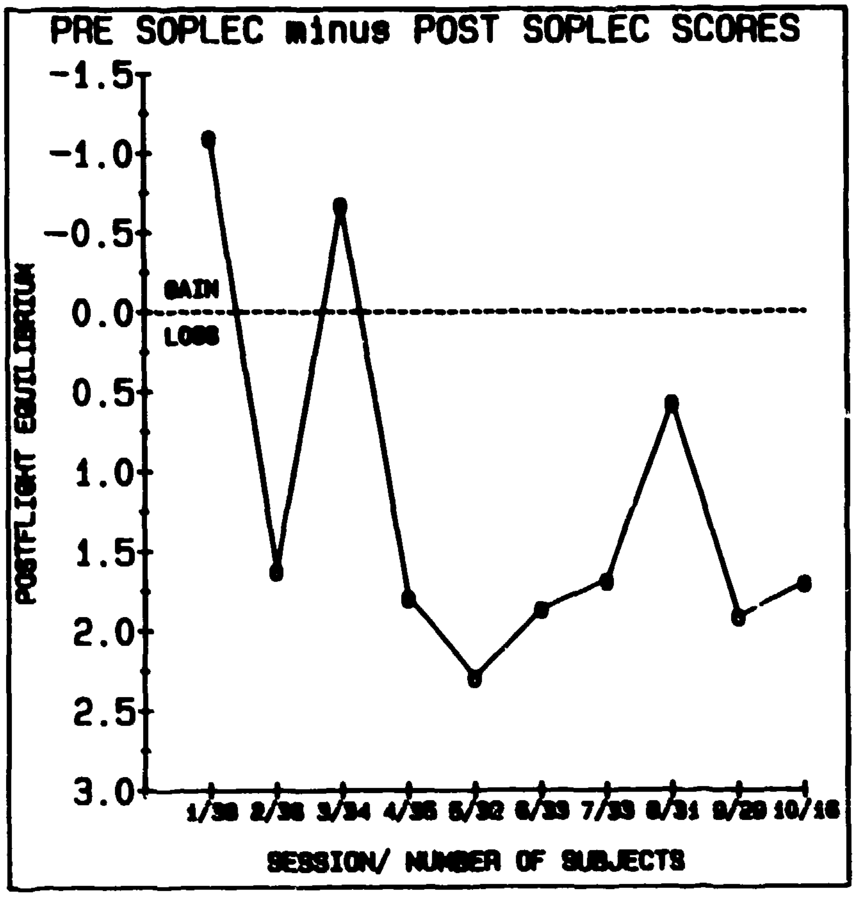

Figure 8. Preflight minus postflight scores (SOPLEC) for student aviators over 10 sessions in the CMS.

Discussion

The results of this Army study are clear. Simulator sickness symptomatology in the AH-64 CMS has shown an overall incidence from 434 observations of 44 percent, a value which is comparable to those reported by the U.S. Navy in their report of 10 different simulators (range = 12 to 60 percent).

The comparative percentages of symptomatology and eye strain in the two differing aviator populations reveal an almost equal amount of simulator sickness symptomatology in the "student" aviators versus the "rated" aviators when flying in the CPG seats, but there appears to be considerably greater incidence of sickness symptoms in "rated" aviators when flying in the pilot's seat. However, the pre- versus postmotion sickness symptomatology scores obtained in the present study are comparable with those of the Navy studies. These differences statistically were significant in the present study, and as indicated above, persons who flew in the pilot's seat appeared to be more affected than those with CPG exposures. Although these differences are small, it would appear they are real.

The postural equilibrium scores generally reveal a significant change from before to after flying in the simulator. These differences support the findings from the Navy study and imply aviators may be at some risk in activities which require balance and manual control after their flights. The individual findings for the different groups reveal that flying in the pilot seat may entail more visual/vestibular recalibration than after equal times in the CPG seat. Whether this is related to the increased amount of time spent in out-the-window activities is problematic, and should be studied further.

The comparison of the postural and symptomatology data in the student aviators who were followed over 10 flights is revealing in this regard: it appears while reported symptoms lessen with continued practice in the simulator, the amount of post adaptation phenomena evident through the ataxia performance implies aviators may be at greater risk in later sessions than earlier ones. The data suggest the price paid for this adaptation is decreased equilibrium. As the aviators' symptoms would appear to be lessening, perhaps their confidence in their own adaptability would be leading them to be less poised to attend to such aftereffects. In our opinion, such a relation could result in compromises to safety, both on the ground and in flight. We believe this should be examined in a larger population of aviators observed longer than the present 15-30 minutes postflight. It must be determined whether or not the duration of these postadaptation effects outlast the stimulus for a period greater than the aviators remained in the simulator building for this study.

Recent research shows not only do long-term simulator sickness effects from simulator exposure occur (Ungs, 1987), but they are far more prevalent than previously considered (Baltzley et al., in preparation). Analysis of the Kennedy et al., (1987b, in preparation) MHQ data (over 700 cases) reveal that of the pilots reporting symptoms (over 300), nearly 40 percent reported symptoms lasting longer than 1 hour, and 14 percent lasted longer than 6 hours.

In the CMS study, 65 pilots reported symptoms on the MHQ. Of these pilots, 21 had symptoms lasting longer than 1 hour, yielding a 35 percent long-term incidence rate. As noted in the report by Baltzley et al., these aftereffects have been grouped into three categories: vestibular, vagal, and visual. The vestibular category showed a 28 percent incidence for those that lasted longer than 30 minutes and 12 percent of those were longer than 1 hour. Had the aftereffects been largely eyestrain or headaches the percentages would not be so troublesome, however, this is not the case. There is reason to believe that these percentages are indicative of the type of aftereffects in the CMS.

It should be noted that these data are confounded by a subset of pilots who reported incidents of sickness from the AH-1 simulator, historically a very nauseogenic apparatus. This leads us to suspect a somewhat inflated percentage of long-term effects for the AH-64. However, the main point remains that if there is one case of disequilibrium problems or flashbacks lasting longer than 1 hour, there is a serious safety factor involved and one that must be addressed for all Army simulators, not just the AH-64 CMS. As shown in Appendix A, there are aftereffects of varying intensity and duration as reported by the aviators surveyed in interviews following the simulator flights.

The results of this study and the continuing dialogue among users of flight simulators will provide an ever-expanding database of simulator sickness experiences. Better design criteria and operational guidelines developed to alleviate the effects of simulator sickness also will be forthcoming. In the meantime, it is apparent that the problem of simulator sickness still exists with new and yet only partially understood ramifications. Managers and aviators alike should become aware of these and take appropriate action to insulate those at risk. The Navy has recommended when simulator sickness symptoms, including disequilibrium, are of sufficient magnitude, such individuals may be considered to be at risk to themselves and to others if they drive themselves home or return to demanding work activities. While simulator exposure in general did not produce gross changes in a person's cognitive or simple motor abilities, simulators induced unsteadiness afterwards. The Navy has recommended pilots should be indoctrinated early to identify whatever postural and symptom changes are occasioned by their simulator exposures and those pilots exhibiting identifiable unsteadiness and severe symptoms should remain in the simulator building until symptoms dissipate and perhaps restrict their flying for 1 day.

This is a prudent step to take in light of current data. It is recommended, therefore, as a result of this study some postflight restrictions should apply to those flying Army visually coupled simulators. For those aviators experiencing no symptoms following a simulator flight, a 6-hour period should elapse before actual flight at the controls of an aircraft. This recommendation is made because ataxia is often not accompanied by other symptoms or discomfort. For those aviators who experience symptoms, especially those accompanied by disequilibrium, it is recommended they remain in the simulator building until their symptoms subside and they also restrict their flying duties for the rest of the day.

These data suggest areas of future research. The results of the Navy survey have been used to provide suggestions and criteria for future simulator design, and recommendations are offered for simulator usage regimen. Incidence of simulator distress for the separate indicants (nausea, dizziness, eye strain, and ataxia) were indexed by simulator and equipment configuration. This approach appears to hold promise to diagnose the problem (e.g., alignment, inertial motion profile, cue asynchrony) since different symptom clusters may follow from different equipment features. Methodological considerations of surveys into simulator sickness (e.g., statistical power, effects of adaptation, individual differences, etc.) also are under investigation.

A list of guidelines for the alleviation of simulator sickness symptomatology has been published by the Navy. (Kennedy et al., 1987a) A similar set is in preparation by this organization in its continuing program in cooperation with the Navy. Further studies into other Army simulators are vital and an ongoing program of research into the phenomenon of simulator sickness is key to fully understanding its scope and implications.

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Appendix A

One shortcoming in using self-report instruments to gather data regarding a physiological phenomenon is the relatively "soft data" that is produced. As a result, the interaction between the investigator and the subject must be one of trust, understanding, and careful communication. One strong point of this type of research is the unique incidents that often are brought out during the interviews both pre- and postflight. The mention of aftereffects and the coping mechanisms used by the pilots involved in simulator flight are vital to more fully understanding the ramifications of this phenomenon. As has been mentioned before, there are two concerns about simulator sickness. One of these is on the ground and inflight safety and the other is the negative habit transfers to the actual aircraft that might occur. To illustrate these facts several incidents of aftereffects and their noted duration are noted below:

Note: The following are extracts of structured interviews with subjects taken at the simulator site and are quoted from the investigator's notes.

o I had mild stomach awareness and feelings that "my gyros had tumbled" for 3 to 4 hours after the flight.

o At 2200 hours, after a 0730 hours flight, I could close my eyes and feel the sensation of spinning and movement.

o The best way I could describe it is that after the flight I felt like I was coming down with a fever.

o I just didn't feel good for about 2 hours after the flight.

o Three-and-a-half hours after the flight I was walking out of my BOQ room and fell against the wall. I thought I was walking straight and was actually walking off balance.

o Two hours after the flight I had walked down the hall of the simulator building and felt like the walls were moving in and was disoriented. I leaned against the wall, blinked my eyes and "recalibrated my brain." I had a lingering feeling of discomfort the rest of the day.

o Felt like I was at "altitude" and I was tired throughout the day.

o I felt lightheaded for about an hour after the flight last night.

o I had feelings of "vertigo" for brief periods after the flight. (This was reported by the same individual for 3 days in a row.)

o I had a severe headache, went to bed early, slept 16 hours and still woke up with a mild headache.

o I can close my eyes and "flashback" to the visual scene in the cockpit. Some times this lasts up to 4 hours.

o I had real problems at Binghamton. Now, they don't last so long. I sometimes feel symptoms for an hour, some times as long as 4 hours after I fly.

o I really feel it after coming out. Normally, it lasts only an hour. (NOTE: This individual nearly fell down doing the Postural Equilibrium Test and reported that he felt bad up until bedtime at 2200 hours.)

o I had a strong feeling of "being in a small rowboat on the ocean" up until 2200 hours after my 1230 flight.

o I've had visual flashbacks after about 30 minutes.

o I had to pull off the road until I could feel staight enough to drive, that was in the AH-1 simulator.

Appendix B

Equipment manufacturers

Martin Marietta Orlando Aerospace Corporation
Orlando, FL 32813

McDonnell Douglas Helicopter Company
5000 East McDowell Road
Mesa, AZ 85205-9797

Singer Link Company
Binghamton, NY 13902

Honeywell, Inc.
1625 Zarthan Avenue, South
Minneapolis, MN 55416

Initial distribution

Commander
U.S. Army Natick Research
and Development Center
ATTN: Documents Librarian
Natick, MA 01760

Naval Submarine Medical
Research Laboratory
Medical Library, Naval Sub Base
Box 900
Groton, CT 05340

Commander/Director
U.S. Army Combat Surveillance
& Target Acquisition Lab
ATTN: DELCS-D
Fort Monmouth, NJ 07703-5304

Commander
10th Medical Laboratory
ATTN: Audiologist
APO NEW YORK 09180

Commander
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