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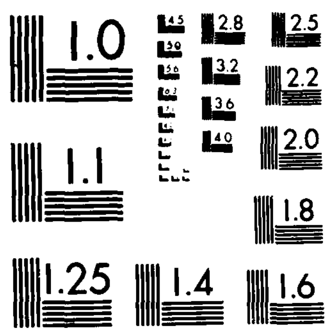

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VEHICULAR SIMULATOR-INDUCED SICKNESS, VOLUME III: SURVEY OF ETIOLOGICAL FACTORS AND RESEARCH FACILITY REQUIREMENTS

by

John G. Casali, Ph.D.
and
Walter W. Wierwille, Ph.D.

Human Factors Laboratory
Department of Industrial Engineering and Operations Research
Virginia Polytechnic Institute and State University

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A site survey of eight Naval and Marine flight training simulators was conducted to ascertain potential simulator design and procedural aspects with potential for influencing simulator-induced sickness. The results of this survey, described in this report, are catalogued in a set of seven tables including information on various simulator subsystems and simulator-induced sickness incidence. These tables include overviews of simulator visual systems, motion-cuing systems, motion-base parameters, cockpit interior systems, operator/training procedures, reported simulator anomalies, and simulator-induced sickness/aftereffects. Based on this survey, a listing of candidate simulator and operating procedure variables for study is provided. These variables were rated according to their priority for research and their feasibility for laboratory investigation as potential etiological factors in the provaction of simulator-induced sickness. Also provided is a listing of dependent measures amenable for use in research on simulator sickness. A variety of physiological, ataxia, psychomotor, perceptual, task performance, and self-report metrics are suggested. The last section of the report is devoted to the specification of a generic simulator facility aimed at the study of simulator-

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induced sickness. Suggested requirements for the visual, motion, and computational systems of such a facility are provided, with the intent of establishing an environment in which as many potential simulator design etiological variables as possible could be investigated.

SUMMARY

A site survey of eight Naval and Marine flight training simulators was conducted to ascertain potential simulator design and procedural aspects with potential for influencing simulator-induced sickness. The results of this survey, described in this report, are catalogued in a set of seven tables including information on various simulator subsystems and simulator-induced sickness incidence. These tables include overviews of simulator visual systems, motion-cuing systems, motion-base parameters, cockpit interior systems, operating/training procedures, reported simulator anomalies, and simulator-induced sickness/aftereffects. Based on this survey, a listing of candidate simulator and operating procedure variables for study is provided. The variables were rated according to their priority for research and their feasibility for laboratory investigation as potential etiological factors in the provocation of simulator-induced sickness. Also provided is a listing of dependent measures amenable for use in research on simulator sickness. A variety of physiological, ataxia, psychomotor, perceptual, task performance, and self-report metrics are suggested. The last section of the report is devoted to the specification of a generic simulator facility aimed at the study of simulator-induced sickness. Suggested requirements for the visual, motion, and computational systems of such a facility are provided, with the intent of establishing an environment in which as many potential simulator design etiological variables as possible could be investigated.

PREFACE

The original objective of this project was to establish a listing of simulator engineering design factors which exhibit potential for contributing to the inducement of sickness and aftereffects in simulator operators and instructors. The listing was "prioritized" in that the apparent criticality of each factor was rated with respect to its role in the provocation of sickness and separately, its feasibility for controlled laboratory study. Also, based on the list of factors, a proposed generic research simulator was configured to enable investigation of a number of the most cogent factors. In collecting background information for the listing, it became apparent that not only engineering design aspects of simulators should be considered, but procedural and operational practices as well. Therefore, a separate listing of these variables was added. Furthermore, while background information was being collected on a variety of training and research simulators and their penchant for inducing operator discomfort, it became necessary to organize the existing literature on simulator-induced sickness in systematic fashion. From this effort, it was possible to produce two additional reports from the research project, one constituting an overview of literature on simulator-induced sickness (Volume I of the final report), and the other constituting a selected, abstracted bibliography of references specific to simulator-induced sickness (Volume II of the final report). Both of these volumes should be beneficial to those embarking on the study of simulator-induced sickness or confronted with the problem from an operational standpoint. Volume I is specifically intended to be used in conjunction with this report.

This Volume (Volume III) draws heavily from the literature background information contained in Volume I and from data collected by the research team during simulator site visits. Also, as originally proposed, the results of NTSC Work Task 3775-1P2 by Mr. Joseph A. Puig, were to be a primary source of information on specific simulators for this project. Wherever possible, information from this report was included in cataloguing Naval and Marine flight simulator characteristics, though the site visits were found to be necessary to obtain much of the needed information. From the results of the site visits, a set of seven charts was constructed to catalogue, in detail, flight simulator characteristics of eight devices which were actually visited and three others devices for which a moderate amount of information was available from other sources. These charts were valuable in determining simulator design and procedural characteristics with potential for contributing to simulator-induced sickness. The questionnaires which were used to collect information for these charts are included as appendices to the report. An acronym glossary is also included.

ACKNOWLEDGMENTS

This report describes work conducted at Virginia Polytechnic Institute and State University for the Office of Naval Research, Arlington, Virginia, who provided funds through ONR Grant Number N00014-84-K0226. Special thanks are due Mr. Donald Woodward, who served as scientific officer, and LCDR Michael Lilienthal of the Naval Training Systems Center (NTSC) who worked closely with the research team on all phases of the project. The authors are indebted to LCDR Lawrence H. Frank of the Navy, Dr. Robert S. Kennedy of Essex Corporation, Dr. Michael E. McCauley of Monterey Technologies, Inc., and Mr. Joseph A. Puig of NTSC for their pioneering efforts in motion sickness and simulator-induced sickness. Mr. Richard Roesch of Virginia Tech is thanked for his work on the simulator sickness survey and Mrs. Sandy Dalton is extended sincere gratitude for her assistance in manuscript preparation.

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RESEARCH APPROACH

Flight Simulator Survey

A number of reports have noted that simulator-induced sickness is a polygenic problem, the etiology for which may emanate from a variety of simulator characteristics, both of an engineering design nature and of an operating procedures nature (e.g., Casali, 1981; Frank, Kellogg, Kennedy, and McCauley, 1983; McCauley, 1984). Due to their complexity, most flight and driving simulators exhibit a number of characteristics which may have the potential of inducing operator discomfort. Provocative characteristics may be manifested within several simulator subsystems including visual out-the-window scene representation, cockpit instrumentation, vestibular cuing, kinesthetic cuing, somesthetic stimulation, control feedback, auditory cuing, and cockpit environment (temperature, humidity, air exchange, etc.), or they may result from procedural aspects such as training mission intensity and duration.

Though the motion sickness and perceptual distortion literature points to certain factors that could be expected to be particularly influential, very little research has been conducted to determine which specific characteristics are truly provocative in the simulator. Because so many potential factors exist, the effect of each of them, or any combination thereof, cannot be assessed in a single study nor with a single existing simulator as a testbed. Therefore, it is necessary to choose the most salient and critical factors for initial study and this can only be accomplished after careful perusal of existing simulator facilities in conjunction with comparing the known sickness incidence rates for those facilities. Because a major objective of this project was to provide a suggested list of simulator variables for study, a survey of several military simulators was essential for cataloguing simulator design and usage characteristics which potentially contribute to simulator-induced sickness.

As originally proposed, this survey was to rely on the engineering design descriptions of Naval flight simulators provided in Work Task 3775-1P2 (Puig, 1984). This report proved to be quite useful for gleaning information regarding the visual display and motion cuing systems of several devices known to induce sickness. From the results of Puig's overview and from previous laboratory research at Virginia Polytechnic Institute and State University (VPI&SU), it became apparent that a multitude of factors could potentially influence simulator discomfort and aftereffects. Therefore, early in the project, it was deemed necessary to increase the scope of the originally planned simulator survey to tap additional simulator characteristics other than those covered in existing simulator documentation.

After discussions with LCDR Michael Lilienthal of the Naval Training Systems Center (NTSC), it was decided that a questionnaire approach to the survey would be attempted. The questionnaire survey was intended to obtain current information on the simulators, as it was realized that some devices had undergone modification or were employed in slightly different uses than those specified in the descriptions from the 1980 Directory of Naval Training Devices (Puig, 1984). The simulator survey questionnaire shown in Appendix I was devised at VPI&SU and copies were sent to NTSC in December, 1984 for distribution to 20 Naval simulator sites. The questionnaire was designed with the intent that questions regarding simulator hardware and operational characteristics could be answered by NTSC on-site personnel, such as field engineering representatives and simulator flight instructors. To remain within the project schedule, it was requested that the questionnaires be returned within two months to allow for cataloguing and analysis of responses. Unfortunately, even with the distribution of questionnaires coordinated through NTSC, response to the survey was poor. In fact, after a period of almost two and one-half months, only one of 20 questionnaires had been completed and returned. Therefore, it was necessary for the research team to institute a third strategy for obtaining information on various simulators.

Simulator Site Visits

When it became apparent that the self-report questionnaire approach would not yield sufficient data, the research team began to assemble an outline of simulator characteristics, drawn from the questionnaire, to use as a basis for interviewing personnel and documenting information during actual training facility site visits. This outline appears as Appendix II.

Selection of simulators. Again with the cooperation of LCDR Michael Lilienthal of NTSC, arrangements were made for the research team to visit eight Naval and Marine flight simulators to gather information on simulator characteristics, usage practices, and anecdotal data on trainee and instructor sickness. In contrast to the originally attempted questionnaire survey, it was not feasible to conduct an exhaustive on-site survey of all existing Naval flight simulators due to time and funding constraints. Therefore, a listing of Naval simulators was scrutinized and eight flight simulators located on the East Coast were selected for review. These eight were selected on the basis of several factors. First, it was desirable to sample as many different types of simulators as possible so that a spectrum of design characteristics could be contrasted with respect to their association with simulator-induced sickness. The eight simulators included two fighter jet simulators (device 2E6/aircraft F-14 or F-4; 2F112/F-14A), one turboprop electronic warfare/tactical aircraft simulator (2F110/E-2C), one attack jet simulator (2F122/A-6E), three helicopter simulators (2F106/SH-2F; 2F117/CH-46E; 2F121/CH-53D), and one V/STOL (Harrier) simulator (2F133/AV-8B). (An acronym glossary for the abbreviations used throughout this report appears on page 145 of this report.) The 2F133 V/STOL device was quite new so the information on it was limited in contrast to the other devices sampled. Among these eight simulators, a number of design differences existed, e.g., fixed-base versus moving-base platforms, projection versus infinity-optics visual display systems, and field-of-view differences.

Another factor impinging on the selection of these particular simulators was that simulator-induced sickness incidence data existed for most of them or for their identical counterparts on the West Coast. Quantification, rather than just anecdotal evidence, of the simulator-induced sickness problem was desirable so that simulator characteristics could be compared with respect to their penchant for inducing operator discomfort on a relatively common scale. Most of the sickness incidence data was obtained from an on-going field study directed by Dr. R. S. Kennedy of Essex Corporation for the Navy, for which preliminary results appear in Kennedy, Dutton, Ricard, and Frank (1984). Other sources of incidence data are noted in the simulator-induced sickness tables to follow.

Site interviews. Final arrangements were made by NTSC for a research team from VPI&SU to visit the eight simulator sites during a three-week period in March 1985. During each site visit, the research team concentrated on completing as much of the outline of simulator characteristics (Appendix II) as possible, so that the various simulators could be documented and later catalogued in tables (1 through 7 herein), on a common scale. Information was obtained at each simulator site from as many individuals working in various capacities as possible. Interviews with these personnel were coordinated by the NTSC field engineering representative at each site. Information was obtained from the field engineers themselves, maintenance personnel, operational staff (e.g., computer operators), flight instructors, flight trainees, and in some cases, simulator manufacturing personnel.

Whenever, possible simulator information pertaining to engineering design characteristics were obtained from the field engineering, operations, and maintenance personnel. Furthermore, because they represented the most current available written source of information, the documents of Puig (1984) and Hendley (1984) were used to obtain display field-of-view dimensions (Puig), visual display imaging techniques (Hendley), motion base parameters (Puig), and various other data regarding the physical nature of the simulators. Interviews with experienced flight instructors were particularly valuable in gleaning information about operational aspects of the simulators, including aircraft control fidelity, training scenarios, mission intensities, flight durations, and operating practices. Instructors and trainees relayed their experiences with simulator-induced sickness and aftereffects and these comments were recorded by the research team. Whenever possible for each simulator, instructors and trainees were queried as to their perceptions of the device's fidelity in the various subsystems and were asked to discuss any potential anomalies inherent in the simulation that they noticed during use. Because the flight instructors were usually quite familiar with the simulators, as a result of their frequent use of the devices and observation of numerous trainees, they were perhaps the best source for targeting potential sickness-provocative characteristics exhibited by the simulators. Therefore, much of the tabled information on simulator anomalies and simulator-induced sickness/aftereffects is based on the instructors' responses.

Simulator site experiences. In each simulator except the 2F112, which was not operational during the site visit, the research team members either flew or rode as passengers for an extended flight through a full range of maneuvers. This actual experience proved to be quite valuable for gaining insight into the sickness problem. Whenever possible, the demonstration flights were conducted so that maneuvers known to the instructor pilots to be sickness provocative were presented. These included such maneuvers as inverted flat-spins in the 2E6 Air Combat Maneuvering (ACM) simulator and violent yaw excursions simulating tail rotor failure in the 2F121 helicopter trainer. Information gleaned from the research team's experiences with the simulators included data on the cockpit interior systems, procedures used during training missions (as observed from the back-seat), and noticeable simulator anomalies and distortions.

The research team's personal experiences with simulator-induced sickness were not included in the information table on simulator-induced sickness and aftereffects (Table 7), because it was felt that their perceptions of symptoms would have largely been pre-biased by previous interviews with trainees and instructors. It should be noted, however, that neither research team member experienced acute sickness nor profound aftereffects in response to any of the simulator experiences. One member (R. Roesch) felt dizziness and mild disorientation during a number of flights in various devices but had no major discomfort. The other member (J. Casali) experienced no symptoms save for an aftereffect of mild dizziness following a flat-spin in the 2E6. Both members noticed eyestrain after flying with a computer-generated image (CGI) display, capable of enriched scene content, in the 2F117 and 2F121 devices for extended periods of time. These effects should be considered as quite mild in relation to those reported by some other simulator users.

SIMULATOR CHARACTERISTICS TABLES

Following the simulator site visits, the information collected was compiled in a set of seven tables so that simulators could be compared against each other with respect to their design characteristics, operating procedures, potential anomalies, and tendency to induce (and conditions of) operator discomfort. Again, simulator characteristic information included in the tables was obtained from a variety of sources, including the site interviews, research team's observations, and documentation in Puig (1984), Hendley (1984), and the Directory of Naval Training Devices (1980-see Puig, 1984), so it was not possible to specifically reference the source of each detail of information included. All information included is believed to be accurate, but of course, because a portion of it is based on flight instructors', trainees', and operating staff members' personal experiences related during the interviews, there is potential for some variability in tabled entries. However, in the interest of conveying the maximum amount of information available to the reader, the results of the site visit interviews are included as fully as possible.

In compiling the seven tables, the information on each simulator was separated as follows: Table 1--visual systems, Table 2--motion cuing systems, Table 3--motion base parameters, Table 4--cockpit interior systems, Table 5--operating/training procedures. Table 6--apparent and/or reported simulator anomalies, and Table 7--simulator-induced sickness/aftereffects. The eight simulators which were visited by the research team are represented in detail in each of these seven tables. When information under a particular column heading was not available, the term "unk." (unknown) appears as the tabled entry, while if a particular column was not applicable to a certain simulator, a "dash" appears as the entry. In addition to the simulators which were site-visited, three other devices for which a limited amount of data were available are included in the tables for informational purposes. These devices include the 2E7/F-18 fighter jet simulator, the 2F64C/SH-3H helicopter devices, and the 2F87F/P-3C anti-submarine warfare/patrol aircraft devices. Most of the information for these three devices was obtained from Puig (1984) and Hendley (1984). In each of the tables that follow, the row margins apply to the individual simulators while the column headings list simulator characteristics under each major subsystem. Following each table is a brief description of column headings which should be referred to in using the table. Again, the simulator acronyms (e.g. ACM) are explained in a glossary at the end of the report.

Table 1. Simulator Visual Systems

Simulator-Aircraft-Mission	Locations	Image Generation System-Manufacturer	Iteration Rate in Hz	Display Imaging Method	Display Medium	Total Field-of-View	Crewmember Effective Field-of-View	Approx. Viewing Distance	Number of Displays & Channels	Cockpit Windows	Scene Luminance Conditions (est.)	Scene Contrast Conditions (est.)	Scene Motion
2F6/F-14,F-4/ACM Fighter (pt-light source imaging system slated for update to projected CGI)	Oceana, VA*	pt-light source projection for sky/earth, TV camera model for target A/C, projector for missiles & flares-(McDonnell-Douglas A/C)	30 Hz est. for TV projection system	pt-lights through 2 separate sky/earth transparent globes (1 projector unit), CCTV camera & 4 projectors for targets	spherical screen dome of 40 ft. dia.	350°H, 280°V	350°H, 290°V for pilot and RIO	20 ft.	n/a for sky/earth, 2 targets can be displayed at once	A/C canopy used	reports of dim appearance, appears true for dusk, dawn & daylight also night capa.	sky/earth-low contrast (as at altitude), targets can have high contrast against bkgd.	sky/earth appear to have pitch, roll, yaw, & limited long., targets have full 6 d-o-f
2F110/E-2C/OFT AEW/Tactical	Norfolk, VA* Miramar, CA	digital CGI-(Rediffusion Novoview SP1)	30 Hz	hybrid calligraphic/raster scan CRT	CRT, folded on-axis virtual image via beamsplitter (& optics)	139°H, 35°V	~ 44°H, 34°V for each display, pilot & copilot each use 1 front window, pilot also has 2 side windows	~ 2 ft. (instructors report that it is apparent CRT is close because of edges)	1 ch for 2 front windows, 1 ch for each side window	6 windows: 2 on copilot side have blinders	dusk & night, variable ground fog & scud fog	relatively high contrast possible	full 6 d-o-f
2F112/F-14A/WST Fighter	Oceana, VA* Miramar, CA	pt-light source projection for sky/sea, TV camera-model for target A/C, frigate, missiles, SAM, projectors for missiles- (McDonnell-Douglas A/C) digital CGI carrier for landing- (McDonnell-Douglas Elec. Vital IV)	30 Hz est. for TV projection system	pt-lights through 2 separate sky/sea transparent globes (2 projector units), CCTV camera & 4 projectors for targets, TV projector for carrier	spherical screen dome of 40 ft. dia.	350°H, 280°V	350°H, 280°V for pilot and RIO	20 ft.	n/a for sky/sea, 2 targets can be displayed at once, CGI carrier-1 ch	A/C canopy used	dusk, dawn, daylight, night for carrier landing, fog	sky/sea-low contrast, targets & ships can have high contrast against bkgd.	sky/sea appear to have pitch, roll, yaw, & limited long., targets have full 6 d-o-f

* charted data on this location

unk. = unknown
-- = not included or not applicable

	Relative Display Complexity/Detail	Displayed Objects	Display Relevance to Training Mission	Display Depth Cuing
	low detail representing high altitude, models detailed but white/grey only, sky/earth (brown & blue)	3 friendly & 3 enemy A/C, targets: 1 or 2 A/C at a time with variable dynamics, missiles: shoot, fly & strike, flares, luminance of targets is adjustable, clouds	display features relevant to: part-task ACM, air-air weapons delivery training	limited depth cuing, some apparent long. translation, relative size of targets change
	moderate detail possible using light points, several colors	mountains, coastline, carrier, field runway, runway lights	display features relevant to field & carrier takeoff/landing training	shading, relative object size, runway markings, line convergence, synthetic texturing capa.
	low bkgd. detail, detailed models, bkgd.-all colors, green targets	model A/C targets & frigate, model & CGI carrier, SAM, missiles: shoot, fly & strike, luminance of target is adjustable, clouds	display features relevant to: carrier takeoff/landing, air-air & air-water weapons delivery, (extensive IFR training done w/o visuals)	limited depth cuing, some apparent long. translation, relative size of targets & carrier changes, size & perspective of CGI carrier changes on approach

Table 1. Simulator Visual Systems. (Continued)

Simulator-Aircraft-Mission	Locations	Image Generation System-Manufacturer	Iteration Rate in Hz	Display Imaging Method	Display Medium	Total Field-of-View	Crewmember Effective Field-of-View	Approx. Viewing Distance	Number of Displays & Channels	Cockpit Windows	Scene Luminance Conditions (est.)	Scene Contrast Conditions (est.)	Sc
2F122/A-6E/NCLT Attack	Oceana, VA* Whidby Island, WA	digital CGI-(Rediffusion Novoview SP1)	30Hz	calligraphic CRT	CRT, folded on-axis virtual image via beamsplitter (no optics)	48°H, 36°V	48°H, 36°V for pilot & BN, pilot & BN each use 1 front window (don't share)	~ 2 ft.	1 ch for 2 front windows	4 windows: 2 quarter windows have blinders, the addition of side window displays being evaluated	dusk & night, variable fog, scud fog	relatively high contrast is possible	fu
2F106/SH-2F/WST Helicopter	Norfolk, VA* North Island, CA	digital CGI-(McDonnell-Douglas Elec. Vital III)	30Hz	calligraphic CRT	CRT, folded on-axis virtual image via beamsplitter (no optics)	144°H, 32°V	44°H, 30°V approx. for pilot & co-pilot, pilot & copilot each use 1 front, and 1 side window	~ 2.5 ft.	1 ch for 2 front windows, 1 ch for each side window	8 windows: 2 front & 2 quarter have displays, other 4 have blinders	night only	relatively high contrast is possible, reported 50:1 contrast ratio	fu
2F117/CH-46E/OFT Helicopter	New River, NC* Tustin, CA	digital CGI-(Rediffusion STS) (shared with 2F121)	30Hz	raster CRT	CRT, folded on-axis virtual image via beamsplitter (no optics)	~ 200°H, ~ 50°V & pilot's chin window	all displays intended for pilot only, copilot can view some displays but they are distorted & hardware is visible	~ 2.5 ft.	5 ch for each of 5 windows & 1 ch for pilot's chin window	3 front & 2 side windows with displays, pilot's chin window with display, 2 ceiling & copilot's chin window w/o displays	dusk, night, daylight, variable fog, weather	relatively high contrast is possible	fu

* charted data on this location

unk. = unknown

-- = not included or not applicable

	Relative Display Complexity/Detail	Displayed Objects	Display Relevance to Training Mission	Display Depth Cuing
	moderate detail possible using light points, several colors	coastline, carrier, ship, runway, horizon lights, runway lights, cloud coverage	display features relevant to carrier takeoff/landing training at night	shading, relative object size, runway markings, horizon light luminance changes, line convergence, synthetic texturing capa.
	moderate detail possible using light points, several colors	field, carrier, & destroyer landing sites, runway, runway lights, air and surface, targets, tower lights, sonobouys, smoke markers, cloud coverage	display features relevant to: carrier, destroyer, & field takeoff/landing, ASW, anti-ship missile defense, cargo handling & rescue training	shading, relative object size, runway markings, line convergence
	high detail possible, 6500 edges, several colors	coastline, whitecaps, field, confined area, carrier, LPH & LST landing sites, runway, runway markings, runway lights, ship wake, loading cubes, bldgs., tower, rotor, rotor lights, ground objects, other helos. for formation flight	display features relevant to: field, confined area, & ship takeoff/landing, in-flight normal and emergency procedures, & maneuvering training	shading, relative object size, runway markings, line convergence

Table 1. Simulator Visual Systems. (Continued)

Simulator-Aircraft-Mission	Locations	Image Generation System-Manufacturer	Iteration Rate in Hz	Display Imaging Method	Display Medium	Total Field-of-View	Crewmember Effective Field-of-View	Approx. Viewing Distance	Number of Displays & Channels	Cockpit Windows	Scene Luminance Conditions (est.)	Scene Contrast Conditions (est.)	Sce No
2F121/CH-53D/OFT Helicopter	New River, NC*	digital CGI-(Rediffusion CT5) (shared with 2F117)	30Hz	raster CRT	CRT, folded on-axis virtual image via beamsplitter (no optics)	~ 200°H, ~ 50°V & pilot's chin window	all displays intended for pilot only, copilot can view some displays but they are distorted & hardware is visible	~ 2.5 ft.	5 ch for each of 5 windows & 1 ch for pilot's chin window	3 front & 2 side windows with displays, pilot's chin window with display, 2 ceiling & copilot's chin window w/o displays	dusk, night, daylight, variable fog, weather	relatively high contrast possible	[illegible]
2F133/AV-8B/OFT VSTOL	Cherry Point, NC*	digital CGI-(McDonnell-Douglas A/C)	unk.	raster (modified General Electric lightvalve projection, 1 projector for each screen)	5 flat screens butted together in arc	~ 210°H, ~ 90°V	~ 210°H, ~ 90°V	~ 20 ft.	5 flat screens each with 1 ch	A/C bubble canopy used	dusk, night daylight, variable fog, weather, lightning	high contrast possible both in luminance & chrominance	[illegible]

* charted data on this location

unk. = unknown

-- = not included or not applicable

	Relative Display Complexity/Detail	Displayed Objects	Display Relevance to Training Mission	Display Depth Cuing
	high detail possible, 6500 edges, several colors	coastline, whitecaps, field, confined area, carrier, LPH & LST landing sites, runway, runway markings, runway lights, ship wake, loading cubes, bldgs., tower, rotor, rotor lights, ground objects, other helos. for formation flight	display features relevant to: field, confined area, & ship takeoff/landing, in-flight normal and emergency procedures, & maneuvering training	shading, relative object size, runway markings, line convergence
	high detail & complexity possible, streaming in periphery for velocity cues	coastline, field & carrier landing sites, runway, runway markings, obstructions on carrier, ground texture, whitecaps, lightning, sun, stars, other ships & A/C, ship wake, bldgs.	display features relevant to: carrier, field, & confined area conventional takeoff/landing & VSTOL training	shading, relative object size, runway markings, line convergence, synthetic texturing capa.

Table 1. Simulator Visual Systems. (Continued)

Simulator-Aircraft-Mission	Locations	Image Generation System-Manufacturer	Iteration Rate in Hz	Display Imaging Method	Display Medium	Total Field-of-View	Crewmember Effective Field-of-View	Approx. Viewing Distance	Number of Displays & Channels	Cockpit Windows	Scene Luminance Conditions (est.)	Scene Contrast Conditions (est.)
2E7/F-18/WTT Fighter	Lemoore, CA	synthesized sky/earth bkgd. using IMI image gen., digital CGI for targets-(Rediffusion CT5)	sky/earth-60Hz, targets-30 Hz	raster (TV projectors for sky/earth, 4 TV projectors for targets)	spherical screen dome of 35 ft. dia.	~ 360°H, ~ 150°V	~ 360°H, ~ 150°V	~ 20ft.	2 sky/earth ch, 2 target ch	canopy	dusk, night, daylight, other conditions unk.	unk.
2F64C/SH-3H/WST Helicopter	North Island, CA Jacksonville, FL	digital CGI-(McDonnell-Douglas Elec. VITAL IV)	30Hz	calligraphic CRT	CRT, folded on-axis virtual image via beamsplitter (= optics)	~ 130°H, ~ 30°V, & pilot's chin window	unk.	unk.	5 ch divided over 7 windows (1 chin)	front & side windows with displays, 1 chin window with display, ceiling windows w/o displays	dusk, night	unk.
2F87F/P-3C/WST ASW/Patrol	Barber's Point, HI Brunswick, ME	digital CGI-(McDonnell-Douglas Elec. VITAL IV)	30Hz	calligraphic CRT	CRT, folded on-axis virtual image via beamsplitter (= optics)	~ 48°H, ~ 36°V	pilot & copilot each view 1 front display, copilot also has 1 side display	unk.	3 ch divided over 5 windows	3 front & 2 side windows with displays, monochrome CRT for flight eng. VFR display	dusk, night	unk.
	Jacksonville, FL Moffett Field, CA	TV camera-model board-(Rediffusion Duoview)	30Hz	CRT	CRT, off-axis reflective = optics	~ 48°H, ~ 36°V	unk.	unk.	unk.	unk.	dusk, night, daylight	unk.

* charted data on this location

unk. = unknown

-- = not included or not applicable

	Relative Display Complexity/Detail	Displayed Objects	Display Relevance to Training Mission	Display Depth Cuing
	unk.	friendly & enemy A/C, targets: enemy A/C & missiles, other objects unk.	display features relevant to: weapons tactics training, air-air & air-ground weapons delivery, ACM, ECM, normal & emergency procedures training	unk.
	high detail and complexity possible	unk.	display features relevant to: ship & field takeoff/landing, search & rescue, ASW, & tactical mission training	unk.
	high detail and complexity possible	unk.	display features relevant to: field takeoff/landing, ASW, IFR, normal & emergency procedures, & tactical mission training	unk.
	high detail on model board	unk.	(same)	relative object size changes, other unk.

Simulator Visual Systems (Headings--Table 1.)

Simulator-aircraft-mission. This heading refers to the commission designation of the simulator (e.g., 2E6), the actual aircraft being simulated (e.g., F-14), and the training mission of the simulator (e.g., ACM-Air Combat Maneuvering, OFT--Operational Flight Trainer, WST--Weapons Systems Trainer, NCLT--Night Carrier Landing Trainer, WTT--Weapons Tactics Trainer-see also glossary). Also, the type of aircraft (e.g., fighter) is specified. This column is the same for all tables 1 through 7.

Locations. Under this heading, the geographic location for each simulator is specified. In some cases, more than one example of a particular simulator exists, sometimes at different sites. In these cases, the simulator location at which the tabled information was obtained is denoted by an asterisk. This column information is the same for all tables 1 through 7.

Image generation system--manufacturer. In this column, the means by which the visual display image is generated is indicated. Among those devices surveyed, three different image generation systems are used. These include digital computer-generated image (CGI--incorporating either CRT or projection screen presentation), point-light source projection through transparency, and closed-circuit television (CCTV) model board imaging. Also, the image generation system manufacturer and model number are noted.

Iteration rate. This rate applies to those simulators incorporating video CCTV or CGI systems and refers to the frequency at which a new "frame" of video information is written.

Display imaging methods. This column denotes the method by which the visual system image is displayed (not generated) or produced in view of the operator. That is, cathode ray tube images may be "drawn" in calligraphic or raster scan fashion, point-light images result from projection of a light source through a transparency (usually in the shape of a sphere) onto a curved screen or dome, and model board images may be displayed via TV projection or on raster CRTs.

Display medium. In this column, the actual physical medium for conveying the visual image, be it real or virtual, is specified. Categories include spherical screens in the form of domes, curved screens, and refractive (e.g., fresnel lens) or reflective (e.g., spherical mirror) infinity-optics CRT display media.

Total field-of-view. This measurement reflects the total horizontal and vertical field-of-view in degrees, defined by the angles subtended by the edges of the display at the eye, when a typical operator would be seated at a centered design eye position. The field-of-view sizes were obtained from Puig (1984) and from on-site engineers.

Crewmember effective field-of-view. Wherever possible, the display field-of-view (horizontal and vertical) from each crewmember's seat (rather than a centered position) is specified. Of course, for some in-line tandem seat cockpits, such as that in the 2E6, the total field-of-view is approximately equal to the field-of-view for each crewmember.

Approximate viewing distance. This distance is the approximate length in feet from the design eye position to the physical display center, along a perpendicular line-of-sight. In some cases this measure was available from the simulator specification manuals while in others it was estimated by the simulator operating personnel.

Number of displays and channels. For the CGI and CCTV-based visual systems, the number of video channels is specified along with the number of separate displays which they feed. Also, where possible, the assignment of displays to cockpit windows is given.

Cockpit windows. In this column, the number of cockpit windows or type of cockpit enclosure is specified.

Scene luminance conditions. The sky/earth lighting condition capabilities are given as dusk, dawn, daylight, night, etc. This information was obtained by direct observation and from Hendley's (1984) survey information on certain visual systems.

Scene contrast conditions. A general subjective estimate of display contrast capabilities is given in this column for each simulator.

Scene motion. The degrees-of-freedom of visually-depicted motion inherent in the displayed scene are specified. These include angular accelerations (pitch, roll, yaw) and translational accelerations (lateral, longitudinal, vertical).

Relative display complexity/detail. In this column, a general, relative (to the other observed simulators) estimate of visual system scene detail capability is given. For instance, point-light source transparency projection of high-altitude situations tends to be relatively impoverished while CCTV model-board and CGI displays depicting low-altitude daylight flight may present considerable detail. Furthermore, detail and complexity may vary greatly within a particular visual system, depending upon the desired flight scenario.

Displayed objects. A general listing of displayed objects (other than the sky/earth background) is presented in this column.

Display relevance to training mission. Here, a brief listing of major training mission aspects for each simulator is provided.

Display depth cuing. A general indication of display features which provide depth cue impression is included.

Table 2. Simulator Motion Cuing Systems.

Simulator-Aircraft-Mission	Locations	Motion-Base Type, Manufacturer	Degrees of Freedom	Excursion Limiting Methods	Acceleration Cuing Logic	Anecdotal Motion-Base Infidelities	g-seat g-suit	Restraint Belt Tensioning	Control/Cockpit/Seat Vibration	Control/Cockpit/Seat Buffet	g-force Display Dimming	Control Loading Changes
2E6/F-14,F-4/ACM Fighter	Oceana, VA*	fixed-base	--	--	--	--	g-suit (pressurized slightly at 1g), g-seat, neither used often	lap belt tightening-not used	control stick vib: 3-45Hz	control stick buffet, rudder shake, seat buffet: 3-45Hz	yes, scene & instruments dimmed with high g	loading increased with g
2F110/E-2C/OFT AEW/Tactical	Norfolk, VA* Miramar, CA	synergistic Reflectone	full 6 d-o-f	computer-control, limit switches on hydraulic rams	washout algorithm with nulling in all d-o-f	Infrequent hydraulic bump reported, reported overly sensitive in longitudinal motion, some PIO reported (by instructors)	none	none	control stick vib, whole cockpit vib due to runway wire arrestment & catapult	cockpit buffet, rudder shake	none	loading increased with g
2F112/F-14A/WST Fighter	Oceana, VA* Miramar, CA	fixed-base	--	--	--	--	g-suit (pressurized slightly at 1g), g-seat, neither used often	none	control stick vib	control stick buffet, rudder shake, seat buffet	yes, entire scene & instruments dimmed with high g	unk.
2F122/A-6E/NCLT Attack	Oceana, VA* Whidby Island, WA	cascade (paddle) Secor	3 d-o-f: roll, and yaw; yaw & lateral coupled, pitch & vertical coupled	computer-control, limit switches on hydraulic rams	washout algorithm with nulling	Infrequent hydraulic bump reported, coupling of d-o-f, relatively small yaw and pitch excursions	none	none	whole cockpit vib, due to touchdown bump, wire arrestment, catapult	cockpit buffet	none	unk.
2F106/SH-2F/WST Helicopter	Norfolk, VA* North Island, CA	synergistic Reflectone	full 6 d-o-f	computer-control, limit switches on hydraulic rams	washout algorithm with nulling in all d-o-f	Infrequent hydraulic bump reported, some lag noted by pilots (motion lag > visual accd. to pilots)	none	none	cyclic, rudder pedal, cockpit vib, also for emergencies, touchdown bump, rotor force	buffeting in emergencies	none	none with g

* charted data on this location

unk. = unknown
-- = not included or not applicable

Table 2. Simulator Motion Cuing Systems. (Continued)

Simulator-Aircraft-Mission	Locations	Motion-Base Type, Manufacturer	Degrees of Freedom	Excursion Limiting Methods	Acceleration Cuing Logic	Anecdotal Motion-Base Infidelities	g-seat g-suit	Restraint Belt Tensioning	Control/Cockpit/Seat Vibration	Control/Cockpit/Seat Buffet	g-force Display Dimming	Control Loading Changes
2F117/CH-46E/OFT Helicopter	New River, NC* Tustin, CA	synergistic Reflectone	full 6 d-o-f	computer-control often overridden by instructor, motion will then freeze if excursion reaches limit switches	washout algorithm with nulling in all d-o-f	infrequent motion surges & bumps reported, overly sensitive esp. w/o stability augmentation, worst at low alt. accd. to instructors & pilots	none	none	cyclic, rudder pedal, seat vib., also for emergencies, touchdown bump, rotor force	buffeting in emergencies	none	none with g
2F121/CH-53D/OFT Helicopter	New River, NC*	synergistic Reflectone	full 6 d-o-f	computer-control often overridden by instructor, motion will then freeze if excursion reaches limit switches	washout algorithm with nulling in all d-o-f	infrequent motion surges & bumps reported, overly sensitive esp. w/o stability augmentation, worst at low alt. accd. to instructors & pilots	none	none	cyclic, rudder pedal, seat vib., also for emergencies, touchdown bump, rotor force	buffeting in emergencies	none	none with g
2F133/AV-8B/OFT VSTOL	Cherry Point, NC*	fixed-base	--	--	--	--	g-suit-pressurized slightly at 1g, g-seat	unk.	unk.	control stick, rudder shake, cockpit buffet	unk.	control stick breakout loading increased with g
2E7/F-18/WTT Fighter	Lemoore, CA	fixed-base	--	--	--	--	g-suit-pressurized slightly at 1g, g-seat	unk.	unk.	control stick buffet, rudder shake	yes, dimmed with g	unk.
2F64C/SH-3H/WST Helicopter	North Island, CA Jacksonville, FL	synergistic Reflectone	full 6 d-o-f	unk.	unk.	unk.	--	unk.	unk.	unk.	--	unk.
2F87F/P-3C/OFT ASW/Patrol	Barber's Point, HI Brunswick, ME Jacksonville, FL Moffett Field, CA	synergistic Singer	full 6 d-o-f	unk.	unk.	unk.	--	--	yes	unk.	--	unk.

* charted data on this location

unk. = unknown
-- = not included or not applicable

Simulation Motion Cuing Systems (Headings--Table 2.)

Simulator-aircraft-mission; Locations. (As before.)

Motion-base type, manufacturer. Entries in this column specify whether the simulator is fixed-base (i.e., the cockpit platform does not rotate or translate), or moving-base, either of synergistic (all actuators work together) or cascade variety (Puig, 1984). Also, if moving-base, the manufacturer is specified.

Degrees-of-freedom (d-o-f). The degrees-of-freedom of vehicular motion represented in the motion base are specified. Again, accelerations may be presented in rotation (pitch, roll, yaw) or in translation (lateral, longitudinal, vertical).

Excursion limiting methods. For moving-base devices, the methods of limiting hydraulic actuator extension are noted. Usually, actuator positioning is computer-controlled and electric limit switches are incorporated on hydraulic rams to prevent hyperextension. A buffering system is usually included to reduce abrupt ram deceleration and jerk.

Acceleration cuing logic. On all moving-base simulators in the survey, acceleration and deceleration of the motion base is controlled by a washout algorithm which tapers off a motion cue after the initial onset of acceleration. This information is noted in this column. After motion cue presentation and washout, most systems utilize a "nulling" strategy in which the motion base is returned to a central position for presentation of subsequent cues. For instance, during a sustained banked turn, the simulator cockpit may not continue to roll during the full period of the turn. After initial roll cue onset presentation and subsequent washout, the simulator may return at a rate below perceptual threshold to a level (null) position even though the instruments and visual scene continue to depict the sustained turn.

Anecdotal motion base infidelities. In this column, any infidelities in motion base operation which were reported by the flight instructors, operating personnel, etc. during the interviews are noted. These include mention of such potential disparities as motion surge or bump, coupling between motion axes, and inaccurate motion response to control input.

G-seat, g-suit. Though not directly imparting motion to the body, these devices are sometimes used to "enhance" the motion cue environment. The g-seat incorporates inflatable seat pan and back pads which inflate or deflate (hydraulically or pneumatically) to provide kinesthetic and somesthetic stimulation associated with acceleration effects. One potential problem with them is that they may change the operator's head position with respect to the displays, potentially resulting in slightly off-axis viewing and distortion. The g-suit provides constrictive pressure on the body which would be associated with g-suit inflation during high-g maneuvers in flight. Of course, the cue is strictly an "associative" one, since a moving-base simulator can only produce a fraction of the g-forces experienced in the analogue aircraft and only for a very short period of time.

Restraint belt tensioning. Another technique to enhance or augment motion cuing, restraint belts (shoulder harness/lap belt) may be tightened during presentation of high accelerations and kinematics in the simulator. This technique attempts to simulate the effects of the pilot's body being pushed against the belts such as that which occurs during sudden deceleration or rapid headward acceleration.

Control/cockpit/seat vibration. In this column in Table 2, the presence of vibration cuing is indicated, along with the components of the simulator to which it is applied.

Control/cockpit/seat buffet. The presentation of aircraft buffeting effects, such as those due to an impending stall condition, are specified.

G-force display dimming. In some simulators which represent aircraft capable of high-g maneuvers, the visual display may be progressively dimmed with simulated increasing-g conditions. This practice is an attempt to convey to the pilot that gray-out, blackout, and/or tunnel vision effects are occurring due to the influence of high-g on the cardiovascular system.

Control loading changes. In some of the simulators surveyed, control loading (resistance to movement) is designed to mimic the behavior of control loading in the actual aircraft. In these devices, control loading is increased as simulated acceleration increases.

Table [illegible]. Simulator Motion-Base Parameters.

Simulator-Aircraft-Mission	Locations	Motion-Base Type Manufacturer	Power Source	Actuators No./Length	Rotational d-o-f: Pitch excur deg	Pitch accel °/sec^2	Roll excur deg	Roll accel °/sec^2	Yaw excur deg	Yaw accel °/sec^2	Translational d-o-f: Lateral excur in	Lateral accel g	Longitudinal excur in	Longitudinal accel g	Vertical excur in	Vertical accel g
2F?/F-14,F-4/ACM Fighter	Oceana, VA*	fixed-base	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2F110/E-2C/OFT AEW/Tactical	Norfolk, VA* Miramar, CA	synergistic Reflectone	hydraulic	6/60in	±25	25	±25	70	±25	70	±34	0.5	±34	0.5	±34	0.5
2F112/F-14A/WST Fighter	Oceana, VA* Miramar, CA	fixed-base	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2F122/A-6E/NCLT Attack	Oceana, VA* Whidby Island, WA	cascade (paddle) Secor	hydraulic	n/a	±10	150	±20	150	±10	150	±12	unk.	—	—	±12	unk.
2F106/SH-2F/WST Helicopter	Norfolk, VA* North Island, CA	synergistic Reflectone	hydraulic	6/60in	±25	25	±25	70	±25	70	±34	0.5	±34	0.5	±34	0.5
2F1?7/CH-46E/OFT Helicopter	New River, NC* Tustin, CA	synergistic Reflectone	hydraulic	6/60in	±25	25	±25	70	±25	70	±34	0.5	±34	0.5	±34	0.5
2F121/CH-53D/OFT Helicopter	New River, NC*	synergistic Reflectone	hydraulic	6/60in	±25	25	±25	70	±25	70	±34	0.5	±34	0.5	±34	0.5
2F133/AV-8B/OFT VSTOL	Cherry Point, NC*	fixed-base	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2E7/F-18/NFT Fighter	Lemoore, CA	fixed-base	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2F64C/SH-3H/WST Helicopter	North Island, CA Jacksonville, FL	synergistic Reflectone	hydraulic	6/60in	±25	25	±25	70	±25	70	±34	0.5	±34	0.5	±34	0.5
2F87F/P-3C/OFT ASW/Patrol	Barber's Point, HI Brunswick, ME Jacksonville, FL Moffett Field, CA	synergistic Singer	hydraulic	6/48in	+30 -25	200	±25	200	±30	200	±36	0.8	+30 -42	0.8	±36	0.9

* charted data on this location

unk. = unknown
— = not included or not applicable

Simulator Motion Base Parameters (Headings--Table 3.)

Simulator-aircraft-mission; Locations. (As before.)

Motion-base type, manufacturer. (As before.)

Power source. For all devices in the survey which included a motion-base, the power source is hydraulic. Although not in current widespread use, electric servo motors have been used in some simulators for powering the motion-base.

Actuators--number/length. For the hydraulic motion-base devices, the number of actuators used and the extended ram length in inches is provided. This information was obtained from Puig (1984).

Rotational d-o-f; Translational d-o-f. Under these column headings, the degrees-of-freedom of movement inherent in the motion-base is specified with their associated excursion distances and maximal acceleration parameters (Puig, 1984). For the rotational motions, excursion envelopes are given in degrees (deg) while maximal accelerations are given in degrees per second^2 ($°/sec^2$). For translation motions, excursion distances are given in inches (in) while maximal accelerations are given in g's, where 1 g = 32.16 feet per second^2.

Table 4. Simulator Cockpit Interior Systems.

Simulator-Aircraft-Mission	Locations	Cockpit Controls	Flight Control Loading	Control Deadspace-Backlash	Cockpit Instrumentation	Head-Up Displays	Audio-Mechanical Systems	Audio-Environ	Audio-Runway	Audio-Communications	Audio-Emergency Conditions	Cockpit Temperature
2F6/F-14,F-4/ACM Fighter	Oceana, VA*	as in A/C used in ACM tactics	hydraulic, breakout	stick deadspace-same as A/C except at slow speed accd. to pilots, no backlash reported	as in A/C used in ACM tactics	unk.	engines, weapons systems & weapons release-all synthesized, canopy actuator	turbulence, wind, wind noise change with wing sweep	--	with instructor, between pilot & RIO	compressor stall warning	~ 65°F, externally controlled
2F110/E-2C/OFT AEW/Tactical	Norfolk, VA* Miramar, CA	column, landing gear, rudder pedals, nose wheel steering, toe brakes, parking brakes, flaps	hydraulic, electronic, elastic, breakout	column deadspace reported less than A/C, backlash same as A/C	as in A/C	--	engines-synthesized, power cart & starting air-taped, rudder shudder	weather-rain & hail	runway rumble and touchdown - synthesized	with instructor, between pilot & copilot	emergency electrical generator-taped	~ 68°F
2F112/F-14A/WST Fighter	Oceana, VA* Miramar, CA	as in A/C	hydraulic	slight column deadspace reported, no backlash reported	as in A/C	unk.	engines, weapons systems & weapons release, flaps, navigation, canopy actuator	turbulence, wind	rolling noise	with instructor, between pilot & RIO	—	~ 68°F
2F122/A-6E/NCLT Attack	Oceana, VA* Whidby Island, WA	as in A/C	hydraulic	no deadspace nor backlash reported	as in A/C	--	engines-synthesized, canopy actuator	unk.	unk.	with instructor, between pilot & BN	--	~ 78°F summer ~ 64°F winter
2F106/SH-2F/WST Helicopter	Norfolk, VA* North Island, CA	as in helo	hydraulic, magnetic, friction on collective	none reported, as in helo	as in helo	--	engine & rotor, sonobuoy launch	turbulence, weather-rain & hail	touchdown noise	with instructor, radio interference simulated	--	~ 55°F "kept cool" accd. to instructors

* charted data on this location

unk. = unknown
-- = not included or not applicable

Table 4. Simulator Cockpit Interior Systems. (Continued)

Simulator-Aircraft-Mission	Locations	Cockpit Controls	Flight Control Loading	Control Deadspace-Backlash	Cockpit Instrumentation	Head-Up Displays	Audio-Mechanical Systems	Audio-Environ	Audio-Runway	Audio-Communications	Audio-Emergency Conditions	Cockpit Temperature
2F117/CH-46E/OFT Helicopter	New River, NC* Tustin, CA	as in helo	hydraulic, elastic, breakout force	slight deadspace reported when boost off, no backlash reported	as in helo	--	engine-taped, landing gear	--	rolling thump over expansion strips	with instructor, between pilot & copilot	compressor stall, gearbox, turbine, & hi-freq. bearing failure noise	~ 63°-69°F
2F121/CH-53D/OFT Helicopter	New River, NC*	as in helo	hydraulic, breakout force, elastic	unk.	as in helo	--	engine-taped, landing gear	--	rolling thump over expansion strips	with instructor, between pilot & copilot	compressor stall, gearbox, turbine, & hi-freq. bearing failure noise	~ 63°-68°F
2F133/AV-8B/OFT VSTOL	Cherry Point, NC*	as in A/C	hydraulic breakout force-increased with g	unk.	as in A/C	yes	engine & turbine run-up, canopy actuators	turbulence, wind	unk.	with instructor	unk.	~ 68°-70°F
2E7/F-18/WTT Fighter	Lemoore, CA	unk.	unk.	unk.	unk.	unk.	missile launch, gun-fire, weapons strike	flight noise-type unk.	unk.	with instructor	engine compressor stall	70°±10°F
2F64C/SH-3H/WST Helicopter	North Island, CA Jacksonville, FL	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.
2F87F/P-3C/OFT ASW/Patrol	Barber's Point, HI Brunswick, ME Jacksonville, FL Moffett Field, CA	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.

* charted data on this location

unk. = unknown

-- = not included or not applicable

Simulator Cockpit Interior Systems (Headings--Table 4.)

Simulator-aircraft-mission; Locations. (As before.)

Cockpit controls. A listing of aircraft controls included in the simulator is provided in this column. Where simulator flight controls are the same as those in the actual aircraft, the entry "as in A/C" appears.

Flight control loading. Aspects of flight control loading and resistance are specified in this column. Possible entries include force breakout (preload), elastic resistance (spring-loading), stiction, sliding (mechanical) friction, magnetic friction, hydraulic loading, viscous damping, and control inertia.

Control deadspace/backlash. An estimation of the amount of deadspace or backlash inherent in flight control manipulation is presented. This estimate (provided by simulator instructor pilots and trainees) is intended to reflect whether or not the control deadspace and/or backlash is representative, in a subjective sense, of that in the actual aircraft.

Cockpit instrumentation. In all of the devices surveyed, the fundamental flight-related instrumentation included is in direct correspondence with that of the aircraft.

Head-up displays. In this column, if a head-up display is projected onto the cockpit windscreen of the simulator, it is so indicated.

Audio systems. In these five columns, the aural feedback systems are specified for each simulator. The auditory displays are divided into: mechanical systems noise, such as that due to engine operation, canopy actuation, and weapons release; environment noise, such as turbulence, wind, and weather; runway noise, such as tire rumble and touchdown noise; communications noise, due to instructor-pilot conversation and radio interference; and, emergency conditions noise, such as turbo-compressor stall, helicopter rotor problems, etc.

Cockpit temperature. Normal operating temperature maintained in each simulator cockpit is specified in this column. Many of these temperature ranges were obtained from Puig (1984) and verified by the flight instructors at each site. However, it should be noted that in some cases, instructors and students typically self-adjust cockpit temperature, so there is considerable potential for variability in the tabled values and therefore, they should only be considered as estimates.

Table 5. Simulator Operating/Training Procedures.

Simulator-Aircraft-Mission	Locations	Part-task, Whole flight	Procedures Training	Takeoff/Landing Training	In-flight Training	Usual est. Mission Intensity	Usual Longest Mission	Situation Freeze Procedure	Situation Slewing Procedure	Flight Instructor, Authority	Ingress-Egress, Visuals On/Off	Do Trainees View Operating Simulator?
2F6/F-14,F-4/ACM Fighter	Oceana, VA*	part-task	--	--	ACM, air-air weapons	moderate to high (combat situations)	~1 hr	yes, pt-light projector freeze, crew sometimes prompted	yes, pt-light projector slewed to reset in crew's view	civilian-F-14 pilots, offer guidance & advice	fixed gantry hand rails retractable but left in view), visuals off	no, not typically allowed in dome during training
2F110/E-2C/OFT AEW/Tactical	Norfolk, VA* Miramar, CA	whole flight#	preflight, start, shutdown, post-flight, normal & emergency procedures	carrier (catapult & arresting wires), field	approach/departure, navigation, operational flight, instrument use	moderate to high	2-2.5 hr with in-simulator breaks	yes, reported to be disturbing, motion nulled upon freeze	yes, display blanked grey during slewing	Navy E-2C pilots, have full instructor authority	retract. gantry, visuals on	yes, from gantry & from floor
2F112/F-14A/WST Fighter	Oceana, VA* Miramar, CA	whole flight#	emergency procedures, ECM	carrier night landing	approach/departure, navigation, radar avoidance, ECM, ACM, SAM tactics, air-air, air-water weapons	moderate to high, combat situations, long-range missile threats	~1.5 hr	yes, pt-light projector freeze, crew sometimes prompted	yes, pt-light projector slewed to reset in crew's view	civilian-F-14 pilots, offer guidance & advice	fixed gantry, handrails retracted out of view, visuals off	no, not typically allowed in dome during training
2F122/A-6E/NCLT Attack	Oceana, VA* Whidby Island, WA	whole flight#	emergency & malfunction procedures	night carrier landing (catapult & arresting wires)	approach/departure, navigation, emergencies	moderate	1-2 hr	yes, reported to be disturbing, motion freeze, freeze upon crash	yes, in crew's view	unk.	ladder stairs, visuals on	yes, from enclosed control room
2F106/SH-2F/WST Helicopter	Norfolk, VA* North Island, CA	whole flight (combat capability to be added)	preflight, start, emergency procedures	carrier, field, destroyer	approach/departure, cargo-handling, sonobouy launch, ASW, emergencies	moderate to high	~1.5 hr	yes, in crew's view, motion nulled upon freeze	none	Marine helo pilots, have full instructor authority	ladder stairs, visuals on	yes, from floor below

* charted data on this location
\# instructors may also use simulator for part-task training

unk. = unknown
— = not included or not applicable

Table 5. Simulator Operating/Training Procedures. (Continued)

Simulator-Aircraft-Mission	Locations	Part-task, Whole flight	Procedures Training	Takeoff/ Landing Training	In-flight Training	Usual est. Mission Intensity	Usual Longest Mission	Situation Freeze Procedure	Situation Slewing Procedure	Flight Instructor, Authority	Ingress-Egress, Visuals On/Off	Do Trainees View Operating Simulator?
2F117/CH-46E/OFT Helicopter	New River, NC* Tustin, CA	whole flight#	preflight, start, shutdown, post-flight, emergency procedures	carrier, LPH, LST (variable sea state), field, confined area	approach/ departure, navigation, cargo-handling, emergencies	high-many types of emergencies are presented	~2 hr	yes, in crew's view, motion nulled, crew prompted, freeze upon crash	yes, crew prompted	civilian-helo and fixed-wing pilots, offer guidance	retract. gantry, visuals on	yes, from gantry (rear waiting area)
2F121/CH-53D/OFT Helicopter	New River, NC*	whole flight#	preflight, start, shutdown, post-flight, emergency procedures	carrier, LPH, LST (variable sea state), field, confined area	approach/ departure, navigation, cargo-handling, emergencies	high-many types of emergencies are presented	~2 hr	yes, in crew's view, motion nulled, crew prompted, freeze upon crash	yes, crew prompted	civilian-helo and fixed-wing pilots, offer guidance	retract. gantry, visuals on	yes, from gantry to rear (waiting area)
2F133/AV-8B/OFT VSTOL (in operation approx. 2 months)	Cherry Point, NC*	whole flight#	preflight, start, shutdown, post-flight	carrier (variable sea state), field, confined area	approach/ departure, navigation	moderate to high	unk.	yes, (whole field flashes red on crash)	yes, in crew's view	Marine pilots, have full instructor authority	ladder stairs, visuals on	unk.
2E7/F-18/WTT Fighter	Lemoore, CA	part-task	emergency procedures, other-unk.	--	ACM, air-air, air-ground weapons, radar, ECM, emergencies	moderate to high (combat situations)	unk.	yes, freeze upon crash with override	unk.	unk.	unk.	unk.
2F64C/SH-3H/WST Helicopter	North Island, CA Jacksonville, FL	whole-flight #unk.	unk.	ship, field	approach/ departure, search & rescue, ASW	unk.	unk.	yes	unk.	unk.	unk.	unk.
2F87F/P-3C/OFT ASW/Patrol	Barber's Point, HI Brunswick, ME Jacksonville, FL Moffett Field, CA	whole-flight #unk.	preflight, start, emergencies, other-unk.	field	approach/ departure, ASW, emergencies	unk.	~4 hr	unk.	unk.	unk.	unk.	unk.

* charted data on this location
\# instructors may also use simulator for part-task training

unk. = unknown
-- = not included or not applicable

Simulator Operating/Training Procedures (Headings--Table 5.)

Simulator-aircraft-mission; Locations. (As before.)

Part-task, whole flight. In this column, the training mission scope is dichotomized into part-task and whole-flight scenarios. Devices listed as part-task are those which are primarily intended for training only a portion of a flight mission, such as air-to-air combat maneuvering. Whole-flight devices are those which include takeoff, aerial tasks, and landing capabilities. Whole-flight devices may, of course, be considered part-task as well in that they are not typically capable of, or used to, simulate all aspects of a mission.

Procedures training. For the purposes of Table 5, procedures training includes those aspects of the training scenario which complement the activities of takeoff, landing, or normal in-flight tasks. These include such procedures as preflight preparation, postflight shutdown, and emergency and malfunction operations.

Takeoff/landing training. For whole-flight devices, the provisions and settings (e.g., carrier, field, etc.) included in the simulation for takeoff/landing training are specified in this column.

In-flight training. Aerial procedures and techniques which are typically included in training sessions are indicated in this column for each simulator. While the list of mission tasks is not exhaustive, it does include the major aspects of in-flight training provided by flight instructors at each site.

Usual estimated mission intensity. Among the simulators surveyed, a gross, relative estimate of the typical training mission intensity is provided. This is based on estimates of intensity provided by flight instructors and trainees during the interviews.

Usual longest mission. Again based on the responses obtained during the interviews, an estimate of the longest training mission duration for each simulator is specified.

Situation freeze procedure. A training-related feature on certain simulators allows the visual presentation to be frozen, or stopped at a given instant in time, in front of the viewers' eyes. The scene is usually fixed at the frozen position, whether or not it is at an off-horizon attitude, and if the simulator is a moving-base type, the motion is usually stopped and nulled at a level position during freeze. There have been numerous reports that the use of freeze may be disquieting and produce ill effects in trainees (McCauley, 1984). This column includes information regarding the freeze capabilities of each simulator.

Situation slewing procedure. Another feature of certain simulators is the ability to reset or fast-forward display presentation, jumping ahead or back in time to a different point within a flight. When this occurs, miles of visual information stream by the viewer in compressed time and this may result in disorientation, eyestrain, and malaise. Visual slewing capabilities for each simulator appear in this column, along with the observed practice of whether or not trainees view the displays during slew. Some flight instructors, recognizing that slewing (and freeze) may influence trainee sickness, suggest that they do not view the display during these periods.

Flight instructor; Authority. Flight instructors for some simulator facilities are civilians while others are ranking military personnel. The type of instructor is given in this column along with a brief description of the instructors' responsibilities. It has been speculated that flight trainees operating under a military instructor who critiques their performance may be more reluctant to relate feelings of discomfort than trainees under a civilian instructor who offers only suggestions and guidance. This is the reason for including the instructor information in this column.

Ingress-egress; Visuals on-off. Ingress and egress systems for access to the simulator cockpit are noted in this column. Some devices include a retractable gantry walkway, accessible from an upper floor, which attaches to the simulator cab, while others utilize a ladder stairway from the base level of the simulator up to the cab. In dome-display devices, the aircrew must enter the dome which fully encloses the cockpit and climb into the cockpit from a catwalk. In some simulators, the visual scene is on during entry/exit, while in others the scene is off or the display area is flooded with light. Some trainees have indicated that entering or exiting a simulator with display on is disorienting.

Do trainees view operating simulator? Certain simulators, such as the dome-display devices are designed such that operation of the simulator is not observable unless one is inside the dome. However, with most other simulators, trainees who are waiting for their flight or who have completed their flight, may sit and observe the simulator in operation from outside. This was observed to be a common occurrence at most sites. Given this practice, it may be the case that trainees learn how the simulator actually responds and what to expect of its motion system when watching its performance externally. For instance, trainees may become quite cognizant of the fact that simulator motions in response to control inputs are greatly attenuated in comparison to the actual aircraft, simply because the trainees have watched the cab in operation. This could pre-bias their expectations regarding the simulator and possibly affect their training benefit and predisposition for discomfort.

On the other hand, if trainees are prevented from viewing the simulator in operation, they may become suspicious of the training program. Furthermore, it may be quite impractical to restrict trainees' view of the simulator while they are waiting for their hop.

Table 6. Apparent and/or Reported Simulator Anomalies.

Simulator-Aircraft-Mission	Locations	Visual System Anomalies	Motion-Cuing System Anomalies	Audio System Anomalies	Control System Anomalies	Extraneous Noise	Other Anomalies	Cockpit Temperatures	Reported Simulator Sensitivity	Reported Simulator Lags/Delays
2F6/F-14,F-4/AOM Fighter	Oceana, VA*	little translational motion apparent from the pt-light earth/sky projection display while target displays depict all 6 d-o-f (relatively), earth/sky display is relatively dim & undetailed white targets tend to be of higher luminance, targets may flicker at hand-off between projectors and when beam crosses handrails, g-force dimming darkens entire display instead of progressive dimming from periphery, no portrayal of sun, shadows from point-light stanchion appear in rear part of dome display, some pilots report unrealistic target movement and contrast against scene	n/a, g-seat & g-suit not typically used	some reports that sounds seem slightly unrealistic	--	some sound created by slewing of pt-light projector	handrails of gantry may be left in view giving unrealistic "ground" reference accd. to operators, use of display freeze & slewing reported to be disturbing	some reports of warm cockpits	some reports that sim. responds differently than A/C at slow speeds, simulation has a full "fidelity check" by experienced pilot every working day	reported same as in A/C

* charted data on this location

unk. = unknown

-- = not included or not applicable

Table 6. Apparent and/or Reported Simulator Anomalies. (Continued)

Simulator-Aircraft-Mission	Locations	Visual System Anomalies	Motion-Cuing System Anomalies	Audio System Anomalies	Control System Anomalies	Extraneous Noise	Other Anomalies	Cockpit Temperatures	Reported Simulator Sensitivity	Reported Simulator Lags/Delays
2F110/E-2C/OFT AEW/Tactical	Norfolk, VA* Miramar, CA	edges of display for out-the-window scene are visible giving pilot cues as to closeness of scene, reflections of interior & instrument lights in collimating mirrors, 1 mirror has slipped leaving gap between displays (scheduled for service), displayed objects may appear suddenly rather than becoming gradually visible, pilot/copilot can look up & see CRT itself, runway "piano keys" may appear to swim, off-axis viewing angle problematic from instructor's seat	infrequent random bump reported felt at ~ 7000 ft. altitude, more sickness reported in motion-off demos	some reports that engine sound is turned down from normal level	some reports that PIC's may result from column pitch feel & also turn & slip indicator response being slightly different from A/C	--	--	~ 58°F, but may be irregular	some reports that sim. is more sensitive than A/C, esp. in longitudinal motion	report same as in A/C
2F112/F-14A/WST Fighter	Oceana, VA* Miramar, CA	some reports that pilots mention targets can be unrealistic in attitude & luminance, g-force dimming darkens entire display instead of progressive dimming from periphery (visual scene not used during some IFR missions-was off during author's visit)	n/a, g-seat & g-suit not typically used	—	some reports that sim. is more sensitive to control inputs than A/C, esp. at low speeds	some sound created by slewing of pt-light projector	handrails of gantry are retracted from view (see 2E6)	"pretty hot" at times accd. to some pilots	some reports that sim. is more sensitive than A/C, esp. at low speeds	unk.

* charted data on this location

unk. = unknown
-- = not included or not applicable

Table 6. Apparent and/or Reported Simulator Anomalies. (Continued)

Simulator-Aircraft-Mission	Locations	Visual System Anomalies	Motion-Cuing System Anomalies	Audio System Anomalies	Control System Anomalies	Extraneous Noise	Other Anomalies	Cockpit Temperatures	Reported Simulator Sensitivity	Reported Simulator Lags/Delays
2F122/A-6E/NCLT Attack	Oceana, VA* Whidby Island, WA	frontal displays only (peripherals to be added) - little forward movement cues apparent except when landing on carrier, some pilots report lack of peripheral velocity cues, pilot/copilot can look up & see CRT itself, reflections of interior/instrument lights in windscreen, lights on horizon occasionally jump & flash	infrequent random bump reported, motion will abruptly freeze if excursion reaches limit switches, cascade (paddle) motion base has inherent motion coupling between yaw & lateral translation & between pitch & vertical translation, relatively small yaw & pitch excursions, g-seat & g-suit capability not typically used	some reports that sounds are unrealistic	unk.	—	limited cuing forward motion	~78°F summer ~68°F winter	some reports that sim. is more sensitive than A/C on approach & landing	unk.
2F106/SH-2F/WST Helicopter	Norfolk, VA* North Island, CA	some exterior light leakage through gaps between displays, reflections of some interior lights & instruments in display mirrors, when displayed image is complex (e.g. landing on a ship) the display noticeably lags inputs accd. to instructors, some gaps noticeable between & below displays, pilot/copilot can look up & see CRT itself, some display priority (bleed-through of background objects) noticed	some reports of more heave sensation in sim. than in helo, sim. feels "lighter" than helo, infrequent hydraulic bump & some cockpit shudder apparent	unk.	some reports that controls feel "lighter" than in helo	some hydraulic actuator noise & exterior activity noise apparent if not wearing headset	some reports that sim. feels least realistic when flying close to ground	kept "cool" accd. to instructors	some reports that sim. is more sensitive and harder to fly than helo, esp. when landing & flying close to objects on ground	some reports from instructors that lags are higher than in helo & may contribute to PIO's, reports that trainees must learn to compensate for lag in sim.

* charted data on this location

unk. = unknown

— = not included or not applicable

Table 6. Apparent and/or Reported Simulator Anomalies. (Continued)

Simulator-Aircraft-Mission	Locations	Visual System Anomalies	Motion-Cuing System Anomalies	Audio System Anomalies	Control System Anomalies	Extraneous Noise	Other Anomalies	Cockpit Temperatures	Reported Simulator Sensitivity	Reported Simulator Lags/Delays
2F117/CH-46E/OFT helicopter	New River, NC* Tustin, CA	displays for pilot only (copilot has no dedicated display), some reports from instructors that loss of orientation during hover & landing can occur due to lack of strong depth cues & lack of terrain undulation, strong forward motion cues from peripheral displays, displays do not match one-one with windscreens (one display appears across 2 windscreens, another windscreen has 2 displays, curvature of display & windscreen is different), some ghosting & priority noticeable-eliminated through calibration, edges of display for out-the window scene are visible giving pilot clues as to closeness of scene (some) training done with visual scene off-no reports of sim. sickness w/o visual)	some reports that motion system is least realistic during hover & landing where ground effects occur, motion system cannot produce sustained cues accompanying some emergency maneuvers, infrequent motion surges & bumps reported, sim. sickness reported much more prevalent with motion off	some reports that due to cockpit speaker location, sounds may not be of same direction- ality as in helo	some reports that sim. is more sensitive to control inputs than helo, esp. w/o stability augmentation on, helo reported to have more "cushion" in controls than sim.	some hydraulic actuator noise apparent	some lack of realism (in visual and/or motion) when landing or "close quarters" maneuvering accd. to trainees & instructors, strong awareness among trainees & instructors of simulator sickness - considerable discussion among some trainees	~ 63°-68°F	some reports that sim. is more sensitive than helo, esp. w/o stability augmenta- tion	pilots report less lag in simulator than in helo

* charted data on this location

unk. = unknown

-- = not included or not applicable

Table 6. Apparent and/or Reported Simulator Anomalies.

Simulator-Aircraft-Mission	Locations	Visual System Anomalies	Motion-Cuing System Anomalies	Audio System Anomalies	Control System Anomalies	Extraneous Noise	Other Anomalies	Cockpit Temperatures	Reported Simulator Sensitivity	Reported Simulator Lags/Delays
2F121/CH-53D/OFT Helicopter	New River, NC*	displays for pilot only (copilot has no dedicated display), some reports from instructors that loss of orientation during hover & landing can occur due to lack of strong depth cues & lack of terrain undulation, strong forward motion cues from peripheral displays, displays do not match one-one with windscreens (one display appears across 2 windscreens, another windscreen has 2 displays, curvature of display & windscreen is different), some ghosting & priority noticeable-eliminated through calibration, edges of display for out-the window scene are visible giving pilot clues as to closeness of scene (some) training done with visual scene off-no reports of sim. sickness w/o visual)	some reports that motion system is less realistic during hover & landing where ground effects occur, motion system cannot produce sustained cues accompanying some emergency maneuvers, infrequent motion surges & bumps reported, sim. sickness reported much more prevalent with motion off	some reports that due to cockpit speaker location, sounds may not be of same directionality as in helo	some reports that sim. is more sensitive to control inputs than helo, esp. w/o stability augmentation, helo reported to have more "cushion" in controls than sim.	some hydraulic actuator noise apparent	one pilot who had flown the similar 2F120 at Tustin commented that the Tustin sim. was more likely to induce sickness in him some lack of realism (in visual and/or motion) when landing or "close quarters" maneuvering accd. to trainees & instructors, strong awareness among trainees & instructors of simulator sickness - considerable discussion among some trainees	~ 63°-68°F	some reports that sim. is more sensitive than helo, esp. w/o stability augmentation	pilots report less lag in simulator than in helo
2F133/AV-8B/OFT VSTOL (in operation approx. 2 months)	Cherry Point, NC*	some flashing/shimmering in display, some object displacement & chrominance misalignment apparent during transition of image from 1 screen/projector to another, whole scene flashes red upon crash	n/a	unk.	unk.	--	unk.	unk.	unk.	unk.

* charted data on this location

unk. = unknown
-- = not included or not applicable

Table 6. Apparent and/or Reported Simulator Anomalies. (Continued)

Simulator-Aircraft-Mission	Locations	Visual System Anomalies	Motion-Cuing System Anomalies	Audio System Anomalies	Control System Anomalies	Extraneous Noise	Other Anomalies	Cockpit Temperatures	Reported Simulator Sensitivity	Reported Simulator Lags/Delays
2E7/F-18/WTT Fighter	Lemoore, CA	unk.	unk.	unk.	unk.	unk.	unk.	70°±10°F	unk.	unk.
2F64C/SH-3H/WST Helicopter	North Island, CA Jacksonville, FL	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.
2F87F/P-3C/WST ASW/Patrol	Barber's Point, HI Brunswick, ME Jacksonville, FL Moffett Field, CA	Flight eng. is 30° off-axis when viewing pilot/copilot CGI displays, addition of monochrome VFR display for flight eng. lessens sickness problem (Crosby & Kennedy, 1982)	unk.	unk.	unk.	unk.	unk.	unk.	unk.	some lags reported

* charted data on this location

unk. = unknown
-- = not included or not applicable

Apparent and/or Reported Simulator Anomalies (Headings--Table 6.)

This table provides a brief listing of potential problems, anomalies, and idiosyncracies specific to each simulator which were noted during the interviews with simulator personnel. Some of these anomalies may impact the incidence of simulator-induced sickness while others may not. However all reported anomalies are noted in Table 6 to provide as much detail as possible regarding potential simulator-induced sickness causes.

Simulator-aircraft-mission; Locations (As before.)

Anomalies columns. Reported anomalies occurring with the major simulator subsystems are divided into four columns: visual system, motion-cuing system, auditory system, and control system.

Extraneous noise. Audible simulator-produced noises which are not an intended auditory cue are listed in this column.

Other anomalies. Simulator problems which do not lend themselves to categorization under the above column headings are listed in this column.

Cockpit temperatures. While recommended cockpit operating temperatures are specified in Table 4, specific comments about actual cockpit temperature from instructors and trainees are included in this column.

Reported simulator sensitivity. For each device, flight instructors and trainees were queried regarding how the simulator's control-response sensitivity compares with that of the actual aircraft. The consensus of the subjective assessments of this relationship is included in this column.

Reported simulator lags/delays. Under this heading, subjective instructor and trainee reports of simulator control-response phasing differences with those of the actual aircraft are included. It was not possible to specify the nature of the delay (e.g., transport, exponential lag, etc.--see Volume I; Casali, 1986) but only to ask experienced users whether the update in the simulator's feedback system response to control inputs took noticeably longer than actual aircraft responses.

Table 7. Simulator Sickness/Aftereffects.

Simulator-Aircraft-Mission	Locations	Kennedy et al. Incidence*	Crewmember Susceptibility	Pilot Experience Factor	Flight Duration Factor	Flight Situation Factor	Workload-Stress Factor	Trainees' Predisposition Knowledge	In-Simulator and Residual Symptoms	Aftereffect Symptoms	Countermeasures Presently Used	Other Potential Problems
2E6/F-14,F-4/ACM Fighter	Oceana, VA#	27% accd. to McGuinness et al., 1981	pilot & RIO susceptible	worse with experienced pilots	reported worse with long flights	flat spins seem to increase symptoms and aftereffects	higher W/L - less sickness	apparent peer pressure not to discuss with other trainees	disorientation, mild discomfort	seem worse for experienced pilots, appear from 15 min to 4 hrs later	recommended: 30 min flight, flooding visual scene with light before freeze (NTEC, 1980)	some dizziness aftereffects esp. after spins, some report of warm cockpit
2F110/E-2C/OFT AEW/Tactical	Norfolk, VA# Miramar, CA*	49%	copilot more susceptible (may be due to fewer visuals)	sickness in first 2-3 hops for inexperienced & experienced pilots, otherwise worse with experienced pilots	unk.	worse with motion off (done in demo ride), worse when flying in an out-of-trim condition, worse when display slewing is used, worse after flying A/C	higher W/L - less sickness	instructors occasionally warn trainees of sickness potential	weak kneed, disorientation, queasiness, no violent symptoms	unk.	occasionally instructors warn trainees of sickness	inexperienced instructors getting sick, one author reported headache & slight nausea, PIOs occur
2F112/F-14A/WST Fighter	Oceana, VA# Miramar, CA*	20% est. 16%	pilot more susceptible	est. that 85% of sick are experienced pilots	unk.	reports of sickness only with visuals on, i.e., not during instrument-only training	higher W/L - less sickness	peer pressure not to discuss with other trainees	disorientation, mild discomfort	horizon movement, discomfort, headaches, (reported to occur 15 min to 4 hrs post-flight)	unk.	gantry handrails out-of-view (see 2E6), reported more sensitive than A/C esp. in slow speed flight
2F122/A-6E/WCLT Attack	Oceana, VA# Whidby Island, WA	unk.	none reported	unk.	unk.	unk.	unk.	unk.	none reported	none reported	unk.	no peripheral display, coupled motion: pitch & vertical, yaw & lateral, 2F122 reported more sensitive than A/C

* Kennedy et al. data on this location.
\# Anecdotal data only.

unk. = unknown
-- = not included or not applicable

Table 7. Simulator Sickness/Aftereffects. (Continued)

Simulator-Aircraft-Mission	Locations	Kennedy et al. Incidence*	Crewmember Susceptibility	Pilot Experience Factor	Flight Duration Factor	Flight Situation Factor	Workload-Stress Factor	Trainees' Predisposition Knowledge	In-Simulator and Residual Symptoms	Aftereffect Symptoms	Countermeasures Presently Used	Other Potential Problems
2F106/SH-2F/WST Helicopter	Norfolk, VA# North Island, CA*	15% (reported headache common) 13%	worse with copilot, susceptibility reported to rapidly decrease with exposure	worse with experienced pilots (who complain about fidelity)	unk.	higher if motion off, higher when flying close to other objects (e.g. landing), none if visuals off, higher with sudden heave motions	higher W/L - less sickness	some discussion among trainees, some peer pressure not to discuss	headaches, mild nausea, disorientation, feeling of claustrophobia	unk.	unk.	claustrophobia mentioned, CO_2 mentioned, PIOs, 2F106 reported more sensitive than A/C
2F117/CH-46E/OFT Helicopter	New River, NC* Tustin, CA	29%	apparently worse with pilot, some copilot sickness reported	worse for experienced pilots (they usually under-go different scenarios)	symptoms usually appear in first 10 min., also sporadically	higher if motion off and visuals on, none if visuals off, higher when flying close to other objects or ground (e.g. when landing), higher when auto-rotations are simulated, presentation of failures (e.g. rotor servo loss) may cause discomfort/headaches	higher W/L - less sickness usually, except during violent maneuvers due to failures	discussion among trainees & instructors, instructors sometimes warn subjects, some reports that sickness incidence may be due to aversion of training or may result in end of training	headaches, nausea, queasiness, disorientation, fullness of head, dyskinesis, emesis	nausea, perceptual distortion, dizziness, fatigue	Instructors warn trainees of sickness, trainee doesn't view slewing, airsickness bags distributed, trainee told to fly simulator in a smooth manner	CO_2 mentioned, PIOs when flying close to other objects (A/C and ground), 2F117 reported more sensitive than A/C, lack of depth cues
2F121/CH-53D/OFT Helicopter	New River, NC*	36%	worse with pilot	most report worse for experienced pilots, some report worse for inexperienced pilots	symptoms appear sporadically	higher if motion off and visuals on, none if visuals off, higher when flying close to other objects or ground (e.g. when landing), higher when auto-rotations are simulated, presentation of failures (e.g. rotor servo loss) may cause discomfort	higher W/L - less sickness usually, except during violent maneuvers due to failures	discussion among trainees & instructors, instructors sometimes warn subjects, some reports that sickness incidence may be due to aversion of training or may result in end of training	headaches, nausea, queasiness, disorientation, fullness of head, dyskinesis, emesis	nausea, perceptual distortion, dizziness, fatigue	Instructors warn trainees of sickness, trainee doesn't view slewing, airsickness bags distributed, trainee told to fly simulator in a smooth manner, "look into distance", and to keep head moving	2F121 reported more sensitive than A/C, PIO's

* Kennedy et al. data on this location.
\# Anecdotal data only.

unk. = unknown
-- = not included or not applicable

Table 7. Simulator Sickness/Aftereffects. (Continued)

Simulator-Aircraft-Mission	Locations	Kennedy et al. Incidence*	Crewmember Susceptibility	Pilot Experience Factor	Flight Duration Factor	Flight Situation Factor	Workload-Stress Factor	Trainees' Predisposition Knowledge	In-Simulator and Residual Symptoms	Aftereffect Symptoms	Countermeasures Presently Used	Other Potential Problems
2F133/AV-8B/OFT VSTOL (in operation approx. 2 mos.)	Cherry Point, NC#	little data-new simulator	simulator is pilot-only	worse with experienced pilots	unk.	unk.	unk.	unk.	queasiness, nausea, near-emesis	unk.	unk.	symptoms occur after extreme maneuvering
2E7/F-18/WTT Fighter	Lemoore, CA*	33%	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.
2F64C/SH-3H/WST Helicopter	North Island, CA* Jacksonville, FL*	13% 55%	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.	unk.
2F87F/P-3C/OFT ASW/Patrol	Brunswick, ME Barber's Point, HI	50% accd. to Crosby & Kennedy, 1982$	flight engineer most susceptible, little or no pilot/co-pilot sickness, Crosby & Kennedy, 1982	unk.	unk.	higher in richly detailed visual situations	unk.	unk.	queasiness, nausea, fullness of head, ataxia	postural disequilibrium	addition of monochrome flight eng. display reduces sickness	flight eng. has off-axis view of pilot/copilot display unless addt. monochrome display used
	Jacksonville, FL* Moffett Field, CA	44%										

* Kennedy et al. data on this location.
\# Anecdotal data only.
$ Incidence rate for flight engineer without an additional display or occluding baffle to prevent view of pilot/copilot display.

unk. = unknown
— = not included or not applicable

Simulator-Induced Sickness/Aftereffects (Headings--Table 7.)

Simulator-aircraft-mission; Locations. (As before.)

Kennedy et al. incidence. As previously discussed, the percentage of trainees experiencing symptoms of simulator-induced sickness in several military flight simulators has been reported by Kennedy, Dutton, Ricard, and Frank (1984). This data is presented in Table 7 for each simulator for which it was available, as indicated by an asterisk beside the specific simulator location. (The reader is referred to Kennedy, Dutton et al. (1984) for a description of the protocol used in the sickness incidence survey along with criterion measures of sickness state.) Other simulators, such as the 2E6, have been surveyed by different authors and their percentage of sickness incidence is referenced to that effect. In still other cases, only anecdotal sickness information and percentage estimates were available from those flight instructors using the devices on a daily basis. These are indicated by a # superscript in the table.

Crewmember susceptibility. It has been well-documented that susceptibility to simulator-induced sickness may largely be a function of the aircrew member's position in the simulator cockpit. This is thought to result from differences in display viewing perspectives (e.g., see device 2F87F in Table 7; Volume I, Casali, 1986), differences in body position with respect to the center-of-motion of the simulator, and differences between flight control responsibilities, among others. In this column, if there exists more than one crew station in the simulator cockpit, susceptibility differences by station is presented, based on the interview results and available literature documentation.

Pilot experience factor. Most available evidence points to the conclusion that more experienced pilots (i.e., experienced with the actual aircraft) are more susceptible to simulator-induced sickness. Wherever possible, anecdotal evidence for the relationship of sickness to experience level is presented in this column for each simulator.

Flight duration factor. Where information was available, the relationship of sickness incidence to flight length is specified in this column. Again, most of this information was obtained during simulator site interviews with flight instructors.

Flight situation factor. Certain flight scenarios (e.g., low altitude flight), simulator operating configurations (e.g., with motion off), and maneuvers (e.g., flat spins) may be associated with heightened provocation of simulator-induced sickness. For each simulator, based on the interview data, the most provocative situations are specified in the table.

Workload/stress factor. Based on interviews with instructors, the observed relationship between incident workload level and trainee sickness in the simulator is indicated in this column.

Trainees' predisposition knowledge. In some cases, trainees have been known to discuss their simulator experiences with others, perhaps pre-biasing naive trainees' tendencies toward simulator-induced sickness. This is often unavoidable. Occasionally a simulator may develop a reputation for inducing sickness and therefore may be tagged as an undesirable training experience. In other instances, peer pressure and self-induced competition among flight trainees may dissuade them from discussing their bouts of simulator-induced sickness with others. These and similar trends are noted for each simulator, based on the information obtained during the site interviews.

In-simulator and residual symptoms. Symptoms reported by trainees during and following simulator flights are specified in this column. Typical simulator sickness symptomatology includes disorientation, dizziness, headache, pallor, burping, nausea, emesis, fatigue, and visual dysfunction.

<u>Aftereffect symptoms</u>. Following the use of some simulators, delayed aftereffects and flashbacks to the simulator experience have been reported by a limited number of trainees (e.g., Kellogg, Castore, and Coward, 1980; see also Volume I, Casali, 1986). Some aftereffects are in the form of discomfort symptoms (e.g., headaches), while others have entailed perceptual illusions, such as inversion of the visual field. For those simulators surveyed, anecdotal information regarding aftereffects reported by trainees and flight instructors is presented in Table 7.

<u>Countermeasures presently used</u>. In an effort to alleviate discomfort in some devices, certain countermeasures have been adapted by instructors and operating personnel; these are reviewed in Volume I of this report (Casali, 1986). Specific operating procedures and countermeasures which were observed to be used in the surveyed devices are reported in this column.

<u>Other potential problems</u>. This column contains anecdotal information on simulator-induced sickness occurrence which does not fit under the other headings in Table 7.

Analysis of Simulator Characteristics Tables

The seven simulator characteristics tables are primarily intended to be used as reference material. The tables have utility for comparing and contrasting existing Naval flight simulators with respect to their design and procedural characteristics and penchant for inducing pilot and crew sickness. In particular, a perusal of Table 6 on simulator anomalies and Table 7 on simulator sickness and aftereffects reveals a number of factors which may impact simulator-induced sickness. Furthermore, by comparing the sickness incidence rates (percentages) in Table 7, it becomes clear that the simulators sampled vary greatly in their tendency to induce operator discomfort.

Because the information in Tables 1-7 covers a broad spectrum of design and usage characteristics among flight trainees, most of which are not quantifiable, the tables are perhaps best utilized through visual scrutiny alone. A rigorous statistical analysis to determine which specific factors are associated with higher incidences of sickness was not possible because of the limited number of observations (low statistical power), qualitative nature of many simulator characteristics (nonquantifiable independent variables), lack of sickness incidence data on certain simulators (missing dependent variable data), lack of simulator characteristics information on certain simulators (missing independent variable data), potential of interaction among characteristics, and somewhat imprecise nature of the available dependent measure (which was percentage incidence of sickness).

However, it was possible to undertake a simple regression approach to ascertain the association between certain isolated characteristics and the incidence of operator sickness for some of the simulators surveyed. Percentage sickness incidence data and certain simulator characteristic information were not available for some of the simulators. Therefore, only those devices for which estimates of sickness incidence data were available from Kennedy, Dutton et al. (1984), McGuinness et al. (1981), or in two cases from the site surveys (see Table 7) were included in the analysis. Again, it should be noted that these incidence data are only estimates, and conclusions should be drawn from them in a judicious manner.

Information included in analysis. Based on the available sickness incidence data, the following eight simulators from Table 7 were included in the regression analysis (% sickness estimate in parentheses): 2E6 Oceana (27), 2F110-Miramar (49), 2F112-Oceana (20), 2F112-Miramar (16), 2F106-Norfolk (15), 2F106-North Island (13), 2F117-New River (29), 2F121-New River (36).

Several simulator characteristics from Tables 1-7 were selected for inclusion as independent variables in the regression analyses. These variables were selected on the basis that they were complete for all simulators (no missing data), and that they were of a form amenable for use as a regression variable. Some characteristics, such as situation freeze (Table 5), were not analyzed because only one level of the variable existed in the sample (i.e., all eight simulators had some form of situation freeze capability). Similarly, most of the quantifiable motion base parameters (e.g., excursions, acceleration capabilities, etc., from Table 3) were identical for all eight devices, and therefore were not analyzed.

Single-variable regression analyses. For the simulator characteristics which were found to be appropriate for analysis, simple one-variable linear regression analyses were performed on each characteristic. Several types of information were available from these analyses for each simulator characteristic. First, the linear regression equations were calculated using each simulator characteristic as a regressor. Therefore, for equations which were found to provide a good prediction model, the expected value of percentage sickness incidence (PSI) could be predicted knowing the value of the x (simulator characteristic) variable. An *F*-test with associated *p*-value was then performed on the regression model to determine if the slope of the regression line was significantly different from zero (using a $p < 0.05$ cut-off), that is, if simulator sickness could be reliably predicted knowing the value of the simulator characteristic. Next, the r^2 (coefficient of determination) values were computed, to indicate the proportion of total variance in PSI that could be explained by the simulator characteristic variable. And for the one-variable regressions, the Pearson product-moment r correlation coefficient was computed to determine the direction and strength of relationship between PSI and each selected simulator characteristic. The results of the single-variable simple linear regression analyses are shown in Table 8. For each simulator characteristic included in the table, the table numbers (from the simulator survey for Tables 1, 3, or 5) which address that particular simulator characteristic are provided in the first column of Table 8. When using Table 8, the reader is referred to these previous tables for more information on each simulator characteristic.

Due to the small sample size (eight simulators), the potential for interactive effects among simulator characteristics, and to the fact that only a few characteristics were represented enough to be amenable to analysis, the results of the regression analysis are somewhat tenuous. Furthermore, because it was necessary to perform multiple *F*-tests (one on each regression), the $p < 0.05$ cutoff criterion for statistical significance must be considered in light of the number of separate tests run. It is clear from Table 8, however, that based on the obtained sample of simulators, few simulator design and usage characteristics exhibited a strong relationship with simulator-induced sickness as measured by the PSI. The only variable to approach statistical-significance was that of flight mission duration, where longer flight periods

Table 8. Results of Single-Variable Linear Regression Analyses Using Simulator Characteristics as Regressors; Data for Eight Simulators.

Table 1-7 reference	Simulator Characteristic (Regression)	r^2	r	Regression Equation PSI = bx + a
1	Horizontal field-of-view (degrees)	.067	-.259	NS = not significant
1	Vertical field-of-view (degrees)	.085	-.291	NS
1	Display viewing distance (feet)	.105	-.324	NS
1	Scene contrast (rated 1=low, 2=med, 3=high)	.097	.311	NS
1	Within-scene motion (0=1 to 5 dof, 1=6 dof)	.097	.311	NS
1	Scene detail (rated 1=low, 2=med, 3=high)	.147	.384	NS
1	Image generation system (0=point-light, 1=CGI)	.097	.311	NS
1	Display medium (0=dome or screen, 1=∞ optics)	.097	.311	NS
3	Motion-base (0=fixed-base, 1=moving-base)	.097	.311	NS
5	Simulator task (0=part-task, 1=whole flight)	.002	-.045	NS
5	Mission intensity (rated 1=low, 2=medium, 3=high)	.119	.344	NS
5	Mission duration (hours)	.473	.688*	PSI=21.23x-9.54**
5	Use of reset/slewing (0=not used, 1=used)	.097	-.311	NS
5	Trainee allowed external view (0=no, 1=yes)	.097	.311	NS
5	Flight instructor (0=civilian, 1=military)	.000	.000	NS

* Pearson product-moment correlation coefficient is statistically-significant using a *t*-test with 6 df and *p* < 0.05 cutoff criterion (see text).

** Slope of regression line is significantly different from 0 using an *F*-test with 1,6 df and *p* < 0.05 cutoff criterion (see text).

were associated with higher sickness incidence rates and 47% of the variance in PSI was accounted for by mission duration.

Interestingly, wide field-of-view devices displayed an inverse relationship (albeit a weak one) with PSI for this sample, which is contrary to previous hypotheses. However, it should be noted that all eight simulators in the sample had wide field-of-view visual presentations, the most narrow being 139 degrees in the 2F110. Furthermore, the high level of scene detail and depicted motion in the CGI system of the 2F110 could have possibly accounted for its greater tendency (49%) to induce sickness than some of the wider display devices, such as the 2E6 (27% sickness), with more impoverished scene content. (This illustrates the potential danger of considering certain simulator characteristics, such as field-of-view, in isolation.)

A weak positive relationship (r = 0.384) was found between the level of scene detail and PSI as well as between scene contrast rating and PSI (r = 0.311), though neither approached statistical-significance. Other variables which exhibited low (though not significant) positive correlations with sickness incidence included within-scene motion (6 d-o-f displays associated with greater sickness than displays with less d-o-f, e.g., as in the 2E6), image generation system (CGI associated with more sickness than point-light; CCTV not represented in sample), display medium (CRT infinity optics associated with more discomfort than projection dome), motion-base (moving-base associated with slightly more discomfort than fixed-base), and mission intensity (higher mission intensity, especially that with associated complex kinematics, associated with higher discomfort levels). Again, these trends should only be considered in the context of this sample of simulators. That is, the relationships with simulator-induced sickness percentage incidence were not statistically-reliable in most cases, nor were the proportion of dependent measure variances accounted for high. A larger or different sample of simulators certainly may yield conflicting results.

Multi-variable regression analyses. Utilizing all possible combinations of the simulator characteristic variables shown in Table 8, two and three variable multiple regression analyses were performed on the data. These analyses were aimed at determining which combination of variables accounted for most of the variance in percentage sickness incidence. The results of only the significant ($p<0.05$) two and three-variable regressions are shown in Table 9. Again, the results from these analyses should be interpreted with caution, as they are based on only eight observations and due to the multiplicity of tests, the $p < 0.05$ value should be considered as high. As can be seen from the significant three-variable regressions, the combinations of horizontal field-of-view with external view and mission duration, as well as horizontal field-of-view with image generation system type and level of scene detail, accounted for a large portion of the total variance in percentage sickness incidence. Again, mission duration was revealed to be positively related to simulator-induced sickness, in this case in combination with the part-task/whole flight variable. No other combinations of variables from Table 8 revealed significant regression prediction equations for the data. All remaining two-variable regression analyses yielded r^2 values less than 0.568 and p-values greater than 0.17. (These were the values for the combination of horizontal field-of-view and mission duration.) All remaining three-variable regression analyses yielded r^2 values less than 0.68 and p-values greater than 0.16. (These were for the combination of scene detail, external view, and mission duration.)

Table 9. Results of Two- and Three-Variable Linear Regression Analyses Using Simulator Characteristics as Regressors. Data for Eight Simulators; Significant Regressions Only.

Simulator Characteristics*	r^2	Regression Equation
Simulator task (ST)/Mission duration (MD)	.923	PSI = −31.27(ST) + 39.6(MD) − 12.6**
Horizontal field-of-view (HV)/ Trainee allowed external view (EV)/Mission duration (MD)	.966	PSI = 0.51(HV) + 102.25(EV) + 185.48(MD) − 440.7***
Horizontal field-of-view (HV)/ Image generation system (IG)/Scene detail(SD)	.917	PSI = −7(HV) − 1859.5(IG) + 410.50(SD) + 2060.5***

* Refer to Table 8 for description of simulator characteristic variable levels.
** Slope of regression line is significantly different from 0 using an *F*-test with 2,5 df and $p < 0.05$ cutoff criterion (see text)
*** Slope of regression line is significantly different from 0 using an *F*-test with 3,4 df and $p < 0.05$ cutoff criterion (see text).

SIMULATOR DESIGN AND PROCEDURAL CHARACTERISTICS FOR STUDY

Organization of Table 10--Specific Characteristics with Potential for Sickness-Provocation

Based on the information from analyses of the simulator site surveys (Tables 1-7) and the review of the literature and documentation on simulator sickness, a listing of simulator design and procedural characteristics with potential for influencing simulator-induced sickness was devised. This listing which appears in Table 10, includes those design and procedural factors which either appear to have some potential to, or have been demonstrated to influence the occurrence of simulator operator/passenger discomfort. The listing of factors is organized under the main headings of visual system factors, motion-cuing system factors, dynamic control loop factors, cockpit environment factors, and operational procedures. (The reader is referred to Casali, 1986, Volume I of this report, for a literature overview of factors under each main heading to be used in conjunction with the tabular entries shown in Table 10.) For each factor listed in Table 10, three types of corresponding information are given under the following columnar headings.

Associated simulator sickness references. For each potential simulator design or procedural factor, a listing of references is given in this column. References are coded by numbers which correspond to the numbered bibliographic entries at the end of this report. If a reference number is listed for a particular factor, it indicates that there is mention, discussion, implication, or investigation of that factor's potential contributory role in simulator-induced sickness in the particular reference document. For further information pertaining to that factor, one may consult the references listed and/or refer to the overview information for most of the references contained in Volume I of this report (Casali, 1986). Also, if a particular factor was found in one or more simulators which were included in the site surveys, as discovered either by direct observation or from personnel interviews, it is so designated by "SS" (simulator survey) in Table 10. To determine the exact occurrence of the design or procedural factor, one may again refer to Tables 1-7.

Priority for research rating. The second column in Table 10 constitutes a research priority rating, based on the judgment of the research team and assigned to each potential factor. This represents an attempt to prioritize the potential etiological factors on the basis of their need for research attention. It does not take into account the feasibility of the factors for research, which is separately rated in the third column. The priority rating is comprised of a dual (number/letter) rating scheme. The numerical score is simply a 3-point (1 = highest potential; 3 = least potential) rating value assigned to each design and procedural factor, which indicates the relative potential of the factor to contribute to simulator-induced sickness. The letter (A,B) assignment indicates whether the design factor represents: A--a significant simulator design question in that primarily hardware changes are implicated, or B--an "adjustment" question where calibration, maintenance, software modification, or procedural changes are implicated. The assigned ratings were arrived at through a review of the collective literature results, the simulator site survey, personal experience with research on simulator-induced sickness, and whenever possible, discussions with simulator users and designers. Because relatively little is known about the true etiology of simulator-induced sickness, it was necessary for the research team to rely on personal judgment and expert opinion for these ratings. While they are not intended to be taken in the absolute sense, the ratings may hopefully prove useful in selecting variables for initial studies on simulator-induced sickness. Again it should be kept in mind that many factors may only exhibit potential for inducing simulator-induced sickness through interaction with other factors. Therefore, one must exercise caution in addressing them in isolation in any single study.

The numerical portion of the priority rating scheme is as follows:

1. Factor appears to have strong potential for contributing to simulator-induced sickness.

2. Factor appears to have moderate potential for contributing to simulator-induced sickness.

3. Factor appears to have little potential for contributing to simulator-induced sickness.

This priority letter/number rating scheme is again summarized in Table 10a. It should be noted that in some instances, factors with a high priority and a B rating may not be among the most important to investigate in initial studies of simulator-induced sickness. Such factors may not have direct bearing on simulator design changes but simply may be eliminated by straightforward adjustments or procedural changes. Therefore, though some procedural factors may have more potential for inducing sickness than some design or adjustment factors, they may not warrant research attention over these latter factors. For instance, the use of visual scene freeze (stop-action) is known to have strong potential (rating of 1) for contributing to simulator-induced discomfort. However, its use may be eliminated, minimized, or trainees may be simply warned prior to its initiation to avoid the effect. Therefore, it probably does not warrant a great deal of research attention. On the other hand, a factor such as that encompassing the motion-base washout design parameters (e.g., time constant, magnitude scaling, etc.) also has a high potential (rating of 1) for inducing discomfort if improperly specified (e.g., Sinacori, 1967). This factor also is rated B because it is largely subject to tuning or adjustment of the motion drive logic, prefilters, and software controlling the motion base. Unlike the freeze factor, however, it seems critical that the washout design parameters receive research attention because the tuning procedure is not so straightforward. There is a definite need for accurately specifying acceptable ranges of these parameters to guard against their influence on simulator-induced sickness. Hopefully, these examples illustrate some of the difficulties encountered in prioritizing simulator factors for research.

The ratings proposed in Table 10 represent a first attempt at targeting important factors for study. One must carefully consider each factor, its potential interaction with other factors, and its ramifications for simulator hardware design, adjustment, or operating procedures before selecting a set of factors for assessment in a simulator.

Feasibility for research rating. The third column in Table 10 includes a dual (number/letter) feasibility for research rating for each factor. Again, this rating was assigned on the judgment of the research team and was based on the obtained information for each factor from the literature and simulator site surveys. The numerical (3-point) portion of the rating is essentially comprised of the apparent amenability of each factor to simulator-based research investigation, given current simulator technology. Factors which have high feasibility for research must be manipulable and controllable so that the effects of different factor levels on selected dependent variables can be ascertained. For the letter portion of the rating, it was assumed that a research facility designed for and dedicated to the study of simulator-induced sickness could be constructed. (Suggested requirements for such a simulator facility are specified in the "Simulator-Sickness Research Facility" section of this report.) Those design factors in Table 10 which appeared to best lend themselves to investigation using such a "specialized" facility were assigned to the second (B) level of feasibility. Design factors which exhibited good potential for investigation using an existing training or research simulator, or a combination of simulators, were assigned to the first (A) level of feasibility. Although the latter approach (using existing simulators) may have capital investment cost advantages over a specialized facility, the problems of experimental control, dependent measure availability, simulator scheduling, etc. may outweigh the lack of an initial investment. Such tradeoffs are discussed more fully in the final section of this report. The 3-point rating scheme for the feasibility for research rating is as follows:

1. Factor appears highly feasible for simulator-based research investigation and independent variable levels appear to be manipulable with minimum difficulty.
2. Factor appears moderately feasible for simulator-based research investigation and independent variable levels appear to be manipulable with some difficulty.
3. Factor exhibits low feasibility for simulator-based research investigation and independent variable levels appear to be difficult to manipulate.

The feasibility rating scheme is also summarized in Table 10a.

Table 10a. Key to Priority/Feasibility for Research Ratings Used in Table 10.

Priority Rating

1 = strong apparent potential for contributing to (or relation with) simulator sickness

2 = moderate apparent potential for contributing to (or relation with) simulator sickness

3 = little apparent potential for contributing to (or relation with) simulator sickness

A = simulator hardware changes are implicated

B = little or no hardware changes are implicated; only software modification, calibration, adjustment, or procedural changes

(Note: In some cases A and B may be used together to indicate possibility of hardware change in conjunction with adjustment or programming modifications.)

Feasibility Rating

1 = apparent high feasibility for simulator-based investigation

2 = apparent moderate feasibility for simulator-based investigation

3 = apparent low feasibility for simulator-based investigation

A = appears best amenable to investigation using existing simulator(s)

B = appears best amenable to investigation using research simulator facility specifically designed for and dedicated to sickness research

Table 10. Simulator Design and Procedural Characteristics with Potential for Influencing Operator Sickness.*

Simulator Design Factor	Associated Simulator-Sickness References**	Priority for Research Rating	Feasibility for Research Rating
Visual System			
Optometric distortion:			
observer-display focal length	4,19,25,30,34,44,50,52	1A	1B
biocular vs. binocular optics	25,30,44,52,64,SS	2A	2B
off-axis perspective & parallax	14,16,19,30,34,40,44,45, 64,SS	1A	1A
lensing effects & magnification	2,24,25,27,30,34,40,44, 45,50,51,SS	2A	1B
projection screen distortion	1,4,25,34,44,45,50,51,61, SS	2A	3B
movement from operator design envelope	14,16,19,25,30,34,40,44, 45,64,SS	1A	1A
Temporal and related problems:			
display flicker/refresh rate	1,19,34,40,50,51,52	2B	2B
image smearing (phosphor persistence)	34,40,52,SS	3A	2B
image swimming (with head movement)	40,52,SS	2B	2B
priority (image bleed-through)	SS	3B	2B
shadowing (ghosting)	SS	3B	2B
double-imaging	25,40,44,SS	2B	2B
display content update lags	1,34,40,52,54	1B	1B
image jitter (sampling problem)	50,51,SS	2B	3B
Display imaging technique: (e.g., raster CRT, calligraphic CRT, TV projection, transparency projection)	1,2,3,30,34,35,40,41,61,64	2A	2A
Infinity view perspective:			
viewing distance	1,4,25,30,34,40,41,44,45, 50,51,52,53,64	1A	2B
appropriate collimation	16,19,24,25,30,40,41,64,SS	1A	1B
inappropriate not-at-∞ cues (e.g., display edges, visible raster)	1,24,25,44,45,50,64,SS	2B	1A
vanishing point	4,44,45,50	2B	1A
Scene luminance level (affecting pupillary dilation & spherical aberration thereof)	1,30,34,35,41,52,SS	2B	1A

* See Table 10a for key to ratings used.

** SS denotes that the factor was noted during the simulator site surveys, so indicated in Tables 1-7.

Table 10. Simulator Design and Procedural Characteristics with Potential for Influencing Operator Sickness.* (Continued)

Simulator Design Factor	Associated Simulator-Sickness References**	Priority for Research Rating	Feasibility for Research Rating
Visual System (Continued)			
Field-of-view and display content:			
field-of-view	1,2,15,16,17,27,30,33,34, 35,39,40,41,47,50,51,52, 53,55,58,61,SS	1A	1B
display detail level	1,16,25,28,30,34,39,40,41, 44,45,50,51,52,57,58,SS	1A,B	1A
scene texturing level	40,SS	2A,B	1A
object static/dynamic geometric distortion	1,25,34,40,44,45,50,51,52, 64,SS	1A,B	2B
object/scene realism	4,13,25,40,44,45,53,57,SS	2A,B	2B
Visually-implied motion:			
phasing factors (leads, lags)	1,16,25,33,34,35,40,41,44 45,50,51,52,54,57,58,64, SS	1A,B	1A,B
gain factors (magnitude scaling)	34,40,45,50,52,57,58,SS	2B	2A,B
visual vection level (e.g., progression effects)	13,15,16,24,27,28,34,39, 40,41,49,50,51,52,53,57, 58,SS	1B	2B
degrees-of-freedom represented	13,40,52,57,58,SS(2E6)	1A	2A,B
Display anomalies:			
light leakage at display edges	53,SS	3B	1A
display discontinuities	14,19,24,25,41,44,SS	2B	1A
misalignment (e.g., displacement, chrominance)	19,24,25,SS	2B	1A
display vibration (affecting accommodation)	1,34,44,50,51,52	2B	2A
Design parameters:			
resolution	1,4,24,25,30,34,40,44,45 50,51,52,57,SS	2A	1B
contrast (e.g., luminance, chrominance)	24,30,44,45,50,51,52,SS	2A	1B
modulation transfer function	30	2A	1B

* See Table 10a for key to ratings used.
** SS denotes that the factor was noted during the simulator site surveys, so indicated in Tables 1-7.

Table 10. Simulator Design and Procedural Characteristics with Potential for Influencing Operator Sickness.* (Continued)

Simulator Design Factor	Associated Simulator-Sickness References**	Priority for Research Rating	Feasibility for Research Rating
Motion Cuing System			
Motion platform:			
fixed-base/moving-base	1,2,3,4,13,15,16,23,24,25,27,28,35,40,41,42,44,45,49,50,51,52,55,56,57,58,SS	1A	1A
degrees-of-freedom represented	4,7,12,27,40,47,50,52,56,58,SS	1A	1A
excursion & acceleration envelope	23,24,36,40,47,50,52,56,58,SS	1A	2B
frequency bandwidth capabilities	24,36,40,50,52,58	1A	1B
phasing factors (leads, lags)	7,12,16,24,33,34,35,40,41,47,50,52,57,58,64,SS	1A,B	1A,B
gain factors (magnitude scaling)	7,12,24,27,34,40,47,50,52,57,58,SS	1A,B	2A,B
washout design parameters (e.g., time constant)	34,36,40,47,50,52,58	1B	1B
spectral characteristics (e.g., problematic vertical 0.2-0.4 Hz)	20,24,27,33,34,40,46,48,52	1A,B	1B
tilt cuing of pure linear accelerations	4,6,7,12,27,40,52,58	1A	1A,B
parasitic motion & axis coupling	52,SS	2A	2B
reverse positional cuing (see Vol. I, p. 57)	SS	2A,B	2B
motion nulling return rate	50,58	2A,B	1B
vehicle center-of-motion location	4,27	1A,B	1B
hydraulic bump/shudder	SS	3B	3A
motion drive stiction effects	SS	3A	3A
Enhancement cuing:			
vibration & buffet	1,2,3,34,40,52	2B	1A
g-seat	40,47,50,52,SS (not used)	1A	2A
g-suit	13,17,40,52,SS (not used)	2A	2A
restraint belt tensioning	13,17,40,SS (not used)	3A	2A
helmet loading	40	3A	2A
g-dependent display dimming (gray-out)	52,SS	3B	2A
g-dependent control loading	52,SS	3A,B	2A

* See Table 10a for key to ratings used.

** SS denotes that the factor was noted during the simulator site surveys, so indicated in Tables 1-7.

Table 10. Simulator Design and Procedural Characteristics with Potential for Influencing Operator Sickness.* (Continued)

Simulator Design Factor	Associated Simulator-Sickness References**	Priority for Research Rating	Feasibility for Research Rating
Dynamic Control Loop Factors			
System delays/lags:			
input-to-output transport delay	1,7,12,20,25,34,35,40,44, 45,50,52,53,54,64,SS	1A,B[1]	1B
exponential and second-order lags	16,20,35,40,44,45,52,SS	1A,B[1]	2B
phasing between visual and motion update	7,12,16,20,24,33,34,35,40, 50,52,58,64	1A,B	1A,B
Vehicle modeling & computation:			
vehicle dynamics math model validity	40,44,52,SS	2B	2B
vehicle dynamics software fidelity	24,40,52,SS	2B	2B
model output sampling rates	52	1B[1]	2B
model output scaling factor	7,12,52,58	2B	1A,B
resolution of dynamics variables during D/A, A/D conversions (if inadequate quantization, non-continuous response may result)		2B	1B
Other dynamic manual control factors:			
control input sampling rates	52	1B[1]	2B
control input scaling factor	24,44,52,57,58	2B	2A,B
control stick damping (influencing PIO)	44*,45*,52,57,58,SS	1A,B	1B
control resistance simulation accuracy (elastic, breakout, stiction, sliding friction, viscous friction, inertia, etc.)	44,50,52,SS	2A	2B
control deadspace & backlash fidelity	SS	2A,B	1B

* See Table 10a for key to ratings used.

** SS denotes that the factor was noted during the simulator site surveys, so indicated in Tables 1-7.

1 Affects total throughput delay.

Table 10. Simulator Design and Procedural Characteristics with Potential for Influencing Operator Sickness.* (Continued)

Simulator Design Factor	Associated Simulator-Sickness References**	Priority for Research Rating	Feasibility for Research Rating
Operational Procedures			
Design-dependent procedures:			
situational freeze (sudden stop-action)	13,15,17,18,20,28,40,41, 44,47,50,51,52,57,SS	1B	1A
situational slewing (rapid reset of visuals)	13,20,40,41,50,51,52,57, 58,SS	1B	1A
scene presentation during entry/exit	13,17,20,28,40,47,50,51,SS	2B	1A
use/non-use of motion system	16,23,24,27,40,42,47,50, 51,55,56,57,SS	1B	1A
complexity of kinematics capabilities	13,15,24,28,32,40,41,44, 45,47,53,57,SS	1A	1A
aircrew/passenger position in cockpit	14,16,19,30,40,41,44,45, 50,51,53,64,SS	1A	1A
User/scenario-dependent procedures:			
mission duration	1,2,14,16,20,27,30,34,35, 40,41,44,45,SS	1B	1A
mission-related workload	24,28,32,34,40,41,SS	2B	1A
kinematics, turbulence, etc. intensity	15,20,24,25,27,28,32,34, 35,40,41,44,45,47,53, 57,58,SS	1B	1A
trainee allowed external view	SS	3B	1A
trainee predisposition (e.g., discussion with others, pre-simulator activity)	3,7,25,28,30,33,34,35,40, 41,44,45,47,53,64,SS	3B	3A
adaptation/habituation effects	15,17,24,25,28,32,33,35, 40,41,44,45,47,50,51,SS	2B	1A
sickness greater with experienced pilots, drivers	13,20,25,28,30,32,33,34, 40,41,44,45,47,50,51,53, 58,SS	2B	1A
Cockpit Environment			
Cockpit control/instrument layout		3A	2B
Auditory cue localization (orientation effect)	1,52,SS	3A	1B
Enclosure, claustrophobic influences	7,12,25,33,40	2A	2B
Temperature & humidity regulation	52,SS	2A,B	1A
Air exchange (avoidance of CO_2 accumulation)		2A,B	2A

* See Table 1-a for key to ratings used.

** SS denotes that the factor was noted during the simulator site surveys, so indicated in Tables 1-7.

Dependent Measures for Assessing Simulator Sickness

It is clear that the effects of simulator-induced sickness may be manifested via a variety of signs and symptoms (see also Volume I, Casali, 1986), and that the selection of valid dependent measures for study of the problem must be made with care. As such, a partial listing of possible metrics, associated data collection strategies, and pertinent reference listings, is provided in Table 11. The metrics are divided into six categories, and one should carefully consider the use of dependent measures from each category when designing a test battery for studying simulator-induced sickness. The importance of recognizing the polysymptomatic nature of the simulator-induced sickness state has been well-demonstrated in the research of Kennedy and others (e.g., Kennedy, Dutton, Ricard, and Frank, 1984).

In addition to its impact on trainees' or subjects' physiologic state (indicated by self-report, bodily instrumentation, or direct observation), simulator-induced sickness may influence in-simulator performance as well as post-simulator behavior and ataxia. Therefore, the measurement of such variables as vehicle path control performance, cognitive processing performance, and postural equilibrium may help reflect the extent of simulator effects. Furthermore, several metrics have some promise for predicting an individual's susceptibility to simulator-induced sickness, based on past motion sickness experiences and perceptual style. These are also noted in Table 11, along with related references.

Table 11. Potential Dependent Measures for Use in Research on Simulator-Induced Sickness.

SELF-REPORT MEASURES

Post-simulator symptomatology/"motion sickness" questionnaires
(e.g., see ref. 7, 25*, 32*, 35*, 41, 53, 55, 61, 66*)

Post-simulator interview

INSTRUMENTED OR OBSERVED PHYSIOLOGIC SYMPTOMATOLOGY MEASURES

Cardiovascular activity (e.g., heart/pulse rate, cardiac waveform, blood volume changes)
--cardiotachometer, plethysmography (photoelectric, impedance, strain gauge), palpation, electrocardiography, phonocardiography, vectorcardiography

Blood pressure
--sphygmomanometer, polygraph with pressure transducer, catheterization, pulse wave transit time measurement using electrocardiogram

Respiratory activity (e.g., breathing rate, tidal depth)
--thermistor air temperature measurement, thorax impedance (chest electrodes), chest strain gauge, air pressure pneumography, spirometry, gas component analysis, capacitive-coupling movement transduction (ref. 12)

Electrodermal activity (e.g., galvanic skin response, skin conductance and skin potential, profuse sweating--esp. volar and forehead)
--surface electrodes and polygraph, direct observation

Temperature (esp. facial)
--surface thermistor, oral thermometer

Pallor
--transmissivity plethysmography (ref. 12), direct observation

Gastrointestinal motility (amplitude and frequency measurement)
--electrogastrography with spectral and autocorrelation analysis

Eye activity (e.g., drowsiness--eyelid droop and closure, vestibulo-ocular reflex (ref. 46), nystagmus)
--photographic and video recording, electrooculography, pupillography

Other less-instrumentable physiological symptoms for direct observation: burping, nausea, retch, emesis, fatigue, visual dysfunction, dizziness, eye strain

(continued on next page)

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* Reference recommended for questionnaire used.

Table 11. Potential Dependent Measures for Use in Research on Simulator-Induced Sickness. (Continued)

SIMULATOR TASK PERFORMANCE MEASURES

Vehicle control measures (e.g., path control deviation--yaw, lateral position, heading, etc.; velocity deviation; yoke, stick, rudder, steering reversals; control response time to disturbance; control movement overshoot and PIO)

Other flight or driving task-related performance measures can be devised as pertinent to training task objectives (e.g., maintenance of instrument scanning patterns (eyetracker, video techniques), response time and strategy for emergencies, detection of radar and visual contact targets, etc.)

PRE-POST SIMULATOR POSTURAL DISEQUILIBRIUM AND PSYCHOMOTOR TESTS

Pre-post exposure static and locomotor ataxia tests
--e.g., stand-on-preferred/nonpreferred-leg-test (ref. 32,35), walk-heel-to-toe-eyes-closed-test (ref. 32,35)

Pre-post exposure manual psychomotor tests
--e.g., video game (esp. air combat maneuvering) performance (ref. 32), tapping speed and regularity (ref. 35), critical tracking task performance, pursuit rotor performance

PRE-POST SIMULATOR COGNITIVE AND PERCEPTUAL TESTS

PETER tests (Performance Evaluation Tests for Environmental Research--ref. 32,35)
--e.g., grammatical reasoning, pattern comparison

Various other tests
--e.g., arithmetic proficiency test (ref. 12)

SICKNESS HISTORY/SUSCEPTIBILITY/PREDICTIVE METRICS

Pensacola Motion Sickness Questionnaire (ref. 32, 35)

Motion History Questionnaire (ref. 35, 53)

Perceptual style (field dependence-independence) tests (ref. 3)
--e.g., body adjustment test, rod-and-frame test, embedded figures test, hidden figures test, tilted room test

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SIMULATOR-SICKNESS RESEARCH FACILITY

(This section was prepared by W. W. Wierwille.)

Because simulator-induced sickness is such a pervasive problem and because it remains poorly understood, research expenditures to solve the problem would appear well-justified. Expenditures toward such goals have already been made at moderate levels, resulting in the enumeration of possible causes of simulator-induced sickness, the examination of certain independent variables in limited amounts, and the attempt to relate etiological factors underlying simulator and motion sickness (e.g., Casali and Wierwille, 1980). Such efforts have been helpful in obtaining a better understanding of the magnitude of the simulator-induced sickness problem and its etiology. However, the problem is far from being solved. As has previously been indicated, there are numerous sources that may individually induce simuator-induced sickness, and in addition they may interact with one another in a manner which is difficult to predict.

One quite feasible approach to the study of simulator-induced sickness is to examine it experimentally, using well-established experimental design principles. This involves the development of independent variables, dependent variables, and the use of appropriate statistical methods. For such an approach to reach fruition, it necessitates an appropriate experimental simulator facility in which carefully-controlled experiments can be conducted. Specifically, this means that the facility must be capable of holding constant or controlling all independent variables other than those being examined.

There appears to be two choices in the development of an experimental facility for the study of simulator-induced sickness. The first is to modify and use one or more existing simulators in which specific sets of independent variables could be examined. The concept here is that a research team would move into an existing facility for a period of time, prepare the facility for a specific group of experiments, conduct the experiments, obtain the results, analyze them, and then move on to another simulator facility. From a logistics point of view, this approach appears fraught with problems. Funding, facility availability, relocation for the researchers, lack of consistency of experimental situations, and lack of familiarity with the operating details (hardware and software) of the facilities are some of the major difficulties that would be encountered. Furthermore, most current facilities exist solely because of their training mission. As such they are not easily adapted to and may not be available for a research mode of operation, which requires adjustment of different independent variables and measurement of a different set of dependent variables. Thus, the use of existing facilities for experimental study of simulator-induced sickness, particularly that aimed at the design-based etiology of the problem, appears to have several drawbacks.

The second approach to the experimental examination of simulator-induced sickness is the development of a dedicated facility. This facility, which should be located in an environment conducive to research (probably a nonprofit research laboratory, government research laboratory, or university) should be designed and developed so that the largest possible range and number of independent variables can be examined.

The largest drawback for the development of an independent facility to study simulator-induced sickness is probably its cost. It is no secret that a high-quality vehicle simulator to be used for training usually represents an initial seven-figure dollar capital investment. For a research facility, costs could be expected to be comparable. While cockpit or cab instrumentation might not have to be as complex as in a training facility (because the equipment fidelity is probably more critical for procedures training than for research), the motion base, visual scene generation system, and the computational support system must be at least as complex and probably more so. As previously discussed, one can take the point of view that simulator sickness occurs because the cues that the subjects receive are not the same as those in the corresponding real vehicle. In the simulator, the cues are approximations of those experienced in the actual vehicle, and the approximations may constitute the causes of simulator-induced sickness. This is a simplistic point of view, but it does shed light on the design of a research facility for the study of simulator-induced sickness. It follows from this notion that the best design of a facility is one in which the approximations are as small as possible. An example illustrates this point. Suppose the research simulator is designed such that overall minimum delay in visual presentation from computational limitations is 150 milliseconds. Under such conditions, the independent variable of visual delay is limited on the low end to 150 milliseconds. While longer delays can be obtained through software modifications, shorter delays cannot, thereby greatly limiting the ability to study the effects of delay which would be of high research priority. Another example involves display field-of-view. The effects of wide viewing angles compared to narrower ones cannot be studied unless the wide viewing angles are available in the research simulator. Viewing angles can always be made narrower by means of opaque shading devices or other optical means, but they cannot be made wider without the addition of substantial amounts of hardware. Hopefully, these simple examples illustrate the main point that the simulation facility must be carefully designed to allow the greatest possible range of manipulation within important independent variables. As a result, the subsystems of the simulator must push the state of the art of simulator design, and usually, must be better than those of existing training simulators in many ways.

The major elements of vehicular simulators that are believed to contribute to simulator-induced sickness have been previously and summarized in Table 10. And as indicated earlier, these elements not only contribute individually, they also are believed to interact in presently unpredictable ways to cause simulator-induced sickness.

Careful examination of the table indicates that most of the factors listed can be grouped under three main hardware systems: the motion-base, the visual display system, and the dynamics/computation system. There are other factors listed which affect simulator-induced sickness, but they are more easily changed, controlled, or otherwise taken into account. For example, several different cab enclosures for a simulator can be easily fabricated of lightweight material and used to examine the effects of enclosure on simulator-induced sickness. Provided the motion-base is designed to handle the incremental load, the enclosure can be considered as a subsidiary element in the design process. Thus, the preliminary characteristics of the three main systems of the simulator will be described in the following sections.

Motion-Base

The main characteristics of the motion-base are the number of degrees of freedom, the allowable excursions in each degree, small signal frequency response, and large signal slew rates. Additional characteristics involve aspects such as inherent delays, resonances, and excursion limit interactions.

It is important for the research simulator to have a full six degree-of-freedom capability. Anything less than this would severely limit the range of problems that could be studied. It is quite likely that a synergistic (six-actuator post or "leg") system would be able to provide the necessary capabilities. The only other alternative is a cascade system, which is likely to require additional expense and design effort, and also has inherent weight disadvantages. The synergistic system has already reached a relatively high state of development and probably could be used with little additional technology advancement in the research simulator.

State-of-the-art characteristics of a synergistic system include those shown in Table 12a. The specifications shown are similar to those already available (e.g., Puig, 1984), and should be adequate for a research facility. Additional specifications would be necessary, however, to ensure that full advantage could be taken of the synergistic motion-base, and they are shown in Table 12b. These specifications are probably also within the present state of the art. They specify that the closed-loop control of each axis should have a closed-loop frequency response that is similar to a first-order lag. The rise time is specified for small input excursions where "handling" aspects are most important. This rise time is faster than that of most degrees-of-freedom of most vehicles. In addition, by specifying a first-order lag, inertial effects are indirectly taken into account. Compensation is also specified so that any closed-loop lag is compensated by a prefilter.

An important associated aspect of the motion base is the mass it must move. The greater the "payload" the more powerful the motion base must be and the higher the cost becomes. Therefore, every effort should be made to minimize the mass of the payload on the motion base. It would be desirable to aim for a total payload mass equivalent to perhaps 1200 pounds. This weight would include the subject, all cab elements and any motion base-borne displays, controls, and additional equipment such as sound generation, air handling, and communications. Overdesigning the payload should be avoided, so that costs can be held down and response times of the motion-base can be kept fast.

Table 12. Proposed Synergistic Motion Base Characteristics.*

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a) MAIN CHARACTERISTICS

1. Excursion for each angular d.o.f.: $\pm$ 35°

2. Acceleration for each angular d.o.f.: 200°/sec^2

3. Excursion for each translational d.o.f.: $\pm$ 36 in.

4. Acceleration for each translational d.o.f.: 0.8 g incremental

b) ADDITIONAL CHARACTERISTICS

5. Frequency response bandwidth (3db) (for each axis) for a peak-to-peak input amplitude that is 10% of full (peak-to-peak) excursion range: 2.5 Hz

6. Phase response bandwidth (45°) for the above input signal: 2.5 Hz

7. Response to a step for each axis. (Step response to be 5% of full (peak-to-peak) excursion range):

   a. Type of response: First order (single time constant in waveshape)

   b. Rise time (0 to 90%): 0.2 sec

8. Compensation:* First-order prefilter, matched to compensate for closed-loop time constant

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*First seven characteristics to be met without compensation.

Display System

As with the motion base, there is a major choice that must be made between two competing display configurations. One of these is a real image projection CRT system and the other is virtual image (standard-viewing) CRT system. The projection system would use a large screen that can be held stationary or attached to the motion platform. This system requires a great deal of maintenance and has a focal distance that is nearly fixed. As a result, focal distance is not adjustable as an independent variable.

There is a common misconception that projection systems produce a larger field-of-view than virtual image systems. This is simply not true. One channel of a projection system with an 8 foot wide screen located 10 feet away from a viewer produces a 44° horizontal field-of-view. For a virtual image system with a 24 inch wide aperture located 28 inches away from the viewer, the horizontal field of view is 46°. Thus, there is really no field-of-view advantage for projection systems. In terms of display luminance and luminance contrast ratios, the projection system is at a distinct disadvantage. Extremely high accelerating potentials must be used to achieve minimally acceptable screen luminance. Under such conditions, projection CRT tube life is likely to be short, and characteristics are likely to change with tube age. Finally, projection optics tend to reduce the image resolution more than virtual image optics. This is a result of the fact that the optics must gather as much light as possible from the object surface of the projection CRT and project it in focus onto the screen. In other words, the light-gathering (aperture) capability competes with the resolution (focus) capability.

Usually, projection systems are used where images must be superimposed, for example, in air combat maneuvering simulators where a target aircraft is superimposed on a surrounding sky/ground background scene. They are also used where multiple crew members must view the same image. These capabilities, however, do not appear to be particularly important for the study of simulator-induced sickness. Therefore, it can be concluded that the virtual image CRT system would be the better choice for examination of simulator-induced sickness.

As mentioned earlier, the virtual image display system should have a wide field-of-view so that this variable can be experimentally investigated. Probably the best arrangement would be a four-channel system, with each channel having a 37° vertical by 50° horizontal field-of-view. To allow for some eye position change, an overlap of 3° on each edge should be used, yielding 44° of horizontal field-of-view per channel for a total of 176°. The major characteristics of each channel are listed in Table 13.

In terms of the optics, the probable choice is reflective (spherical mirror) infinity optics in a folded optical path. The disadvantage associated with refractive lenses is that they become bulky (thick) for the set of optical properties required or that fresnel lenses must be used, with their attendant diffraction at the edges of the lens etchings. Consequently, reflective optics seem to have the advantage for this application.

An important aspect of the optics is the apparent distance of the image from the subject's eyes. As indicated, a projection system would require that the image distance be fixed. Reflective optics, on the other hand, have the potential advantage of allowing adjustment of the apparent image distance. This can be accomplished by moving the object surface (the CRT in this case) inward or outward from the viewer a short distance. While it is true that these position shifts also cause a change in image size, the change is relatively small and can probably be compensated computationally in the scene. Thus, reflective optics allow apparent image distance to be treated as an

Table 13. Characteristics of Each Channel of Proposed Visual Display System.

Optics: Folded path reflective, with virtual image adjustable from 8 ft. to infinity.

Field-of-view should be adjustable by 10° horizontal increments by insertable shades at the aperture.

CRTs: Shadow-mask color type with 750 vertical by 1000 to 1200 horizontal addressable pixels.

Refresh rate: 60 Hz for full picture with 2:1 interlace (120 Hz for half picture).

Persistence: Matched to 60 Hz refresh rate

Luminance: 60 candelas/m^2 (at aperture)

Luminance contrast ratio: 100:1 (at aperture)

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independent variable. The desired range of adjustment would be 8 feet to infinity, as indicated in Table 13.

Since field-of-view is a very important independent variable in the study of simulator-induced sickness, it should be adjustable over a wide range. This could be easily accomplished by using shades allowing decreasing widths of field-of-view in 10° increments.

The CRT's to be used in the visual system should be such that they allow a minimum of 1000 addressable points (pixels) horizontal by 750 vertical. Actually 1200 points horizontally would be better, if attainable, because of cropping. Each addressable point should have a range of color as in a high-quality shadow mask color CRT.

The refresh rate (scan rate) of the CRT's should be 60Hz, that is, double the rate normally associated with standard CRT's. The normal mode of address should be interlaced to further reduce flicker. Thus, a "half" picture would be produced every 120th of a second. The reason for using this higher scan rate is to ensure that the presented image is above the flicker threshold for most individuals. There is a possibility that flicker may affect simulator-induced sickness, and therefore, for purposes of comparisons a high scan rate must be available. Apparent scan rates can then be lowered in submultiples by software to determine the effects of flicker.

As indicated earlier, one major advantage associated with CRT's viewed through reflective optics is that they can produce relatively high luminance levels. It has been observed that simulators capable of high brightness have a greater tendency to induce uneasiness. Therefore, to study the effect of brightness, the obtainable luminance should be relatively high. Particular effort should be directed toward achieving a minimum of 60 candelas/m^2 at the aperture. This is relatively high value and would only be used part of the time. However, unless it is available, the effects of high screen brightness could not be properly studied.

Similarly, high contrast may have an effect on simulator-induced sickness. To achieve high contrast, e.g. 100:1, it is first necessary to have high luminance. Thus, the specified contrast ratio will only be achievable if the brightness specification is first met. Contrast ratio is important in the study of "flashbacks" and other aftereffects of simulator-induced sickness. Furthermore, brightness, contrast, and flicker may interact to create uneasiness. The simulator should be designed so that it encompasses this realm of problems.

The combination of high luminance and high contrast ratio can be more easily achieved using refractive optics. This is a result of the fact that the refractive optics have only a lens loss, whereas reflective optics have losses created by half-silvered mirrors, used first in reflection and then in transmission. While the recommended design here is reflective, it may become necessary after a detailed design process to specify refractive optics in order to meet the lunimance and luminance contrast ratio specification.

Emphasis in this section has been on the optics and associated CRT's. Scenes to be presented on the CRT's will be discussed in the next section. However, before leaving the topic of displays, it is important to discuss the drive electronics briefly. In particular these electronics must not compromise the resolution of the scene, that is, they must allow the pixel elements to be individually addressable in sequence and must perform the D/A conversions accurately such that the digital video data received are faithfully transformed to color pixel levels at the CRT face.

Dynamics/Computation System

The effects that computations have on simulator-induced sickness are profound and well-recognized. Delays, distortions, and other dynamic inaccuracies can create many kinds of difficulties in simulation, and consequently, the computational system is of utmost importance in simulation design.

The problems associated with computation are best viewed from a historical point of view. As simulators first began to be developed, the primary method of computation was by means of electronic analog computers. These computers had the advantage of providing dynamically accurate representations of the vehicle equations of motion because they were parallel devices. They could solve differential equations accurately, without any problems of delays or unwanted lags. However, these computers were temperamental, required point-to-point wiring, and had to be carefully amplitude-scaled to avoid unacceptable inaccuracies. Furthermore, they were limited in versatility because they had very limited storage capability and because accuracy was fixed at about 0.5% of full scale. These limitations encouraged simulator manufacturers to move toward digital computer technology as soon as it was feasible to do so.

Digital computation from the outset has historically been performed in serial fashion. While there is fundamentally no reason why parallel digital computation could not have been developed, the tradition of digital computers has been and remains to perform computations serially.

Because digital computers are serial devices, they always introduce delays of some magnitude in every computation performed. High-speed machines can perform simple computations rapidly, but not instantaneously. The more complex the computation is and the slower the speed of the machine is, the longer it takes to complete the computation. In simulation work, the basic computational process involves sampling inputs, performing computations on the inputs, and then providing outputs or commands for the simulator hardware. In display generation, the process also includes mass retrieval of information from storage, operations on the information, and mass transfer to display buffers. Regardless of the specific tasks involved, delays occur and therefore must be considered in simulator design. Insofar as a simulator to study sickness is concerned, the delays must be sufficiently short that they can be considered negligible. Otherwise, the effects of delays cannot be studied.

Table 14 contains a proposed delay budget for the dynamics/computation system of the simulator. This budget was developed using the idea that total computational delay must not exceed 25 milliseconds from control input to system response. This delay is the additional delay encountered as a result of serial computation in digital systems, and does not of course include the lags which are normally associated with vehicle dynamics (as a result of the equations of motion).

Most researchers involved in manual control system design would probably agree that a total loop delay of 25 milliseconds would not appreciably affect system handling performance. However, they probably would also indicate that delays greater than 25 milliseconds would affect performance. Therefore, maximum allowable delay should not be greater than 25 milliseconds.

In examining the table, it should be noted that the motion base has already been specified as compensated so that it does not introduce delays or lags in and of itself. In any case, once the vehicle state is computed, it can be outputted to a subsidiary processor which can handle coordinate transformation and washout. In other words, major delays are not expected to occur in the motion-generating system. Rather, they are expected to occur in the visual display system.

The most difficult problem is the retrieval, processing, outputting, and

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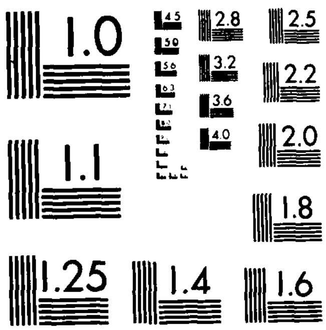

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Table 14. Delay Budget for the Dynamics/Computation System.

Process	Allowable Delay (milliseconds)
Input vector sampling and computation of vehicle state	2
Retrieval of scene information from storage	4
Processing of scene information	6
Outputting of scene information to display buffer	3
Update of display visual output	10
Total	25 milliseconds

displaying of the visual information. To give some idea of the magnitude of the problem, one need only recognize that for color, 2.7 megabytes of data are necessary to complete one full picture for 1/60 second (750 x 1200 x 3 data points). Manipulating these data quickly and displaying them with only small delays represents a state-of-the-art design problem that is only now becoming possible. Most visual systems already in existence have delays approaching 100 milliseconds, which are too long for research purposes involving simulator-induced sickness. In any case, regardless of the computational techniques used, total delays must not exceed 25 milliseconds. If necessary, parallel processing can be used to bring delay times down to acceptable levels.

Other important aspects of the dynamics/computation system include the accuracy of computations and software versatility. There is a tendency to think of these machines as absolutely accurate; but, in fact, they are not. Input sampling and quantization introduces small errors, as does word size within the machine. Computation algorithms can also introduce errors, particularly when truncated. Therefore, every effort should be made to maintain accuracy throughout the computational process.

The versatility of the software is as important in a simulator designed for study of simulator-induced sickness as it is for any other application. In particular, the range of manipulation of variables should be substantial. For example, scene clutter or density must be specifiable so that it can be studied as an independent variable. However, because of the range of the independent variables, particular care must be taken to ensure that the software is user-friendly and that programming time can be held within reasonable limits for new research problems.

Concluding Remarks

In this section of the report dealing with simulator design for the study of simulator-induced sickness an attempt has been made to present the most important design aspects of such a research simulator. In particular, emphasis has been placed on the motion base, the visual system, and the dynamics/computation system. These three topics have been emphasized because they are the most important and because they must be correctly specified if the resulting facility is to do the job for which it was designed.

It appears at this point that the motion-base for such a simulator is within the present state-of-the-art and that the major considerations involve correctly specifying the system while holding payload mass to a reasonable level.

In terms of the display system, the use of folded reflective optics appears relatively straightforward and versatile, but the CRTs may be at the very edge of the state-of-the-art. In particular, doubling the usual 60 Hz scan rate while maintaining a full 750 by 1200 pixel color picture in each of four channels may cause some degree of technical difficulty. By using four channels in the display system, a field-of-view approaching 180° would be obtainable.

The dynamics/computation system represents a substantial design problem that is again at the edge of the state-of-the-art. In particular, total throughput delays from control inputs to visual scene update should not exceed 25 milliseconds. Scene generation equipment presently in use usually has delays of 100 to 150 milliseconds and would not be acceptable. It is likely that parallel computation techniques will be necessary to meet the necessary specification on throughput delays.

There is no question that many important aspects of simulator design have not been covered in this section. However, these other aspects are not as critical as the ones presented and in general do not require pushing the state-of-the-art. For example, sound generation can be handled without any particular problem. Furthermore, if found unsatisfactory, modifications or retrofits could probably be made. The system emphasized in this section, on the other hand, could not be easily retrofitted, and if incorrectly designed or constructed would severely limit the ability of the resulting simulator to perform its mission of investigation of design influences on simulator sickness.

Finally, the authors wish to emphasize one main point regarding simulator-induced sickness and a facility for its study; namely, that simulator-induced sickness is a problem that can be studied scientifically by the usual tools of behavioral research. In particular, it can be studied using a properly-designed simulator with well-defined independent variables, dependent variables, and the usual accepted experimental design methods.

SELECTED REFERENCE LIST*

1. Barrett, G. V. and Nelson, D. D. (1965, December). Human factors evaluation of a driving simulator -- summary of human factors evaluation, 15, (Goodyear Engineering Report No. 12400). Goodyear Aerospace Corporation.*

2. Barrett, G. V. and Nelson, D. D. (1966, March). Human factors evaluation of a driving simulator -- summary of virtual image display studies, 20, (Goodyear Engineering Report No. 12400). Goodyear Aerospace Corporation.*

3. Barrett, G. V. and Thornton, C. L. (1968b). Relationship between perceptual style and simulator sickness. Journal of Applied Psychology, 52 (4), 304-308.*

4. Beinke, R. E. and Williams, J. K. (1968, July) Driving simulator. Paper presented at the General Motors Corporation Automotive Safety Seminar, Milford, Michigan.*

5. Benson, A. J. (1978). Motion sickness. In G. Dhenin and J. Ernsting (Eds.), Aviation medicine--physiology and human factors, volume I. London: Tri-Med Books, Ltd.

6. Breda, W. M., Kirkpatrick, M., and Shaffer, C. L. (1972). A study of route guidance techniques (Report No. DOT-FH-11-7708). Columbus, OH: North American Rockwell Corporation.*

7. Casali, J. G. (1979). A multivariate investigation of the effects of various design alternatives on driving simulator discomfort. Master's thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.*

8. Casali, J. G. (1981). Evaluation of various design alternatives influencing discomfort in a driving simulator. In J. Moraal and K. F. Kraiss (Eds.), Manned systems design, methods, equipment and applications (pp. 449-463). New York: Plenum.*

9. Casali, J. G. (1986, August). Vehicular simulator-induced sickness, volume I: An overview. (Report No. NTRS-TR86-010). Orlando, Fl: Naval Training Systems Center.*

10. Casali, J. G. and Frank, L. H. (1986, January). Perceptual distortion and its consequences in vehicular simulation: Simulator sickness. Paper presented at the Transportation Research Board Meeting, Washington, D.C. and in press in Transportation Research Record.

* References with an asterisk are cited in this report. Other references are selected readings pertinent to simulator sickness. A more complete reference list may be found in reference 11.

11. Casali, J. G. and Roesch, J. R. (1986, August) Vehicular simulator-induced sickness, volume II: A selected annotated bibliography. (Report No. NTSC-TR86-011). Orlando, FL: Naval Training Systems Center.

12. Casali, J. G. and Wierwille, W. W. (1980). The effects of various design alternatives on moving-base driving simulator discomfort. Human Factors, 22 (6), 741-756.*

13. Casto, J. H. (1982, September). Simulator sickness. Weekly Summary of Aircraft Mishaps (U.S. Naval Safety Center), No. 38-82, 1.*

14. COMPATWINGSLANT, (1980, April). 2F87(F) serial no. 5 FE and co-pilot display. U.S. Navy message from COMPATWINGSLANT, Brunswick, ME, to CNO, Washington, D.C.*

15. Coward, R. E., Kellogg, R. S., and Castore, C. H. (1979, December). Which way is up? SAACing the dizzies. Tac Attack, 12-14.*

16. Crosby, T. N. and Kennedy, R. S. (1982, May). Postural disequilibrium and simulator sickness following flights in a P3-C operational flight trainer. Paper presented at the 53rd Annual Scientific Meeting of the Aerospace Medical Association, Bal Harbor, FL.*

17. FITRON ONE TWO FOUR, (1981, October). F-14 WST 2F112/WAVS aircrew readjustment. U.S. Navy message from FITRON ONE TWO FOUR to COMFITAEWWINGPAC, San Diego, CA.*

18. Frank, L. H. (1981, August). Simulation sickness. Invited address, NASA Ames Research Center, Moffett Field, CA.*

19. Frank, L. H. and Crosby, T. N. (1982). Psychophysiological disturbances in the 2F117A, CH-46A WST (Memorandum N-712: LHF). Orlando, FL: Human Factors Lab, Naval Training Equipment Center.*

20. Frank, L. H., Kellogg, R. S., Kennedy, R. S., and McCauley, M. E. (1983, April). Simulator aftereffects: sensorimotor disturbances induced in flight. In Proceedings of the Second Symposium on Aviation Psychology. (pp. 587-596). Columbus, OH: Department of Aviation, The Ohio State University.*

21. Gibson, J. J. (1950). The perception of the visual world. Boston: Houghton-Mifflin.

22. Guedry, F. E., Jr. (1970, August). Conflicting sensory orientation cues as a factor in motion sickness. In Fifth Symposium on the Role of the Vestibular Organs in Space Exploration (NASA SP-314) (pp. 45-51). Pensacola, FL: Naval Aerospace Medical Institute.

23. Hall, E. R. and Parker, J. F. (1967, June). A study of Air Force flight simulator programs. (Tech. Report No. AMRL-TR-67-111). Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratories.*

24. Hartman, B. O. and Hatsell, C. (1976, October). Field study: SAAC simulator. Brooks Air Force Base, TX: USAF School of Aerospace Medicine.*

25. Havron, M. D. and Butler, L. F. (1957, April). Evaluation of training effectiveness of the 2FH2 helicopter flight trainer research tool. (Tech. Report NAVTRADEVCEN 1915-00-1). Port Washington, NY: Naval Training Device Center.*

26. Hendley, G. L. (1984, May). A listing of trainee visual systems. Paper prepared by Code 214, Orlando, FL: Naval Training Equipment Center.*

27. Jex, H. R. and Ringland, R. F. (1973, September). Notes on car simulator state of the art, motion, and visual requirements (Working Paper No. 2039-2). Hawthorne, CA: Systems Technology, Inc.*

28. Kellogg, R. S., Castore, C., and Coward, R. (1980). Psychophysiological effects of training in a full vision simulator. In Preprints of the 1980 Aerospace Medical Association Meeting (pp. 203-215).*

29. Kennedy, R. S. (1970, January). Visual distortion: A point of view. (Monograph No. 15). Pensacola, FL: Naval Aerospace Medical Institute.

30. Kennedy, R. S. (1981, March). 2F87 (#5) aircraft operational flight trainer, trip report of sickness. U.S. Navy memorandum from CDR R. S. Kennedy to C.O., Naval Biodynamics Laboratory, New Orleans, LA.*

31. Kennedy, R. S., Berbaum, K. S., and Frank, L. H., (1984). Visual distortion: The correlation model. (Tech. Paper 841595). Warrendale, PA: Society of Automobile Engineers.*

32. Kennedy, R. S., Dutton, B., Ricard, G. L., and Frank, L. H. (1984). Simulator sickness: A survey of flight simulators for the Navy. (Tech. Paper 841597). Warrendale, PA: Society of Automotive Engineers.*

33. Kennedy, R. S. and Frank, L. H. (1983, September, revised 1984, March). A review of motion sickness with special reference to simulator sickness. Paper prepared for distribution at the National Academy of Sciences/ National Research Council, Committee on Human Factors, Workshop on Simulator Sickness, September 1983, Naval Post-Graduate School, Monterey, CA.*

34. Kennedy, R. S., Frank, L. H., and McCauley, M. E. (1983, July). Simulator sickness: Reaction to a transformed perceptual world--II. sourcebook and suggested readings. Report available from Head, Human Factors Division, Naval Training Systems Center, Orlando, FL.*

35. Kennedy, R. S., Frank, L. H., McCauley, M. E., Bittner, A. C., Jr., Root, R. W., and Binks, T. A. (1984, April). Simulator sickness: Reaction to a transformed perceptual world--VI. preliminary site surveys. Paper presented at the AGARD Aerospace Medical Panel Symposium, Williamsburg, VA and published in Conference Proceedings No. 392.*

36. Key, D. L., Odneal, B. L., and Sinacori, J. B. (1978, April). Mission environment simulation for Army rotorcraft development-requirements and capabilities. Paper presented at the AGARD Flight Mechanics Panel Specialists' Meeting on Piloted Aircraft Environment Simulation Techniques, Brussels, Belgium.*

37. Lackner, J. R. and Graybiel, A. (1983). Etiological factors in space motion sickness. Aviation, Space, and Environmental Medicine, 54 (8), 675-681.

38. Leibowitz, H. W. and Post, R. B. (1982). Two modes of processing concept and some implications. In J. Beck (Ed.), Organization and representation in perception (pp. 345-363). Hillsdale, New Jersey: Lawrence Erlbaum.

39. Leibowitz, H. W., Post, R. B., Brandt, T. H., and Dichdans, J. (1982). Implications of recent developments in dynamic spatial orientations and visual resolutions for vehicle guidance. In A. Wertheim, W. Wagenaar, and H. Leibowitz (Eds.), Tutorials in motion perception (pp. 231-260). New York: Plenum.*

40. McCauley, M. E. (Ed.). (1984). Research issues in simulator sickness: Proceedings of a workshop. Washington, D.C.: Committee on Human Factors, National Research Council, National Academy Press.*

41. McGuinness, J., Bouwman, J. H., and Forbes, J. M. (1981). Simulator sickness occurrences in the 2E6 air combat maneuvering simulator (ACMS) (Tech. report NAVTRAEQUIPCEN 80-C-0135-4500-1). Orlando, FL: Naval Training Equipment Center.*

42. McLane, R. C. and Wierwille, W. W. (1975). The influence of motion and audio cues on driver performance in an automobile simulator. Human Factors, 17, 488-501.*

43. McNally, W. J. and Stuart, E. A. (1942). Physiology of the labyrinth reviewed in relation to seasickness and other forms of motion sickness. War Medicine, 2, 683-771.

44. Miller, J. W. and Goodson, J. E. (1958, February). A note concerning "motion sickness" in the 2FH2 hover trainer (Report No. 1, Project NM 7 01 11, Subtask 3). Pensacola, FL: Naval School of Aviation Medicine, Bureau of Medicine and Surgery.*

45. Miller, J. W. and Goodson, J. E. (1960). Motion sickness in a helicopter simulator. Aerospace Medicine, 31, 204-212.*

46. Money, K. E. (1970). Motion sickness. Physiological Review, 50, 1-39.*

47. Money, K. E. (1980). Flight simulator motion sickness in the Aurora CP 140 FDS (DCIEM Tech. Communication 80-C-44). Downsview, Ontario: Defense and Civil Institute of Environmental Medicine.*

48. O'Hanlon, J. F. and McCauley, M. E. (1974). Motion sickness incidence as a function of the frequency and acceleration of a vertical sinusoidal motion. Aerospace Medicine, 45(4), 366-369.*

49. Parker, D. M. (1964). An investigation of autonomic function in motion sickness and revulsion. Unpublished doctoral dissertation, University of California at Los Angeles.*

50. Puig, J. A. (1970). Motion in flight training: A human factors view (Tech. Report NAVTRADEVCEN IH-177). Orlando, FL: Naval Training Device Center.*

51. Puig, J. A. (1971, November). The sensory interaction of visual and motion cues. In Commemorative Technical Journal, NTDC 15th Anniversary. Orlando, FL: Naval Training Device Center.*

52. Puig, J. A. (1984). Engineering design aspects of simulator aftereffects. Report available from Head, Human Factors Divison, Naval Training Systems Center, Orlando, FL.*

53. Reason, J. T. and Diaz, E. (1971, July). Simulator sickness in passive observers. (Report No. FPRC/1310; AD 753560). London: Flying Personal Research Committee, Ministry of Defense.*

54. Ricard, G. L. and Puig, J. A. (1977). Delay of visual feedback in aircraft simulators. Applied Psychology, 59, 2250-2258.*

55. Ryan, L. E., Scott, P. G., and Browning, R. F. (1978, September). The effects of simulator landing practice and the contribution of motion simulation to P-3 pilot training (TAEG Report No. 63). Orlando, FL: Naval Training Analysis and Evaluation Group.*

56. Seevers, J. A. and Makinney, R. L. (1979). Simulator for air-to-air combat motion system investigation (Tech. Report AFHRL-TR-79-18). Brooks Air Force Base, TX: Air Force Human Resources Laboratory.*

57. Sinacori, J. B. (1967, November). V/STOL ground-based simulation techniques (USAAVLABS Tech. Report 67-55). Fort Eustis, VA: U.S. Army Aviation Material Laboratories (Prepared by Northrop Corporation, Norair Division, Hawthorne, CA).*

58. Sinacori, J. B. (1983, September). Coping with simulator sickness -- an engineer's view. Position paper prepared for the National Research Council workshop on Simulator Sickness, Monterey, CA.*

59. Steele, J. E. (1968, September). The symptomatology of motion sickness. In Fourth Symposium on the Role of the Vestibular Organs in Space Exploration (NASA SP-187) (pp. 89-96). Pensacola, FL: Naval Aerospace Medical Institute.

60. Tang, P. C. (1970, August). Artifacts produced during electrical stimulation of the vestibular nerve in cats. In Fifth Symposium on the Role of the Vestibular Organs in Space Exploration (NASA SP-314). Pensacola, FL: Naval Aerospace Medical Institute.

61. Testa, C. (1969). The prediction and evaluation of simulator illness symptomatology. Unpublished doctoral dissertation, The University of California at Los Angeles.*

62. Treisman, M. (1977). Motion sickness: An evolutionary hypothesis. Science, 197, 493-495.

63. Tyler, D. B. and Bard, P. (1949). Motion sickness. Physiological Review, 29, 311-369.

64. Wenger, J. E. (1980). Motion sickness in the P-3C fleet readiness trainer at Naval Air Station, Brunswick, ME. (Tech. memorandum NBDL:60:jah;6500). U.S. Navy memorandum from C.O., Naval Biodynamics Laboratory to Commander, Naval Air Systems Command, Washington, D.C.*

65. Wierwille, W. W. (1975). Driving simulator design for realistic handling. In H. K. Sachs (Ed.), Proceedings Third International Conference on Vehicle Systems Dynamics (pp. 186-199). Amsterdam: Swets and Zeitlinger.

66. Wilker, S. F., Kennedy, R. S., McCauley, M. E., and Pepper, R. L. (1979). Susceptibility to seasickness: Influence of hull design and steaming direction. Aviation, Space, and Environmental Medicine, 50, 1046-1051.*

APPENDIX I

Survey of Navy Flight Simulators

(Questionnaire)

INSTRUCTIONS

Survey of Navy Flight Simulators

The following questions were developed in a joint effort between Virginia Tech and the Naval Training Equipment Center and are designed to gather information on the training tasks, operating procedures, physical characteristics and operating environment for a variety of Navy simulators.

The questions have been designed to accommodate a wide range of experience and backgrounds among responders. Please answer each question to the best of your knowledge and please indicate by writing a question mark in the margin if you are unsure of an answer that you give. If you do not have or cannot determine the information necessary to provide an answer, simply leave the answer blank.

Please feel free to call Richard Roesch at (703) 961-7962 if you wish to discuss any aspect of this questionnaire, your simulator or simulator training in general.

An example of how to complete the questionnaire follows.

Given a simulator which is used to train take-off, in-the-air tasks (such as air-to-air, air-to-ground, and air-to-ship weapons delivery), and landing on an aircraft carrier during the day and at night, the first part of section 3 in the questionnaire should be completed as follows.

3 TRAINING TASK

3.1. Full Flight Task (take-off/in the air task/landing) ☑

3.2. Part Task ☐

3.2.1. Maneuvers ☐

3.2.1.1. air (no combat maneuvers) ☐

3.2.1.2. combat ☐

3.2.2. Weapons delivery ☑

3.2.2.1. air to air ☑

3.2.2.2. air to ground ☑

3.2.2.3. air to water ☑

3.2.3. Take-off & landing ☑

3.2.3.1. carrier ☑

3.2.3.2. field ☐

3.2.3.3. confined area ☐

3.2.3.4. daylight ☑

3.2.3.5. dusk ☐

3.2.3.6. night ☑

Simulator Device Number (e.g., 2E6) ____________

Aircraft Number (e.g., F-14) ____________

Simulator Type (e.g., ACMS) ____________

SURVEY OF NAVY FLIGHT SIMULATORS

1. YOUR NAME, BUSINESS PHONE NUMBER & CORRECT MAILING ADDRESS FOR THE SIMULATOR FACILITY

____

____

____

____

____

2. SIMULATOR MANUFACTURER, ADDRESS & DATE OF MANUFACTURE, OPERATIONAL DATE (and the name of a knowledgeable contact at the manufacturer, if possible)

____

____

____

____

____

FOR EACH OF THE FOLLOWING ITEMS
PLEASE MARK A CHECK IN THE APPROPRIATE BOX ☐
OR
ANSWER "YES" OR "NO"
AND/OR
MAKE COMMENTS ON THE APPROPRIATE LINE

3. TRAINING TASK

3.1. Full Flight Task (take off/in the air task/landing) ☐

3.2. Part Task ☐

3.2.1. Maneuvers ☐

3.2.1.1. air (no combat maneuvers) ☐

3.2.1.2. combat ☐

3.2.2. Weapons delivery ☐

3.2.2.1. air to air ☐

3.2.2.2. air to ground ☐

3.2.2.3. air to water ☐

(continued on next page)

3.2.3. Takeoff & landing ☐

3.2.3.1. carrier ☐

3.2.3.2. field ☐

3.2.3.3. confined area ☐

3.2.3.4. daylight ☐

3.2.3.5. dusk ☐

3.2.3.6. night ☐

3.2.4. Navigation ☐

3.2.4.1. cross-country ☐

3.2.4.2. tactical terrain-following ☐

3.2.4.3. NOE (nap of the earth) flight ☐

3.2.4.4. approach/departure ☐

3.2.5. Reconnaissance and or photographic mission ☐
Please specify typical mission altitude(s):

____

____

3.2.6. Procedures training ☐
Please list and describe the procedures that are trained in the simulator:

3.2.7. List and describe other training tasks performed with simulator (if any).

4. VISUAL SYSTEMS

4.1. Image Generation System

4.1.1. Manufacturer, address and the name of a knowledgeable contact at the manufacturer

____

____

____

____

4.1.2. What is the type of image generation system and what is the model (e.g., "Vital IV", "Novoview", "Duoview") ?

4.1.2.1. computer *generated* image (CGI) ☐

model ______________________________

4.1.2.2. computer *synthesized* image (computer digitizes photographics into images for the display) ☐

model ______________________________

(continued on next page)

4.1.2.3. TV camera with model board ☐

model ______________________________

4.1.3. Number of video information channels (note : one channel may serve more than one display)

____

4.1.4. How many *edges* does the image generation system store (if unknown please leave blank) ?

____

4.1.5. How many *faces* does the image generation system store (if unknown please leave blank) ?

____

4.2. Image Display System

4.2.1. Manufacturer, address and the name of a knowledgeable contact at the manufacturer

____

____

____

4.2.2. Image display medium (type)

4.2.2.1. direct view CRT ☐

4.2.2.1.1. the CRT is a *raster scan* type (please do not check if you are unsure) ☐

4.2.2.1.2. the CRTis a *calligraphic* type (please do not check if you are unsure) ☐

4.2.2.2. collimated CRT (infinity optics) ☐

4.2.2.2.1. picture is generated by the raster scan method ☐

4.2.2.2.2. picture is generated by the *calligraphic method* ☐

4.2.2.2.3. a fresnel lens is used to collimate the display ☐

4.2.2.2.4. a beam splitter is used to collimate the display ☐

4.2.2.3. light valve projection system ☐

4.2.2.3.1. projector is behind the screen ☐

4.2.2.3.2. projector is in front of the screen ☐

(continued on next page)

4.2.2.3.3. the screen is flat ☐

4.2.2.3.4. the screen is slightly curved ☐

4.2.2.3.5. the light valve-generated image is projected onto a dome ☐

4.2.2.4. point-light-source projection ☐

4.2.2.4.1. projects earth & sky ☐

4.2.2.4.2. projects targets ☐

4.2.2.4.3. other items that can be displayed by the point-light source projection system

____

____

____

4.2.2.5. field-of-interest display (requires a mechanism to track where the pilot is looking) ☐

4.2.3. Number of displays (e.g., the number of CRT screens)

____

4.2.4. Physical dimensions of *each* out-the-window display (i.e., not the displays inside the cockpit that are instruments; please list each separately)

____

____

____

4.2.5. Design eye position boundary (the location the pilot's eye is supposed to be in - sometimes referred to as "exit pupil")

4.2.5.1. How far (in inches, degrees etc.) can the pilot move his/her head before the display appears distorted ?

4.2.5.1.1. vertically

____

4.2.5.1.2. side-to-side

____

4.2.5.1.3. forward

____

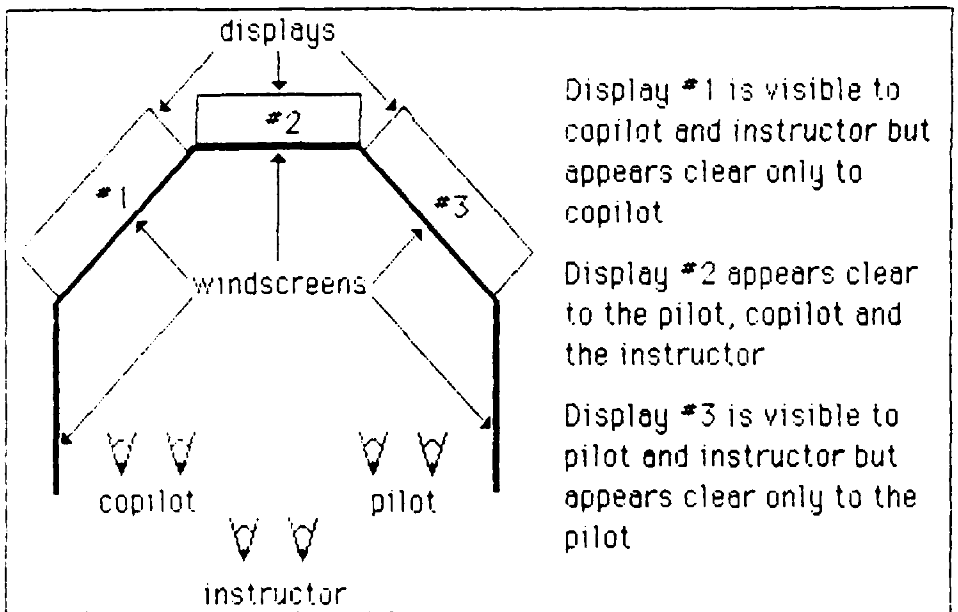
4.2.5.1.4. rearward

____

4.2.5.2. distance (in inches) from the design eye position to the out-the-window display

____

4.2.6. Please provide a rough, top-view sketch of the cockpit layout showing the locations of the displays, cockpit windows, crew and instructor. Note the visibility and distortion (if any) of each of the displays to each crew member. (A sketch of a helicopter simulator is shown below as an example).



4.2.7. The items the out-the-window display can portray :

- 4.2.7.1. friendly aircraft ☐
- 4.2.7.2. enemy aircraft ☐
- 4.2.7.3. weather ☐
- 4.2.7.4. targets ☐
  - 4.2.7.4.1. in the air ☐
  - 4.2.7.4.2. on the ground ☐
  - 4.2.7.4.3. on the water ☐
- 4.2.7.5. landing site ☐
  - 4.2.7.5.1. ground ☐
  - 4.2.7.5.1. carrier ☐
- 4.2.7.6. missiles
  - 4.2.7.6.1. the firing of missiles is displayed ☐
  - 4.2.7.6.2. missile flight is displayed ☐
  - 4.2.7.6.3. missile strike is displayed ☐

(continued on next page)

4.2.7.7. daylight can be displayed ☐

4.2.7.8. night can be displayed ☐

4.2.7.9. dusk can be displayed ☐

4.2.7.10. the sky (clouds etc.) can be displayed ☐

4.2.7.11. terrain features of earth can be displayed ☐

4.2.7.12. objects on the earth can be displayed ☐

4.2.7.13. wing movement (sweep fore/aft) can be displayed ☐

4.2.7.14. displayed items are depicted with surface texture ☐

4.2.7.15. please list other items that can be displayed

____

____

____

____

____

4.2.8. In which of the following ways can the displayed images appear to move ?

4.2.8.1. roll ☐

4.2.8.2. pitch ☐

4.2.8.3. yaw ☐

4.2.8.4. move fore/aft ☐

4.2.8.5. move sideways ☐

4.2.8.6. move vertically ☐

4.2.9. Please comment on the resolution of the out-the-window display (e.g., if you know the number of pixels, raster lines etc., please list; otherwise use comments like "sharp", "clear", "poor").

____

____

____

____

____

4.2.10. How complex a picture can the out-of-the window display present (e.g., if you know the maxium number of *faces* or *edges* that can be displayed please list; otherwise use comments like "very complex and realistic" or "very simple and not very realistic") ?

4.2.11. What is the refresh rate of the display system (i.e., how frequently is the display updated) ?

4.2.12. What is the luminance (brightness) of the out-of-the window display (if you can quantify this please do so; otherwise use comments like "display appears bright" or "display needs to be brighter") ?

4.2.13. Does the out-the-window display have good contrast (please comment) ?

____

____

4.2.14. Can the out-the-window display present colors and if so what colors can be displayed ?

____

____

4.2.15. Do viewers complain of, or can you see any distortion in the out-the-window display ?

____

4.2.15.1. Do viewers complain that the display appears to flicker ?

____

4.2.15.2. Does the display distort if not viewed from directly in front of the display (i.e., if viewed slightly to the side) ?

____

4.2.15.3. Do parts of the display appear to move in relation to other parts of the display ? (known as "swimming")

____

4.2.15.4. Does the display appear to *shimmer* ? (known as "alaising")

____

4.2.15.5. Does the display smear when the motions portrayed in the display are rapid ?

____

4.2.15.6. Can you see shadows or *ghosts* in the display ?

____

4.2.15.7. If two objects (in the display) overlap one another can you see the object behind through the object in front ? (known as "priority")

____

4.2.15.8. Do viewers complain of *streaming* in the display (i.e., objects in the periphery of the display appear to move too fast) ?

____

4.2.15.9. Do viewers complain that objects in the periphery move too slowly ?

____

4.2.15.10. Does the display ever appear to make a sudden and rapid ("jerky") movement up, down or sideways) ?

____

4.2.15.11. If the simulator has instrument and display dimming to simulate the "tunnel vision" effects of g-forces, do pilots ever complain that the dimming is unrealistic ? If so, do the pilots ever complain that the dimming is disturbing ?

____

4.2.15.12. Does the windscreen of the simulator cause any distortion (if so please describe) ?

4.2.15.13. Are adjacent displays well-matched ? If not, then please describe the mismatch (mismatch may occur in several ways - images on adjacent displays may appear to *jump* or there may be physical gaps between adjacent displays, etc.).

4.2.15.14. Are there any other distortions or defects in the out-the-window display (if so, please describe) ?

5. MOTION SYSTEM

5.1. Type

5.1.1. Fixed-base (i.e., the base or the complete cockpit does not move other than perhaps vibration) ☐

5.1.2. Moving-base (i.e., the simulator cockpit is actually moved in space) ☐

5.1.2.1. the cockpit can :

5.1.2.1.1. roll ☐

5.1.2.1.1.1. excursion distance (in degrees)

____

5.1.2.1.1.2. velocity (in degrees per second)

____

5.1.2.1.1.3. acceleration (in degrees per second ^{2} or g)

____

(continued on next page)

5.1.2.1.2. pitch □

5.1.2.1.2.1. excursion distance (in degrees)

____

5.1.2.1.2.2. velocity (in degrees per second)

____

5.1.2.1.2.3. acceleration (in degrees per second ^{2} or g)

____

5.1.2.1.3. yaw □

5.1.2.1.3.1. excursion distance (in degrees)

____

5.1.2.1.3.2. velocity (in degrees per second)

____

(continued on next page)

5.1.2.1.3.3. acceleration (in degrees per second ^{2} or g)

____

5.1.2.1.4. move fore/aft (longitudinal translation) ☐

5.1.2.1.4.1. excursion distance (in inches)

____

5.1.2.1.4.2. velocity (in degrees per second)

____

5.1.2.1.4.3. acceleration (in degrees per second ^{2} or g)

____

5.1.2.1.5. move sideways (lateral translation) ☐

5.1.2.1.5.1. excursion distance (in inches)

____

(continued on next page)

5.1.2.1.5.2. velocity (in degrees per second)

____

5.1.2.1.5.3. acceleration (in degrees per second ^{2} or g)

____

5.1.2.1.6. move vertically (heave) □

5.1.2.1.6.1. excursion distance (in inches)

____

5.1.2.1.6.2. velocity (in degrees per second)

____

5.1.2.1.6.3. acceleration (in degrees per second ^{2} or g)

____

5.2. Do pilots comment that the simulator movement is :

5.2.1. Not realistic in any movements □

(continued on next page)

5.2.2. Not realistic in some movements (specify which ones) ☐

5.2.3. Very realistic in all movements ☐

5.3. Other motion cueing devices used :

5.3.1. G-suit (worn by pilot) ☐

5.3.2. G-seat ☐

5.3.3. Lap and shoulder belt tightening ☐

5.3.3. Display dimming ☐

5.3.5. Whole cockpit vibration ☐

5.3.6. Control stick vibration ☐

5.3.7. Seat vibration ☐

5.4. What method does the simulator use to limit moving past the stops ?

5.4.1. Electrical limit switches ☐

5.4.2. Mechanical stops (e.g., shock absorbers or other physical methods) ☐

5.4.3. Computer logic controlled ☐

5.4.4. Controlled by the hydraulic system ☐

5.4.5. Other methods used to limit motion as the simulator approaches the maximum excursion (please explain).

____

____

5.5. Does the simulator ever jerk, "bump" or tend to oscillate in its motions (if so please explain) ?

____

____

____

6. COCKPIT ENVIRONMENT

6.1. Flight Controls

6.1.1. Please list each flight control in the simulator cockpit (e.g., center stick, collective, yoke stick, side stick; yaw control pedals, brake control pedals; thrust controllers; and configuration controllers such as flaps and gear) and the type of control loading for each flight control (e.g., stiction, coulomb friction, viscous damping, spring-centering).

____

(continued on next page)

6.1.2. Do pilots ever complain that any of the above flight controls are not realistic (if so, please identify the controller along with the complaints) ?

6.2. Audio System

6.2.1. What simulated sounds can be presented ?

6.2.1.1. hydraulic control systems ☐

6.2.1.2. life support systems ☐

6.2.1.3. engine(s) ☐

6.2.1.4. weapons release ☐

6.2.1.5. turbulence ☐

6.2.1.6. wind ☐

6.2.1.7. weather (rain etc.) ☐

6.2.1.8. brakes ☐

6.2.1.9. runway rumble ☐

6.2.1.10. tire squeal ☐

6.2.1.11. alarms ☐

6.2.1.12. other simulated sounds (please list)

____

____

6.2.2. Do pilots complain that the simulated sounds are unrealistic in any way (if so, please explain) ?

____

____

6.2.3. Communications systems

6.2.3.1. communications with instructor ☐

6.2.3.2. communications with a simulated ground control or ship-based control ☐

6.2.3.2. communications with *other aircraft* ☐

6.3. Are there any sounds heard in the simulator which are not part of the simulation (e.g., noises from the cockpit air conditioner or from the hydraulic power unit) ?

____

____

____

____

6.4. What temperature (in degrees) is maintained in the cockpit ?

____

6.5. What humidity level (in percent) is maintained in the cockpit ?

____

6.6. What illumination level is maintained in the cockpit (if you cannot make a quantified estimate in *Lux* or *Footcandles*, use comments like "bright" or "dim") ?

____

____

6.7. Is the cockpit open or enclosed ?

____

6.8. What is the pilot's field-of-view (how many viewing windows are there and how large is each window) ?

____

____

____

6.9. Are there any odors from (or in) the :

6.9.1. Pilot's life support breathing system ☐

6.9.2. Hydraulic system ☐

6.9.4. Are there other odors (if so, please list) ?

____

____

6.10. Briefly describe what getting in and out of the simulator is like (e.g., do you have to climb a ladder and then walk across a gang plank that is 30' in the air to enter and exit or do you enter and exit while the simulator is on the ground floor level).

____

____

____

____

____

____

____

____

____

7. CALIBRATION OF SIMULATOR SYSTEMS

Please mark the systems that are calibrated and how frequently they are checked for calibration (comment on any problems any of the system[s] has had with calibration or complaints that any of the pilots have had concerning a poorly calibrated system).

7.1. Motion System ☐ ____________________

____

____

____

7.2. Visual System ☐ ____________________

____

____

____

7.3. Computers ☐ ____________________

____

____

____

(continued on next page)

7.4. Audio System ☐ ______________________________

____

____

____

7.5. Other Systems ☐ ______________________________

____

____

____

8. LAGS OR DELAYS

Do you hear complaints about lags or delays (if so please check the appropriate box; if the amount of delay is known please specify and comment) ?

8.1. Is the delay between the pilot control inputs and the visual scene movement unrealistic ? ☐

____

____

____

8.2. Is the delay between the pilot-control input to the response movement of the motion system unrealistic ? ☐

____

____

8.3. Is the delay from the pilot-control input to the response in the instrument readout unrealistic ? ☐

____

____

____

8.4. Delays in the audio system responses (specify) ☐

____

____

8.6. Delays between the motion system responses and the instrument responses (specify) ☐

____

____

____

8.7. Delays between the instrument responses and the display responses (specify) ☐

8.5. Delays between the motion system movement and the visual display movement (and if there are delays does the motion system appear to lead or lag the visual system) ☐

9. COMPUTER(S)

9.1. Manufacturer, address, the date of manufacture and the name of a knowledgeable contact at the manufacturer (if possible)

9.2. For each computer please fill in the table on the following page.

*and task of this unit (e.g., algorithms of motions)	manufacturer and mfg. model number	type (e.g., analog, digital, hybrid)	disk space	processing time	memory (core) size	software language

9.3. Please enter the iteration rates for each of the following (i.e., how frequently does the computer sample or update the item listed)

9.3.1. the control stick input ____________________

9.3.2. the aerodynamic equations ____________________

9.3.3. input signal to the motion base ____________________

9.3.4. input signal to the visual system ____________________

10. CHARACTERISTICS OF THE IMMEDIATE BUILDING (eg., size of the immediate room and any other facilities that are available such as briefing rooms)

____

____

____

11. OPERATING PROCEDURES

11.1. Duration of the longest training missions typically conducted

____

11.2. Estimates of the work load and stress involved in the training process (e.g., "because we train pilots under the strain of simulated combat and with many engaging enemy aircraft, I would estimate the training to be very intense" or "we allow the pilots to work at their own pace and therefore I would not estimate the intensity of the training to be very high")

____

____

____

____

11.3. Is the action of the training ever stopped with the display still in place (i.e., is the scene frozen) ?

____

11.4. Is the displayed scene ever run in reverse while still on the display screen (e.g., to review a previous error) ?

____

11.5. Is the display ever suddenly changed ("reset") to present a new scene while the pilot views the screen ?

____

11.6. Is the display always off when the pilot is entering or exiting the simulator ?

____

11.6. Are pilots that train in the simulator ever allowed to view the simulator (from the outside) while it is in operation with someone else inside ?

____

11.7. Are there any particular maneuvers performed that appear to cause some uneasiness or symptoms of sickness among the pilots (if so, please comment on the nature of the maneuver and the nature of the uneasiness in terms of symptoms reported or observed) ?

12. Please comment on the level of uneasiness or sickness the pilots have experienced in the simulator and any features of the simulator (or other factors) that you think might have caused their uneasiness.

____

____

____

____

____

____

13 Do pilots report that the simulator is a realistic representation of the intended aircraft in actual 1flight (if not please explain) ?

____

____

____

____

____

____

APPENDIX II

Aircraft Simulator Characteristics and Independent Variable Outline

AIRCRAFT SIMULATOR CHARACTERISTICS AND INDEPENDENT VARIABLE OUTLINE

1. Location & Date of Installation

2. Manufacturer & Date of Manufacture

3. Training Task

    3.1 Full flight (take-off/task/landing)

    3.2 Part task

    3.3 Air combat maneuvers

    3.4 Weapons delivery

        3.4.1 air-to-air

        3.4.2 air-to-ground/water

        3.4.3 air-to-water

    3.5 Take-off/landing

        3.5.1 carrier

        3.5.2 field

        3.5.3 confined area (& pinnacle)

        3.5.4 daylight capability

        3.5.5 dusk capability

        3.5.6 night capability

    3.6 Navigation

        3.6.1 cross-country

        3.6.2 tactical terrain

        3.6.3 NOE (nap of the earth) flight

    3.7 Reconnaissance/photographic

    3.8 Other training tasks

4. Visual Systems

4.1 Image generation system

4.1.1 manufacturer

4.1.2 type

4.1.2.1 computer-generated (CGI)

4.1.2.2 computer-synthesized (hybrid)

4.1.2.3 model board/camera

4.1.3 # of video information channels (one channel may serve more than one display)

4.1.3.1 # of stored <u>points</u>

4.1.3.2 # of stored <u>faces</u>

4.2 Image display system

4.2.1 manufacturer

4.2.2 type of display medium

4.2.2.1 CRT (direct view)

4.2.2.1.1 raster

4.2.2.1.2 calligraphic

4.2.2.2 collimated CRT (infinity optics)

4.2.2.2.1 raster

4.2.2.2.2 calligraphic

4.2.2.2.3 fresnel lens

4.2.2.2.4 beam splitter

4.2.2.3 TV projection system

4.2.2.3.1 behind screen

4.2.2.3.2 in front of screen

4.2.2.3.3 flat screen

4.2.2.3.4 slightly curved screen

4.2.2.3.5 dome

4.2.2.4 point-light-source (onto dome)

4.2.2.4.1 projects earth & sky

4.2.2.4.2 projects targets

4.2.2.5 field of interest (uses eye tracking)

4.2.3 field of view (vertical & horizontal)

4.2.3.1 total fov

4.2.3.2 each display fov

4.2.3.3 design eye position - boundary size

4.2.3.3.1 vertical

4.2.3.3.2 horizontal

4.2.3.3.3 fore/aft

4.2.3.3.4 distance of design eye position to display

4.2.4 # of displays and size of each display

4.2.5 # of windows with a display

4.2.6 # of windows without a display

4.2.7 item (object) type, & # that can be displayed

4.2.7.1 friendly aircraft

4.2.7.2 weather

4.2.7.3 targets

4.2.7.3.1 air

4.2.7.3.2 ground

4.2.7.3.3 water

4.2.7.4 landing site

4.2.7.4.1 ground

4.2.7.4.2 carrier

4.2.7.5 missiles

4.2.7.5.1 shoot

4.2.7.5.2 fly

4.2.7.5.3 strike

4.2.7.6 day

4.2.7.7 night

4.2.7.8 dusk

4.2.7.9 sky

4.2.7.10 earth

4.2.7.11 wing sweep

4.2.7.12 other items that can be displayed

4.2.8 degrees of freedom of motion in the display

4.2.9 raster scan CRT display resolution

4.2.9.1 # of addressable pixels in each display

4.2.9.2 # of raster lines in each display

4.2.10 calligraphic CRT display resolution

4.2.11 point-light-source display resolution

4.2.12 scene complexity

4.2.12.1 maximum # of faces that are displayed at any one time

4.2.12.2 maximum # of edges that are displayed at any one time

4.2.13 visual system refresh rate

4.2.14 visual depth-of-field presentation

4.2.14.1 CRT direct-view

4.2.14.2 dome - (20' feet equals infinity)

4.2.14.3 collimated display - (infinity optics)

4.2.15 luminance

4.2.16 luminance contrast

4.2.17 display colors

4.2.18 sources of display distortion

4.2.18.1 flicker

4.2.18.2 off-axis viewing

4.2.18.3 swimming

4.2.18.4 alaising/shimmering

4.2.18.5 phosphorus persistence (display bleeding or smearing)

4.2.18.6 shadowing (ghosting)

4.2.18.7 priority (bleed-through)

4.2.18.8 operating procedures

4.2.18.8.1 use of "freeze"

4.2.18.8.2 use of "reset"

4.2.18.8.3 scene on display at entry/exit

4.2.18.9 peripheral screen context (e.g. "streaming" in periphery)

4.2.18.10 presentations of visual heave

4.2.18.11 G-force display dimming (simulation of visual tunneling as a function of g-force)

4.2.18.12 other display distortions

5. Motion System

5.1 Type

5.1.1 fixed-base

5.1.2 moving-base

5.1.2.1 synergistic method

5.1.2.2 cascade method

5.1.2.3 other method of moving-base

5.1.2.4 degrees-of-freedom presented

5.1.2.5 rotational

5.1.2.5.1 yaw

5.1.2.5.1.1 excursion (degrees)

5.1.2.5.1.2 velocity (degrees/sec)

5.1.2.5.1.3 acceleration (degrees/sec^2)

5.1.2.5.2 pitch

5.1.2.5.2.1 excursion (degrees)

5.1.2.5.2.2 velocity (degrees/sec)

5.1.2.5.2.3 acceleration (degrees/sec^2)

5.1.2.5.3 roll

5.1.2.5.3.1 excursion (degrees)

5.1.2.5.3.2 velocity (degrees/sec)

5.1.2.5.3.3 acceleration (degrees/sec^2)

5.1.2.6 translational

5.1.2.6.1 longitudinal

5.1.2.6.1.1 excursion (inches)

5.1.2.6.1.2 velocity (inches/sec)

5.1.2.6.1.3 acceleration (inches/sec^2)

5.1.2.6.2 lateral

5.1.2.6.2.1 excursion (inches)

5.1.2.6.2.2 velocity (inches/sec)

5.1.2.6.2.3 acceleration (inches/sec^2)

5.1.2.6.3 vertical

5.1.2.6.3.1 excursion (inches)

5.1.2.6.3.2 velocity (inches/sec)

5.1.2.6.3.3 acceleration (inches/sec^2)

5.2 Parasitic motion/coordinate transformation (dependent on the instantaneous position of the simulator cab)

		Rotational		
		yaw	pitch	roll
Translational	longitudinal	y/lo = lo/y =	p/lo = lo/p =	r/lo = lo/r =
	lateral	y/la = la/y =	p/la = la/p =	r/la = la/r =
	vertical	y/v = v/y =	p/v = v/p =	r/v = v/r =

5.3 Other motion cueing devices

5.3.1 G-suit

5.3.2 G-seat

5.3.3 lap & shoulder belt tightening

5.3.4 display dimming (luminance/G)

5.3.5 whole cockpit vibration (simulate gun firing, engines, etc.)

5.3.6 control stick (vibration freq)

5.3.7 whole cockpit buffeting (vibration freq)

5.3.8 seat buffeting (shaker) (vibration freq)

5.4 Method to limit motion (i.e. motion stops)

5.4.1 electrical limit switches

5.4.2 mechanical stops (e.g. shock absorbers)

5.4.3 computer (logic) controlled

5.4.4 controlled by hydraulic system

5.4.5 other methods to limit motion

5.5 Acceleration relationship (simulator to real)

5.5.1 slope

5.5.2 attainable amplitude

5.6 Motion spectral distribution of the simulator

5.7 Resonant freq of the simulator

5.7 Hydraulic reversal "bump"/oscillation

6. Cockpit Environment

6.1 Audio system

6.1.1 simulated sounds

6.1.1.1 hydraulic control systems

6.1.1.2 electronic control systems

6.1.1.3 mechanical systems

6.1.1.3.1 landing gear deployment

6.1.1.3.2 life support systems

6.1.1.3.3 engine(s)

6.1.1.3.4 weapons release

6.1.1.3.5 canopy movement

6.1.1.4 turbulence/wind

6.1.1.5 weather

6.1.1.6 rolling resistance (noise)

6.1.1.6.1 brakes

6.1.1.6.2 runway

6.1.1.6.3 tire squeal

6.1.1.7 other simulated sounds

6.1.2 communications

6.1.2.1 with instructor

6.1.2.2 with "ground control"

6.1.2.3 with other aircraft

6.2 Temperature & humidity (range & ventilation rate)

6.3 Simulator artifacts (e.g. simulator-created noises that are not part of the simulation)

6.3.1 air conditioner vibration/noise

6.3.2 other sources of vibration/noise in the cockpit

6.4 Method of control loading, i.e., control dynamics (note if different for each control)

6.4.1 spring loading

6.4.2 static (stiction) loading

6.4.3 coulomb friction

6.4.4 viscous friction

6.5 Control deadspace

6.6 Control backlash

6.7 Olfactory cuing & sources of odors

6.7.1 hydraulic oil

6.7.2 chemical warfare odors

6.7.3 breathing system odors

6.7.4 other sources of odors found in the simulator

6.8 Field-of-view

6.9 Illumination levels (ambient in cockpit)

6.10 Access/egress method

6.11 Windshield distortion

6.12 Head movement/field of view/parallax

7. Calibration

7.1 Which systems are specified on a calibration schedule

7.1.1 motion system

7.1.2 visual system

7.1.3 computer system(s)

7.1.4 audio system

7.1.5 other systems that are calibrated

7.2 What is the recommended/actual calibration schedule

7.2.1 motion system

7.2.2 visual system

7.2.3 computer system(s)

7.2.4 audio systems

7.2.5 schedule of other systems

7.3 Which systems have been out of calibration

7.3.1 motion system

7.3.2 visual system

7.3.3 computer system(s)

7.3.4 audio systems

7.3.5 other systems

7.4 How far out of calibration was each system & the date of calibration of each system

7.4.1 motion system

7.4.2 visual system

7.4.3 computer system(s)

7.4.4 audio systems

7.4.5 other systems

8. Lags/Delays

8.1 Pilot controls to display

8.2 Pilot controls to motion feedback

8.3 Pilot controls to instruments

8.4 Input to audio system

8.5 display to motion system
(does motion system lead or lag display)

8.6 instruments to motion system

8.7 instruments to display

9. Computer

9.1 Manufacturer(s) and date of manufacture

9.2 Type

9.2.1 analog

9.2.2 digital

9.2.3 hybrid

9.3 Manufacturer model(s) #

9.4 Core memory/disk space memory

9.5 Software language

9.6 Computer processing time for each simulator subsystem

9.7 Aircraft dynamics modeling techniques (i.e. "drive logic")

9.7.1 scaling (note if different on each axis)

9.7.2 motion system algorithm

9.7.2.1 as per aircraft/experienced pilots

9.7.2.2 parasitic motion/coordinate transformation

9.7.2.3 washout algorithm

9.7.2.4 motion limiting algorithm

9.7.2.5 other motion system algorithms

9.8 Frequency at which computer samples the control inputs used in computational dynamics

9.9 Effective system update rate (from time input samples are obtained to time that computed outputs are available for display/motion/audio system use)

9.10 Other specific interface time influences (e.g. control input to computer; computer output to cuing systems)

9.10.1 # of digital to analog conversions

9.10.2 digital to analog conversion time

9.10.3 # of analog to digital conversions

9.10.4 analog to digital conversion time

9.10.5 field of interest display (requires eye tracking)

10. Building (simulator facility)

10.1 Size of immediate room

10.2 Illumination level in immediate room

10.3 Sources of odors

10.3.1 hydraulic oil

10.3.2 chemicals

10.3.3 other sources of odors found in the building

10.4 Temperature & humidity (range) & ventilation rate

10.5 Facilities available

10.5.1 control room

10.5.2 briefing room

10.5.3 other facilities available

10.6 Sources of noise/vibration

10.6.1 hydraulic power unit

10.6.2 motion base hydraulic noise

10.6.3 mechanical noise (e.g. from motion base)

10.6.4 other sources of noise/vibration found in the building

11. Operating Procedures

11.1 Duration of training mission

11.2 Intensity of training mission

11.3 Use of "freeze" (i.e., stop-action with the display on the screen)

11.4 Use of "reset" (i.e., is displayed on screen during rewind)

11.5 Is screen blanked at entry/exit

11.6 Are trainees allowed external view of simulator while it is in motion

11.7 Use of suspect maneuvers (list - e.g., sudden stops in flight of VSTOL aircraft)

ACRYNYM GLOSSARY

ACM - air combat maneuvering

AEW - airborne early warning

ASW - anti-submarine warfare

BN - bombardier/navigator

CCTV - closed-circuit television

CGI - computer-generated image

Ch - channel

CRT - cathode ray tube

d-o-f - degrees-of-freedom (usually of vehicular motion)

ECM - electronics countermeasures

f-o-v - field-of-view

helo - helicopter

IFR - instrument flight rules

NCLT - night carrier landing trainer

NTEC - Naval Training Equipment Center (Now Naval Training Systems Center)

NTSC - Naval Training Systems Center

OFT - operational flight trainer

PIO - pilot-induced oscillation

RIO - radar intercept officer

SAM - surface-to-air missile

VFR - visual flight rules

VPI&SU - Virginia Polytechnic Institute and State University

VSTOL - vertical/short takeoff and landing

WST - weapons system trainer

WTT - weapons tactics trainer

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ATTN: Col F. S.Pettyjohn
Naval Air Station
Pensacola, FL 32508-5000

Mr. Chuck Gainer
Chief, ARI, Field Unit
ATTN: PERI-SR
Fort Rucker, AL 36362

Naval Training Systems Center
Code 002
ATTN: MAJ L. Rohloff
Orlando, FL 32813-7100

LT David Gleisner, MSC, USNR
Naval Air Systems Command
Code 5313X
Washington, DC 20361-5310

Mr. Franklin G. Hempel
Office of Naval Research
Code 1141
800 N. Quincy Street
Arlington, VA 22217

Dr. John Casali
Dept of Industrial Engineering and
Operations Research
Virginia Polytechnic Institute
& State University
Blacksburg, VA 24061

CAPT Michael Curran, MSC, USN
Office of Chief of Naval Operations
Director, Naval Medical (OP-939)
Pentagon, - Room 4D461
Washington, DC 20350-2000

LCDR Thomas Crosby, MSC, USN
Naval, Air Systems Command
ATTN: Code 933G
Washington, DC 20361-3300

LCDR Larry Frank, MSC, USN
Pacific Missile Test Center
Code 4025
Point Mugu, CA 93042-5000

Dr. Michael Lentz
Naval Aerospace Medical Research
Laboratory - Bldg 1811
Naval Air Station
Pensacola, FL 32508-5766

CDR Wade Helm, MSC, USN
Naval Aerospace Medical Research
Laboratory (Code 05)
Naval Air Sttion
Pensacola, FL 32508-5700

CAPT Thomas Gallagher, MSC, USN
Naval Air Development Center
Code 60A
Warminister, PA 18974-5000

CAPT Joseph F. Funaro, MSC, USN
Naval Training Systems Command
Code 71
Orlando, FL 32813-7100

LT C. Barrett
Naval Air Development
Code 6021
Warminster, PA 18974-5000

LT James Hooper, MSC, USNR
Naval Air Systems Command
ATTN: APC205-ON
Washington, DC 20361-1205

Dr. George Anderson
Dept. of Psychology
University of Illinois
603 E. Daniel Street
Champagne, IL 61820

LT Lee Goodman, MSC, USN
Naval Air Development Centeer
Code 6022
Warminister, PA 18974-5000

CDR Chuck Hutchins, MSC, USN
Naval Post Graduate School
Code 55MP
Monterey, CA 93940

LCDR Dennis McBride, MSC, USN
Pacific Missile Test Center
Code 4025
Point Mugu, CA 93042-5000

CAPT James Goodson, MSC, USN
Operational Psychology Dept
Naval Aerospace Medical Institute
Code 11
Naval Air Station
Pensacola, FL 32508-5600

CDR Thomas Jones, MSC, USN
Office of Naval Research
Code 125
800 N. Quincy Street
Arlington, VA 22217-5000

CAPT William Moroney, MSC, USN
Naval Air Development Center
Code 602
Warminster, PA 18974-5000

LCDR Tom Singer, MSC, USN
Naval Air Development Center
Code 60B5
Warminster, PA 18974-5000

LCDR Dave Norman, MSC, USN
DTDAC
3280 Progress Drive
Orlando, FL 32826-3229

CAPT Paul Chatelier, MSC, USN
OUSR7E (R&AT)
Washington, DC 20301-3080

Commander
Naval Air Force
U. S. Pacific Fleet (J. Bolwerk)
Naval Air Station North Island
San Diego, CA 92135

Commanding Officer
Air Force Office of Scientific Research
Washington, DC 20301

National Defense University
Research Directorate
Fort McNair, DC 20319

Dr. Jesse Orlansky/STD
Institute for Defense Analyses
Science and Technology Division
801 N. Beauregard St.
Arlington, VA 22311

Commanding Officer
405TTW/SEF
Luke Air Force Base, AZ 85309

Ms. Rachel Gadolin
Naval Aerospace Medical Research
Naval Air Station
Pensacola, FL 32508-5700

Dr. B. E. Mulligan
Department of Psychology
Collefe of Arts and Science
University of Georgia
Athens, GA 30602

AFHRL/OTA
ATTN: LT Scott Horowitz
Williams AFB, AZ 85240-6457

CDR Jerry Owens, MSC, USN
Naval Air Systems Command
ATTN: Code APC205-OM
Washington, DC 20361-1205

American Psychology Association
Psyc. Info, Document Control Unit
1200 Seventeenth Street
Washington, DC 20036

LCDR Ed Trautman, MSC, USNR
Psychology Department
Human Factors Labvoratory
University of South Dakota
Vermillion, SD 57069

LTC M. McGaugh
PM Training Devices
ATTN: AMPC-AUD
Orlando, FL 32813-7100

Technical Library
Naval Training Systems Center
Orlando, FL 32813-7100

Systems Engineering Test Directorate
Naval Air Test Center
ATTN: CDR Douglas W. Call, Head,
Aircrew Systems Department
Patuxent River, MD 20670-5304

Naval Research Laboratory
ATTN: Library
Washington, DC 20375

CDR R. Moore
Commandant (G-KOM-1)
U. S. Coast Guard
Washington, DC 20590

Dr. Stan Deutsch
Committee on Human Factors
National Academy of Science
2101 Constitution Ave., NW
Washington, DC 20418

AFHRL/OTU
ATTN: Dr. Wayne Waag
Williams AFB, AZ 85240-6457

Commander, USAARL
ATTN: SGRD-UAB/ Dr. Siering
Box 577
Frt Rucker, AL 36362

Commander, Naval Air Force
U. S. Pacific Fleet
ATTN: Code 014, LCDR W. Bigham
Naval Air Station, North Island
San Diego, CA 92135

LT COL J. R. Pfaff
Command Surgeon Division
Headquarters Air Command
West Win, Manitoba, Canada R2R0TD

Commanding Officer
Wheeler Army Aviation Activity
ATTN: APZV-AVZ, Mr. Nakamura
Stop 202
Ft Schafter, HI 96858-5000

LT COL Bill R. Baltazar
HQ USAF/X00TD
Pentagon, Room BF870
Washington, DC 20330-5054

Directorate, Safety and
Standardization
Third Marine Air Wing
ATTN: Lt Eichner
Santa Ana, CA 92079

Commanding Officer
Naval Medical Research and
Development Command
NMC NCR
ATTN: Code 404, LCDR Banta
Bethesda, MD 20814-5044

Commanding Officer
MAG-29
ATTN: MAJ Roxbury
Marine Corps Air Station
New River
Jacksonville, NC 28545

Defense and Civil Institute
of Environmental Medicine
1133 Shephard Avenue
P. O. Box 2080
ATTN: L. McGee
Downsview, Ontario M3M3BU

Commanding Officer
Wheeler Army Aviation Activity
ATTN: APZV-AVZ, STOP 202
Fort Schafter, HI 96858-5000

Commander
ASWWINGPAC
ATTN: LCDR T. Turner
Naval Air Station, North Island
San Diego, CA 92135

MAJ D. Gower
USAARL
Box 577
Fort Rucker, AL 36362-5000

COL M. R. Kambrod
Office, Assistant Secretary
of the Army
Pentagon, Room 2E673
Washington, DC 20310

Dr. Henry Mertens
FAA/CAMI, AAC-118
P. O. Box 25082
Oklahoma City, OK 73125

Commander
U.S. Pacific Fleet
ATTN: Code 31M, LT Col D. R. Powers
Naval Air Station, North Island
San Diego, CA 92135

Commander
Fighter Airborne Early Warning
Wing, U. S. Pacific Fleet
Naval Air Station, Miramar
ATTN: CDR Harry Hunter
San Diego, CA 92145

Dr. Timothy J. Ungs
Aerospace Medicine Residency
Wright State University School
of Medicine
P. O. Box 927
Dayton, OH 45401

Commander
Naval Safety Center
ATTN: Code 14, CDR Terry O'Leary
Naval Air Station
Norfolk, VA 23511-5796

Edward A. Martin
Technical Advisor
ASD/ENETS
Wright-Patterson AFB, OH 45433

Naval Personnel Research and
Development Center
ATTN: Code 71, Mr. A. Harabedian
San Diego, CA 92152

LT J. Reeves
Naval Aerospace Medical Laboratory
Naval Air Station
Pensacola, FL 32508

END
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