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SIMULATOR SICKNESS:
REACTION TO A TRANSFORMED
PERCEPTUAL WORLD

II. Sourcebook and
Suggested Readings

Robert S. Kennedy
Canyon Research Group, Inc.
741 Lakefield Road, Suite B
Westlake Village, California 91361

Lawrence H. Frank
Naval Training Equipment Center
Orlando, Florida 32813

Michael E. McCauley
Canyon Research Group, Inc.
741 Lakefield Road, Suite B
Westlake Village, California 91361

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<p>➤ This paper traces the history of the phenomenon of simulator sickness from the time it was first reported in 1957-58. Although the literature is sparse (less than 300 printed pages), a large body of anecdotal evidence has accumulated and a series of reports have been published. The focus of this document is to survey the available literature and to reproduce it to be easily accessible by engineers and scientists. The report is organized into three sections and an appendix. Section I is an introduction and serves to orient the reader to the remaining sections. Section II deals with the issue of motion sickness and its relationship to simulator sickness. Section III reviews the studies of simulator sickness and surfaces hypotheses for research. These suggestions in the form of research initiatives, have been offered to stimulate further</p>						
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> discussion. Appendix A contains reproductions of articles dealing with simulator sickness, including reports of simulator sickness outcomes, provocative experiments, messages, dispatches, and documentations of the aftereffects. Much of this material was originally of limited distribution. The theme of this report, and others in the series, is that simulator sickness is a reaction to a transformed perceptual world.



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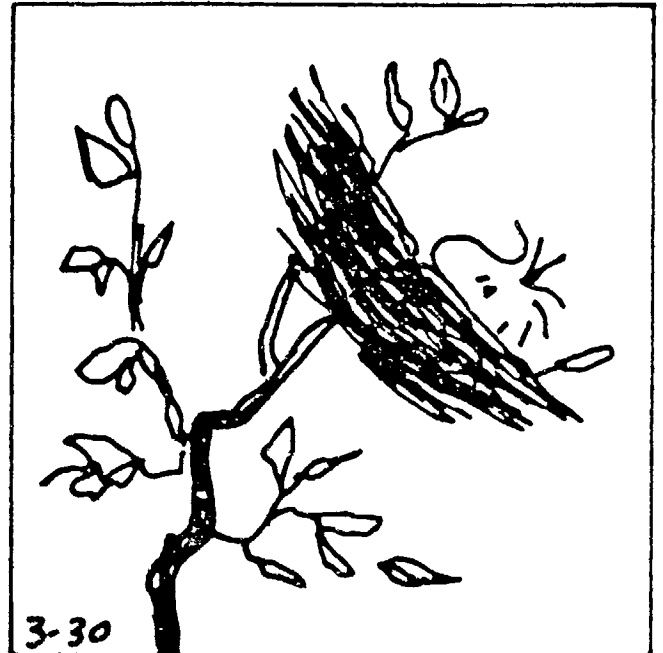
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Peanuts

by Charles M. Schulz



From the Orlando, Florida *Sentinel*, 30 March 1983

SECTION I

INTRODUCTION

Since World War II, flight training simulators have come into ever increasing use due to their obvious economy in equipment and fuel savings plus their other attendant advantages of maintenance, availability and safety. Orlansky (1982), and Orlansky and String (1977, 1979), have provided eloquent summary statements of their effectiveness. New types of simulators, such as those for training air combat maneuvering and Skylab crews, seem to be in great demand. Unfortunately, there has been a recent increase in reports of discomfort and distress associated with the use of flight simulators.

Since the phenomenon of simulator sickness was first reported by Havron and Butler (1957), and Miller and Goodson (1958), a large body of anecdotal evidence has accumulated. This evidence suggests that simulator sickness symptomatology resembles motion sickness and other forms of distress which occur after exposure to altered and rearranged sensory information (Frank, Kennedy, Kellogg, and McCauley, 1983).

The following questions regarding simulator use remain to be answered: 1) What causes simulator sickness? 2) What is the incidence? 3) To what degree does simulator sickness degrade performance and impede training? 4) What can be done to prevent the occurrence of simulator sickness?

PURPOSE AND OBJECTIVES OF THIS SOURCEBOOK

Scientific investigations and resultant reports in the literature on simulator sickness have been sparse (e.g., < 300 printed pages). Therefore, any student of simulator sickness would need to search the information on related topics such as postural equilibrium, visual/vestibular interaction, motion sickness, adaptation to the environment, etc. Yet, simulation is a high technology enterprise and team approaches to design and acquisition of systems have been followed almost from the first simulator. Therefore, simulator sickness is of interest to the practitioners of several different disciplines, including engineering, medicine, psychology, training, and fleet operations. Quite rightly, these specialists are often less familiar with information available in domains outside their own. Thus far, no one has collated the information from these disparate areas and made it available to the technological and scientific communities. Hence, the primary purpose of this Sourcebook is to survey the available literature and reproduce it in a form that will enable the

appropriate professionals to quickly upgrade their knowledge of simulator sickness.

Out of this fundamental purpose, several subsidiary objectives have emerged:

- a. To define simulator sickness.
- b. To determine the incidence and magnitude of the problem.
- c. To review the literature concerning simulator sickness, including articles, reports, instructions, military messages, and other pertinent documents.
- d. To collect and present the most cogent publications in the field of simulator sickness and related areas.
- e. To offer suggested readings for the further study of simulator sickness and related issues.
- f. To introduce opportunities for new research initiatives.
- g. To contribute to the understanding and prevention of simulator sickness.

PROCEDURE

In order to create a simulator sickness sourcebook that would achieve these objectives, an extensive literature search was conducted. This search determined who had addressed the issue, what they studied, and what has been learned. The search unearthed studies that dealt with: a) simulator sickness directly; b) visual/vestibular interactions and their relevance for flying and flight simulation; c) motion sickness symptomatology and adaptation; d) perceptual experiences as real and apparent motion perception, parallax, focal and ambient visual information disordered, distorted, or otherwise perceptually transformed worlds; and f) engineering issues for flight trainers, such as visual and inertial motion delays and frequency responses.

For all the documents in this series, the primary source has been the personal files of the authors. We attempted to consult every other possible resource, including DIALOG, NTIS, MEDLARS, and Cumulated Index Medicus. No substitute was found for spending many hours "digging" through files, bibliographies and reference libraries (e.g., Naval Aerospace Medical Research Laboratory, Pensacola, Florida; Naval Training Equipment Center, Orlando, Florida). The assistance of key investigators (e.g., Herschel Leibowitz) to whom we sent preliminary copies of the reference list (Kennedy and Miller, 1983b) is also recognized as a very useful approach to the problem of literature retrieval.

The initial literature search resulted in a reference list (to be published separately in fall 1985) containing approximately 1,800 items. A first "cull" of the reference list yielded approximately 250 titles, all of which were read or scanned and annotated. A second cull resulted in the selection of 31 titles for this document. The most significant 25 articles were included in their entirety. An additional document (Kennedy, McCauley, and Miller, 1985a) cites what we consider the 100 most helpful items ancillary to, but integral to, an understanding of simulator sickness; it also reproduces what we considered to be the more important pages of these documents.

ORGANIZATION OF THIS REPORT

This report is organized into three sections plus Appendix A. The present section serves to introduce and orient the reader to the remaining sections. Section II deals with the issue of motion sickness and its relationship to simulator sickness. The most important part of this report is contained within Section III. In that section the studies of simulator sickness are reviewed. As we conducted the literature review and reviewed the modest state of our knowledge in this area we surfaced and refined hypotheses for research. These suggestions, in the form of research initiatives, have been offered to stimulate further discussion in the scientific community. Section III also introduces Appendix A, which contains reproductions of articles dealing with simulator sickness -- including reports of simulator sickness outcomes, provocative experiments, messages, dispatches, and other documentation of the aftereffects.

DOCUMENTS IN THIS SERIES

It is intended that six documents will appear in this series, all under the general title, "Simulator Sickness: Reaction to a Transformed Perceptual World." The prospective subtitles are:

I. Scope of the Problem (Frank, Kennedy, Kellogg and McCauley, 1983). This NTEC Technical Note was originally a paper presented at the Annual Symposium of Aviation Psychology, Ohio State University, 24 April 1983.

II. Sourcebook and Suggested Readings (this document)

III. Workbook on Related Topics (Kennedy, McCauley, and Miller, 1984b, in preparation).

Here, subjects related to motion sickness will be discussed. This document will be separated into five sections, each of which, in turn, will be divided into article reproductions (or excerpts) and a list of suggested readings for that category. The sections and their contents may be briefly described as: Motion Sickness, Visual/Vestibular

Interaction, Motion Perception, Adaptation/Habituation, Simulators and Simulation Engineering.

IV. A Content-Oriented Reference List (Kennedy, McCauley, and Miller, 1985a, in preparation). This will cover simulator sickness and related subjects.

V. An Integrated Review of Simulator Sickness (Kennedy, Frank, McCauley, and Berbaum, 1985c, in preparation).

This will include what is known of previous incidences. It will encompass the topics of simulator aftereffects and simulator maladaptation. This document will review, interpret, evaluate, and summarize existing simulator sickness research, developments, and literature. It will provide a connection between related areas of research and it will advance new theory and propose new research relevant to the origins and prevention of simulator sickness.

VI. Preliminary Site Surveys (Kennedy, Frank, and McCauley, 1984).

WHO MAY BENEFIT FROM THESE DOCUMENTS

These series of documents and others forthcoming in this series on simulator sickness are intended to be used as workbooks by technologists who desire to gain a rapid education in the area of simulator sickness and related issues. The technologist may use these documents for individual study or as accompaniments to training sessions concerning flight simulator technology. Lists of suggested readings should satisfy further informational needs, whether for historical background or general reference.

SECTION II

PROBLEM DEFINITION

MOTION SICKNESS--A DEFINITION

Motion sickness is a general term for a constellation of symptoms and signs, generally adverse, due to exposure to abrupt, periodic or unnatural accelerations. One must have organs of equilibrium for the malady to develop. Overt manifestations (signs) are pallor, sweating, salivation, and vomiting (Reason and Brand, 1975). Drowsiness, dizziness, and nausea are the chief symptoms. Less frequently reported, but often present, are postural changes, sometimes referred to as "leans," "staggers," or "sea legs." Other signs (viz. Money, 1970) include changes in cardiovascular, respiratory, gastrointestinal, biochemical, and temperature regulation functions. Other symptoms include general discomfort, apathy, dejection, headache, stomach awareness, disorientation, lack of appetite, desire for fresh air, weakness, fatigue, confusion, and occasionally, incapacitation. The consequences for human performance and operational efficiency are decreased spontaneity, carelessness, and incoordination, particularly in manual control. Table 1 lists the different categories of symptoms (Kennedy, Dutton, Ricard, and Frank, 1984).

Motion sickness is theoretically preventable, but prevention is not always practical. Once symptoms become severe, treatment other than time may be impossible for subsistence. Experimental evidence for the findings which are reported above appears in Alexander, Cotzin, Hill, Ricciuti, and Wendt (1945a, b, c; 1955a); Alexander, Cotzin, Klee, and Wendt (1947)); Brand, Colquhoun, Gould, and Perry (1967); Clark and Graybiel (1961); and Graybiel, Kennedy, Knoblock, Guedry, Mertz, McCleod, Colehour, Miller, and Fregly (1965).

Many types of motion produce motion sickness. Generally, acceleration of the environment is required, but there is strong evidence that visual motion alone is sufficient (Reason and Brand, 1975). The effects usually are limited to the period of exposure, but post-adaptation phenomena occur (Fregly and Kennedy, 1965; Witkin, 1949).

Ataxia induced by vestibular stimulation is known to occur but is not often reported. For example, it occurs following exposure to centrifuge and ships at sea (viz. Fregly, 1974). Data are available whereby comparisons can be made between ataxia performances due to blood alcohol levels and simulator exposure (Fregly, 1974). Because both postural equilibrium and manual control are closed-loop control systems under voluntary

TABLE 1. MODIFIED DIAGNOSTIC CATEGORIZATION
TIME SHEET

PATHOGNOMIC SYMPTOM

Vomit

MAJOR SYMPTOMS

Increased salivation	moderate and severe
Nausea	" " "
Sweating	severe
Pallor	"
Retch	"
Drowsiness	"

MINOR SYMPTOMS

Increased salivation	slight
Nausea	"
Pallor	moderate and slight
Sweating	" " "
Drowsiness	" " "

MENTAL SYMPTOMS ("minor" and "other" symptoms)

Difficulty concentrating (minor symptom)
 Confusion (minor symptom)
 Fullness of head (other symptom)
 Depression (other head)
 Apathy (other symptom)

VISUAL SYMPTOMS ("minor" and "other" symptoms)

Difficulty focusing (minor symptom)
 Visual flashbacks (minor symptom)
 Blurred vision (other symptoms)
 Eye strain (other symptom)

"OTHER" SYMPTOMS

Character facies
 Increased yawning
 Stomach awareness
 Anorxia
 Burping
 BM desire
 Headache
 Dizziness
 Aerophagia
 Vertigo
 General fatigue

control in the cerebral cortex, and involuntary (motor) control in the cerebellum, it would not be unreasonable to hypothesize that if posture is disrupted by exposure to a simulator, so too will human manual control (e.g., steering a car).

The other chief simulator sickness symptom of relevance to the Navy is the soporific drowsiness often reported with vestibular sickness. Reports from squadrons -- particularly in Air Combat Maneuvering (ACM) -- are that even brief exposures (e.g., less than one hour in the simulator) result in long-term fatigue effects.

Woodward and Nelson (1976) have described the types of performance impairment associated with lack of sleep and, therefore, by inference, drowsiness. These include a slower reaction time, short-term memory decrement, impairment in reasoning and complex decision making, errors of omission, and lapses of attention. Sleep loss has been shown to have a deleterious effect on vestibular processes. Dowd (1974) reported increased vestibular sensitivity, decreased recovery rate, and abnormal vestibular habituation to be associated with sleep deprivation. He warned of the implications of sleep loss for increasing the hazards of flying due to degraded vestibular function. It is possible that the drowsiness that often accompanies vestibular sickness may have similar effects on human performance.

SIMULATOR SICKNESS

Motion sickness has been found in nearly all transportation modes -- on land, sea, and air. Although sickness is not new in simulation, the report and investigation of this phenomenon has lagged behind other modes. The history of simulator sickness, per se, is sparse. Those studies available in the published literature include Miller and Goodson (1960); Reason and Diaz (1971); Barrett and Thornton (1968); Puig (1971); Ryan, Scott, and Browning (1978); Casali and Wierwille (1980); Kellogg, Castore, and Coward (1980); and McGuinness, Bouwman, and Forbes (1981). Additional information is available in the form of official correspondence within the Navy and Air Force, between flight surgeons, systems commands, training personnel, and training equipment centers. This information supports the findings reported in the open literature on altered or rearranged perceptions. We feel that simulator sickness is a subclass of these phenomena.

A theoretical model and historical bibliography has been prepared concerning visual distortion (Kennedy, 1970) and the general argument was advanced that adaptation to altered perceptions (visual/vestibular, spatio/temporal) is similar to an explanatory model of motion sickness (Reason and Brand, 1975).

Figure 1 is a schematic depiction of the relationship among simulator sickness and other classes of subject matter. We feel that the largest category is perception. Another category, which overlaps with perception but is not exactly homologous, is motion sickness. Simulator aftereffects exist within both worlds but are not perfectly encompassed by either. Motion sickness indeed has some perceptual components and some which are largely physiologic. The world of perception can be used to understand, somewhat, problems of motion sickness. Moreover, while simulator sickness exists within both worlds, it is possible that some aspects of simulator aftereffects are outside of both the motion sickness and the perceptual worlds (some geometric illusions not necessarily involving motion may be good examples). Because so much of what we view as simulator sickness has a perceptual component, the following have been given heavier emphasis in this text than motion sickness, per se: visual information processing, vestibular information processing, central nervous system integration of those visual and vestibular inputs and interactions, and the adaptation and habituation thereto. Thus, we have used these categories reported above to decompose simulator sickness into more manageable units.

EVIDENCE OF SIMULATOR SICKNESS. Studies by Havron and Butler (1957), and Miller and Goodson (1958, 1960) were the first published reports of simulator sickness. They found a substantial incidence of symptoms among users of the Navy's 2FH2 helicopter simulator. (Instructor pilots were found to be more susceptible than students.)

In recent years, there has been increasing reference to the problem of simulator sickness, although the extent of the problem is still not clearly defined.

An investigation of simulator sickness in the Navy's 2E6 Air Combat Maneuvering Simulator (ACMS) found that 27% of the aircrews using the ACMS reported varying degrees of symptoms. The more experienced aircrews (over 1500 flight hours) had a higher incidence of symptoms than less experienced flight crews (McGuinness, Bouwman, and Forbes, 1981).

One of the first attempts to document the problem in the Air Force was reported recently by Kellogg, Castore, and Coward (1980 and in press). They surveyed 48 pilots using the Air Force Simulator for Air-to-Air Combat (SAAC) and found that a majority (88%) had experienced some symptoms of simulator sickness (primarily nausea) during SAAC training.

Representatives of NAVTRAEQUIPCEN and NAVBIODYNLAB have documented cases of simulator sickness in the Navy's P-3C Operational Flight Trainer (2F87-OFT), particularly at the flight engineer's position (Crosby and Kennedy, 1982). This work was stimulated, in part, by earlier reports of

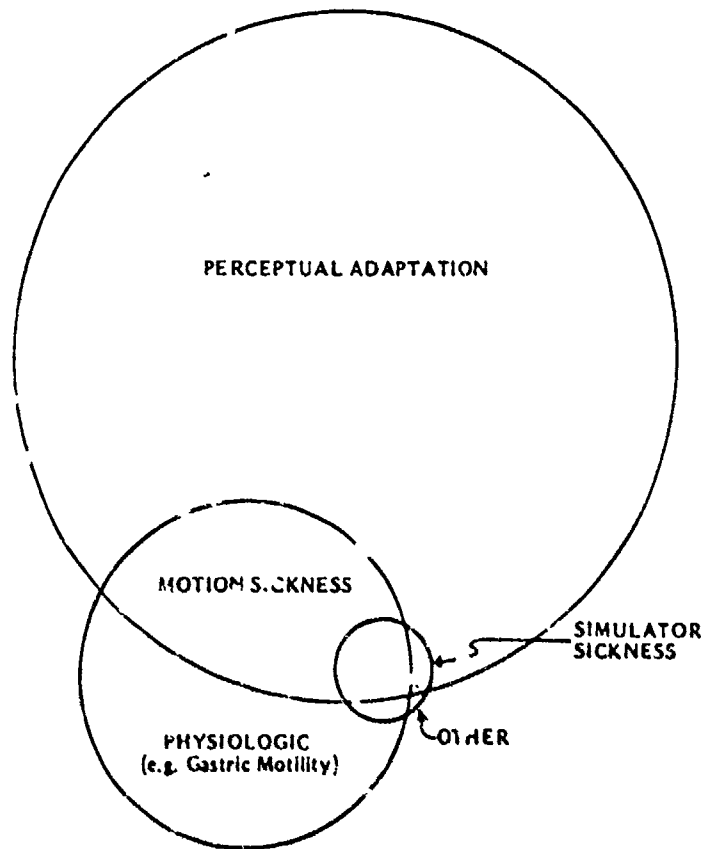


Figure 1. Schematic representation of the relationship among Perceptual Adaptation (sensory rearrangement), Motion Sickness and Simulator Sickness.

symptomatology in the 2F87 by several instructor pilots (Ryan, Scott, and Browning, 1978).

In a study of flight simulator motion sickness conducted for the Canadian Department of National Defence, Money (1980) reported that nearly half of the pilots using the Aurora Simulator experienced sickness ranging from slight discomfort to mild nausea. He provided a summary of the current theoretical bases for motion sickness (sensory conflict theory), and described how aircraft maneuvers performed in a simulator may generate conflict between the visual and vestibular senses.

IMPLICATIONS OF SIMULATOR SICKNESS. For the Navy, and for the Naval Training Equipment Center, the possible negative implications of simulator sickness can be grouped into three broad categories.

Compromised Training. First, symptomatology may interfere with and retard learning in the simulator through distraction. Secondly, since humans are flexible, trainees may adapt to unpleasant perceptual experiences. If new learned processes are not similar to responses required in flight then the new responses could lead to negative transfer to in-flight conditions. We believe this is a most critical problem because of its safety of flight implications.

Decreased Simulator Use. Because of the unpleasant side-effects, simulators may not be used or persons may lack confidence in the training they receive in such simulators.

Simulator Aftereffects. Simulator exposure may result in aftereffects or post-effects. These are not unlike the post-effects of other motion devices, but their relevance to safety (e.g., egress down a ladder, or driving home) is not known.

EVIDENCE OF NEGATIVE IMPLICATIONS. The consequences and practical significance of varying degrees of simulator sickness have been alluded to in the past. Crosby and Kennedy (1982) in a Navy study of the 2F87-OFT stated:

"The cause(s) of these symptoms should be eliminated for the following reasons. The flight engineers are at risk when walking on the ladders at the exit of the simulator following training because of extreme unsteadiness induced by the simulator. The students become reluctant to take more training after this experience. Additionally, the symptoms of simulator sickness reduce the effectiveness of the flight engineers and hence jeopardize the flight crew in real flights that follow the training on the same day. Training is probably less effective because the flight engineers attend to their malaise rather than to

the flight being simulated. Scheduling problems due to illness result in lost crew time on the simulator following aborts."

The postural disequilibrium which sometimes results from exposure to this environment should be studied further. The purpose of the above study was to use equilibrium as a sensitive probe for effects. It is not known whether the postural disturbances observed are symptomatic of more general incoordination (e.g., fine or gross motor control), nor is it known whether certain conditions might amplify the effects (e.g., sleep loss, alcohol, impoverished sensory conditions). Other questions include: What is the time required for return to baseline levels? Do all moving environments produce like changes? Are individual differences large? Should particular activities be avoided?

In the Navy's 2E6 Simulator, similar problems of simulator sickness were reported by McGuinness et al. (1981). Dizziness was the most frequent symptom, followed by vertigo, disorientation, "leans," and nausea. The incidence of symptomatology was greater in pilots than in radar intercept officers (RIOs). The authors suggested that one reason for the reduced levels of simulator sickness found in the 2E6, relative to the Air Force SAAC, may have been the less intensive schedule of simulator time.

Exposure duration and frequency appear to be potentially important variables, as has been found in other environments that produce motion sickness (McCauley and Kennedy, 1976; McCauley, Royal, Wylie, O'Hanlon, and Mackie, 1976).

Perceptual aftereffects also have potential consequences of disorientation and degraded motor control. Some F-4 pilots, after training in the SAAC at Luke AFB, have reported sensations of climbing and turning while watching TV, or experiencing an 180-degree inversion of the visual field while lying down (Kellogg, Castore, and Coward, 1980). These authors cogently suggested that "users of such (wide field of view) simulators should be aware that some adjustment may be required by pilots when stepping back into the real world from the computer-generated world."

SECTION III

SIMULATOR SICKNESS REVIEW AND SUGGESTIONS FOR RESEARCH

BACKGROUND

Humans, along with other species, adapt biologically to ecological changes; otherwise, they do not survive. Ordinarily, adaptation involves long-term evolutionary modifications of structure and function. However, less permanent modifications occur which capitalize on the human central nervous system's plasticity. These short-term changes may be considered under the general rubric of adaptation to the environment; but persons who study learning, habituation, acclimatization, adjustment, compensation, satiation, and other time-course events may be involved in examining similar processes. These short-term changes make simulator sickness an important problem for the Navy.

It is axiomatic that motion is the basis for motion sickness and the constellation of symptoms which occur under some force environments illustrates that this is an ecological change to which humans have not yet adapted. Whether individual differences in resistance may reflect differential levels of development in this regard is speculative and will be discussed later. The fact that the moving systems are usually conceived and developed by humans (viz. ships, aircraft, and space stations), rather than evolving through the course of natural events, is probably not a logically meaningful distinction for this argument. Admittedly, though, man-made systems have introduced new force environments more rapidly than would be the case for most ecological changes.

It is our view that motion sickness is an ordinary consequence of exposure to certain moving environments. The incidence, time course, symptom mix, etc., follow certain rules, some of which are known. Frequently, if the stimulus parameters of the force environment are sufficiently specified, our technology can predict whether and how greatly sickness will occur (McCuley and Kennedy, 1976). It follows that, to the extent that the real system produces motion sickness, a simulator which replicates the real environment is liable to induce the same responses.

Howe¹, when a simulator produces effects which are dissimilar (and indeed worse) than those which ordinarily occur (example, in the aircraft), then the adequacy of the simulator must be challenged. Thus, we propose that the term "simulator sickness" be reserved for those circumstances where the sickness

occurs only (or to a far greater extent) in the simulator. In other cases, the terms car, air, camel, sea or motion sickness should continue to be employed. It is with this philosophical perspective that we have studied the research literature on simulator sickness. It will only be through an adequate understanding of how simulator sickness compares with more "ordinary" varieties of motion sickness that remedies will be forthcoming.

FACTORS CONTRIBUTING TO SIMULATOR SICKNESS

KEY FINDINGS FROM THE RESEARCH LITERATURE. A large literature is available on altered and transformed perceptions. Occasionally in these studies, discomfort similar to the symptoms of motion sickness has been reported. Although the findings have not been clearly connected with simulator sickness, we believe much is to be learned from the study of this literature. For example, in addition to the spectacles and prism work, binoculars (Sternberg and Banks, 1970), striped drums (Crampton and Young, 1953), rods/frames and tilted rooms (Witkin, 1949), and other devices have been employed. In addition to central nervous system plasticity issues, in all of these studies a theme recurs; not all persons respond the same. Individual differences in adaptation constitute a potent variable, whether due to an acquired perceptual style or an endowed nervous system predisposition. The practical consequence of this factor is that, while individually tailored simulator presentations are not feasible at this time, individual regimens of exposures to simulators form a probable approach in order to minimize the problem of simulator sickness.

Most reports of simulator sickness suggest that there is only temporary discomfort resulting from the simulator, if any occurs at all, and that such discomfort is a small price to pay for the kind of training provided. Moreover, even when there are problems initially, they appear to subside with continued exposure to the simulator. It should be mentioned, however, that if this adaptation occurs it implies that changes have occurred in the central nervous system. If these changes do not coincide with activities which are appropriate for control of the aircraft, then safety of flight is compromised.

Several reports have shown that the stimulus for emesis can summate, so that with radiation (Cordts, 1982) and the flu (de Wit, 1957), thresholds for emesis are lowered under the combined stress. It would seem likely that hangover, allergic reactions, colds, flu shots, or other maladies might have a similar effect on simulator sickness. Thus, stimulus conditions which might be otherwise mildly distressing would provoke more severe symptoms if trainees (students, pilots) were not in their usual state of fitness. Attention to this factor with appropriate warnings of possible limited simulator usage for persons so afflicted may contribute towards lowering the simulator sickness problem and its incidence.

Simulator sickness resembles motion sickness in that the signs and symptoms are very similar. Most of the distress and upset present in true motion sickness are also present in simulator sickness. Occasionally, the reports which occur in connection with simulators, which may not involve nausea and vomiting, include headache, visual streaming, and other more migraine-like symptoms. However, careful perusal of the motion sickness literature will reveal that these symptoms are also present occasionally in motion sickness experiences. It should be possible to alert individuals to symptoms and enable them to diagnose their illness prior to it becoming debilitating. Treatment should include termination of the training session. Proper early diagnosis can mitigate the severity of the symptoms.

The best theory of motion sickness resembles the template matching model of Reason (1978), Oman (1980), and others who posit a cue conflict type of notion. In this theory, perceptions ordinarily are ordered and are generally in accord. When perceptions are not in accord, the central nervous system interprets the problem as one which requires "trouble-shooting." If the vestibular system is one of the sensory domains involved in the conflict, and if the stimuli are in the appropriate bandwidth for it to be involved, then the central nervous system interprets these events as though it has been poisoned and sets in motion the requirement to regurgitate the stomach contents to expel the poison (Treisman, 1977).

When cue conflict occurs, adaptation to distortion occurs following certain rules. In general, the organism samples over time, or past history (neural store), in order to determine whether these things which are not in accord are at least orderly, coherent, and systematic. To the extent that they are, adaptation occurs in the form of new connections. These new connections occur at some cost -- some penalty. In order to write new programs, one has to pay for the software. This may help to explain why people get drowsy in connection with motion sickness; indeed, why they are drowsy following long-term car rides or train trips. Included in this model is an explanatory corollary for why performance is degraded during motion sickness. Specifically, if the body undergoes extreme duress, and has gone into the "I am poisoned" mode, it taps available resources. Several theorists have suggested analogous ideas; the "functional reserve" of Graybiel (1969), the "distraction principle" of Teichner (1958), or the "competition for the final common path" of Sherrington (1906).

In the early reports of simulator sickness, for example, in the 2FH2 helicopter simulator, there were limitations in system fidelity. These included vibration of the visual displays, other distortions of the visual, and foggy, blurred, and generally out-of-focus presentations.

Later simulators, for example SAAC, also have produced simulator sickness and the sickness which occurs in the latter is probably not due to spatial distortion. In the 2FH2, reported airsickness appeared to have the most pronounced effect on hovering performance and students frequently lost control of the helicopter and wound up in extreme oscillations. A case in point is the Miller and Goodson (1958) report where sickness prompted engineers to reevaluate the simulation. The sickness present was far greater than was to be expected in a similar exposure in flight. In their analysis (pages 12-15), "...lags...two to three times normal." "Transparency begins to shudder..." "Horizon rises to a peak corresponding to a corner of the plate." "...too complex..." "Three dimensional objects...appear tremendously distorted." "Picture is dim and blurred" and "blur gives impression of motion" and may lead to "poor performance by a student ...[because]...during hovering maneuvers, one must respond to the slightest impression of movement." "Usual cues for retinal disparity and ocular convergence are lacking." "From the cockpit, the furthest point upon which a pilot is called to focus is about 12 feet. The closest point on the screen is about 6 feet from his eyes. This difference of about 6 feet represents, in the scene, a distance of a matter of miles." On page 18 they state:

Obviously, the represented distance to an object in the scene is some exponential function of the actual distance to that given point on the screen. Therefore, any movement of the head will increase or decrease the represented distance to an object in an exponential manner, and any correction effected by increasing the radius of the screen would alleviate this problem in the same manner.

Because neither of the seats is located at the focal point of the screen, a parallax is perceived by an observer from either seat....If this distortion were constant, the observer would likely be able to adapt. Unfortunately, however, the degree of the distortion is changing continually with movements of either the scenery or the observer's head. Since these distortions are due to the offset position of the seats, the only area free of parallax is that area on the screen which is aligned with the observer's eyes and a vertical line from the light source. The greater the distance from this area to a point being attended, the greater the distortion will be. Thus, a pilot performing a turn on a spot to the left may observe that a fence post or telephone pole which slants about fifteen degrees to the left, gradually approaches the vertical as it approaches this area of the screen, and then begins to slant to the right. If this parallax contributes to the cause of 'motion sickness,' one may readily account for the fact that a greater percentage of instructors get sick than do students; the instructors have learned to scan the visible area constantly, whereas the students tend

to fixate on a particular area of the screen and simply to attend to that portion of the scene which comes into this area.

A number of individuals have commented independently that the apparent movement of the scenery in the 2FH2 is considerably more rapid than the corresponding movement observed from a helicopter. The cause of this effect is not clear. It may be, however, the end result produced by certain factors discussed previously such as blurring, distorted size perspective, distorted movement parallax, etc.

Women exhibit larger fields of view than men from the standpoint of the functional peripheral fields (Burg, 1968, cited in Leibowitz, 1973, Figure 1, p. 65). Sickness is more prevalent in simulators with wide fields of view (Frank et al. 1983). Perhaps this mechanism partly explains the greater incidence of motion sickness in females. One might look to find greater incidence of simulator sickness in females also.

A subtle distinction runs through the documents supporting design criteria for simulators. The philosophy of fidelity is different depending on whether visual or inertial inputs are being discussed. The attempt is often made to depict reality as faithfully as possible for the visual image and, therefore, to inform the eye. However, we set about to fool the vestibular system through washout and other cues. It is proposed that a self-conscious appreciation for these differences in design philosophy may be helpful in understanding why simulator sickness may occur. For example, not only must the visual system and the vestibular system be informed, but they must also be informed within the dynamic range over which they both operate. Moreover, in those ranges where the two operate together, care must be taken that the peak sensitivities of each are informed both spatially and temporally, simultaneously, in terms of the perceptual simultaneity. Furthermore, it should be recognized that, generally, visual information is more available to consciousness than vestibular. Visual information (e.g., ambient) that is less conscious is also more likely to be implicated in motion and simulator sickness since it is also more likely to be in conflict with the vestibular information in these environments.

SUMMARY OF FINDINGS

From the literature review, we have listed according to our estimate of importance the following predisposing or contributing factors to the incidence of simulator sickness: a) motion base frequency effects (real motion and visual/spatial); b) input/output lags in the simulator, both visual and inertial; c) visual/vestibular mismatch; d) individual differences; e) frequency of exposure; f) field of

view; g) off-axis, poor resolution, flicker, and other distortions in viewing; h) subject's physical state (flu, fatigue, or anxiety); i) incidental head movement; j) task or intensity of dynamic environment; i.e., landings versus air-to-air combat [Effect = frequency X intensity X time X individual susceptibility-adaptation]; k) use (i.e., freeze while upside down); l) adaptation; m) scene content (e.g., too much detail); n) duration of exposure; o) model board vs computer-generated imagery; p) high frequency vibration (> 3 Hz) which disrupts visual accommodation; and q) dark focus interacting with display viewing distance.

The chief outcomes of simulator distress and sickness are in the form of: 1) adverse training -- due to the plasticity of the human nervous system; b) creature comforts and motivational features -- which will surface in the form of mistrust in the simulator's capabilities; and c) safety and health -- where some of the aftereffects may produce problems.

RESEARCH INITIATIVES

RATIONALE. Through reading the studies in Appendix A, other materials on simulator sickness, and the items collected and cited in the Workbook (Kennedy, McCauley, and Miller, 1985b), and through the context provided by the 1500 or so references which will appear in the Reference List (Kennedy, McCauley, and Miller, 1985a), we began to recognize the need for more research in this area. A series of discussions among us led to the identification of problems and unresolved issues. To provide a structure for communicating these issues, we decided upon a matrix where content areas versus lead time for solution were compared. Thus, on the one hand, we pointed out where our technological information may provide present-day answers (e.g., conduct a spectral analysis of moving-base simulators to determine whether the distribution of energy is in the same region found conducive to sea sickness); and where there appear to be opportunities for longer term research initiatives, either in the form of experiments for specific problems (e.g., lags, off-axis viewing), or among more general themes (e.g., the time course of adaptation and post-adaptation following different schedules of exposure). We have also included more programmatic efforts (the relevance of focal versus ambient visual information processing for minimizing conflict between and within sensory systems in ground-based flight simulators). We have listed first those cases for which we believe there is sufficient ex information to suggest solutions ("Near Term"). Next, we have cited items where it is likely that it will be possible to develop an answer, although engineering analyses may need to be performed ("Midterm"). Lastly, there are forms of solution which may only become available when research programs are put in place to systematically study the problem ("Long Term").

TABLE 2A. FLIGHT SIMULATOR CHARACTERISTICS

Designation	2FH2	2E6	SAAC	2F87
Alternate Desig.		2F112		
Aircraft	Bell HTL	F4/F14	F4	P3-C
Type	Helo	Fixed Wing	Fixed Wing	Fixed Wing
Mission	Hover Train	AirComb Maneuver	Air/Air Combat	Flight Train
When Introduced	1956	1979		
Base				
Type	Fix	Fix	Motion	Motion
Deg. Freedom			6	6
Max g			= .2 g	
Enhanced*		Yes	Yes	
.2 -.4Hz				
Component			Yes	Maybe
Noise Simulated	Yes	Yes	Yes	Yes
Vibration Simulated	Yes			
Cockpit				
Type	Open	Encl	Encl	Encl
No. Crew Stns	2	2	1	3
No. Cockpits	1	2	2	1
Display				
Type	Project	Project	CIG	CIG
Medium	Screen	Dome	8 CRTs	CRTs
Source	Point	Pt. Source	& CIG	& CIG
Content	Source	TGT Proj	Model	Model
Sky/Earth	Sky/Earth	Sky/Earth	Sky/Earth	Sky/Earth
Targets		Targets	Targets	
Luminance	"Dim"	Mesopic	Mesopic	Mesopic
Resolution	"Blurred"	Soft	Good	High
Motion Range	6DOF	6DOF	6DOF	6DOF
View Distance	6-12'	8-10'	2-3'	2-3'?
FOV Horizon				
(deg)	260	360	296	>20?
Vertical	75	270	142	>20?
Lag Visual	2-3xNorm	>.20"	>.20"	>.15"?
Inertial			?	Yes?
Typical Miss. Length		30-45'	30-45'	4 Hrs.
Role: Cont/Pass	Both	Both	C	Both
Source:	Miller & Goodson et al. (1958, 1960)	McGuinness et al. (1981)	Hartman & Hatsell (1976)	Various

* use of g-suit, g-seat, dim lights, etc.

@ pilot = 2; copilot = 1; flight engineer = 0.

TABLE 2B. FLIGHT SIMULATOR STUDIES

AUTHORS		Hartman & Hatsell (1976)	Kellogg et al. (1980)	McGuinness et al. (1981)
Report Name		SAACa	SAACb	2E6
Type Study		Survey	Survey	Survey
Focus of Study		Incidence Sim Sick	Incidence Sim Sick	Incidence Sim Sick
Simulator Type		a/c	a/c	a/c
Simulator Desig.		SAAC	SAAC	2E6
Trial Duration			2.5 hrs	1 hr
No. Trials			4	1
Subjects	Who	IPs	Pilot	Pilot
	No.	114	48	66
	Role Cont/Pass	C	C	C
Performance Deficit Symptoms				
How Obtained		Quest/Int	Interview	Quest
Onset		During	Dur/Post	Dur/Post
Max Duration			All Week	6 hrs
Max % w. Symptoms		52%	88%	27%
Max % Quitting				+
% Reporting				
Vomiting		2%		
Nausea		14%	79%	9%
Dizziness			7%	17%
Ataxia/Kinesthetic			60%	10%
Sweat			54%	
Pallor				
Visual		50%	71%	8%
Headache		32%		6%
Drowsiness/Fatigue		32%		
Disorientation		52%		11%
Attentional			35%	
Habituation/Adaptation			Some	
Experience Effects*		No		+
Instr/Stud Effects*		No		

TABLE 2B. FLIGHT SIMULATOR STUDIES (cont'd)

AUTHORS	Havron & Butler (1957)	Miller & Goodson (1958; 1960)	Ryan, Scott & Browning (1978)	Crosby & Kennedy (1982)
Report Name	2FHa	2FHB	P-3a	P-3b
Type Study	Eval	Field Exp	Field Exp	Field Exp
Focus of Study	Train Effect	Etiology Mot.Sick	Motion Effects	Off-Axis Viewing
Simulator Type	Helo	Helo	a/c	a/c
Simulator Desig.	2FH2	2HF2	2F87	2F87
Trial Duration	30'	"Hcp"	4 hrs	4 hrs
No. Trials	12	4	1	1
Subjects Who No.	Inst/Stud 36	Inst/Stud 10+	Inst/Stud 47	Flight Eng 20+
Role Cont/Pass	Both	C	C	P
Performance Deficit Symptoms				
How Obtained	Quest	Q/Int@	Quest	Quest/Int@
Onset	Dur/Post	Dur/Post		Dur/Post
Max Duration	24 hrs			
Max w. Symp	78%	60% Inst	11%	50
15% Stud				
Max Quitting				%
% Reporting				
Vomiting				
Nausea	+			
Dizziness	+			
Ataxia/Kinesthetic		+	11%	50%
Sweat				
Pallor				
Visual	+			
Headache	+		6%	
Drowsiness/Fatigue		+		
Disorientation				
Attentional	+			
Habituation/Adaptation	Some		No	
Experience Effects*			No	
Instr/Stud Effects*	+	+	No	

@ Symptomatology either not evaluated or not evaluated in detail

* + = Instructor or experienced person with greater effects.

TABLE 3A. DRIVING SIMULATOR CHARACTERISTICS

Designation	D1	D2	D3	D4
Type	Auto	Auto	Auto	Auto
Mission	Driving	Driving	Driving	Driving
Base				
Type	Fix	Fix	Motion	Fix
Deg. Freedom			4	
Max g				
Enhanced*				
.2-.4Hz Component			Yes	Maybe
Noise Simulated		Yes		
Vibration Simulated		No		
Cockpit				
Type	?	Encl	Both	Open
No. Crew Stns	1	2	1	1
No. Cockpits	1	1	1	1
Display				
Type	Project	Project		Project
Medium		Screen		Dome
Source	Model Bd.	Pt. Source		Film
	Source	Tgt Proj	Model	Model
Content	Terrain/ Road	Terrain/ Road		Terrain/ Road
Luminance	Mesopic	Mesopic		Mesopic
Resolution	500 lines	50 ft		?
Motion Range	?			
View Distance	?	6'		10'
FOV Horizon (deg)	50			165
Vertical	?			130
Lag Visual			.30 sec	
Inertial			.30 sec	
Source:	Barrett & Reason Thornton & Diaz (1968)	(1971)	Casali & Benfari Wierwille (1964) (1980)	

TABLE 3B. DRIVING SIMULATOR STUDIES

AUTHORS	Barrett & Reason Thornton & Diaz (1968)	(1971)	Casali & Wierwille (1980)	Benfari (1964)
Report Name	Auto a	Auto b	Auto c	Auto d
Type Study	Lab Exper	Lab Exper	Lab Exper	Lab Exper
Focus of Study	Perc Styl & Sick	Lack of Control	Design Features	Stimulus Effects
Simulator Type	Auto	Auto	Auto	Auto
Simulator Desig.	D1	D2	D3	D4
Trial Duration	-	10'	12'	11'
No. Trials	14	1	1	1
Subjects Who	Employee	Stud/Stf	Paid	Misc
No.	50	31+	64	9
Role Cont/Pass	C	P	C	P

Performance Deficit Symptoms

How Obtained	Quest	Q/Int@	Quest
Quest/Int@			
Onset		During	
Max Duration			
Max w. Symp	?	90%	
Max Quitting	50%		22%

% Reporting

Vomiting			
Nausea		42%	22%
Dizziness		71%	66%
Ataxia/Kinesthetic			33%
Sweat		29%	+
Pallor		29%	+
Visual			
Headache		45%	
Drowsiness/Fatigue		3%	
Disorientation			
Attentional			
Habituation/ Adaptation	Some		No
-Experience Effects*			No
Instr/Stud Effectr*	+	+	No

@ Symptomatology either not evaluated or not evaluated in detail.

* + = Instructor or experienced person with greater effects.

TABLE 4. INCIDENCE REPORTS, GUIDELINES,
INFORMATION REPORTS, SUMMARIES, ETC.

AUTHORS	TYPE REPORT	SIMULATOR	FOCUS OF REPORT
Matheny et al. (71)	Summary		Motion & Visual Illusions
Sinacori (69)	Incidence	V/STOL	Simulation Techniques
Frank & Crosby (82)	Incidence	2F117A	Psychophysio- logical Disturbed
USN Message (81)	Guidelines	2F112	Aircrew Re- adjustment
Casto (82)	Information	2E6/ 2F112	Simulator Sickness
Money (80)	Incidence & Recommendations	Aurora CF140	Simulator Sickness
Wenger (80)	Incidence	2F87	Simulator Sickness
USN Message (80)	Requirements	2F87	Visual Display Upgrade
Kennedy (81)	Incidence & Recommendations	2F87	Simulator Sickness
Kellogg, Castore & Coward (1980)	Information	SAAC	Simulator Sickness

NEAR TERM

MOTION SICKNESS. Motion sickness due to vertical oscillation has maximum symptomatology occurring at frequencies of about .2 Hz (McCauley and Kennedy, 1976; O'Hanlon and McCauley, 1974). It would be enlightening to plot the density distributions of various moving-base flight simulators against the acceleration by frequency design criteria of US Military Standard 1472C (1981). For example, the motion density distribution within simulators may be of the wrong wave form for avoiding motion sickness. The aircraft that these simulators are to depict usually have a higher frequency (> 1.0 Hz) of motion themselves, but washout and other methods employed to provide the impression of movement in the simulator, as well as the local adjustments sometimes performed in order to minimize maintenance problems, may shift the frequency downward in the simulator. Thus, even though the simulated aircraft dynamics may not be particularly nauseogenic (probably around 1 Hz) (Kennedy, Moroney, Bale, Gregoire, and Smith, 1972), the simulator's resonant frequency may be in a "bad" region (e.g., around .2 Hz).

Figure 2A presents exposure limits which are prescribed in MILSTD 1472C (1981) for motion and vibration. These two solid lines serve as design criteria in the test and evaluation of moving vehicles (aircraft, ships, tanks) acquired by the Department of Defense. The original document (MILSTD 1472C) used: 1) the 90% protection limit from vomiting due to motion sickness; and 2) the fatigue decreased performance efficiency limit of the International Standards Organization for vibration. In this figure, it may be seen that the most disadvantageous area for very low frequencies is between 0.13 and 0.40 Hz, and for vibration, 3.0 - 8.0 Hz.

In 1975, Hartman (personal communication, 1983) recorded the vertical motion of the Simulator for Air-to-Air Combat (SAAC) over the course of a typical mission scenario. We have transformed his power spectral density analysis to RMS g and replotted the data in Figure 2B along with the MIL-STD 1472C data of Figure 2A. Clearly, the major amount of energy is in a frequency where seasickness predominates, but it also appears to be below the point where 10% vomit over 8 hours.

However, if a more relaxed standard of sickness than 10% vomiting were to be used (e.g., dizziness, nausea, drowsiness, sweating, or pallor, etc., in half the subjects), then a reasonable limit may be the curve drawn below the 10% vomit curve of this figure. Moreover, if either a symptom DURING, or an effect AFTER, in 50% of the population were to be the criterion, then the lower curve of Figure 2C may apply. This mapping reveals quite clearly that the predominant frequency of the SAAC inertial systems intersects our estimated tolerance envelopes and, therefore, could be conducive to simulator sickness. Indeed, Hartman (1975) reported incidence rates for

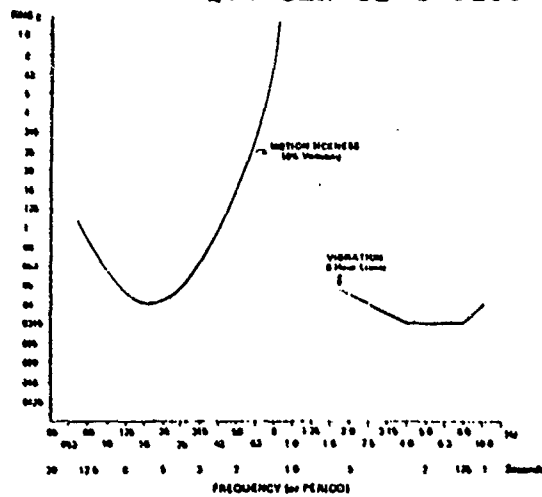


Figure 2A. Exposure limits prescribed in U.S. Military Standard 1472C for motion and vibration.

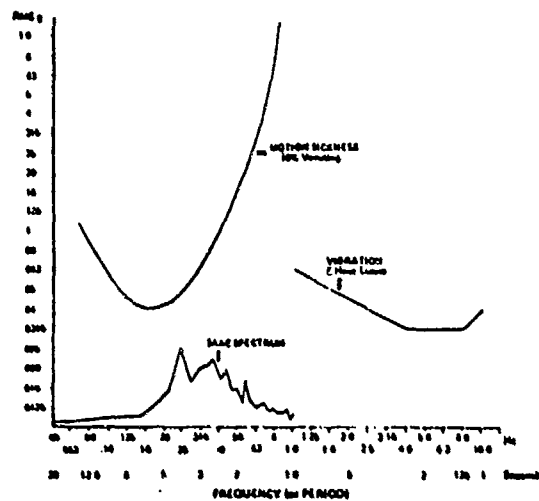


Figure 2B. Vertical motion spectrum of Simulator for Air to Air Combat (SAAC) added to Figure 2A.

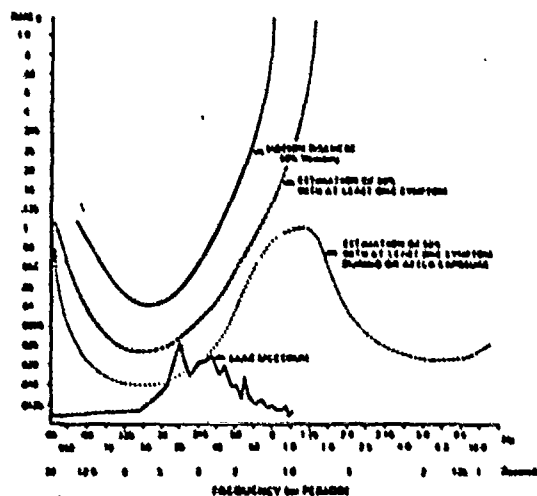


Figure 2C. Addition of occurrences of lesser symptomatology.

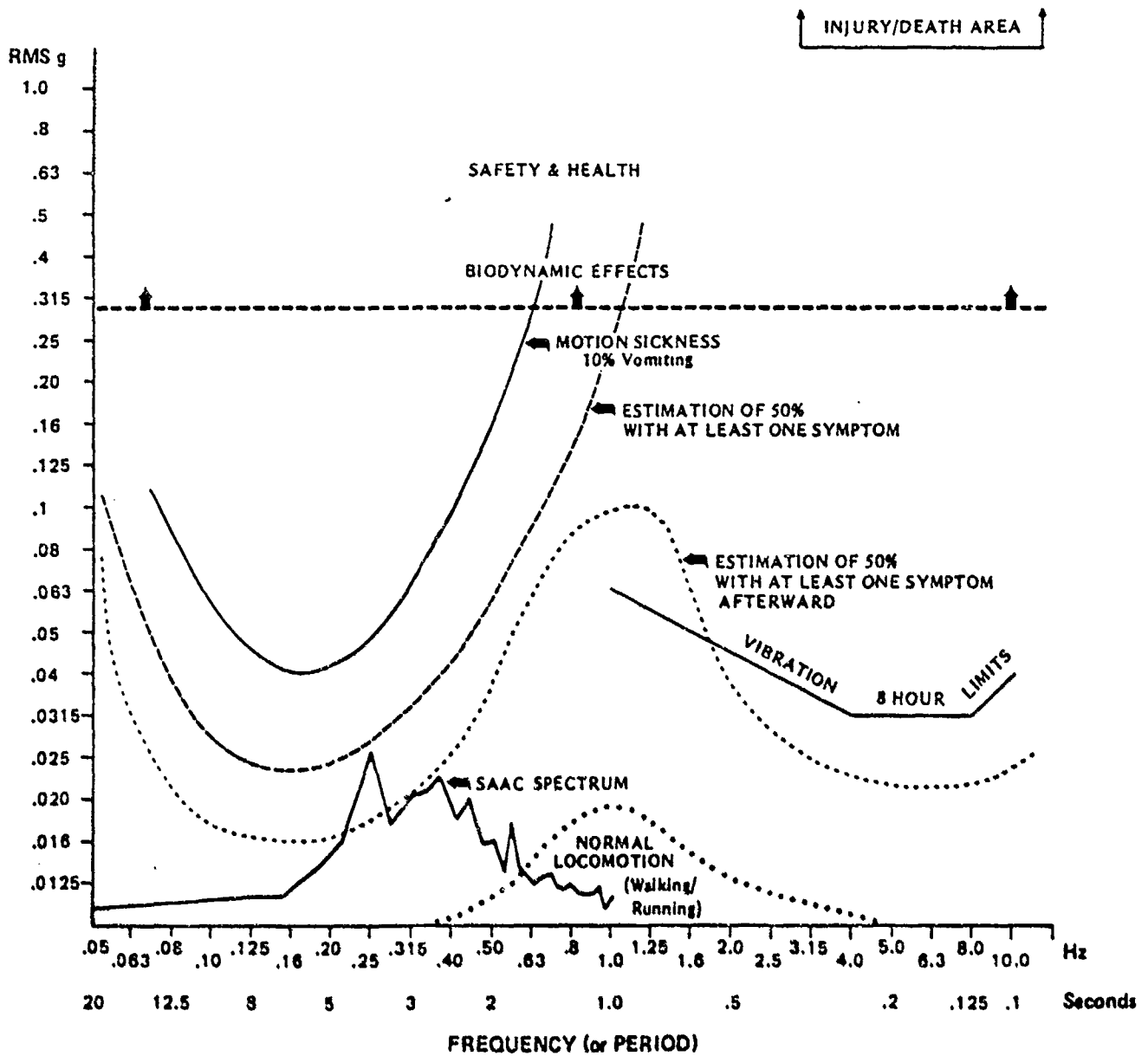


Figure 20. A comparison between MILSTD 1472C vomiting criteria and a projected envelope for lesser symptomatology. (Derived from Kennedy & McCauley, 1982.)

spatial disorientation, eye strain, tiredness, headache, and nausea of 52%, 50%, 38%, 32%, and 14%, respectively. It is readily apparent from this figure that simulator inertial resonant frequency is of critical saliency relative to simulator sickness and that simulators should be designed (or filtered) with this in mind.

In Figure 2D, the post-adaptation effects have been extended into the vibration range; walking has been added, as well as a schematic representation of regions where other effects may occur. Note that we have shown the tolerance limits for each of these envelopes shifts upwards coincident with the spectrum for normal locomotion. This figure overstates what is presently available in our theory and scientific data. However, it does not overstate what is technologically feasible to obtain. It is proposed that more precise measurement be undertaken in order to base these functions on more substantive scientific evidence.

DELAYS AND LAGS. Simulators do not always do what the command signals tell them. Evidence for such occurrences appears in a paper by Seevers and Makinney (1979) where the Air Force Simulator for Air-to-Air Combat (SAAC) was shown to have "a reasonable doubt as to how well, if at all, the motion system onset cuing scheme contributes to simulator effectiveness. Erroneous onset cues are provided the pilot, tending to compound further the dilemma of utility of motion systems employed on visual system simulators;" and "A comparative evaluation of responses of each lag disclosed discrepancies, including excessive lag times and cross-coupling between movements, that indicate errors exist in movement of the platform" (Seevers and Makinney, 1979). It also has been reported to one of the authors that a Navy helicopter simulator has been "out of spec" with its specification for no visual lag greater than 280 msec. We submit that these discrepancies can contribute to the problem of simulator sickness. The standard in question is Military Standard 1558, which governs motion platform systems (MILSTD-1558, Six-Degree-of-Freedom Motion System Requirements for Air Crewmember Training Simulators).

Speech and eye movement tracking exhibit distinctive closed-loop temporal characteristics. Speech (delayed auditory feedback) is affected most by temporal lags around .2 of a second, and is less affected by delay values above and below this value. Eye movement tracking may be seriously impaired by feedback lags of 1 second or less. "The general rule is that the more accurate and precise the motor-sensory system, the more it is affected by small magnitudes of feedback delay" (Smith and Sussman, 1969). In a paper by Rapin, Costa, Mandel, and Fromowitz (1963), where key tapping was used as an indicator of performance disruption due to auditory feedback delays, performance disruption was proportional to the length of delay, up to 1000 msec for tapping; but speech disruption occurred at between 160 and 200 msec. These different time

constants should be viewed in connection with a visual delay time constant, which may be about 100 msec.

Most modern flight trainers employ computer image generation (CIG) visual displays. Operating at 30 Hz would require about 33 msec to generate an updated image, but conventional wisdom is that phase shifts of less than 30 degrees to 45 degrees at 1 Hz (83 - 125 msec) probably will not affect the control of a flight simulation (Ricard and Puig, 1977). Indeed, nearly all the information dealing with visual displays in flight simulators is based on performance deficit as a function of delay. Not taken into account is whether certain delays are more or less conducive to simulator sickness. It is not necessary that performance deficit and physical discomfort follow the same functional relationship relative to the magnitude of delay.

One of the best papers on CIG system delay is by Ricard, Norman, and Collyer (1976). These authors suggest that adding low pass filters to the linear depiction scheme may overcome the limitations of lags. They also point out that there could be negative transfer if the real system and the practicing system do not have the same delay. This paper was prompted by the question of pilot-induced oscillation. Simulator sickness is not mentioned, per se, but the general content of the article and its emphasis on temporal characteristics in simulation leads to the simple projection of different temporal characteristics for visual and vestibular responses in a simulator environment.

With respect to lags, Puig (1970) pointed out that lag time, i.e., optimal lag time, is probably not a constant but is a function of the intensity of the stimulus.

Much of the literature of K. U. Smith reports on the effects of lag and perceptual feedback with temporal or space displaced vision. Howard and Templeton (1966) have seriously questioned the results, although it is fairly well accepted that lags and space displaced feedback impede learning and disrupt performance. This literature should be critically reexamined; two-dozen studies are cited in the Kennedy, McCauley, and Miller (1985a) reference list. The work of Smith (1963) has shown that there are difficulties when information is visually delayed. The magnitude of the delay which degrades motor performance may not be the same value (in msec) as the interval which one might find most distressing. Both of these forms of delay are present in flight simulators, but generally only the delay which intrudes on performance is studied. The latter is of importance for understanding simulator sickness. In general, the motor deficit is proportional to the magnitude of the visual delay, but delayed auditory feedback is most disturbing at about 100 msec.

Observed effects of feedback delays indicate that little or no learning occurs in most response systems with feedback delays longer than .4 seconds or, if limited learning occurs, it is likely to be unstable. These and other findings indicate that every motion system of the body is specialized in terms of the temporal feedback compliances that regulate it.

ADAPTATION EFFECTS. Fineberg (1977) showed that previous learning with visually displayed information has an effect on subsequent perceptions of velocity. Fried (1962) has obtained a similar outcome. The fact that motion perceptions can be modified by previously experienced visual information suggests that perceptions or estimates of velocity when driving an automobile could be influenced by previous exposures in simulators. In their study of the 2FH2 helicopter simulator, Miller and Goodson (1960) reported that "on one occasion, an instructor had to get out of his car on the way home and walk around in order to regain his equilibrium" (page 208). When persons were exposed to long periods under rotation (Fregly and Kennedy, 1965), the post-effects were still measurable three and four days after the exposure ceased. And in some cases (Goodenough and Tinker, 1931), an aftereffect can be shown to be retained as long afterwards as two years. Guedry (1965) has shown post-adaptation effects of several weeks.

Many studies of adaptation to altered perceptual inputs have been reported. One in particular by Taub (1973) showed that most of the laboratory experiments performed on prisms have used massed practice, where subjects put on the prisms and were exposed to the experimental test. When this was done, the magnitude of the effects were measured in the form of post-effects. However, in Taub's study, distribution of practice showed an extensive amount of transfer. One might also infer, from the standpoint of simulators, that with distributed practice -- perhaps once a day over a long period of time -- the habits that are built up may become very strong, so that when one does get into an aircraft, it may be more difficult to unlearn them. These adaptation effects need not result from active operations. Templeton, Howard, and Lowman (1966) showed that post-adaptation effects from passive adaptation can still be strong and this has direct relevance to steering an automobile after simulator exposure.

Rosinski (1982) makes the important point that graphic displays provide accurate representations of three-dimensional space only when viewed from the geometric center of projection; otherwise, there are distortions. He goes on to show that with familiar display systems geometric distortions are well tolerated and are, indeed, discounted by the perceptual system (e.g., a windshield). If simulator distress is occasioned by off-axis viewing and by other perceptual distortions, scene content composed of familiar items and possibly even those with "good form" may be less conducive to simulator distress than those which are unfamiliar.

HEAD MOVEMENT. Head movement may be an important issue in simulator sickness. The relationship between simulator sickness and head movement has not been determined. It has been shown that head movements increase motion sickness susceptibility in gliders, a slow rotation room and, perhaps, in space flight. Motion sickness may be expected to decline in flight simulators if head movements are restricted.

However, this potential efficacy may be lost because head movement incidence may be related to the available and useful field of view. Thus, if head movements, per se, are restricted, field of view may also be restricted. If there are requirements for extraction of information from other than the central field, as in air combat maneuvering, then whether interactions occur is an empirical question.

At least one author (Sinacori, 1969) has shown that pilot head movements during moving-base operations are similar to head movements found in-flight with a helicopter. Alternatively, head movements in the simulator during fixed-base operations were different. Conceivably, the head movements are made in accord with the inertial inputs following vestibular stimulation. In a fixed-base, nonvestibular stimulation mode, these head movements may not be in accord and may be the source of conflict in some future simulators. It is possible that moving-base helicopter simulators may be less conducive to simulator sickness than their fixed-base counterparts. This conclusion is supported by the findings in the 2FH2 Helicopter Simulator studies of Havron and Butler (1957) and Miller and Goodson (1958, 1960).

POSTURAL EQUILIBRIUM AND ADAPTATION. Aftereffects occur following exposure to transformed visual/proprioceptive inputs (prisms, mirrors, moving devices). Frequently, these have been measured using walking and standing tests of equilibrium. It is also possible to measure a bias or an increased dispersion by a method of past pointing, first reported by Slinger and Horsely (1906; see also Barany, 1906). Those authors used a grid to measure felt position of limb in various different meridians, both sagittal and horizontal. Tests like these should be devised for use with motion aftereffects. Changes in felt position of the limb are directly relevant to the manual control of vehicles following simulator exposure.

Post-adaptation effects, which have been shown in the form of postural disequilibrium ("leans") and kinesthetic aftereffects, might be expected to influence manual control in the subsequent operation of aircraft, in egress from the flight simulator, or when driving home. The oculobrachia illusion (Lackner and Levine, 1978) can be considered analogous to the motor output characteristics of a pilot subsequent to simulator exposure.

In his paper "Sensory Feedback in Human Posture Control," Nashner (1970) offers an engineering approach to the modeling of control processes for remaining upright. Very likely, the adaptation occurring in simulators is logged and registered in the neural store as proposed by Nashner and the post-effects represent either a bias or increased sway subsequent to those exposures.

Obviously, changes which occur in postural equilibrium from rotation and from alcohol do not have a common genesis from the standpoint of the stimulus; yet, they very likely operate through the same central nervous system pathways to the motor system. Tracking performance has been disrupted by alcohol and has been related to distortions and potential changes in driving behavior (cf. Money and Myles, 1974, for interaction between alcohol and vestibular function). Because alcohol affects posture and tracking in a specific way that is not unlike the way alcohol affects walking, it is not inconceivable that simulator motion, which produces ataxia, may also produce changes in manual control.

The "adaptation" literature and simulators may be viewed analogously to the time when "habit patterns" were implicated in aircraft accidents early in the study of human factors. Compatibility and consistency have since been recommended as design criteria for aircraft systems in order to avoid accidents. If it can be shown that either anthropometry or convention dictates a good and less-than-good design approach, then it behooves designers to design controls and displays so that they are operated in an optimal way. In addition, whatever these design criteria turn out to be, they should be consistently repeated throughout all systems where the same individual is expected to operate. For example, in different aircraft, the windshield wiper, radios, triggers, etc., should be in the same positions. This consistency in design is required in order to avoid inadvertent or improper usage or to minimize accidental operations and errors. If one is to design flight simulators with the same view in mind, and if it then turns out that responses that are learned in simulators need to be unlearned later in aircraft, then this constitutes negative transfer and is to be avoided.

Information from massed long-term exposures shows that post-effects are liable to surface, not only immediately after the exposure is terminated but also days later. Astronauts have reported feelings of levitations; persons who go to sea report le mal de débarquement, or disembarkation sickness; "sea legs" is a special case, as is the feeling of gliding one experiences after two to four hours at a roller rink. It is suggested that these post-effects of motor output are governed by the same laws of learning and forgetting as other learned activity.

Many methods for assessing postural equilibrium are offered. Stockwell (1981) points out that the control of spinal-cerebellar pathways by vestibular inputs can be a problem. Of more importance, however, "It may seem that powerful methods of testing human postural stability are at least several years away" (Fregly, 1974, p. 334). In an extensive effort to develop a battery of simple clinical balancing tests, Fregly (1974) was able to make reliable discriminations among normal individuals and patients with unilateral or bilateral peripheral vestibular lesions. "These investigators assume, as Nashner did, that the body behaves as a single linking pendulum" (p. 334). No good clinical test is available for measuring postural stability that includes considerations of the multiinputs/multilevel nature of human postural control. In our opinion, the work of Fregly and his test are the best to date.

MIDTERM

MOTION PERCEPTION. It is possible that the nauseogenic properties of visually induced (heave) motions may be similar to those of inertially presented stimuli. That is, for fixed-base trainers, it is possible that .2 Hz may be particularly distressing. The visual environment could be characterized in the same way that the inertial environment was in MILSTD-1472C. Possibly, the two envelopes overlap. A spectral analysis of the visual system's response characteristics, similar to what has been described in MILSTD-1472C for motion sickness, should be prepared (Figure 2). Specifically, the displacement, in visual angle, and the cycle, in terms of frequency of a visual input which serves as a forcing function for vection, should be determined. Insufficient research is available in this area of optokinetic stimulation for sinusoidally presented stimuli.

The frequency response of the visual and the vestibular systems to vertical oscillations may or may not coincide. If they are differentially sensitive to various frequencies in the form of gain, phase angle, etc., this difference could serve as the measure of the magnitude of the conflict when the two are not in accord. All cue conflict theories of motion sickness would predict increased incidence where this occurs, but no good measures of the magnitude of the conflicts are available. It would be helpful if we could diagram the frequency response of the visual system for linear oscillation for focal and ambient stimuli.

In a paper by Brandt, Wist, and Dichgans (1975), dynamic visual-spatial orientation was shown to rely mainly on information from the scene periphery -- both retinally and in depth. Moreover, vestibular information can be confused (e.g., the oculogyral illusion) and visual motion information can be interpreted as either object-motion or self-motion. The authors studied contrast density in the moving field and

considered that when stationary and moving contrasts are simultaneously present at different distances, self-motion would be more affected when either the stationary or the moving contrasts are located in the background, as opposed to the foreground. "This hypothesis implies that dynamic spatial orientation (in this case, self-motion perception) relies mainly upon background information, whereas object-motion perception depends predominantly upon foreground information. Thus, in analogy to the finding that the retinal periphery is dominant in determining self-motion perception, the depth periphery is dominant as well" (Brandt, Wist and Dichgans, 1975, 497-498). The authors conclude that background information is of greater significance than foreground information. Consequently, visually induced self-motion and spatial orientation rely mainly on the information from the scene periphery, both the retinal and the depth periphery. The question should be raised as to whether computer image generation provides adequate stimulation for the depth periphery. Scene content is not infrequently a higher spatial frequency than one is accustomed to channeling through the peripheral visual system.

OPTICAL TRANSFORMATION. Several authors have shown the primacy of vision over vestibular function, both from the standpoint of resolution of conflict as well as the apparent validity of sensory input (cf. Young, 1976). Research workers studying transformed visual worlds (using displacing and reversing prisms) have compared vision and proprioception. In those studies, the primacy of vision over proprioception is reasonably clear-cut. It would appear, from the standpoint of the cue conflict theory, that visual disruptions are likely to be most distressing because vestibular and proprioceptive disruptions, if present, are liable to be brought into correspondence by the central nervous system's plasticity. The primacy of the visual system over these other two, from the standpoint of perceptual rearrangement, does not imply (indeed, may suggest otherwise) that disruption of the other two sensory systems, particularly the vestibular system, may lead to motion discomfort. The irony is that the other two are likely to be weaker and vision stronger. In general, simulators are designed philosophically to depict visual information as veridically and faithfully as possible. The notion of an eye-limited system is a design goal. Alternatively, the announced approach, from the standpoint of stimulation of the vestibular and proprioceptive systems, is to fool those systems into thinking that they are flying. It is suggested that consideration of simulator aftereffects (rescaling of vestibular and proprioceptive function) may lead design engineers to reconsider their design philosophy.

MOTION SICKNESS. Drowsiness is reported for nearly all simulators exhibiting aftereffects. Drowsiness, of course, is a well-known symptom of motion sickness, and the so-called sopite syndrome is likely to be the most debilitating problem

of motion sickness and may be of simulator sickness also. Ryan, Scott, and Browning (1978) report drowsiness after simulator exposures. It is well known that the pontine reticular formation receives some control from the vestibular nuclei (Yules, Krebs, and Gault, 1966). Moreover, one paper (Allen, Oswald, Lewis, and Tagney, 1972) has shown the effects of distorted visual input on sleep. Conceivably, this effect can occur from exposure to distortion in visual inputs during simulator exposures.

The soporific effects of motion are well known; moreover, sleep deprivation itself has an adverse effect on the vestibular habituation process (Dowd, 1974). Various methods have been used to measure motion sickness symptomatology. One which uses a seven-point scale (Wiker, Kennedy, McCauley, and Pepper, 1979) has shown inter-rater reliabilities exceeding .95; and it would seem that the simulator sickness symptomatology might be scorable using diagnostic categorization worksheets reported by Wiker et al. (1979).

The results of the Wendt studies (Alexander et al., 1945a, b, c, 1947, 1955a, b) and the human factors research studies (McCauley et al. 1976) on whole-body sinusoidal oscillation show that .2 Hz is maximally conducive to motion sickness symptoms. Both of these experiments were conducted in cabs, where the subjects were denied visual information outside the moving cabin. The studies performed on a swing by the Air Force (Hemingway, 1942) show that .25 Hz is an adequate stimulus for motion sickness induction. The differences in those studies from the Wendt and HFR studies are: a) the swing involved linear plus angular changes since the swing moved along a 120-degree displacement from a 14-foot arm; and b) vision was permitted. This has relevance for the visual presentation in simulators. It is conceivable that .2 Hz also may be maximally effective in producing motion sickness for a visual stimulus only.

Biofeedback (Levy, Jones, and Carlson, 1981) is considered by some to be a method of choice for minimizing the problems of motion sickness in flight. Caution should be used, however, in suggesting the use of biofeedback, hypnosis, or other methods for minimizing symptomatology in simulators, because it is not known to what extent performance is degraded by the motion or the simulator distress; moreover, it is not known whether biofeedback, per se, is intrusive and/or interactive with performance -- even when it may minimize the neuro-vegetative symptoms occasioned by the motion stimuli.

Lowered thresholds to motion sickness have been shown with flu (de Wit, 1957; Kellogg, Kennedy, and Graybiel, 1965) and radiation induced emesis (Cordts, 1982). The prospective summation of different causes of emesis suggest that other symptomatology may occur with different simulation aspects.

Flu shots, hangover, or anything else that may lower one's tolerance in general may have a similar effect in simulators.

Exposure to a slow rotation room, a kind of simulator, increased a person's tolerance to airsickness over previous tolerance levels (Cramer, Graybiel, and Oosterveld, 1976). If there is positive transfer from a centrifuge to an airplane, there is evidence that modification occurs in the visual/vestibular integrating mechanism. However, it cannot be overemphasized that positive transfer does not imply positive consequences.

LONG TERM

INDIVIDUAL DIFFERENCES. "Subject-to-subject differences exist, both in overall ability and in ability to improve performance with the addition of motion cues....The data of the individual subjects permit differences among the data due to subject differences to be allowed for" (Shirley, 1968). In other words, there are group-specific outcomes; however, group functions are manufactured out of individual differences. This averaging is performed in order to obtain general functions. It needs to be recalled, however, that even in a careful control-theory experiment individual differences are present, and that the stimulus properties employed in the models may, more or less, fit an idual case. It is not suggested that all simulators need to be individually tailored for inertial inputs, but it needs to be understood that all averaging techniques are compromises for some operators. Perhaps simulator distress occurs because of a particular mismatch of signals for an individual that may not be noticed as conflicting by subjects with different sensory transduction characteristics.

The overwhelming evidence for individual differences in response to intensive stimuli suggests that simulator visual and inertial inputs are not phenomenally of the same intensity across all people (Benson and Reason, 1966). The conclusion is inescapable; much simulator sickness may be due to stimuli that are discordant for some individuals but not for others. Solutions to this problem include better definition of the frequency response of visual and inertial presentator individuals and for groups.

Individual differences in past experience are positively correlated with increased motion sickness susceptibility in simulators (Reason, 1968). Others have shown individual differences in figural aftereffects (Over, 1970), apparent motion thresholds (Henn, Cohen, and Young, 1980), simulator sickness (Barrett and Thornton, 1970), perception of velocities and accelerations (Puig, 1970), and exposure history as measured by a motion sickness questionnaire (Reason and Graybiel, 1972). We believe that study of the neuropsychologic origins of these individual differences will be a profitable

line of investigation, both from the standpoint of understanding what causes simulator sickness, in order to prevent it, and also to offer individual simulator regimens to susceptible persons.

MOTION SICKNESS. Reason (1969) has posited that purely visual stimulation can provoke motion sickness symptoms if the visual angle subtended by the stimulus is sufficiently large, and the visual stimulus is of the sort that would normally be accompanied by vestibular stimulation. In other words, expectancy from past experience sets up a correlation, and when new events do not agree with expectancy, the lack of correlation provokes sickness (shown unequivocally by Dichgans and Brandt, 1973). It follows that more conflict may be more provoking and the question of how to quantify the size of the conflict puzzles cue conflict theorists. We believe that the magnitude of this conflict is proportional to the sensitivity of the two channels involved at the point where they are not in accord. If both of the sensory channels involved are within ranges where both are sensitive, then the lack of accord will be more disturbing than if the lack of concordance was in a stimulus range beyond the sensitivity of one or both channels. These points are important in terms of both the filter concept and the channel concept (Regan and Beverley, 1982) which, in turn, may be a useful explanatory principle for simulator sickness. Since we claim that the magnitude of the conflict may be proportional to the sensitivity of a particular channel, this would imply that if one is outside the good sensitivity region of either the vestibular or the visual system, sickness should be reduced. For this reason, we suggest that detuning either the visual or vestibular system will reduce the conflict and thereby the symptoms.

MOTION PERCEPTION. Papers by Regan and Beverley (1973, 1982), "Dealing with Disparity Detectors in Human Depth Perception" and "Confounding the Direction We Are Looking with the Direction We Are Moving," suggest that perceptions in a simulator may not be identical with perceptions in the real world. For example, although parallax can be created in simulators and relative motions can be produced similar to those experienced in the real world, this only is true when the eye is fixed relative to the cockpit. However, head movements often occur incidental to the cockpit movement and parallax, as one experiences in the real world, only occurs when the head is stationary relative to the cockpit. These differences, plus the fact that distortion increases the further the eye moves from the design eye position, need to be examined. The research literature on prismatic displacement (i.e., Held, 1970) may provide useful leads. Miller and Goodson (1958) make a very similar point in discussing issues other than cue conflict that they believed contributed to the high sickness rates of the 2FH2 helicopter simulator.

In a paper by Wist, Diener, Dichgans, and Brandt (1975) it was found that with the angular speed of the visual surround held constant, perceived speed and rotary self-motion increased linearly with increasing perceived distance. Subjective speed as a function of perceived distance using computer image generation should be studied psychophysically. Such studies could provide important information for design criteria for simulators.

Both Kinchla (1971) and the work of Harrington and Harrington (1978a, b) suggest that the two kinds of motion -- absolute motion perception (seen in an otherwise homogeneous visual field) and relative motion perception -- are used in the real world. Simulators should be checked to determine whether they veridically represent these motions. To the extent that the perception of both relative and, particularly, self-motion is more difficult in the simulator than in life, this may contribute to simulator sickness.

FOCAL AND AMBIENT VISUAL SYSTEMS. According to Leibowitz, Post, Brandt, and Dichgans (1982), "The peripheral visual fields play a major role in spatial orientation. In a simulator, the question of how much of a peripheral visual field should be stimulated is important, both with respect to transfer of training and economic considerations...A number of studies suggested during psychological or physiological stress, the functional visual fields are narrowed, but the implications of this literature are not clear. We have suggested the possibility that under some kinds of stress, narrowing may be limited to focal processing while ambient functions remain intact." These same authors have also indicated that the ambient visual system in spatial orientation may be contrasted with the focal visual system. The latter has a multisensory basis of orientation, and disorientation is assumed to result from a mismatch in comparison either with the previous experience of the individual or of the simultaneously occurring signal patterns. They suggest that disorientation in aircraft under instrument flight conditions may result from the substitution of an unnatural symbolic indicator to replace the visual stimuli normally involved in orientation and the failure of learned cognitive skill to compensate for mismatched signals. Attributes of these two modes of processing spatial information need to be better understood.

"The complexity of the visual field was an important determiner of the dominance of visual factors. In a well-structured field, motion and flicker could be integrated; whereas, in a field with poor differentiation, the visual world and the visual field cannot be distinguished from one another" (Gibson, 1950, p. 637). For example, the focal visual system is sensitive to high spatial frequency detail, as one would experience in a computer-generated image; the ambient visual system to middle and lower spatial frequency detail, to large objects, wide fields of view, and briefly (< 70 msec) presented

stimuli. We believe that spatial frequency, contrast, and luminance may be useful in minimizing simulator sickness because of their differential influence on ambient and focal visual systems.

Disruptions of off-axis viewing are likely due to focal problems, whereas rapidly moving wide field-of-view stimuli, as in the Air Combat Maneuvering Simulator 2E6, may lead to discomfort due to disruptions of ambient systems. It is not inconceivable that there are visual/visual conflicts wherein the focal and ambient are not in accord in the same way that vestibular/vestibular conflicts (where the canals and the otoliths purportedly are in conflict) have been speculated to be a problem in space flight and in rotating centrifuges (cf. Guedry, 1968).

In a review paper by Stenger, Zimmerlin, Thomas, and Bronstein (1981), the authors comment that most CIG systems do not produce a strong impression of self-motion. One wonders whether the CIG displays have a high concentration of high spatial frequency/high contrast imagery which forces the focal visual system to conflict with the ambient visual system. This conflict may be less imposing with model board displays which may not set off so much apposition between these two visual systems in wide FOV displays. The conflict between these two visual systems, if it occurs, while it may not produce vomiting and nausea, may challenge the adaptive characteristics of the subject's nervous system and the extra energy expended in "writing new software" may produce drowsiness. It would also be interesting to determine whether a spectral analysis of visual information is different for model board and CIG displays.

The prismatic adaptation which can occur during scotopic and photopic stimulus conditions (Graybiel and Held, 1970) implies that the ambient visual system and the focal system can both adapt to prismatic rearrangement. It follows that it would be possible for the ambient and the focal systems to be in conflict with each other. Held (1970) has pointed out that while wearing prisms the ambient functions such as eye-head coordination adapt readily, but distortions of perceived shape persist. It is conceivable that motion sickness-like symptoms in the form of neurovegetative discomfort are associated with disruption of the ambient system; while other forms of simulator distress (distortions of depth of field, perceived shape) may be due to perturbations in focal system functioning. It is attractive to hypothesize that the former may occur with wide field-of-view systems and the latter to CIG systems, but this notion may be too speculative for the data.

Leibowitz and Post (1982) have stated "Metamorphosis resulting from 'buckling' of the retina produces an irregular distortion of the retinal image which usually cannot be compensated optically" (viz., Duke-Elder, 1966). Because the

distortion of perceived shapes shows little adaptation, it is very disruptive to the patient when in central vision. "Treatment" involves blurring the distorted image (p. 349). Under circumstances where distortion of focal inputs may be a cause of discomfort, blurring may be a useful remedy. This should be explored.

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APPENDIX A

READINGS ON SIMULATOR SICKNESS

(Copies of reprints available upon request.)

RELATIONSHIP BETWEEN PERCEPTUAL STYLE AND SIMULATOR SICKNESS

GERALD V. BARRETT AND CARL L. THORNTON

Goodyear Aerospace Corporation, Akron, Ohio

Simulator sickness was hypothesized to be caused by the conflict between the visual presentation of apparent motion and the lack of any corresponding body sensation of motion. The hypothesis was tested by correlating individual differences in scores on the Rod and Frame Test (RFT; which measures accuracy of adjustment of a rod to true vertical under conditions of visual-kinesthetic conflict) and degree of simulator sickness. The data for Series 3 of the RFT and the indexes of sickness were best represented by hyperbolic functions yielding correlations of .40-.52. Implications for simulation technology and for a general conflict of cue theory are discussed with emphasis on supporting evidence from several areas of investigation.

Since World War II, simulators have been developed which give the visual illusion of motion without any actual physical motion. Unfortunately, certain Ss became ill while operating these devices. The illness phenomenon was first intensively studied by Miller and Goodson (1958, 1960), who labeled it motion sickness because the symptoms resembled those experienced by some people in moving vehicles. There was, however, no reason to prematurely so label this phenomenon motion sickness since motion is not involved in fixed-base simulators. As Tyler and Bard (1949) have pointed out, the primary cause of motion sickness is probably motion, and the failure to appreciate this fact can lead to confusion in conceptualization. In this paper the term "simulator sickness," rather than motion sickness, will be used to denote the symptoms which occur in fixed-base simulators incorporating a moving visual scene.

A number of hypotheses have been informally advanced to explain simulator sickness: distortion of vertical objects, rapid change in brightness, too much detail, poor resolution, excessive lag between simulator controls and corresponding shift in visual display, high-frequency vibrations which disrupt accommodation, distance between the visual display and the observer such that accommodation is different from that usually experienced, and conflict between the apparent motion seen on the visual display and lack of any corresponding motion of the simulator.

This last hypothesis was investigated in the present study.

Several other conflict situations have been found to produce sickness. Wood (1895) described an amusement park device with a large immobile swing inside a movable room. When the room moved many individuals experienced considerable discomfort. Crampton and Young (1953) induced nausea in Ss seated in a fixed chair in the center of a rotating room. Discomfort lasted for some time after the experience, for one S up to 2 days. This wide range of sickness time (from 0 to 48 hr.) is noteworthy, since all Ss were subjected to the same experience.

While conflict between visual and body cues may be the dominant cause of simulator sickness, other factors such as type of simulator, fidelity of simulation, S's experience, and S's involvement are also important. Fixed-base simulators may have two types of visual displays: outside-in (O-I), such as a child's remote control car, or inside-out (I-O), in which the operator views the scene as he would from inside a real vehicle. While sickness has been quite common with an I-O display, none has been reported for O-I simulators. Low involvement resulting from being unable to put oneself psychologically into the vehicle is probably the reason that O-I displays do not cause sickness. A comparison of I-O and O-I displays (Matheny, Dougherty, & Willis, 1963) revealed that performance improved with an I-O display (but not O-I) when motion cues were added. Since the op-

erator "expects" motion in an I-O situation, cue conflict which leads to sickness and/or decrement in performance can occur when such expected motion is not present.

Concerning S's experience, Miller and Goodson (1958) found that 60% of the experienced helicopter pilots but only 12% of the student pilots tested reported simulator sickness. There was probably no cue conflict for the student pilots since they had not learned the particular body inputs which occur during helicopter operation. Fitts (1951) suggested that visual control was important when an individual first learns a perceptual-motor task, and proprioceptive feedback or "feel" becomes more important as experience increases. Fleishman and Rich (1963), for example, using predictors of a perceptual-motor task, found that a visual test correlated significantly with the task in early but not later trials. Conversely, a kinesthetic test correlated on the later but not the early trials. This indicates that initially visual cues guide performance, but with experience individuals sensitive to proprioceptive cues can become most proficient.

The importance of body cues was also demonstrated by a factor analysis of 12 driving tests (Herbert, 1963). One of the main factors was labeled proprioception because of the high loading of a nonvisual driving task. Experience with the necessary proprioceptive feedback, then, appears to be necessary before cue conflict can result.

Fidelity of simulation would be the degree to which the simulated conditions approach conditions of the real world. If the simulator were of low fidelity no conflict or sickness would result since Ss cannot become involved in the very unrealistic task.

The Ss will also not become involved in the task if they have a "play set." Their behavior will not be pertinent to good driving performance with, for example, an attempt to crash the simulated vehicle. Low involvement yields no conflicting cues and therefore no simulator sickness. This conclusion is consistent with the finding that people do not become ill in amusement park simulators even though all the other necessary conditions may be present.

Recently Barrett and Nelson (1965d, 1966b) evaluated an automobile simulator which had all the aforementioned parameters: high fidelity, I-O display, and experienced and involved Ss. They found symptoms which were quite similar to those reported in previous simulator research, including cold sweating, upset stomach, vertigo, dizziness, nausea, feeling of faintness and disorientation. About half of the Ss became too ill to continue after only 5-10 min. Two Ss became so ill as to regurgitate.

A research program was initiated to test the cue conflict and conflict sensitivity hypothesis, as measured with a Rod and Frame Test (RFT) apparatus following the field-dependence conceptualization of Witkin, Lewis, Hertzman, Machover, Meissner, and Wapner (1954). Field-independent Ss were deemed more sensitive to body cues than field-dependent Ss. On this basis it was predicted that the field-independent Ss would experience more discomfort in the simulated situation than field-dependent Ss.

METHOD

Automobile Simulator

An unprogrammed automobile simulator was the basic research tool. A terrain model, an 87:1 (HO gauge) scale representation of several flat roads, supplied the visual scene. Mounted above the terrain model was a television camera with motions in direct response to the movements of the brake, accelerator, and steering wheel of the automobile. Thus, S had complete control over the part of the terrain model that the camera traversed.

A projected image visual display was used with half of the Ss and a virtual image display with the remainder. Both visual displays gave the driver approximately a 50° horizontal angle view of the terrain model and a center resolution of approximately 500 lines. There was no significant difference between the displays in the percentage who left the simulator because of discomfort. Therefore, the two displays were considered to be functionally equivalent. With each visual display the driver sat in the automobile and performed the usual control movements associated with driving a car. A more detailed description of the simulator and associated visual displays has been reported by Barrett and Nelson (1965c, 1966a).

Perceptual style was measured with a standard RFT (Witkin et al., 1954). The apparatus consisted of a luminous frame (40 in. sq) pivoted at its center so that it could be tilted left or right. Pivoted at the same center, but moving independently of

TABLE 1
RELATIONSHIP BETWEEN PERCEPTUAL
STYLE AND DISCOMFORT

Measure of discomfort	Rod and frame measures			
	1/S ₁	1/S ₂	1/S ₃	1/OI
Discomfort	.14	.13	.40*	.23
Illness after	.22	.31	.52**	.44*
No. trials	-.22	-.11	-.45**	-.25
Stayed left	-.18	-.14	-.47**	-.26

Note.—S₁ = Series 1; S₂ = Series 2; S₃ = Series 3; OI = Orientation Index.

* $p < .01$.
** $p < .001$.

the frame, was a luminous rod (39 in.). The *S* was seated 8 ft. from the rod and frame in a chair which could be placed in three positions: erect, tilted 28° to the left, or tilted 28° to the right. Testing was done in a completely darkened room and *S* wore goggles with dark lenses so that he could see only the rod and frame.

Subjects

A random sample of 50 male *Ss* between the ages of 30 and 45 were selected from approximately 1,200 employees in an engineering division of an aerospace corporation. Approximately 6 mo. after the completion of the simulator evaluation, 46 *Ss* (23 from each display) were able to be recontacted and tested with the RFT.

Procedure for Automobile Simulator Investigation

Each *S* drove three orientation trials around the terrain model followed by a pretrial run for a study of driving at requested speed. After making the tenth and final speed judgment, *S* was exposed to an emergency situation where he had to stop for a suddenly emerging pedestrian dummy. The procedures have been described in greater detail by Barrett and Nelson (1965a, 1966b). During the evaluation of the simulator, *S* was observed by the experimenter. If *S* complained of discomfort he was told that he was free to leave at any time.

RFT Procedure

Approximately 6 mo. after the data emergency behavior study, the perceptual style of *Ss* was measured following the standard procedure (Witkin et al., 1954). Series 1 (S₁) of the RFT consisted of eight trials in which *S* and the frame were tilted 28° in the same direction; Series 2 (S₂) were eight trials in which *S* and frame were tilted 28° in opposite directions; Series 3 (S₃) consisted of eight trials with the frame tilted 28° to the right or left while *S* remained upright. The *S*'s task was to position the rod to what he considered to be true vertical by asking

the experimenter to move the top of the rod right or left. The *S*'s score was the number of degrees in error in each series. In addition, an Orientation Index (OI) was computed from the standard scores of the three series.

RESULTS

Four measures of discomfort were compared to RFT scores. The first measure was *S*'s rating of discomfort, using a 0-10 graphic rating scale. The scale was part of a 10-item questionnaire concerning the simulator which was administered 6 mo. after the simulator study. A second questionnaire measure was *S*'s estimate of the length of time after leaving the simulator that the discomfort persisted—termed "illness after." Responses to this question ranged from zero illness to 48 hr. Third, the number of trials *S* was able to remain in the simulator was used as an index of discomfort. The range was from 1/4 trial to completion (14 trials). Fourth, *Ss* were divided into two categories: those who completed all trials and those who did not. Twenty-three of 46 *Ss* were able to complete the simulator study.

Linearity was approximated by reciprocal transformations of the perceptual style measures. Correlations are shown in Table 1 where it can be seen that the only consistently significant relationships were between S₂ and the four measures of sickness.

Table 2 shows an apparent threshold phenomena. The *Ss* were classified according to an adult standardization sample for S₃ (Witkin et al., 1954) with those who were either 1 standard deviation above or below the mean labeled extreme field dependent or extreme

TABLE 2
RELATIONSHIP BETWEEN LEAVING SIMULATOR AND
PERCEPTUAL STYLE CLASSIFICATION
ON SERIES 3

Subject	Extreme field independent	Field independent	Field dependent	Extreme field dependent
Left simulator (N = 23)	12	6	2	3
Remained in simulator (N = 23)		21		2

field independent. All the extremely field-independent Ss left the simulator.

In order to determine if other aspects of the RFT test would significantly add to the relationship, multiple-regression equations were calculated using x , x^2 , $1/x$, in x -data transformations of S_1 , S_2 , S_3 , and OI . No measures were found to add significantly to the variance accounted for by S_3 .

Mention should be made of the possible reason for S_3 being the only measure which was related to simulator discomfort. Witkin et al. (1954) statistically analyzed 10 perception subtests and found three general groupings. S_3 was not in the same grouping of perception tests as were S_1 and S_2 , indicating that the RFT taps at least two perceptual factors and that only one of them was related to simulator sickness.

DISCUSSION

If the conflict of cue hypothesis is correct, an obvious remedy to the simulator sickness problem is to introduce a certain degree of physical motion into the simulated system. An interesting question is the degree of motion required to give the necessary body cues. Simple random vibration may be enough to eliminate the cue conflict, a possibility having considerable practical and economic import for the simulation art.

Besides the specific cue conflict when motion is lacking, the results may have implications for motion sickness research, in which case motion is present with inappropriate or missing visual cues. This is supported by the finding that those who experience motion sickness were also likely to experience sickness in a conflict situation (Crampton & Young, 1953). It has been reported (Clark, 1963) that some pilots become disoriented while flying in extreme haziness or cloud covering. They may be receiving adequate motion cues but not the corresponding visual inputs. In much the same manner, while flying under instrument conditions (again motion but no vision), some pilots become disoriented and mistrust their instruments.

Simulation of zero gravity in aircraft produced illness for 50-70% of the Ss tested by Loftus (1963). It is possible that cue conflict experienced in this unusual situation in-

duced the illness. The finding that labyrinthine-defective Ss (fewer body cues) showed no signs of zero gravity sickness, while 64% of the normal Ss did, supports this hypothesis (Kellogg, Kennedy, & Graybiel, 1964).

Wendt (1951) concluded that the vestibular apparatus per se causes motion sickness since people with no vestibular sensitivity do not become sick. An alternate conclusion might be that, since labyrinthine-cue-related body sensitivity is low for deaf people, it is less likely that they will experience any conflict in cues.

It is possible that both cue conflict and vestibular stimulation are important, but under different conditions. Walsh (1962) oscillated Ss in the horizontal plane. At 1 cps the Ss correctly felt they were traveling in a given direction. When the oscillations were 1/3 cps or slower, the sensations of moving were in anticipation of the motion, there being a phase advance. Sensations of motion in one direction were frequently aroused when the person was still traveling rapidly in the opposite direction, thus conflict. It is possible that motion sickness may have different causes depending upon the rate of motion. At slow rates the conflict of cues may apply; with greater accelerative forces the associated symptoms might be due to excessive stimulation of the vestibular mechanism.

The fact that pilots and drivers rarely become sick and passengers often do (Tyler & Bard, 1949) can be explained by the conflict of cue hypotheses. Since the driver receives direct feedback from the vehicular controls, it is understandable that he does not experience conflict, while the passenger has no such referent and may become ill.

The question remains as to why certain field-dependent people became ill in the simulator situation. Other variables such as the physical condition of Ss may have had some influence. Another explanation can be found from early perceptual style research. Witkin et al. (1954) stated that some Ss experienced great difficulty in making a judgment on the Body Adjustment Test. They appeared to be influenced by the visual scene but also aware of body position. Being unable to consistently utilize body position, their responses were quite variable. They eventually become dis-

oriented, with some experiencing physical discomfort akin to simulator sickness. The field-dependent Ss who function in this manner may also experience simulator sickness. To probe this possibility the 10 most-field-dependent Ss were compared as to variability of responses. Of the five sick Ss, four were extremely variable (range = 20°) and four of the five nonsick Ss were very consistent in their responses (range = 5°). While the results were suggestive, a large subsample would be required for statistical confirmation.

Although cue sensitivity in terms of perceptual style appears to explain the extreme discomfort that some people experience, Witkin, Dyk, Faterston, Goodenough, and Karp (1962) recently discussed perceptual style in terms of being able to extract an item from an embedded context. The results of the study could be explained in these terms also. In a simple laboratory study of kinesthetic sensitivity where cues are isolated there may be no differences between field-dependent and field-independent Ss. However, in the complex simulator (an embedding context) the field-independent person may be more aware of the cues which are in conflict (i.e., can disembed them), and thus he becomes ill.

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PERCEPTUAL VERTIGO: A DIMENSIONAL STUDY

ROBERT C. BENFARI

U. S. Naval Training Device Center, Port Washington, New York

Summary.—Nine Ss were used in an experiment to determine the effects of peripheral flicker and the degree of structure of the stimulus field upon the incidence and degree of vertigo. The groups of Ss were defined as: (a) Susceptible, (b) Non-susceptible, and (c) a highly-trained Aviator group. Visual presentation of the stimuli was accomplished by means of a hemispherical scene and a wide-angle lens system. Ss' verbal responses were recorded and analyzed. The groups responded with a greater degree of vertiginous response to the stimuli of peripheral flicker in a field of low structure.

Previous research in the area of motion sickness has centered around the search for the environmental and physical conditions that gave rise to this functional disorder. Some of the older theories of motion sickness or vertigo have stated that the causes for the symptoms were related to two factors, (a) overstimulation of the nervous system and (b) the interaction of conflicting stimulation of different receptors in the organism (Miller & Goodson, 1958). In addition to these two theories, recently there have been explanations in terms of perceptual activity, such as the analysis and integration of sensory inputs from the stimulus field (Steele, 1961). In a number of incidents, such as in distorted lens experiments, observations in cinerama presentation and in experiments with rotary visual field (Crampton, 1955), there have been reports of motion sickness. The role of vision or perception, as an independent factor in motion sickness, was corroborated.

It was the intent of the present research to: (a) demonstrate that visual stimuli can affect the incidence of motion sickness and (b) isolate the particular stimulus dimensions that were effective in producing the phenomenon. In the past it has been shown that a rotating cylinder, total field flicker, and reversal lens can produce the effect (Vogel, 1931). The present design attempted to use stimulus variables that corresponded very closely to Gibson's concept of the visual world (Gibson, 1950), i.e., structured stimuli such as objects in a real world (motion picture presentation of a vehicle which moved in various perceptual contexts). By carefully constructing and analyzing the film sequences, dimensions were varied so as to permit systematic analysis of certain independent variables such as flicker, figure-ground differentiation (contrast of the field), and velocity.

Research using physiological measurements of blood sugar level, respiration, blood pressure, CSR, EEG and central retinal artery pressure have yielded low correlations with the presence of symptoms. For this reason, introspective re-

ports by *Ss* were used as the measure of the degree and incidence of motion sickness or vertigo.

METHOD

The apparatus included a 35-mm. Ashcraft Century Projection Unit, fitted with a wide-angle lens, a 165° cine dome projection screen, and selected movie footage. The cine dome was an approximate hemisphere, 22 ft. in diameter. It was constructed of fiberglass and plaster, with the inner or reflecting surface painted white. Fig. 1 depicts the shape of the cine dome and the position of *S* during the experiment.

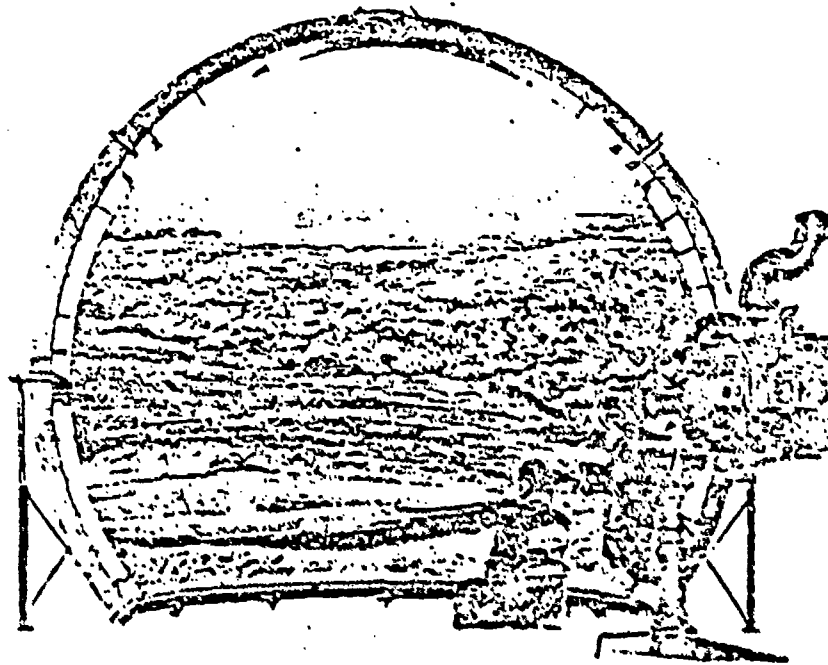


FIG. 1. Photograph of experimental situation

The film run consisted of 2,000 ft. of 35-mm. tape. Subject matter ranged from scenes viewed when: (a) driven along a densely-wooded road at high and low speeds, rated as a poorly-structured field with peripheral flicker; (b) driven in and out of traffic at dusk (abrupt stops and turns), rated as a poorly-structured field with no flicker; (c) driven over a bridge with enclosed girder work, rated as a highly-structured field with peripheral flicker; and (d) driven

TABLE 1
ORDER OF PRESENTATION AND LENGTH OF TIME OF STIMULUS
DIMENSION ON FILM STRIP

Stimulus Dimension and Order	Time (sec.)
1 Poor Structure—No Flicker	160
2 High Structure—No Flicker	170
3 Poor Structure—Flicker	165
4 High Structure—Flicker	170
Total Time	665

over a wide-open expanse, rated as a highly-structured field with no flicker. The order of presentation and the length of exposure are shown in Table 1.

A poorly-structured field was defined as: (a) having a figure-ground contrast ratio of less than 2:1, (b) having poorly-articulated objects in the field, (c) lacking a definite frame-of-reference such as an horizon or vertical border, and (d) having a relatively homogeneous textural gradient.

The four sequences were classified with these criteria in mind. Peripheral flicker was determined as present or absent in the sequences according to the following criteria: (a) light flickering at 5 to 15 cps and (b) 60° from center of vision at either side of the visual field.

Subjects

Ss volunteered from a larger group and were classified according to their own ratings of susceptibility to motion sickness. Ages ranged from 22 to 37 yr. Three Ss were rated as extremely susceptible, 3 were reported as not affected, and 3 other Ss were pilots stationed on the Base. The above sampling appeared to cover the entire subjective range of motion sickness susceptibility.

Procedure

S was placed within the radius of the cine dome so that the screen subtended his entire range of vision. The instructions were that S was to report any sensation, such as: (a) motion perceived in the field, (b) kinesthetic or vestibular sensations of movement, (c) bodily sensations such as sweating, temperature changes, stomach cramps, eye pressure, muscular tension, spatial disorientation, or dizziness. To each S it was emphasized that all sensations were to be reported as the moment of incidence. A time-line report of the verbal responses was kept, and the film was marked to determine the stimulus or content that corresponded to the report. The 9 protocols were checked for similarity of stimuli and responses. The first analysis involved Ss considered as three subgroups (Susceptible, Non-susceptible, and Aviator Groups). The second analysis involved the pooled responses.

RESULTS

The reactions to the film varied from extreme motion sickness to adaptive reactions. Although the individual behavioral reports differed, all Ss reacted to the various stimuli depicted on the film. The time-line description of Ss' verbal report, and the time-line graph of the film's content, demonstrated that there were points of consistent communality in Ss' reactions. The common elements were reactions to changes in peripheral flicker in fields of high and low structure.

Susceptibility Ratings

The individual reactions were examined according to prior susceptibility of Ss to motion sickness. When this was done, it was apparent that the susceptible Ss had the most extreme reactions in that 2 of the 3 Ss could not continue testing after 9 min. of the film due to extreme dizziness and nausea. The third S continued, but suffered a mild spell of dizziness, profuse sweating, and blood pressure disturbances.

The 3 non-susceptible Ss reported mild initial reactions of dizziness, sweating, and flushing, but in time they adapted to the film's stimuli. These non-susceptible Ss continued viewing the film for the full length of the presentation.

In the aviator group there were no reports of dizziness or adverse physiological reactions, however, they did experience the most vivid kinesthetic sensations of the 3 groups. It almost appeared as if they were experiencing actual vestibular stimulation. The responses of the aviator group were characterized by a large number of compensatory body movements. They perceived themselves as moving in a stable environment, while on the other hand, the susceptible group perceived that the external environment moved. This group described the screen as whirling about them.

Characteristics of Pooled Responses

Most reactions were related to specific stimulus content on the film. Vertiginous behavior was most common when there was a combination of poorly-

TABLE 2

NUMBER OF VERBAL RESPONSES* TO FOUR STIMULUS DIMENSIONS	
Stimulus Dimension	n
Poor Structure—No Flicker	26
High Structure—No Flicker	27
Poor Structure—Flicker	33
High Structure—Flicker	21
Total Responses	107

$\chi^2 = 2.71, n.s.$

*A response was any verbal reaction to the film, such as perceived motion, physiological reactions and dizziness. The total represented all the responses given by the 9 Ss.

perception. It is in these situations that one loses equilibrium" (Gibson, 1950).

In the present experiment there was a compelling illusion of confinement by the boundaries of the visual field. Since the frame-of-reference was the boundaries of the cine dome, no other reference could be used to separate *S* from the visual field. *Ss* who stood outside the boundaries of the cine dome were not affected as strongly by the vertigo inducing stimuli. It seemed as if they were able to stand aside from the visual field and integrate the sensations into stable perceptions. The same integrative functioning was found in the non-susceptible and the aviator groups. The susceptible *Ss* appeared unable to separate the visual sensations and the visual world. A non-adaptive perception resulted (the environment was seen as moving and *S* passively experienced this).

Two response patterns were generated by the stimulus conditions. *S* experienced the illusion that he was moving in a stable field; motion, in that sense, was translated to *S* and vivid kinesthetic sensations resulted. This appeared to be a congruent perception. In the second instance, the visual world or field was perceived as moving. This perception seemed to involve a literal translation of the motion picture stimuli. This became an unstable field which appeared to be related to the stimulus correlates of nystagmus brought about after rapid spinning about. *S* now translated the environment as revolving around him.

In the former condition, the perceiver was an active participant in the translation of the sensory messages and a stable perception resulted. In the latter condition, it almost appeared that the visual field dominated and *S* was a passive recipient of the inputs. The result was poor integration of the stimulus inputs. Vertiginous behavior depended upon the nature of the stimulus field and on some degree of individual differences (Woolworth, 1955).

The individual differences are not discussed further since no personality or other *S* variables were measured.

In summary, it appeared that the responsible stimulus was the varying degree of differentiation of the field (ambiguous figure-ground) which led to domination of the stimulus field by such sensations as peripheral flicker and apparent movement. At the same time, the lack of differentiation of the field led to a loss of a definite frame-of-reference. In this instance, integrative processing of the stimulus inputs was more difficult. The flicker and velocity of objects in the field were misinterpreted as moving.

The question arose as to whether the susceptible *Ss* experienced nystagmus (induced by the motion on the screen) or whether the vertigo was produced on a higher level rather than just retinal nystagmus. Investigations with electro-ocular recordings could clarify this contention.

The present data suggest that perceptual vertigo could be due to individual

structured field and peripheral flicker. Velocity and motion in combination with a highly-structured field did not induce vertigo. Velocity with flicker in a poorly-structured field did induce vertigo.

Data in Table 2 demonstrate that the gross measures of number of verbal responses to the 4 stimulus segments of the film were not significantly different from each other. Although there were no quantitative differences in the total number of responses to the different content on the film, there were differences in the number of vertiginous responses. Table 3 shows that there were significant differences between stimulus segments when vertiginous responses were measured.

TABLE 3
NUMBER OF VERTIGINOUS RESPONSES* TO FOUR STIMULUS DIMENSIONS

Stimulus Dimension	n
Poor Structure—No Flicker	2
High Structure—No Flicker	2
Poor Structure—Flicker	18
High Structure—Flicker	4
Total	26

$\chi^2 = 27.18, p < .001.$

*Vertiginous responses were verbal reports of dizziness, disorientation or any adverse physiological reaction. The total represented only the vertiginous responses in the larger response pool of Table 2.

It seemed to be apparent that most vertiginous responses occurred in a viewing of a poorly-structured field in combination with peripheral flicker. It also seemed that flicker or poor structure by itself had no apparent effect. Since the order of presentation was randomly assigned, the effects of this variable could not be evaluated. It seems that vertiginous behavior was the cumulative result of several factors and the order of presentation should have some effect in inducing the phenomenon.

DISCUSSION

The data appeared to support the contention that there were individual differences in the processing of perceptual data. The vertigo conditions showed clearly that certain stimuli were necessary for inducing perceptual motion sickness. Although discrete variables were apparently operating, the combination in a given perceptual context and the subsequent processing of these data led to the experience of varying degrees of vertiginous behavior.

The complexity of the visual field was an important determiner of the dominance of visual factors. In a well-structured field, motion and flicker could be integrated; whereas, in a field with poor differentiation "the visual world and the visual field cannot be distinguished from one another, and some illusory frame-of-reference—a non-gravitational vertical—may then dominate

differences relative to: (a) physiological dispositions, (b) personality variables associated with field dependence-independence (Witkin, *et al.*, 1954), (c) stimulus conditions of figure-ground definition, and (d) peripheral flicker.

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The Effects of Various Design Alternatives on Moving-Base Driving Simulator Discomfort

JOHN G CASALI and WALTER W. WIERWILLE¹, Virginia Polytechnic Institute and State University

The effects of three independent variables on eight measures of driving simulator discomfort were investigated using a high-fidelity, moving-base driving simulator. The between-subjects simulator variables were: (1) simulation of lateral acceleration (LAT)—by lateral translation (standard method) versus by angular rotation; (2) presence or absence of delay in the visual and motion systems (DEL)—nondelayed (normal) versus delayed; and (3) simulator platform (CAB)—open (normal) versus enclosed.

Sixty-four subjects were divided into eight groups, each group having equally distributed scores on a test of field independence-dependence. Each group was then assigned to one of the eight simulator conditions.

After subjects drove the simulator, a multivariate analysis of variance was performed on the data and resulted in significance for each main effect and the LAT \times DEL interaction. Subsequent analyses demonstrated that dependent measures of pallor, skin resistance, respiration rate, yaw deviation, and steering reversals were each reliably sensitive to at least one of the simulator independent variables. It is concluded that future simulator designs should avoid: rotation of the platform to simulate translation, delay in the system dynamics, and complete enclosure of subjects.

INTRODUCTION

One of the most serious yet least publicized shortcomings associated with the use of vehicular simulators, especially driving simulators, is a recurring malady termed "simulator sickness." Residual symptoms including disorientation, increased perspiration, altered heart and respiration rate, dizziness, pallor, and even nausea and vomiting have been exhibited by subject drivers in both fixed and moving-base simulators (Barrett and Nelson, 1965; Barrett and Nelson, 1966; Barrett and Thornton, 1968b; Breda, Kirkpatrick, and Shaffer, 1972; Jex and

Ringland, 1973; and Testa, 1969). Unfortunately, little definitive research has been done to determine either the symptomatology or the etiology of the sickness problem.

One particularly important study concerning the prediction and evaluation of fixed-base driving simulator sickness was reported by Testa (1969). The research did not directly address simulator design influences on sickness, but did demonstrate that both physiological measures and self-report measures were needed to identify a state of simulator sickness. Testa concluded that further research was required "to verify that results from fixed-base simulators can be applied to dynamic [moving-base] situations" (Testa, 1969).

¹ Requests for reprints should be sent to Dr. Walter W. Wierwille or John G. Casali, Vehicle Simulation Laboratory, IEOR Department, VPI&SU, Blacksburg, VA 24061.

There are many potentially useful applications of driving simulators in training, selection, performance assessment, research, and system design. It is important, therefore, to determine the causes of simulator sickness and eliminate them in the design stage, if possible. As Leonard and Wierwille (1975) have pointed out, a nausea-inducing simulator cannot be relied upon to yield accurate and valid human response data. The occurrence of sickness serves as an inappropriate extraneous variable, confounding the simulator data.

While symptoms attributable to "simulator sickness" appear at least superficially akin to those of "motion sickness," the two terms should not be used synonymously. In the case of fixed-base driving simulators, many of which have a history of subject nausea, no translational or rotational movement of the subject is present, suggesting that illness may be induced by factors other than motion. Also, it is doubtful that motion is solely responsible for nausea in moving-base simulators, considering the large number of simulator-produced stimuli that a subject experiences. As noted by Barrett and Nelson (1965), the precipitating causes of sickness may be specific for each individual simulator.

This study was conducted to determine causes of simulator sickness in moving-base driving simulators. There appear to have been no previous studies aimed directly at this objective. It would be impossible to examine in a single study all of the potential causes of simulator sickness. Therefore, selecting the independent variables for an initial study required some degree of judgment. Published studies utilizing moving-base simulators were examined for statements concerning uneasiness and nausea. Also, several researchers who had driven various driving simulators were interviewed regarding the degree of uneasiness they had experienced. Based on all available information,

characteristics common to those simulators that had a history of inducing nausea were determined. Among moving-base simulators, three characteristics that appeared as potential contributors to simulator sickness were: (1) the manner in which translational motion was achieved; (2) the presence of any lag or delay in the simulator response variables; and (3) the use of enclosing devices about the subject. Less prominent causes included lack of display collimation, display distortion, overabundance of detail in the display, large lateral field-of-view, and discrepancies between visual and physical motion cues (other than delay, as mentioned above). In this study, the three major potential contributors were examined as independent variables. However, the remaining, less prominent causes are also worthy of future investigation.

SIMULATOR (INDEPENDENT) VARIABLES

Rotational Simulation of Translation Versus True Translation

The extent to which motion cues are accurately modeled directly affects the fidelity of a driving simulator. The importance of motion cues in driving simulator research has been demonstrated in earlier investigations (McLane and Wierwille, 1975).

With each degree of freedom of movement added, the cost of the simulation increases considerably. Also, the number of motions included and their associated excursion distances are often restricted by space limitations of the simulator laboratory. Because of economic and space constraints, certain compromises have appeared in the motion bases of several driving simulators. The most prominent compromise is associated with the method of simulating lateral and longitudinal translation. The platform of a simulator must travel considerable distances if lateral and longitudinal accelerations are sustained for any period of time, using the "standard"

method for simulating these motions. This standard method is to translate the driver platform forward and backward for longitudinal translation and side-to-side for lateral translation. Several simulator designers have chosen to delete translational simulation of lateral and longitudinal motions and have instead adopted the approach of using roll and pitch motion to approximate translation. By rotating the subject in the roll axis, the lateral acceleration forces of cornering and lane changing are simulated. Similarly, by rotating the subject in the pitch axis, longitudinal acceleration and braking forces are simulated. In both cases, the subject supposedly experiences the sensation of lateral or longitudinal acceleration.

If the technique of simulating translational acceleration by rotation is indeed a contributing factor to the incidence of simulator sickness, its influence may be explained in terms of a cue conflict theory. While angular rotation does produce a lateral or longitudinal component of acceleration to a seated subject, cue conflict may arise when the subject senses the rotational aspect of the motion, which is in this case an artifact. In other words, the possibility exists that the subject actually perceives the motion as rotational, when the motion the subject expects is translational.

Delayed Versus Nondelayed Dynamics

In a vehicle simulation that is closed loop, the vehicle dynamics equations must be solved on line and in real time. The outputs of these equations provide the necessary signals to drive the displays and instruments. A problem associated with some driving simulators is that they introduce computational or response lags in addition to the normal vehicle dynamic responses. In these simulators the subject experiences delayed scene updating, delayed physical motion cues, or both.

The lag may be the result of any of the following: (1) a lack of computational speed, such as that due to serial processing in the computer that solves the vehicle dynamics equations; (2) a delay in the response of servo systems used in the image generation process, such as those used to control the movement of a video camera over a terrain board, and (3) a delay in the response of the hydraulic, mechanical, or electrical equipment used to move the platform (or the instruments) physically.

Regardless of their form, time lags in the cues presented to the subject cause two problems. First, an apparent delay between the simulator's manual controls and driver feedback cues may cause the simulator to be difficult to handle. Inappropriate control-to-feedback delay places the additional burden on the subject of anticipating the vehicle's response and introducing lead compensation. Also, the delay is apt to contribute to subject discomfort. When delay occurs and is perceived by the subject, a cue disparity exists between actual feedback cues and expected feedback cues.

Enclosed Versus Open Platform

A third characteristic common to several simulators known to induce uneasiness is the presence of a box-type cab over the driver's platform. Usually windowless, these cabs enclose the subject by four walls and a roof, with the display serving as the front wall. The only light inside the cab is that emitted by the roadway scene. Interestingly, a lower incidence of illness has generally been reported with automobile body-cabbed and unenclosed simulators than in box-cabbed simulators.

The explanations for the potential influence of enclosure on uneasiness are at best speculative but will be offered here. First, the simple knowledge of being enclosed within a box-shaped structure may be initially dis-

comforting to a subject, prebiasing his or her expectations. Furthermore, certain individuals may experience claustrophobic reaction to enclosure. Finally, the lack of any peripheral reference points other than the visual display, which appears to be suspended in dark space inside the cab, may be disorienting to the subject. Unenclosed and automobile body-cabbed simulators (with windows) do not have the last problem, since room reference cues may be discernible, even in a dark room.

METHOD

Experimental Design

A three-factor, totally randomized, factorially complete design was applied in this research. The independent variables, having two levels each, consisted of the following:

- (1) Simulation of lateral acceleration (LAT)
 - a. by true translation (standard method)
 - b. by angular (roll) rotation
- (2) Presence or absence of delay in simulator visual and physical feedback dynamics (DEL)
 - a. nondelayed (normal method)
 - b. delayed
- (3) Simulator platform (CAB)
 - a. open (normal method)
 - b. enclosed

With this design, each subject was exposed to only one of the eight ($2 \times 2 \times 2$) experimental conditions (a unique combination of one level of each of the three factors). This design was chosen to eliminate the possibility of differential transfer effects which might confound the assessment of simulator sickness.

Eight dependent measures were used to identify the state of driving simulator discomfort. These included physiological, performance, and self-report measures, each of which will be described in the apparatus section.

Subjects

Sixty-four subjects were used in the experiment, eight in each of the eight experi-

mental conditions. Subjects ranged in age from 18 to 36 yr, had a minimum of 2 yr driving experience, and had no previous experience with any driving simulator. Subjects were paid for their participation. All subjects were requested to abstain from drugs and stimulants and to obtain at least 8 h sleep the night before each experimental session.

Perceptual Style Test

Several earlier studies have indicated that the incidence of driving simulator sickness is related to subjects' perceptual style as located on a field independence-dependence continuum (Barrett and Thornton, 1968b; Barrett, Thornton, and Cabe, 1969; and Testa, 1969). In general, these studies have suggested that field-independent subjects are more susceptible to simulator sickness than field-dependent subjects. Unlike the present study, prior research concerning the driving simulator sickness-perceptual style relationship was performed on fixed-base simulators.

In the current study, the Hidden Figures Test (HFT) was employed as a measure of field independence-dependence, for the single purpose of systematically assigning subjects to experimental conditions (Ekstrom, French, Harman, and Derman, 1976).

Apparatus

The driving simulator. The fundamental apparatus used in this experiment was the highway driving simulator located in the Human Factors Laboratory at Virginia Polytechnic Institute and State University (VPI&SU). The simulator is a research tool, providing the subject with the illusion of highway driving, including realistic vehicle handling via a 4-degree-of-freedom physical motion system (roll, yaw, lateral translation, and longitudinal translation) coordinated with a dynamic visual scene. The driver-simulator interface constitutes an interactive closed-loop system in which steering wheel,

accelerator, and brake pedal movements provide input signals to the simulator dynamics, which, in turn, produce appropriate feedback for the driving subject. A complete description of the simulator is provided in Wierwille (1975).

Among the simulator's capabilities is the ability to introduce driving disturbances, such as random gusts of wind and road curvature. These disturbances, often encountered in everyday driving, were used in the driving task for the present study. A random noise generator, interfaced with the dynamics computer, was used to simulate randomly occurring crosswind gusts of a continuous 9-min duration. These gusts, having a root mean square lateral velocity of 8 mi/h (12.9 km/h), were believed to be typical of wind experienced while driving down an open highway on a breezy day. Also, a 3-min predetermined sequence of curves simulating a superhighway winding through moderately hilly terrain was presented to each subject. Programming and actuation of the curvature was performed on the hybrid computer.

Driving simulator modifications. The VPI&SU driving simulator was adaptable to the current investigation of driving simulator sickness for two reasons: (1) *in its normal operating configuration, the simulator has never induced observable illness in any of over 800 driving subjects*, thereby enabling the researchers to "degrade" the subsystems of the simulator in an effort to expose specific determinants of sickness, and (2) the rapidly responding motion base of the simulator, coupled with the analog/hybrid computer-controlled dynamics, allowed the simulation of alternative motion techniques and delays in addition to the normal vehicle dynamics characteristic of problematic simulations.

Replacement of normal translational simulation of lateral acceleration by angular rotation of the subject in the roll axis was performed by modifying the programming of

the lateral-directional dynamics. A switch was used to change the method of simulating lateral acceleration between experimental runs.

In experimental conditions specifying angular-rotational simulation of lateral acceleration, a 35% of full-size cue was used. (The usual roll motion cue was retained in all experimental conditions.) After preliminary testing of various increments of roll angle simulation of lateral acceleration, ranging from full-size cue to 10% of full-size cue, it was decided that the 35% cue was optimum. Considering a naive subject's ability to control the driving simulator without prior experience, it was concluded that rotational excursions exceeding 35% of full size were overly violent, both from a controllability standpoint and for reliable data collection.

Briefly, the side force on a subject when rotated during roll is

$$F = W \sin \theta$$

where W is the subject's weight and θ is the roll angle in radians. The side force on a subject for true lateral translation is

$$F = \frac{W a}{g}$$

where a is the lateral acceleration of the subject and g is the acceleration due to gravity. Using the small angle approximation for $\sin \theta$ and eliminating F above yields

$$\theta = \frac{a}{g}$$

If full angular rotation had been used, the roll angle per m/s^2 of lateral acceleration is 0.102r (5.84 deg). For 35% of full size, the roll angle becomes 0.036r (2.04 deg) per m/s^2 of lateral acceleration.

The second independent variable involved delaying the normal simulator dynamics. In half of the experimental conditions, the normal (nondelayed) dynamics characteristic of

a typical late-model, intermediate size, domestic sedan were used. In the other half of the conditions, the dynamics were delayed. For a given steering wheel input by the subject, both visual display and physical motion feedback systems were simultaneously delayed by 0.30 s over the normal vehicle response.

The 0.30-s duration of delay was selected because it appeared to be representative of the feedback lags inherent in several sickness-inducing simulators. Furthermore, after preliminary investigation of steering input delays of 0.30 s and larger, it was determined that durations of greater than 0.30 s required too much compensating lead on the part of the subject for controlled simulator handling.

The third independent variable involved enclosure of the motion platform. In half of the conditions, the simulator operated in its normal mode, that is, with the subjects unenclosed. In the other half, the subjects were enclosed in a removable, windowless cab which completely enclosed the subjects and eliminated any possibility of visual room reference cues.

The enclosure was fabricated from plywood and painted flat black on the inside and outside. The narrow, box-like cab was designed to resemble the enclosures used on several other simulators, such as the Volkswagen (Linke, Richter, and Schmidt, 1973) and the 1968 General Motors Technical Center (Beinke and Williams, 1968) devices. The cab structure included flow-through ventilation, a sliding door for normal egress, and a pop-off top for emergency egress.

Physiological (dependent) measures. After reviewing the symptomatology of simulator sickness as reported in several papers (e.g., Barrett and Nelson, 1965; Miller and Goodson, 1960; and Testa, 1969), four physiological measures were selected for assessment of subjects' bodily responses to the driving

simulator experience. The measures selected were heart rate, pallor, forehead perspiration, and respiration rate.

Subjects' heart rates were monitored using a plethysmograph attached to the antihelix of the left ear in conjunction with a Hewlett-Packard Patient Monitor, Model 78203C. The analog outputs of the Patient Monitor were fed into the hybrid computer for on-line data processing. A mean heart rate value was computed for each data-taking period.

The individual transducers used for monitoring pallor, respiration rate, and forehead perspiration were designed by laboratory personnel at VPI&SU solely for the current experiment.

A second earpiece module, fitted on the right ear, was used to monitor pallor. This transducer is sensitive to slow changes in opacity of the skin of the ear over time, such as those due to vasoconstriction. The pallor earpiece includes a light source which is thermally isolated from the ear by fiber optics. This avoids heating of the ear by the light source and thereby contaminating the measurement. Since pallor does not occur instantaneously, this transducer is insensitive to the quick opacity changes produced by a single heartbeat. An increase in pallor results in a decrease in skin opacity over a period of time. Such a pallor increase is represented by an increase in voltage output from the photocell receptor located opposite the light source. An amplifier circuit and digital volimeter were used to obtain pallor readings.

Subjects also wore a headband which incorporated two integral surface electrodes used to measure forehead perspiration. Nominal current applied to the electrodes was 15 microamperes using a floating battery-powered circuit. Skin conductance (voltages) was recorded from a digital volimeter and later converted to resistance values for data analysis.

The respiration rate monitor was used to obtain the number of breaths taken by a subject per minute (where one breath consists of one inhalation and one exhalation). A subject was seated in a driving position, and the respiration rate transducer was placed near the bottom of the subject's ribcage. The sensing unit consisted of a flexible metal belt, positioned around the subject's upper abdomen, which supported a transducer located about 1.5 cm in front of the subject. The transducer is sensitive to the expansional and contractional movements of the abdomen during inhalation and exhalation. Basically, the subject's body serves as an antenna. The closer the body moves to the transducer, the more noise the transducer receives. This 60-Hz noise is then conditioned, amplified, and detected as a slowly varying voltage signal output. In the present study, the respiration signal was recorded on a strip chart recorder.

Performance (dependent) measures. Frequently accompanying the physiological symptoms experienced and exhibited by simulator-sick subjects are degraded performance abilities of various forms (Barrett and Thornton, 1968a; and Miller and Goodson, 1960). It was hypothesized for this experiment that the subject's ability to control the driving simulator would decrease as a function of simulator discomfort and, correspondingly, as a result of the degraded conditions of the simulator. The two dependent measures of vehicle controllability affecting driver performance were yaw (standard) deviation and the number of steering wheel reversals per minute.

Vehicle yaw was defined as the horizontal angle between the instantaneous roadway tangent and the simulated longitudinal axis of the vehicle. A continuous yaw position signal was obtained from the simulated vehicle dynamics. The standard deviation of the yaw

angle over the 3-min data-taking period was computed on line by the hybrid computer.

The steering signal was also processed on line using the hybrid computer. Movement of the steering wheel of 2 deg or more, after the time derivative of steering passed through zero, constituted one steering reversal.

In addition to the assessment of performance of vehicle control, it was of interest to investigate the influence of degraded simulator conditions on cognitive processing and the performance of mental tasks. While no studies incorporating the use of a driving simulator have addressed this problem, several research efforts have demonstrated that *motion sickness* is often accompanied by a decreased ability to perform mental tasks, such as arithmetic computations and estimation of elapsed time (Brand, Colquhoun, and Perry, 1968; Clark and Graybiel, 1961; and Graybiel, Kennedy, Knoblock, Guedry, Mertz, McCleod, Colehour, Miller, and Frenly, 1965). For the current study, a simple pre- and post-simulator arithmetic test was used as the mental task measure. Two 4-min tests were used, each having an equal number and type of multiplication and columnar addition problems. The only differences between the before and after simulator tests were the actual numbers used in the problems, which were selected from a random number table. Both tests were scored on the basis of each correct-answer digit for a particular problem.

Self-report (dependent) measure. A post-simulator reactions questionnaire constituted the sole self-report measure used for assessing driving simulator discomfort. The questionnaire was a slight modification of that used by Testa (1969). The symptoms listed on the questionnaire for the current study included: nausea, cold sweating, change in breathing rate, change in salivation, dizziness, drowsiness, headache, eye-strain, and disorientation. Immediately fol-

lowing exposure to the driving simulator, subjects were instructed to indicate the level at which each symptom was experienced. Allowable levels were slight or not noticeable; medium; and extreme.

Procedure

Each subject completed two separate experimental sessions separated by approximately 4 weeks.

Session I. After reading and signing a participant's consent form, the subject performed the first (presimulator) arithmetic test. At the end of 4 min, the subject was instructed to stop working.

Next, instructions for the HFT were presented. The HFT was administered in two parts, with a time limit of 12 min for each part. Following completion of the HFT, the subject was paid for participating in Session I, scheduled for Session II, and dismissed.

Assignment of subjects to experimental conditions. After all 64 subjects had completed Session I, HFT scores (one for each subject) were rank-ordered. This ranking was then separated into quartiles with 16 scores (subjects) to a quartile. Two subjects were randomly drawn from each quartile and assigned to a particular experimental condition. This procedure was continued for all eight conditions of the experiment, resulting in a cross-sectional representation of perceptual styles in each of the eight conditions.

Session II. Upon arrival, the subject was seated in the driver's seat of the simulator. Next, the four physiological receptors were placed on the subject. Subjects were not informed (until after the experiment) as to the precise function of each receptor, in an effort to avoid biases such as a "conscious" breathing rate. The subject was then familiarized with the simulator controls and displays. Next, subjects read an instruction sheet describing the driving task. After answering questions concerning the driving task, the ex-

perimenter instructed the subject to "relax and sit quietly for about five more minutes" and added that the subject would be informed over the intercom system when the practice driving task would commence.

By this time, the subject had been seated in the stationary simulator for at least 12 min. After this stabilization period, physiological baseline data were recorded over a continuous 3-min period. (It should be noted that physiological baseline data were obtained with the enclosure in place, if the experimental condition specified enclosure of the subject.)

Upon completion of the baseline period, the subject was informed that the actual driving task was about to begin. Room lights were turned off, the simulator's systems were activated, and the subject was instructed to bring the vehicle up to a speed of 55 mi/h (88.5 km/h). Upon reaching the desired speed, the subject was told to "steer the vehicle from the right lane into the left and back several times to get the feel of the car's handling during the three minutes of practice driving."

At the end of the initial 3 min of practice driving, the subject was informed that the practice period was over. The subject was then reminded over the intercom to "strive to stay in the right lane and maintain 55 mi/h (88.5 km/h) for the remainder of the driving task." The second 3-min period consisted of the presentation of random crosswind gusts in the straight road condition. After 6 min of driving, these crosswinds were accompanied by 3 min of road curvature. The curvature ceased after 3 more minutes of driving time, and the straight road condition, with random crosswind gusts, was presented to the subject for the final 3 min. During the final 3 min of the simulated driving task, physiological, yaw deviation, and steering reversal data were obtained. It should be noted that the 12-min driving task was designed to be representative, both in type and in duration, of

typical simulator tasks used in other studies of an applied nature.

After data collection, the subject exited the motion platform and was immediately escorted to a desk for testing. First, the subject was given 4 min to work the second (post-simulator) arithmetic test. Next, the subject was allowed as much time as needed in completing the postsimulator reactions questionnaire. After the subject's psychological and physical well-being were established, the subject was debriefed, paid, and allowed to leave.

Data Reduction

Following data collection for all 64 subjects, the raw data were reduced to a form applicable to statistical analysis. A single experimental-versus-baseline difference score was computed for each physiological measure (heart rate, pallor, forehead skin resistance, and respiration rate) for each subject. An arithmetic pretest/posttest difference score was also obtained for each subject. The postsimulator reactions questionnaire, yaw deviation, and steering reversals were each computed as a single score for each subject.

RESULTS

Multivariate Analysis of Variance

The data were first applied to a multivariate analysis of variance (MANOVA) procedure to determine if the group of eight dependent measures was sensitive to changes in the three simulator variables. The Wilk's U criterion values were obtained for each main effect and all two-way and three-way interaction effects. The U -values were then transformed into exact F -ratios, using the standard conversion formulae (Kramer, 1972). The results of the MANOVA are presented in Table 1.

The MANOVA revealed that the eight dependent measures, as a group, were statistically significant for the method of simulating lateral acceleration (LAT), $F(8,49) = 5.13, p =$

TABLE 1

Multivariate Analysis of Variance Summary Table

Source	df	F	p
LAT	1	5.13	0.0001
DEL	1	3.76	0.0017
CAB	1	2.44	0.0265
LAT \times DEL	1	2.24	0.0403
LAT \times CAB	1	1.43	0.2080
DEL \times CAB	1	0.97	0.4733
LAT \times DEL \times CAB	1	0.45	0.8841
Subjects/LAT \times			
DEL \times CAB	56		
Total	63		

0.0001; for the effect of delay in the dynamics (DEL), $F(8,49) = 3.76, p = 0.0017$; and for the simulator cab effect (CAB), $F(8,49) = 2.44, p = 0.0265$. Therefore, statistical significance was obtained for each main effect. However, a two-way interaction effect was also found, indicating that LAT interacted with DEL, $F(8,49) = 2.24, p = 0.0403$. As shown in Table 1, no other interactions were significant ($p > 0.05$).

Individual Analyses of Variance

Subsequent to the MANOVA, a simple between-subjects analysis of variance (ANOVA) was performed on each individual dependent measure. Therefore, eight three-way ANOVAs were executed. For each ANOVA, the sources of variance and degrees-of-freedom were identical to those of the MANOVA as shown in Table 1. The intent of the individual ANOVA procedures was to determine which specific dependent measures were reliably affected by the different levels of the simulator (independent) variables. However, only those independent effects found significant by the MANOVA were included in the subsequent investigations.

Due to the large number of dependent measures and independent variables, it was not possible to include all eight ANOVA tables in this paper. Therefore, Table 2 was compiled

TABLE 2.

Summary of Significant Sources of Variance for Each Dependent Measure

Dependent Measure	Source of Variance	df	MS	F	p
Pallor	LAT x DEL	1	99.5031	6.51	0.0135
	LAT	1	61.5931	4.03	0.0495
Forehead Skin Resistance	CAB	1	895.6104	5.08	0.0281
Heart Rate	(none significant)	—	—	—	—
Respiration Rate	LAT x DEL	1	60.9748	9.74	0.0029
	LAT	1	86.9626	13.89	0.0005
	DEL	1	29.8785	4.77	0.0331
	CAB	1	62.2501	9.95	0.0026
Arithmetic Test Reactions	(none significant)	—	—	—	—
Questionnaire	(none significant)	—	—	—	—
Yaw Deviation	DEL	1	1.4424	25.26	0.0001
Steering Reversals	LAT	1	2085.5206	13.51	0.0005

and is intended to summarize the ANOVA tables in a concise record of significant effects ($p < 0.05$).

As shown in Table 2, the first ANOVA revealed that the method of simulating lateral acceleration had a significant main effect on pallor. The graph of the 95% confidence intervals for both levels of the lateral acceleration variable clearly predicted this result (Figure 1). However, this main effect was restricted by its interactional effect with the delay variable. The ANOVA results demonstrated that the lateral acceleration-by-delay interaction significantly influenced pallor ($p = 0.0135$). A Newman-Keuls post hoc analysis was subsequently performed to determine between which conditions the significant differences existed (Table 3). Because the number of degrees-of-freedom of the ANOVA error term (56) was not included exactly in the available tables for the Studentized Range Statistic (Q), the criterion values were linearly interpolated. The lateral translation-nondelayed feedback dynamics condition (the normal simulator configuration) differed significantly from each of the other three conditions (lateral translation delayed dynamics, angular rotation-nondelayed dynamics, and

angular rotation-delayed dynamics), at $p < 0.05$. All other comparisons were nonsignificant at the 0.05 level. The corresponding confidence intervals for the lateral acceleration-by-delay interaction are presented in Figure 2.

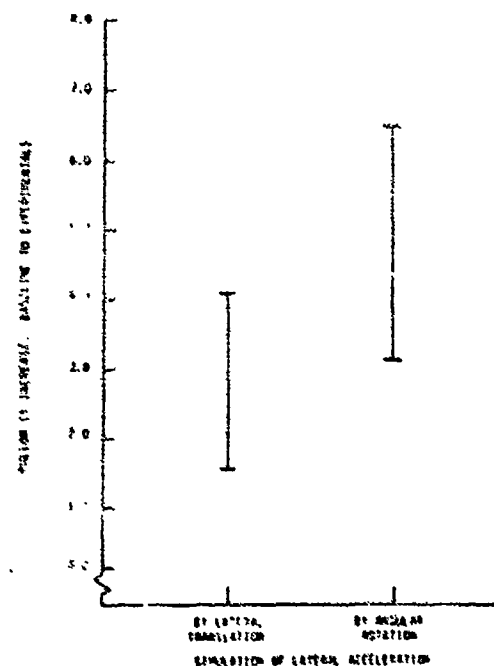


Figure 1. Lateral acceleration simulation effect on pallor (95% confidence limits).

TABLE 3

Results of Newman-Keuls Analysis Using Pallor as the Dependent Measure

Treatment Combination Number	1	4	2	3
Treatment Combination Mean	1.2718	4.0610	4.5928	5.7276

$p < 0.05$
where:

1 corresponds to lateral translation-nondelayed dynamics
2 corresponds to lateral translation-delayed dynamics
3 corresponds to angular rotation-nondelayed dynamics
4 corresponds to angular rotation-delayed dynamics

The second ANOVA, using skin resistance as the dependent measure, revealed that the simulator cab variable had a significant effect on forehead perspiration ($p = 0.0281$). The 95% confidence intervals, graphed in Figure 3, present a visual representation of this effect.

Respiration rate was discovered to be sensitive to all of the main effects, with a par-

ticularly strong effect for the method of simulating lateral acceleration ($p = 0.0005$) and moderately strong effects for simulator cab ($p = 0.0026$) and delay ($p = 0.0331$). These results are shown in the confidence interval differences depicted in Figures 4, 5, and 6. However, the lateral acceleration and delay effects were restricted by the two-way interaction effect. Again, a Newman-Keuls

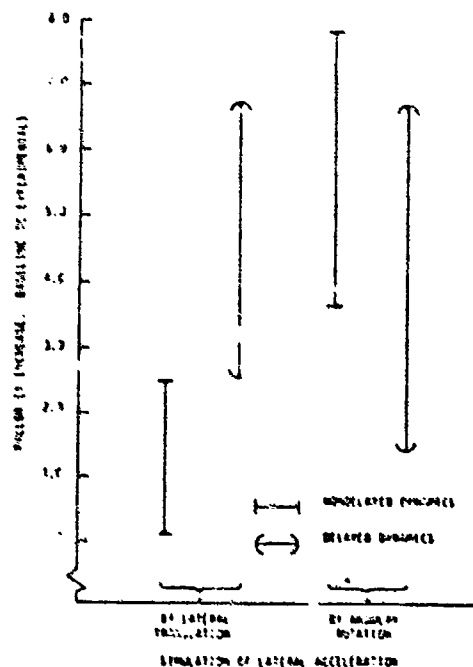


Figure 2. Lateral acceleration-by-delay interaction effect on pallor (95% confidence limits).

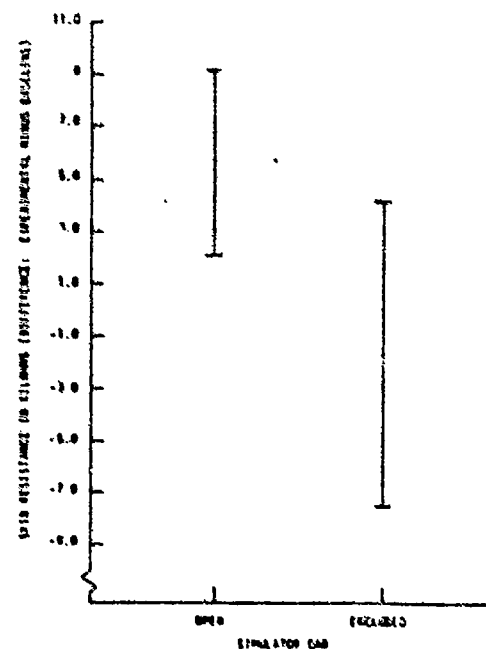


Figure 3. Simulator cab effect on forehead skin resistance (95% confidence limits).

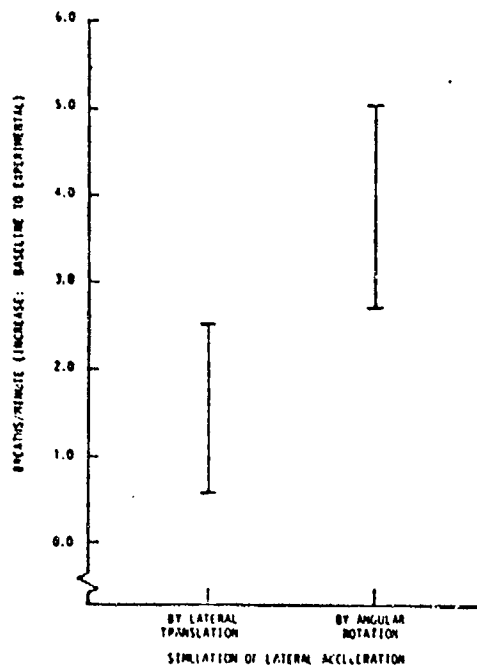


Figure 4. Lateral acceleration simulation effect on respiration rate (95% confidence limits).

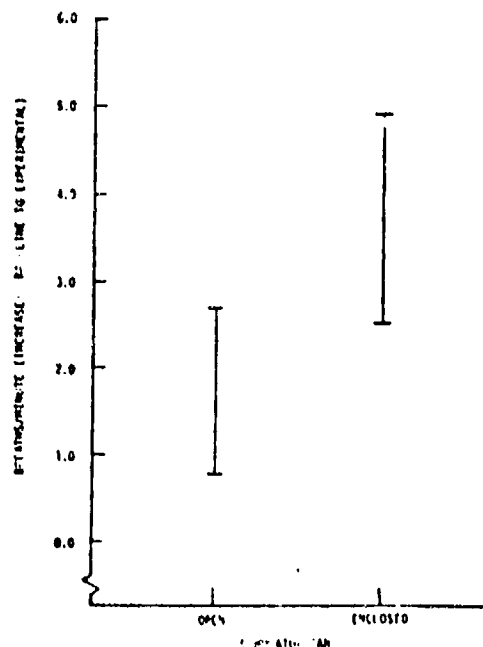


Figure 5. Simulator cab effect on respiration rate (95% confidence limits).

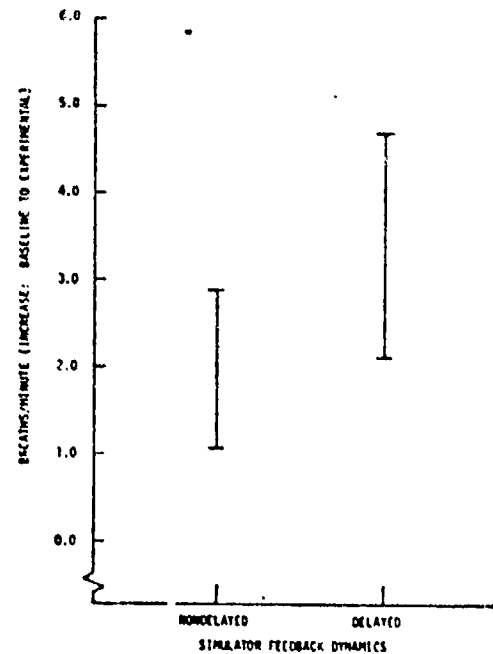


Figure 6. Simulator dynamics delay effect on respiration rate (95% confidence limits).

procedure was performed and the criteria for rejection values were linearly interpolated as before. This analysis revealed that the angular rotation-delayed feedback dynamics condition (the most degraded simulator configuration) was significantly different from each of the other three conditions, ($p < 0.05$) (Table 4). No other comparisons were significant at the 0.05 level. These differences are visible in the 95% confidence intervals shown in Figure 7.

As shown in Table 2, the ANOVA for the performance measure of yaw deviation demonstrated that the presence or absence of delay in the visual and physical feedback dynamics had a strong effect ($p < 0.0001$) on subjects' ability to maintain a steady vehicle heading. Similarly, the ANOVA for the steering reversals performance measure revealed that the number of steering reversals was reliably different ($p < 0.0005$) for the two methods of simulating lateral acceleration (by

TABLE 4

Results of Newman-Keuls Analysis Using Respiration Rate as the Dependent Measure

Treatment Combination Number	2	1	3	4
Treatment Combination Mean	1.2633	1.8489	2.2281	5.5468

 $p < 0.05$

where:

- 1 corresponds to lateral translation-nondelayed dynamics
- 2 corresponds to lateral translation-delayed dynamics
- 3 corresponds to angular rotation-nondelayed dynamics
- 4 corresponds to angular rotation-delayed dynamics

translation or by angular rotation). Again, these differences are graphically depicted by the confidence intervals in Figures 8 and 9.

The ANOVA procedures found that three of the eight dependent measures were not individually sensitive to changes in any of the variables of interest or their interactions. No significant differences (within the MANOVA domain of significance) were obtained for the heart rate, the arithmetic test, and the post-simulator reactions questionnaire measure (Table 2).

CONCLUSIONS

Conclusions Concerning the Simulator (Independent) Variables

As previously discussed, the three-way MANOVA revealed that, as a group, the eight dependent measures were highly sensitive to changes in the three simulator variables.

In particular, the baseline to experimental increase in pallor was significantly greater

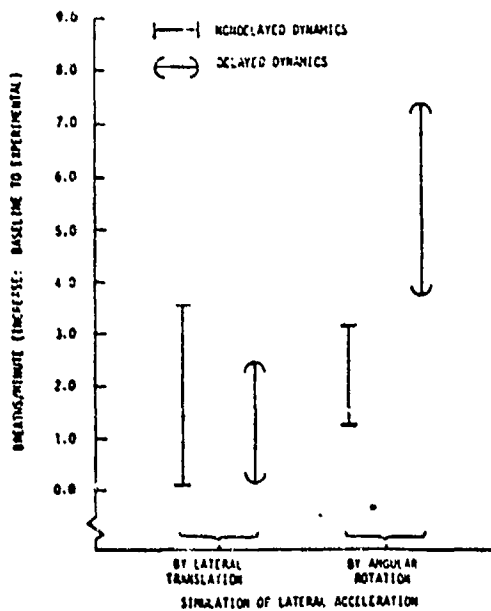


Figure 7. Lateral acceleration-by-delay interaction effect on respiration rate (95% confidence limits).

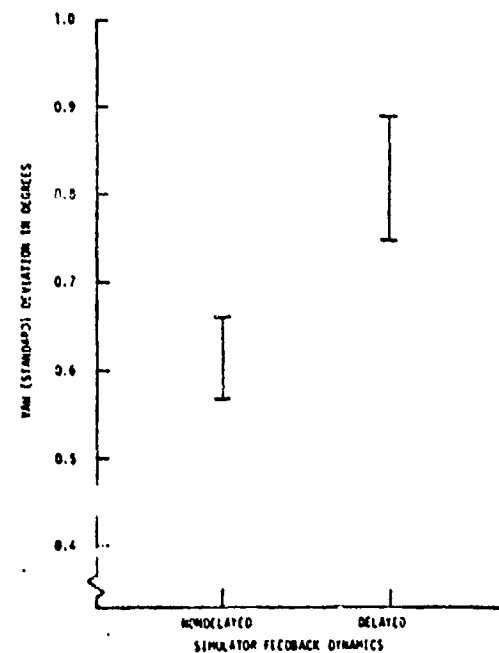


Figure 8. Simulator dynamics delay effect on yaw deviation (95% confidence limits).

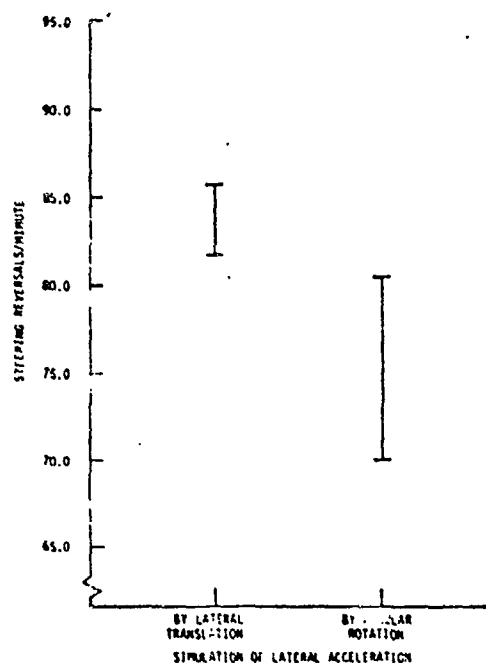


Figure 9. Lateral acceleration simulation effect on steering reversals (95% confidence limits).

for the simulation of lateral acceleration by angular rotation than for the normal method of lateral translation. However, the interaction of the lateral acceleration with the delay variable restricted the interpretation of the main effect of lateral acceleration. Whenever computational delay was introduced, regardless of the method of simulating lateral acceleration, the baseline to experimental change in pallor increased significantly from the normal lateral translation-nondelayed dynamic condition. Therefore, the normal simulator configuration produced the lowest level of pallor.

The amount of increase in subjects' respiration rates from baseline measurement to experimental measurement was demonstrated to be a very sensitive measure of discomforting simulator effects. The significance obtained for all three main effects suggests that subjects tend to heighten their breathing rate when experiencing any degraded simulator

conditions. Also, within the significant lateral acceleration-by-delay interaction effect, the combination of angular rotation with delayed dynamics (the most degraded configuration) was responsible for the largest increase in respiration rate.

In addition to significantly increasing respiration rate, the presence of the enclosure over the subject was responsible for an increase in forehead perspiration in comparison to the open cab conditions. Enclosed subjects reliably exhibited a decrease in skin resistance from baseline to experimental data-recording periods. This corresponded to increased perspiration. No subjects in the open cab conditions demonstrated a decrease in forehead resistance. It is unlikely that the increased perspiration was due to increased temperature or humidity inside the enclosure, as adequate flow-through ventilation was incorporated into the cab design.

The yaw deviation performance measure clearly indicated that delayed feedback dynamics adversely affected vehicle controllability. Significantly lower yaw deviation values for the conditions containing normal vehicle dynamics were obtained in comparison to the yaw deviation values of conditions incorporating delayed dynamics.

The method of simulating lateral acceleration showed a significant main effect for the number of steering reversals. However, the results are surprising at first glance. The number of steering reversals is generally thought to increase as a function of driving task difficulty, which is in turn influenced by a number of factors, such as vehicle handling qualities. Following this logic, it appears that the simulation of lateral acceleration by angular rotation would be associated with a greater number of steering reversals than the normal lateral translation method. As shown in the confidence interval graphs of Figure 9, the opposite effect was found to be true. One possible explanation for the lower number of

steering reversals in response to angular rotation is that due to the "oversize" roll cue. Subjects may quickly learn to refrain from making quick steering reversals which cause the simulator to move in successive rotational excursions. Continued rotational excursions, of the magnitude used in simulating a lateral acceleration cue, may be unpleasant to a subject. Therefore, during the early segment of the driving task, the subject may learn to make fewer steering corrections, thereby lessening the number of large rolling motions.

General Recommendations

On the basis of the data reported herein, it is clear that all three of the alternate (degraded) simulator conditions should be avoided, or at least given careful consideration before inclusion in a driving simulator design. The technique of simulating lateral acceleration by roll-axis rotation, the presence of delay in the visual and motion dynamics, and the practice of enclosing the subject all produced mild discomforting effects in subjects.

It is evident that any reduction in cost or space saved by simulating translational movements with rotational motions may be outweighed by the disadvantages of the rotational method. The use of angular rotation was accompanied by increases in subjects' skin pallor and breathing rates over the normal method of lateral translation. This finding suggests that angular rotational simulation of lateral acceleration may at least contribute to the onset of driving simulator uneasiness in subjects.

The presence of simulated computational delay in addition to the normal vehicle response was found to induce mild subject uneasiness, as well as reduce vehicle controllability. On the subject's part, this was evidenced by the effects of delayed dynamics on respiration rate and the interactional effect of

delayed dynamics with angular rotation on pallor. Also, the presence of delay showed an associated significant increase in yaw deviation over the normal simulator dynamics. This finding suggests that delayed feedback of the effect of steering control inputs causes the subject to have to compensate in order to control the vehicle's direction. The constant attentional demand placed on the subject by the increased work load may heighten the overall stress level. At any rate, the negative effects of delay, such as those due to camera servo lag or to the serial processing time of some computers, are compelling and demonstrate that they should be avoided in simulator design.

Finally, the forehead skin resistance and respiration rate measures clearly indicate that enclosing the subject in a box-like cab has a disquieting influence. As the graphs show, the presence of the enclosure over the driving simulator was sufficient to cause increased forehead perspiration and respiration rate.

In the present study, the overall lack of overt driving simulator sickness, such as nausea or vomiting, is in part borne out by the lack of significance obtained on the reactions questionnaire. The questionnaire had been demonstrated to be a sensitive and reliable measure of driving simulator sickness in other research (Testa, 1969). However, Testa also reported (experimenter) observable symptoms of sickness, such as nausea and profuse perspiration, in addition to the subjective reports of sickness on the questionnaire.

Two explanations for the lack of sensitivity of the questionnaire in the current study are as follows. First, the actual construction of the questionnaire may be partly responsible for the results obtained. The first column under "level experienced" on the questionnaire is indicative of "slight or not noticeable" symptoms of simulator sickness. Re-

sponses in this column are in agreement with the overall absence of acute symptoms of driving simulator sickness in the present study. Furthermore, in an effort to hide information concerning physical feelings, so as to not appear "inadequate" or for other reasons, subjects may have checked the "slight or not noticeable" column frequently.

As previously discussed, other driving simulator research has been plagued with the occurrence of acute sickness symptoms while not directly addressing the problem. This experiment purposely used attenuated roll motion and limited duration of delay. It is distinctly possible that had full-size roll-simulation of lateral acceleration and longer computational delays been used, acute symptoms might have resulted.

ACKNOWLEDGMENTS

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WEEKLY SUMMARY



NO. 38-82 (19-25 SEPTEMBER 1982)

OF AIRCRAFT MISHAPS

Simulator Sickness

F-14 and F-4 pilots are experiencing a phenomenon identified as Reverse Sensory Conflict (RSC) by aviation physiologists and Naval Aerospace Medical Research personnel. This physiological phenomenon is experienced after a session in the 2E6 2F112 simulator, hence the popular name for RSC has become "simulator sickness."

"Navy and Air Force aircrews have reported symptoms such as nausea, dizziness, headaches, and disoriented feelings while operating training Device 2E6, Air Combat Maneuvering Simulator (ACMS). Reports of both delayed reactions and persistence of symptoms after leaving the trainer have raised concern over possible impact on flight safety and negative training" (NAVTRAEQUIPCEN 80-C-0135-4500-1, Feb 1981).

This phenomenon has been with us for some time, and articles have been written on portions of its effects on aircrewmembers being trained in wide angle visual systems. The more familiar articles deal with "motion sickness" symptoms and "spatial disorientation."

"Although the phenomenon has been known for 3 years, identifying the reasons for simulator sickness is a difficult task. The causes are complex and, most probably, interrelated. While precise reasons are not fully understood, research efforts are establishing a base which may someday provide the design specifications or procedures necessary to mitigate or eliminate the problem."

Aircrewmembers become accustomed to experiencing some pretty peculiar physical sensations in conjunction with associated visual observations while riding out rapid rolls, reversals, or other relatively violent or sudden maneuvers. G-forces and the like are a fact of life for the professional aviator — comes with the territory.

The forces felt are stored in the brain's data bank, along with visions associated with those unusual sensations. When the brain digests the picture that the eyes see, your preconditioning lets the brain tell your body to get ready to experience some hairy sensations . . . only it doesn't happen. You are conditioned to forces that the simulator cannot duplicate. Since the brain is accustomed to experiencing both the visual and vestibular sensations simultaneously, when one is experienced without the other, strong conflicting internal sensory cues are felt and result in RSC symptoms . . . simulator sickness.

"The 2E6 ACMS consists of two fixed-base, tandem crew cockpits, each surrounded by a

40-foot dome which approximates a 360-degree field of view. Visual scenes are created by projecting aircraft, missile and earth sky scenes onto the domes. The device is designed to provide close-in air combat maneuvering training.

"The cockpits in the domes are mockups of the F-4J and F-14A aircraft and are interchangeable. Spatial orientation is provided by computerized control of the sky-earth projector. There is no provision to simulate visual altitude cues or relative direction and velocity progression over the terrain."

Simulator sickness works best against experienced pilots. This is because the more hours you have in the air, the more conditioned to associated visual and vestibular sensory perception your body becomes. So, relatively older pilots will probably incur more unpleasant experiences from the 2E6 ACMS than their younger contemporaries.

COMFITA EWINGPAC Notice 3750 addresses this problem and seeks to limit the dangers of RSC by setting up minimums of required ground time between bouts with the simulator and actual flights. 3750 orders that "no one shall be scheduled to fly within 12 hours of the first exposure to the F-14 flight simulator" and cautions aircrews to "ensure this readjustment period includes a good night's rest. For subsequent flights, a 2-hour interval will be observed from exiting the simulator until actual aircraft flight. Aircrews in this category are expected to use good judgment in determining their own ability to perform, based on previous experience (the first exposure when 12 hours was observed, or any unusual reactions thereafter)."

COMFITA EWINGPAC Notice 3750 also directs that the device be started and stopped in a wings-level, nose-on-horizon attitude, with the visual portion secured and the white dome lights turned on before the aircrew emerges from the trainer. Aircrews are to wear, at least, minimum flight gear, torso harness, and G-suit.

COMFITWING ONE Instruction 1542.11) also addresses this problem and sets maximum time exposure to the simulator.

The 2E7 ACMS will soon be introduced for

Prepared by U.S. Naval Safety Center
RADM T. C. Steele, Commander

Command Feature Writer/Editor
Mr. J. H. Casto

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use by the F-18 communities. This is significant because the Marine Corps F-4 and Navy A-7 communities have not been exposed to the wide-angle ACM-type simulator. With the advent of gearing up for the F-18 on the part of both communities, we'll see a surge of simulator training in the new 2F7 by aircrews with no previous exposure to simulator sickness. Adherence to the directives quoted in this article can minimize adverse physiological phenomenon. A further step that reduces the incidence of simulator sickness is to complete each maneuver and avoid the reset function available on newer simulators. For instance, avoid resetting from bolter to 1½-mile ball call. Adherence to the suggestions herein contained can successfully minimize all of the following.

- Disorientation
- Dizziness
- Headache
- Pallor
- Stomach awareness
- Loss of appetite
- Nausea
- Emesis
- Fatigue
- Laxitude
- Yawning
- Burping
- Confusion
- Spinning sensation
- Extreme unsteadiness
- Motor dyskinesia
- Flashbacks
- Visual Dysfunction

For an in-depth review of the incidence of simulator sickness, read Technical Report NAVTRAEQUIPCEN 80-C-0135-4500-1, titled "Simulator Sickness Occurrences in the 2E6 Air Combat Maneuvering Simulator (ACMS) by authors James McGuinness, J. H. Bowman, and Jim Forbes of Person-System Integration, Ltd., Alexandria, VA.

Casto, J. H.
Simulator Sickness.
Weekly Summary of
Aircraft Mishaps,
19-25 September
1982, 38-82, 1.

WHICH WAY

...OR SAACING THE DIZZIES

"He's coming. . . 2 o'clock low, John, I'm engaged. . . you're free. . ."

"I'm bingo plus two, Sam, I'm separating. . ."

"OK, John, I'm high in his six--I've got him wired!"

This scenario could have taken place in many USAF squadrons, but today we're in the Simulator for Air-to-Air Combat (SAAC) at Luke AFB.

"FREEZE--hold it right there guys. See where you are, Sam. You'll overshoot him, and he'll wind up right in your six. Now if you had yo-yo'd then, you'd be in good shape to drive him out of the fight and separate with your wingman. . ."

"Now let's reinitiate and try it again. . ."

There's another side to the successful story of SAAC. . . you might hear it like this at the bar. . .

"It's a super trainer, but wait till your bed does a 3-turn spin in the middle of the night. . ."

"Does that SAAC ever make me sweat. . . I've never worked so hard. . ."

Sounds pretty stimulating for a simulator, but just this sort of response has been taking place in the SAAC. Recent investigations by the AF Human Resources Laboratory have turned up some interesting psychophysiologic reactions on the part of F-4 pilots while flying simulated dog fights in the SAAC. Some pilots have been experiencing orientation disturbances which have been labeled "simulator sickness" for lack of a better term. (No, this doesn't mean you can get out of a simulator mission just 'cause you're

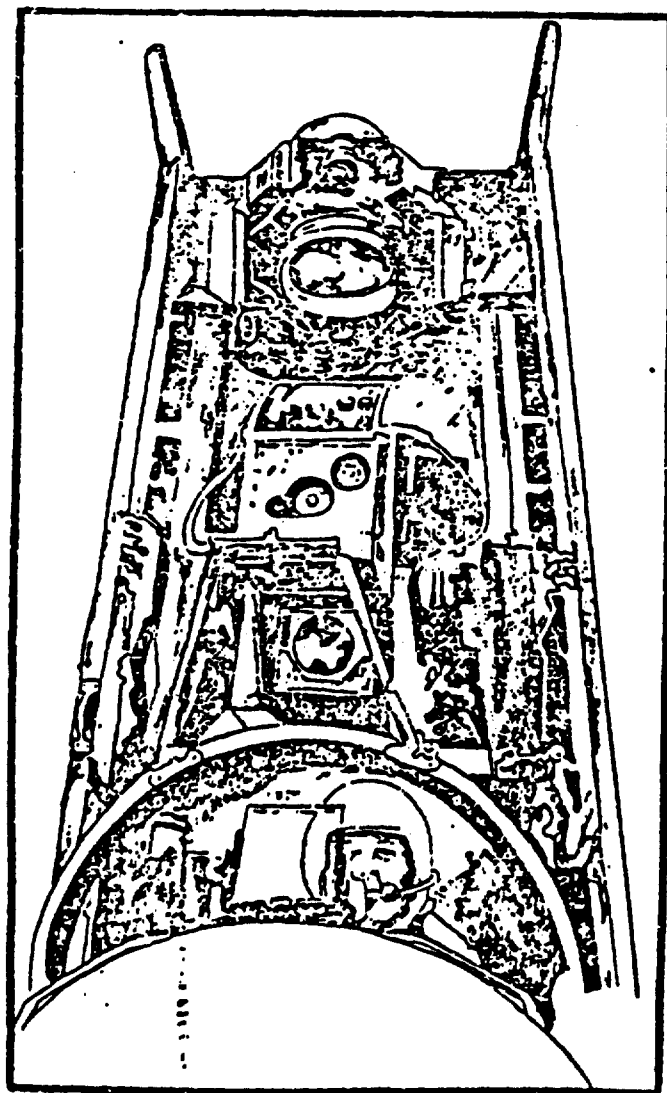
sick of it.) "Sim sickness" is not strictly motion sickness which many people have experienced. Rather, it is caused by internal imbalances which arise when the body compares what's happening to it in the SAAC to past experiences in the aircraft.

During your flying career you have become accustomed to certain physical sensations occurring in conjunction with certain visual sensations. Rapid rolls, reversals, loading the airplane with G, unloading, etc. have accompanying visual pictures which are part of your brain's data bank. You have become conditioned to a force environment which isn't there in the simulator. One sense (visual) indicates changing attitudes in space while another (vestibular) indicates no change in body position. Since you have become accustomed to having both sensory systems react to the change simultaneously, when they don't occur together or one happens alone, strong conflicting internal sensory cues are produced which result in the symptoms of "sim sickness." Wide field-of-view simulators can present most of the visual cues arising from motion without any physical motion present. This addition of a motion platform to the simulator doesn't appear to reduce this sensory conflict either. The stresses of rapid rolling maneuvers and sustained high-G loading cannot be provided. A motion system simply cannot mimic the physical strains created on the F-4 pilot in

IS UP IS?

By Robert E. Coward
Robert S. Kellogg
Carl H. Castore
AFHRL/OTO
Luke AFB AZ

Continued



actual flight--no neck strain--no mask pull--no upper body compression--no sustained G.

But what are these symptoms anyway? Well, they can be as mild as a slight disorientation or as severe as physical reactions including nausea and vomiting. Between these two extremes are symptoms such as profuse sweating, vertigo, dizziness, unusual fatigue, and feeling totally washed out. Some pilots have reported disrupted sleep and short sessions of dizziness.

The most common place where these symptoms are experienced is in the SAAC cockpit while you're flying. Now don't get the impression that everyone who steps into the SAAC gets his gyros tumbled. Far from it. Most people experience mild disorientation during the initial flight, but that usually passes rather quickly. A few individuals have reported a "replay" of certain visual sequences from SAAC missions. These "replays" may occur during any period of light mental activity--later that day while working over a paper or just relaxing in the BOQ. A few other interesting perceptual disturbances have also been reported. One pilot was watching TV and experienced all the physical sensations of a climbing turn and had the impression that the TV was now suspended from the ceiling. Another pilot reported that while lying down his visual field temporarily became inverted 180 degrees until he sat upright! (J. D. Black or Green Label will do that to me)

Which Way Is Up?



Coward, Kellogg & Costello
are this month's
Fleagle T-shirt winners

every time. Ed) One of the most frequently reported sensations is that of imbalance similar to that experienced after a long boat or train ride. Many people who have been on a boat all day still occasionally experience the rocking sensation of the waves several hours later. Reactions from the SAAC are basically the same as these, but perhaps a bit more vivid.

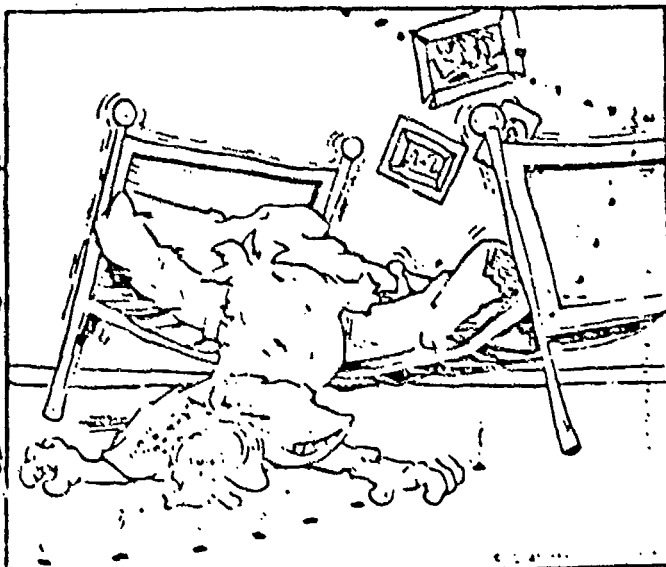
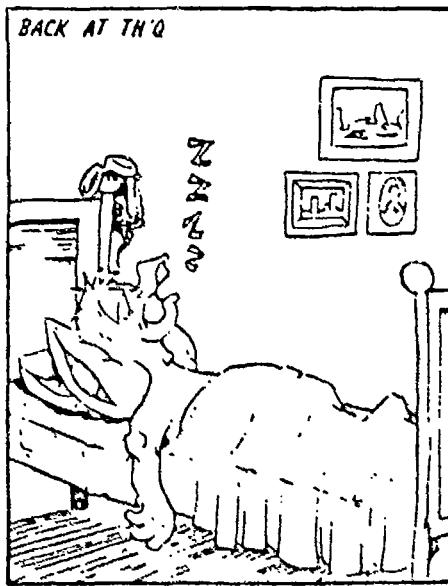
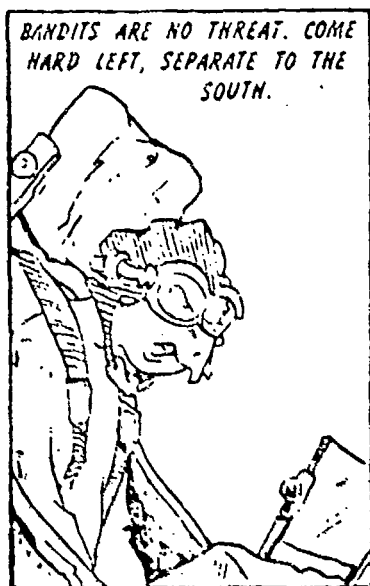
Some concern has been expressed by pilots, "... if I report these kind of things, I'll be grounded" or "... fighter pilots don't have these problems." These kinds of physical reactions can be expected and are normal reactions to an initial experience in a wide field-of-view simulator! These symptoms do not occur in all aircrews and tend to disappear due to adaptation with repeated experience in simulators like the SAAC.

Full mission simulators with wide field-of-view capabilities will play an increasing role in the development of new tactics and the enhancement of force readiness. The F-4 pilots who have flown the SAAC are enthusiastic about its value as a combat trainer. However, the users of such simulators and future simulators with these capabilities should be aware that some adjustment may be required by pilots when stepping back into the real world from the computer-generated world to "SAAC" the dizzies. An awareness of the nature and possible extent of the symptoms of "sim sickness" can help the pilot deal with such symptoms when and if they arise. The consensus of TAC pilots who have participated in the SAAC training program is that the temporary discomfort brought on by these symptoms is a small price to pay for the kind of combat training afforded by the SAAC.

Additional information can be obtained from the Tactical Research Branch at this address:
➔ AFHRL/OTO Luke AFB AZ 85309.



FLEAGLE



Crampton, G. H., & Young, F. A. The differential effect of a rotary visual field on susceptibles and nonsusceptibles to motion sickness. *Journal of Comparative and Physiological Psychology*, 1953, 46(6), 451-453.

THE DIFFERENTIAL EFFECT OF A ROTARY VISUAL FIELD ON SUSCEPTIBLES AND NONSUSCEPTIBLES TO MOTION SICKNESS¹

GEORGE H. CRAMPTON² AND FRANCIS A. YOUNG

State College of Washington

Most studies reporting symptoms of motion sickness resulting from various visual stimuli indicate that angular displacement of the visual field is the most effective stimulus.

This displacement of the visual field has usually been accomplished in two ways. It may be an entire room which either oscillates about a horizontal axis from which the *S* is suspended in a swing (7, 9), or tips right and left about a horizontal axis with a stationary *S* (8). A second method is to have *S* fixed and to rotate around him a cylinder, the inside of which is painted with vertical stripes (2, 3, 6). These conditions impart an apparent motion of the body, and some *Ss* experience nausea. Those stimuli which revolve about a vertical axis result in optokinetic nystagmus, to which Vogel (6) related the occurrence of nausea and dizziness at a critical frequency of 12 rpm. At this particular frequency, with his apparatus, he recorded the most regular nystagmus. At higher and lower frequencies, he found either irregular or no nystagmus and none of the motion sickness symptoms.

There is some doubt as to whether a vigorous horizontal optokinetic nystagmus is a necessary condition for the development of motion sickness symptoms, though, perhaps, visual attention and probably some attempt at fixation are required. Such a nystagmus was not present in the situation described by Wood (9), wherein the visual field did not rotate but merely oscillated about a horizontal axis which was lateral to *S*. In Witkin's situation (8), nystagmus was also not a factor. Here, relatively slow tipping movements of the room about a horizontal axis medial to the stationary *S* brought about nausea. Interestingly enough, the nausea was alleviated by the introduction

of simultaneous movement of the *S* and the room.

Apparently, mere optokinetic nystagmus and apparent body movement are not sufficient to arouse nausea. Lebensohn (5) could not inhibit gastric activity with just the small surface of a kymograph drum, though apparent motion and nystagmus were present. Colley (3), however, utilizing a cylinder rotating about the whole body, found inhibition of contractions and an atonic condition of the stomach by roentgenological examination. His description of the alteration in gastric activity coincides with Hatcher's (4) as to the sequence of events at the commencement of nausea and vomiting. It is apparent that an adequate visual stimulus for nausea requires a relatively large, moving visual area.

In most such experiments it was customary to find that only a few *Ss* became nauseated. The purpose of this investigation was to determine if these individual differences in susceptibility to nausea induced by visual stimulation could be related to individual differences in susceptibility to motion sickness.

METHOD

Subjects

The motion sickness questionnaire utilized and validated by the Wesleyan studies (1) was used as a basis for the selection of *Ss*. Seven women and 9 men were chosen for the susceptible group (scores 24 and below), and 5 women and 14 men for the nonsusceptible group (a score of 38). All *Ss* were students attending the summer session.

Apparatus

A room 8 ft. square with 70 in. high walls of fiber board and a ceiling of stretched burlap was constructed. The cream-colored interior was unpainted. The entire room was centered on a revolving horizontal wheel, 42 in. in diameter, driven by a $\frac{1}{4}$ -h.p. motor. A Variac, type 200-CU, manufactured by the General Radio Company, was introduced into the motor circuit to adjust the angular velocity. The velocity could also be varied by means of a lever which changed the

¹ From a thesis submitted to the graduate school of the State College of Washington in partial fulfillment of the requirements for the Degree of Master of Science.

² Now at Army Medical Service Graduate School, Walter Reed Army Medical Center, Washington, D. C.

tension of the belt which drove the base wheel. The angular velocity could thus be varied from zero to 24 rpm. The S's chair was in the exact center of the room, supported by a pipe which extended from the bottom of the chair seat down through the wheel bearing to the wheel base. A second pipe extended from the top of the chair frame up through the ceiling of the revolving room and was anchored to the rafters of the experimental room. The chair was completely independent of the rotating room and remained stationary when the room revolved. It was possible, however, to revolve the chair by hand when standing in the room. For illumination, a 60-w. bulb was placed on the forward edge of the upper framework of the chair.

Procedure

After being seated, the Ss were instructed to keep their eyes open and watch the floor, walls, and ceiling of the room, rather than some part of their body. If they felt they were going to vomit, they were to instruct E to stop. The Ss were not told the chair would revolve, but after they were in the chair, it was spun around once to give the suggestion that they, and not the room, would be spinning. The program of velocities was to accelerate the room during 14 sec. to 24 rpm and maintain a period of constant velocity for 20 sec., and then switch off the current and allow the room to decelerate for 20 sec. to a velocity of 9 rpm. The cycle was immediately repeated and continued for 10 min., or until S requested rotation to stop.

RESULTS AND DISCUSSION

The resulting symptoms were the basis for categorizing Ss:

a. *Nausea*. Those Ss who requested the motion to stop before the 10-min. period was completed, and those Ss who by their own reports indicated they were just able to last out the full 10 min. This group was typified by having to rest before leaving the experimental room, and by their fear of immediate vomiting.

b. *Light nausea*. These Ss lasted out the full 10 min., but upon being questioned afterwards reported "feelings" of nausea. They expressed the belief that they would have vomited if they had been exposed for a longer period of time.

c. *Dizziness*. This group reported dizziness after stimulation, but no nausea.

d. *No nausea and no dizziness*.

The results are presented in Table 1. When questionable, all judgments were made conservatively, that is, in the direction of lesser nausea. Most, though not all, judgments were made without the knowledge of the susceptibility group in which S fell.

Of the four Ss classified in the "nausea" category, three requested that rotation be stopped before the 10-min. period had elapsed. Two men lasted for 2½ and 5½ min., respectively, while one woman requested rotation to stop after 7½ min. No decided sex differences in the occurrence of nausea were noted.

TABLE 1
Incidence of Nausea in Relation to Susceptibility

GROUP	N	NAU-SEA	LIGHT NAU-SEA	DIZZI-NESS	NO NAUSEA
Susceptibles					
Male	9	3	3	2	1
Female	7	1	2	3	1
Both sexes	16	4	5	5	2
Nonsusceptibles					
Male	14	0	0	6	8
Female	5	0	0	1	4
Both sexes	19	0	0	7	12

TABLE 2
Incidence of Nausea in Relation to Perceived Rotation

PERCEIVED ROTATION	NAU-SEA	NO NAUSEA	ALL GROUPS
Positive chair was revolving	1	14	15
Thought chair was revolving	4	9	13
Thought room was revolving	2	3	5
Positive room was revolving	2	0	2
All groups	9	26	35

An inspection of the results reveals very clearly that individuals susceptible to motion sickness are also susceptible to nausea in a rotary visual field, and, conversely, non-susceptibles are resistant. By grouping the data of Table 1 into four cells, using susceptibles and nonsusceptibles as the first and second classifications, symptom categories a and b as the third, and categories c and d as the fourth, a fourfold table results. The null hypothesis that such a distribution of individuals arose by chance is refuted by a probability value of .012 as indicated by chi square computed by the direct method. It may be concluded that some of the individual differences found in previous studies may be related to the Ss' motion sickness susceptibility.

Informal discussion with several of the Ss a few days afterward indicates that the effects

of this particular form of stimulation may last for some time. One of the nonsusceptible men reported only dizziness immediately following stimulation, but after he left the experimental room he began to feel slightly nauseated. This condition lasted for about 2 hr. The Ss were categorized in terms of the reports immediately following rotation, and no changes were made on the basis of any later information. One susceptible man in the "light nausea" category lost his appetite for lunch. A susceptible man in the "nausea" category, who requested rotation to stop after 2½ min., vomited upon reaching home and complained of aftereffects consisting of a severe headache and light nausea for the following two days. These aftereffects were particularly noticeable when he was watching large, moving objects.

The Ss' reports as to whether the room (true motion) or the chair (apparent motion) was actually revolving are of interest. Table 2 presents these data in terms of those Ss who fell into symptom categories *a* and *b* (nausea group), and those Ss who fell into symptom categories *c* and *d* (no-nausea group). Thirty-three Ss were ignorant of the structural features of the equipment and were subjected only to the E's indirect suggestion that the chair would be turning. Two Ss knew the true nature of the equipment; one (a susceptible) was classified as "light nausea," and the other (a nonsusceptible) as "dizziness." Both Ss reported that the chair seemed to be revolving in spite of their previous knowledge to the contrary. In the breakdown in Table 2, these two Ss were arbitrarily placed in the "thought chair was revolving" category.

For those Ss who thought that either the chair or the room could be revolving and were not positive as to the true state of affairs, the illusion of rotation would shift from room to the chair and back. For some, this alternation would occur without conscious effort. Other Ss within this group found they could alternate the illusion voluntarily by watching some part of their body, or momentarily closing their eyes, even though they were specifically instructed not to do so.

From an inspection of Table 2 it is suggested that the individuals who perceived the ap-

parent rotation tended to be unaffected, and, conversely, those who perceived the actual motion tended to experience nausea. The N's involved in each cell are too small to permit adequate analysis, and further work is needed to determine if such a relationship is a true one.

SUMMARY AND CONCLUSIONS

1. Two groups of Ss, one susceptible and the other not susceptible to motion sickness, were subjected to a rotating room situation in which they remained stationary. The resulting nausea symptoms were categorized on an arbitrary four-point scale.

2. The results indicate that individuals susceptible to motion sickness are also susceptible to nausea in a rotary visual field situation, and, conversely, nonsusceptibles are resistant.

3. It is concluded that some of the individual differences in regard to nausea found in previous studies utilizing rotary visual fields may be related to the motion sickness susceptibility of the subjects.

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Crosby, T. N., & Kennedy, R. S. Postural disequilibrium and simulator sickness following flights in a P3-C operational flight trainger. Presented at the 53rd Annual Scientific Meeting of the Aerospace Medical Association, Bal Harbor, FL, 10-13 May 1982.

ABSTRACT

Variable amounts of standing and walking unsteadiness have been reported following training missions in the Navy's ground-based P3-C operational flight trainer (2F87). This disequilibrium is accompanied by other symptoms related to vestibular upset (dizziness, vertigo, stomach awareness, headache). Reviews of previously published reports of Air Force and Navy simulator sickness studies show that while leans, unsteadiness, ataxia and incoordination had been reported before, this aspect of simulator sickness has not previously been emphasized. It is believed that these conditions can reduce the effectiveness of training, and perhaps more importantly, pose a threat to aircrew safety in the event of air or motor vehicle operations during the period of the post simulator exposure.

INTRODUCTION

Along with the increased usage of ground-based flight simulators has been the increased incidence of disturbances due to the optokinetic relationships of the visual displays and the motion platforms. Simulator sickness is the collective term for this malady and the symptoms which occur are generally similar to the symptoms of air, sea, and space sickness. As with other forms of motion sickness, the disturbances are probably caused by visual-vestibular interactions (Reason & Brand, 1975). However, preliminary evidence suggests that different classes of symptomatology after-effects occur in different simulators. We find it convenient to consider simulator sickness in three main classes of aftereffects which have significance for military aircrew training. These include: 1) nausea and other neurovegetative symptoms; 2) postural disequilibrium and other psychomotor aftereffects; 3) drowsiness, dizziness and other cerebro/visual anomalies.

Recently a computer image generation (CIG) system was installed in a P3-C operational flight trainer at NAS, Brunswick, ME. The new system replaced a camera modelboard system which had permitted a wide field of view for pilot, copilot and flight engineer. The pilot and copilot, in the previous configuration, each have forward viewing CRT/CIG displays and the pilot has an additional side view CRT/CIG display for use in circling-to-landing approaches. However, the flight engineer has no display of his own and is 30 degrees off-axis when viewing the pilots' and copilots' CIGs. With the introduction of the new system came reports of simulator sickness in flight engineers, but generally favorable reactions from pilots and copilots. These sickness reports included symptomatology from each of the three categories listed above. The study which follows evaluates the sickness which occurred and reports on two human factors engineering design options set up to minimize the problem.

SUBJECTS. Subjects were NATOPS qualified P3-C

flight crews, i.e., pilot, copilot, and flight engineer, who were regularly attached to fixed-wing, patrol squadrons that comprise Patrol Wing 5 stationed at NAS Brunswick, Maine. Subjects were accessed from crews scheduled for normal refresher and certification training at Fleet Aviation Specialized Operational Training Group, Atlantic (FASOTRAGRULANT) Detachment Brunswick. Additional observations were made using instructor pilots and flight engineers from PATWING-5 and one group of training devicemen from the FASO unit operating the simulator.

APPARATUS. The basic apparatus used in this study was the P3-C operational flight trainer which is designated as training device 2F87F. This high fidelity simulator manufactured by the Link Division of the Singer Company, reproduces the flight deck environment (with the addition of an instructor/operator station) mounted upon a motion platform with six-degrees-of-freedom.

Visual displays representative of external aircraft environments are provided by McDonnell Douglas Vital IV Computer Image Generation (CIG) system. This CIG system provides high resolution, chromatic displays collimated to the pilot and copilot positions, respectively, and is described in detail in service manuals.

Ancillary apparatus used in this investigation included a styrofoam baffle, painted flat black. This baffle fashioned by hand from commercially available styrofoam was used in two distinct configurations in order to occlude the flight engineers' visual input from the pilots' displays. Additionally, a Hewlett-Packard monochromatic video monitor was used to provide the flight engineer with a low fidelity repeat of the pilots' visual presentation.

PROCEDURE. The investigation was conducted in two phases. Phase one addressed problem identification while phase two evaluated the feasibility of an additional display for the flight engineer. In each phase two provocative tests of vestibular effects were employed: 1) Pensacola Motion Sickness Symptomology forms were filled out and scored according to the method described in Wiker, Kennedy, McCauley, & Pepper, 1979; 2) postural equilibrium tests just prior to commencement of a simulator hop and immediately upon completion of the exercise were conducted. The posture tests employed were the walk-on-floor eyes-closed and stand-on-one-foot eyes-closed of Fregly, Graybiel, and Smith (1972). According to Fregly (1974) these two tests possess excellent reliability and predictive validity for the full scale rail walking performance of the Graybiel-Fregly posture test (Fregly & Graybiel, 1966). The tests are described in detail elsewhere (Fregly et al 1972) but in summary each subject's session scores were: a) walking - the best three trials out of five with a maximum score of 30 steps; b) standing - the best three trials out of five

with a maximum score of 180 seconds.

Typical flight simulation session duration was approximately four hours. [Anecdotal reports had indicated postural disequilibrium was rarely encountered when the visual scene content during the majority of the exercise was impoverished (e.g., over water flights). Therefore, only hops whose training objectives would necessitate rich visual scenes (e.g., repeated approach and take-offs) were used.] Data were obtained under four conditions 1) with, and 2) without occlusion (baffle) of flight engineer's view while platform motion was 3) on, or 4) off.

EVALUATION OF LOW FIDELITY FLIGHT ENGINEER DISPLAY. Procedures for this phase of the investigation were almost identical to those described in the preceding subsection except for the following departures. The baffle was modified to allow the engineer visual access to a Hewlett-Packard monochrome repeater temporarily installed for this evaluation. Motion was not used during this phase and only two conditions (with and without baffle) were tested.

RESULTS

These results can be summarized as follows. Motion (either "on" or "off") had no effect upon the dependent measures in the problem identification phase. The occlusion of the flight engineer from the pilots' visual input by the insertion of the baffle significantly ($p < .01$) eliminated the symptoms of postural disequilibrium seen in approximately fifty percent of the engineers in control conditions with no baffle. These results were repeated in the second phase of the experiment along with the observation that addition of the low fidelity CRT display for the flight engineer had no significant impact upon the relationships described above with no display. In other words, baffle and display results were no different than baffle alone, while display without baffle was not different from unbaffled condition in the problem identification phase.

DISCUSSION

The results of this study are clear cut. Off-axis CIG viewing of CRTs by flight engineers produces ataxia and other symptoms of motion sickness. Longer exposures result in more pronounced and protracted effects. Occluding the flight engineer's view of the forward viewing displays obviates the problem but also makes that aircrew position IFR. A low fidelity CRT affords some protection and allows the flight engineer a form of VFR. Obviously, off-axis viewing should be avoided if possible in the design of future systems.

Although symptoms of simulator sickness observed in this study resemble those reported elsewhere, enough differences occur (incidence, time course, symptom mix, etc.) that it is probable this malady is polygenic. Presently

insufficient data are available to identify the aetiological significance of the different equipment features which are most sickness provoking in the different simulators. It appears that in addition to the off-axis viewing reported here, field of view, visual inertial lags, highly dynamic visuals, are all provocative.

Because of the extraordinary advantage for training of ground based flight simulators it can be expected that their use will increase greatly. Thus the problems of simulator sickness should be studied more because they can be expected to compromise training effectiveness so greatly. It is probable that display properties which are most conducive to problems can be identified and perhaps avoided in future designs. For this reason, a survey should be undertaken.

While simulator sickness is not a unitary category for biomedical diagnosis, it continues to be employed as such by the manager of human resources who attaches his problems (i.e. the adverse effects of simulator sickness) to the simulator. It is our view that it would help to distinguish whether: 1) unpleasant side effects will reduce pilot acceptance and therefore lower simulator usage; 2) perceptual aftereffects from simulator exposure may place a subject at risk exiting the simulator or at sometime later; and 3) habits (e.g., adaptation) learned in the simulator will transfer to the aircraft and may have negative consequences. This taxonomy combined with the three classes of aftereffects listed above might provide a common language for all to employ when discussing the difficulties of simulator sickness. For instance, while the biomedical complaint (e.g. discomfort) may be obviated by shorter exposures, it does not ensure that the other problems (e.g., learning incorrect habits) may also be removed.

The authors are encouraged with the use of tests of postural disequilibrium as diagnostic signs of adverse effects of the different displays which were employed. The significant differences between the with and without VFR condition in the first study enabled us to understand with greater confidence the efficacy of the low fidelity CRT display. Moreover the objective nature of tests of postural equilibrium make it a better prospect for routine use at simulator centers by technicians rather than the more subjective symptomology scoring procedure (cf Wiker, et al 1979). We feel that development of more sophisticated objective measures of postural equilibrium (cf Penman) holds promise for better understanding of simulator sickness problems. The utility is: 1) as a sensitive diagnostic tool in order to determine whether an effect is present from exposure, and 2) as a metric device, between and within subjects, where different display features could be compared for relative magnitude of effects.

MEMORANDUM

From: N-712
To: N-221 (R. L. Cannaday)

Subj: 2F117A CH-46A WST; psychophysiological disturbances in

1. Preliminary evaluation of the CH-46E WST (2F117A) at Reflectone, Inc., Tampa, FL revealed several factors which could lead to psychophysiological disturbances in aircrew members and the instructor pilot. For instance, it was noted that the horizon did not form a continuous line from one wind-screen to the other when the simulator was in a bank or turn. There was also considerable flicker of the display which would lead to visual fatigue. This is noteworthy since it is well documented that fatigue is a major contributor to disorientation. Furthermore, the copilot can only see portions of the display since all optics are focused to the pilot's design eye position. This is extremely awkward and disturbing to the copilot. He is receiving unfocused, somewhat uninterpretable signals. One would predict a priori that the copilot would be more susceptible to simulator-induced problems than the pilot. Similarly the instructor pilot, although having a better field of view, is observing optics focused for the pilot.
2. Additional items could be listed that may lead to psychophysiological disturbances. However, it is too premature to unequivocally state that the 2F117A contributes towards "simulator sickness." The etiology of simulator sickness is not well understood and currently under investigation in this laboratory.
3. It is our recommendation that the simulator be closely monitored after its on-site installation for incidences of simulator sickness. The monitoring can be easily accomplished by a questionnaire. The questionnaire, which we would develop at N-712, would help elucidate the relative incidence of disturbance (if any), under what circumstances it occurred, and some experiential characteristics of the users. Based upon the results of the questionnaire, we could then make a more detailed analysis of the defined problem and recommend a solution.
4. Setting aside the problem of simulator sickness, we believe a more immediate and significant problem of the 2F117A is its capability to provide adequate training for the copilot in other than IFR flight conditions (i.e., no visual). Due to the incomplete visual scene the copilot can observe, it appears on the surface at least, that the only actions he can take are instrument monitoring and radio communication. Navigation by visual means and terrain rotor blade clearance calls, for example, cannot be performed. It is strongly recommended that an immediate training effectiveness evaluation be performed.

Frank, L.H., & Crosby, T.N. Psychophysiological disturbances in the 2F117A, CH-46A WST (Memorandum N-712:LHF). Orlando, FL: Human Factors Laboratory, Naval Training Equipment Center, 1 Feb. 1982.

N-712:LHF
1 February 1982

Subj: 2F117A CH-46A WST; psychophysiological disturbances in

5. We greatly appreciate being invited to consult on the 2F117A. We regret that our evaluation could not be more definitive. Please contact us at any time for additional assistance on this or any other human factor problem.

L. H. FRANK
LCR, MSC, USN

L. H. Frank

T. N. CROSBY
LT, MSC, USN

T. N. Crosby Ph.D.

1. The USAF School of Aerospace Medicine has conducted a staff study of the Simulator for Air-to-Air Combat (SAAC) located at Luke AFB AZ. The problem arises from a variety of psychophysiologic symptoms in pilots occurring while or following flying the SAAC. The requirement for this staff study originated in the Phase I FOT&E report. There was a subsequent letter request from TAC/DR (Major General Leaf) through AFSC/SGB to AMD.

2. The SAAC is designed for training in visual air-to-air combat simulation. The system provides two F-4E cockpits on six-degree-of-freedom motion bases. Each cockpit has a canopy formed by eight CRTs which provide a total FOV of 300° horizontal and 142° vertical. Visuals are a combination of TV presentation of a slaved aircraft model as a target with a CGI background showing sky and terrain. Motion effects are further simulated by "G" suit, "G" seat, and light dimming operations. This system is manufactured by Singer with visuals by Farrand and computers by Aerox.

3. An on-site study was conducted at Luke AFB AZ by the USAF School of Aerospace Medicine during the period 3-6 August 1976. Pilot complaints and symptoms resulting from "flying" missions on the SAAC were quantitatively and qualitatively assessed. Several data sources were utilized:

a. Interviews with 14 pilots, including most of the IPs who flew multiple missions as part of Phase I FOT&E, student pilots who had flown only one or two SAAC missions, and 3 pilots as they emerged from a SAAC mission

b. Review of approximately 100 questionnaires obtained during Phase I from IP test subjects

c. The Phase I FOT&E report

d. Two rides on SAAC, the second of which was "maximum maneuvers" to try to induce motion sickness and/or other symptoms in the investigator

e. One ride on the ASUPT simulator (Williams AFB) and the Formation Flight Trainer (FFT) simulator to compare visual display systems

f. A conference with the commander, the chief flight surgeon, and the staff ophthalmologist at the USAF Hospital, Luke AFB

4. The complaints from Phase I and our initial analysis were as follows:

a. Spatial disorientation (52%). Reported on only the first one or two rides. None of the classic symptoms were present. The pilots are basically reporting that the simulator "feels strange at first." The report is made even when the motion system is inoperative. Spatial disorientation in the classical sense did not appear to be a problem.

b. Eye strain (50%). Initially reported for only the first one or two rides. During interviews, it was established that it occurs on every ride for those pilots who report it at all. The visual display system appears to have some deficiencies. It is an infinity optics system using an array of CRTs; the CRT resolution permits pilots with excellent visual acuity to see the raster lines. Our initial hypothesis was that the pilots found themselves in a state of visual accommodative conflict, trying to accommodate on near stimulus cues while required to achieve an infinity view with zero accommodation. The problem is complicated by focus/brightness differences between adjacent CRTs, which need to be routinely tuned and matched, possibly a little out of focus. The visual problem is further complicated by resolution difficulties in tracking the target ship at apparent distances beyond 1-2 miles. Analysis of the visual problems was conducted subsequently by the hospital ophthalmologist (Lt Col Kennedy). His final conclusions are that:

DYNAMIC VISUAL
ACCOMMODATION
TOO GOOD?

TARGET ACQUISITION
TOO GOOD?

(1) There are some near vision cues which stimulate the accommodative conflict initially identified, but these become less significant after a couple of rides.

(2) The problem seems to be a larger physiologic conflict involving (in combination) disrupting vestibular inputs, unnatural "cerebral" (perceptual) inputs, and conflicting/disturbing inputs to the eye.

This will be a continuing but tolerable problem with the SAAC.

c. Headaches (32%). The result of eyestrain. Reported to occur on only the first one or two rides, but actually occurs for every pilot who experiences eyestrain. This will be a continuing but tolerable problem with the SAAC.

d. Nausea (14%). Reported for only the first one or two rides. Is most likely the result of the combination of eyestrain/headache and the extreme rates of perceived motion during typical F-4 ACM (motion system on or off may be somewhat irrelevant to this problem). May occur infrequently probably only for those pilots who do not feel up-to-par the day of the ride. Not a significant problem, but probably will occur periodically.

e. Tiredness (38%). The natural result of a high workload ACM simulator mission.

A further statistical description of the extent of these symptoms is given in Table 1. Note that, overall, impairment of performance is infrequent (e.g., no ratings of 4).

5. Further analysis of the contribution of the motion system to the reported symptoms was performed. Motion picture films were obtained of the simulator, including external film clips with the simulator in motion, and cockpit film clips of the visual display "motion." Film clips were provided by the IG Safety Center, Norton. Review of the clips on visually displayed "motion" did not reveal anything particularly provocative, but this analysis was limited because of the quality of the filmed shots. (Good-quality films are exceptionally difficult to obtain under the conditions confronting the photographer in the cockpit. The Norton photographer did an exceptional job in providing us with photographic data.) The external shots were of superior quality and allowed USAFSAM to perform an approximate frequency analysis of the behavior of the motion system. The external clips were scored for vertical and horizontal displacement on a frame-by-frame basis. Motion platform displacement scores were analyzed for spectral content using a fast Fourier transform computer program. Supplementary data on the motion system were also obtained from the contractors' proposal documents and used to verify the analysis of empirical data.

6. Problems addressed in the motion system analysis are as follows:

a. Nausea. There have been two cases of emesis in subjects flying the SAAC. In at least one of these cases the motion system was on. Numerous (14%) subjects report mild nausea which apparently occurs with or without the motion system engaged and which is no longer a problem after two or three missions.

b. Visual display/motion system synchronization. Subjects report that the simulated aircraft feels oversensitive.

7. As background for the subsequent paragraphs, a review of the motion sickness literature reveals a surfeit of theories; however, there are some common threads. Pilots integrate visual and proprioceptive information in order to maintain an inertial reference frame and perceive motion relative to it. This requires adaptation, after which orientation can be maintained with relative ease. When placed in a novel situation in which learned visual-proprioceptive relationships are no longer valid, a pilot must work hard to solve the orientation problem and thus may feel disoriented and queasy. Readaptation must occur before the subject again feels at ease. This phenomenon could explain the disorientation and mild nausea experienced by pilots on their initial SAAC missions (ref. 1).

8. It is known that vertical periodic motion in the range of 0.2 Hz to 0.4 Hz is a very effective stimulus for motion sickness (ref. 2). In

order to determine if the SAAC motion has significant frequency components in this range, spectral analysis previously described was performed on a two-dimensional time series derived from a single 250-sec. filmed sequence of the SAAC motion. Figure 1 shows that there is indeed a major portion of acceleratory energy in the 0.2 Hz to 0.4 Hz range. Lacking detailed physical characteristics of the motion system, it is not possible to determine the origin of this phenomenon with certainty; however, a preliminary analysis suggests that it may be caused by the nonlinear restorative forces near the limits of vertical motion (buffer regions) in the same sense that a Duffing oscillator can have a low-Q resonance. In any case, the acceleratory motion spectrum of the single time series analyzed would be sufficient to cause motion sickness in moderately susceptible subjects over a period of exposure of one hour. It must be emphasized that longer time series of higher quality must be analyzed before definite conclusions can be reached. The SAAC project office at Luke is acquiring higher quality data. We are prepared to support or analyze in parallel this new data.

9. The overly sensitive feel of the simulator is probably due to the low-level motion system cues presented to the subjects by the SAAC motion system. Specifically, experiments have shown that subjects can generate greater rate/displacement sensing and thus better tracking performance and a less sensitive "feel" in a motion base simulator than in a fixed base simulator. A review of data in the Singer proposal suggests that with the 18,240 pounds motion system payload a vertical acceleration increment of only +0.2 g is attainable (computed by assuming a maximum increment of +1.0 g for an 11,000 pound payload as reported in the Singer proposal). This certainly cannot reliably reproduce motion cues familiar to trained pilots and undoubtedly contributes to the sensitive feel of the simulator. It may also explain why, at times, subjects are unable to report whether or not the motion system was turned on during a mission.

10. With regard to the motion system, the following recommendations are made:

a. Initial familiarization period of at least one and preferably two missions with motion system "on" to allow establishing visual-proprioceptive relationships. Avoid switching from motion-system-on to motion-system-off modes after familiarization.

b. For a more refined analysis of the motion system problem, record motion data simultaneously from 3-axis accelerometer located at pilot position and from the visual system to allow quality spectral analysis to at least 5.0 Hz. This will allow determination of the significance of the spectral peak discussed in paragraph 8 and additionally will allow closed-loop modeling with the goal of determining the origin of this spectral peak and a method of correction.

c. The equation of motion governing the visual display should not be damped in order to bring motion and visual cues in step. This could increase the acceleration spectral energy at frequencies below 0.5 Hz with a resulting increase in motion sickness incidence.

d. There are some merits to initiating a motion system upgrade of the SAAC; though we feel some concern about the cost effectiveness. (See reference 3.) Upgrading of the SAAC motion system should have two goals:

(1) Increased motion cue quality

(a) Increased motion amplitude capability (both acceleration and displacement) while maintaining cue-onset delays less than 0.1 sec.

(b) Minimization of conflictual cues.

NOTE: A mixture of reliable and conflictual cues are present in all simulators. It has been shown, however, that even low-level simulator motion can increase system stability over fixed base. (See reference 4.)

(c) Motion cues of increased quality will reduce the sensitive feel of the simulator. This results primarily from the pilot's increased lead generation with motion base simulators, i.e., for a pilot describing function

$$Y_p(j\omega) = K_p (j\omega T_L + 1) e^{-j\omega \tau}$$

T_L (motion base) > T_L (fixed base) , overall result for most systems
 K_p (motion base) < K_p (fixed base) } is increase in stability.

(2). Minimization of any tendency of the system to produce significant acceleratory spectral energy in the 0.2 → 0.4 Hz range.

(a) If it is suspected after further analysis that the resonance is due to restorative forces comprising the buffer regions, the resonant frequency could be raised by placing the buffer region onset point nearer the motion limits.

(b) If there are no system resonances in the 0.2 → 0.4 Hz range, accomplishment of d.(1) above will likely satisfy (2).

11. With regard to the remaining problems identified in this staff study:

a. Some attention should be given to the visual accommodative conflict as described in paragraph 4.b. above. Eyestrain and mild headaches may continue to be a problem because the state-of-the-art on CRT displays will not permit much improvement at this time. The

discomfort is mild. The current rule in 2 squadrons at Luke which prohibits a student flight following a simulator ride without an IP on board errs on the conservative side but reflects a realistic concern for flight safety. Squadron commanders obviously have this option.

b. The visual motion/physical motion systems are out of sync. Roll and Pitch are overly sensitive (as discussed above), exceeding the characteristics of the aircraft. There is the significant problem of "false cues" (reference 3). Damped equations of motion (perhaps 10%) might help.

c. The initial orientation ride should be carefully structured. The current draft training syllabus exposes pilots to normal maneuvers and familiarization only, but lasts one hour. We recommend (from the visual system point of view) not less than one familiarization ride limited to one-half hour and to contain two periods when the pilot backs out of the visual cockpit enclosure for a few minutes to relax and reorient to a normal visual scene.

12. We are prepared to assist further on this problem. If the USAF School of Aerospace Medicine becomes further involved, we recommend a coupled effort with the Air Force Human Resources Laboratory.

ROBERT G. MCIVER, Colonel, USAF, MC
Commander

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TABLE 1. STATISTICAL SUMMARY OF REPORTS OF SYMPTOMS

Data from FOT&E Phase I
(Provided by TAWC/CLAH)

<u>SYMPTOM</u>	<u>RATING SCALE SCORES*</u>				<u>SCORE FREQUENCY</u>			
	<u>MEAN</u>	<u>STD DEV</u>	<u>MEDIAN</u>	<u>MODE</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
SPATIAL DISORIENTATION	1.66	0.60	1.67	2	30	38	5	0
NAUSEA	1.15	0.39	1.08	1	64	9	1	0
HEADACHES	1.32	0.46	1.23	1	50	23	0	0
EYESTRAIN	1.58	0.52	1.62	2	32	41	1	0
TIREDMESS	1.40	0.54	1.30	1	45	25	2	0

*The scale for psychophysiological effects was developed to determine the severity of any adverse effects experienced in the simulator. It is assumed that these effects will adversely affect performance. A four-point scale was adopted in which these psychophysiological effects ranged from none to severe.

(1) None. No effects were experienced.

(2) Mild. There were some mild effects, but they did not affect performance.

(3) Moderate. There were moderate effects that may have slightly affected performance.

(4) Severe. There were severe effects, and performance was seriously affected.

FREQUENCY

$$\frac{10}{\sqrt{f}} \frac{G}{\sqrt{Hz}}$$

POWER

MULTIPLY EACH POWER BY 0.0010

0.0 0.2000 0.4000 0.6000 0.8000 1.0000 1.2000 1.4000 1.6000 1.8000

0.0
0.031
0.063
0.094
0.125
0.156
0.188
0.219
0.250
0.281
0.313
0.344
0.375
0.406
0.438
0.469
0.500
0.531
0.563
0.594
0.625
0.656
0.688
0.719
0.750
0.781
0.813
0.844
0.875
0.906
0.938
0.969
1.000

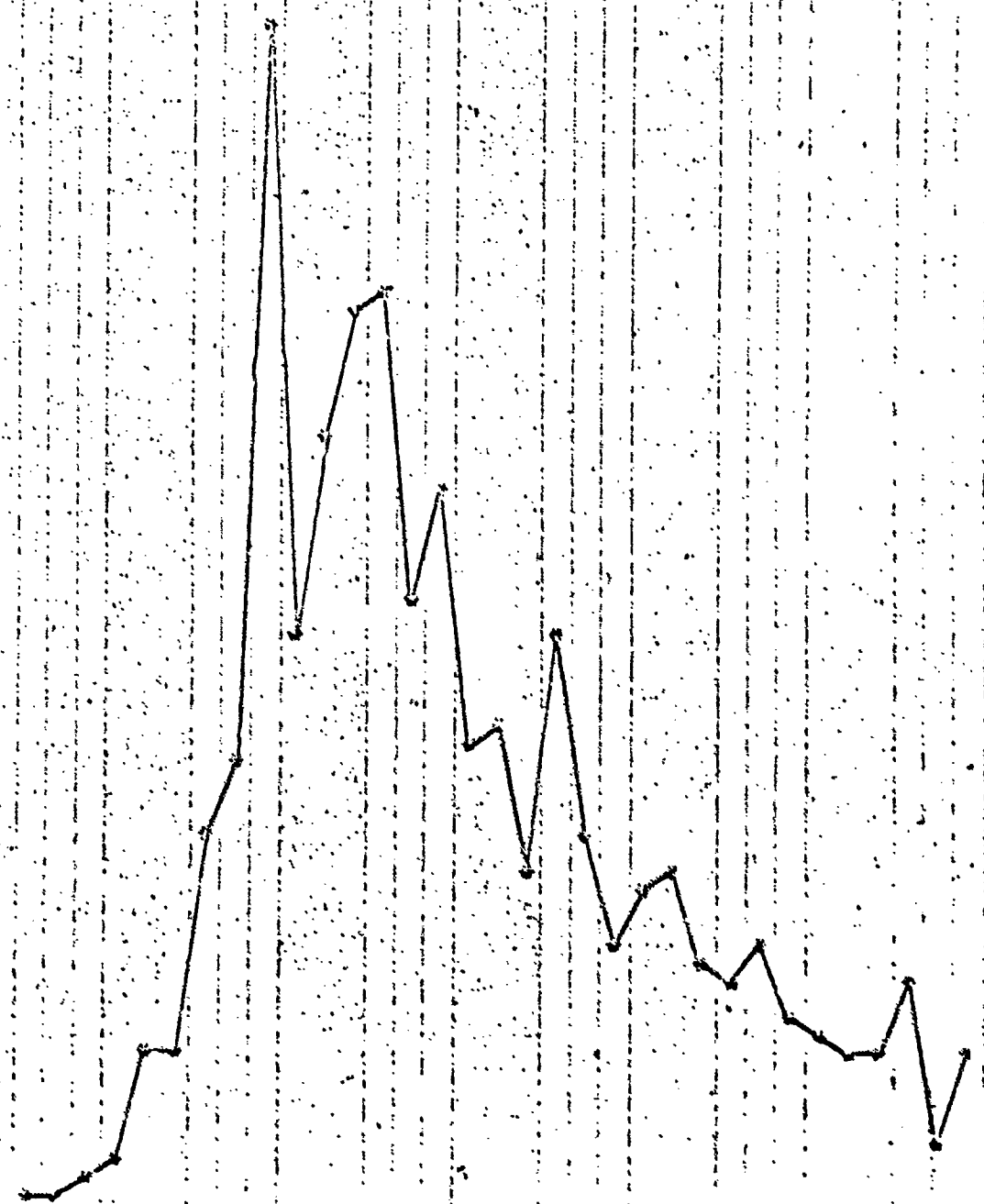


FIGURE 1 SAAC ACCELERATION SPECTRUM

continued

Havron, M. D., & Butler, L. F. Evaluation of training effectiveness of the 2FH2 helicopter flight trainer research tool (Technical Report No. NAVTRADEVCEM 1915-00-1). Port Washington, NY: Naval Training Device Center, April 1957.

FORWARD

INTRODUCTION

THIS EVALUATION WAS CONDUCTED TO DETERMINE THE EFFECTIVENESS OF DEVICE 2-FH-2, HELICOPTER FLIGHT TRAINER RESEARCH TOOL. THE DEVICE CONSISTS OF A UNIQUE TYPE OF VISUAL DISPLAY, A COCKPIT WITH ACTIVATED INSTRUMENTS AND CONTROLS, AND A GENERALIZED FLIGHT SYSTEM COMPUTER. IT WAS ORIGINALLY CONSTRUCTED TO DETERMINE THE FEASIBILITY OF UTILIZING AN INTERNAL NON-PROGRAMMED POINT-SOURCE-OF-LIGHT PROJECTION SYSTEM TO CREATE THE ILLUSION OF THREE DIMENSIONAL SPACE ON A CURVED PROJECTION SCREEN. THE FLIGHT COMPUTER IS DESIGNED TO APPROXIMATE IN A GENERAL WAY THE FLIGHT CHARACTERISTICS OF THE BELL HTL-4 HELICOPTER.

PURPOSE

AS A FIRST STEP IN THE STUDY OF THIS NOVEL NON-PROGRAMMED PROJECTION TECHNIQUE, DEVICE 2-FH-2 WAS INSTALLED AT ELLYSON FIELD, FLORIDA, AND THE TRAINING SYLLABUS WAS STUDIED AND ANALYZED IN ORDER TO INTEGRATE THE DEVICE INTO THE ROUTINE HELICOPTER FLIGHT TRAINING PROGRAM. THE EVALUATION SOUGHT TO DETERMINE TO WHAT EXTENT THE DEVICE WAS USEFUL IN INITIAL STAGES OF HELICOPTER TRAINING AND WHAT PROBLEMS AROSE AS THE RESULT OF THE EXPOSURE OF STUDENTS TO A NUMBER OF HOURS OF PRACTICE IN THE DEVICE PRIOR TO FLIGHT IN AN OPERATIONAL HELICOPTER.

RESULTS

1. THE DEVICE DID NOT DEMONSTRATE ANY TRAINING ADVANTAGE OVER THE ROUTINE METHOD OF TRAINING IN HELICOPTER BASIC FLIGHT TRAINING.

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EVALUATION OF TRAINING EFFECTIVENESS OF THE 2-FH-2 HELICOPTER FLIGHT TRAINER RESEARCH TOOL

1. BRIEF OF STUDY

INTRODUCTION

THIS IS THE REPORT OF AN EVALUATION OF DEVICE 2-FH-2, HELICOPTER HOVERING RESEARCH TOOL. DEVICE 2-FH-2 WAS CONSTRUCTED BY THE BELL AIRCRAFT CORPORATION, BUFFALO, NEW YORK UNDER CONTRACT TO THE U. S. NAVAL TRAINING DEVICE CENTER. THE DEFLOREZ COMPANY OF NEW YORK CITY, NEW YORK WAS A SUB-CONTRACTOR TO BELL AIRCRAFT CORPORATION AND WAS RESPONSIBLE FOR THE INITIAL DESIGN OF THE COMPLETE DEVICE. THE DEVICE WAS DEVELOPED AS AN ENGINEERING PROTOTYPE TO DETERMINE THE FEASIBILITY OF A NON-PROGRAMMED VISUAL DISPLAY FOR TRAINING IN HOVERING AND OTHER MANEUVERS PERFORMED NEAR THE GROUND. LATER, ITS CAPABILITIES WERE EXTENDED TO PERMIT SIMULATION OF HIGH ALTITUDE MANEUVERS WITHOUT EXTENSIVE MODIFICATION OF THE FLIGHT COMPUTER SYSTEM. THE DEVICE USES A POINT-LIGHT-SOURCE TO PROJECT IMAGES FROM A TRANSPARENCY PLATE CONTAINING OBJECTS AND SCENERY TO A WIDE ANGLE SCREEN SURROUNDING THE COCKPIT. THE 2-FH-2 IS DESIGNED TO SIMULATE APPROXIMATE FLIGHT CHARACTERISTICS OF THE HTL-4. TWO INTERCHANGEABLE TRANSPARENCY PLATES CAN BE USED. THE "LOW-ALTITUDE PLATE" PROVIDES A VISUAL EXTRA-COCKPIT DISPLAY FOR A FLYSPACE OF 570 BY 570 FEET IN LENGTH AND WIDTH AND 55 FEET IN ALTITUDE. THE "HIGH-ALTITUDE PLATE" PERMITS MANEUVERS IN A SIMULATED AREA 2400 FEET BY 2400 FEET WITH AN ALTITUDE OF 500 FEET.

IN AN INITIAL APPRAISAL CONDUCTED BY PSYCHOLOGICAL RESEARCH ASSOCIATES (PRA) (10), INSTRUCTORS OF HELICOPTER TRAINING UNIT ONE (HTU-1) FLEW THE DEVICE AND WERE INTERVIEWED. RESPONSES AND EXAMINATION OF THE A-STAGE TRAINING SYLLABUS INDICATED THAT THE LOW-ALTITUDE PLATE THEN INSTALLED WOULD PERMIT PRACTICE IN ABOUT HALF THE A-STAGE MANEUVERS. LACKS OF FIDELITY WERE NOTED BUT NONE APPEARED

SUFFICIENTLY SERIOUS TO INDICATE THAT THE DEVICE WOULD HAVE NO TRAINING VALUE. ALL INSTRUCTORS RECOMMENDED FURTHER INVESTIGATION OF THE OPERATIONAL CAPABILITIES OF THE DEVICE. THIS IS A REPORT OF THE METHODS USED AND THE RESULTS OBTAINED IN THE RECOMMENDED INVESTIGATION.

METHOD

THE EVALUATION WAS CONDUCTED BY THE STEPS SUMMARIZED BELOW AND DESCRIBED IN DETAIL IN THE APPROPRIATE SECTIONS OF THE REPORT AS INDICATED:

STEP 1. COLLECTION AND INTEGRATION OF CONTENT

OPERATIONAL HANDBOOKS, TEXTS ON HELICOPTERS AND RESEARCH REPORTS WERE REVIEWED; HTU-1 INSTRUCTORS AND STUDENTS WERE INTERVIEWED TO IDENTIFY AND INTEGRATE THE CRITICAL COMPONENTS OF HELICOPTER FLIGHT. (SEE SECTION II AND APPENDICES A, B AND C.)

STEP 2. DEVELOPMENT OF A TRAINING SYLLABUS

A SYLLABUS TO TRAIN STUDENTS IN THE 2-FH-2 WAS DEVELOPED, PRETESTED AND PREPARED FOR USE IN STEP 4. (SEE SECTION III. THE SYLLABUS IS APPENDIX D.)

STEP 3. DEVELOPMENT OF A FLIGHT CRITERION

AN IN-FLIGHT CRITERION CONSISTING OF A RATING FORM DESCRIPTIVE OF FIVE CRITICAL HELICOPTER MANEUVERS WAS DEVELOPED, PRETESTED AND PREPARED FOR USE IN STEP 4. (SEE SECTION IV. THE FLIGHT CHECK IS APPENDED AS APPENDIX E.)

STEP 4. ADMINISTRATION OF TRAINING SYLLABUS AND FLIGHT CRITERION

THE TRAINING SYLLABUS WAS ADMINISTERED TO EIGHTEEN HTU-1 STUDENTS PRIOR TO SQUADRON FLIGHT TRAINING. EIGHTEEN COMPARABLE CONTROL STUDENTS RECEIVED NO TRAINING IN THE DEVICE. EXPERIMENTALS AND CONTROLS WERE TESTED ON THE FLIGHT CRITERION AFTER FIVE HOURS OF HTU-1 TRAINING. (SEE SECTION V.)

STEP 5. ANALYSIS OF DATA

CRITERION SCORES OF EXPERIMENTAL AND CONTROL STUDENTS AND THEIR GRADES OF THE TWO GROUPS DURING EARLY SQUADRON TRAINING PERIODS WERE COMPARED. (SEE SECTION V.)

STEP 6. REPORT OF RESULTS

NEGATIVE RESULTS IN STEP 5 LED TO EXAMINATION OF MOTION SICKNESS AND LACKS OF FIDELITY IN THE DEVICE AS POSSIBLE CAUSATIVE FACTORS. MOTION SICKNESS IS DISCUSSED IN SECTION VI, THE QUESTIONNAIRE ON MOTION SICKNESS IS APPENDIX F. LACKS OF FIDELITY AS DESCRIBED BY INSTRUCTORS AND THEIR IMPLICATIONS FOR LEARNING ARE DISCUSSED IN SECTION VII.

RESULTS

1. TRAINING IN THE 2-FH-2 LED TO NO APPARENT IMPROVEMENT IN FLIGHT PERFORMANCE IN THE AIRCRAFT.
2. TRAINING IN THE 2-FH-2 PRODUCED SICKNESS SOMEWHAT SIMILAR TO MOTION SICKNESS AMONG MOST PARTICIPATING INSTRUCTORS AND STUDENTS.
3. FLIGHT CHARACTERISTICS OF THE DEVICE THAT SPECIFY DISPLAY-CONTROL RELATIONSHIPS LACK FIDELITY IN A NUMBER OF IMPORTANT RESPECTS. IT

IS PROBABLE THAT THESE FAULTS CONTRIBUTE TO SICKNESS. THERE IS SOME EVIDENCE OF NEGATIVE TRANSFER BECAUSE OF THEM.

4. FOR THESE REASONS THE 2-FH-2 AS PRESENTLY CONSTITUTED, IS NOT RECOMMENDED FOR OPERATIONAL TRAINING. HOWEVER, BECAUSE OF THE VERY CONSIDERABLE POSSIBILITIES OF A WORKABLE DEVICE OF THIS SORT, THE CONCEPT OF PRESENTING EXTRA-COCKPIT VISUAL DISPLAYS AND ITS IMPLEMENTATION SHOULD NOT BE DISCARDED. (SEE SECTION VIII.)

II. COLLECTION AND INTEGRATION OF CONTENT

PREREQUISITE TO THE DEVELOPMENT OF THE TRAINING SYLLABUS AND THE FLIGHT CRITERION THE FOLLOWING OBJECTIVES HAD TO BE ACCOMPLISHED:

- A. IDENTIFICATION OF CONTENT (MANEUVERS AND TASK COMPONENTS* TO BE TAUGHT AND EVALUATED).
- B. DETERMINATION OF THE IMPORTANCE AND DIFFICULTY OF TASK COMPONENTS.
- C. ANALYSIS OF THE RELATIONSHIPS AMONG MANEUVERS, TASK COMPONENTS AND SKILL REQUIREMENTS**.

THE ABOVE THREE OBJECTIVES WERE ACCOMPLISHED CONCURRENTLY. BACKGROUND INFORMATION WAS COLLECTED AS DESCRIBED BELOW.

THE STANDARDIZATION MANUAL (12), DEVELOPED BY HTU-1 PROVIDED A CONVENIENT STARTING POINT FOR ACCOMPLISHMENT OF THIS PHASE. WELL WRITTEN AND DETAILED, IT DESCRIBES ALL MANEUVERS TAUGHT IN A AND B STAGES OF HTU-1 AND LISTS THE MORE COMMON ERRORS ASSOCIATED WITH EACH.

USING THIS MANUAL, A FOUR PART QUESTIONNAIRE WAS DEVELOPED TO OBTAIN INFORMATION BEARING ON THE OBJECTIVES MENTIONED ABOVE. THIS QUESTIONNAIRE WAS SUBMITTED TO 23 INSTRUCTORS, AND WITH MINOR MODIFICATIONS, TO 15 STUDENTS IN TRAINING IN HTU-1. QUESTIONS AND RESPONSES ARE DISCUSSED BRIEFLY BELOW AND PRESENTED IN APPENDICES A AND B.

-
- * THE WORD MANEUVER IS USED HERE AS IT IS IN HTU-1. IT SPECIFIES A DESIRED AIRCRAFT PATH THAT HAS OPERATIONAL SIGNIFICANCE GENERALLY WITH RESPECT TO THE GROUND, FOR A GIVEN TIME PERIOD. THE TERM TASK COMPONENT IS USED HERE TO DENOTE PARTICULAR PHASES OR ASPECTS OF A MANEUVER.
 - ** SKILL REQUIREMENTS ARE THE SKILLS NEEDED TO EXECUTE SPECIFIED TASKS AND MANEUVERS PROPERLY.

QUESTION 1 REQUIRED THE RESPONDENTS TO RANK 19 OF THE 30 MANEUVERS LISTED IN THE STANDARDIZATION MANUAL IN TERMS OF THE DIFFICULTY STUDENTS ENCOUNTER IN LEARNING THEM*. THE TEN MANEUVERS RANKED AS MOST DIFFICULT ARE LISTED BELOW IN ORDER.

10 MOST DIFFICULT MANEUVERS

<u>INSTRUCTOR RANKING</u>	<u>STUDENT RANKING</u>
1. HOVERING	1. HOVERING
2. VERTICAL LANDING	2. VERTICAL LANDING
3. NORMAL APPROACH TO A DEFINITE SPOT	3. NORMAL APPROACH TO A DEFINITE SPOT
4. AUTOROTATIONS	4. TURNS ON A SPOT
5. NORMAL APPROACH	5. AUTOROTATIONS
6. FIGURE EIGHTS	6. FIGURE EIGHTS
7. TURNS ON A SPOT	7. VERTICAL TAKE-OFF
8. SQUARES	8. NORMAL APPROACH
9. SIDEWARD & REARWARD FLIGHT	9. SIDEWARD & REARWARD FLIGHT
10. VERTICAL TAKE-OFF	10. CLIMBING TURNS

THE HIGH AGREEMENT BETWEEN INSTRUCTORS AND STUDENTS IS, OF COURSE, NOT SURPRISING. MANEUVER RANKS PROVIDED A GUIDE FOR THE DEVELOPMENT OF THE TRAINING SYLLABUS AND THE FLIGHT CRITERION.

QUESTION 2 WAS DIVIDED INTO THREE PARTS. THE FIRST TWO PARTS SOUGHT TO

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- * ELEVEN OF THE 30 MANEUVERS LISTED IN THE MANUAL WERE EXTRACTED BY ELIMINATING NON-FLIGHT PROCEDURES (COCKPIT PROCEDURES, GROUND TAXIING, ETC.) AND MANEUVERS NOT TAUGHT PRIOR TO SOLO (RUNNING LANDING, BACKWARD TAKE-OFF, ETC.).

ASCERTAIN WHICH CONTROL MANIPULATIONS AND COORDINATIONS ARE MOST DIFFICULT TO LEARN; THE THIRD ATTEMPTED TO IDENTIFY THE MORE CRITICAL CUES REQUIRED TO EXECUTE MANEUVERS PROPERLY. RESPONSES INDICATED THAT THE CYCLIC CONTROL IS THE MOST DIFFICULT TO LEARN; ALSO THAT THE REQUIREMENTS OF MANEUVERS DETERMINE TO A CERTAIN EXTENT THE DEGREE OF DIFFICULTY ENCOUNTERED IN LEARNING TO USE AND COORDINATE THE CONTROLS PROPERLY.

QUESTION 3 WAS A CHECK ON ERROR COVERAGE IN THE STANDARDIZATION MANUAL WHICH LISTS ERRORS COMMON TO EACH MANEUVER. FIRST, INSTRUCTORS WERE ASKED TO LIST ERRORS NOT INCLUDED IN THE MANUAL; STUDENTS WERE ASKED TO LIST THEIR OWN ERRORS. NEXT, ERRORS LISTED BY INSTRUCTORS AND STUDENTS WERE COMBINED WITH THOSE DESCRIBED IN THE MANUAL. FINALLY, THE COMBINED LIST WAS RESUBMITTED TO INSTRUCTORS WHO WERE ASKED TO RATE ERRORS IN TERMS OF THEIR FREQUENCY, THE DIFFICULTY IN CORRECTING THEM, AND THEIR CRITICALITY TO THE SAFE FLIGHT OF THE AIRCRAFT. THE RESULTS OF THESE ERROR RATINGS ARE PRESENTED IN APPENDIX C.

A SUMMARY OF RESPONSES INDICATED THAT THE COVERAGE OF ERRORS PROVIDED BY THE STANDARDIZATION MANUAL IS RELATIVELY COMPLETE. IN GENERAL, ERRORS ADDED BY INSTRUCTORS WERE NOT RATED AS CRITICAL AS THOSE DESCRIBED IN THE MANUAL WITH RESPECT TO THE ABOVE THREE CRITERIA.

QUESTION 4 WAS CONCERNED WITH THE SEVERAL EXTRINSIC CONDITIONS THAT THE 2-FH-2 CAN SIMULATE. THESE INCLUDE WIND DIRECTION, VELOCITY, AND GUSTS, CENTER OF GRAVITY CHANGE, CHANGES IN TEMPERATURE (DENSITY-ALTITUDE), AND WEIGHT CHANGES. INSTRUCTORS SPECIFIED WHETHER OR NOT EACH OF THESE CONDITIONS SHOULD BE INCLUDED IN THE 2-FH-2 TRAINING SYLLABUS, AND RANKED CONDITIONS RECOMMENDED FOR INCLUSION IN ORDER OF IMPORTANCE. RESPONSES INDICATED THAT WIND VELOCITY AND GUSTS ARE MOST IMPORTANT AND THAT THEY SHOULD BE INCLUDED IN A TRAINING SYLLABUS.

BACKGROUND MATERIALS PERMITTED IDENTIFICATION OF THE MORE IMPORTANT

MANEUVERS AND THE MORE CRITICAL TASK COMPONENTS TO BE INCLUDED IN THE TRAINING SYLLABUS AND THE FLIGHT CHECK AND GAVE INSIGHTS AS TO THE SKILLS REQUIRED TO EXECUTE MANEUVERS PROPERLY. BACKGROUND MATERIAL IS INTEGRATED BELOW INTO AN ANALYSIS OF HELICOPTER FLIGHT PARAMETERS.

HELICOPTER FLIGHT REQUIREMENTS AND SKILLS

BEFORE ATTEMPTING TO DEVELOP TRAINING AND TESTING INSTRUMENTS, IT WAS NECESSARY TO RECOGNIZE CERTAIN LIMITATIONS TO USING THE BACKGROUND MATERIAL EXACTLY AS COLLECTED. FIRST, A NUMBER OF MANEUVERS AND THE TASKS THEY REQUIRE OVERLAP WITH ONE ANOTHER. FOR EXAMPLE, THE NORMAL APPROACH INCLUDES THREE OTHER MANEUVERS THAT SUBJECTS WERE INSTRUCTED TO RANK AGAINST IT: GLIDING TURNS, HOVERING, AND VERTICAL LANDING. FURTHER, IT WAS DIFFICULT TO PREDICT FROM THE INFORMATION COLLECTED THE EXTENT TO WHICH THE LEARNING OF ONE MANEUVER OR TASK WOULD FACILITATE THE LEARNING OF OTHERS. SUCH KNOWLEDGE HAS OBVIOUS IMPLICATIONS FOR THE SELECTION OF TASKS FOR BOTH TRAINING AND TESTING. THESE LIMITATIONS MADE IT DESIRABLE TO IDENTIFY THE BASIC PARAMETERS OF HELICOPTER FLIGHT AND THE TASKS THE PILOT MUST PERFORM TO CONTROL THE AIRCRAFT EFFECTIVELY WITHIN THEM. THIS DONE, IT BECOMES POSSIBLE TO ESTABLISH WORKING HYPOTHESES AS TO THE TYPE AND DEGREE OF SKILLS REQUIRED TO CONTROL THE AIRCRAFT IN THE VARIOUS MANEUVERS. THE TRAINING SYLLABUS AND THE FLIGHT CRITERION WOULD THEN BE PREDICATED ON THESE HYPOTHESES AS WELL AS UPON MANEUVER RANKS.

DISCUSSED BELOW ARE THE FLIGHT PARAMETERS, THEIR RELATIONSHIP TO THE FLIGHT CONTROLS AND TO THE SKILLS REQUIRED TO MANIPULATE AND COORDINATE CONTROLS.

THERE ARE SIX BASIC FLIGHT DIMENSIONS OR FREEDOMS OF FLIGHT. THREE OF THESE ARE TRANSLATIONAL OR DIRECTIONAL, NAMELY FORE-AFT, LATERAL (TO EACH SIDE) AND VERTICAL. IN ADDITION, THERE ARE THREE ROTATIONAL FREEDOMS - PITCH, ROLL, AND

YAW. WITHIN EACH OF THESE BASIC PARAMETERS THE AIRCRAFT HAS THE CAPABILITY OF SPEED AND ACCELERATION. THESE SIX FREEDOMS CONSIDERED TOGETHER CAN ACCOUNT FOR MOVEMENT OF THE AIRCRAFT IN ALL DIRECTIONS AND AT ALL SPEEDS, HENCE, THEY ARE SUFFICIENT TO DESCRIBE ALL POSSIBLE HELICOPTER MANEUVERS. THE PILOT MANEUVERS THE AIRCRAFT WITHIN THESE PARAMETERS BY MEANS OF FOUR CONTROLS - THE THROTTLE, THE COLLECTIVE PITCH, THE DIRECTIONAL CONTROL PEDALS, AND THE CYCLIC CONTROL. THE COORDINATED OPERATION OF THESE CONTROLS, PLUS THE THRUST OF THE POWER PLANT, THE LIFT OF THE AIRFOIL, THE WEIGHT, DRAG AND INERTIA OF THE AIRCRAFT, AND EXTERNAL CONDITIONS SUCH AS WIND AND PRESSURE ALTITUDE, DETERMINE THE FLIGHT PATH OF THE AIRCRAFT WITHIN THE FREEDOMS. CONTROLS ARE DISCUSSED BRIEFLY BELOW. FOR FURTHER INFORMATION, SEE HELICOPTER TRAINING MANUAL (11), AND FLIGHT HANDBOOK NAVY MODEL HTL-5 HELICOPTER (7).

A. THROTTLE AND COLLECTIVE PITCH

CONSIDER THE AIRCRAFT IN THE HORIZONTAL PLANE, THE THROTTLE CONTROLS THE RPM; THE COLLECTIVE PITCH CONTROLS THE POWER (COLLECTIVE-THROTTLE CAM LINKAGE) OF THE ENGINE, AND ALSO THE MECHANICAL PITCH OF THE MAIN ROTOR. BETWEEN THE TWO THEY DETERMINE THE THRUST OF THE AIRCRAFT, AND IN CONJUNCTION WITH THE WEIGHT AND INERTIA OF THE AIRCRAFT ITS VERTICAL SPEED AND ACCELERATION. AS THE AXIS OF ROTATION IS TILTED FROM THE VERTICAL THE POWER HELPS DETERMINE THE SPEED AND ACCELERATION OF THE AIRCRAFT IN FORE-AND LATERAL DIRECTIONS, HENCE, THROTTLE AND MAIN ROTOR PITCH PROVIDE THE POWER FOR THE FLIGHT OF THE AIRCRAFT IN THE THREE TRANSLATIONAL FREEDOMS.

B. DIRECTIONAL CONTROL PEDALS

DIRECTIONAL CONTROL OF THE AIRCRAFT IS ACCOMPLISHED BY DIRECTIONAL CONTROL PEDALS (SIMILAR TO RUDDERS) WHICH GOVERN THE PITCH OF THE TAIL ROTOR. CONTROL IS COMPLICATED BY TORQUE WHICH VARIES WITH THE SPEED OF THE MAIN ROTOR. THE DIRECTIONAL CONTROL PEDALS CONTROL THE HTL IN THE ROTATIONAL OR YAW FREEDOM.

C. CYCLIC PITCH

THE CYCLIC PITCH CONTROL PREDOMINANTLY CONTROLS THE MOVEMENT OF THE AIRCRAFT WITHIN THE PITCH AND ROLL AND FORWARD-REARWARD AND LATERAL MOVEMENT FREEDOMS. MOVEMENT OF THE CYCLIC IN THE PITCH AND ROLL DIMENSIONS TILTS THE TIP-PATH-PLANE OF THE MAIN ROTOR FROM THE VERTICAL. THIS MOVEMENT OF THE CYCLIC CONTROL GIVES DIRECTIONAL THRUST WHICH PRODUCES TRANSLATIONAL MOVEMENT IN THE DIRECTION IN WHICH THE CYCLIC IS MOVED. FUNDAMENTALLY THE AIRCRAFT FOLLOWS THE TILT OF THE ROTOR.

AS STATED EARLIER, THE POWER AND BLADE PITCH DETERMINE THE VERTICAL THRUST AND HENCE, THE LIFT OF THE AIRCRAFT. HOWEVER, AS TRANSLATIONAL MOVEMENT BECOMES FASTER, THE SPEED OF THE AIRCRAFT GIVES ADDED LIFT TO THE ROTOR BLADES; THIS IS CALLED TRANSLATIONAL LIFT. A USEFUL DISTINCTION CAN THEN BE MADE

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BETWEEN LOW SPEED OR HOVERING MANEUVERS IN WHICH LIFT IS PROVIDED PRIMARILY BY THE ROTATION OF THE MAIN ROTORS AND MANEUVERS IN WHICH EFFECTIVE TRANSLATIONAL LIFT COMES INTO PLAY, AS DISCUSSED LATER.

IN SUMMARY, THE MOVEMENT OF THE AIRCRAFT WITHIN THE SIX PARAMETERS IS DETERMINED BY THE MOVEMENT AND COORDINATION OF THE FOUR CONTROLS. BECAUSE OF THE TORQUE OF THE ROTOR, THE CONFIGURATION OF THE AIRFOIL, AND EXTERNAL AND OTHER CONDITIONS, THE RELATIONSHIP BETWEEN CONTROL MOVEMENTS AND MOVEMENT OF THE AIRCRAFT IS BY NO MEANS CONSTANT OR RECTILINEAR. THE TRAINEE THEREFORE MUST LEARN FOR EACH CONTROL ITS LAG AND THE AMOUNT OF MOVEMENT REQUIRED TO EXECUTE PROPERLY TASKS A GIVEN MANEUVER REQUIRES.

INTEGRATION OF VISUAL INFORMATION WITH MOTOR RESPONSES

THIS DISCUSSION OF FREEDOMS AND CONTROLS NECESSARILY PUTS EMPHASIS ON THE MOTOR COMPONENTS OF THE FLIGHT TASK; OF EQUAL OR GREATER CONCERN FOR THIS STUDY IS THE QUALITY OF INFORMATION AVAILABLE TO THE SENSORY RECEPTORS. THIS CONTINUOUS FLOW OF INFORMATION-FEEDBACK ALLOWS THE PILOT TO CLOSE THE LOOP, I.E., TO NOTE HOW THINGS ARE GOING AND TO ADJUST THE FLIGHT PATH OF THE AIRCRAFT. THE PILOT ACQUIRES THIS INFORMATION BY ATTENDING TO AND INTERPRETING VISUAL, AURAL, AND PROPRIOCEPTIVE STIMULI. SINCE THE 2-FH-2 PRIMARILY PROVIDES A VISUAL DISPLAY, ONLY VISUAL STIMULI ARE CONSIDERED HERE.

THE MOTOR RESPONSES OF THE PILOT MAY BE VIEWED AS THE RESULT OF DECISIONS WHICH THE PILOT MAKES (HOWEVER RAPIDLY) ON THE BASIS OF SENSORY INFORMATION HE RECEIVES. WITH RESPECT TO VISUAL INFORMATION, THE DECISIONS CAN BE CONVENIENTLY CLASSIFIED ACCORDING TO:

1. CHANGES IN THE POSITION OF THE AIRCRAFT IN THREE-DIMENSIONAL SPACE, WITH PARTICULAR REFERENCE TO AN

APPARENT PLANE (SURFACE OF EARTH) IN ONE DIMENSION.

(DEGREES OF FLIGHT FREEDOM INVOLVED: TRANSLATIONAL
FORE-AFT, LATERAL AND VERTICAL.)

2. CHANGES IN THE AXIAL ORIENTATION OF THE AIRCRAFT
IN THREE-DIMENSIONAL SPACE, AGAIN WITH PARTICULAR
REFERENCE TO THE SURFACE OF THE EARTH. (DEGREES
OF FLIGHT FREEDOM INVOLVED: ROTATIONAL PITCH, YAW
AND ROLL.)

3. RATES OF CHANGES IN 1 AND 2 ABOVE. (SPEED AND
ACCELERATION PARAMETERS.)

THE FUNDAMENTAL PROBLEM IS TO ACCOUNT FOR THE WAY IN WHICH DECISIONS OF THE
THREE TYPES ABOVE ARE MADE ON THE BASIS OF VISUALLY MEDIATED INFORMATION. PRIOR
RESEARCH AND OPERATIONAL EXPERIENCE MAKE IT APPARENT THAT THERE IS NO SINGLE
SET OF NECESSARY AND SUFFICIENT VISUAL CUES. INFORMATION CAN BE ACQUIRED FROM
CUES:

- A. ORIGINATING IN INSTRUMENTS WITHIN THE COCKPIT,
E.G., YACH, AIRSPEED, ALTITUDE.
- B. ORIGINATING IN THE "WORLD" EXTERNAL TO THE COCKPIT,
E.G., SURFACE AND OBJECT CUES.
- C. ORIGINATING IN VISUAL FIELD RELATIONSHIPS BETWEEN
THE AIRCRAFT STRUCTURES (E.G., COCKPIT FRAME, BUBBLE,
ANTENNA, ETC.) AND OBJECTS IN THE EXTERNAL ENVIRONMENT.

THUS A "CUE" MAY BE DEFINED AS A CRITICAL RESPONSE-INDUCING STIMULUS,
WHICH STIMULUS MAY BE ONE OF SEVERAL TYPES:

- (1) FUNDAMENTAL OR BASIC PROPERTIES OF THE VISUAL FIELD,
E.G., PERCEIVED TEXTURE OF SURFACES, CONTOURS OF

OBJECTS, MOTION PERSPECTIVE OF VISUAL FIELD ITSELF,
AND OF THE HUMAN ORGANISM, E.G., RETINAL DISPARITY.

- (2) PERCEIVED VALUE OF EXTRA-CLASS CHARACTERISTICS OF
OBJECTS AND RELATIONSHIPS OF OBJECTS IN VISUAL FIELD,
E.G., CHANGES IN SIZE AND SHAPE OF OBJECTS, INTER-
POSITION, ETC., WHICH CHANGES ARE CORRELATED WITH
CHANGES IN POSITION, AXIAL ORIENTATION, AND RATES
OF CHANGES ON THE BASIS OF PAST EXPERIENCE.
- (3) ANALOGUE OBJECTS (E.G., AIR SPEED), WHICH GIVE
INFORMATION IN DIRECT FASHION.

THE ABOVE PRIMARY INFORMATIONAL CONTENT OF THE VISUAL FIELD MAY NOT ALWAYS
BE UTILIZED IN THE WAYS SUGGESTED ABOVE, BUT RATHER ACCORDING TO "EXPECTANCIES"
AS DISCUSSED BELOW.

THE COMPLETELY PROFICIENT PILOT KNOWS, FOR ANY MANEUVER, HOW THE PLANE WILL
RESPOND TO THE MOVEMENT OF THE CONTROLS. HE KNOWS WHAT CUES TO ATTEND TO IN
ORDER TO OBTAIN ACCURATE INFORMATION AS TO HIS POSITION, SPEED AND RATE OF
MOVEMENT SO AS TO DIRECT HIS AIRCRAFT PROPERLY. HE HAS LEARNED - ONE MIGHT SAY
HE HAS IN HIS HEAD - AN APPROPRIATE SET OF EXPECTATIONS. HE KNOWS WHAT HIS
ENVIRONMENT OUGHT TO LOOK LIKE. HE FLIES THE AIRCRAFT SO THAT AT ANY TIME IN
FLIGHT, HE MAKES HIS PERCEIVED ENVIRONMENT CONFORM TO THE LEARNED, EXPECTED
ENVIRONMENT BY MAKING CONTROL CHANGES TO MOVE THE AIRCRAFT FROM ONE DESIRED SET
OF CUE CONDITIONS TO THE NEXT, MEANWHILE CORRECTING ANY DISCREPANCIES BETWEEN
HIS ACTUAL VISUAL PICTURE AND HIS EXPECTATION SET BEFORE SUCH DISCREPANCIES
BECOME LARGE.

IT SHOULD BE RECOGNIZED THAT THE OBJECTS IN THE VISUAL FIELD ARE HIGHLY
REDUNDANT, THAT IN MOST INSTANCES THE PILOT HAS MANY MORE CUES THAN HE NEEDS.

THE COMPLETELY PROFICIENT PILOT WILL KNOW HOW TO SORT CUES SO AS TO SELECT THOSE THAT WILL EFFICIENTLY GIVE HIM THE REQUIRED INFORMATION WITH RESPECT TO HIS POSITION, AXIAL ORIENTATION, AND MOVEMENT WITHIN THE FREEDOMS. HE HAS ACQUIRED THE PROPER SCANNING HABITS.

IT FOLLOWS THAT THE OBJECTIVES OF TRAINING - MAKING AN INEXPERIENCED PILOT INTO AN EXPERIENCED ONE - ARE TO:

- (A) TEACH CORRESPONDENCE BETWEEN CONTROL MOVEMENTS AND MOVEMENT OF AIRCRAFT.
- (B) BUILD APPROPRIATE EXPECTATIONS.
- (C) TEACH SELECTION OF APPROPRIATE CUES FOR EVALUATING DISCREPANCIES BETWEEN THE ACTUAL AND EXPECTED VISUAL INFORMATION.
- (D) TEACH MOTOR SKILLS OR HABITS SO THAT THE PILOT CAN MANEUVER THE AIRCRAFT SO THAT HIS ACTUAL PERCEPTIONS CONFORM TO HIS EXPECTATIONS.

THE OBJECTIVE OF PRESENT PROFICIENCY TESTING WAS TO DETERMINE WHAT DEGREE OF PROFICIENCY HAD BEEN REACHED IN THESE SKILLS.

WORKING HYPOTHESES

FROM THE PRECEDING DISCUSSION OF THE TASK OF THE HELICOPTER PILOT, AND INSTRUCTORS' AND STUDENTS' RANKINGS OF MANEUVERS, CONTROLS, CONTROL COORDINATIONS AND ERRORS, ONE CAN ESTABLISH CERTAIN WORKING HYPOTHESES THAT SERVE TWO PURPOSES. FIRST, THEY HELP EXPLAIN THE RANKINGS WITHIN A MINIMAL SET OF CONCEPTS. SECOND, THEY GUIDE THE SELECTION OF TASKS AND DISTRIBUTION OF TIME IN THE TRAINING SYLLABUS AND THE FLIGHT CHECK.

WHILE THE TREATMENT IS, OF COURSE, NOT EXHAUSTIVE, A STATEMENT OF WORKING

HYPOTHESES ON WHICH THE TRAINING AND TESTING WAS PREDICATED FOLLOWS

- A. THE PILOT SHOULD BE TRAINED AND TESTED ON THE CONTROL OF THE HELICOPTER IN ALL FLIGHT FREEDOMS.
- B. MANEUVERS MAY BE DIVIDED INTO TWO KINDS; THOSE THAT INVOLVE EFFECTIVE TRANSLATIONAL LIFT (TRANSITION TO FORWARD FLIGHT, NORMAL APPROACH, GLIDES, TURNS, ETC.) AND THOSE THAT DO NOT (HOVERING, VERTICAL LANDINGS, TURNS ON A SPOT, SQUARES, ETC.). THE FIRST TYPE OF MANEUVER IS REASONABLY FAMILIAR TO STUDENTS OF HTU-1 ALL OF WHOM ARE FIXED WING PILOTS. AS INDICATED IN THE BACKGROUND INFORMATION, THE HTU-1 STUDENT HAS LITTLE DIFFICULTY WITH MOST OF THESE MANEUVERS. HIS LEARNED FIXED WING EXPECTATIONS ARE EASILY MODIFIED TO ENABLE HIM TO PERFORM THESE MANEUVERS. CONSEQUENTLY, GREATEST EMPHASIS WAS PLACED ON MANEUVERS OF THE SECOND TYPE. THESE ARE EXECUTED NEAR THE GROUND. THE FIXED WING PILOT NEEDS TO BE TAUGHT THE PERCEPTUAL EXPECTATIONS AND THE MOTOR HABITS THAT WILL ENABLE HIM TO PERFORM THEM PROPERLY.
- C. A TIME DELAY BETWEEN THE MOVEMENT OF A CONTROL AND THE RESPONSE OF THE AIRCRAFT INCREASES THE DIFFICULTY OF THE TASK WITH WHICH THIS DELAY IS ASSOCIATED. IN THE HTL THERE IS A MARKED LAG IN THE RESPONSE TO BOTH THE CYCLIC CONTROL, WHICH IS INSTRUMENTAL IN GOVERNING THE MOVEMENT OF THE AIRCRAFT IN FOUR OF THE SIX MOVEMENT FREEDOMS, AND THE THROTTLE. SPECIAL EMPHASIS WAS

PLACED ON CYCLIC LAG IN TRAINING. CERTAIN LACKS OF FIDELITY IN THE CORRELATION BETWEEN MOVEMENT OF THE THROTTLE AND COMPENSATORY ENVIRONMENTAL CHANGES IN THE 2-FH-2 MADE IT SEEM DESIRABLE NOT TO PLACE TOO MUCH EMPHASIS ON THROTTLE CONTROL IN THE 2-FH-2.

D. THE DIFFICULTY IN LEARNING A MANEUVER IS CLOSELY ASSOCIATED WITH THE PRECISION WITH WHICH IT MUST BE PERFORMED. FOR EXAMPLE, THE VERTICAL LANDING WHICH REQUIRES TOUCHDOWN WITH NO SKIDDING OR FORE-AFT MOVEMENT IS MORE DIFFICULT TO PERFORM THAN THE VERTICAL TAKE-OFF. IN THE LATTER MANEUVER, THE WEIGHT OF THE AIRCRAFT TENDS TO PREVENT MOVEMENT BEFORE THE CRAFT IS AIRBORNE AND ONCE AIRBORNE TOLERANCES ARE NOT SO STRINGENT. PRECISE CONTROL MANIPULATIONS AND MANEUVERS THAT REQUIRE THEM WERE EMPHASIZED IN THE TRAINING SYLLABUS AND MEASURED IN THE FLIGHT CHECK.

E. HOVERING IS THE MOST DIFFICULT MANEUVER FOR THE NEW STUDENT. THIS IS LIKELY TRUE FOR FOUR REASONS:

1. SINCE IT IS A NEAR GROUND MANEUVER IT MUST BE PERFORMED PRECISELY.
2. THE PILOT MUST COUNTER THE INHERENT INSTABILITY OF THE AIRCRAFT, ACCENTUATED IN THIS CASE BY CONTINUOUS VARIATIONS IN THE "BLOW BACK" FROM THE GROUND CUSHION.
3. THE HOVER DIFFERS FROM ALL FIXED WING MANEUVERS IN THAT THE SAME LOCUS OF THE PLANE IS MAINTAINED.

IT IS THE ONLY MANEUVER WHICH REQUIRES DECISIONS, AND THUS CONTROL MOVEMENTS TO MAINTAIN A ZERO RATE OF CHANGE OF CUES IN THE PILOT'S EXTRA-COCKPIT VISUAL FIELD. THE PILOT CANNOT DO THIS BY LOOKING AT ONLY ONE OBJECT SINCE BY SO DOING HE DOES NOT RECEIVE SUFFICIENT INFORMATION TO SOLVE THE EQUATIONS NECESSARY TO MAINTAIN THE POSITION OF THE PLANE WHEN IT CAN MOVE SIMULTANEOUSLY IN ALL FREEDOMS.

4. THESE DIFFICULTIES COMBINE WITH THE LAG IN THE CYCLIC CONTROL TO ENCOURAGE OVER-CONTROLLING IN THE HOVER.

FOR THE ABOVE REASONS TRAINING EMPHASIS IS GIVEN TO HOVERING AND NEAR-GROUND MANEUVERS, AND TO DEVELOPMENT OF SCANNING HABITS THAT WILL PROPERLY INTEGRATE VISUAL CUES.

- F. AMONG THE MORE DIFFICULT MANEUVERS OR TASK ELEMENTS ARE THOSE WHEREIN THE MANIPULATION OF ONE CONTROL PRODUCES A COMPENSATORY MOVEMENT IN A PARAMETER OTHER THAN THAT GOVERNED BY THE CONTROL. CONSIDER, FOR EXAMPLE, TURNS ON A SPOT. BECAUSE OF PITCH CHANGE ON THE TAIL ROTOR, TURNS TO THE RIGHT TEND TO CAUSE THE RPM TO INCREASE, TURNS TO THE LEFT TEND TO CAUSE THE RPM TO DECREASE. THESE RPM CHANGES, IF NOT COMPENSATED, INCREASE OR DECREASE THE LIFT OF THE MAIN ROTOR, HENCE, THE ALTITUDE OF THE AIRCRAFT. THEREFORE, COMPENSATORY THROTTLE AND

COLLECTIVE CONTROL ADJUSTMENTS ARE REQUIRED. TASK
ELEMENTS WHEREIN THE PROPER MANIPULATION OF ONE
CONTROL CALLS FOR A COMPENSATORY MOVEMENT OF OTHERS
WERE EMPHASIZED.

IN SUMMARY, INFORMATION PROVIDED BY INSTRUCTORS AND STUDENTS WAS CONSIDERED
IN SEVERAL CONTEXTS IN THE DEVELOPMENT OF THE TRAINING SYLLABUS AND THE FLIGHT
CHECK. CONSIDERATIONS OF THE SIX FREEDOMS PROVIDED A MEANS OF CLASSIFYING
MANEUVERS AND ASSURED THAT EACH WAS COVERED IN THE TRAINING AND TESTING. BY
RELATING FREEDOMS TO CONTROLS, PROCEDURES COULD BE SPECIFIED AND MANEUVER TASKS
LIKELY TO PROVE MOST DIFFICULT COULD BE IDENTIFIED. THESE COULD BE STRESSED IN
TRAINING. IN ADDITION, CONSIDERATION OF POSITION, PATH AND AXIAL ORIENTATION OF
THE AIRCRAFT WITH RESPECT TO THE GROUND, AND THE SMOOTHNESS OF CONTROL MANIPULA-
TION PROVIDED TWO CONTEXTS FOR EVALUATION IN THE FLIGHT CHECK. BY DIVIDING
MANEUVERS INTO THOSE ASSOCIATED WITH EFFECTIVE TRANSLATIONAL LIFT AND THOSE THAT
ARE NOT; EMPHASIS WAS PLACED ON INSTRUCTION IN CONTROLS AND CONTROL RESPONSES
UNFAMILIAR TO THE FIXED WING PILOT. INSTRUCTION IN SUCH CONTROL RESPONSES WAS
GIVEN SPECIAL TRAINING EMPHASIS AND THE MANNER IN WHICH THESE CONTROLS WERE
COORDINATED WAS MEASURED IN THE FLIGHT CHECK. FINALLY, EXAMINATION OF THE
VARIOUS TYPES OF CUES HELPED TO DESCRIBE THE SCANNING HABITS WHICH THE TRAINING
SYLLABUS SOUGHT TO DEVELOP. THE ABOVE CONSIDERATIONS PROVIDED THE BASIS FOR THE
USE OF THE BACKGROUND MATERIAL IN THE TRAINING SYLLABUS AND THE FLIGHT CRITERION.

III. THE TRAINING SYLLABUS

THE TRAINING SYLLABUS WAS INTENDED TO MAXIMIZE LEARNING OF THE MORE CRITICAL CONTENT AS REVEALED BY RELATED MATERIALS (5 & 6) AND AS DETERMINED FROM THE BACKGROUND MATERIAL AND FROM ITS ANALYSIS PRESENTED IN SECTION II. THE FOLLOWING GUIDES WERE USED:

- A. EMPHASIS WAS PLACED ON THE MANEUVERS WHICH INSTRUCTORS AND STUDENTS JUDGED MOST DIFFICULT TO LEARN.
- B. ESSENTIAL TRAINING POINTS WERE IDENTIFIED FROM 1) EVALUATIONS OF THE DIFFICULTY OF USING CONTROLS PROPERLY AND OF EFFECTING PROPER COORDINATION OF CONTROLS, AND 2) ERROR RANKINGS.
- C. VISUAL CUES AND CUE CONDITIONS (SEE APPENDICES A & B) THAT PROVIDE THE MOST EFFECTIVE FEED-BACK WERE IDENTIFIED FOR EACH MANEUVER. THIS MATERIAL WAS USED TO TEACH SCANNING HABITS AND TO TEACH STUDENTS TO CORRELATE CONTROL MOVEMENTS AND CUES.

ON THE BASIS OF THE ABOVE INFORMATION AND THE RATIONALE DISCUSSED IN SECTION II, THE TRAINING SYLLABUS WAS OUTLINED AND DISCUSSED WITH HTU-1 INSTRUCTORS. THEIR SUGGESTIONS WERE NOTED AFTER WHICH THE PROGRAM WAS DELINEATED FURTHER. THIS INITIAL PROGRAM WAS LIMITED IN COVERAGE TO THE MANEUVERS THAT COULD BE TAUGHT WITH THE LOW ALTITUDE TRANSPARENCY PLATE. UPON RECOMMENDATION OF INSTRUCTORS (SEE APPENDIX A), WIND VELOCITY AND GUSTS WERE INTRODUCED IN THE LATER PERIODS. THESE COULD BE ADJUSTED TO THE LEARNING RATE, SINCE THE ADDITION OF WIND SERVES TO MAKE THE MANEUVER MORE DIFFICULT. DURING INITIAL PRETESTS OF THE SYLLABUS 2-FH-2 MALFUNCTIONS DELAYED THE PROJECT SEVERAL WEEKS. MEANWHILE,

THE HIGH-ALTITUDE PLATE WAS INSTALLED AND ADDITIONAL LESSONS WERE DEVELOPED TO TAKE ADVANTAGE OF ITS CAPABILITIES.

THE AMPLIFIED TRAINING SYLLABUS CONSISTED OF TWELVE 30 MINUTE SESSIONS. THE SYLLABUS WAS PRETESTED BY THREE INSTRUCTORS WHO TRAINED FIVE STUDENTS. THE PRETESTINGS SERVED TO CHECK ON THE PACE OF INSTRUCTION, TO ELIMINATE "BUGS", TO TRAIN INSTRUCTORS FURTHER AND TO MAKE SURE THE SYLLABUS COULD BE SCHEDULED AND ADMINISTERED PRACTICALLY. INSTRUCTOR AND STUDENT COMMENTS WERE RECORDED AFTER EACH LESSON. IN GENERAL, THE SYLLABUS WAS FOUND SATISFACTORY. HOWEVER, A CONSIDERABLE NUMBER OF SUGGESTIONS HELPED IMPROVE THE REVISED PROGRAM WHICH IS FOUND IN APPENDIX D. EIGHT OF THE TRAINING PERIODS INCLUDE MANEUVERS TAUGHT NEAR THE GROUND AND MAKE USE OF THE LOW-ALTITUDE TRANSPARENCY PLATE. THE GREATER FLY-ROOM PROVIDED BY THE HIGH-ALTITUDE PLATE WAS UTILIZED FOR FOUR PERIODS TO PROVIDE INSTRUCTION IN MANEUVERS ASSOCIATED WITH EFFECTIVE TRANSLATIONAL LIFT. THUS, SUBSTANTIALLY ALL MANEUVERS TAUGHT IN A-STAGE OF HTU-1 ARE INCLUDED.

THE SYLLABUS CONSISTS OF FIVE STAGES OF INSTRUCTION:

1. ORIENTATION AND FAMILIARIZATION. (PERIOD 1)
2. PRACTICE WITH INDIVIDUAL CONTROLS. (PERIODS 1 & 2)
3. PRACTICE IN NEAR-GROUND MANEUVERS. (PERIODS 3 - 8)
4. PRACTICE IN MANEUVERS ASSOCIATED WITH EFFECTIVE
TRANSLATIONAL LIFT. (PERIODS 9 & 10)
5. DIAGNOSIS AND CORRECTION OF ERRORS AND FINAL CRITIQUE.
(PERIODS 11 & 12)

THE SYLLABUS WAS PREPARED FOR BOTH INSTRUCTOR AND STUDENT. ESSENTIAL POINTS OF EACH PERIOD OF INSTRUCTION (TYPED ON 5 X 8 CARDS) SERVED AS GUIDES FOR INSTRUCTORS. IN ADDITION, AT THE COMPLETION OF EACH INSTRUCTION PERIOD, THESE POINTS PROVIDE A BASIS FOR A STUDENT CRITIQUE. RECOGNIZED PRINCIPLES OF GOOD

PEDAGOGY SUCH AS THOSE LISTED BELOW WERE FOLLOWED:

- A. THE BURDEN OF LEARNING IS PLACED ON THE STUDENT. HE IS RESPONSIBLE FOR UNDERSTANDING THE SYLLABUS AND THE STANDARDIZATION MANUAL SO THAT HE IS PREPARED TO TALK THROUGH THE CONTENT OF EACH LESSON.
- B. FLEXIBILITY OF INSTRUCTION IS PROVIDED BY ALLOCATING TIME AT THE END OF EACH INSTRUCTION PERIOD FOR THE INSTRUCTOR AND STUDENT TO CONCENTRATE ON PARTICULAR DIFFICULTIES ENCOUNTERED BY THE STUDENT.
- C. FLIGHT IS "FROZEN" AND STUDENTS CRITIQUES ARE GIVEN AS REQUIRED. IN ADDITION, STUDENTS ARE CRITIQUED AT THE END OF EACH PERIOD.
- D. EMPHASIS IS PLACED UPON BREAKING MALADAPTIVE FIXED-WING HABITS SUCH AS THE HABIT (ESPECIALLY STRONG IN NAVY PILOTS) OF BRINGING THE STICK FULL BACK ON LANDING.

FROM COMMENTS OF HTU-1 INSTRUCTORS AND STUDENTS TRAINED IN THE 2-FH-2, IT IS BELIEVED THAT THE TRAINING SYLLABUS SATISFACTORILY EXPLOITS THE PRESENT CAPABILITIES OF THE DEVICE.

IV. THE CRITERION

THE CRITERION CONSISTS OF A FLIGHT CHECK. IT WAS USED TO ASSESS THE TRAINING CAPABILITIES OF THE SIMULATOR BY COMPARING PERFORMANCE OF STUDENTS WHO WERE TRAINED IN THE 2-FH-2 WITH THE PERFORMANCE OF COMPARABLE STUDENTS HAVING NO SUCH EXPERIENCE. THE BACKGROUND MATERIAL DISCUSSED IN SECTION II HELPED DETERMINE THE CRITERION CONTENT; RESEARCH REPORTS WERE OF ASSISTANCE IN DEVELOPING TECHNIQUES OF EVALUATION (4, 8, 15 & 16). MANEUVERS WERE SELECTED FROM THOSE JUDGED MOST DIFFICULT AND CRITICAL. APPLICATION OF THE CONCEPT OF FLIGHT FREEDOMS ALLOWED SELECTION OF MANEUVERS TO PROVIDE COVERAGE OF THE PILOT'S ABILITY TO OPERATE THE AIRCRAFT IN EACH FLIGHT PARAMETER AND IN THE MORE COMMON COMBINATIONS OF PARAMETERS. STUDY OF THE DIFFICULTY OF MANIPULATING THE VARIOUS CONTROLS AND AN EXAMINATION OF THE MORE CRITICAL ERRORS PERMITTED CRITICAL SKILL REQUIREMENTS TO BE IDENTIFIED. THE MANEUVERS SELECTED WERE:

- A. HOVERING
- B. VERTICAL TAKE-OFF AND VERTICAL LANDING
- C. CONSTANT HEADING SQUARES
- D. TURNS ON A SPOT
- E. NORMAL APPROACH

THE MANEUVER RANKS, THE MORE DIFFICULT CONTROLS AND CONTROL COORDINATIONS, AND THE MORE CRITICAL ERRORS ASSOCIATED WITH EACH MANEUVER CAN BE FOUND IN APPENDICES A, B AND C.

A PRELIMINARY DRAFT OF THE FLIGHT CHECK WAS DEVELOPED, DISCUSSED WITH INSTRUCTORS, AND MODIFIED ACCORDING TO THEIR SUGGESTIONS. THE CHECK LIST WAS REDUCED TO KNEE-PAD SIZE FOR SAFE AND EFFICIENT ADMINISTRATION. FOUR INSTRUCTORS PRETESTED THE FLIGHT CHECK IN THE AIR BY ADMINISTERING IT TO THEIR STUDENTS.

INSTRUCTOR RATINGS AND COMMENTS WERE SUMMARIZED WITH RESPECT TO HOW APPROPRIATELY ITEMS DESCRIBED LEVELS OF PERFORMANCE OF BEHAVIOR BEING EVALUATED, THEIR COMPREHENSIVENESS, AND THE PRACTICALITY OF USING THE CHECK FORM AS PRESCRIBED. IN ADDITION, INSTRUCTOR RATINGS ON THE COMPLETED FORMS WERE EXAMINED TO DETERMINE WHETHER ALL ITEM CATEGORIES WERE BEING USED, AND HENCE, WHETHER ITEMS COULD REASONABLY BE EXPECTED TO DISCRIMINATE BETWEEN EFFECTIVE AND INEFFECTIVE PERFORMANCE. SEVERAL CHANGES WERE MADE IN ITEMS AND FORMAT ON THE BASIS OF PRETESTS. STANDARD NAVAL ABBREVIATIONS AND PHONETIC SPELLINGS WERE USED IN THE FORMAT. THIS MADE IT POSSIBLE TO RATE EACH MANEUVER ON A SINGLE PAGE. SINCE THE CHECK PILOT MUST ALSO ACT AS A SAFETY PILOT, THE ABRIDGED FORM IS MUCH EASIER FOR HIM TO HANDLE.

THE FINAL FORM OF THE FLIGHT CHECK IS PRESENTED AS APPENDIX E. THE NATURE OF THE ITEMS REFLECTS SOME OF THE DIFFICULTIES INHERENT IN ACCURATE EVALUATION OF HELICOPTER FLIGHT. MOST CRITERION MANEUVERS ARE PERFORMED NEAR THE GROUND AT LOW AIRSPEEDS AND WITH SMALL ALTITUDE TOLERANCES. IN SUCH MANEUVERS THE AIRSPEED INDICATOR AND ALTIMETER ARE PRACTICALLY USELESS. PERFORMANCES IN THESE PARAMETERS WERE EVALUATED SUBJECTIVELY. CRITERION ITEMS ARE OF THREE SORTS:

1. RELATIVELY OBJECTIVE MEASURES WHEREIN THE CHECK PILOT RECORDS THE READINGS OF COCKPIT INSTRUMENTS. THIS TYPE OF ITEM IS, OF COURSE, REGARDED AS MOST RELIABLE AND HENCE, MOST DESIRABLE. READINGS OF THE COMPASS AND TACHOMETER WERE USED AND AIRSPEED READINGS WERE RECORDED IN THE TRANSLATIONAL LIFT PORTION OF THE NORMAL APPROACH.
2. SUBJECTIVE RATINGS OF THE CORRECTNESS OF THE ALTITUDE, POSITION OR TRACK OF THE PLANE WITH REGARD TO SOME

GROUND REFERENCE POINT.

3. SUBJECTIVE EVALUATIONS OF THE SMOOTHNESS WITH WHICH
THE STUDENT USED INDIVIDUAL CONTROLS OR EFFECTED
CONTROL COORDINATIONS.

EVALUATIONS OF ALL THREE TYPES ARE USED WITH EMPHASIS UPON THOSE TASK COMPONENTS INDICATED FROM BACKGROUND MATERIALS AS MOST CRITICAL. TO AVOID, INsofar AS POSSIBLE, THE LACK OF DISCRIMINATION AND RATER BIAS OFTEN ASSOCIATED WITH SUBJECTIVE RATINGS AND TO MAKE SURE THAT CHECK PILOTS USED HIGH AND CONSISTENT STANDARDS OF RATINGS, A SET OF INSTRUCTIONS WAS DEVELOPED WHICH DESCRIBE THE ERRORS COMMONLY ASSOCIATED WITH FLIGHT RATINGS. THESE INSTRUCTIONS ARE APPENDED IN THE FIRST PAGES OF APPENDIX E.

THE CRITERION YIELDS AN OVERALL SCORE AND PROVIDES MEANS FOR COMPUTATION OF A NUMBER OF SUBSCORES. ADMINISTRATION OF THE CRITERION AND THE COMPARISON OF CONTROL AND EXPERIMENTAL STUDENTS WITH RESPECT TO VARIOUS CRITERION SUBSCORES IS DISCUSSED IN THE NEXT SECTION.

V. ADMINISTRATION OF TRAINING SYLLABUS AND CRITERION

GENERAL CONSIDERATIONS

CONSIDERATION WAS GIVEN TO THE MANNER IN WHICH THE TRAINING SYLLABUS AND FLIGHT CRITERION SHOULD BE ADMINISTERED. SEVERAL RESEARCH DESIDERATA AND OPERATIONAL LIMITATIONS HAD TO BE KEPT IN MIND:

- A. THIRTY-SIX STUDENTS WERE OBTAINED FOR THE STUDY; HALF OF THESE COULD BE UTILIZED FOR SIX HOURS OF TRAINING IN THE 2-FH-2. THIS HALF WOULD BE DESIGNATED AS EXPERIMENTAL SUBJECTS, THE OTHER HALF AS CONTROL SUBJECTS.
- B. THE EVALUATION PROGRAM SHOULD INTERFERE AS LITTLE AS POSSIBLE WITH OPERATIONAL SCHEDULES.
- C. SAFETY PRECAUTIONS REQUIRED ALL SUBJECTS TO HAVE SOME HTL FLIGHT TRAINING BEFORE THE FLIGHT CHECK COULD BE ADMINISTERED.
- D. IF THE 2-FH-2 IS AN EFFECTIVE TRAINING DEVICE, AS MORE AND MORE IN-FLIGHT HOURS ARE INTERSPERSED BETWEEN 2-FH-2 TRAINING AND ADMINISTRATION OF THE FLIGHT CRITERION, THE MORE DIFFICULT IT BECOMES TO ASSESS THE DEGREE OF TRANSFER. THIS CONSIDERATION WAS BALANCED AGAINST THE ONE JUST ABOVE WITH THE RESULT THAT FOUR HOURS OF FLIGHT TRAINING WERE ADMINISTERED BETWEEN THE ADMINISTRATION OF THE TRAINING SYLLABUS AND THE FLIGHT CRITERION.

SEVERAL DESIGNS FOR THE EVALUATION WERE CONSIDERED. ONE INVOLVED INTERSPERSING 2-FH-2 TRAINING PERIODS BETWEEN HOURS OF FLIGHT INSTRUCTION; PART OF

THE FLIGHT TRAINING PERIOD COULD BE USED TO ADMINISTER FLIGHT CHECKS COVERING MANEUVERS JUST PRACTICED IN THE 2-FH-2. THE TIME, OR THE NUMBER OF TRIALS REQUIRED TO REACH AN ACCEPTABLE CRITERION, COULD THEN BE USED AS THE MEASURE OF THE EFFECTIVENESS OF SIMULATOR TRAINING IN THAT MANEUVER (8). THIS METHOD COULD NOT BE IMPLEMENTED OPERATIONALLY. A BLOCK TRAINING METHOD WHICH CONSISTED OF GIVING ALL TRAINING IN THE 2-FH-2 PRIOR TO FLIGHT TRAINING WAS THEREFORE UTILIZED. THERE IS SOME EVIDENCE TO THE EFFECT THAT THIS METHOD UTILIZES SIMULATORS MORE EFFECTIVELY (3, 13 & 14).

TWO ALTERNATIVE METHODS FOR EQUATING TRAINING TIME OF EXPERIMENTAL AND CONTROL SUBJECTS WERE CONSIDERED. (AS STATED EARLIER SOME FLIGHT TRAINING HAD TO BE GIVEN TO BOTH GROUPS BEFORE THE CRITERION WAS ADMINISTERED). BY ONE METHOD, TOTAL TIME WOULD BE EQUATED; I.E., 2-FH-2 TIME PLUS FLIGHT TIME FOR EXPERIMENTALS WOULD BE EQUATED TO FLIGHT TIME FOR CONTROLS. BY ANOTHER METHOD, EXPERIMENTALS COULD BE GIVEN A SPECIFIED NUMBER OF TRAINING HOURS IN THE 2-FH-2. EXPERIMENTALS AND CONTROLS WOULD THEN BE GIVEN EQUAL FLIGHT TIME PRIOR TO ADMINISTRATION OF THE FLIGHT CRITERION.

THE LATTER PROCEDURE WAS FOLLOWED BECAUSE OF POSSIBLE AMBIGUITY OF INTERPRETATION OF CERTAIN TYPES OF POSSIBLE RESULTS: IF CRITERION SCORES OF EXPERIMENTALS AND CONTROLS DID NOT DIFFER SIGNIFICANTLY, THE TRAINING VALUE OF THE 2-FH-2 WOULD HAVE TO BE ASSUMED TO BE EQUIVALENT TO THAT OF THE SAME NUMBER OF HOURS OF FLIGHT TRAINING. ACCEPTANCE OF THIS ASSUMPTION WITHOUT FIRST HAVING ESTABLISHED THAT THE CRITERION ADMINISTERED OPERATIONALLY COULD DISCRIMINATE BETWEEN EFFECTIVE AND INEFFECTIVE PERFORMANCES COULD LEAD TO FAULTY CONCLUSIONS.

ADMINISTRATION OF INSTRUMENTS

THIRTY-SIX SUBJECTS WERE SELECTED, EIGHTEEN EXPERIMENTALS AND EIGHTEEN CONTROLS. SUBJECTS WERE STUDENT PILOTS REPORTING TO HTU-1. TRAINEES VARIED

GREATLY IN THE AMOUNT OF FLIGHT EXPERIENCE. SUBJECTS INCLUDED AVIATION CADETS, NON-DESIGNATED AND DESIGNATED NAVAL AVIATORS. MANY OF THE LATTER WERE OFFICERS WHO HAD HAD EXTENSIVE FLIGHT EXPERIENCE. CONTROL AND EXPERIMENTAL SUBJECTS WERE SELECTED FROM THREE HTU-1 CLASSES: 5-57, 7-57 AND 8-57. SIX EXPERIMENTAL STUDENTS AND SIX CONTROLS WERE SELECTED FROM CLASS 5-57; FOUR OF EACH GROUP FROM CLASS 7-57 AND EIGHT OF EACH GROUP FROM CLASS 8-57. STUDENTS WERE TRAINED AND TESTED AS FOLLOWS*:

SUBJECTS REPORTED FOR TRAINING IN THE 2-FH-2 AFTER THEY HAD BEEN GIVEN THEIR A-1 FAMILIARIZATION FLIGHT AND ON COMPLETION OF GROUND SCHOOL. SUBJECTS WERE THEN ADMINISTERED TWO HALF HOUR LESSONS PER DAY IN THE 2-FH-2 FOR SIX DAYS. INSTRUCTION WAS SPACED SO THAT THERE WAS AT LEAST A THIRTY MINUTE BREAK BETWEEN TRAINING PERIODS ON THE SAME DAY.

2-FH-2 INSTRUCTION WAS ADMINISTERED BY QUALIFIED HTU-1 INSTRUCTORS ASSIGNED TO THE PROJECT.

PRETEST AND TRAINING SCHEDULES WERE HAMPERED BY 2-FH-2 BREAK-DOWNS AND INSTRUCTOR SICKNESS CAUSED BY THE DEVICE.

ALTHOUGH THREE INSTRUCTORS SHOULD HAVE BEEN SUFFICIENT, ELEVEN WERE ASSIGNED; SEVEN OF THESE HAD TO QUIT, PRIMARILY BECAUSE OF SICKNESS. MORE INSTRUCTOR TIME WAS THEREFORE REQUIRED TO CHECK OUT NEW INSTRUCTORS IN THE STANDARDIZED ADMINISTRATION OF THE TRAINING SYLLABUS.

THE FLIGHT CHECK WAS ADMINISTERED AFTER THE STUDENT HAD COMPLETED TRAINING HOUR A-5 AND PRIOR TO TRAINING HOUR A-6. THIS

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- * THIS PROCEDURE WAS FOLLOWED WITH EXCEPTIONS REQUIRED TO COORDINATE THIS STUDY WITH SQUADRON SCHEDULES.

REPRESENTED A COMPROMISE BETWEEN SAFETY ON THE ONE HAND AND ADMINISTRATION OF THE CHECK AS SOON AS POSSIBLE ON COMPLETION OF THE 2-FH-2 TRAINING ON THE OTHER. THERE WERE FOUR FLIGHT CHECK INSTRUCTORS, EACH OF WHOM WAS BRIEFED ON THE CRITERION AND REVIEWED THE INSTRUCTIONS FOR ITS ADMINISTRATION. THE FLIGHT CHECK REQUIRED ABOUT THIRTY MINUTES TO ADMINISTER; THE PLANE WAS LANDED DIRECTLY AFTER EACH MANEUVER SO THAT PERFORMANCE OF THAT MANEUVER COULD BE RATED.

IN ADDITION TO THE FLIGHT CHECK, ADMINISTRATIVE RECORDS CONSISTING OF THE SCORES MADE BY EXPERIMENTAL AND CONTROL SUBJECTS ON THE SQUADRON FLIGHT CHIT REPORTS FOR HOURS A-2 THROUGH HOURS A-5 WERE OBTAINED.

THE RATING FORMS WERE TABULATED SO THAT ANALYSIS COULD BE MADE BY MANEUVER AND BY FLIGHT TASK. SCORING PROCEDURES ARE DESCRIBED NEXT. BOTH SETS OF CRITERION DATA, THAT COLLECTED ON THE FLIGHT CHECK AND THE TRAINING FLIGHT CHIT SCORES, ARE SUMMARIZED IN TABLES 1, 2 AND 3.

SCORING PROCEDURES

PERFORMANCE WAS SCORED AS FOLLOWS: THREE-CATEGORY ITEMS WERE SCORED 2 FOR GOOD OR EFFECTIVE PERFORMANCE, 1 FOR FAIRLY GOOD PERFORMANCE, AND 0 FOR POOR PERFORMANCE. IN THE CONSTANT HEADING SQUARES MANEUVER, REPEATED ITEMS (GROUND SPEED, FOLLOWS TRACK, ANTICIPATES STOPS AND MAINTAINS ALTITUDE) WERE SCORED 1, $\frac{1}{2}$ AND 0. ALL TWO-CATEGORY ITEMS WERE SCORED 2 OR 0.

OCCASIONALLY, INSTRUCTORS HAD TO TAKE OVER THE AIRCRAFT FOR REASONS OF SAFETY, AND WHEN THIS HAPPENED THE WEIGHT OF THE ITEM WAS SUBTRACTED FROM THE SCORE. ITEMS WERE SCORED ZERO DURING TIMES WHEN THE INSTRUCTOR HAD TO KEEP CONTROL OF THE AIRCRAFT.

QUANTITATIVE SCORES WERE CONVERTED INTO THIS SCORING SYSTEM AS FOLLOWS:

COMPASS (OPTIMAL-0° HEADING) SCORE

MAINTAINED HEADING WITHIN 5° - - - - - 2

MAINTAINED HEADING WITHIN 10° - - - - - 1

VARIATIONS GREATER THAN 10° - - - - - 0

AIRSPED IN NORMAL APPROACH (OPTIMAL 45 KNOTS)

WITHIN 42-48 KNOTS - - - - - 2

WITHIN 38-52 KNOTS - - - - - 1

BELOW 38, ABOVE 52 KNOTS - - - - - 0

TACHOMETER (OPTIMAL 3100 RPM)

WITHIN 3050-3150 RPM - - - - - 2

WITHIN 2975-3225 RPM - - - - - 1

BELOW 2975, ABOVE 3225 RPM - - - - - 0

INSTRUCTORS, AT TIMES, EITHER FAILED TO OBSERVE OR FAILED TO RATE ACTIONS COVERED BY SOME ITEMS. VALUES OF THESE ITEMS WERE SUBTRACTED FROM THE TOTAL POSSIBLE SCORE. THIS ACCOUNTS FOR THE DISCREPANCY BETWEEN TOTAL POSSIBLE SCORE IN VARIOUS COMPARISONS.

COMPARISON OF CRITERION SCORES OF EXPERIMENTAL AND CONTROL SUBJECTS

THE SCORES OF EXPERIMENTAL AND CONTROL SUBJECTS ON THE FIVE MANEUVERS AND THE COMPONENT TASKS ARE SUMMARIZED IN TABLES 1 AND 2. COMPARISONS INDICATE THAT TOTAL SCORES ARE SUBSTANTIALLY THE SAME. SCORES MADE BY CONTROL SUBJECTS ON FOUR MANEUVERS AND TOTAL SCORES ARE SLIGHTLY HIGHER THAN THOSE MADE BY EXPERIMENTAL SUBJECTS BUT THESE DIFFERENCES ARE NOT STATISTICALLY SIGNIFICANT. IT WAS ORIGINALLY PLANNED TO HAVE THREE INSTRUCTORS EVALUATE TWO CONTROL AND TWO

EXPERIMENTAL STUDENTS FROM EACH CLASS SO THAT THE EFFECT OF THE DIFFERENT INSTRUCTOR STANDARDS AND DIFFERENT CLASSES COULD BE CONTROLLED. HOWEVER, IT WAS POSSIBLE TO MAKE SUCH A COMPARISON IN ONLY 18 CASES. NINE CONTROL AND NINE EXPERIMENTAL SUBJECTS FROM THE SAME CLASSES WERE RATED BY CHECK PILOTS WITH EQUAL EXPERIENCE. DATA ON THESE CASES YIELDED ESSENTIALLY THE SAME RESULTS.

SCORES WERE COMPARED BY FLIGHT TASK UNDER THE ASSUMPTION THAT ONE GROUP MIGHT HAVE PERFORMED CONSISTENTLY BETTER ON CERTAIN TASKS AND POORER ON OTHERS. COMPARISONS FAILED TO SHOW CONSISTENT DIFFERENCES. (SEE TABLE 2.)

A CHECK WAS MADE TO DETERMINE WHETHER THESE RESULTS MIGHT BE ATTRIBUTABLE TO DIFFERENCES AMONG CHECK PILOTS IN THEIR STANDARDS OF RATING, OR CONSISTENT DIFFERENCES BETWEEN SCORES OF STUDENTS CHECKED IN THE HTL-6 AS AGAINST THOSE CHECKED IN THE HTL-5. NO CONSISTENT DIFFERENCES WERE OBSERVED.

AS A FURTHER CHECK, FLIGHT CHIT SCORES FOR EXPERIMENTAL AND CONTROL SUBJECTS FOR FLIGHTS A-2 THROUGH A-5 WERE COMPARED. THESE WERE THE INTERVENING PERIODS BETWEEN TRAINING IN THE 2-FH-2 AND THE ADMINISTRATION OF THE FLIGHT CHECK FOR EXPERIMENTAL SUBJECTS. RESULTS ARE SHOWN IN TABLE 3. NO CONSISTENT PATTERN IS APPARENT. EXPERIMENTAL SUBJECTS RECEIVED SLIGHTLY HIGHER AVERAGE GRADES IN HOUR A-2 BUT THIS TREND DOES NOT HOLD IN THE HOURS THAT FOLLOWED.

THESE NEGATIVE RESULTS MAY BE ATTRIBUTABLE TO A NUMBER OF CAUSES. AMONG THESE ARE: 1) FAILURE OF THE THE FLIGHT CHECK TO DISCRIMINATE WHEN ADMINISTERED BY SQUADRON CHECK PILOTS, AND 2) LACK OF FIDELITY OF THE 2-FH-2 COMPOUNDED BY NUMEROUS INSTANCES OF MOTION SICKNESS. THE FIRST HYPOTHESIS IS HARDLY TENABLE SINCE SCORES ON THE FLIGHT CHECK ARE WELL DISPERSED AND THERE IS A MARKED CORRELATION IN SCORES AMONG MANEUVERS. THE SECOND, LACK OF FIDELITY COMPOUNDED BY MOTION SICKNESS, IS DISCUSSED IN THE NEXT TWO SECTIONS.

TABLE 1

CRITERION SCORES BY MANEUVER

GROUP	MANEUVER					TOTALS
	HOVER	1 2 3 VTO-HVR-LDG	4 K-HDG-SQ	5 TOS	6 N-APP	
<u>EXPERIMENTAL*</u>						
POINTS MADE	217	459	371½	327	489	1863½
TOTAL POSSIBLE POINTS**	324	682	560	526	818	2910
PERCENT SCORE	67%	67%	66%	62%	60%	64%
<u>CONTROL*</u>						
POINTS MADE	235	491	331	301	518	1876
TOTAL POSSIBLE POINTS**	324	680	480	502	818	2804
PERCENT SCORE	73%	72%	69%	60%	63%	67%

* N - 18 EXPERIMENTAL SUBJECTS; 18 CONTROL SUBJECTS.

** IN SOME INSTANCES TOTAL POSSIBLE POINTS FOR A MANEUVER DIFFER SINCE CERTAIN ITEMS WERE NOT OBSERVED AND/OR EVALUATED BY THE CHECK PILOT.

NOTE: THE FOLLOWING ABBREVIATIONS ARE USED:

- 1 VTO - VERTICAL TAKE-OFF
- 2 HVR - HOVER
- 3 LDG - LANDING
- 4 K-HDG-SQ - CONSTANT HEADING SQUARE
- 5 TOS - TURNS ON A SPOT
- 6 N-APP - NORMAL APPROACH

TABLE 2

CRITERION SCORES BY TASKS

TASK	GROUP					
	EXPERIMENTAL			CONTROL		
	POINTS MADE	TOTAL POSSIBLE	PERCENT SCORE	POINTS MADE	TOTAL POSSIBLE	PERCENT SCORE
1. ALTITUDE	213	322	66%	221½	306	72%
2. ATTITUDE	173	242	71%	178	242	72%
3. AIRSPEED, ACCEL.	114½	178	64%	102½	158	65%
4. HEADING, TORQUE	151	238	63%	159	238	67%
5. RATE OF TURN	30	66	45%	26	62	42%
6. PSN RE: SPOT OR TRACK	210	357	59%	216	332	65%
7. PWR-RPM	106	212	50%	100	202	50%
8. COLLECTIVE	276	387	71%	271	380	71%
9. CYCLIC	208	320	65%	211	312	68%
10. RUDDER	233	376	62%	239	368	65%
11. THROTTLE	149	212	70%	152	204	73%
TOTALS	1863½	2910	64%	1876	2804	67%

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TABLE 3

PERCENT DISTRIBUTION OF FLIGHT CHIT GRADES*
FOR EXPERIMENTAL & CONTROL SUBJECTS FOR HOURS 2-5 OF HTU-1 INSTRUCTION

PERCENT SCORE	HOUR	UNSATIS- FACTORY**	%	BELOW AVERAGE	%	AVERAGE	%	ABOVE AVERAGE	%	TOTAL
		EXPERIMENTAL SUBJECTS***								
72%	A-2	-	-	-	-	197	79%	51	21%	248
72%	A-3	-	-	5	2%	256	78%	68	20%	329
66%	A-4	-	-	19	5%	294	76%	73	19%	386
67%	A-5	-	-	22	6%	318	81%	52	13%	392
42%	TOTAL GRADES	-	-	46	3%	1065	79%	244	18%	1355
65%		CONTROL SUBJECTS***								
50%	A-2	-	-	-	-	166	84%	31	16%	197
71%	A-3	-	-	8	2%	258	78%	67	20%	333
68%	A-4	-	-	15	4%	279	75%	77	21%	371
55%	A-5	-	-	19	5%	311	76%	77	19%	407
75%	TOTAL GRADES	-	-	42	3%	1014	78%	252	19%	1308

NOTE: THE TABLE CAN MOST EASILY BE READ FROM LEFT TO RIGHT.
PERCENT SCORES ARE COMPUTED ON THE BASIS OF THE NUMBER OF GRADES
FALLING IN A GIVEN GRADE CATEGORY TO THE TOTAL NUMBER OF GRADES
GIVEN TO THE GROUP FOR THE HOUR.

EXAMPLE: FOR HOUR A-3 THE EXPERIMENTAL SUBJECTS RECEIVED 2%
BELOW AVERAGE, 78% AVERAGE, AND 20% ABOVE AVERAGE; THE
TOTAL GRADES RECEIVED WAS 329.

- READERS WILL NOTE THAT THERE IS NO STANDARDIZED NUMBER OF GRADES
FOR ANY HOUR. THIS IS BECAUSE INSTRUCTION (COVERAGE) IS GREATLY
DEPENDENT ON STUDENT-INSTRUCTOR PROGRESS AND STUDENTS ARE GRADED
ON CURRENT AND PRIOR FLIGHT ACHIEVEMENTS AT THE DISCRETION OF THE
INSTRUCTOR.

** NO GRADES WERE GIVEN IN THIS CATEGORY.

*** N - 18 EXPERIMENTAL SUBJECTS; 18 CONTROL SUBJECTS.

(2)

VI. SICKNESS INDUCED BY THE 2-FH-2

THERE WAS NO PROVISION IN THE ORIGINAL STUDY PLAN TO STUDY MOTION SICKNESS*. HOWEVER, THE PROBLEM BECAME SO ACUTE THAT PRA AND NTDC PERSONNEL DECIDED THAT SOME EFFORT SHOULD BE MADE TO INVESTIGATE SICKNESS INDUCED BY THE 2-FH-2 AND FACTORS RELATED TO IT. SINCE THIS HAD TO BE DONE IN THE MIDDLE OF THE STUDY, IT WAS NOT POSSIBLE TO ARRIVE AT DEFINITIVE ANSWERS. HOWEVER, SOME IDEAS ON THE NATURE OF THE SICKNESS, POSSIBLE CAUSES, AND INFORMATION THAT MAY SUGGEST RELATIONSHIPS BETWEEN THESE CAUSES AND SICKNESS ARE DISCUSSED BELOW.

THERE IS A GOOD DEAL OF LITERATURE ON VARIOUS TYPES OF MOTION SICKNESS: SEASICKNESS, AIRSICKNESS, ALTITUDE SICKNESS, ETC., (1, 2, 9). MOST SICKNESS OF THIS TYPE REPORTED IN THE LITERATURE IS PRODUCED BY THE MOVEMENT OF THE SUBJECT. STATEMENTS SUCH AS "VISUAL, KINESTHETIC, AND OLFACTORY STIMULI ARE INFLUENCING FACTORS BUT WILL NOT PRODUCE SICKNESS BY THEMSELVES" (9) ARE FAIRLY COMMON. THE DISCUSSION BELOW IS LIMITED TO A DESCRIPTION OF THE SITUATION FACED IN THE STUDY. THE SICKNESS ENCOUNTERED WITH THE 2-FH-2 IS APPARENTLY UNIQUE IN THAT ONLY VISUAL CUES WERE A PART OF THE CAUSAL COMPLEX.

SICKNESS AND OTHER UNDESIRABLE SENSATIONS WERE REPORTED AT BELL AIRCRAFT CORPORATION WHERE THE 2-FH-2 WAS DEVELOPED, AND AMONG THREE OF TWELVE INSTRUCTORS IN PRELIMINARY EVALUATIONS CONDUCTED AT ELLYSON FIELD (10). IN THIS STUDY, IT WAS ENCOUNTERED IN A MORE VIRULENT FORM. FURTHERMORE, THE 2-FH-2 MAY NOT REPRESENT AN ISOLATED CASE OF SICKNESS AMONG CONTACT FLIGHT SIMULATORS, WHICH PROVIDE EXTRA-COCKPIT CUES, AS THERE HAVE BEEN SOME REPORTS OF SICKNESS IN THE F-15I AERIAL FIXED GUNNERY TRAINER.

* THIS TERM IS USED HERE TO REFER TO THE SICKNESS ENCOUNTERED, IN THE 2-FH-2.

A QUESTIONNAIRE WAS DEVELOPED TO OBTAIN INFORMATION CONCERNING THE SICKNESS. IT WAS COMPLETED BY THIRTY-SIX RESPONDENTS - INSTRUCTORS, STUDENTS, AND OTHER PERSONNEL EXPERIENCED IN THE 2-FH-2 AND THE HTL. THE QUESTIONNAIRE FORM IS PRESENTED AND RESPONSES ARE SUMMARIZED IN APPENDIX F, AND DISCUSSED BELOW.

TWENTY-EIGHT OF THIRTY-SIX RESPONDENTS REPORTED SICKNESS IN SOME DEGREE. IT WAS MORE FREQUENTLY REPORTED EARLY IN TRAINING AND IT WAS MORE LIKELY TO OCCUR IN THE FIRST TEN MINUTES OF THE TRAINING PERIOD.

NAUSEA, DIZZINESS, VERTIGO, HEADACHES, BLURRED VISION AND SWEATING WERE FREQUENTLY REPORTED SYMPTOMS. THE FIRST THREE AND SWEATING, ARE COMMONLY REPORTED AS ASSOCIATED WITH AIRSICKNESS. HOWEVER, BLURRED VISION AND HEADACHES ARE NOT SO COMMONLY REPORTED IN THE LITERATURE. THERE WERE A NUMBER OF REPORTS OF "DOUBLE VISION."

THE SICKNESS WAS OFTEN QUITE PERSISTENT. MORE THAN HALF THE RESPONDENTS REPORTED IT LASTED AN HOUR OR LONGER AFTER THE FLIGHT AND FIVE SAID IT LASTED OVERNIGHT. THERE WERE A NUMBER OF REPORTS THAT IT INTERFERED WITH READING, PAPER WORK, ETC., SEVERAL HOURS AFTER A FLIGHT. ALTHOUGH SOME RESPONDENTS REPORTED GETTING OVER THEIR SICKNESS AFTER A FEW HOPS, SEVERAL DID NOT; AND THERE WERE INSTRUCTORS WHO REPORTED NO SICKNESS THE FIRST HOURS BUT BECAME SICK LATER.

SPECULATIONS AS TO WHAT FEATURES OF THE DEVICE WERE RESPONSIBLE FOR THIS SICKNESS RELATE TO COMPONENTS OF THE MACHINE AND THE PERCEPTIONS OF THE OPERATORS. THESE ARE LISTED BELOW.

A. FIDELITY LIMITATIONS.

1. REFLECTIONS FROM BOTH PLATES, WHEN THE LIGHT IS NEAR THE GROUND, RESULT IN DOUBLE IMAGES ON THE SCREEN.

2. AT LOW ALTITUDES AND ON APPROACHING THE DECK, OBJECTS BECOME PROGRESSIVELY MORE BLURRED AND APPEAR FOGGY. TEXTURE CUES ARE THEREFORE OF NO VALUE IN PROVIDING INFORMATION AS TO ALTITUDE.
3. NEAR THE INDICATED MACHINE LIMITS OF 15° IN PITCH AND ROLL PILOTS REPORTED AN APPARENT PITCH OF 45° TO 60° IN THE LOW-ALTITUDE PLATE.
4. BOTH PLATES VIBRATE DURING YAWING AND TURNS.
5. THREE INCOMPATIBLE APPARENT MOTIONS ARE VISIBLE: THE MAIN MOTION OF THE PANORAMA, THE MOVEMENT OF THE PLATE OVERHEAD WHEN IN CERTAIN POSITIONS, AND APPARENT MOVEMENTS PRODUCED BY DUST OR LINT ON THE LENS.
6. WITH TRANSLATIONAL MOVEMENT, OBJECTS ON THE FLOOR OF THE PLATE PROVIDE INTERPOSITION CUES. NO INTERPOSITION CUES ARE, OF COURSE, POSSIBLE AMONG OBJECTS PAINTED ON THE SIDES OF THE TRANSPARENCY.
7. THERE IS A LACK OF ROTATIONAL PITCHING OR ROLL MOTIONS OF THE COCKPIT; THERE ARE NO KINESTHETIC AND VESTIBULAR SENSATIONS NORMALLY PRODUCED BY G-CHANGES IN FLYING AN AIRCRAFT.
8. DISCREPANCIES EXIST BETWEEN CONTROL LAG AND CONTROL DISPLACEMENT REQUIRED IN THE 2-FH-2 AS CONTRASTED TO THE HTL
9. THE COCKPIT IS POSITIONED WRONG RELATIVE TO THE LIGHT.

10. THERE IS A LACK OF RETINAL DISPARITY - THE SAME
IMAGE IS SEEN BY BOTH EYES.

B. IN ADDITION, THERE ARE CERTAIN FACTORS THAT MAY BE
REGARDED AS "PSYCHOLOGICAL". THIS IS A CATCH-ALL
CATEGORY BUT INCLUDES:

1. DISPARITY BETWEEN PERCEIVED VISUAL DISPLAY AND
EXPECTED VISUAL DISPLAY. THIS ARISES FROM ALMOST
ALL LACKS OF FIDELITY LISTED ABOVE.
2. SUGGESTION. PERSONNEL COULD BECOME AIRSICK IN
THE DEVICE BECAUSE THEY BECAME AIRSICK IN IT
EARLIER OR BECAUSE PERSONNEL IN THE SQUADRON
TOLD THEM THEY WOULD.
3. CLAUSTROPHOBIA, ESPECIALLY IN THE LOW-ALTITUDE
PLATE. A SENIOR OFFICER WITH THOUSANDS OF HOURS
OF FLIGHT EXPERIENCE SAID, "THE 2-FH-2 INITIALLY
GIVES ONE THE SENSATION RELATED TO CLAUSTROPHOBIA -
A FEELING OF BEING ENCLOSED OR ENTRAPPED IN AN
ENCLOSURE WHEREIN ALL LIGHT AND OBJECTS ARE HAZY,
DULL, AND GENERALLY OUT OF FOCUS. THIS FEELING
AUTOMATICALLY IMPOSES A PSYCHOLOGICAL BLOCK TO THE
PROCESS OF PHYSICAL AND MENTAL EFFICIENCY". A
NUMBER OF OTHER HTU-1 INSTRUCTORS REPORTED SIMILAR
FEELINGS.

THERE ARE BITS OF EVIDENCE THAT TEND TO REFUTE OR
LEND SUPPORT TO THESE SUGGESTED CAUSES.

- (A) BLURRED VISION, DOUBLE VISION, EYESTRAIN AND IMPAIRMENT OF READING. THESE WERE FREQUENTLY REPORTED BY PILOTS, BUT ARE NOT COMMONLY REPORTED IN THE LITERATURE ON MOTIONSICKNESS AND AIRSICKNESS. THESE REPORTS SUGGEST THAT LACK OF RETINAL DISPARITY IS A PRIME CAUSE. THE FACT THAT SICKNESS WAS REPORTED LESS OFTEN IN THE HIGH-ALTITUDE PLATE ESPECIALLY AT HIGH-ALTITUDES SUPPORTS THIS HYPOTHESIS. IT WOULD APPEAR, HOWEVER, THAT THIS IS NOT THE ONLY CAUSE. SOME PERSONNEL TRIED WEARING A PATCH OVER ONE EYE. ONE INSTRUCTOR SAID THIS ALLOWED HIM TO DO PAPERWORK AFTERWARD EVEN THOUGH HE COULD NOT DO THIS TYPE OF WORK SUBSEQUENT TO FLYING WHEN HE DID NOT WEAR THE PATCH. HOWEVER, HE AND OTHERS WHO USED THE PATCH REPORTED UNPLEASANT SENSATIONS OR SICKNESS WHILE WEARING IT.
- (B) THE HIGH PLATE PRODUCED NOTICABLY LESS SICKNESS, ALTHOUGH UNPLEASANT SENSATIONS WERE REPORTED BY SOME SUBJECTS IN IT. THIS MAY BE TAKEN AS EVIDENCE THAT THE LACK OF BINOCULAR DISPARITY IS A CAUSE. HOWEVER, THE FUZZINESS OF TEXTURE CUES AT LOW ALTITUDES AND PLATE REFLECTIONS ARE EQUALLY TENABLE ALTERNATIVE HYPOTHESES.
- (C) INSTRUCTORS REPORTED SICKNESS SOMEWHAT MORE FREQUENTLY AND IN A MORE EXTREME FORM THAN STUDENTS.

THIS COULD BE EXPLAINED ON THE ASSUMPTION THAT INSTRUCTOR'S EXPECTANCIES ARE MORE FIRMLY FIXED, HENCE, MORE SENSITIVE TO LACKS OF FIDELITY IN THE MACHINE. IT COULD ALSO BE ATTRIBUTED TO THE FACT THAT STUDENTS PROBABLY HANDLED THE CONTROLS MORE OFTEN.

- (D) SICKNESS WAS EXPERIENCED ONLY WHEN THE DISPLAY MOVED. THIS WOULD SUGGEST THAT REFLECTIONS, ETC., WOULD NOT IN THEMSELVES PRODUCE SICKNESS.
- (E) ONLY 1 OF 8 SUBJECTS WHO TOOK DRAMAMINE REPORTED THAT IT HELPED HIM. SEVERAL SUBJECTS REPORTED UNPLEASANT SIDE EFFECTS FROM DRAMAMINE.
- (F) NTDC REPRESENTATIVES MOVED THE COCKPIT BACK ABOUT A FOOT ABOUT MIDWAY IN THE TRAINING SYLLABUS. THIS HAD NO NOTICEABLE EFFECT ON SICKNESS.
- (G) AIRSICKNESS WAS REPORTED MOST FREQUENTLY IN PITCH AND ROLL OSCILLATIONS, HOVERING, AND FIGURE EIGHTS. VERY STRONG AIRSICKNESS WAS REPORTED BY 7 RESPONDENTS IN TURNS ON A SPOT. IT WOULD SEEM THEN, TO BE MOST CLOSELY ASSOCIATED WITH MOVEMENT IN THE ROTATIONAL RATHER THAN TRANSLATIONAL FREEDOMS. (ATTEMPTS TO MOVE OFTEN WOUND UP IN OSCILLATIONS.)
- (H) SUGGESTION ALONE PROBABLY DID NOT CAUSE SICKNESS, ALTHOUGH IT MIGHT HAVE BEEN A CONTRIBUTING FACTOR.

SEVERAL PILOTS WHO HAD NOT BEEN IN THE MACHINE OR HEARD ABOUT SICKNESS INDUCED BY THE DEVICE, BECAME SICK AFTER FLYING THE 2-FH-2.

- (I) INSTRUCTORS WHO FLEW THE 2-FH-2 AT BELL AIRCRAFT CORPORATION WHEN THERE WERE GAPS IN THE SCREEN, REPORTED THEY BECAME AIRSICK MORE QUICKLY THAN WHEN FLYING WITH THE COMPLETE SCREEN AT PENSACOLA.
- (J) NO SICKNESS HAS BEEN REPORTED IN A SOMEWHAT SIMILAR ENGINEERING PROTOTYPE DEVELOPED BY LINK AVIATION COMPANY. THIS PROTOTYPE IS ESSENTIALLY A SYMBOLIC PRESENTATION CONTAINING NO OBJECTS OF KNOWN SIZE. THE PILOT FLIES OVER A CHECKERED STRIP. THE SEAT PITCHES AND ROLLS. THE SUGGESTION HAS BEEN MADE THAT PITCH AND ROLL OF THE COCKPIT OF THE 2-FH-2 WOULD REDUCE THE SICKNESS. THE WRITERS DOUBT THIS UNDER THE ASSUMPTION THAT SEAT MOTION WOULD NOT IN ITSELF PRODUCE A REALISTIC SIMULATION OF GRAVITY FORCES. HOWEVER, IN THE ABSENCE OF DATA IT WOULD BE WORTHWHILE TO INVESTIGATE THIS HYPOTHESIS.

FROM THIS LISTING, IT IS OBVIOUSLY NOT POSSIBLE TO PINPOINT ANY ONE FACTOR AS A SOLE CAUSE OF SICKNESS. IT IS PROBABLE THAT SEVERAL FACTORS ARE RESPONSIBLE. ALL OF THESE MUST BE RELATED IN SOME WAY TO LACK OF FIDELITY IN THE MOVING DISPLAY. FOR INSTRUCTORS REPORT RELATIVELY LITTLE AIRSICKNESS IN HELICOPTER TRAINING.

HOWEVER, IT IS VERY DOUBTFUL THAT ANY VISUAL EXTRA-COCKPIT DISPLAY THAT CAUSES SICKNESS AS COMMON, INTENSE AND PERSISTENT AS THE 2-FH-2 CAN EVER BE OPERATIONALLY ACCEPTABLE, WHATEVER ITS MERITS.

VII. LEARNING AND FIDELITY

ADMITTEDLY, "EXPLANATIONS" AS TO WHY THE 2-FH-2 FAILED TO TRAIN ARE "AD HOC". HOWEVER, WHEN WE COMBINE THE DISCUSSION OF CONTROLS AND FLIGHT PARAMETERS IN SECTION II WITH THE INSTRUCTOR COMMENTS CONCERNING PERFORMANCE OF STUDENTS TRAINED IN THE 2-FH-2, A NUMBER OF HYPOTHESES ARE SUGGESTED. WHEN THIS MATERIAL IS CONSIDERED FROM THE VIEWPOINT OF LEARNING, IT SEEMS PLAUSIBLE THAT STUDENTS TRAINED IN THE 2-FH-2 LEARNED A NUMBER OF WRONG HABITS. CONSIDER THE COMPLEX SKILLS REQUIRED TO FLY AN AIRCRAFT. IN HIS COMPENSATORY SYSTEM, THE FUNCTION OF THE PILOT IS TO CLOSE SEVERAL LOOPS, TO TAKE CARE OF SEVERAL SUB-TASKS MORE OR LESS SIMULTANEOUSLY. HE MONITORS AND CONTROLS THE PATH OF THE AIRCRAFT IN THE SIX FLIGHT PARAMETERS BY CORRELATING HIS ONGOING OBSERVATIONS WITH HIS EXPECTANCIES BY APPROPRIATE MANIPULATION OF THE FLIGHT CONTROLS. HE DOES THIS BY DEVELOPING TWO TYPES OF HABITS:

- A. MONITORING AND RESPONDING PROPERLY TO THE INDIVIDUAL DISPLAY-CONTROL RELATIONSHIPS - CLOSING INDIVIDUAL LOOPS.
- B. PROPER TIMESHARING BETWEEN LOOPS - COMBINING A NUMBER OF LOOPS.

WHAT ARE THE STAGES OF LEARNING BY WHICH THE NOVICE BECOMES PROFICIENT? IT SEEMS REASONABLE TO ASSUME THAT AN INITIAL STAGE CONSISTS OF LEARNING GROSS EXPECTANCIES, I.E., WHAT IT LOOKS AND FEELS LIKE TO FLY A HELICOPTER. THE PILOT PULLS UP COLLECTIVE AND SENSES THE AIRCRAFT RISING, HE LEARNS THAT THERE IS A LAG IN RESPONSE TO MOVEMENTS OF THE CYCLIC CONTROL; THAT HIS AIRSPEED INDICATION IS OF LITTLE USE IN SOME NEAR GROUND MANEUVERS. BUT, HE HAS NOT YET LEARNED TO CLOSE THE LOOP EFFECTIVELY.

LATER IN TRAINING THE PILOT BEGINS TO OBSERVE THE DISPLAY AND MANIPULATE FLIGHT CONTROLS SO AS TO CLOSE THE LOOP EFFICIENTLY. WHILE HE MAY LEARN ONE LOOP AT A TIME (FOR EXAMPLE, CYCLIC AND ASSOCIATED DISPLAY CHANGES) OR SEVERAL AT ONCE, CONSIDER THE STAGES BY WHICH HE LEARNS TO BE A MONITOR-CONTROLLER OF ONE DISPLAY-CONTROL LOOP. AT FIRST HE MUST LEARN HOW MUCH TO DISPLACE THE CONTROL TO PRODUCE A GIVEN RATE AND ACCELERATION OF AIRCRAFT MOVEMENT IN THE FREEDOMS THE CONTROL GOVERNS. HE MUST LEARN THE CHARACTERISTIC CONTROL LAG AT VARIOUS SPEEDS. FOR EACH MANEUVER HE MUST LEARN THE CORRECT EXTRA AND INTRA-COCKPIT VISUAL PICTURE SO HE CAN RELATE TO IT THE PICTURE HE OBSERVES BY PROPER CONTROL MOVEMENT. AT THIS LEARNING STAGE HE MUST CONSCIOUSLY THINK OF EACH MOVE; HE CAN, AND OFTEN DOES, VERBALIZE WHAT IS HAPPENING TO THE VISUAL PICTURE; THE AMOUNT HE MUST MOVE THE CONTROL. TO DO THIS ALMOST REQUIRES THE PILOT'S FULL TIME. AS LEARNING PROGRESSES, THE MONITOR-CONTROL FUNCTION BECOMES LESS ATTENTION-DEMANDING, LESS TIME CONSUMING, MORE EFFICIENT. HABITS ARE DEVELOPED WHICH MAKE IT UNNECESSARY TO CONSCIOUSLY THINK THROUGH EACH MOVE. THE TIME SAVED CAN BE APPLIED TO LEARNING OTHER LOOPS.

CONTROL OF TWO OR MORE LOOPS IS LIKELY ACHIEVED AS FOLLOWS: THE PILOT SAMPLES ALTERNATELY THE CUES THAT PROVIDE NECESSARY INFORMATION AS TO HIS POSITION, SPEED AND ACCELERATION. HE MAKES A RAPID JUDGMENT AS TO WHETHER HE MUST MOVE A CONTROL. IF HE MUST, HE KNOWS THE APPROXIMATE AMOUNT OF DISPLACEMENT REQUIRED. HENCE, HE DOES NOT HAVE TO WAIT AND WATCH TO SEE THAT THE PLANE RESPONDS PROPERLY. INSTEAD, HE SHIFTS ATTENTION TO THE CUES PROVIDING INFORMATION ON A SECOND LOOP; MAKES THE NECESSARY CONTROL MOVES AND CONTINUES IN THIS MANNER UNTIL THE FLIGHT IS COMPLETED. THUS, WHEN THE PILOT BECOMES PROFICIENT, HE MONITORS AND CONTROLS SEVERAL CONTROL-DISPLAY LOOPS BY TIME SAMPLING EACH, QUICKLY CORRELATING HIS PERCEPTION WITH HIS EXPECTANCIES SO AS TO ADJUST AND READJUST THE POSITION,

MOVEMENT AND ACCELERATION OF THE PLANE. DEPENDING ON AIRCRAFT TYPE, MISSION, MISSION PHASE, ETC., THE TIME REQUIRED TO MONITOR VARIOUS LOOPS DIFFERS GREATLY. THE PROFICIENT PILOT VARIES HIS TIME-SHARING PROCEDURES AS A FUNCTION OF SUCH FACTORS SO HE CAN EXECUTE ANY MANEUVER EFFICIENTLY.

HOW CAN A TRAINER THAT LACKS FIDELITY FAIL TO PRODUCE POSITIVE TRANSFER, OR LEAD TO NEGATIVE TRANSFER? FOR MOST EFFECTIVE LEARNING, CONTROLS AND DISPLAYS SHOULD BE LINKED IN THE SAME WAY IN TRAINER AND AIRCRAFT. BUT, CONSIDER THE DIFFICULTIES ENCOUNTERED BY THE SIMULATOR-TRAINED PILOT IN THE AIRCRAFT. MOVEMENT OF A CONTROL LEARNED IN THE SIMULATOR EITHER MOVES THE CUES SPECIFYING PLANE-EARTH RELATIONSHIPS TOO LITTLE OR TOO MUCH, OR AT THE WRONG RATE. THE HABITS LEARNED IN THE SIMULATOR ARE INAPPROPRIATE IN THE AIRCRAFT. ONE CRITICAL HABIT IS THAT OF MOVING THE CONTROL, THEN NOT ATTENDING TO THE INFORMATION PROVIDED BY ITS ASSOCIATED DISPLAYS. THE PILOT MUST LEARN THIS HABIT SO HE CAN ATTEND TO DISPLAY ELEMENTS THAT DETERMINE HOW HE MUST MOVE A SECOND CONTROL. WHILE ATTENDING TO THESE ELEMENTS ASSOCIATED WITH THE SECOND CONTROL, HE ASSUMES IMPLICITLY THAT HIS MANIPULATION OF THE FIRST CONTROL THAT BROUGHT THE SIMULATOR BACK INTO ALIGNMENT WILL PROPERLY REALIGN THE AIRCRAFT. AS THE SIMULATOR LACKS FIDELITY REALIGNMENT IS NOT EFFECTED. SO, TO FLY THE AIRCRAFT PROPERLY HE MUST BREAK LEARNED HABITS, AND IN DOING SO BRING HABITUAL SKILLS BACK TO THE CONSCIOUS THRESHOLD.

IT WOULD SEEM REASONABLE TO PREDICT THAT THE TIME REQUIRED TO RELEARN IS A FUNCTION OF THE NUMBER OF LOOPS THAT LACK FIDELITY AND THE DEGREE OF DISSIMILARITY BETWEEN TRAINER AND AIRCRAFT IN EACH. AND FINALLY, WHEN THE DISPLAY CONTROL RELATIONSHIPS ARE PHENOMENALLY DISSIMILAR, NOT ONLY MUST THE STUDENT RELEARN TO MONITOR EACH LOOP PROPERLY, HE MUST, TO VARYING DEGREES, RELEARN TIME-SHARING HABITS.

THE CONCEPT OF THE PILOT CLOSING DISPLAY-CONTROL LOOPS HELPS TO IDENTIFY AND EVALUATE CRITICAL FIDELITIES OF THE 2-FH-2. TO MAXIMIZE TRANSFER, THE PICTURE PRESENTED IN THE 2-FH-2 SHOULD BE SIMILAR TO THAT OBSERVED FROM THE AIRCRAFT SO THE PILOT CAN LEARN PROPER EXPECTATIONS. THE MOVEMENT OF CONTROLS REQUIRED SHOULD BE SIMILAR IN LAG, SENSITIVITY AND DISPLACEMENT SO THE PROPER MOTOR HABITS CAN BE LEARNED; THUS, THE SAME MOVEMENTS THAT CORRELATE OBSERVED CUE CONDITIONS IN THE 2-FH-2 WITH THE EXPECTED CUE CONDITIONS WILL CORRELATE THEM EQUALLY WELL IN THE HTL.

WITH THE ABOVE IN MIND, COMMENTS FROM INSTRUCTORS AND STUDENTS WERE CLASSIFIED UNDER THE CRITICAL LOOPS GOVERNED BY THE COLLECTIVE-THROTTLE, DIRECTIONAL CONTROL PEDALS AND CYCLIC CONTROL. THESE COMMENTS SHOULD NOT BE REGARDED AS PRECISE DESCRIPTIONS AND THEY MAY, IN SOME INSTANCES REFLECT EMOTIONAL BIAS. HOWEVER, IT IS BELIEVED THAT THEY ARE REASONABLY ACCURATE.

THROTTLE AND COLLECTIVE PITCH

THROTTLE AND COLLECTIVE PITCH CONTROL THE LIFT AND HENCE, THE ASCENT AND DESCENT OF THE AIRCRAFT BY ADJUSTMENT OF THE PITCH OF THE MAIN ROTOR AND THE POWER. THE THROTTLE IS MOST FREQUENTLY USED TO COMPENSATE FOR COLLECTIVE ADJUSTMENTS.

AMONG THE MORE CRITICAL EXTERNAL STIMULUS PATTERNS THAT ALLOW THE PILOT TO HANDLE THESE CONTROLS PROPERLY ARE CUES ARISING FROM THE EXPANDING OR CONTRACTING GROUND PATTERN, INTERPOSITION AND CHANGES IN INTERPOSITION OF OBJECTS IN THE VERTICAL TRANSLATIONAL FREEDOM, THE APPARENT MOVEMENT OF GROUND OBJECTS ALONG THE CANOPY, THE SIZE OF KNOWN OBJECTS, AND SURFACE TEXTURE AND APPARENT TEXTURE CHANGES WITH CHANGING ALTITUDE. INSIDE THE COCKPIT THE MOST CRITICAL INDICATION IS THE RPM, WHICH IS TO THE ROTARY WING PILOT "WHAT AIRSPEED IS TO THE FIXED WING PILOT." IN ADDITION THERE ARE THE SOUNDS OF THE ROTOR AND ENGINE WHICH

VARY WITH ROTOR SPEED AND HENCE, PROVIDE HELPFUL AURAL CUES.

THE 2-FH-2 DEFINITELY GIVES THE ILLUSION OF FLYING BECAUSE IN A GROSS SENSE, THE EXTERNAL CUES "ACT RIGHT". THE EXPANDING AND CONTRACTING GROUND PATTERN IS PERCEIVED, THE INTERPOSITION OF OBJECTS, AND AT HIGHER ALTITUDES, TEXTURE CHANGES OCCUR NATURALLY. HOWEVER, AT LOW ALTITUDES, OBJECTS BECOME FUZZIER AS THEY ARE APPROACHED. ALSO BECAUSE OF ENGINEERING COMPROMISES REQUIRED IN THIS MODEL, WHEN ON THE DECK, THE PILOT FEELS THAT HE IS SITTING TOO HIGH IN A BOWL. THIS IS ESPECIALLY TRUE WITH THE LOW-ALTITUDE PLATE. THIS MAY IMPAIR JUDGMENT OF ALTITUDE AND HENCE, THE CAPABILITY OF THE DEVICE TO TEACH MANEUVERS SUCH AS NORMAL APPROACHES AND VERTICAL LANDINGS.

THE MOST CRITICAL FAULT IN THIS LOOP SEEMS TO BE THE RPM INDICATION. IN THE HTL, THE RPM IS VERY SENSITIVE. THE CONTINUOUS MANIPULATIONS OF COLLECTIVE REQUIRED ARE CALLED "MILKING". A VETERAN INSTRUCTOR SAYS: " 'MILKING' IS A PROCESS WHEREBY RPM IS BUILT UP BY REDUCING COLLECTIVE (WITH FULL THROTTLE) THEN INCREASING COLLECTIVE TO AVOID SETTLING TO THE GROUND. HOWEVER, 'MILKING' IS USED IN ALL MANEUVERS AT ALL SPEEDS AND ANY ALTITUDE. ANYTIME THE COLLECTIVE IS DECREASED THE THROTTLE MUST ALSO BE DECREASED TO AVOID OVERSPEEDING THE ENGINE. ALSO WHEN COLLECTIVE IS INCREASED THE THROTTLE MUST BE ADDED TO KEEP FROM LOSING RPM. IT MATTERS NOT IF THE PLANE IS IN LEVEL FLIGHT AT 500' OR IS MAKING A NORMAL APPROACH OR IN A HOVER 'MILKING' IS USED TO CONTROL RPM AS WELL AS REGAIN LOST RPM."

ONCE SET, THE RPM INDICATION IN THE 2-FH-2 DOES NOT REQUIRE THE CONTINUOUS ATTENTION AND ADJUSTMENT OF COLLECTIVE AND THROTTLE REQUIRED IN THE AIRCRAFT. A NUMBER OF INSTRUCTORS SAID THAT STUDENTS TRAINED IN THE 2-FH-2 HAVE A TENDENCY TO IGNORE RPM IN THE HTL LETTING IT GET DANGEROUSLY LOW OR OVERSPEED. ALSO, THE UNREALISTICALLY STABLE RPM INDICATION REDUCES THE VALUE OF INSTRUCTION IN

THROTTLE CONTROL SINCE THROTTLE ADJUSTMENTS DO NOT HAVE TO BE MADE TO COMPENSATE FOR COLLECTIVE CHANGES. CHANGES IN THE SPEED OF THE ROTOR AND MOTOR PROVIDE SOUND DIFFERENCES THAT CAN BE USED AS CUES TO MAINTAIN PROPER RPM. THE SOUND OF THE ROTOR AND MOTOR IN THE 2-FH-2 ARE REGARDED AS SOMEWHAT LIKE THAT IN THE HTL-5; TONE OF THE SOUND CAN BE ADJUSTED. SOUND AND SOUND CHANGES ARE NOT REGARDED BY INSTRUCTORS AS ESPECIALLY CRITICAL IN INITIAL HOURS OF INSTRUCTION.

DIRECTIONAL CONTROL PEDALS

DIRECTIONAL CONTROL IS EFFECTED PRIMARILY BY "RUDDERS". THE EXTRA-COCKPIT DEFINITION IS THE POSITION OR SWING OF THE PILOT AND AIRCRAFT NOSE ACROSS THE HORIZON OF EARTH AND SKY. WITHIN THE COCKPIT, THE LOCUS OF THE PLANE IN THE YAW DIMENSION IS INDICATED BY THE COMPASS. A COMPLICATING FACTOR IS THE REQUIREMENT FOR GREATLY VARYING AMOUNTS OF RUDDER WITH POWER CHANGES.

THE SITUATION INVOLVING THE COMPARATIVE SPEEDS OF MOVEMENT OF THE NOSE OF THE 2-FH-2 AND HTL-5 WITH MOVEMENT OF RUDDERS IS NOT ENTIRELY CLEAR. SOME INSTRUCTORS AND STUDENTS REPORT THAT THE REACTION OF THE 2-FH-2 TO APPLICATION OF RUDDER IS SLUGGISH. THERE IS GENERAL AGREEMENT HOWEVER, THAT THERE IS NOT SUFFICIENT YAW TENDENCY IN THE 2-FH-2 WITH APPLICATION AND REDUCTION OF POWER. AN INSTRUCTOR SAYS "TORQUE IS A GREAT PROBLEM TO STUDENTS BEGINNING HELICOPTER TRAINING. IT IS VERY IMPORTANT THAT THE RESPONSE BE THE SAME IN THE 2-FH-2 AS IN THE HTL-5 OR HTL-6". ANOTHER SAYS "IN GROUNDWORK THE SMALLEST (POWER) CHANGE IN THE HTL-5 CAUSES A DIFFERENT TORQUE LOAD". THIS IS NOT TRUE OF THE 2-FH-2.

IN THE HIGH-ALTITUDE PLATE INSTRUCTORS REPORT THAT AIRSPEED VARIES TOO MUCH WHEN RUDDER IS USED.

IN SUMMARY, INSTRUCTORS FEEL THAT THE YAW LOOP GOVERNED BY DIRECTIONAL CONTROL PEDALS IS SUBJECT TO SERIOUS LACKS OF FIDELITY.

CYCLIC CONTROL

THE CYCLIC STICK CONTROLS THE PITCH AND ROLL OF THE AIRCRAFT AND HENCE, ITS TRANSLATIONAL MOVEMENT IN FORWARD AND LATERAL DIRECTIONS. EXTRA-COCKPIT CUES ARE SIMILAR TO THOSE USED TO MONITOR FREEDOMS ASSOCIATED WITH THE COLLECTIVE BUT WITH GREATER EMPHASIS ON THE SPEED AND ACCELERATION OF MOVEMENT OF THE GROUND-SKY PANORAMA. INSIDE THE COCKPIT THE MAIN INDICATION IS THE AIRSPEED. AGAIN THERE ARE A NUMBER OF COMPLAINTS.

THE 15° LIMITS OF THE 2-FH-2 IN THE PITCH AND YAW FREEDOMS DO NOT ALLOW ENOUGH FREEDOM FOR COMPLETE INSTRUCTION IN TURNS AND AUTOROTATIONS. THIS IS ESPECIALLY TRUE WHEN WIND IS ADDED. THE STUDENT LEARNS TO USE "TOO MUCH RUDDER, NOT ENOUGH STICK". IT IS ALSO CLAIMED THAT WITH A PITCH OR ROLL NEAR THE LIMIT OF 15° , THE 2-FH-2 APPEARS TO BE IN A 45° TO 60° BANK. THIS WOULD ENCOURAGE OVERCONTROL.

THE CYCLIC CONTROL IN THE 2-FH-2 IS MUCH MORE SLUGGISH THAN THE CYCLIC IN THE AIRCRAFT. UNLIKE THE AIRCRAFT THERE IS NO FEEDBACK IN THE STICK OF THE 2-FH-2.

ANOTHER INSTRUCTOR HAS THESE COMMENTS ABOUT THE CYCLIC AND CORRESPONDING AIRSPEED AND GROUND SPEED INDICATIONS ESPECIALLY IN THE HIGH-ALTITUDE PLATE. "AIRSPEED IS PRODUCED ONLY WHEN THE CYCLIC IS DISPLACED FORWARD. WHEN THE STICK IS REDUCED TO NEUTRAL, AIRSPEED DROPS TO ZERO. GROUND SPEED DOES NOT INCREASE IN RELATION TO STICK DISPLACEMENT OR AIRSPEED INCREASE. FOR THIS REASON, FORWARD FLIGHT AT ALTITUDES IS ALMOST INDEPENDENT OF AIRSPEED RELATIONSHIPS".

IN ADDITION, THE WIND EFFECTS AND GUSTS ARE NOT REGARDED AS REALISTIC. "IN VERTICAL TAKE-OFFS THERE IS NO WAY TO FEEL DRIFT UNTIL YOU ARE PRACTICALLY OUT OF CONTROL".

IN SUMMARY, COMMENTS OF INSTRUCTORS AND STUDENTS INDICATE QUITE SERIOUS LACKS OF FIDELITY IN LOOPS GOVERNED BY THE THROTTLE-COLLECTIVE, THE DIRECTIONAL CONTROL PEDALS AND THE CYCLIC CONTROLS. UNTIL THESE ARE CORRECTED, THE STUDENT LIKELY LEARNS CONTROL ADJUSTMENTS DISSIMILAR TO THESE REQUIRED IN THE HELICOPTER. FURTHER, THE STUDENT COULD HARDLY BE EXPECTED TO LEARN THE CORRECT TIME-SHARING PROCEDURES IN THE 2-FH-2 AS IT EXISTS NOW. LEARNING TIME-SHARING INVOLVES BRINGING ATTENTION-SHARING HABITS INTO HARMONY WITH THE TIME-SHARING DEMANDS OF THE FLIGHT SITUATION. THOSE ELEMENTS OF FLIGHT THAT ARE MOST ATTENTION DEMANDING SHOULD BE FAITHFULLY REPRODUCED IN SIMULATORS. IF THEY ARE NOT, SIMULATORS CAN DEVELOP INEFFECTIVE AND DANGEROUS TIME-SHARING HABITS.

THE ABOVE COMMENTS, MANY OF WHICH COME FROM INSTRUCTORS WHO WERE FREQUENTLY SICK IN THE MACHINE AND OFTEN HOURS AFTERWARDS, MAY REFLECT NEGATIVE BIASES IN UNKNOWN AMOUNTS. HOWEVER, IT MUST BE RECOGNIZED THAT THE DEVELOPMENT OF COMPENSATORY SIMULATORS THAT PRESENT EXTRA-COCKPIT CUES PLACES ADDED BURDENS ON THE DESIGNER. PERHAPS THE MOST CRITICAL OF THESE, IF THE SIMULATOR IS TO HAVE MAXIMUM TRAINING VALUE, IS THE INCORPORATION OF THE CORRECT FLIGHT CHARACTERISTICS.

VIII. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

A SIX-HOUR TRAINING SYLLABUS FOR THE 2-FH-2 AND A FLIGHT CHECK CONSISTING OF COMMON HELICOPTER MANEUVERS WERE DEVELOPED TO EVALUATE THE TRAINING CAPABILITIES OF THE 2-FH-2 ENGINEERING PROTOTYPE. THE TRAINING SYLLABUS WAS ADMINISTERED TO EIGHTEEN HTU-1 TRAINEES (EXPERIMENTAL SUBJECTS). THE FLIGHT CHECK WAS ADMINISTERED TO THESE SUBJECTS AND TO EIGHTEEN COMPARABLE CONTROL SUBJECTS WHO HAD NO TRAINING IN THE 2-FH-2. MAJOR OUTCOMES WERE THESE:

- A. EXPERIMENTAL STUDENTS PERFORMED NO BETTER THAN CONTROLS EITHER ON THE FLIGHT CHECK, OR ON TRAINING CHIT SCORES FOR TRAINING PERIODS IMMEDIATELY FOLLOWING TRAINING IN THE 2-FH-2.
- B. THE 2-FH-2 GAVE APPROXIMATELY SEVENTY-FIVE PERCENT OF THE INSTRUCTORS AND STUDENTS UNPLEASANT SENSATIONS SOMEWHAT SIMILAR TO MOTION SICKNESS. A SUBSTANTIAL NUMBER OF SUBJECTS REPORTED NAUSEA, VOMITING, BLURRED VISION, AND OTHER INTENSE AND RELATIVELY PERSISTANT UNPLEASANT SENSATIONS.
- C. THE 2-FH-2 GIVES THE ILLUSION OF FLYING. HOWEVER, SUBJECTS REPORT A NUMBER OF SERIOUS LACKS OF FIDELITY OF RELATIONSHIPS BETWEEN CONTROL MOVEMENTS AND COCKPIT AND EXTRA-COCKPIT DISPLAYS. THESE DEFICIENCIES ARE KNOWN BY DESIGNERS BUT BECAUSE OF TECHNICAL PROBLEMS AND LACK OF FUNDS HAD NOT BEEN CORRECTED WHEN THIS STUDY WAS CONDUCTED.

D. FACTORS IN C. ABOVE CONSIDERED, IT IS DOUBTFUL THAT THE 2-FH-2 AS CONSTITUTED AT THE TIME OF THIS STUDY, PROVIDED AN ADEQUATE TEST OF THE CONCEPT OF VISUAL FLIGHT SIMULATION.

THERE ARE, OF COURSE, AMPLE REASONS NOT TO RECOMMEND THE 2-FH-2 FOR OPERATIONAL TRAINING.

DISCUSSION AND RECOMMENDATIONS

STUDY FINDINGS SUGGEST THAT A REASSESSMENT OF EFFORT CHanneled TOWARD THE DEVELOPMENT OF TRAINERS DESIGNED TO PRESENT VISUAL EXTRA-COCKPIT CUES IS IN ORDER. MANY FACTORS THAT BEAR CONSIDERATION ARE BEYOND THE SCOPE OF THIS STUDY: THEIR IMPORTANCE TO PROJECTED FUTURE PLANS AND OPERATIONS MUST BE DETERMINED BY MILITARY PERSONNEL. LET US EXAMINE THE CONCEPT OF A TRAINER DESIGNED TO PRESENT EXTRA-COCKPIT CUES, AND NOTE ITS ADVANTAGES AND POSSIBLE USES ASSUMING IT CAN BE IMPLEMENTED AS A FUNCTIONAL AND RELIABLE HARDWARE ITEM WITH HIGH TRANSFER TRAINING VALUE. AMONG ADVANTAGES ARE THESE:

- A. IT ALLOWS MORE FLEXIBILITY IN TRAINING. IT ALLOWS USE OF TECHNIQUES OF INSTRUCTION IMPOSSIBLE TO IMPLEMENT IN AIRCRAFT. ACTION CAN BE FROZEN AND CRITIQUED. STUDENT - INSTRUCTOR COMMUNICATIONS CAN BE FACILITATED.
- B. TIME REQUIRED TO MAN, WARM UP PLANES, TO FLY TO TRAINING SECTORS ETC., CAN BE ELIMINATED.
- C. IT CAN BE USED TO SIMULATE ESPECIALLY DANGEROUS ATTITUDES AND MANEUVERS THAT CANNOT BE PRACTICED IN THE AIRCRAFT.

D. TRAINING IS NOT HAMPERED BY CLIMATIC CONDITIONS.

THE VALUE OF TRAINERS PRESENTING EXTRA-COCKPIT CUES WILL DEPEND ON THEIR USEFULNESS TO FUTURE OPERATIONS. THEIR USES ARE NOT CONFINED TO ROTARY WING TRAINING. AMONG POSSIBLE USES ARE:

1. TO TRAIN HELICOPTER PILOTS, WHO, UNLIKE THOSE STUDIED HERE, HAVE LITTLE OR NO FIXED WING EXPERIENCE.
2. TO TRAIN PILOTS IN NUCLEAR POWERED AIRCRAFT WHERE RADIATION EXPOSURE MUST BE MINIMIZED.
3. TO TRAIN TEST PILOTS PRIOR TO INITIAL TEST FLIGHTS IN NEW AIRCRAFT.
4. TO PROVIDE TRANSITION TRAINING IN FIXED WING AIRCRAFT.
5. TO TRAIN FOR ESPECIALLY CRITICAL OPERATIONAL MISSIONS.

THESE ADVANTAGES AND USES CONSIDERED, IT IS FELT THAT FURTHER INVESTIGATION AND STUDIES SHOULD BE SERIOUSLY CONSIDERED. DEVICES LIKE THE 2-FH-2 ARE NEW IN CONCEPT AND LIKE THE FIRST PLANES, TIME AND PATIENCE WILL BE REQUIRED TO DEVELOP MODELS THAT WILL ACCOMPLISH THEIR INTENDED MISSIONS. IF, AFTER CONSIDERATION OF ALL PERTINENT FACTORS, IT IS DECIDED TO CONTINUE EFFORT IN THIS FIELD, THE FOLLOWING RECOMMENDATIONS ARE MADE:

- A. DEFINE QUANTITATIVELY AND PRECISELY THE LACKS OF FIDELITY. DETERMINE WHICH OF THESE CAN BE CORRECTED, AND WHICH ARE APPARENTLY INHERENT IN THE POINT SOURCE PROJECTION TECHNIQUE. IT WAS THE IMPRESSION OF THE WRITERS THAT MANY FIDELITY LACKS THAT ATTENUATED THE TRAINING VALUE OF THE 2-FH-2 CAN BE CORRECTED BY KNOWN TECHNIQUES.
- B. ESTABLISH AND INVESTIGATE HYPOTHESES AS TO CAUSES OF MOTION SICKNESS BY EXPERIMENTATION WITH VARIOUS REDUCED

CUES SITUATIONS, ETC., AND BY COMPARISON OF THE
ENGINEERING FEATURES OF 2-FH-2 AND SICKNESS SYMPTOMS
PRODUCED BY IT WITH PRESENCE OR ABSENCE OF SYMPTOMS
ENCOUNTERED IN OTHER PROJECTION SYSTEMS.

- C. DEVELOP A METHOD OF EVALUATING THE MECHANICAL AND
TRAINING CAPABILITIES OF VARIOUS PROJECTION SYSTEMS
TO SIMULATE ROTARY WING AND FIXED WING FLIGHT. THIS
FIELD IS STILL TOO NEW TO SETTLE ON ONE SYSTEM OF
PROJECTION.

MOST OF THE ABOVE SHOULD BE ACCOMPLISHED BY A TEAM CONSISTING OF PHYSIC
SCIENTISTS, PERSONNEL FAMILIAR WITH LEARNING PRINCIPLES AND PILOTS WORKING I
CLOSE CONSULTATION. THIS WILL HELP TO ASSURE THAT RESEARCH HOURS ARE ALLOCA
TO DEVELOPMENT AND INVESTIGATION OF FEATURES OF THESE DEVICES THAT ARE MOST
CRITICAL TO THE ACCOMPLISHMENT OF THE PURPOSES FOR WHICH THEY ARE DESIGNED.

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APPENDIX F

MOTION SICKNESS QUESTIONNAIRE AND RESPONSES

QUESTIONS AND ANSWERS ARE SUMMARIZED ON THE FOLLOWING PAGES. WHERE APPROPRIATE, RESPONSES ARE BROKEN DOWN IN TERMS OF STUDENTS IN THE HTU-1 PROGRAM, INSTRUCTORS, AND INTERESTED PARTIES. INTERESTED PARTIES ARE SQUADRON INSTRUCTORS OTHER THAN THOSE WHO INSTRUCTED STUDENTS IN THE 2-FH-2.

MOTION SICKNESS IN THE 2-FH-2

THE FOLLOWING QUESTIONS ARE ASKED IN ORDER TO GATHER AS MUCH FACTUAL INFORMATION AS POSSIBLE ON THE PROBLEM OF MOTION SICKNESS. THE DIRECT CONCERN, OF COURSE, IS TO DIAGNOSE ITS CAUSES SO THAT IT CAN BE PREVENTED IN THE 2-FH-2 AND SIMILAR TRAINERS THAT PRESENT VISUAL DISPLAYS. THE VALUE OF THE INFORMATION OBTAINED HERE WILL DEPEND ON HOW ACCURATELY YOU CAN RECORD YOUR EXPERIENCES.

CONSIDER EACH QUESTION AND ALTERNATIVE RESPONSES BEFORE ANSWERING. ALL QUESTIONS WILL NOT BE APPLICABLE TO EVERYONE; PLEASE ANSWER AS MANY QUESTIONS AS APPLY TO YOUR OWN EXPERIENCES.

MAKE MARGINAL COMMENTS TO QUESTIONS THAT DO NOT PROVIDE ADEQUATE COVERAGE AND/OR WHEN ALTERNATIVES DO NOT DESCRIBE YOUR OWN EXPERIENCES PROPERLY. YOUR COMMENTS ARE ESPECIALLY SOLICITED ON QUESTION 26 WHICH REQUESTS OPINIONS ON ASPECTS OF SICKNESS NOT COVERED IN THE QUESTIONNAIRE.

FILL IN BELOW

DATE _____

A. NAME _____ B. RANK _____

C. NUMBER OF FIXED WING FLIGHT HOURS

<u>FIXED WING HOURS</u>	<u>TOTAL</u>
0 - 250	3
250 - 500	16
500 - 1000	9
1000 - 2000	2
2000 - 3000	1
3000 - 5000	3

D. NUMBER OF HELICOPTER FLIGHT HOURS

<u>HELICOPTER HOURS</u>	<u>TOTAL</u>
0 - 50	19
50 - 150	0
150 - 300	0
300 - 500	1
500 - 1000	6
1000 - 2000	8

QUESTIONNAIRE ON MOTION SICKNESS

1. WHAT WAS YOUR INITIAL FEELING ABOUT FLYING THE DEVICE JUST PRIOR TO YOUR FIRST HOP IN IT?

YOUR OBJECTION TO FLYING IT WAS - -

1 VERY STRONG 1 STRONG 5 MODERATE 8 NONE 20 WANTED TO FLY

2. AFTER FLYING THE DEVICE A FEW TIMES HOW DID YOUR FEELINGS ABOUT IT CHANGE?

YOU LIKED IT - -

0 MUCH MORE 11 MORE 13 ABOUT THE SAME 5 LESS 7 MUCH LESS

3. DID YOU FLY THE DEVICE AGAINST YOUR WILL?

5 YES 30 NO

4. DID YOU FEEL ANY TENDENCY TO SICKNESS WHILE FLYING THE DEVICE?

6 CONSISTENTLY 4 MOST OF THE TIME 6 SOME OF THE TIME

12 ONLY OCCASIONALLY 8 NEVER

5. IF YOU EXPERIENCED ANY DEGREE OF MOTION SICKNESS, PLACE A CHECK IN ONE COLUMN FOLLOWING EACH MANEUVER ACCORDING TO THE PART IT PLAYED IN CAUSING SICKNESS OR TENDENCY TO SICKNESS.

TENDENCY TO SICKNESS

	VERY STRONG	CONSIDERABLE	SLIGHT	NONE
A. HOVER	<u>2</u>	<u>3</u>	<u>8</u>	<u>23</u>
B. VERTICAL TAKE-OFF	<u>0</u>	<u>4</u>	<u>7</u>	<u>25</u>
C. VERTICAL LANDING	<u>1</u>	<u>2</u>	<u>7</u>	<u>26</u>
D. TURNS ON SPOT	<u>3</u>	<u>10</u>	<u>6</u>	<u>17</u>
E. PARA. HDG. SQUARES	<u>3</u>	<u>8</u>	<u>4</u>	<u>21</u>
F. CONSTANT HEADING SQUARES	<u>1</u>	<u>7</u>	<u>7</u>	<u>21</u>
G. FIGURE EIGHTS	<u>8</u>	<u>5</u>	<u>4</u>	<u>20</u>
H. CLEARING TURNS	<u>1</u>	<u>4</u>	<u>11</u>	<u>20</u>
I. NORMAL APPROACH	<u>0</u>	<u>3</u>	<u>8</u>	<u>25</u>

(TABLE CONT. FROM F-3)

	VERY STRONG	CONSIDERABLE	SLIGHT	NONE
J. AUTOROTATIONS	<u>1</u>	<u>0</u>	<u>6</u>	<u>29</u>
K. GLIDING TURNS	<u>0</u>	<u>2</u>	<u>6</u>	<u>28</u>
L. OSCILLATIONS-FORE AND AFT	<u>7</u>	<u>6</u>	<u>7</u>	<u>16</u>
M. OSCILLATIONS-LATERALLY	<u>8</u>	<u>10</u>	<u>4</u>	<u>14</u>

6. DO YOU THINK THIS SICKNESS WAS AN ACCUMULATION EFFECT PRODUCED BY SEVERAL OF THE ABOVE MANEUVERS?

26 YES 7 NO

IF SO, LIST THEM AND EXPLAIN.

7. WHAT PERIODS AND HOW QUICKLY AFTER A FLIGHT STARTED DID YOU FIRST NOTICE A TENDENCY TO SICKNESS? (USE BACK OF PAGE IF MORE SPACE IS NEEDED.)

PERIOD	No. OF RESPONDENTS	HOW SOON AFTER STARTING PERIOD		
		0 - 10 MIN.	11 - 20 MIN.	21 - 30 MIN.
1	14	9	1	2
2	13	8	1	1
3	8	2	4	1
4	4	3	0	0
5	3	2	1	0
6	3	2	1	0
7	1	1	0	0
8	2	1	1	0
9	1	0	0	0
10	1	0	1	0
11	1	0	1	0
12	<u>1</u>	<u>0</u>	<u>1</u>	<u>0</u>
TOTAL	52	28	12	4

8. FROM YOUR OWN EXPERIENCE, DO YOU THINK THIS SICKNESS CORRELATED WITH

A. ALCOHOLIC INTAKE THE NIGHT BEFORE: 2 Yes 1 PROBABLY 15 No
15 NO DRINKING

B. BAD COLDS, STOPPED NASAL PASSAGES: 2 Yes 1 PROBABLY 12 No
16 NO COLDS

C. ANY OF YOUR FOOD OR SOFT DRINK INTAKE PRIOR TO FLYING THE DEVICE:

FOOD: 2 Yes 20 No; DRINK: 2 Yes 30 No

D. LIST ANY MEDICINE YOU TOOK WITHIN 12 HOURS PRIOR TO FLYING DEVICE.

9. PLACE A CHECK BESIDE ALL OF THE WORDS BELOW WHICH DESCRIBE HOW YOU FELT.
QUALIFY ANY CHECKS THAT YOU FEEL ARE NOT CLEAR.

<u>14</u> DIZZINESS	<u>12</u> HEADACHE
<u>5</u> NERVOUSNESS	<u>0</u> INSOMNIA
<u>4</u> DROWSINESS	<u>0</u> NIGHTMARES
<u>12</u> BLURRED VISION	<u>0</u> PAINS OR TINGLING
<u>11</u> SWEATING	<u>0</u> DIARRHEA
<u>0</u> DRY MOUTH	<u>0</u> CONSTIPATION
<u>3</u> WEAKNESS	<u>0</u> TROUBLE URINATING
<u>5</u> TIREDNESS	<u>0</u> SKIN RASH
<u>0</u> TINNITUS (RINGING IN EARS)	<u>6</u> VOMITING
<u>13</u> VERTIGO	<u>5</u> DOUBLE VISION
<u>18</u> NAUSEA	<u>-</u> OTHER (EXPLAIN)
<u>8</u> "BUTTERFLIES" IN STOMACH	

COMMENTS:

1. GENERAL LIGHT FEELING ALMOST LIKE DRUNK.

2. EYES WERE SLOW TO FOCUS SIX HOURS AFTER MOTION SICKNESS.

3. EXTREME AMOUNT OF SALIVA, SLIGHT FEELING OF MELANCHOLY, LIGHTNESS IN STOMACH.

4. NOT ABLE TO DO WHAT I WANTED TO DO.

5. UNABLE TO FOCUS EYES PROPERLY SEVERAL HOURS AFTER FLIGHT.

10. PLACE A CHECK BESIDE THE APPROPRIATE WORDS TO SHOW WHAT HAVE BEEN SOURCES OF SUCH SICKNESS FOR YOU IN THE PAST. QUALIFY ANY YOU CHECK WHICH YOU FEEL ARE NOT CLEAR.

<u>3</u> AUTO	<u>0</u> SHIPS ON QUIET SEA
<u>0</u> TRAIN	<u>8</u> SHIPS ON ROUGH SEA
<u>1</u> SMALL BOATS	<u>2</u> AIRPLANES (SMOOTH FLIGHT)
<u>4</u> AS A STUDENT PILOT (FIXED WING)	<u>5</u> AIRPLANES (ROUGH FLIGHT)
<u>0</u> AS A FIXED WING INSTRUCTOR	<u>0</u> HELICOPTER STUDENT
	<u>0</u> HELICOPTER INSTRUCTOR
	<u>3</u> OTHER (EXPLAIN)
	<u>12</u> NEVER

11. WITH WHAT FREQUENCY DID YOU EXPERIENCE SICKNESSES CAUSED BY THE ITEMS CHECKED IN QUESTION 10?

1 CONSISTENTLY
1 MOST OF THE TIME
4 SOME OF THE TIME
4 INFREQUENTLY
6 RARELY

12. COMMENT ON YOUR ANSWER TO QUESTION 11 - -

1. IN CABIN OF HUP DURING AUTO ROTATIONS; AT NAVIGATION TABLE AND TAIL SECTION OF P4Y-2; ACROBATICS IN SNJ (PARTICULARLY THE BACK SEAT); IN AIRCRAFT WHEN WITHOUT VISUAL REFERENCE TO THE HORIZON.
2. AS A FLIGHT STUDENT, I'VE BEEN "WRUNG-OUT" BY INSTRUCTORS IN FIXED WING A/C; I'VE GOTTEN SICK A FEW TIMES ABOARD SHIP DURING ROUGH WEATHER AND HEAVY SEAS.
3. HAPPENED ON 2 OCCASIONS IN FLYING EXPERIENCE. MOSTLY DUE (I BELIEVE) TO CONCENTRATION ON A VERY SMALL PATTERN OF INSTRUMENTS; TRYING TOO HARD TO CORRECT SMALL ERROR AND LOSING SIGHT OF WHOLE PICTURE.
4. I CROSSED THE ATLANTIC IN 1953 ON A DESTROYER. I WAS SICK FOR ABOUT 10 DAYS UNTIL I GOT ADJUSTED TO THE CONTINUOUS MOTION.
5. ONLY ONE TIME - THE INSTRUCTOR WAS FLYING AND WE WERE DOING TURNS ON THE SPOT - WE DID ABOUT EIGHT IN A ROW.

13. CHECK YOUR PRESENT AGE.

0 15 - 20

10 20 - 24

7 25 - 29

6 30 - 34

3 35 - 39

0 40 PLUS

14. HOW MUCH DO YOU WEIGH? _____

15. HOW MUCH DID YOU WEIGH WHEN YOU EXPERIENCED MOST OF THE MOTION SICKNESS? _____

16. LIST ANY DRUGS (TABLETS, PILLS, ETC.) WHICH YOU HAVE TAKEN TO COMBAT MOTION SICKNESS.

DRAMAMINE 6; BONAMINE 1; BENZIDRINE 1

17. IN WHAT QUANTITIES WERE THESE DRUGS TAKEN AND AT WHAT INTERVALS IN RELATIONSHIP TO YOUR ENTERING THE OBJECT CAUSING SICKNESS?

3 HOURS PRIOR TO FLIGHT 1; 1 OR 2 PILLS 2; AFTER I GOT SICK 1

1 PILL 30 - 45 MINUTES PRIOR TO HOP 1

18. WHAT EFFECTS DID THESE DRUGS HAVE ON YOU? (SEE LIST QUESTION 9 FOR SUGGESTIONS

19. DO YOU HAVE ANY PERSONAL REMEDIES (NON-MEDICAL) FOR PREVENTING SICKNESS. LIST AND/OR EXPLAIN.

1. FORGET IT, BE OPTIMISTIC.
2. YES, IN THE TRAINER I CONCENTRATED ON FLYING A GOOD HOP AND I SEEMED TO FORGET HOW I FELT.
3. I BELIEVE THAT TO A HIGH DEGREE IT IS A RESULT OF MENTAL ANTICIPATION. I HAVE SEEN AND HEARD MANY PEOPLE EXPRESS THEIR FEAR OF SEASICKNESS, ETC., BEFORE THEY EXPERIENCED IT AND WHEN THEY ACTUALLY ENCOUNTERED IT THE RESULTS WERE BAD.
4. IN THE TRAINER IT HELPS TO CONTINUALLY SHIFT YOUR GAZE. CLOSE EYES WHEN FEELING TIRED.
5. VISUALIZE THE PATTERN OF FLIGHT AND HAVE ORGANIZED SCAN OF PANEL OR COCKPIT.
6. NONE EXCEPT TRYING TO REALLY PUT MYSELF INTO THE PICTURE AND PRETEND I WAS REALLY FLYING.

20. DID YOU EVER HAVE TO STOP A HOP OR LESSON IN THE 2-FH-2 BECAUSE OF SICKNESS?

9 Yes 20 No

21. HOW LONG AFTER LEAVING THE 2-FH-2 DID YOU FEEL ITS EFFECTS?

	<u>STUDENT</u>	<u>INSTRUCTOR</u>	<u>INTERESTED PARTY</u>	<u>TOTAL</u>
IMMEDIATE CESSATION	5	2	2	9
1 HOUR	5	-	-	5
4 HOURS	1	2	1	4
8 HOURS	1	2	1	4
12 HOURS	1	-	-	1
OVERNIGHT	1	2	2	5
LONGER THAN ANY OF ABOVE	<u>-</u>	<u>-</u>	<u>-</u>	<u>-</u>
TOTAL	14	8	6	28

22. DESCRIBE ANY LASTING EFFECTS YOU HAD.

1. LIGHT DIZZY FEELING
2. UNCOMFORTABLE
3. VOMITED
4. I COULD STILL SEEM TO SEE THE SCREEN AND FEEL MOVEMENT FOR ABOUT ONE HOUR AFTER A HOP.
5. SENSATION BEHIND EYES; SLIGHT NAUSEA.
6. STRONG DESIRE TO DO NOTHING BUT SLEEP.
7. I NEVER HAD LASTING EFFECTS EXCEPT FROM THE TRAINER. I ACTUALLY HAD MORE NAUSEA AND DIZZINESS AFTER I GOT HOME AT NIGHT AND HAD FLOWN THE TRAINER THAT MORNING THAN SHORTLY AFTER THE FLIGHT.
8. SLEEPY, TIRED, DISINTERESTED IN FOOD, AND JUST PLAIN FELT UNFIT TO LIVE WITH FOR 8 TO 10 HOURS AFTER LEAVING THE 2-FH-2.
9. LIGHT HEADINESS AND SLIGHT HEADACHE.

23. WERE THEY DIFFERENT FROM THE IMMEDIATE EFFECTS?

3 Yes 9 No

How?

IMMEDIATE EFFECTS WERE SICKNESS AND HEADACHES, LASTING EFFECTS WERE NAUSEA AND DIZZINESS.

24. HOW MUCH TIME HAVE YOU HAD IN THE 2-FH-2?

	<u>STUDENT</u>	<u>INSTRUCTOR</u>	<u>INTERESTED PARTY</u>	<u>TOTAL</u>
0 - 30 MINUTES	-	-	-	-
30 - 60 MINUTES	-	1	4	5
1 - 3 HOURS	-	-	1	1
4 - 5 HOURS	15	2	-	17
7 - 12 HOURS	2	1	-	3
13 - 20 HOURS	1	1	2	4
20 - PLUS HOURS	<u>-</u>	<u>3</u>	<u>2</u>	<u>5</u>
TOTAL	18	8	9	35

25. YOU WERE --

- 10 AN INSTRUCTOR IN 2-FH-2 PROGRAM.
- 18 A STUDENT IN 2-FH-2 PROGRAM.
- 5 AN INTERESTED PARTY IN 2-FH-2
- 3 OTHER (EXPLAIN)

26. DISCUSS ANY ASPECTS OF SICKNESS YOU ENCOUNTERED WHICH YOU FEEL ARE INCOMPLETE COVERED ABOVE. (USE BACK OF PAGE IF NECESSARY.)

* Kellogg, R. S., Kennedy, R. S., & Graybiel, A. Motion sickness symptomatology of labyrinthine defective and normal subjects during zero gravity maneuvers. Aerospace Medicine, 1965, 36, 315-318.

Labyrinthine defective (L-D) and normal subjects were flown through zero-gravity maneuvers and their motion sickness symptomatology observed. The L-D subjects showed no signs of motion sickness, whereas 64 per cent of the normal subjects developed symptoms. The absence of functional labyrinthine mechanisms appreciably decreased, and probably completely eliminated susceptibility to motion sickness during zero-gravity maneuvers.

THE PRIMARY OBJECTIVE of this investigation was to compare the functional symptoms of two groups of subjects during exposure to the force environment in a C-131B aircraft flying through standardized Keplerian trajectories. One group of subjects was made up of persons with bilateral labyrinthine defects (L-D), while a second group had normal vestibular function (normal subjects). A secondary objective was to compare the findings obtained in this environment with those obtained earlier on some of the same subjects exposed to standardized acrobatics, wave action at sea,⁴ coriolis acceleration in a slowly rotating room and centripetal force in a counter-rotating room.⁵

A survey of the pertinent literature has not disclosed any report dealing with exposure of L-D subjects to weightlessness. There are a few reports describing their participation in other types of experimental flights but no comment was made regarding symptoms of motion sickness.^{1,6}

Persons with normal vestibular function have been exposed to weightlessness in a variety of experiments. The experiment which has been used most extensively is the parabolic flight which produces weightlessness periods of 10 to 60 seconds, preceded and followed by high positive-G loads. In these flights subjects were either "restrained"^{7,10} or "free floating."⁹ Gerathewohl¹ has summarized his experience at the USAF School of Aviation Medicine in which 16 subjects were exposed to a total of 300 parabolas, during which six of the subjects developed motion sickness. Von Beckh,¹ summarizing the experience at Holloman Air Force Base, reported that six of 18 subjects became motion sick during zero-gravity flights in a T-33 jet aircraft. Loftus⁶ has summarized the extensive experience of two groups of sub-

jects at Wright-Patterson Air Force Base. In the first group 45 persons participated in zero-G flights and 23 vomited on one or more flights. In the second group 90 persons participated, 21 vomited and 23 others reported nausea. Of the total of 44 who vomited 60 per cent experienced a recurrence of nausea in the evening of the day they were motion sick.

Three generalizations may be drawn from these experiences with parabolic flights: (1) the incidence of motion sickness was greater when subjects were "free floating" as compared with being "restrained," (2) susceptibility to motion sickness is generally lower with increased flight experience and (3) weightlessness was not the only variable and the motion sickness produced may have been influenced by the other flight stresses, particularly the positive G's.

More prolonged exposures to weightlessness have been experienced in other types of flights, namely, the X-15,¹² the suborbital and the orbital flights. From the information available only Cosmonaut Titov^{13,14} experienced symptoms characteristic of motion sickness. The fact that Glenn¹ reported slight seasickness while in a life raft after impact points up the lack of transfer from whatever adaptation to unusual force environments he acquired in flying to the environment at sea.

METHODS

Subjects—The 6 L-D subjects tested ranged in age from 20 to 48 years. The principal clinical findings on these subjects are summarized in Table 1. The tests of otolith function revealed sufficient variance to raise the question of residual function in some instances.

The 19 normal subjects were made up of two groups, student subjects and regular subjects. The former consisted of nine healthy medical students, 21 to 25 years old. A tenth candidate was not allowed to participate because his susceptibility to motion sickness under other circumstances indicated undesirable complications might ensue. The regular subjects consisted of 10 enlisted men, 18 to 21 years old, who were assigned to the Naval School of Aviation Medicine for the express purpose of participating in experiments. All 19 subjects were free of functional disorders, defect or disease of the sensory organs of the inner ear as determined by history, audiogram and the caloric test.

The Force Environment—The force environment of the zero-gravity airplane is described elsewhere. A typical flight procedure, for convenience termed "maneuver," consisted of a shallow dive followed by a

This research was conducted jointly by the Human Engineering Division, Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, and the U. S. Naval School of Aviation Medicine, U. S. Naval Aviation Medical Center-54, Pensacola, Florida. This paper has been cataloged by the Aerospace Medical Research Laboratories as AMRL-TDR-04-47.

TABLE I. CLINICAL FINDINGS AND RESULTS OF FUNCTIONAL TESTS OF AURICULAR ORGANS OF SIX SUBJECTS WITH LABYRINTHINE DEFECTS

Subject	Age	Etiology	Age of Onset	History of Motion Sickness	Hearing Threshold		Caloric Test		Counterrolling Index (min. of arc)
					R	L	R	L	
A	20	Meningitis	12 1/2 yrs.	Car. bus*	130db	135db	*Neg	*Neg	117
B	21	Meningitis	4 1/2 yrs.	None	145db	145db	*Neg	*Neg	89
C	20 1/2	Meningitis	5 1/2 yrs.	None	135db	134db	None	None	76
D	25	Meningitis	8 yrs.	None	None	None	None	None	82
E	22	Meningitis	3 yrs.	None	None	None	None	None	85
F	48	Mastoidectomy	12 yrs.	None	None	160db	None	None	90

*Sheik nausea: "occasionally long trips."

No vertigo or observable nystagmus when tympanum irrigated with cold water (4.5° to 6°C). Numerals refer to nystagmograms obtained during irrigation with cold water for three minutes: 1, questionable vertical nystagmus; 2, questionable nystagmus; 3, minimal nystagmus.

Natural counterrolling range (9 subjects) 286 to 463 Minutes of Arc.

pullup generating 2.5 G and a pushover into a ballistic trajectory with approximately 10 to 12 seconds of weightlessness. Recovery involved a pullup generating about 2.5 G. Unless interrupted a flight sequence consisted of 40 maneuvers.

Procedure—The subjects were thoroughly briefed regarding the nature of the experiment and were indoctrinated in safety procedures. They were seated in airline-type seats and restrained by seat belts. The information sought was obtained with the aid of four questionnaires. The first questionnaire dealt with the fitness of the subject to participate and with his estimate of his concern and expected performance in relation to others. The second questionnaire was used by the experimenter and consisted of a check-off list with rating scales of the signs and symptoms of motion sickness. The third and fourth questionnaires were used to assist the subject and experimenter in the final evaluation immediately after the flight.

RESULTS

As indicated in Table II only two symptoms were reported for the entire group of L-D subjects and these symptoms were barely detectable. The L-D's as a group were essentially symptom free. They enjoyed the flight and grasped every opportunity to fly as an assistant or passenger. In these additional flights they appeared to enjoy the experience of free-floating.

The normal subjects were ranked in order of decreasing susceptibility to the functional symptoms of motion

sickness. Four of the 10 regular subjects (Table III) were regarded by the experimenter as less fit than normal although they rated themselves as "fit." All except one regular subject completed the series of 40 maneuvers. This subject requested termination because of severe discomfort. There were individual differences among the regular subjects but these differences were not predictable from their own estimate of concern or performance. Of particular interest were the effects in the case of L whose verbatim report follows:

"Immediately after the flight I noticed no ordinary after effects except a little difficulty walking and a slight nausea. This lasted for about an hour after the flight. Everything was fine until late Friday (day of flight) night. At approximately 10:45 I noticed difficulty in walking when I was getting ready to turn in. (Since about 8:00 I was watching TV and noticed nothing.) Whenever I would take a step, my foot would seem to keep falling. When I lay in my bed I seemed to be tossing from side to side. I know I wasn't because I was holding on to my bed. Several times I got out of bed and walked to the bathroom and while in the bathroom would walk up and down seeing if it would stop. It would stop for a while and start up again. I went to sleep and when I woke up I felt normal until approximately 10 when it started again. I noticed it the most when I would come from one extreme to the other, i.e., from very bright light to a place of shade, from a warm space into a cold space or vice-versa or when I would stand up rapidly. Saturday, around noon, I went to town and it seemed to get worse. When I would sit down it would have a strong effect. This lasted until that (Saturday) night, varying from a point of strong effect to a weak one and at times it would disappear entirely. When going to sleep Saturday night I felt fine. Sunday morning I noticed it very slightly every once in a while, then it seemed to clear up com-

TABLE II. FINDINGS IN SIX SUBJECTS WITH LABYRINTHINE DEFECTS EXPOSED TO WEIGHTLESSNESS IN PARABOLIC FLIGHTS

Subject	Subject's Estimate of Fitness*	Experimenter's Estimate of Fitness	Subject's Estimate of Concern (1)	Subject's Estimate of Discomfort (2)	Symptoms of Anxiety	Experiment Completed	Vomit (No. X)	Retch (No. X)	Nausea (1)	Sweat (1)	Pallor (1)	Restless Movements	General Discomfort (1)	Other Symptoms	Remarks
A	Yes	Slightly less	1	Av+	0	Yes	0	0	0	0	0	No	1	0	Not Applicable
B	Yes	Yes	1	Av+	0	Yes	0	0	0	0	0	No	0	0	Not Applicable
C	Yes	Yes	1	Av+	0	Yes	0	0	0	0	0	No	0	0	Not Applicable
D	Yes	Yes	1	Av+	0	Yes	0	0	0	0	0	No	0	0	Not Applicable
E	Yes	Yes	1	Av+	0	Yes	0	0	0	0	0	No	0	0	Not Applicable
F	Yes	Yes	1	Av+	0	Yes	0	0	0	0	0	No	0	0	Not Applicable

(1) Three-point scale, 1 = slight or minimal

(2) Av, above; Av- = Av

*Expressed in terms of "usual fears"

TABLE III. FINDINGS IN TEN REGULAR SUBJECTS EXPOSED TO WEIGHTLESSNESS IN PARABOLIC FLIGHTS

Subject	Age	Subject's Estimate of Fitness ¹	Observer's Estimate of Fitness	Subject's Estimate of Concern (1)	Subject's Estimate of Performance (2)	Experiment Completed	Symptoms of Anxiety (3)	Vomit (No. X)	Retch (No. X)	Nausea (1)	Sweat (1)	Pallor (1)	Restrict Movement	General Discomfort (1)	Other Symptoms (4)	Recovery
G	19	Yes	Yes	III	Av	No*	1,3	1	1	III	II	II	Yes	III	1,2,4,5,6	Slow
H	19	Yes	Slightly Less	II	Av	Yes	0	1	0	II	1	0	Yes	1	1,3	Rapid
I	19	Yes	Slightly Less	III	Av	Yes	1,3,5	0	1	1	1	II	Yes	1	1,2,4,5,6	Rapid
J	20	Yes	Yes		Av	Yes	0	0	0	II	1	1	No	1	1	Rapid
K	19	Yes	Yes	II	Av	Yes	1	0	0	1	1	1	Yes	1	1,4,5	Rapid
L	18	Yes	Yes	III	Av	Yes	0	0	0	1	1	1	No	1	4	Delayed
M	18	Yes	Slightly Less	II	Av	Yes	0	0	0	1	1	1	No	1	0	Rapid
N	18	Yes	Slightly Less	III	Av	Yes	4	0	0	1	0	0	No	1	1,3,7	Fast Fatigued
O	20	Yes	Slightly Less	III	Av+	Yes	3	0	0	0	1	0	No	1	7	Not Applicable
P	21	Yes	Yes	III	Av—	Yes	0	0	0	0	1	0	No	1	0	Not Applicable

(1) Three-point scale, 1 = slight or minimal

(2) Av: above Av = Av+; below Av = Av—

(3) 1. Characteristic sighing, 2. Frequent sighing, 3. Awareness of breathing, 4. Blurred vision, 5. Dry mouth

(4) 1. Stomach awareness, 2. Anorexia, 3. Drowsiness, 4. Dizziness, 5. Headache, 6. Yawn, 7. Includes salivation, 8. Desire bowel movement

*Terminated at subject's request

**Expressed in terms of "usual fitness"

pletely. Today, Monday, I have no feelings of unstableness at all. 10:30."

Careful inquiry revealed no explanation for the symptoms in terms of medical history or associated symptomatology. Subsequently this subject participated in a series of flights in which he was exposed to even longer periods of weightlessness without delayed aftereffects. This incident points up a troublesome deviation from the usual pattern of vestibular sickness.

The student subjects (Table IV) also varied greatly in susceptibility but differed from the regular group in that more fell at one extreme or the other. One flight sequence was terminated after ten maneuvers at the

request of two subjects. One of the two subjects, Q, felt sick after one maneuver and both subjects manifested symptoms of anxiety, suggesting that the flight acted in part as a nonspecific stressor. Two other subjects who were on the same flight necessarily failed to complete the predetermined number of maneuvers but the early appearance of pallor and sweating suggested that they were to be included among those who were quite susceptible. At the other extreme were two "insusceptibles" who showed no symptoms of motion sickness.

The L-D subjects and the nine student subjects had been exposed to unusual force environments other than

TABLE IV. FINDINGS IN NINE STUDENT SUBJECTS EXPOSED TO WEIGHTLESSNESS IN PARABOLIC FLIGHTS

Subject	Age	Subject's Estimate of Fitness ¹	Observer's Estimate of Fitness	Subject's Estimate of Concern (1)	Subject's Estimate of Performance (2)	Experiment Completed	Symptoms of Anxiety (3)	Vomit (No. X)	Retch (No. X)	Nausea (1)	Sweat (1)	Pallor (1)	Restrict Movement	General Discomfort (1)	Other Symptoms (4)	Recovery
Q	23	Yes	Yes	II	Av	No	1,2,3	1	1	III	II	II	Yes	III	1,2,3,4,5,7	Slow
R	21	Yes	Yes	I	Av	No	1,2,3,5	0	0	III	II	II	No	III	1,2,4	Rapid
S	24	Yes	Yes	III	Av	Yes	3,5	0	0	1	1	1	No	1	1,3,6	Rapid
T	24	Yes	Slightly Less	II	Av	No	0	0	0	0	II	II	No	1	1,4	Rapid
U	25	Yes	Yes	I	Av	No	0	0	0	0	II	1	0	0	0	Rapid
V	22	Slightly Less	Slightly Less	I	Av	Yes	0	0	0	0	1	1	0	1	1,3	Rapid
W	21	Yes	Slightly Less	I	Av	Yes	0	0	0	0	II	0	No	0	0	Not Applicable
X	22	Yes	Yes	I	Av+	Yes	0	0	0	0	0	0	No	0	0	Not Applicable
Y	21	Yes	Yes	III	Av+	Yes	0	0	0	0	0	0	No	0	0	Not Applicable

(1) Three-point scale, 1 = slight or minimal

(2) Av: above Av = Av+; below Av = Av—

(3) 1. Characteristic sighing, 2. Frequent sighing, 3. Awareness of breathing, 4. Blurred vision, 5. Dry mouth

(4) 1. Stomach awareness, 2. Anorexia, 3. Drowsiness, 4. Dizziness, 5. Headache, 6. Yawn, 7. Includes salivation, 8. Desire bowel movement

Terminated at subject's request

*Expressed in terms of "usual fitness"

TABLE V. FINDINGS IN NINE STUDENT SUBJECTS EXPOSED TO VARIOUS FORCE ENVIRONMENTS

Student Subject	Age	History of Motion Sickness					
		C-131 ¹	ADP ²	Sea ³	SRR ⁴	CRR ⁵	
Q	23	V	V	IV	IV	V	III
R	21	V	V	IV	V	IV	V
S	24	III	III	IV	Nil	V	II
T	24	V	III	III	III	V	IV
U	23	III	III	III	Nil	III	IV
V	22	Nil	I	II	Nil	II	I
W	21	Nil	Nil	Nil	Nil	I	—
X	22	Nil	Nil	II	I	I	Nil
Y	21	Nil	Nil	Nil	Nil	II	—

Five-point scale, I = slight or minimal

1. Zero-gravity flights
2. Standardized aerobics for 30 minutes
3. Exposure in small boat
4. Exposure in slow-rotation room (ref 5), which stimulates the semicircular canals in an unusual pattern
5. Exposure in counter-rotating room (ref 6); absence of angular velocity permits avoidance of stimulation to the semicircular canals

parabolic flight. A listing of the student subjects symptomatology is given in Table V. Since the L-D subjects showed no symptoms in any of the force environments these subjects are not included in the table. The student subjects, ranked in order of susceptibility to symptoms in the C-131 aircraft, show the same general trend of susceptibility which occurred in the other force environments.

DISCUSSION

Subjects with bilateral vestibular defects not only failed to show or report symptoms of motion sickness in parabolic flight but actually enjoyed the experience. The likelihood of obtaining similar results in six normal persons with minimal flight experience is small. We assume the L-D subjects were representative of labyrinthine defective subjects in general and that loss of vestibular function in the L-D subjects was responsible for their lack of symptoms.

The incidence of symptoms in the normal subjects corresponds closely to the results reported by Loftus.⁸ Although Loftus reported a 51 per cent incidence of symptoms as compared to 64 per cent in this study, he used vomiting as the only indicator of motion sickness. The percentages would very likely have been in even closer agreement if other symptoms had been considered.

Apparently symptoms such as the ones Titov experienced in orbital flight may be ascribed to vestibular function. That the other participants in orbital flight did not experience symptoms might have been due either (1) to low basic susceptibility, (2) to transfer of adaptation acquired in other types of flight or acceleration devices, (3) to the fact that weightlessness is not a strong precipitating factor or (4) to a combination of these. Our findings indicate some persons are resistant to motion sickness when making transitions in and out of the weightless state, whereas the majority of naive persons with a normally functioning labyrinth are highly susceptible. Although there is some evidence that experienced pilots¹ are resistant to vestibular sickness in weightlessness, there is little actual proof of transfer of adaptation. We believe if weightlessness is a factor in

precipitating symptoms of motion sickness it is not a strong factor.

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PSYCHOPHYSIOLOGICAL EFFECTS OF TRAINING IN A FULL VISION SIMULATOR

Dr. Robert S. Kellogg
University of Dayton Research Institute
Operations Training Division
Human Resources Laboratory
Williams AFB, Arizona

Dr. Carl Castore
Department of Psychology
Purdue University

Mr. Robert Coward
Human Resources Laboratory
Luke AFB, Arizona

Kellogg, R. S., Castore, C., & Coward, R.
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PSYCHOPHYSIOLOGICAL EFFECTS OF TRAINING IN A FULL VISION SIMULATOR

I. INTRODUCTION

In response to a series of reports that pilot trainees had, on occasion, experienced dizziness, fatigue, nausea, motor imbalance, and flash-back of visual experiences after periods of extensive training in the Simulator for Air-to-Air Combat (SAAC), the Tactical Air Command (TAC) requested the Air Force Human Resources Laboratory's (AFHRL) assistance in studying these responses. These effects were experienced by students participating in the TAC Air Combat Engagement Simulator II (TAC ACES II) course (F-4000Z 00 AL) provided at Luke AFB, AZ. A previous study of these responses was carried out by B. Hartman, School of Aerospace Medicine Brooks, AFB, Texas. Hartman revealed some significant psychophysiological responses and made recommendations with respect to platform motion and training procedures to reduce these negative reactions. Reports of simulator sickness in the A-7 moving base simulator were also investigated by R. Kellogg and were found to be frequently experienced by the pilot trainees. Accordingly, an experimental program was instituted to study these psychophysiological responses in the SAAC simulator.

II. METHODS

Training Course

The course of training for the TAC ACES consists of an intensive week of air-to-air combat engagements in which each pilot has the experience of flying against each member of the group. During the course, each student receives approximately 12 hours in the SAAC (the equivalent of approximately 550 simulated combat engagements). The students do not fly any airborne missions during this program. In addition to their time in the simulator, the students receive approximately 25 hours of orientation, briefing, multi-media training and engagement debriefings. The training program was designed to provide the student with an intensive experience in the mechanics of air-to-air combat in a short period of time.

Subjects

The subjects used in this study (N=48) were combat ready F-4 pilots who were selected for the advanced simulation training. No special selection beyond their participation in the training program was used. Table 1 shows a breakdown of pilot experience in flying and simulation.

TABLE 1. PILOT EXPERIENCE DATA

	<u>N</u>	<u>% of Ss</u>
F-4 Flying Experience		
More than 1,000 hours	15	31.3
500-1000 hours	9	18.8
Less than 500 hours	24	50.0
Visual Simulator Experience		
Prior SAAC training	8	16.7
Other visual simulators	11	22.9

Design

An individual interview technique was employed to gain information from each pilot. The interview took place on the afternoon of the fourth day of the five-day training program. Tape recordings of each interview were made. Results of analysis of these tapes were summarized on worksheets and frequencies of various types of responses were tabulated.

Facilities

The simulator used in this study was essentially a two cockpit device, oriented so as to allow one-on-one air-to-air combat. The facility (described in detail in Kelly et al.) has a full screen visual display system with an eight-channel mosaic of CRTs which provides a field of view ± 148 degrees horizontally and $\pm 150/-30$ degrees vertically. The computer

generated image is provided by a dual raster, monochrome television system using one raster for the background (simulated terrain and sky) and one raster for projecting an opposing aircraft image. Using the two cockpit complex, the trainees can thus engage in air-to-air combat.

III. RESULTS

The results show that a very high proportion of these experienced pilots, exposed to intensive training in the SAAC, exhibit some degree of aversive symptomatology. Some 87.5% of the group described some forms of response to the simulator which was considered to be a perceptible change from normal (Table 2).

The most prevalent symptom was clearly nausea, which was reported by 79.2% of the Ss. The range of severity of symptoms was from mild or barely detectable to severe, bordering on emesis (vomiting). None of the subjects in this study vomited, but it should be pointed out that in the Hartman study cited above, two cases of emesis were reported. The largest proportion of occurrences of nausea took place in the simulator during the first 1-2 days of training. There was a marked reduction in nausea later on in the week. In addition, the occurrences of nausea outside the simulator were more frequent from 5-30 minutes after training than on-half to 10 hours after training. It appears also that a sleep period between exposures to the simulation greatly reduced or eliminated symptoms of nausea.

Profuse sweating also occurred in 26 of the Ss (54.2%). Of this group, 22 (84.6%) of those exhibiting this symptom) experienced this condition in the cockpit. The other four Ss experienced this problem within 5-30 minutes after emerging from the SAAC. In all cases, the sweating experienced was far greater than normal for a comparable amount of work.

Balance problems, like "sea legs" or motor dyskinesia were next in frequency, occurring in 60.4% of the Ss. The highest proportion of dyskinesia occurred not in the simulator, but shortly after leaving the simulator cockpit. It should be noted that 14.6% exhibited symptoms as much as one-half to 10 hours later.

0.015, 0.019, 1.9, 1.9

11-11-1963

The sensation of spinning or being rotated in some orthogonal plane was experienced by 26 (54.2%) of the Ss. These symptoms occurred anywhere from .5-10 hours after training sessions in the SAAC by 14 of the 26 subjects (53.8%).

Twelve of the Ss (25%) reported kinesthetic sensations typical of various maneuvers (i.e., roll etc.) after having completed one or more training sessions in the SAAC. These reactions were spaced over a wide time period subsequent to leaving the cockpit and included some strong sensations of flying specific maneuvers which had been flown in the simulator. These sensations persisted for the entire week of training for 10 of the 12 persons who experienced them.

Some 11 (22.9%) of the Ss experienced the additional symptoms of one or more of the following: headache, "leans", dizziness (produced by the Barány chain) and momentary loss of situational awareness.

The visual perception reactions to the SAAC training are summarized in Table 3. As can be seen, 17 of the Ss (35.4%) reported not unusual or otherwise disturbing visual-attentional difficulties occurring during the training period. Another 17 Ss (35.4%) reported noticeably "vivid" visual reactions including daydreams, dreams, and recall of the missions with more vivid than usual visual components. Virtually all of this group attributed these reactions to the highly distinctive visual scene presented by the SAAC. However, another 17 Ss (34.4%) reported some degree of highly vivid involuntary visual flashback of the SAAC visual scene. These visual flashbacks were accompanied in all cases by kinesthetic sensations described as if they were flying a climbing roll.

In addition, 17 of the Ss (35.4%) reported persistent attentional difficulties, chiefly in the evenings, during the training week. The Ss generally described these problems variously as an inability to focus on written material, an inability to concentrate on anything for more than 3-4 minutes, wandering attention, etc. These problems tended to be described in conjunction with the Ss attempting to work on written materials.

TABLE 3. VISUAL PERCEPTION REACTIONS

Symptoms	Following Days 1 and 2	Persisted All Week	Total
No Unusual Visual Reactions			14 (29.2%)
Vivid Involuntary Visual Flashbacks	1 (2.1%)	16 (33.3%)	17 (35.4%)
"Vivid" Dreams, Daydreaming Recall of Missions		17 (35.4%)	17 (35.4%)
Persistent Attentional Difficulties (Difficulty focusing while reading, inability to concentrate on written material, wandering attention, etc.)		17 (35.4%)	17 (35.4%)
Temporary Inversion of Visual Field		5 (10.4%)	5 (10.4%)

Finally, five of the Ss (10.4%) reported periodic, temporary inversions of their visual field during the week. These would typically occur in the evening while the Ss were resting, watching TV, etc. in their quarters. For example, one of the Ss reported that while reading in the TV lounge, he momentarily dozed off and when he awakened, he had the perceptual sensation that the TV set was located on the overhead and that his body had rotated backwards by 90°. Others reported complete inversions of the visual field similar to those described by Graybiel and Kellogg (1967) while flying zero gravity maneuvers.

The subjective responses of the pilots with respect to fatigue in the simulator as opposed to the aircraft are detailed in Table 4.

TABLE 4. SUBJECTIVE RESPONSES WITH RESPECT TO FATIGUE,
SIMULATOR VS AIRCRAFT

	<u>N</u>	<u>%</u>
Mental Fatigue		
Greater in SAAC	38	79.2
Same	2	5.2
Greater in F-4	8	16.7
Physical Fatigue		
Greater in SAAC	10	20.8
Same	4	8.3
Greater in F-4	34	70.8

It is clear that the simulator flights produce greater mental fatigue (in the majority of cases, 79.2%) as compared with flight in the aircraft, 16.7%. On the other hand, physical fatigue is reversed, with 70.8% of the pilots experiencing more in the aircraft than in the simulator, 20.8%.

IV. DISCUSSION

It is clear from the interviews with the F-4 pilots that significant psychophysiological responses to complex simulation are taking place. Although the literature on motion sickness is quite voluminous (see Money, 1970, for a review), only a relatively modest number of studies have been performed specifically on the subject of simulator sickness (Miller and Goodson, 1960; Barrett and Nelson, 1965, 1966; Barrett and Thornton, 1968; Reason and Diaz, 1971). Inasmuch as severe sickness can be produced in a complex fixed based simulator, it seems clear that such sickness is not caused solely by vestibular overstimulation from the gravitoenertial field presented to the pilot. The etology of simulator sickness appears to follow the "sensory conflict" theory which has emerged so prominently in recent formulations (see Reason and Brand, 1974).

In the present study, a version of the sensory conflict theory may be invoked to explain the occurrence of simulator sickness. It is known from the animal work of Henn, 1974, that purely visual stimuli are capable of driving the vestibular nuclei in the same way that gravitoenertial forces drive the vestibular system. Thus, when the pilot is exposed to complex, wide screen moving visual presentations, his vestibular system gives him the sensation of moving in space (linear and circularvection). The highly trained pilot has developed a neural program of expectancy with respect to gravitoenertial flight patterns. When he is presented with maneuvers in the simulator, in the absence of true vestibular input, there may thus be a neural mismatch between his highly trained acceleration sensing system and the zero input from the vestibular system, when there is no real motion. This neural mismatch or sensory conflict may in large part be the cause of the experienced simulator sickness.

It would follow from the above discussion that, the more highly trained the pilot, the greater would be his vulnerability to simulator sickness, since his highly developed percept of aircraft motion is so finely tuned. conversely, a novice pilot would have less difficulty with simulator sickness since he has not yet developed a neural expectancy of the motion/vision complex. This result seems to be borne out by the preliminary investigations of A. Kellogg (cited above), in that the more experienced A-7 pilots tend to be more reactive to simulator sickness.

From the standpoint of symptomatology, nausea was the most prevalent, followed by dyskinesia, profuse sweating, sensation of post flight spinning and maneuvering and other reactions such as headache and loss of situational awareness. These are all symptoms which are characteristic of conventional motion sickness. Therefore, the sensory conflict theory, which is generally accepted as the underlying cause of motion sickness, appears to be directly applicable to simulator sickness. Nausea, as experienced in the simulator was indistinguishable from nausea produced in flight. A very interesting finding was that a few of the pilots who had never experienced nausea during their flying careers, experienced it for the first time in the simulator! The implication here is that the simulator produced for them the strongest sensory conflict situation they had yet encountered.

With respect to dyskinesia, a significantly high proportion of the subjects experienced this difficulty. Such motor imbalance takes place when there has been a strong sensory conflict or when there has been a sustained vestibular or kinesthetic input, which continues to affect the subject even after cessation of the stimuli. It would seem that both of these conditions are operative in the case of simulator sickness. Since the occurrence of this symptom is in large part directly following the simulator flight and normally of short duration, it would appear to follow a habituation pattern similar to post rotatory after nystagmus.

The visual perceptual responses to simulation are quite interesting. It appears that the visual and perhaps the psychomotor system are driving the vestibular system in such a way as to produce quite striking perceptual illusions. Involvement of the vestibular system is further implied in that several of the subjects reported that while experiencing reactions like the inversion illusion, if they shook their heads, the illusion would be eliminated. The act of shaking their heads may be akin to recaging the internal gyros and putting the visual perception back on track. There must be a complex interplay of cognitive, visual, vestibular and kinesthetic factors in the formation and alteration of these visual perceptions.

Along this same line, it was noted that from a visual standpoint, two functions carried out during the training were stressful to the pilots. The first was the simulator freeze, which is instantly stopping the visual scene movement, and ingress into the simulator while the visual scene was being presented. The freeze mode evoked consistently negative comments by the pilots. For example, if the pilot were in an active attack on the other aircraft and at the moment of firing the guns or releasing the rockets a freeze took place, the pilot felt a great deal of dissonance and in some cases, spatial disorientation. Many of them felt that such freezes were instrumental in producing their symptoms of simulator sickness. During ingress to the simulator, they also felt a sense of dissonance at being confronted with a full blown active visual scene.

A high percentage of the subjects exhibited profuse sweating and unusual fatigue, which appeared to be much greater than would be expected from the amount of physical exertion required in the simulation. The high cognitive and motor work load was probably the cause, along with the sensory conflict discussed above. The pilots were clearly aware that flying the simulator, which could not produce G forces as were produced in the F-4, was not as physically demanding as the aircraft. However, the massing of complex workloads produced a result which was clearly a stress response and resulted in profuse sweating and fatigue.

V. RECOMMENDATIONS

It seems clear that with the continued development of complex wide screen simulators and with their ever expanding role in flight training, that attention to the problem of psychophysiological responses to simulation require more attention. The dynamics of the production of simulator sickness needs to be studied in much more detail, so as to develop methodologies of reducing its negative effects of training. The following are specific areas of recommendation which the authors agree could reasonably be made at this point in time.

(1) Inform the Pilot Population: It is believed that if the pilot population has a greater awareness of the potential reactions of the kind described in this report, they will be better equipped to deal with them when they occur. To this end, a dissemination of this information could be instituted through wing level briefings, flight surgeon briefings and through the general pilot literature. A thorough briefing on this area is strongly suggested for each of the TAC ACES II courses given at Luke AFB.

(2) Situation Freeze: Since the simulator freeze has been identified as a strong producer of symptoms, its judicious use is recommended in any complex simulation.

(3) Ingress: Since ingress with the simulator visual system turned on appears to stress the pilots, a system is recommended which allows the visual to go on only after the pilot is in the simulator and ready to go.

(4) Post Flight Caution: It is further recommended that caution be exercised when flying directly after exposure to complex flight simulation. Post simulator flight reactions may interfere with the ability of the pilot to perform to full capacity.

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Kennedy, R. S. 2F87 (#5) Aircraft Operational Flight Trainer, Trip report of sickness. Unpublished memorandum, Naval Biodynamics Laboratory, New Orleans, LA, 6 March 1981.

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6 March 1981

MEMORANDUM

From: CDR R. S. Kennedy, Administrative Assistant to Scientific Director
To: Commanding Officer, Naval Biodynamics Laboratory, New Orleans, LA 70189
Via: Scientific Director

Subj: 2F87 (#5) P-3C Aircraft Operational Flight Trainer, trip report of sickness

Encl: (1) Roster of FASODET personnel who assisted project team

Ref: (a) CO NBDL ltr to NAVAIRSYSCOM Code 413
(b) Wiker, Kennedy, McCauley, Pepper, Aero Environ and Space Med. 1980, 51
(c) Fregly, 1968, Aero Med 39
(d) Fregly, Graybiel, & Smith, 1972, Aero Med 43
(e) Coward, Kellogg, Castore, USAFRL Report TAC Attach, Dec 1979
(f) Miller & Goodson, Aero Med 1960, 31
(g) Schroder, & Collins, FAA AM 79-9, 1979
(h) Money, DCLEM Tech Memo, 80-C-44, 1980

1. Training at the facility, (FASODET) involving the moving base simulator of two main types - coupled (to the tactical trainer) and uncoupled. About two-thirds of all missions are uncoupled (i.e., 12-15 4 hour hops/week). Uncoupled flights involve mainly take-offs and landings. A benefit of this trainer is that take-offs and landings can be more rapidly recycled than in actual flight. Coupled flights occasion minimal visually displayed information (night time at sea, etc) and evoke negligible reports of illness. Many flight engineers report discomfort during uncoupled missions. The symptoms they report resemble motion sickness (reference (a)).

2. A team formed by three persons from NTEC and one each from McDonnell Douglas and NBDL, convened in Brunswick, 10 February, in an attempt to alleviate the symptoms of motion sickness experienced by flight engineers in these uncoupled flights (reference (a)). An initial evaluation was conducted of the optical louvers originally suggested by NBDL (reference (a)), after which a baffle was designed. Test and evaluation data concerning efficacy of the baffle were collected between 11-19 Feb by me. Data collection assistance was provided during the first week by Lt. Crosby (NTEC) and in the second week by TDX Williams (FASO). Evaluations were conducted using simulator sickness symptomatology reports, (reference (b)) postural equilibrium (standing and walking) scores (references (c) and (d)) and pilot opinion forms.

3. The important findings are:

a. Concerning the louver: The optical geometry of the simulator is such that it was not possible to place the filters at the image plane of the CRT. Thus, the computer generated image was broken up due to spherical and chromatic aberrations. An optician from NTEC (Dennis Braglia) was provided with a sample of the material and will evaluate it further and then communicate those

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findings to 3M. I will probably participate in these discussions. It is my opinion that when properly milled and placed in the right position on the CRT, this material might be used either in the 2F87 (#6) presently undergoing acceptance testing at Singer-Link, or in the planned updates for 2F87 (#'s 1,2,3 or 4), should those simulators employ the same visual display geometry as #s 5 and 6.

b. Baffle/occluder - this was somewhat NBDL's design also, although all members of the team (including FASODET Brunswick) participated in the installation. After initial fabrication, mainly by McDonnell Douglas, it was possible subsequently to install or remove the baffle in five minutes. Estimated cost of material for this fix is \$4.50 including the paint. Preliminary evidence suggests that with the occluder: (1) motion sickness symptomatology in flight engineers is vastly reduced or eliminated; (2) the design properties of the occluder are such that pilots and co-pilots report no interference in viewing the visual displays (sickness had not been a major problem for them previously); and (3) flight engineers do report a desire for a display of their own. The success of the present baffle recommends a consideration of that option. In its present form, with the flight engineer's seat in the extreme forward position, the baffle occludes up to 100% of both pilot's and co-pilot's view of their CGI. When the engineer's seat is in its typical position (third detent), only 10-20% of each CGI is visible, but this reduction in field of view appears to convey good advantages also. It is not unreasonable to consider that separation to this extent may obviate the binocular rivalry which may be occasioned when the two CGI displays fall on the two disparate retinae of the flight engineer. Since both displays image objects at infinity, everything on both displays is in focus, but fall on different retinal loci in the two eyes. The depth distortions which may result from these displays, particularly during turning motions, where the lack of concordance between the two displays is most noticeable, may contribute to the motion sickness problem perhaps in ways similar to what has been observed with visually coupled systems. Binocular rivalry and depth illusions may make the simulator sickness in the 2F87C related more to problems believed to occur in other simulators which also have two separate CGIs (viz., Lamps, S-3, etc.) In addition, the simulator sickness is etiologically different from the sickness and symptoms which are reported in point source projection and multiple CRT systems (e.g., 2E6 and the USAF simulator at Williams, reference (e)).

c. Postural disequilibrium appears to be a significant consequence of simulator exposure and seems not to have been reported previously. In these present studies, the following generalizations may be communicated further provided new experiences do not contradict the preliminary evidence:

(1) Flight engineers are ataxic immediately after flight following no-baffle conditions, particularly but not necessarily, when inertial motion was experienced during the previous four hours; a difference that was statistically significant ($p < .04$). The decrement resembles that reported by persons with elevated blood alcohol levels, (reference (g)).

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Subj: 2F87 (45) P-3C Aircraft Operational Flight Trainer, trip report of sickness

(2) Pilots flying in left seats are more ataxic post-flight than co-pilots flying in right seats. The geometry of the simulator is such that the pilot has two CGI displays, one forward and one side looking. The co-pilot has only the forward display.

(3) Persons with recent flight experience (particularly when coupled with sleep loss) have revealed baseline postural disequilibrium performances at or below the 5th percentile for this population. Recovery is sometimes found when the baseline testing is performed 24 hours later.

(4) Flights of one hour or less appear to have no effect on postural equilibrium.

(5) Flight engineers with more than 2500 hours occasionally exhibit postural disequilibrium baseline scores at or below the 5th percentile. It is well known that toxic agents and environmental stresses which affect the cochlea also affect the vestibular apparatus (e.g., noise, hyperbaria, streptomycin sulfate). Most flight engineers with more than 2500 flight hours exhibit hearing losses. They may have vestibular defects too. In this regard, reports from the Canadian simulator (Aurora) reveal far less simulator sickness than has been reported with our 2F87C. Important differences between the U.S. and Canadian situations are: (a) their cockpit lighting is low temperature white, while ours is red; (b) they have no side panel CGI for the first pilot, and (c) their flight engineers frequently have more than 5000 flight hours. It is felt that the side window for the pilot probably contributes to his greater ataxia but it is not believed a factor in the flight engineer's sickness. The cockpit lighting may modify the adaptive luminance of his retina such that more photopic than scotopic levels are available in the Aurora. The influence of this factor on overall simulator performance should be studied. It is not known to what extent this factor contributes to the greater sickness of pilots in the Aurora (reference (h)) and greater sickness of flight engineers in 2F87C. The very high flight times in reciprocating engines in this population can be suspected to result in some sensory loss greater than may be seen in persons with average lower flight times (viz, flight engineer trainees at NAS Brunswick). Concomitant loss of auditory and vestibular sensitivity may convey protection from simulator sickness as it has been shown to do for other forms of motion sickness. If so, then it may be difficult to estimate the true nauseogenic properties of various simulators unless care is taken to evaluate the positive function of the octavomotor nervous system (particularly the nonacoustic labyrinth) in the persons on which the data are based.*

*This factor may explain why the present simulator reports more symptoms in seemingly less experienced personnel--counter to what has been customarily found in simulator sickness elsewhere (i.e., more flight hours lead to--more sickness--because of an experience x cue conflict interaction (cf. reference (f)).

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It follows logically that visual acuity loss may also afford some protection from simulator sickness and although most crew members have 6/6 corrected vision, degraded visuals might also produce fewer problems. This factor may also be important in explaining why such a range of opinions is available concerning whether or to what extent simulator sickness occurs in the 2FC87.

(6) The fidelity of the visual scene either due to acuity loss in operators or detuning the simulated visual scene should be studied for its effects. According to "conflict" (or "correlation") theory of motion (and simulator) sickness, greater conflict would occur between high fidelity inputs (e.g. visual and inertial) when not concordant (spatially or temporally) than between low fidelity inputs. An alternative explanation following the modulation transfer function studies would suggest that wide field of view, low spatial frequency inputs (e.g., stimulating rods and peripheral vision) would be more disruptive than small, high spatial frequency visual displays. These relationships warrant further discussion.

4. Presently data are being collected by persons in the PASODET at NAS, Brunswick. Flight engineers are being tested before and after their four hour flights on a non-interference basis with their training. The major objective is to determine whether motion sickness symptoms and ataxia are less by statistical test after the no-baffle versus baffle condition. When sufficient data are available, they will be communicated to AIR 413 and at that time, permission will be requested to report these findings in a technical report or at a scientific meeting.

5. The following recommendations are made:

a. The basic design of the occluder should be adopted as an ad lib option to be employed at the discretion of flight engineers to reduce problems of motion sickness.

b. The training requirements for VFR vs IFR for flight engineers should be reviewed in order to be able to consider the utility of a low fidelity monochrome CRT for the flight engineers. The occlusion of the pilot and co-pilot visuals with concomitant success of removing motion sickness was a necessary first step towards evaluating this option.

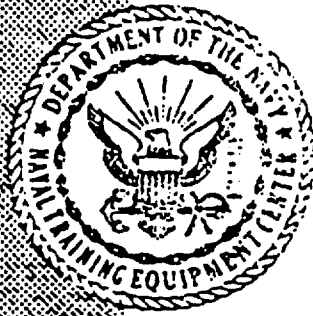
c. The postural disequilibrium which appears to be occasioned by exposure to this environment should be studied further. The purpose in this study was to use equilibrium as a sensitive probe for effects. It is not known whether the postural disturbances observed are symptomatic of more general incoordination (e.g., fine or gross motor control) and whether certain conditions might not amplify the effects (e.g., sleep loss, alcohol, red versus white light, impoverished sensory conditions). Other questions include: The amount of time required for return to baseline levels? Do all moving environments produce like changes? Do individual differences exist? Should particular activities be avoided?

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sickness

7. Enclosure (1) contains a list of persons who facilitated the conduct of this project. In particular, TDCS Thomson and TDI Williams provided day-to-day direct assistance and TDCS McDine and LT Pluto offered overall help including staying after normal working hours when required. I believe that this project's success depended principally on their cooperation and propose that this be communicated to their commanding officer. If you will entertain such a proposal, I will draft what I feel would be an appropriate letter of commendation.


R. S. KENNEDY



Technical Report NAVAERD-100-60-0-0151-1500-1

497 (Rev. 10-60)

SIMULATOR SICKNESS OCCURRENCES IN THE 286
AIR COMBAT MANEUVERING SIMULATOR (ACMS)

James McGuinness, J. H. Bouwman and
Jim W. Forbes
Person-System Integration, Limited
3012 Duke Street
Alexandria, Virginia 22314

February 1981

FINAL REPORT JULY - NOVEMBER 1980

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SUMMARY

A few fighter crews using the Navy's 2E6 Air Combat Maneuvering Simulator (ACMS) have experienced psychological effects similar to motion sickness symptoms.

A questionnaire was designed to collect data to define the incidence and severity of this "simulator sickness." The questionnaire was given to 66 aircrew members on an individual basis. The sample included participants from the F-4 and F-11 squadrons at NAS Oceana.

Twenty-seven percent (18) of the aircrew experienced varying degrees of "simulator sickness" during, and/or after use of the 2E6 Air Combat Maneuvering Simulator (ACMS). Sixty-one percent (41) of those experiencing symptoms reported persistence of the symptoms from 15 minutes up to 6 hours after a simulator session ended. The data compiled in this study indicates that susceptibility increases with experience levels. The highest incidence rate occurred among those aircrew members (52 percent) with more than 1500 flight hours (47 percent) as compared to 17 percent for 44 crew members with 1500 or fewer flight hours.

A recent USAF study revealed that 88 percent of aircrew who used the simulator for air-to-air combat (SAAC) also experienced simulator sickness symptoms. The SAAC differs from the 2E6 in the type of display used and the manner of use.

At the time of the study, the Device 2E6 was a new air simulator installed at NAS Oceana in November 1979 and commissioned in February 1980.

Significant changes in the length or intensity of training in the 2E6 ACMS may be accompanied by corresponding changes in the occurrence of simulator sickness. Further examination of simulator sickness rates should be pursued when a training curriculum is defined and modifications to the simulator (such as addition of ground growth cues) are made.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
<p>In March 1980, it was reported that a few Navy personnel were experiencing some disorientation or discomfort while flying the Air Combat Maneuvering Simulator (ACMS), designated Device 2E6. Recognizing the need for pursuing this matter further, a study was initiated to determine the extent of the problem.</p> <p>This report describes the methods and results of a preliminary study undertaken to assess the rate of occurrence and the (cont)</p>		

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degree of severity of "simulator sickness" experienced by individuals who have "flown" the Device 2E6, Air Combat Maneuvering Simulator.

Twenty-seven percent of the aircrews from F-4 and F-14 squadrons at NAS, Oceana, Virginia Beach, Virginia experienced varying symptoms during and/or after use of this simulator. Sixty-one percent of those experiencing symptoms reported persistence of the symptoms from fifteen minutes to six hours after a simulator session ended. At the time of the study, this was a new simulator installed in November 1979, therefore, the period of observation was limited.

Further investigation of simulator sickness is planned when a structured curriculum is incorporated into the training program and modifications are made to the simulator.

SUMMARY

A few fighter crews using the Navy's 2E6 Air Combat Maneuvering Simulator (ACMS) have experienced physiological effects similar to motion sickness symptoms.

A questionnaire was designed to collect data to define the incidence and severity of this "simulator sickness." The questionnaire was given to 66 aircrew members on an individual basis. The sample included participants from both F-4 and F-14 squadrons at NAS Oceana.

Twenty-seven percent (18) of the aircrews experienced varying degrees of "simulator sickness" during, and/or after use of the 2E6 Air Combat Maneuvering Simulator (ACMS). Sixty-one percent (11) of those experiencing symptoms reported persistence of the symptoms from 15 minutes up to 6 hours after a simulator session ended. The data compiled in this study indicates that susceptibility increases with experience levels. The highest incidence rate occurred among those aircrew members (22) with more than 1500 flight hours (47 percent) as compared to 18 percent for 44 crew members with 1500 or fewer flight hours.

A recent USAF study revealed that 88 percent of aircrews who used the simulator for air-to-air combat (SAAC) also reported simulator sickness symptoms. The SAAC differs from the 2E6 in the type of display used and the manner of use.

At the time of the study, the Device 2E6 was a new simulator, installed at NAS Oceana in November 1979 and commissioned in February 1980.

Significant changes in the length or intensity of training in the 2E6 ACMS may be accompanied by corresponding changes in the occurrence of simulator sickness. Further examination of simulator sickness rates should be pursued when a training curriculum is defined and modifications to the simulator (such as the addition of ground growth cues) are made.

PREFACE

The authors wish to acknowledge the assistance and cooperation of the Navy personnel who contributed to this study. In particular, appreciation is expressed to the Commander, Fighter Wing One and officers of the Oceana based Fighter Squadrons.

We also wish to acknowledge the willingness of the Tactical Research Branch, Air Force Human Resources Laboratory and the Operating Location of the 57th Tactical Fighter Wing in providing the briefings and discussions which were so valuable in comparing Air Force and Navy experiences with simulator sickness. In particular, we would like to express our appreciation to Lieutenant Colonel Joe E. Robinson, 57TTW/OLAA/CC and Mr. Robert E. Cowart, who is now with the Aeronautical Systems Division, Wright-Patterson AFB, Ohio.

FOREWORD

In March 1980, it was reported that a few Navy personnel were experiencing some unsteadiness and discomfort while flying the Air Combat Maneuvering Simulator (ACMS), designated Device 2E6. The discomforting symptoms described, especially when not associated with real motion, are usually referred to as "simulator sickness" to differentiate them from true motion sickness.

Recognizing the need for pursuing this matter further, this study was initiated by the Naval Training Equipment Center (NAVTRAEQUIPCEN) to determine the extent of the problem. CDR Charles Hutchins of the Naval Air Systems Command (COMNAV-AIRSYSCOM) (AIR 340F) provided financial support for the study.

Results, obtained through questionnaires administered to 66 aircrew members from F-4 and F-14 squadrons, indicated that 27 percent (18 crew members) reported varying symptoms and degrees of simulator sickness. Although some pilots reported similar symptoms while flying aircraft, this study dealt primarily with simulator induced problems. However, some opinions concerning mental and physical fatigue experienced in the simulator compared to actual aircraft ACM training sorties, were also solicited.

In an attempt to compare the 2E6 experiences with those in a similar device, the NASA, Langley Research Center, Virginia was contacted in reference to the Differential Maneuvering Simulator (DMS) located at their facility. Detailed documentation of simulator sickness had not been kept on this simulator, but a NASA representative stated that out of 600 to 800 pilots who have operated this device, he could only recall two who experienced extreme simulator sickness. The effects on these pilots were so disorienting that they could not complete the training sessions. Unfortunately, less dramatic symptoms such as fatigue, headaches, excessive sweating, and other minor discomforts were not documented.

This brings up the question of the definition of "simulator sickness." The term has been used rather loosely and has included symptoms as mild as sweating or a slight disorientation, to more severe physical reactions including nausea and vomiting. Between these extremes are symptoms such as vertigo, dizziness, and visual, mental, or general physical fatigue. In some cases, the symptoms persist for several hours after leaving the simulator. In assessing a simulator for its adverse effects on the trainee population, it is important to be specific about the type of "sickness" it produces. In some cases, the symptoms may be minor and of a transient nature, and no worse than would be experienced under operational flight conditions.

There are several hypotheses that have been advanced in an effort to explain simulator sickness. It is probably safe to state that not all instances of this phenomenon can be explained

by any one hypothesis. One of the most favored explanations is that it is the result of conflict of sensory cues; for example, the conflict between the apparent motion seen on a visual display and lack of any corresponding real motion of the simulator. Another instance would be excessive time lag between the simulator control system and the corresponding movement in the visual display. Situation freeze also imposes sensory conflict on the pilot. In these cases, the visual and proprioceptive (bodily feel) senses are not in phase. This imbalance can create a perplexing state that may be manifested in some of the symptoms discussed above.

McDonnell Douglas Astronautics was also contacted to determine the manufacturer's experience with the dome simulator type systems representative of Device 2E6. Although varied populations (e.g. experienced and inexperienced pilots, civilian and military dignitaries, foreign visitors, etc.) operated the simulator, McDonnell employees could not recall any incidents of simulator sickness. All of their simulator missions, however, had been highly structured in procedures and of less than 30 minutes duration per session.

Another simulator system with different characteristics was also investigated. This was the Air Force's simulator for air-to-air combat (SAAC) which has produced sickness in 88 percent of the users. A direct comparison of the SAAC data to that of the 2E6 should be made with reservation, however, since training on this device is very intensive over a short period of time (approximately 12 hours of actual simulator use over a four-day period) and the visual systems are of different types (dome projection real image vs "pancake window" virtual image display on SAAC). This comparison is useful in some respects, however, since it demonstrates that despite the high incidence of discomforting sensations, it continues to be used for training. The consensus of Tactical Air Command (TAC) pilots who have participated in the training program is that the temporary discomfort brought on by these symptoms is a small price to pay for the kind of combat training provided by the device. Another useful bit of information gained from this simulator corroborates the adaptation phenomenon. Most occurrences of nausea experienced on the SAAC took place during the first one or two days of training. There was a marked reduction in nausea later on in the week.

There are two recommendations already in effect at the 2E6 simulator complex that are designed to reduce the incidence of sickness. One is limiting the time duration of individual sessions to 30 minutes. The second is flooding the simulator area with light before visual system freeze.

With no detailed training syllabus available for guidance, operation of the Device 2E6 is being conducted in a non structured manner. It has been noted that the length of individual

sessions vary and in some cases may be excessive. Uninterrupted time and specific tasks in the simulator, of course, are important considerations in evaluating the severity of the problem. Once a structured curriculum is adopted, the incident of simulator sickness can be studied further and perhaps reduced by curriculum refinement and/or other changes in use. Therefore the integration of a comprehensive training syllabus into the Device 2E6 program is essential to the assessment of simulator sickness in this simulator.

The fleet is currently establishing a Fleet Project Team to coordinate and direct efforts related to all ACM training objectives and requirements. One effort will be directed at integrating the 2F112, 2E6 and TACTS (Tactical Aircrew Combat Training System) syllabi.

The NAVTRAEQUIPCEN, with contractor support, will continue monitoring the occurrence of simulator sickness on devices 2E6 and 2F112 when a structured training program goes into effect and the new device modifications (e.g. ground-growth) are incorporated into the Device 2E6. At the conclusion of this study, another report will be issued with recommendations for alleviation of simulator sickness if any is found under the new circumstances.

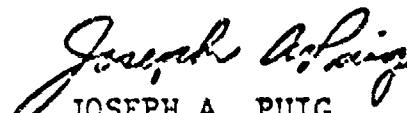

JOSEPH A. PUIG
Scientific Officer

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SECTION I

INTRODUCTION

Introduction of wide-angle visual simulators into the operational and training communities of military aviation has been accompanied by reports of aircrews experiencing "simulator sickness." U.S. Navy aircrews have reported symptoms such as nausea, dizziness, headaches, and disoriented feelings while operating Device 2E6, Air Combat Maneuvering Simulator (ACMS). Reports of both delayed reactions and persistence of symptoms after leaving the trainer have raised concern over possible impact upon flight safety and negative training. This report details the methods and results of a short-term project undertaken to assess the rate of occurrence and the degree of severity of simulator sickness experienced by individuals who have flown the 2E6.

The 2E6 ACMS consists of two fixed-base, tandem crew cockpits, each surrounded by a 40-foot dome which approximates a 360-degree field of view. Visual scenes are created by projecting aircraft, missile and earth/sky scenes onto the domes. A more detailed description of the 2E6 is provided in Appendix A.

SECTION II

BACKGROUND

Occurrence of "motion sickness" symptoms in flight simulators has been reported in various simulators using wide angle visual systems (e.g., Miller and Goodson, 1960, and Coward, Kellogg and Castore, in preparation). The concern over the possible impact upon flight safety has prompted articles dealing with spatial disorientation (e.g., Porter, 1979, and Coward, Kellogg and Castore, 1979). Although the phenomenon has been known for years, identifying the reasons for "simulator sickness" is a difficult task. The causes are complex and, most probably, interrelated. While precise reasons for "simulator sickness" are not fully understood, research efforts are establishing a knowledge base which may someday provide the design specifications or procedures necessary to mitigate or eliminate the problem.

Prior research efforts have documented many of the types of "simulator sickness" conditions occurring in the 2E6. Four studies in particular provide insight into issues specific to the 2E6 and contribute to a better understanding of the problem as a whole. A brief description of each study follows, including a short synopsis of pertinent conclusions as they relate to the 2E6.

First Study Puig, 1971

Puig (1971) provides a review of the problems associated with simulator sickness in a paper entitled The Sensory Interaction of Visual and Motion Cues. In this treatise, Puig states that an individual senses movements and accelerations by means of his visual system. He also receives and senses this information from within his own body through proprioceptive cues (i.e., through muscles, joints and inner ear). The visual and proprioceptive cues interact with each other. "Motion can be sensed visually and proprioceptively. Acceleration cannot be sensed visually, however, until increasing velocity is noted. Conversely, the proprioceptive sense, though insensitive to velocity, is quite sensitive to acceleration." Puig states that the body relates visual and "kinesthetic" (feel) and "vestibular" (balance) cues to interpret combinations of motion and/or accelerations. When an individual uses a fixed-base simulator, his eyes will sense motions and/or accelerations from the moving visual displays, while his

proprioceptive senses (particularly the vestibular) indicate that he is not moving or accelerating. The normal sensory interactions are disrupted and internal conflicts arise resulting in feelings of "uneasiness" or "simulator sickness." Thus, "it is not the visual illusion of motion per se, but the visual sensation of apparent acceleration and/or change in direction that triggers off the initial feeling of discomfort."

Puig further states that in addition to sensory conflicts, poor visual fidelity may also be a contributing factor in simulator sickness. "...in the presence of a well-structured visual display, therefore, the visual mode will be the primary overriding input. With a poor visual reference, however, the motion cues [vestibular response] will tend to take priority. In situations where the visual and motion inputs are sensed as being equally demanding, they will be reinforcing or contradictory depending upon whether the cues are in or out of phase."

Another potential complicating factor regarding simulator sickness mentioned by Puig involves a study (Olive, 1969) which correlated physical and medical data of 1,000 Naval aviators over a twenty-year period. The analysis indicated that susceptibility to vertigo and disorientation increase with age.

In reviewing previous research efforts, Puig reported ten hypotheses which have been advanced in an effort to explain simulator sickness:

1. Conflict between the apparent motion seen on the visual display and lack of any corresponding real motion of the simulator.
2. Optical distortion (both static and dynamic) in the visual display, particularly of vertical objects; the synthetic presentation of a visual scene which is a distorted representation of a real environment.
3. Poor resolution.
4. Rapid changes in brightness (flicker).
5. Wide field of view.
6. A highly structured field of view (too much detail).
7. A poorly structured field combined with peripheral flicker.
8. Excessive lag between simulator control and corresponding movement in the visual display.
9. High frequency vibrations which disrupt accommodation.
10. Projection screen-to-observer distance insufficient for infinity focus of the eyes, producing conflict between actual distance of the display and the apparent distance of the screen.

Puig concludes by emphasizing the necessity for considering the sensory interactions between the visual and vestibular apparatus when designing simulators with visual displays.

Second Study
Miller and Goodson, 1960

Miller and Goodson examined simulator sickness occurring among Navy helicopter pilots. During the early stages of visual flight simulation development, the Navy procured the 2-FH-2 helicopter simulator. The device was built by Bell Aircraft Company in conjunction with De-Florez Company of New York and installed at Ellyson Field, Pensacola, Florida in February, 1956. Two projectors provided 260 degrees azimuth by 75 degrees elevation display coverage. The upper projector displayed the sky scene while the lower projector depicted the near terrain, the far scenery and a portion of the sky. The cockpit was fixed-based. Significant occurrences of simulator sickness symptoms resulted from using the 2-FH-2.

In an attempt to identify some of the possible causes of the simulator sickness symptoms, Miller and Goodson mentioned that previous researchers suggested the symptoms were a result of internal conflicts resulting from the absence of real motion accompanied by the presence of visual cues designed to give the impression of movement. While admitting this might have been a contributing factor, they generally dismissed this hypothesis as a major consideration. They felt the slight accelerations and decelerations in a helicopter were too imperceptible to cause symptom onset. They suggested instead that the underlying problem involved conflicting visual cues resulting from distortions in the visual display rather than a conflict between visual and proprioceptive cues. Major findings included:

1. Sixty percent of the instructors reported sickness as compared to 12 percent for the students.
2. Sometimes the ill feelings did not occur until several hours after simulator usage.
3. One instructor had to get out of his car on his way home to regain his equilibrium.
4. Some instructors, after much simulator time, would experience significant discomfort from merely looking at the simulator.
5. Even those individuals who did not report sickness symptoms became very fatigued after simulator use; this condition often lasted throughout the day.
6. Lag in the simulator at times resulted in

overcontrol, sometimes leading to loss of control. The loss of control produced a violent maneuver; the more violent the maneuver, the greater the degree of simulator sickness.

7. Instructors sitting as passengers during these conditions were more prone to simulator sickness than if they were at the controls.

Miller and Goodson concluded their study by saying the simulator sickness problem became so serious that it was one of the chief reasons for discarding the device from the operational inventory.

Third Study Reason and Diaz, 1971

In Reason and Diaz's study the effects of simulator sickness upon experienced automobile drivers as compared to passengers was examined. Reason and Diaz theorized that the major underlying cause of simulator sickness results from what they termed "sensory rearrangement." That is, an individual in his real-world experience learns to subconsciously associate visual scenes of motion with his proprioceptive senses of corresponding accelerations. An individual retains these associations in his "spatial memory store." The more experience a person has in these real-world experiences, the stronger the association that is stored in his memory. Thus, when real-world experienced individuals are placed in a simulator environment in which visual scenes of motion and acceleration are depicted without the accompanying acceleration forces, "unfulfilled expectations" occur. These experienced individuals expect to feel acceleration forces in conjunction with the visual scenes. When this does not occur, internal conflicts arise which can initiate onset of simulator sickness symptoms. Under this theory a novice would not be expected to be as apt to get sick as an experienced individual since the novice has not developed the "spatial memory stores."

Reason and Diaz felt the Miller and Goodson study partially bore out this theory by the findings that instructors experienced a five times greater incidence rate than their students. In a further investigation of the "sensory rearrangement" theory, Reason and Diaz examined individuals with automobile driving and passenger experience in an automobile driving simulator in which the individuals viewed a ten-minute driving scene as passive observers. The experiment used a 6 x 12 foot screen located six feet away from the subjects. Major findings included:

1. Twenty-eight out of the 31 individuals exhibited some form of simulator sickness.

2. Active participation in the control of the vehicle is not necessary in order to induce simulator sickness symptoms.
3. Women were significantly more susceptible to simulator sickness than men.
4. The more the driving and passenger experience of individuals the higher the degree of simulator sickness.
5. Evidence suggests that driver experience exerts a more powerful influence on simulator sickness than passenger experience.

Fourth Study

Coward, Kellogg and Castore, in preparation

In a study conducted on subjects training ACM in the Air Force Simulator for Air-to-Air Combat (SAAC), at Luke AFB, Arizona, Coward, Kellogg and Castore reported a simulator sickness incidence rate of 88 percent in the subjects interviewed. The SAAC is an ACM training system that utilizes cathode ray tube (CRT) displays to provide a near 360-degree field of view to the trainee. The six degree of freedom motion base was not used during the training of the subjects interviewed in the Coward, et al., study. The SAAC consists of two F-4 cockpit trainee stations, instructor operator stations and debrief stations. Capabilities include simulation of 1v1 ACM in an integrated mode or in an independent mode with each trainee flying against an instructor controlled or computer programmed target.

The SAAC students were reported to have high levels of operational experience; 50 percent had over 500 flight hours and 31 percent had in excess of 1000 flight hours. The SAAC subjects participated in one week of intensive training and experienced approximately 500 engagements in 12 hours of simulator time. The most prevalent symptoms reported were nausea - 79 percent; motor dyskinesia - 60 percent; and a sensation of being rotated in some orthogonal plane - 54 percent. Significantly, the study also reported persistence of symptoms up to ten hours after completion of simulator training and delayed reactions after training, such as visual "flashbacks" in as many as 33 percent of the subjects. Delayed reactions were also reported by the subjects involved in the Miller and Goodson study addressed above.

SECTION III

METHOD

The conduct of the study included the administration of a questionnaire presented during individual interviews. The questionnaire (a copy is included as Appendix B) solicited information concerning experience levels in ACM flight training, experience in visual simulators and the type and degree of severity of sickness symptoms. The interviews were conducted in squadron spaces away from the simulator complex. Each individual was carefully briefed concerning confidentiality of any information which he provided.

The sample of subjects was selected on the basis of availability and experience in the use of the 2E6 ACMS. The Commanding Officers of the four squadrons involved were briefed thoroughly on the confidentiality and content of the questionnaire and were included as subjects in the interviews. A total of 66 subjects were interviewed. The group included 65 individuals from four separate fighter squadrons and one test pilot from the Naval Air Test Center (NAVAIRTESTCEN), Patuxent River, Maryland. All subjects were exposed to the 2E6 through squadron training programs or as a result of personal interest in the device, with the exception of the NAVAIRTESTCEN test pilot. The experience level of the subjects ranged from 250 to 4000 flight hours; all were operational fleet aircrew members. The training they received consisted of four flight missions of one hour duration and was generally designed as a structured prelude to an Air Combat Maneuvering program. The simulator "instructor" operator position was normally assumed by a peer, aircrew member, or training device operator (TD).

SECTION IV

RESULTS

The study indicated that 27 percent of the aircrew members interviewed experienced some degree of simulator sickness symptoms. Table 1 provides a breakdown of the subjects according to aircrew designation, types of aircraft flown and extent and related numbers of symptoms experienced. Of the total subjects interviewed, 39 were Pilots and 27 were Radar Intercept Officers (RIOs). The flying experience of the subjects and the rate of occurrence is presented in Figure 1. The highest incidence rate of simulator sickness occurred among those aircrew members (22) with more than 1500 flight hours in which 47 percent of the subjects reported some degree of symptoms (Figure 2). Forty-four aircrew members had 1500 or fewer flight hours with 18 percent reporting sickness symptoms. (Note: As flight hours increase, N decreases and reliability decreases.) The rate and type of symptom occurrence is reported in Appendix C.

The severity of symptoms ranged from mild to severe. In several cases subjects terminated the training sessions because of the severity of sickness onset. None of the subjects reported emesis, but several reported loss of appetite until after a sleep period; in each of these cases, the symptoms subsided completely after a night's rest. The most common symptom reported was dizziness which occurred in 17 percent of the subjects interviewed (Figure 2); vertigo and disorientation were reported by 11 percent of the subjects; "leans" and nausea were noted by nine percent.

Although each subject was asked if he experienced "flashbacks" or "visual replays", no occurrences were reported among the 66 aircrew members interviewed. Subject number 7 (Appendix C) is an Air Force exchange pilot flying with the Navy who is a graduate of the USAF SAAC training program. During his SAAC training he experienced visual "flashbacks" but did not experience these symptoms when training in the 2E6. The subject reported, during the course of his SAAC training, "seeing the checkerboard pattern of the SAAC background display painted on the inside of my eyelids" when lying down to sleep. The symptoms terminated after the last day of flying in the SAAC and did not recur. (These reported simulator sickness symptoms are consistent with findings from Coward, Kellogg and Castore; discussed in Section II.) Subject number 7 stated the SAAC CRT display was much harder on the eyes than the 2E6 display. He experienced no simulator sickness symptoms during his six hours of 2E6 use.

TABLE 1. DATA SUMMARY

Sixty-five total individuals interviewed from four fighter squadrons plus one NAVAIRTESTCEN test pilot.

Number of Aircrew Members Interviewed
and Reporting Sickness Symptoms

Aircrew Position	Number Interviewed	Number Reporting Sickness Symptoms	Percentage Reporting Sickness	Category
Pilots	21	9	42.9%	F-4
RIOs	16	3	18.8%	
Pilots	18	5	27.8%	F-14
RIOs	11	1	9.1%	
Pilots	39	14	35.9%	TOTAL
RIOs	27	4	14.8%	

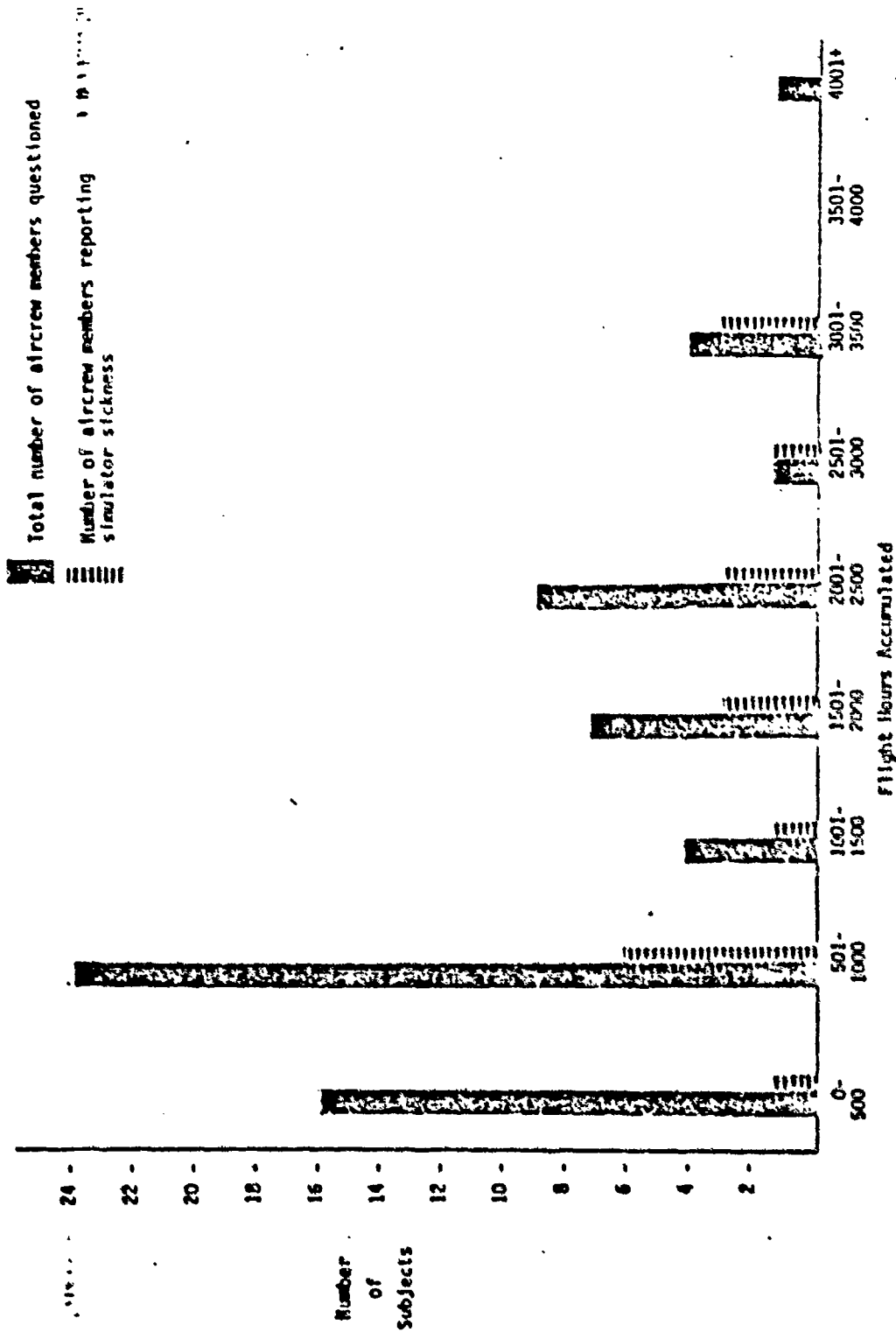


Figure 1. Simulator Sickness Symptom vs. Flight Hour Experience

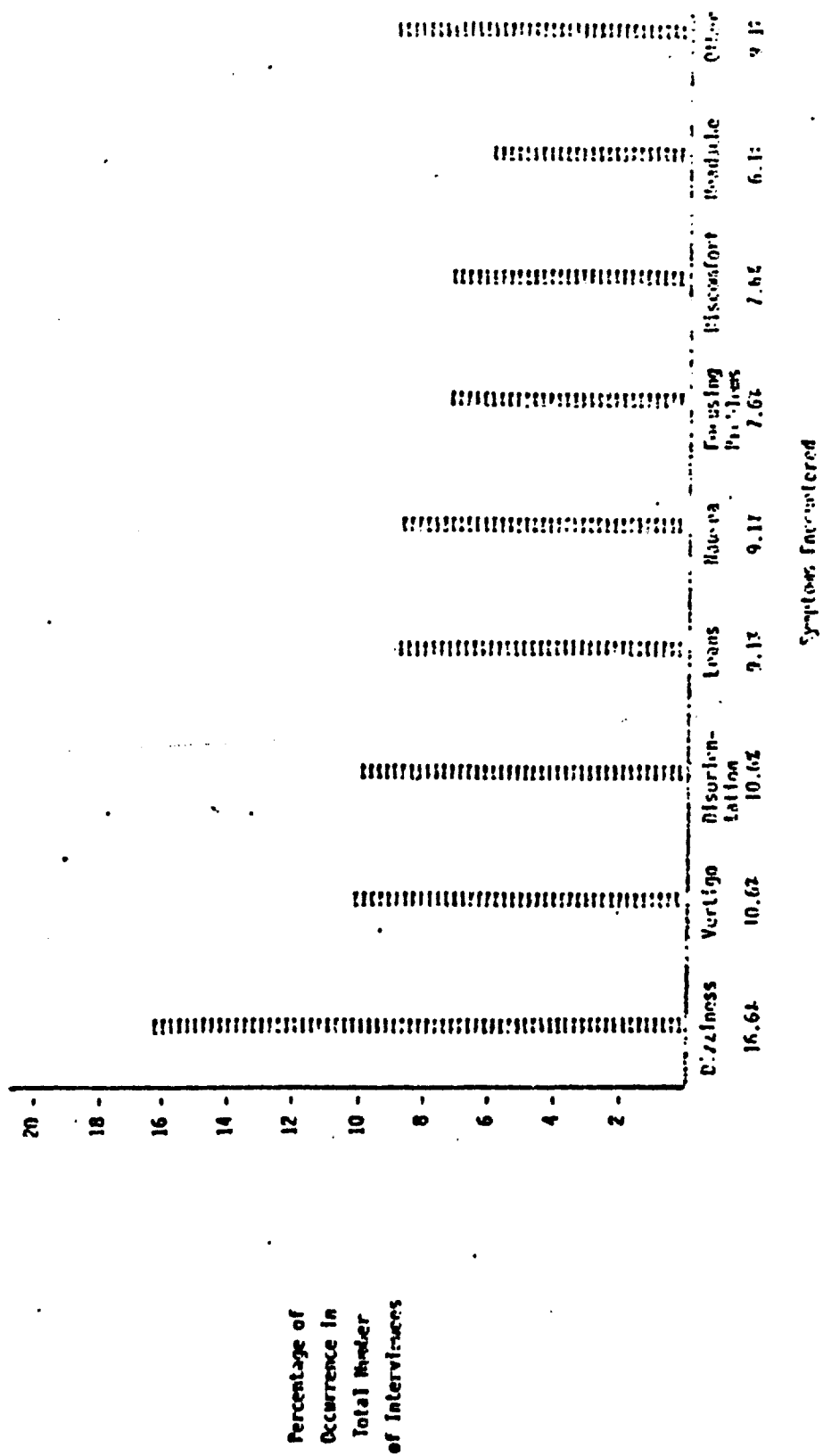


Figure 2. Symptom Occurrence

Mental fatigue was reported as being the same, greater or less than actual ACM flight training by equal numbers of the subjects. However, as reported in Table 2, 83 percent of the subjects interviewed reported physical fatigue as being equal to that experienced in the air during ACM training. All but three percent of the subjects interviewed reported perspiring less or much less than in actual flight, the exception being profuse sweating accompanied by nausea for some of those individuals experiencing simulator sickness.

There were some unique symptoms reported. These were "eye-ball jitter," tired feeling, loss of depth perception, knees weak, and fullness of the stomach. One aviator reporting "eye-ball jitter" had participated in tests to examine the cause of this phenomenon in centrifuge experiments. The occurrence of this unique symptom may demonstrate a preconditioned body response which was transferred from the centrifuge to the fixed-base simulator.

Only two subjects reported delayed reactions in which symptom onset occurred after leaving the trainer. However, 61 percent of those experiencing symptoms reported persistence of the symptoms from 15 minutes up to six hours.

Another subject of special interest, due to his intensive exposure to the 2E6, is reported individually (subject number 19). He is a test pilot with 3400 hours of flight time conducting tests on the simulated aircraft models utilized in the 2E6. His experience in the 2E6 consisted of four hours per day for five consecutive days. His symptoms were described as severe, with nausea bordering on emesis, and persisting until after a night's sleep. The symptoms were most severe after the second day's training and dissipated over the next three days. He attributed the lessening of symptom severity to breaking his mission into 30 to 45 minute periods with 30 minute breaks and becoming familiar with the visual system. At the end of the fifth day, the subject reported mild disorienting feelings that persisted until bed time. Specifically, the subject stated he would not fly on a day in which he participated in a 2E6 training period. This experience relates closely to findings by Coward et al., dealing with intensity and length of training.

Possible Simulator Sickness Causes

The "reset"¹ function was reported by 33 percent of the subjects experiencing symptoms as being the most probable cause of symptom onset. Performing loops and nose high

¹"Reset" - the freezing of the simulator visual display and returning to a new set of initial conditions.

TABLE 2. INTERVIEWEE OPINIONS CONCERNING RESULTING
2E6 MENTAL AND PHYSICAL FATIGUEMental Fatigue in Relationship to Actual Aircraft ACM Training Sorties

Greater in 2E6	33.3%
Same in 2E6	33.3%
Less in 2E6	33.3%

Physical Fatigue in Relationship to Actual Aircraft ACM Training Sorties

Greater in 2E6	11.1%
Same in 2E6	83.4%
Less in 2E6	5.5%

attitudes without visual altitude references was reported by an additional 44 percent as being a contributing factor to the onset of symptoms. The twilight environment of the display was also reported to be disturbing by 20 percent of the subjects.

10/10/80

SECTION V

DISCUSSION

DIFFERENCES AMONG 235 USER GROUPS

Flight experience, aircrew position (function), and type of aircraft all revealed certain relationships to simulator sickness susceptibility.

Flight Experience

The hypothesis advanced by Miller and Goodson (1960) that experienced aviators are more susceptible to simulator sickness than their less experienced counterparts is supported by the results of the present study. Aviators with more than 1500 hours of flying experience sustained a symptom occurrence rate of 50 percent, while aviators with 1500 hours or less sustained a symptom occurrence rate of 20 percent. The significant disparity between the two groups may indicate a greater degree of conflict between visual and proprioceptive senses because of increased preconditioning gained through airborne experience. Physiological body changes resulting from physical aging may also be a contributing factor to this phenomenon, since those with more flight hours naturally tend to fall into older age groups (Puig, 1971).

Aircrew Position (Function)

More pilots (36 percent) reported simulator sickness symptoms than RIOs (15 percent). These findings support Reason and Diaz's (1971) observations from an automobile driving experiment which indicated those with driving experience might be more susceptible to simulator sickness than those with only passenger experience. Two hypotheses may account for these differences:

1. Internal body conflicts arise between the visual scenes and the "G" force and acceleration cues.

Pilots, particularly in tactical aviation, learn to rely heavily upon "flying by the seat of the pants" to perform their mission. This requirement stems from the necessity to focus nearly 100 percent of the visual attention span outside the cockpit in order to maneuver the aircraft to the "piece" of the sky which will accomplish the desired tactical objectives. During critical flight regions, slow airspeed or nose high maneuvers, changes in

"G" forces and accelerations serve to warn the pilot to momentarily focus his attention "inside" the cockpit and concentrate on controlling the aircraft to avoid out-of-control flight conditions. Thus, pilots are preconditioned to react to "G" forces and acceleration cues received through their "feel" senses. Since the "G" force and acceleration cues received by the "feel" senses do not correspond with the visual scene represented in the 2E6, conflicts may arise when pilots see visual scenes which initiate anticipatory signals from these senses. The conflict between feel and the visual scene may be greater in experienced individuals. Because of the increased conditioning of the "feel" senses in these individuals, the degree of uneasiness or "simulator sickness" may increase. This hypothesis is further supported by the fact that 44 percent of the aircrews reported loops and nose high attitudes as a contributing factor to the onset of simulator sickness symptoms. During vertical maneuvers, the airspeed tends to decay rapidly which requires sensitivity to subtle "G" force and acceleration cues to recognize when to focus one's attention inside the cockpit. It follows that absence of these cues in these situations might induce feelings of anxiety and contribute to conflicts between the visual scene presentations and the interaction of the internal "feel" senses of the aircrews, thus, inducing simulator sickness symptoms.

2. RIO and pilot training differences tend to make RIOs less susceptible and pilots more susceptible to simulator sickness.

Another contributing factor to the low number of simulator sickness reports for the RIOs may be their type of training background. During the undergraduate portions of the RIO training pipeline, they are tasked with conducting intercepts in the back of a T-39 aircraft with no access to windows for relating aircraft maneuvers to visual scenes. It has been reported within the community that this operating environment is very conducive to air sickness and individuals are "washed out" of training in this phase if they cannot overcome the negative effects of these symptoms. The remaining individuals have been conditioned to "deny" the conflict between the visual senses and the sensations created by "G" forces and accelerations in the performance of their missions. This is just the opposite of pilot training which requires developing increased sensitivity to the "G" forces and accelerations to perform their prescribed role.

The above discussions must remain hypotheses since there are confounding sources in the data. For example, in the "real world" and in the simulator, a RIO must perform a different type of visual timesharing task than does a pilot.

This also could account for the differences between RIO and pilot sickness rates.

Aircraft Type

The data indicates that F-4 aviators got sick more often than F-14 aviators. Forty-three percent of the F-4 pilots experienced symptoms while only 28 percent of the F-14 pilots reported sickness symptoms. This result may be related to differences in aircraft flight characteristics or to varied training approaches.

It should also be noted that many potentially confounding factors may have influenced these preliminary findings. For example, F-14 aircrews had not used the 2E6 in over 90 days at the time of the interviews while the F-4 aircrews had utilized the 2E6 within 30 days of the conduct of the interviews; therefore, memory decay could have resulted in fewer reported cases of F-14 aircrew sickness. Also, other factors such as age, which might affect results, were not analyzed. Further analysis is required before firm conclusions can be drawn.

DIFFERENCES BETWEEN THE 2E6 AND SAAC

This preliminary effort revealed that fewer individuals are reporting simulator sickness in the 2E6 than in the Air Force SAAC. Simulator sickness occurred in 27 percent of 2E6 subjects and their symptoms appeared less severe than the 88 percent sickness rate reported in the SAAC (Coward, Kellogg and Castore, in preparation). Differences in utilization of the simulators, fidelity, degree of realism/capability and visual display hardware make it impossible to precisely determine why these differences are occurring at the present time. However, a preliminary cross-comparison of these differences may provide some insight into the problem.

Manner of Use

The subjects experiencing simulator sickness in the SAAC were generally exposed to the simulator through a well-defined, intensive syllabus and experienced more hours of training in a more compressed period of time. The greatest number of 2E6 subjects, nearly 50 percent, had five or less total hours of simulator time, taken in one hour time blocks in a five to ten day period. In comparison, the SAAC subjects received 12 hours of simulator time in a five day period. Additionally, the SAAC subjects experienced

their training in a concentrated, structured environment, while the 2E6 subjects trained in a more conventional setting. These differences in the training programs might account for some of the disparity between the 2E6 and SAAC in the percentages of aircrews reporting simulator sickness.

Only one of the 2E6 aircrew members interviewed experienced the intensity of simulator usage which the SAAC aircrews experienced (Subject 19, Appendix C). Significantly, he was the only subject interviewed whose symptoms persisted until after a full night of rest. He also experienced the greatest variety of symptoms and the most severe episodes of nausea.

Fidelity

Miller and Goodson (1960) reported the low fidelity of the visual display in the 2-FH-2, specifically the distortion apparent in the visual scene, as a primary contributor to the onset of symptoms. The 2E6 display, however, while having a low degree of structure in the field of view, has very little distortion. It is felt that low structure in the field of view does not induce significant occurrences of symptoms. However, low light levels, flicker and a nondescript background may play a limited role in initiating simulator sickness onset.

Realism/Capability

The "ground growth" and "progression" features of the SAAC (not currently installed in the 2E6) enhance the realism by providing visual cues representing changing altitude and velocity. While these features are highly desirable for ACM training, they may provide the trainee with a greater degree of conflict between the missing proprioceptive cues and the enhanced visual motion cues. It is possible, that if these features were to be incorporated in the 2E6, some increase in the incidence rate of simulator sickness may occur.

Visual Display Hardware

Differences in visual display hardware appear to account for variations in symptoms, also. The 2E6 projects model images onto a domed screen 20 feet from the aircrews. Aircrews observe indirect image displays reflected from the dome screen. The SAAC on the other hand, surrounds the aircrews with large CRT displays located three to four feet away from the aircrews. SAAC aircrews view direct light CRT

displays collimated at infinity. Interestingly, one-third of the SAAC aircrew members from Coward's study (in preparation) reported instances of involuntary "flashbacks" or "after images" following SAAC training sessions. But, out of 66 226 users interviewed, no instances of flashbacks were reported.

Numerous crossing attacks referred to as "high-angle gunshots" were practiced on the SAAC. Considering Young's (1977) studies at the Massachusetts Institute of Technology on peripheral viewing, this is an important point to consider in evaluating the occurrence of simulator sickness in the SAAC.

The Advanced Simulator for Pilot Training (ASPT) located at Williams AFB uses the same type of visual display as the Luke AFB SAAC. During on-site discussions with ASPT personnel, experiences of trainees in the ASPT were reported as similar to those experienced in the SAAC. Although incidence rates for the ASPT were not available, a tape of one subject's experience in the ASPT was reviewed in which he described symptom occurrence, severity, or persistence nearly identical to those of SAAC trainees.

Certain amounts of simulator sickness may occur in all simulators utilizing wide-angle visual systems. It is felt, however, that the training benefits which can be derived from these dynamic visual displays far outweigh the negative impact resulting from the simulator sickness phenomena. Experimental laboratory research efforts are continuing to try to determine the platform motion requirements for wide-field visual display simulators (e.g., Young, 1977). It may be feasible some day to correctly mate motion/force platforms with visual display presentations and mitigate incidents of simulator sickness. In the meantime, applied research efforts which can more thoroughly compare operational equipment and user differences might be capable of more accurately ascertaining the internal body functions which lead to the onset of simulator sickness. Once these internal body functions have been positively identified, simulator design engineers may be able to construct simulators which will reduce or eliminate this problem.

Since the Air Force study on SAAC was completed, there has been significantly less apprehension and simulator sickness among the students. This is probably the result of a new briefing procedure that was initiated to familiarize them with the problem. After they were briefed on what to expect in the simulator, the students seemed to feel more comfortable and better able to cope with the discomfort, especially after being told that others were affected also but that they adapted readily with time. In essence, they were told: "The symptoms are very transient and you will adapt to it (the simulation)." (Personal communication with Mr. Robert E. Coward.)

Best Available Copy

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APPENDIX A.

DESCRIPTION OF 2E6

The 2E6 Air Combat Maneuvering Simulator (ACMS) was installed at the Naval Air Station, Oceana, Virginia and became operational in November 1979. The device is designed to provide close-in Air Combat Maneuvering training. The device has two trainee stations (pilot and NFO in tandem cockpit configuration) located inside each of two 40-foot domes which provide a 360-degree field of view (see Figure A-1). Inside the domes are sky-earth projectors that project a blue sky and green-brown earth displays separated by a white haze band. The cockpits in the domes are mock-ups of the F-4J and F-14A and are interchangeable. Each cockpit is fixed-based with spatial orientation provided by computerized control of the sky-earth projector. There is no provision to simulate visual altitude cues or relative direction and velocity progression over the terrain.

Each dome is also provided with a missile projector, capable of displaying one missile in flight at a time, and target projectors capable of displaying two aircraft simultaneously. Four cathode ray tube projectors in each dome project a maximum of two targets and accurately simulate target altitude and range, from 300 feet to 25,000 feet.

An Instructor Operator Station (IOS) associated with each dome (or trainee station) provides control for that station in the independent mode or for both stations in the integrated mode. In the independent mode, all activity occurs in a single dome; the integrated mode requires an interaction of activity between domes. In either mode, a pilot can fly against a computerized bogie, if desired.

In either the independent or the integrated mode, the Instructor Pilot (IP) can choose computer control of a programmed target (adversary) or "choose to fly" the adversary himself from a modified throttle and stick at a control station located at the IOS (see Figure A-2). Each IOS and trainee station is operated by an independent computer system. Figure A-3 provides a functional diagram of the complete 2E6 ACMS.

A normal training mission consists of seven to ten engagements in a 30 to 45 minute period with each engagement lasting two to four minutes. At the beginning of each mission, the IP selects aircraft and adversary type, initial conditions (airspeed, altitude, heading), weapons, fuel loads and other mission specific criteria. The mission can be frozen in time and restarted from that point, reset to the initial conditions, or reset and new initial conditions

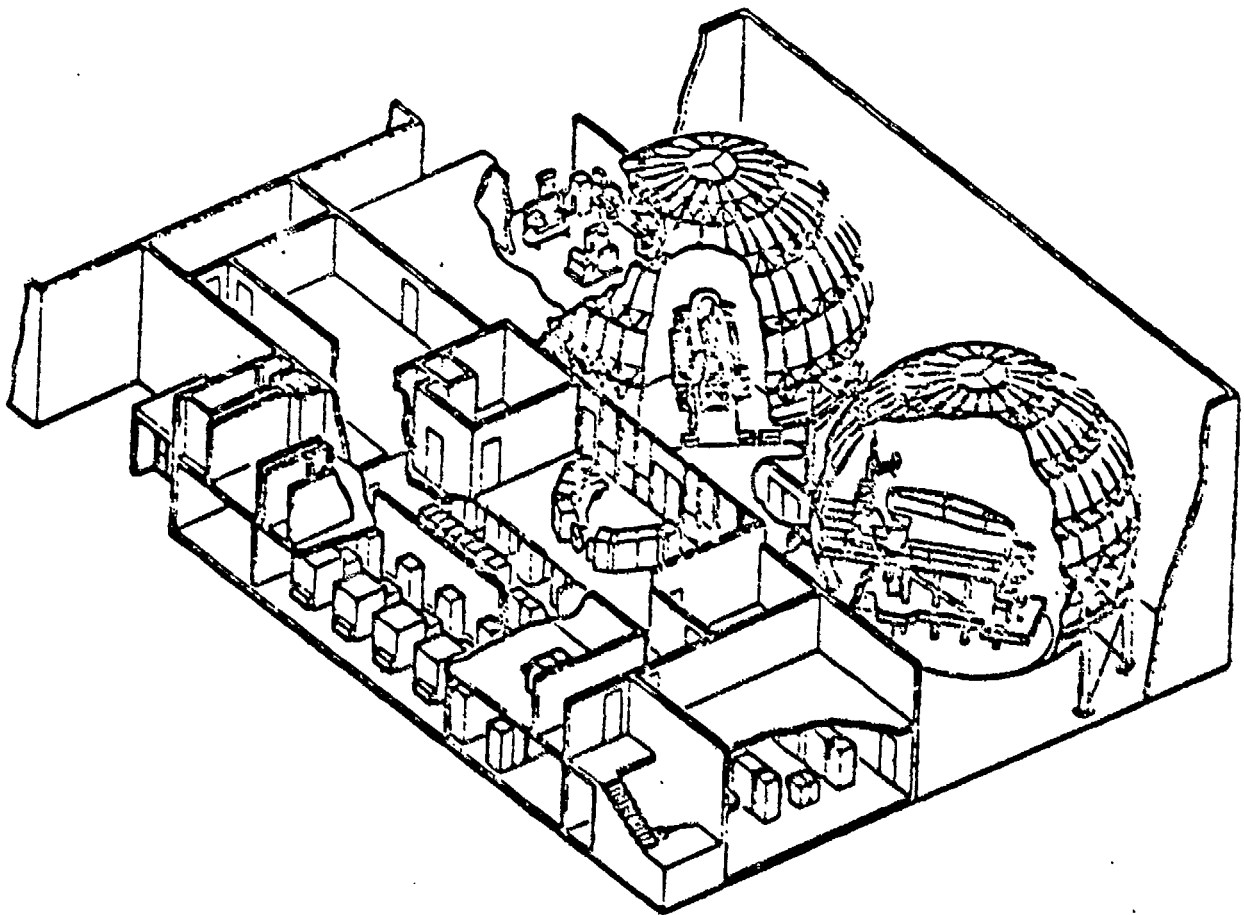


Figure A-1. Air Combat Maneuvering Simulator, Device 2E6

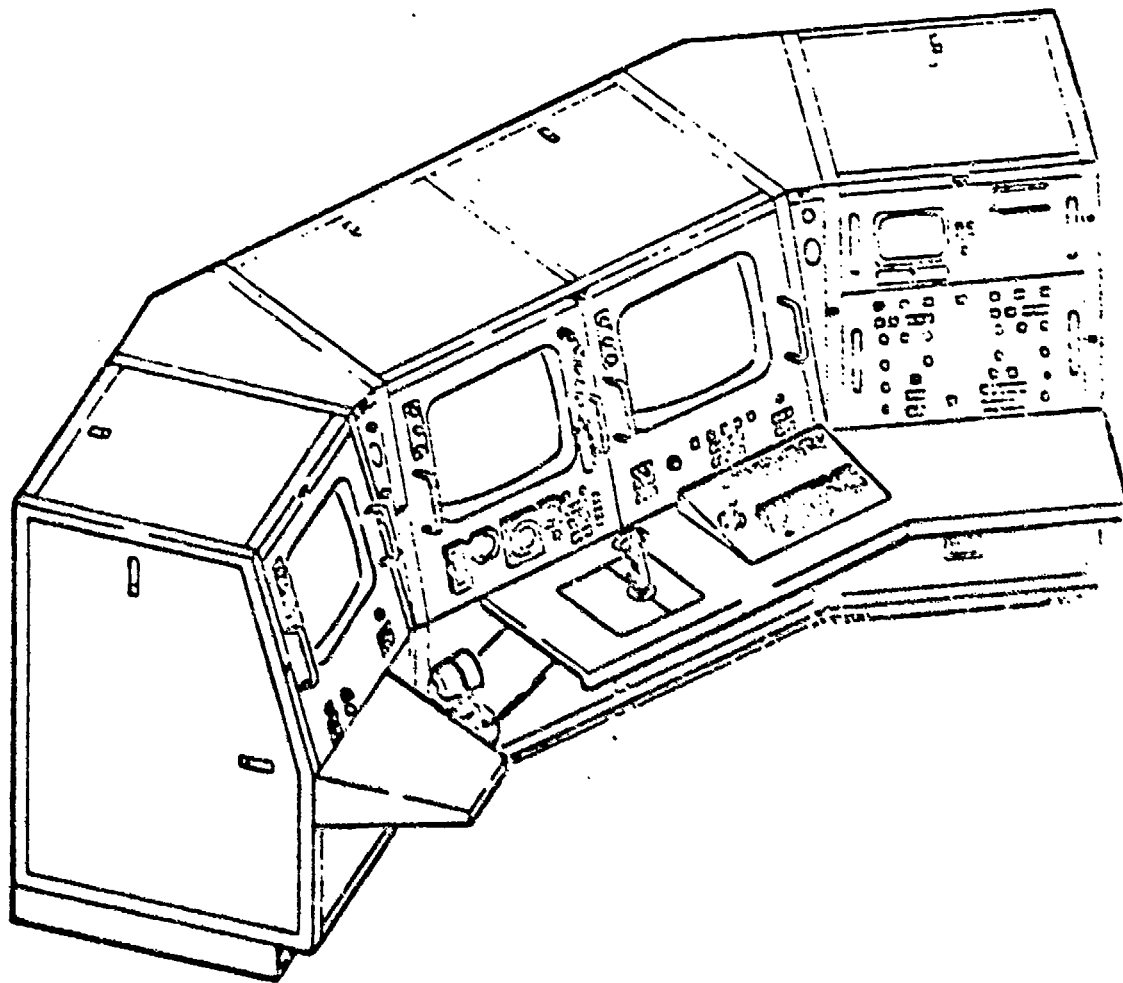


Figure A-2. Instructor Operator Station

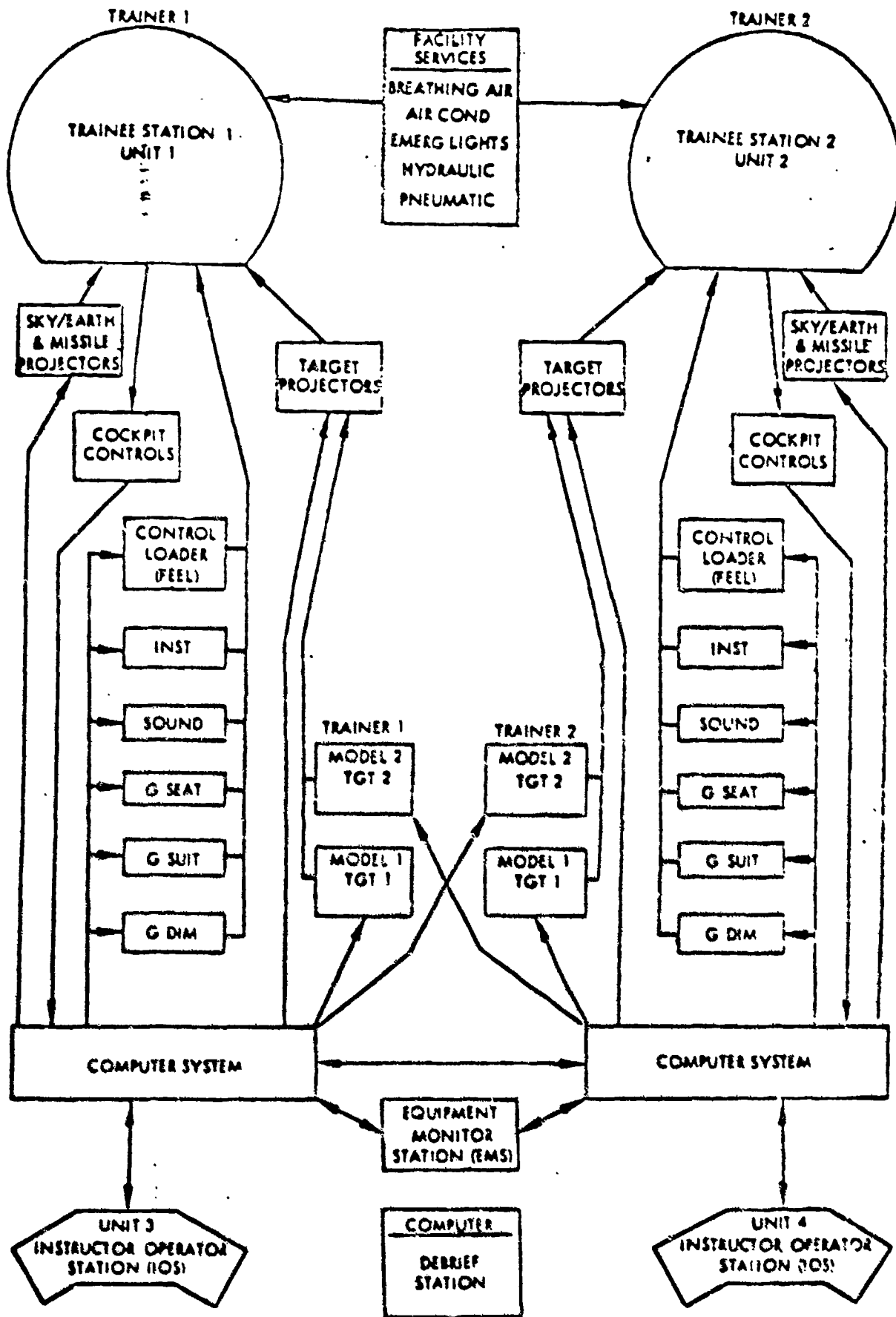


Figure A-3. ACMS Functional Diagram

selected. During the reset function all mission conditions are reset, including spatial orientation; the sky/earth display "snaps" back rapidly to the zero degrees pitch, roll and yaw.

Debrief of the mission is available at an independent console and display system, allowing extensive review and hard copy extraction of selected parameters. Up to 15 minutes of replay also is available within the dome. During replay, all training displays and conditions are replayed with the exception of aircraft control movement.

APPENDIX B

SIMULATOR EFFECTS QUESTIONNAIRE

Introduction

This questionnaire is designed to provide information pertinent to a study of the design and use of visual full-mission simulators such as the 2E-6 AQMS. The focus of the questionnaire is on reported cases of physiological symptoms similar to motion sickness or other forms of discomfort associated with simulator use in both the Navy 2E-6 and the Air Force Simulator for Air-to-Air Combat (SAAC).

The study is funded by Naval Air Systems Command through the Naval Training Equipment Center. Permission to circulate the questionnaire has been obtained from Commander Fighter Wing ONE. All information provided is confidential to this study.

The questionnaire items are directed at four categories:

General background information.

Discussion of any discomfort or symptoms associated during use of the 2E-6.

Discussion of any discomfort or symptoms which may occur after 2E-6 use.

General questions related to the application of the 2E-6 in AQM training.

The questionnaire will take approximately 30 minutes. We are very interested in your opinions. Very little information exists relative to the physiological effects of high technology simulator usage. Please be as specific as you can and feel free to add any comments you might have about the questionnaire or the general topic.

EFFECTS WHICH OCCURRED DURING 2E-6 USE

Using a flight simulator such as the 2E-6 presents aircrews with very distinctive visual cues. The lack of motion and the high fidelity of the synthetic visual display provided by the 2E-6 have been noted as being a possible source of discomfort reported by aircrews, or what the Air Force has termed "Simulator Sickness". The impact of the synthetic visual cueing is of great interest. The following questions seek to examine your opinions of visual simulator use of the 2E-6.

5. Did you experience an adequate introduction to the 2E-6 as a part of your first mission? _____
 How long were you in the dome on your first mission? _____
 Did you break your first training session into 1 or more training periods in the dome? _____
6. Did you experience symptoms of motion sickness or discomfort that you attributed to training in the dome on your first mission? _____

 How long were you in the dome when your symptoms occurred? _____
 What symptoms did you experience? _____
 Nausea? _____
 Dizziness? _____
 Leans? _____
 Feeling of being disoriented? _____
 Vertigo? _____
 Headache? _____
 Visual problems such as focusing? _____
7. Have you experienced discomfort or symptoms of motion sickness during successive missions? _____
 What were the symptoms? _____

 Specifically, did you experience any nausea while in the 2E-6? _____
 Do you now experience these symptoms when in the dome? _____
 If not, after how many mission/hours did the symptoms subside? _____
 In what order did the symptoms subside? _____

8. If you experience symptoms of discomfort or motion sickness in the trainer, can you identify a specific maneuver or simulator function that usually initiates symptom onset? _____

Did the aircrew member you were training with get sick on the same mission that you did? _____

Was the 2E6 fully operational or were there any known discrepancies on the flights in which you experienced your discomfort or symptoms? _____

On missions which you experienced symptoms or discomfort, were you flying against the computer or another aircrew? _____

9. While training in the 2E6, are there any particular distractions which interfere with your concentration on the tasks required to perform ACM? _____

10. When in the 2E6, how much do you perspire as compared to an actual ACM training flight?

Much more

More

Same

Less

Much less

EFFECTS THAT OCCUR AFTER USING THE 2E-6

The following questions are pertinent to effects that occur after missions in the 2E-6.

11. Generally, how do you feel after completing a 2E-6 mission as compared to an ACM training flight?

More FatiguedSameLess Fatigued

Physically

Mentally

12. After using the 2E-6, have you ever experienced any discomfort, visual after effects or other symptoms? _____

What were your symptoms? _____

What aspects of your simulator experience do you think caused the symptoms? _____

13. After using the 2E-6, have you experienced any difficulty in reading of other CRT displays or any other type of displays? _____

Reading books? _____

Watching T.V.? _____

Focusing difficulty? _____

Headaches? _____

Dizziness? _____

Leans? _____

14. If you experienced visual after effects (i.e., replay of visual sequences, flashbacks) that you associated with 2E-6 training, how long after the training session did they occur? _____

What activity were you engaged in at occurrence? _____

Please describe in detail the characteristics of the visual after effects.

Have you ever experienced flashbacks of any sort associated with any other activities or training? _____

Have the effects noted above subsided? _____

How long after your last training session did they subside? _____

GENERAL QUESTIONS RELATED TO 2E-6 TRAINING

The items below are of a general nature, but are important for an understanding of how simulator characteristics affect aircrews. The answers could impact the future design and implementation of simulators such as the 2E-6.

15. Can you identify any deviation from your normal ACM cockpit scan when training in the 2E-6? _____

16. When attempting to achieve a high G turn do you have the sensation of really pulling G? _____ If so, what articles of flight gear were you wearing at the time? _____
If not, have you flown in the 2E-6 with your normal flight gear on? _____
17. While training in the 2E-6, do you perceive differences in your ability to focus when transferring from outside the cockpit to inside as compared to inflight ACM training? _____
Can you cite examples? _____

18. Prior to your experience in a visual mission simulator, what was your opinion of training ACM in a simulator? _____

- What is your opinion now? _____

- Do you see any difficulty in flying after a simulator mission? _____
If so, why? _____

Provision of your name, organization and phone number on the questionnaire is voluntary and would only be used if information you provide on the questionnaire indicates further research is desired.

Name _____

Organization _____

Phone _____

SIMULATOR SICKNESS SYN

S	Designator	A/C Type	2E6 Experience	Flight Hours	Prior Visual Experience	Nausea	Dizziness	Headache	Leans
1	Aviator	F-4J	4 hrs.	3200	No	Yes	Yes		Yes
2	Aviator	F-4J	6 hrs.	780	28-35 4 hrs.		Yes		Yes
3	MFO	F-4J	3 hrs.	1000	No		Slight		Yes
4	MFO	F-4J	8-10 hrs.	2200	No				
5	Aviator	F-4J	4 hrs.	2000	No				
6	MFO	F-4J	3 hrs.	1800	No				
7	Aviator (1)	F-4J	6 hrs.	2500	SAAC 14 hrs.				
8	Aviator	F-4J	4 hrs.	2200	No			Slight	
9	Aviator	F-4J	4 hrs.	650	28-35 8-10 hrs.				Yes
10	Aviator	F-4J	18 hrs.	800	28-35 5 hrs. A-7 MCLT 5 hrs.		Yes		
11	Aviator	F-4J	15 hrs.	1600	28-35 4 hrs. A-7 MCLT 3 hrs.	Yes	Yes	Severe	Yes
12	Aviator	F-4J	25-30 hrs.	1000	28-35 10 hrs.	Slight	Yes	Severe	Yes
13	MFO	F-14	4 hrs.	520	No		Momentary		
14	Aviator	F-14	2 hrs.	410	28-35, 28-35 10-15 hrs. each		Yes		
15	Aviator	F-14	4 hrs.	2800	No	Slight			
16	Aviator	F-14	4 hrs.	1300	No		Slight		
17	Aviator	F-14	2 hrs.	2400	HASAC DMS 10-15 hrs. F-18 MAX 3 rd	Yes	Yes		
18	Aviator	F-14	20 hrs.	3500	F-18 MAX 3 rd 2 hrs.				
19	Aviator	F-45/J	20 hrs.	3400	No	Yes	Yes	Yes	Yes

(1) Visual Replays experienced in SAAC training did not occur in the 2E6 (information on the chart is relevant to SAAC experience). Subject 7 did not experience any sickness on Device 2E5.

ENDIX C

PTOM OCCURRENCE

Vertigo	Visual Focusing Problems		Discomfort	Disorienting Feelings	Other	Onset	Persistence
Yes			Yes			Simulator malfunction	6 hrs. after malfunction
	Yes					Operate initiate	Each mission, 15 mins. after completion
Yes	Slight		Yes			First reset	2-3 hrs. after every mission
Mild						Rose high maneuvers	3-4 mins. while in trainer
				Slight		Operate initiate	None after leaving trainer
Yes				Yes		Upon entering trainee station	10 mins. while still in trainer
					Visual replay	Lying down to sleep	Ceased 1 day after end of training (1)
Slight				Slight		Rose high maneuvers	None
Slight	depth perception loss			Yes		After 1 hr. of operation	2 missions of 1-2 hrs. duration
Yes				Yes		Operate initiate	10-15 mins. into each mission
	Slight			Yes	Tired feeling	45 mins. in trainer	3-4 hrs. after each mission
					Weak knees, eyes hurt	30 mins. in trainer	4 hrs. after every mission
	Yes					Reset function	Unknown
						Reset function	30-45 mins. after leaving simulator
			Yes		Fullness in stomach, slight headed feeling	Immediately after leaving trainer	1-2 hrs. after each mission
						5 mins. after leaving trainer	10-20 mins. after each mission
						Operate initiate	3-4 hrs. after each mission
			Yes		Gyball filter	Reset function	1 min. while in the trainer
	Yes		Yes	Yes		After 3 hrs. in trainer	Until after a sleep period

Indicates the same symptoms as described in other visual training experiences.

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GLOSSARY

Emesis	Vomiting.
Flashbacks	Retinal after-images which occur following exposure to simulator visual scenes.
Ground growth	The expansion or contraction of the background visual scenes to simulate descents or ascents in altitude.
Ground progression	The movement of the background visual scenes in relation to the observer to simulate movement over the ground.
Independent mode	Permits the Instructor Operator Station (IOS) to control only one cockpit trainer.
Integrated mode	Permits the selected Instructor Operator Station (IOS) to control both cockpit trainers interactively.
Kinesthetic	Literally "feeling of motion"; refers to the sensitivity of movements of parts of the body (e.g., arms, legs, tongue and eyeballs) in relation to the whole due to the excitation of receptor cells located in the muscles, tendons and joints of the body.
Leans	A false sensation of bank or tilt.
Motor dyskinesia	Impairment of an individual's power of voluntary locomotion.
Ocular	Of or pertaining to the eye.
Proprioceptive	The sense of position, movement, pressure and equilibrium. It is divided into two major subclasses: Kinesthetic and Vestibular.
Reset function	The freezing of the simulator visual display and returning to a new set of initial conditions.
Vertigo	False sensation of bodily position and/or movement.
Vestibular	Involves the perception of spatial movements and spatial orientation of the body as a whole, resulting from excitation of receptor cells located in the nonauditory labyrinth of the ear.

U. S. NAVAL SCHOOL OF AVIATION MEDICINE
U. S. NAVAL AVIATION MEDICAL CENTER
PENSACOLA, FLORIDA

A NOTE CONCERNING "MOTION SICKNESS" IN THE 2-FH-2
HOVER TRAINER

Bureau of Medicine and Surgery
Project NM 17 01 11 Subtask 3
Report No. 1

Report by

James W. Miller, Ph. D.
and
James E. Goodson, ENS, MSC, USNR

Approved by

Captain Ashton Graybiel, MC, USN
Director of Research

Released by

Captain Langdon C. Newman, MC, USN
Commanding Officer

20 February 1958

SUMMARY PAGE

THE PROBLEM

What are the possible factors which contribute to "motion sickness" in the 2-FH-2 Hover Trainer?

FINDINGS

A review was made of the development of Device 2-FH-2, including two evaluations. These evaluations pointed with no little concern to the problem of "motion sickness" experienced in the simulator.

The writers feel that the hypotheses offered by others to the effect that these symptoms were elicited by the conflict between visual cues of motion and static physiological cues is false. The problem seems to lie in one or a combination of several modes of distortion: There exist both static and dynamic distortions in the projected scenery; there are errors in the perceived directional changes of motion; and there are dynamic errors in the perceived angular rate of motion. These distortions are pointed out herein and suggestions are made as to how they might be alleviated.

INTRODUCTION

In 1952, the Bell Aircraft Corporation was awarded a contract by the Special Devices Center of the Navy for the development of a device to aid research in training helicopter pilots by means of simulated visual contact. The contract specified also that the device was to furnish realistic training for helicopter pilots in hovering and autorotation flight maneuvers. The de Florez Company of New York City was engaged under sub-contract to develop a method of attaining the required visual realism and to design and construct the essential components demonstrating the capabilities of the method devised.

The hovering operation of the device was first demonstrated in December 1954, at the Bell Aircraft Corporation, Wheatfield, New York. In April 1955, a demonstration of combined hovering and two-projector method of autorotation was held for representatives of the armed forces.

After certain improvements were made in the original device, it was installed at Helicopter Training Group One (HTG-1), Ellyson Field, Pensacola, Florida, in February 1956. A modification kit (composed of a light source demagnifier, autorotation transparency, and a transparency storage rack) which was added in July 1956, completed the device, and it was subsequently referred to as Device 2-FH-2.

It should be made clear at this point that the function originally intended for Device 2-FH-2 was to make possible the investigation of certain problems including those involving visual contact encountered in flight training. It was also to provide a means of evaluating the point-source system of visual presentation and to provide training in autorotation and hovering maneuvers in order to permit correlation of its characteristics statistically with human subjects.

DESCRIPTION OF DEVICE 2-FH-2

The three principal components of the device are the projection system, the cockpit, and the computer. These components are presented schematically in Figure 1.

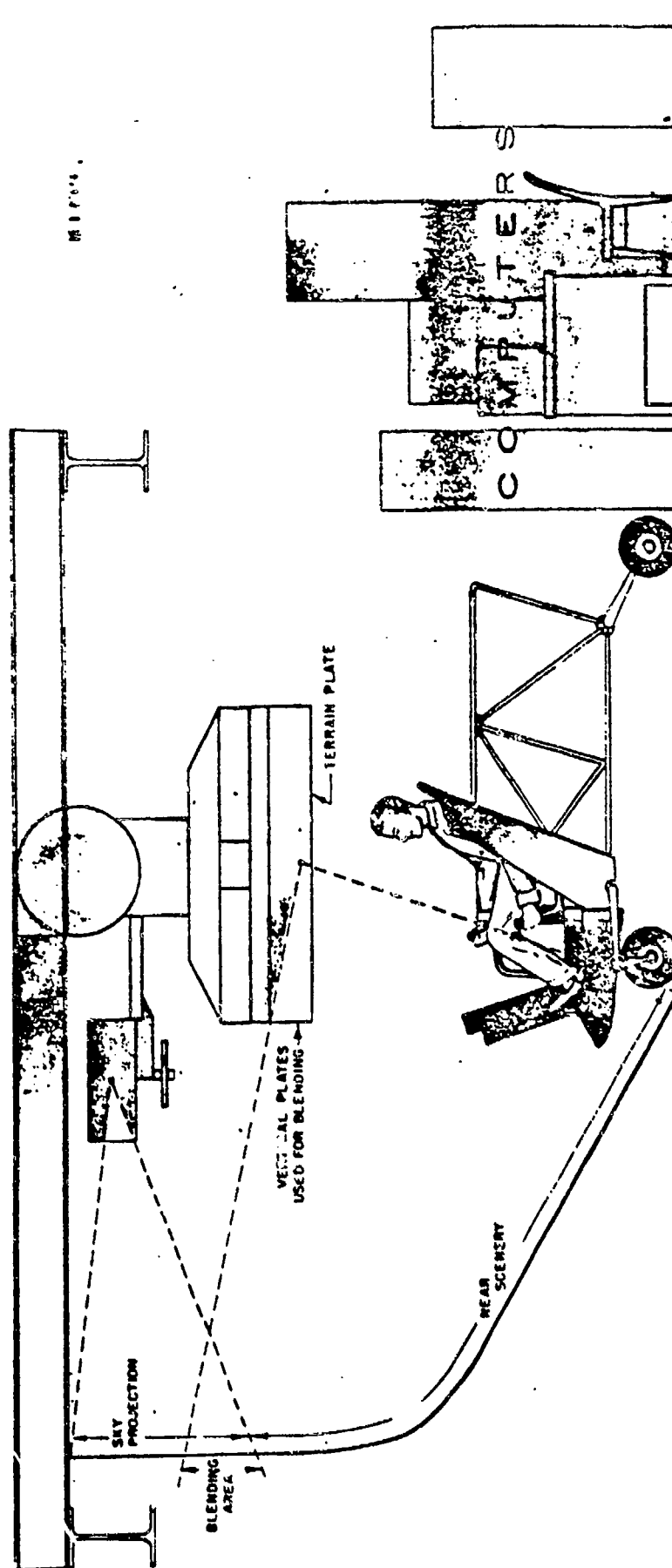


FIGURE 1
A SCHEMA OF THE 2-FH-2 DEVICE

Projection System

The projection system developed for this device is based on the assumption that the combination of a small diameter point source of light and a transparency plate containing special scenery can provide a realistic terrain perspective and motion presentation. Through the use of this technique, a realistic, non-programmed, wide-angle, presentation of scenery in excess of 260° azimuth by 75° elevation has been achieved.

Unlike conventional projection systems, this system does not depend basically upon wide angle lenses. Projection of the scenery is obtained by the emission of light from a high intensity, extremely small diameter source. As the rays of light from this source pass through a transparent film depicting a particular scene, the scene is very much enlarged and projected on a specially contoured screen. Motion of the scenery is obtained by the displacement of the transparency relative to the light source. Two separate, overlapping, projectors are used in Device 2-FH-2: the terrain projector and the sky projector. The terrain projector is used to depict the near terrain, the far scenery, and a portion of the sky. The sky projector continues the sky to the upper limits of the screen (Figures 1 and 2). The point source lamp which was found to be most suitable was an OSRAM, high pressure, mercury arc lamp. This lamp was used in conjunction with a specially devised demagnifier composed of a wide aperture camera lens, a microscopic condenser, a mirror, and a dispersion tip.

Two transparencies were included with the original device. The low altitude plate (0-55 feet) projected a simulated area of 780 feet by 780 feet. The high altitude plate (0-500 feet) simulated an area of 3,000 feet by 3,000 feet. The movement of the transparencies is accomplished by means of six integrated servo systems. These systems are capable of producing three translational and three attitudinal freedoms. Thus, relative motion between the transparency and the lamp is used to achieve changes in the projected picture which describe what a pilot would see if he were actually flying a helicopter.

The remaining component of the projection system is the screen, the general shape of which is shown in Figure 1. The screen is constructed of fiber glass sections which are surfaced with glass beads to ensure a high reflection factor. The final shape of the screen was determined by Dr. Francis Murray of Columbia University and was designed so as to minimize irregular illumination, errors in velocity judgment, distortions of size and distance, and to provide as correct ocular convergence as possible.



FIGURE 2
PROJECTION SYSTEM

Cockpit

The cockpit contains the usual flight controls and essential flight instruments in as realistic an environment as possible (see Figure 3). The instrument panel is similar to that found in the HTL-5 helicopter. However, only the following instruments have been activated: the manifold pressure gauge dual tachometer, airspeed indicator, altimeter, and compass. An intercommunication system is provided between the instructor and trainee. Dynamic effects of vibration and rough landing jolts are produced by rotating eccentric weights of the vibration system within the cockpit framework. These are the only motions actually experienced in the cockpit. Two instruments, the computer reset and the freeze switch, not conventionally found in helicopters, are located at the base of the instrument panel in the simulator. The computer reset provides a five-second period in which the pitch and roll angles and all of the attitudinal and translational velocities for the projectors and computer are returned to zero. This function has been found beneficial to the novice at various stages of training. The freeze switch stops all computer activity with the exceptions of manifold pressure, engine rpm, and rotor rpm.

Two speakers are mounted in the cockpit behind the pilot to provide simulated engine noise. The noise frequency changes with engine rpm.

Computer

The purpose of the computer is to take inputs from motion of the cockpit flight controls and produce electrical outputs representing the angular and translational velocities an actual helicopter would assume from similar control inputs. The computer consists of many electromechanical components such as: summing amplifiers, integration servos, position servos, resolvers, functional potentiometers, relays, demodulators, and servo amplifiers. In addition, various regulated and unregulated power supplies, which furnish the power to do the computation, are located within the computer.

A more detailed description of Device 2-FH-2 may be found in references (1) and (2).

PREVIOUS STUDIES

The preliminary demonstrations of the 2-FH-2 at the Bell Aircraft Corporation indicated that the simulation of actual flying conditions was quite realistic. Although their tests were admittedly inconclusive, there was some evidence of positive transfer of training from performance in the 2-FH-2 to that in a helicopter.

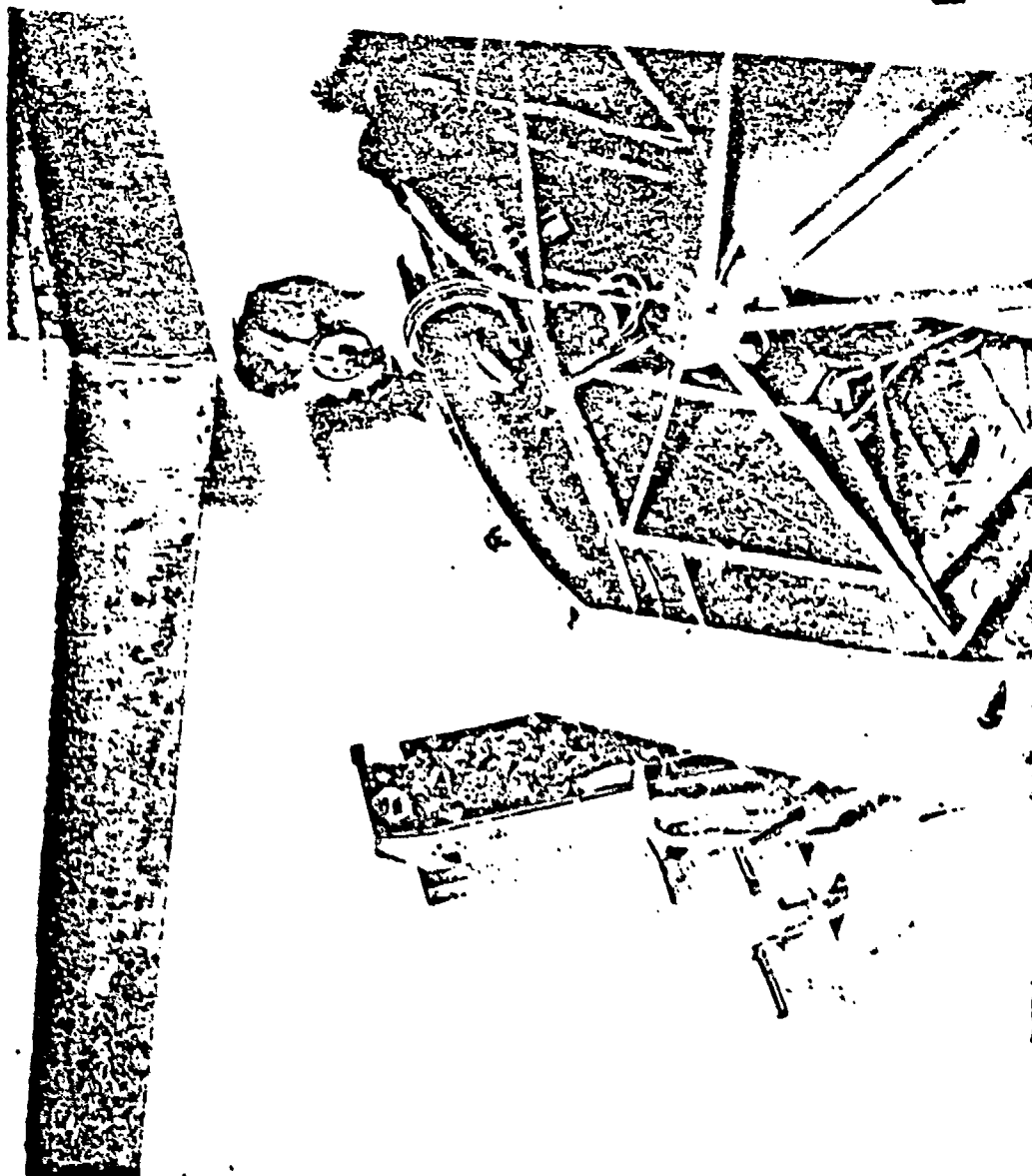


FIGURE 3
COCKPIT

It was found, however, that a large number of observers (mostly helicopter pilots) experienced some degree of vertigo during these demonstrations. The feeling of vertigo was found to be worse when the affected operator lost control of the device. The comments of the workers involved in these demonstrations suggested strongly that the cause of the vertigo "did not stem from incorrect visual presentation, but rather from the lack of associated effects on the body." (1) The similarity of the equations of motion in the 2-FH-2 presentation to those in actual helicopter motion supports the hypothesis quoted above in that it demonstrates that the real and simulated motions were indeed of the same order.

It was subsequently concluded that these induced feelings of vertigo do not indicate a lack of training ability of the device. "Rather it indicates a lack of completeness in the simulated environment and in addition to the visual requirements, helicopter pilots require body accelerations to complete cue inputs. This effect was not ignored in early planning, but early demonstrations indicated satisfactory illusion of flight was attainable with its omission. It now appears that future operational trainers might be improved, or at least be granted easier acceptance by seasoned helicopter pilots, by the addition of body motion to satisfy developed visual and inertial motion sensing. But, it remains to be proven that the inclusion of approximated body accelerations will enhance the training capabilities of the device for non-pilot or non-helicopter pilot trainees and thus be economically justified." (1) It was thus concluded by the Bell Aircraft investigators that it would be an improvement in future simulators if a compatible body-projector motion could be produced.

Following installation of the Device 2-FH-2 at Ellyson Field, an evaluation study was conducted by Havron and Butler, representatives of the Psychological Research Associates. Only a brief summary of this evaluation will be presented at this time.

The purpose of the above evaluation was "to determine to what extent the device was useful in initial stages of helicopter training and what problems arose as a result of the exposure of students to a number of hours of practice in the device prior to flight in an operational helicopter." Thirty-six subjects were used in the study and were divided evenly into experimental and control groups. A special training syllabus was devised for the experimental group slated to receive training in the simulator. Subsequently, a rating form was devised which served as a criterion upon the completion of the study. The criterion appearing on this form consisted of the five helicopter maneuvers which were considered to be the most critical and the most difficult.

The experimental procedure was as follows: All subjects were first given their A-1 familiarization flight and their ground school training. The experimental group was then given twelve thirty-minute training sessions on the simulator totaling six hours. Following this, both the experimental and control groups were given training in the HTL-5, up through the fifth training period (a-5). Finally, both groups were given a test hop in the HTL-5 in which the five maneuvers contained in the rating scale were graded by experienced instructors.

The results of analyzing these data demonstrated that there was no significant difference in the performance of the two groups. This lack of significance was not considered to be surprising in view of the fact that the student learns the basic maneuvers in about ten hours anyway and usually has little difficulty in doing so.

The fact that the performance of the experimental group was found not to be superior to that of the control group may be attributed to a number of factors, e.g., lack of fidelity of controls. Until these factors are corrected, the student may be likely to learn adjustments on the simulator which are dissimilar to those required in the helicopter. Havron and Butler (3) stated that the deficiencies concerning the lack of fidelity were known to the designers but that "because of technical problems and lack of funds, had not been corrected" at the time of their evaluation. In view of this, it is unfortunate indeed that the 2-FH-2 was installed and declared finished when known deficiencies were left uncorrected. Inasmuch as simulation of this nature is inherently complex, a negative evaluation, no matter how thoroughly qualified the recommendations are, might well have a deleterious effect on future investigation along similar lines. It is fortunate that Havron and Butler gave a straightforward report of what they felt to be the reasons for the lack of fidelity and the subsequent ineffectiveness of the instrument as a training device.

As was mentioned previously, during the early demonstrations of the 2-FH-2 at the Bell Aircraft Corporation, it was noted that a number of individuals experienced vertigo, nausea, and similarly unpleasant sensations. Similar experiences have been encountered in connection with other visual contact flight simulators (e.g., the F-151 Aerial Fixed Gunnery Trainer). In the Havron and Butler study a questionnaire revealed that twenty-eight of thirty-six respondents experienced some degree of sickness. These respondents included instructors, students, and other personnel experienced both in the 2-FH-2 and the HTL-5. The more experienced instructors seemed to be the most susceptible to these unpleasant sensations. Most cases of sickness were reported in the early stages of the experiment. It was also revealed that the "motion sickness" usually occurred in the first ten minutes of a given training session. Interestingly, these feel-

ings of sickness were frequently felt for several hours after leaving the trainer and, in some cases, individuals reported no immediate sickness but became sick later in the day. This so-called motion sickness became such a serious problem that it was felt that unless it can be remedied in some way the utilization of such simulators as training devices would be limited considerably. The Havron-Butler study lists a large number of possible causes for this sickness and discusses them in detail. Consequently, they will not be reiterated at this time.

In spite of the problems encountered in their evaluation, Havron and Butler concluded in general that a visual contact simulator can indeed prove to be an extremely useful instrument in a number of different areas of aviation. Some of the advantages of using such a simulator as opposed to using actual aircraft are: safety for the aircraft and the pilot, independence of weather, training for special missions, minimizing radiation exposure in pioneer studies in nuclear powered aircraft, and the possibility of large economical savings. These advantages can be realized, however, only if the existing problems of fidelity, motion sickness, control characteristics, and other difficulties are overcome.

As is emphasized in the Havron-Butler report the most pressing problem to be faced at present in the 2-FH-2 is that of simulated motion sickness. Obviously this limits the efficacy of the machine in both its role as a research tool and as a hover trainer. Consequently, the Naval School of Aviation Medicine was asked to review the problem and make recommendations which might alleviate this problem.

PROCEDURE

In an attempt to become more familiar with the device, the authors first interviewed a number of individuals acquainted with its operation and some who had been present during previous studies. Following a familiarization "flight" in the simulator, a brief flight in the HTL-5 was made by the writers and three other members of the staff of the Naval School of Aviation Medicine in order to make comparisons.

Next, several of the instructors who had been used in the Havron-Butler evaluation study were interviewed. One of these men had been so badly disoriented in the simulator that he was later forced to stop his car, get out, and walk around in order to regain his bearings enough to continue driving. An interesting point here is that several hours had

elapsed since he had "flown" the simulator, and he was well on his way home before these effects were experienced. There were many similar cases in which no particular ill effects were felt while "flying" but in which such symptoms as headache, disorientation, and dizziness occurred later.

Finally, it was decided that two men, Y and G, should learn to operate the 2-FH-2 for the purpose of later running subjects. The former, however, was forced to discontinue this after six hours of training because he began to have severe symptoms of motion sickness. G became fairly proficient in flying the simulator with about thirty hours of training. The only ill effect he reported was a marked fatigue experienced after each "hop". It may be well to note here that four men from Ellyson Field, who were checked out on the 2-FH-2 at the Bell Laboratories were able, after four hours in the simulator, to successfully hover the HTL-5. This is accomplished usually within about two hours in the helicopter training program. Also, G had the opportunity later to fly the HTL-5. With some fifty hours of experience in the simulator he was able to fly maneuvers required of a man with about ten hours in the Training Command. It should be understood that neither the group of four men nor G had the advantage of a programmed syllabus of instruction on the simulator. The task was nearly one of trial and error.

The decision was made at the start as to what was probably the most obvious and accessible facet of the problem: the distortion of distance cues provided by the lack of retinal disparity and convergence. A black patch worn over one eye would eliminate these cues and thus any distortion which might have been present due to them.

The subjects used in this experiment were ten U. S. Navy enlisted men, stationed at U. S. Naval Air Station, Pensacola, whose ages ranged from 17 to 21 years. They were divided into two equal groups. Each of the men was given four hops in the simulator which consisted of the maneuvers reported by Havron and Butler to most frequently provoke "motion sickness." These maneuvers were practiced by G for approximately six hours in an attempt to standardize the "flight plan." They were used in the following order: 1) an orientation flight around the limits of the area; 2) hover at approximately 5 feet above the runway; 3) fore and aft oscillations; 4) turns on a spot; 5) lateral oscillations; 6) landing. Group A was given two hops without the patch, followed by two hops with the patch; Group B was given two hops with the patch, followed by two hops without the patch. Each man was interviewed and given a questionnaire upon the completion of each hop in an effort to determine the nature and degree of the effects which he experienced.

No statistical difference was found between the two groups, nor was there a difference due to the presence or absence of the patch. However, two very definite conclusions were drawn: 1) A great many more than ten subjects are needed to distinguish cases of actual sickness from malingerers and from subjects who have accepted a suggested sickness. 2) A means much more reliable than the questionnaire is needed to determine both the existence and the degree of sickness.

At this point the writers estimated that a period of about two years would be required to evaluate systematically all properties of the simulator which might contribute to motion sickness. They were informed, however, that due to space demands and maintenance problems the machine could not be committed for more than four months. The problem of maintenance had already been forcefully brought to the writers' attention: The machine required about three hours repair for every two hours of operation. It was thought advisable therefore to spend the available time in an attempt to localize the trouble spots and make recommendations for further research, rather than to begin the project with little hope of being able to finish it.

DISCUSSION

With the Havron and Butler Report, the Bell Engineering Report, the Special Devices Maintenance Manual, and the machine itself at their disposal, the writers began an attempt to pinpoint the trouble areas of the 2-FH-2. These reports were used as general references and while in some cases similar findings were made, the following results were found independently of previous investigations.

PHYSIOLOGICAL CUES

At first glance a "flight" in the 2-FH-2 appears to be so similar to an actual flying situation in the Bell HTL-5 that it is rather difficult to account for the fact that there is so much difference in their respective effects on the operators. In trying to account for these differences, the first thought of those most concerned with the simulator was that the basis lay in the conflict between the visual and physiological cues of motion. Inasmuch as the seat in the simulator does not move, the cues of motion are received from a visual source without the expected accompanying physiological use. This conflict may indeed be one of the elements contributing to "motion sickness," but its relative importance in the complexity of contributing factors is rather doubtful. Aviators are quite often called upon to choose between two or more conflicting cues without any resulting sickness.

Any physiological cue to motion is elicited only by changes in rate of motion, i.e., acceleration or deceleration, and these changes in rate are normally almost imperceptible in the HTL-5. Furthermore, the instructors know what to expect, whereas the student, having had essentially no experience in helicopters, has not had the opportunity of building up such expectancies. Instructors, however, report that they must relax in order to "feel" these cues of motion. Now, since virtually all of the students are very "tense" in at least their first two or three hops in both the simulator and helicopter, it becomes difficult to account for the fact that 10 to 15 per cent of the students experience "motion sickness" in their first few hops. In considering the above, one is led to believe that the basic problem is concerned with conflicting visual cues, rather than a conflict between visual and proprioceptive cues.

CONTROLS

One of the most difficult problems in learning to fly helicopters is that of overcontrolling. This is due primarily to the slight (one to two seconds) lag between movement of controls and the student's recognition of response by the aircraft. The helicopter begins its directional movement as it makes the required attitudinal adjustment, whereas the simulator executes the full attitudinal adjustment before beginning a directional movement. The characteristic increases the lag in cyclic control to two to three times that of the HTL-5. Since the only way for the simulator to assume a nose down attitude, in preparation for forward flight for instance, is to shift the scenery upward on the screen, an illusion is produced of flying backward. This, in turn, encourages even greater overcontrolling. In at least one instance this situation of negative feedback has caused an experienced helicopter pilot to completely reverse his cyclic control. For example, he began to correct for undesired forward movement with back cyclic.

In overcontrolling, the pilot soon begins to "chase" the aircraft and often loses control of it completely. Obviously, this loss of control produces a violent maneuver. The more violent maneuvers were found to produce a greater degree of "motion sickness." Subjects have reported that they are more prone to become sick when sitting as a passenger with nothing to do than when they are actually "flying" the simulator. This may well account for the reports that a higher percentage of instructors than students become sick, since the students have the controls the majority of the time.

In an effort to remedy the problem of overcontrolling it is suggested that an instrument indicating the position of the cyclic be installed. This will provide the student with a means of immediate feedback as to cyclic position. This instrument might be in the form of an oscilloscope, an auditory tone, or a spring loading system in the cyclic itself.

TRANSPARENCY

Movement of the transparency plate provides the cues for all attitudinal and directional movements except those in the vertical plane. All these movements are well coordinated with the controls and, with the exception of the turning movement, are quite satisfactory. Quite often, when effecting a turn on a spot or some similar maneuver, the transparency begins to shudder. This in turn causes the scene on the screen to shake violently and resemble an earthquake. Subjects have reported that this contributes to the "motion sickness."

The main point of reference used by aviators in visual flying is the horizon. In the simulator, an image projected from the square transparency plate upon the round screen produces an illusion of a horizon with corners. The horizon rises up to a peak corresponding to a corner of the plate, and then begins to drop off. This is somewhat disturbing to the pilot in his effort to stay oriented.

In the present location of the simulator at Ellyson Field, it is nearly impossible to keep the transparency free from dust. Subjects have reported that this dust provides a distraction in the scene; however, this is thought not to be of major importance since the dust particles remain in a constant position relative to other objects in the scene.

The scene presented by the transparency may be too complex. It is not uncommon for an individual, upon finding himself in a strange situation with a multitude of stimuli bombarding him, to experience a degree of nausea, dizziness, et cetera. An example of this may be found in the case of a newcomer in a large city, or a stranger at a big party. Hayron and Butler support this idea in noting the difference between ill effects suffered while using the complex low altitude plate and those suffered while using the much simpler high altitude plate. Perhaps it would be of benefit to simplify the mass of stimuli with which the pilot must deal.

Also, it is suggested that the three dimensional objects, especially the ones nearest the landing field, be removed from the transparency plate. In addition to their contribution to complexity, they appear tremendously distorted from simulated positions of low altitude and short range. Movement in the vertical plane is provided in the simulator by vertical movement of the light source. When the pilot is performing precision maneuvers near the hangar, for instance at about 5 feet, the light source is far below the top of the hangar on the transparency. This causes the hangar, which should be approximately 35 feet tall, to loom up on the screen to an apparent height of 75 to 100 feet. This height varies, of course, with the altitude and distance from the hangar.

A second transparency provides the top portion of the picture, i.e., sky and clouds. A problem here is that the two pictures overlap approximately 2 feet. This fusion of the pictures provides an obscure band across the screen just above the horizon.

LIGHT SOURCE

The picture presented on the screen is dim and blurred. This may be a function of the light source, the screen surface, or the transparency. Whatever the source these properties should be modified since blur gives the impression of motion, and this may well be a contributing factor to the motion sickness involved. This impression of motion may also be a factor causing poor performance by a student in that, during hovering maneuvers, one must respond to the slightest impression of movement.

The Bell Engineering Report recommends that the light source be 24 inches above the eyes of the observer in order that optimum perspective and clearness may be obtained at a simulated altitude of 3 to 5 feet. The source moves a distance of 7 inches during the scope of operation, but at a simulation altitude of 5 feet, it is 9.8 inches lower than the recommended distance from a subject 5 feet, 11 inches tall.

As is mentioned above, this projection system is distorted in that the usual cues for retinal disparity and ocular convergence are lacking.

An alternative method of projection is suggested in the Bell Engineering Report (1). The method is composed essentially of two polarized light sources appropriately separated so as to project two images onto a specular reflecting surface. If the observer is wearing properly adjusted polarized goggles, the illusion of depth is produced by virtue of the fact that the images do not originate from the same source. This method consequently decreases the severity of the screen contour requirements. Although this system has certain advantages as mentioned above, a serious shortcoming is that the observer must keep his head perpendicular to the plane of polarization on the screen at all times or the effect is destroyed.

SCREEN

Two of the primary factors to be considered in the design of the screen are housing and light return. In an effort to avoid problems in these respects, however, the designers have created other, perhaps more serious problems. Let us first consider the size of the

screen. From the cockpit, the furthest point upon which a pilot is called to focus is about 12 feet. The closest point on the screen is about 6 feet from his eyes. This difference of about 6 feet represents, in the scene, a distance of a matter of miles. Obviously, the represented distance to an object in the scene is some exponential function of the actual distance to that given point on the screen. Therefore, any movement of the head will increase or decrease the represented distance to an object in an exponential manner, and any correction effected by increasing the radius of the screen would alleviate this problem in the same manner.

If it were possible for the light source and the pilot's eyes to be at the same point, the ideal shape of the screen would be spherical. However, this is not possible. Thus, a deviation in the shape of the screen from that of a sphere was made in an effort to correct for the distance from the light source to the pilot's eyes. This deviation may or may not have achieved its purpose. In view of the fact that, at its present site, the light source is several inches too low and the cockpit has two seats with the focal point of the screen between them, it would be rather difficult to determine the adequacy of the intended design.

In referring to Figure 1 the reader will note that at the bottom of the screen, the curve is nearly flat and that it is greatly accelerated about halfway up the screen and flattens out again at the top. In the area of greatest curvature, projected scenery appears to be slightly "squeezed in." This causes a great deal of distortion during pitching and rolling maneuvers. Also, in straight and level flight scenery appears to be accelerated as it passes that area of the screen.

Because neither of the seats is located at the focal point of the screen, a parallax is perceived by an observer from either seat. For example, from the left seat, as the curvature of the screen increases upward, all objects appear to slant to the left. As the transition is made in the curvature of the screen from acceleration to deceleration, a transition is also being made in the direction of the parallax. An object then appears to be slightly bowed and squeezed in at the point of greatest curvature in the screen, and finally appears in true vertical perspective in the flat portion at the top. However, clouds are the only objects which are usually presented in the upper portion of the screen. Thus, virtually all of the stimuli which provide important cues to the pilot are distorted.

There is a similarly varying distortion evident in the lateral plane. Figures 4 and 5 are time exposures taken of a scene from different locations in the cockpit of the 2-FH-2. Figure 4 was taken from a point directly under the light source. Figure 5 was taken at approximately the same height from a point 2 feet to the right of the light source. It is

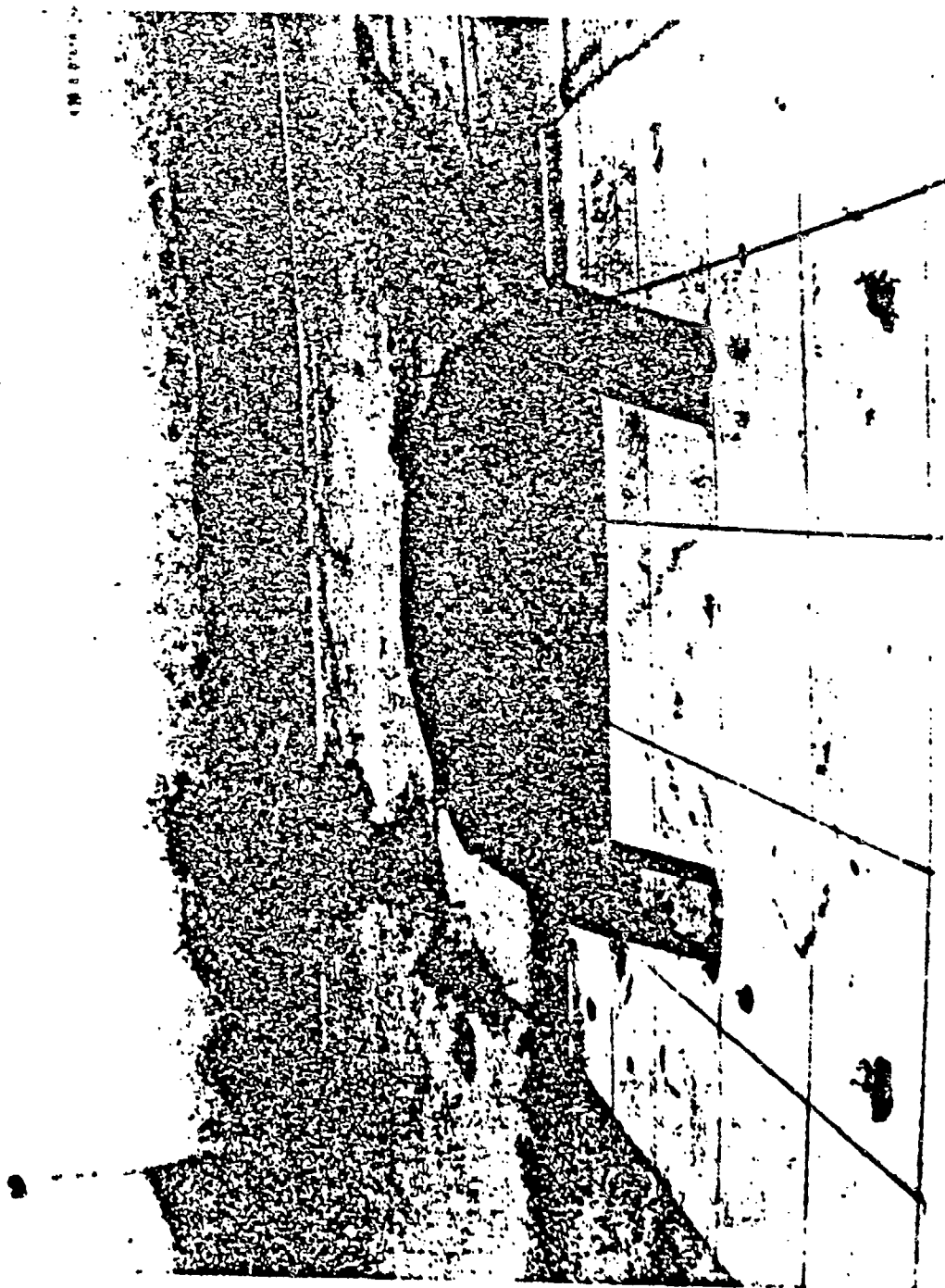


FIGURE 5
VIEW FROM RIGHT SIDE OF COCKPIT

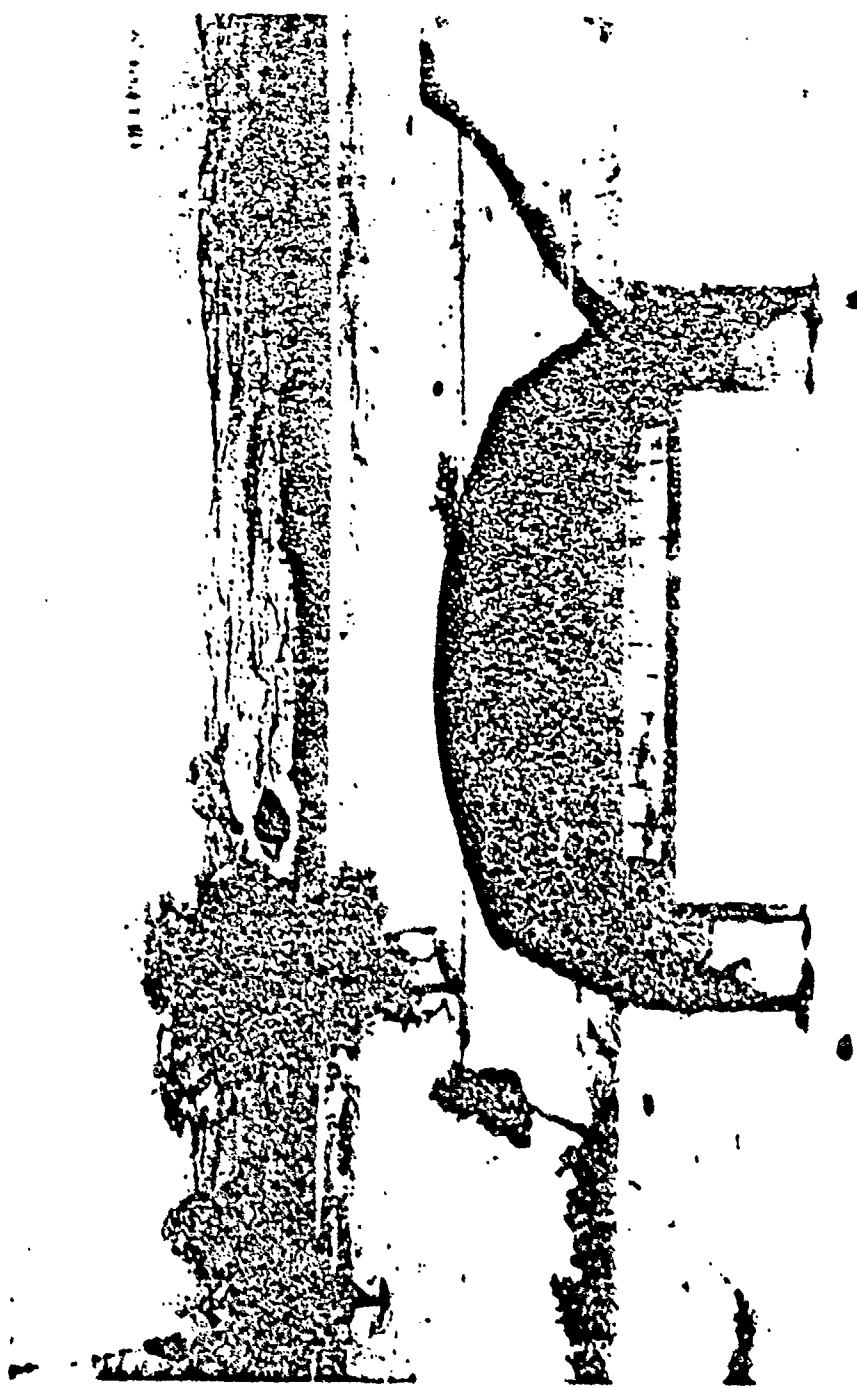


FIGURE 4
VIEW FROM CENTER OF COCKPIT

apparent immediately when comparing these figures that a considerable amount of distortion is produced when the scene is viewed from points other than directly under the light source. If this distortion were constant, the observer would likely be able to adapt. Unfortunately, however, the degree of the distortion is changing continually with movements of either the scenery or the observer's head. Since these distortions are due to the offset position of the seats, the only area free of parallax is that area on the screen which is aligned with the observer's eyes and a vertical line from the light source. The greater the distance from this area to a point being attended, the greater the distortion will be. Thus, a pilot performing a turn on a spot to the left, may observe that a fence post or telephone pole which slants about fifteen degrees to the left, gradually approaches the vertical as it approaches this area of the screen, and then begins to slant to the right. If this parallax contributes to the cause of "motion sickness", one may readily account for the fact that a greater percentage of instructors get sick than do students; the instructors have learned to scan the visible area constantly, whereas the students tend to fixate on a particular area of the screen and simply to attend to that portion of the scene which comes into this area.

Any cues which remain at a fixed position with respect to the screen will be perceived as conflicting with the cues of motion which are projected upon the screen. Dust presents a greater problem here than on the transparency, and it is much more difficult to remove. An attempt to vacuum the screen resulted only in making more definite streaks on it. This problem can probably be alleviated only by resurfacing the screen. Also, there are several large oil spots on the lower portions of the screen which were made while lubricating the overhead transmission.

Another reference point on the screen which remains fixed is the line between the upper and lower sections of the screen. Unfortunately, this line serves also as a very good reference cue to the horizon; during straight and level flight it is situated just above the horizon. This factor may contribute to faulty learning as well as to motion sickness in the 2-FH-2.

A number of individuals have commented independently that the apparent movement of the scenery in the 2-FH-2 is considerably more rapid than the corresponding movement observed from a helicopter. The cause of this effect is not clear. It may be however the end result produced by certain factors discussed previously such as blurring, distorted size perspective, distorted movement parallax, etc. This problem has been recognized and discussed in the Bell Aircraft Engineering Report (1).

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Motion Sickness in a Helicopter Simulator

JAMES W. MILLER, Ph.D., and LIEUTENANT (JG) JAMES E. GOODSON, MSC, USNR

SIMULATION of operational aircraft has become an increasingly important aspect of flight training. A recent report by Lybrand and his associates² points out the fact that as the complexity and cost of modern weapon systems increase, the availability of these aircraft for transitional flight training will decrease. They say further that "the loss of a pilot and aircraft in a training accident not only costs in terms of money and manpower, but also in terms of decreased overall operational capability. Still, adequate training must be accomplished; the use of flight simulators to make up the deficit in aircraft availability cannot be overlooked." One must keep in mind, however, that realistic simulation is not the goal in itself, but simply a means of facilitating a training program. The impression is sometimes given in the literature that realism *per se* is the single most desirable feature in a simulation device. Gibson and Smith¹ state in a recent report that "an objection can be made to this criterion of success for a training device or simulator. The sensory inputs necessary for realism may not be the same

as those necessary for correct perception of the environment and for adaptive behavior with respect to it. Instead of aiming to reproduce the inputs for a satisfactory illusion, the designer should aim to reproduce the inputs that are especially relevant for the performance in question."

The 2-FH-2 helicopter simulator was designed by the Bell Aircraft Company in conjunction with the DeFlorez Company of New York. It was installed at Helicopter Training Group One, Eglin Field, Pensacola, Florida in February, 1956. The function originally intended for the device was to make possible the investigation of certain problems including those involving visual contact encountered in helicopter flight training. It was also to provide a means of evaluating the point-source system of visual presentation, and to provide training in autorotation and hovering maneuvers.

DESCRIPTION OF SIMULATOR

The three principal components of the simulator are the projection system, the cockpit, and the computer. These components are presented schematically in Figure 1. The device has been described in detail in reports by Seigel³ and others.⁴

Projection System.—The projection system developed for this device is based on the assumption that the combination of a small diameter point

From the Kresge Eye Institute, Detroit, Michigan and the U. S. Naval School of Aviation Medicine, Pensacola, Florida. Dr. Miller is now in the Human Factors Section, Hughes Aircraft Company, Fullerton, California.

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source of light and a transparency plate containing special scenery can provide a realistic terrain perspective and motion presentation (Fig. 2).

Two transparencies were included with the original device. The low altitude plate (0 to 55 feet) projected a simulated ground area of 780 feet

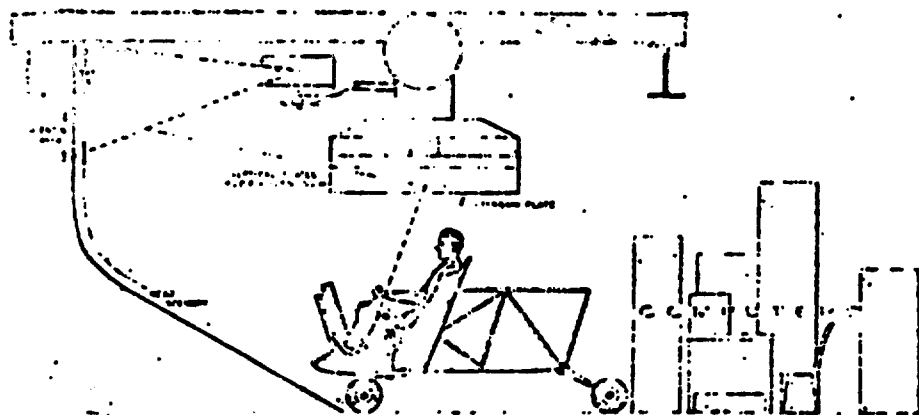


Fig. 1. Schema of Bell 2-P11-2 helicopter simulator.

Through the use of this technique, a realistic, non-programmed, wide-angle, presentation of scenery in excess of 360° azimuth by 75° elevation has been achieved.

Unlike conventional projection systems, this system does not depend basically upon wide angle lenses. As the rays of light emitted from the point source pass through a transparent film depicting a particular scene, the scene is projected on a specially contoured screen. Motion of the scenery is obtained by the displacement of the transparency relative to the light source. Two separate overlapping projectors are used in this device: the terrain projector and the sky projector. The terrain projector is used to depict the near terrain, the far scenery, and a portion of the sky. The sky projector continues the sky to the upper limits of the screen.

by 780 feet. The high altitude plate (0-500 feet) simulated an area of 3,000 feet by 3,000 feet. The movement of the transparencies is accomplished by means of six integrated servo systems. These systems are capable of producing three translational and three attitudinal freedoms. Thus, relative motion between the transparency and the lamp is used to achieve changes in the projected picture which describe what a pilot would see if he were actually flying a helicopter.

The remaining component of the projection system is the screen, the general shape of which is shown in Figure 1. The screen is constructed of fiber glass sections which are surfaced with glass beads to ensure a high reflection factor. The shape of the screen was designed to provide as correct ocular convergence as possible, and to minimize errors in velocity

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judgment, irregular illumination, and distortions of size and distance.

Cockpit.—The cockpit contains the usual flight controls and essential flight

cockpit. Two instruments are not conventionally found in helicopters, the computer reset and the freeze switch, are located at the base of the instrument panel in the simulator. The com-

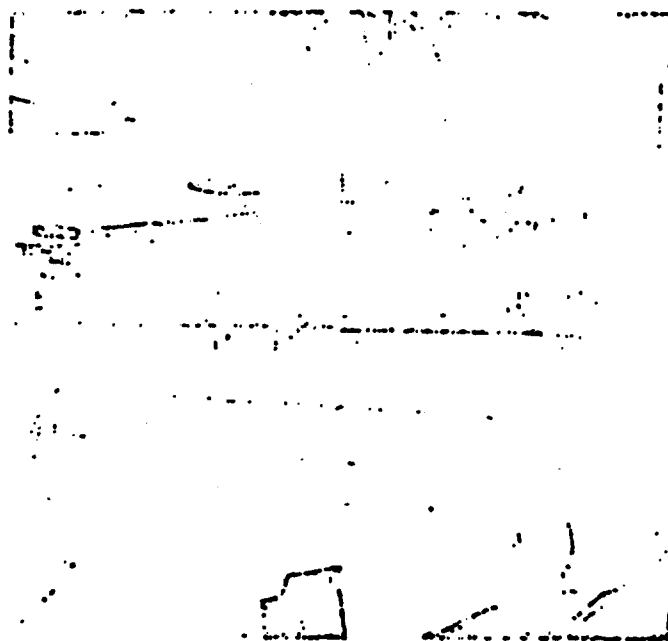


Fig. 2. Projection system of 2 FH-2 helicopter simulator.

instruments in as realistic an environment as possible (Fig. 3). The instrument panel is similar to that found in the UH-15 helicopter. However, only the following instruments have been activated: manifold pressure gauge, dual tachometer, airspeed indicator, altimeter, and compass. An intercommunication system is provided for the instructor and trainee. Dynamic effects of vibration and rough landing jolts are produced by rotating eccentric weights within the cockpit framework. These are the only motions actually experienced in the

cockpit. Two instruments are not conventionally found in helicopters, the computer reset and the freeze switch, are located at the base of the instrument panel in the simulator. The computer reset provides a five-second period in which the pitch and roll angles and all of the attitudinal and translational velocities for the projectors and computer are returned to zero. This function has been found to be beneficial to the student at various stages of training. The freeze switch stops all computer activity with the exceptions of manifold pressure, engine rpm, and rotor rpm.

Two speakers are mounted in the cockpit behind the pilot to provide simulated engine noise. The noise frequency changes with engine rpm.

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Computer.—The purpose of the computer is to take inputs from movements of the cockpit flight controls and produce electrical outputs representing the angular and translational velocities that an actual helicopter would assume from similar control inputs.

pilots, experienced some degree of vertigo during these demonstrations. The feeling of vertigo was found to be worse when the affected operator lost control of the device. The comments of the workers involved in these demonstrations suggested strongly that the cause of the vertigo "did not stem

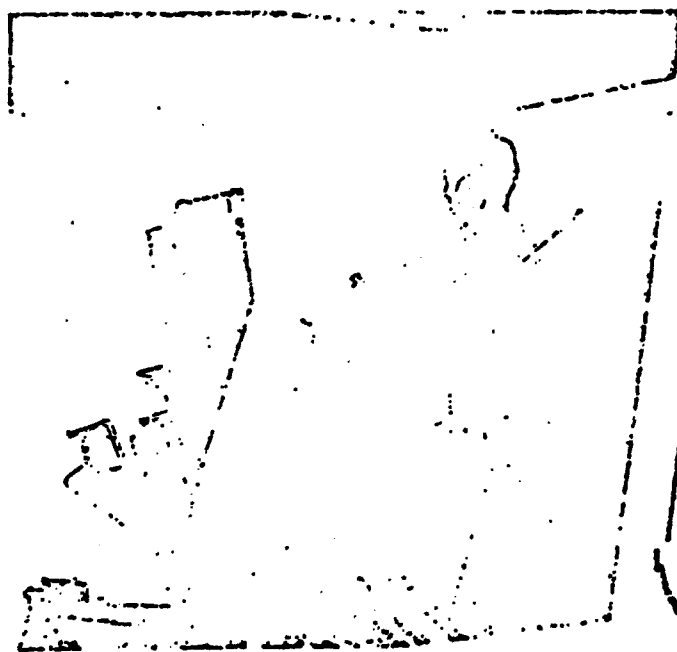


Fig. 3. Cockpit of helicopter simulator.

DISCUSSION

The preliminary demonstrations of the 2-FH-2 by the manufacturer indicated that the simulation of actual flying conditions was quite realistic. Although their tests were admittedly inconclusive, there was some evidence of positive transfer of training from performance in the 2-FH-2 to that in a helicopter.

It was found, however, that a large number of observers, mostly helicopter

from incorrect visual presentation, but rather from the lack of associated effects on the body."³ Havron and Butler arrived at the same conclusion in a subsequent report⁴.

The primary purpose of the evaluation by Havron and Butler was "... to determine to what extent the device was useful in initial stages of helicopter training and what problems arose as a result of the exposure of students to a number of hours of

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practice in the device prior to flight in an operational helicopter." It was found that there was no significant difference in the subsequent performance in a helicopter between students trained on the simulator and those receiving no such training. A questionnaire, however, revealed that twenty-eight of thirty-six respondents experienced some degree of sickness. These respondents included instructors, students, and other personnel experienced in both the Z-FH-2 and the HTL-5. The more experienced instructors seemed to be those most susceptible to unpleasant sensations. Most cases of sickness were reported in the early stages of the experiment. It was also revealed that the "motion sickness" usually occurred in the first ten minutes of a given training session. Interestingly, these feelings of sickness frequently were felt for several hours after leaving the trainer, and, in some cases, individuals reported no immediate sickness but became sick later in the day. This so called motion sickness became such a serious problem that it was felt that unless it could be remedied in some way the utilization of such simulators as training devices would considerably be limited. The Butler-Havron study lists a large number of possible causes for this sickness and discusses them in detail.

After familiarizing themselves with the physical components and operation of the simulator, the present writers attempted to locate some of the possible causes of the "motion sickness." As mentioned earlier, no provision for producing actual motion was included in the simulator. Previous investigators have suggested that

this absence of real movement accompanied by the presence of visual cues designed to give the impression of movement produced a conflict situation. This conflict was thought to be the primary cause of the "motion sickness." The lack of accompanying bodily cues may indeed be one of the elements contributing to "motion sickness," but its relative importance in the complexity of contributing factors is rather doubtful. Any physiologic cue to motion is elicited only by changes in rate of motion, that is, acceleration or deceleration, and these changes in rate are normally almost imperceptible in the HTL-5. The lack of such barely perceptible cues can hardly be thought to cause a conflict great enough to produce such severe symptoms.

An interesting feature of the symptoms is that the ill feelings sometimes did not come on until several hours had elapsed. On one occasion an instructor had to get out of his car on the way home and walk around in order to regain his equilibrium. Other instructors became conditioned to the simulator to the extent that the very sight of it made them sick. The senior author found that after any appreciable time in "flight" in the simulator it was indeed pleasant to get out as soon as possible. Even those individuals who did not become ill reported that they usually felt very tired after a run. This fatigued feeling lasted frequently throughout the day. Approximately 60 per cent of the instructors reported symptoms of "motion sickness" while only about 12 per cent of the students reported similar experiences as a result of a "hop" in the

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simulator. It is probably true that some students would not report such feelings as readily as would the instructors because of fear that it would affect their flight status. It is unlikely though that this factor would account for the large differences found.

It is possible then that the basic problem underlying the "motion sickness" reported involves conflicting visual cues rather than a conflict between visual and proprioceptive cues.

One of the most difficult problems encountered when learning to fly helicopters is that of overcontrolling. This is due primarily to the slight (one to two seconds) lag between movement of controls and the student's recognition of the response by the aircraft. The helicopter begins its directional movement as it makes the required attitudinal adjustment, whereas the simulator executes the full attitudinal adjustment before beginning a directional movement. This characteristic increases the lag in cyclic control to two to three times that of the UH-1A. Since the only way for the simulator to assume a nose down attitude is to shift the scenery upward on the screen, an illusion is produced of flying backward. This, in turn, encourages even greater over-controlling. In at least one instance this situation of negative feedback has caused an experienced helicopter pilot to completely reverse his cyclic control.

In overcontrolling, the pilot soon begins to "chase" the aircraft and often loses control of it completely. This loss of control produces a violent maneuver. The more violent maneuvers were found to produce a greater degree of "motion sickness." Instructors

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have reported that they are more prone to become sick when sitting as a passenger under these conditions than when they are actually "flying" the simulator.

The main point of reference used by aviators in visual contact flying is the horizon. In the simulator, an image projected from the square transparency plate upon the round screen produces an illusion of a horizon with corners. The horizon rises up to a peak corresponding to a corner of the plate, and then begins to drop off. This is disturbing to the pilot in his effort to stay oriented.

The scene presented by the transparency may be too complex. It is not uncommon for an individual, upon finding himself in a strange situation with a multitude of stimuli bombarding him, to experience a degree of nausea and dizziness. Hayron and Butler support this idea in noting the difference between ill effects suffered while using the low altitude plate containing a complex of scenery and those suffered while using the much simpler high altitude plate. Perhaps it would be of benefit to simplify the mass of stimuli with which the pilot must deal.

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the light source is far below the top of the hangar on the transparency. This causes the hangar, which should be approximately 35 feet tall, to loom up on the screen to an apparent height of 75 to 100 feet. This height varies, of course, with the altitude and distance from the hangar.

The picture presented on the screen is dim and blurred. This may be a function of the light source, the screen surface, or the transparency. Whatever the source, these properties should be modified since blur gives the impression of motion, and thus may well be a contributing factor to the motion sickness involved. This impression of motion may also be a factor causing poor performance by a student in that, during hovering maneuvers, one must respond to the slightest impression of movement.

Another aspect of the projection system which must be considered is the size of the screen. From the cockpit, the furthest point upon which a pilot is called to focus is about 12 feet. The closest point on the screen is about 6 feet from his eyes. This difference of about 6 feet represents, in the scene, a distance of a matter of miles. The represented distance to an object in the scene is some exponential function of the actual distance to that given point on the screen. Therefore, any movement of the head will increase or decrease the represented distance to an object in an exponential manner, and any correction effected by increasing the radius of the screen would alleviate this problem in the same manner.

If it were possible for the light source and the pilot's eyes to be at the

same point, the ideal shape of the screen would be spherical. However, this is not possible. Thus, a deviation in the shape of the screen from that of a sphere was made in an effort to correct for the distance from the light source to the pilot's eyes. In referring to Figure 1, the reader will note that the curvature at the bottom of the screen is nearly flat, that it is greatly accelerated about halfway up and decreases again at the top. In the area of greatest curvature, projected scenery appears to be slightly "squeezed in." This causes a great deal of distortion during pitching and rolling maneuvers. Also, in straight and level flight, movement of the scenery appears to be accelerated as it passes that area of the screen.

Because neither of the seats is located at the focal point of the screen, a parallax is perceived by an observer from either seat. For example, from the left seat, as the curvature of the screen increases upward, all objects appear to slant to the left. As the transition is made in the curvature of the screen from acceleration to deceleration, a transition is also being made in the direction of the parallax. An object then appears to be slightly bowed and squeezed in at the point of greatest curvature in the screen, and finally appears in true vertical perspective in the flat portion at the top. However, clouds are the only objects which are usually presented in the upper portion of the screen. Thus, virtually all of the stimuli which provide important cues to the pilot are distorted.

There is a similarly varying distortion evident in the lateral plane.

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Figures 4 and 5 are time exposure photographs made of a scene from different locations in the cockpit of the 2-FH-2. Figure 4 was taken from a point directly under the light source. If this distortion were constant, the observer would likely be able to adapt. Unfortunately, however, the degree of

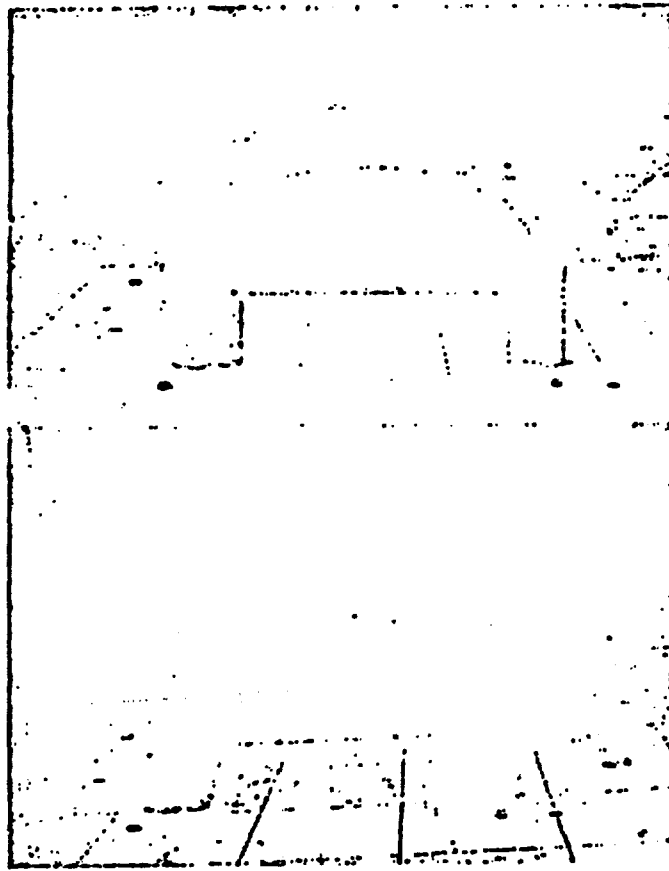


Fig. 4 (above). Forward view from center of cockpit of helicopter simulator.

Fig. 5 (below). View from right side of cockpit of helicopter simulator.

point directly under the light source. Figure 5 was made at approximately the same height from a point 2 feet to the right of the light source. It is immediately apparent when comparing these figures that a considerable amount of distortion is produced when the scene is viewed from points other

than directly under the light source. If this distortion were constant, the observer would likely be able to adapt. Unfortunately, however, the degree of the distortion is changing continually with movements of either the scenery or the observer's head. Since these distortions are due to the offset position of the seats, the only area free of parallax is that area on the screen which is aligned with the observer's eyes and a vertical line from the light

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source. The greater the distance from this area to a point being attended, the greater the distortion will be. Thus, a pilot performing a turn on a spot to the left, may observe that a fence post or telephone pole which slants about fifteen degrees to the left, gradually approaches the vertical as it approaches this area of the screen, and then begins to slant to the right.

A number of individuals have commented independently that the apparent movement of the scenery in the 2-F11-2 is considerably more rapid than the corresponding movement observed from a helicopter. The reason for this is not clear. It may be however the end result produced by certain factors discussed previously such as blurring, distorted size perspective, and distorted movement parallax.

Vertigo and concomitant symptoms probably are caused by a combination of several visual distortions. As was pointed out earlier, some of these distortions are continually changing with movements of the head, body and/or transparency thereby producing a totally unrealistic elastic environment. Static distortions can often be tolerated and even adapted to. Dynamic distortions on the other hand present a difficult pill to swallow. In designing a non-programmed visual presentation using a point light source system, these factors of dynamic distortion should be taken into account. The "motion sickness" problem in the 2-F11-2 was one of the chief reasons for discarding it as an operational flight trainer.

SUMMARY

Simulation of operational aircraft

has become an increasingly important aspect of flight training for reasons of economy, safety, expediency. In 1956 a helicopter simulator was designed and installed as a training device in Pensacola, Florida, for the dual purpose of evaluating a point source system of optical projection and as a possible means of facilitating the training of helicopter pilots. During the initial stages of utilization a number of problems arose concerning the desirability of employing this device as a training instrument. One of the most serious difficulties encountered was that of so called "motion sickness" in a cockpit that did not actually move. The problem became so serious that it was one of the chief reasons for discontinuing the use of the simulator.

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**FLIGHT SIMULATOR MOTION SICKNESS
IN THE AURORA CP 100 FDS**

K.E. Money

**Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West, P.O. Box 2000
Downsview, Ontario, Canada M3M 3B9**

DEPARTMENT OF NATIONAL DEFENCE - CANADA

FLIGHT SIMULATOR MOTION SICKNESS IN THE AURORA CP 140 FDS

Most of the aircrew conversion and continuation training for the Aurora aircraft is going to be done in a flight simulator, with resulting benefits to aircraft availability for operations, and with savings in aircraft maintenance and fuel. A very elaborate simulator is therefore needed, and the CFI40 FDS includes such advanced features as a motion platform and a computer-generated visual display. With the "motion" and the "visual" came simulator motion sickness.

The Magnitude of the Problem

On conversion course #1 (conversion of aircrew from the Argus to the Aurora), 4 of the 6 pilots experienced some motion sickness while flying the simulator. On the second and most recent course, conversion course #2, only 2 of 8 pilots experienced some motion sickness in the simulator. Three additional persons, in addition to pilots on formal conversion courses, have experienced some degree of motion sickness while working, observing, or flying in the simulator. One of these three was a flight engineer.

The sickness varied in degree from slight discomfort to mild nausea; no severe nausea was reported and no vomiting was reported. The problem appears to be the creation of a negative attitude early in the training, not a prolonged physical impediment to learning.

In most individuals who experienced the sickness, it occurred only on the first one or two simulator exercises. Subsequent exercises were flown symptom-free.

The Cause of the Sickness

The standard theory of motion sickness (1,2) is that it is caused by a mismatch or conflict in sensory inputs, i.e., a conflict in sensory information either (a) between two simultaneous inputs or (b) between the pattern of inputs being sensed and the pattern expected on the basis of past experience. In a simulator with visual there is, in several situations, an unavoidable conflict between visual information and information from the body's inertial receptors (the vestibular receptors of the inner ear, pressure receptors in skin, and receptors of muscles, tendons and joints). For example, (a) during a turn of 180 degrees while taxiing, the visual will show the turn of 180 degrees and the eyes will sense a turn of 180 degrees, but the body's inertial receptors will not sense such a turn because the simulator does not in fact rotate through 180 degrees. The pilot might feel that the visual scene is rotating too fast for the rotation that he is "really" (inertially) undergoing. The motion platform can only partly compensate for the lack of real rotation in

yaw. The conflict between the sense of vision (saying "we rotated through 180 degrees") and the inertial senses (saying "we did not rotate") promotes the feeling of nausea and other signs and symptoms of motion sickness.

It is perhaps valid (3,4) to say that the brain mistakenly interprets the mismatch in sensory inputs as a situation caused by ingested poisons, saying in effect, "My vision tells me that my inertial receptors are providing false information; my inertial receptors are exceptionally susceptible to malfunctions caused by poisons, and therefore I have probably been poisoned; probably something I ate; therefore, if the condition persists, vomit."

There are many such situations in a simulator with visual. Another example is (b) a level coordinated banked turn. During such a turn the visual scene will show the degree of bank (and usually the visual scene rotating against the turn), but the increased resultant acceleration, g , that experienced pilots expect in such a turn will of course be missing. If the visual shows low altitude and a noticeable high ground speed as well as a large angle of bank and a high rate of heading change, then the absence of large g forces will be particularly striking: the sense of vision will say to the pilot, "We are definitely pulling g ", and the inertial senses will say "We are not pulling g ". (Some simulators provide an inflatable pilot's seat, and when g is "pulled" the inflation pressure is reduced and the pilot sinks into the seat. This adds realism and helps to fool the pilot, but it does not, for purposes of motion sickness, fool the inertial receptors in the inner ear. Even if the pilot consciously "feels" g , the lack of real g on the inner ear can cause sickness. For reasons not understood, the inertial receptors of the inner ear play the major sensory role in motion sickness, and in fact, people without inner ears are totally immune to all varieties of motion sickness).

There are also sensory conflicts in simulators with visual during rolls into turns, rolls out of turns, pull-ups, bunts, accelerations, decelerations, etc, all for the reason that the normal inertial input to the body during such manoeuvres is not fully provided by the motion platform.

It is interesting that almost all of the pilots who experienced sickness in the simulator, when asked (in Major Bisang's survey) what they felt was causing the sickness, replied that it was "conflict" or lack of "coordination" or "correspondence" between vision and motion. This is precisely correct, and that it was almost universally understood by the pilots is a tribute either to the quality of their instruction in aviation medicine or to their perceptiveness.

Prognosis, and Experience of Other Simulator Users

The simulator sickness was a serious problem on conversion course #1, but was less so on course #2. With some variability or noise, that apparent development should continue. It is safe to predict that the problem will not be eliminated completely, because other long-term users have not eliminated it, and the structure of human beings demands that sickness occur in the circumstances of these simulators, but the sickness can be much reduced by users dealing with it properly. The process of reducing the problem has already been started by the users. The users were surprised by the sickness when it appeared with such a high incidence on conversion course #1, and it was a worrisome development. By avoiding the recognized worst sickness-producing manoeuvres, the problem was, apparently, alleviated during conversion course #2. Further experience will enable the users to further diminish the problem.

In the experience of other users of simulators with visual, the incidence of simulator sickness is surprisingly high, considering the population that is exposed to the stress, but the severity of the sickness is much less than in real flights (1), and the speed of habituation is also surprisingly high (a few hours until near-immunity is acquired). Apparently, everyone who operates a simulator with a large visual has a motion sickness problem to some extent, although with "night-only visual simulation" the problem is slight. The consensus is that the motion sickness problem is worse in simulators with wider fields of view in the visual. Enquiries were made concerning "visual simulators" for airliners, and for the P3, A10, F4, F14, and F16 aircraft, and all of them were causing some degree of motion sickness in some of the pilots. The occurrence of motion sickness in simulators with visuals that are both small and "night-only" is quite rare.

The worst problem seems to be in an F14 simulator which is causing disorientation as well as motion sickness. Peculiar sensations occur after flying the simulator, and pilots are required to have one night's rest after the simulator before flying real aircraft.

It is of interest that one of the users who has a "beautiful motion system" always leaves it turned off because it "really doesn't contribute anything to the training". He did not know whether the motion system made the motion sickness problem worse or better. It appears that most users with wide field visuals consider the motion base useful for pure instrument flying only, and most turn it off for VFR flying (in some cases because it is thought to aggravate the motion sickness problem). In general, users seem to dislike the motion systems for a variety of reasons, some of them unrelated to motion sickness. One user felt that his motion sickness problem was much relieved by conscientious maintenance of the motion base.

On the basis of theory it can be predicted that, when they arrive for training on the Aurora, the "pipeline" pilots (pilots with relatively little experience and without operational experience on any kind of aircraft) will on average have less susceptibility to simulator sickness than the very experienced pilots who have flown the simulator up to now, in spite of the fact that susceptibility to motion sickness generally decreases with age in adults. The reason for this prediction is that the pipeline pilots are less susceptible to the kind of conflict labelled (b) above, in which pilot experience is necessary to the expectation of a pattern of sensory input. The pipeline pilots, because they have less experience, should have less prominent (and less effective) expectation of what the patterns of sensory input should be in an aircraft such as the Aurora. When an inappropriate or inconsistent pattern of sensory input is presented, the inexperienced pilots should be less able to recognize it as such, consciously or otherwise.

Consistent with the above prediction on the basis of theory, in one of the earliest reports (5) of simulator sickness, in a U.S. Navy helicopter simulator with visual, it was noted that the problem was worse in the instructors than it was in the students. Similarly, the U.S. Navy found that several instructors suffered nausea while evaluating a modern P3 simulator, called the 2F87F, whereas two subsequent classes of students reported only more minor symptoms of motion sickness (6). It is probably reasonable to expect that the Canadian CP 140 FDS staff will, with experience, reduce the motion sickness problem to the relatively small proportions currently found on the American 2F87F.

Specific Suggestions

It is recommended that, aside from careful maintenance of the motion base, no adjustment or alteration or addition to the FDS machinery be made in response to the motion sickness problem unless it is found that adjustments in the way it is used are ineffective in reducing the problem to liveable proportions. The users will of course, in response to simulator sickness, make their own adjustments in the way the simulator is used, on the basis of their experience and their objectives, as they have done already. The users have implemented a carefully designed training programme, and some of the following suggested procedures would, to some extent, compromise the effectiveness of that programme because they involve doing some of the more difficult flying tasks before the easier ones have been learned. It might be decided to try those compromising procedures only in those rare students who reveal an unusually high susceptibility and unusually slow habituation. Some of the suggested procedures can be implemented for all students, with little inconvenience and without decrement in learning.

Until habituation has provided immunity, i.e., for the first 2

or 3 exercises:

- 1) Get the student seated and organized before turning on the visual.
- 2) Keep to a minimum the number and magnitude of turns during taxiing.
- 3) Keep to a minimum the amount of turbulence in flight.
- 4) Use the freeze mode and resetting mode as little as possible.
- 5) Use the night visual rather than the twilight visual.
- 6) Use mostly instrument flying in layer cloud and not too much clear hood flying.
- 7) Keep to a minimum the number of steep turns.
- 8) Keep to a minimum the number of times the pilot is required to make head movements, especially large nodding movements during turbulence or during changes of aircraft heading, vertical speed, or airspeed. Head movements during real or perceived accelerations are peculiarly effective in provoking motion sickness (7).
- 9) Whatever is seen or perceived to be the cause of the sickness should be minimized.
- 10) To promote rapid habituation, use frequent exposures to the stress (once or twice daily with no days off until habituation is achieved), increasing the stress gradually with each exposure. The exposure to the stress should always cease before the nausea becomes severe. The key to rapid habituation is having frequent episodes not beyond the point of moderate nausea, with complete recovery between episodes.
- 11) Antimotion sickness drugs can be prescribed by an M.O. and will help prevent the sickness without impeding the habituation process (although most antimotion sickness drugs tend to make the patient slow and sleepy).
- 12) Try turning off the motion base, as a last resort.

It is recommended that the FDS staff have frequent interaction with American military users of similar equipment. Such interaction would facilitate the exchange of current information about practical aspects of dealing with the problem.

For further assistance with this problem, for points of clarification or curiosity, or for any motion sickness problem in the simulator or in flight, please call DCIEM (416) 633-4240 ext 233, Dr. Ken Money.

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The Sensory Interaction of Visual and Motion Cues

Mr. JOSEPH A. PUIG

Research Psychologist, Human Factors Laboratory, Naval Training Device Center

Effective training design requires that the significance of cue interactions be established. Care must be taken to incorporate into the training device not only the cues required for training specific tasks, but the essential combinations of cues as well.

This paper discusses visual and motion interaction from the standpoint of: (1) illusions and spatial disorientation; (2) spatial orientation training; and (3) simulator sickness.

Experience with flight trainers has shown that motion cues are perceived and used differently when external visual cues are displayed. Motion can be sensed visually and proprioceptively. Acceleration cannot be sensed visually, however, until increasing velocity is noted. Conversely, the proprioceptive sense, though insensitive to velocity, is quite sensitive to acceleration.

Highly significant interactions take place when the visual and proprioceptive senses are stimulated simultaneously. As a result, a secondary stimulus, presented at the same time as a stimulus of primary importance to a control task, may act as a distracting cue or as a source of confusion. Conversely, a secondary stimulus may supplement the primary one and aid in performance of the task.

Related to the problem of whether a secondary cue will inhibit or enhance the primary cue is the effect of the secondary cue upon the sensory threshold level for the primary cue. Experimentation has produced human sensory threshold data which can be applied to simulator design. However, sensory thresholds which have been determined for a particular sense modality must be used with caution in practical applications, because of the influence of other stimuli acting simultaneously on other senses. The combined effect of several cues could radically shift the sensory threshold level for any or all of the stimuli. The resultant sensory interaction should be given primary consideration in the design of training devices.

Since much of the following discussion is dependent upon descriptions of the human sensory system, some of the terminology will be

defined. There has been some confusion concerning the terminology used in sensory psychology. This has resulted from the inability to distinguish clearly between closely related sensory functions and from the arbitrary grouping of these functions under different names, depending upon the classification scheme used. For instance, under the term *somesthesia*, are included the sense of movement (kinesthesia) mediated by joints, muscles, and tendons; visceral sensations, touch, pressure, and other skin sensations. The term *somatic senses* is also used in reference to these senses and is used interchangeably with *somesthesia*.

To confuse the issue further, we have the classification by Sherrington (1906). According to this scheme, the human receptor system can be divided into three groups: (1) exteroceptors, (2) interoceptors, and (3) proprioceptors.

The exteroceptors mediate such sensibilities as touch, superficial pain, temperature, tactile discrimination, vision, and audition.

The interoceptors underlie general and special interoceptive (visceral) sensibilities. General interoceptive sensibility includes perception of hunger, thirst, respiratory movements, and visceral pain.

The proprioceptors mediate such sensibilities as sense of position, sense of movement, pressure sense, and equilibrium. The proprioceptive system may be divided into two subclasses: the kinesthetic and the vestibular. Kinesthesia (literally "feeling of motion") refers to the sensitivity of movements of parts of the body in relation to the whole (for example, arms, legs, tongue, and eyeballs) due to the excitation of receptor cells located in the muscles, tendons, and joints of the

body. The vestibular sense involves the perception of spatial movements and spatial orientation of the body as a whole, due to the excitation of receptor cells located in the non-auditory labyrinth of the ear (Crosco, 1967).

THE VESTIBULAR SYSTEM

The sensory information which conflicts most frequently with visual perception is that originating in the vestibular apparatus of the inner ear. This apparatus consists of two sets of sensors, one in each inner ear. One set, the semicircular canals referred to as the six "spirit levels" of the body by William James (1948) acts as the chief receptors for rotational acceleration. The second set, the otolith organs (utricle and saccule), responds primarily to gravity and linear acceleration. The semicircular canals and otolith organs interconnect and are filled with a fluid called endolymph. Currents are set up in the endolymph as a result of head movements and the resultant pressure triggers off the nerve impulses. In steady rotation the semicircular canals become habituated so that when the rotation is stopped, a sensation of rotating in the opposite direction is felt. This can persist for a relatively long time, up to 30 seconds or more. The otolith organs, however, cannot be habituated, and as long as the linear acceleration continues it will be sensed.

Under the influence of complex motion stimulus there appears to be an interaction of linear and angular accelerations on the vestibular receptors. In such situations the duality of function of canal and otolith mechanisms becomes hazy. The two organs no longer contribute separately but appear to behave as a unit in sensing the motion stimuli (Benson and Bodin, 1966). This is not surprising, considering the structural continuity of the two sensors. There is evidence that the semicircular canals are stimulated to some degree by position and linear acceleration (Wendt, 1951). In addition to possible vestibular cross-coupling effects, interactions presumably take place between the vestibular and somesthetic senses (Srnode, 1971).

The vestibular apparatus senses the orientation and movements of the head, then stabilizes the eyes, thereby maintaining clear vision. The reflexes that stabilize the eyes during head movements are the results of the united control of the muscles of the eyes by four separate sources: vestibular, visual, neck muscle-receptor, and cortical (Wendt, 1951).

THE VISUAL SYSTEM

The visual system appears to lack proprioceptive feedback regarding moderate motions and the position of the eyes. The exact direction of gaze of the eye is known only by reference to the position of the object being observed and the observer's orientation in space. In the absence of a structured field, the observer rapidly loses the sense of direction of his gaze. An example is the autokinetic illusion—the apparent motion of a fixed point of light being fixated in the dark.

An illusion which serves to illustrate vividly the interaction between the visual and vestibular systems is the oculogyral illusion. This effect is associated with prolonged passive rotation and, like the autokinetic illusion, also involves apparent motion of a visual target. Under flight conditions, it is difficult to differentiate between apparent motion of a visual target. Under flight conditions that resulting from autokinesis, but both contribute to disorientation (Clark, 1963).

Tilting the head about one axis while it is being rotated about another axis (Coriolis effect) can modify sensations of turning and cause illusions (Stewart and Clark, 1955). Other effects conducive to spatial disorientation are listed in table 1.

THE VISUAL AND MOTION CLOSED-LOOP SYSTEM

Many experimental studies have tried to prove that in making spatial judgments, more reliance is placed on visual than on proprioceptive cues or vice versa. However, a survey of the literature, particularly the studies of Witkin and Asch (1948), indicate that both senses interact to the extent that the result is a derivative of their combined actions. When the two senses are in accord, perception of spatial orientation is correct. When the sensations are in conflict, however, the outcome is a compromise. The perception is then unstable and incorrect.

The human organism stimulates himself as he acts, and this stimulation, in turn, affects his action. The process is circular and has been compared to the feedback of servomechanisms (Wiener, 1961). In the words of Norbert Wiener, "The central nervous system no longer appears as a self-contained organ, receiving inputs from the

TABLE 1. FLIGHT SITUATIONS CONDUCTIVE TO DISORIENTATION

Actual situation	Subjective experience (false perception)	Cause
Level turn	Straight flight	Rate of change is insufficient to stimulate semicircular canals.
Level turn	Ascent	Resultant forces on otoliths are equivalent in both situations
Recovery from a level turn	Descent	Resultant forces on otoliths are equivalent in both situations
Protracted turn	Straight and level flight	Rate of change is insufficient to stimulate semicircular canals.
Left turn and head is bent forward suddenly	Falling to right	Stimulus is resultant of combined motions (Coriolis effect).
Skidding in a flat turn	Banking in opposite direction	Resultant forces on otoliths are equivalent in each case.
Maintenance of straight and level flight by successive corrections	Gradual turning	Rotary stimuli from yawing actions are cumulative due to endolymph inertia.
Straight and level flight parallel to another aircraft but at different speed	Turning	Misinterpretation of resultant of the two motions.
Straight and level flight at night approaching a row of ground lights at an angle to the direction of flight	Tilting or banking	Misinterpreting the row of lights as the true horizon dead ahead.
Level flight after a slow recovery from sudden roll	Continuing tilt and lean in opposite direction to compensate ("The leans")	Rate of change is not sufficient to stimulate perception of recovery movement.
Ascent or descent between two cloud banks. Aircraft attitude tilted from true horizontal.	Level of flight	Erroneous use of a tilted cloud layer as the horizon reference
Gradual ascent or descent	Level flight	Forces are not sufficient to stimulate otoliths.

TABLE 1. FLIGHT SITUATIONS CONDUCTIVE TO DISORIENTATION (Cont'd)

Actual situation	Subjective experience (false perception)	Cause
Slow bank	Level flight	Forces are not sufficient to stimulate otoliths.
Bank, correctly shown by attitude indicator	Tilt in opposite direction and increase true angle excessively in attempt to correct	Reversal of figure-ground relationships of attitude indicator resulting in control response to horizon bar instead of miniature aircraft
Approaching a fixed external light (e.g., star or beacon)	Approaching or following a moving light (e.g., tail light of other aircraft)	Autokinetic illusion
Approaching fixed external object	Object is approaching	Misinterpretation of relative motion
Approaching the lights of two aircraft which are separating rapidly	One aircraft approaching	Visual cues from angular separation are equivalent in both situations.
Following lights of two aircraft in parallel flight	Seeing one aircraft which will be near or distant depending on amount of separation	Visual cues from angular separation are equivalent in both situations.
Approaching familiar terrain	Approaching strange terrain	Temporary dissociation or impairment of memory, fatigue.
Approaching strange terrain	Approaching familiar terrain	Temporary dissociation or impairment of memory, fatigue.
Propeller rotating normally during moonlit night flight	Propeller standing still during moonlit night flight	Stroboscopic illusion produced by moonlight streaming through propeller blades and reflecting back onto propeller
Flight in propeller-driven aircraft or helicopter	Disorientation ranging from mild irritation to nausea; even complete confusion and unconsciousness	Flicker vertigo caused by sunlight streaming through idling propeller or helicopter blades. (Light flashes at a frequency between seven and thirteen Hz.)

Source: Modified after Vinacke (1947)

senses and discharging into the muscles. On the contrary, some of its most characteristic activities are explicable only as circular processes, emerging from the nervous system into the muscles, and re-entering the nervous system through the sense organs, whether they be proprioceptors or organs of the special senses." The interdependence of the spatial behavior of the body with visual and proprioceptive motion feedback is shown in figure 1.

The importance of the integration of these three feedback loops is dramatically shown by persons suffering from ataxia, a disorder characterized by a marked disturbance in the coordination of voluntary movements. A person afflicted with locomotor ataxia cannot walk without constantly looking at his feet and the ground. If blindfolded he cannot walk, or even stand. Such a person has lost an important part of his kinesthetic sense and must depend on his vestibular and visual senses to guide his actions.

Figure 1 may be expanded to illustrate the man/machine relationships in a simulator incorporating a visual display and a motion system, as shown in figure 2. By reference to this diagram it can be seen that the operator of a simulator which incorporates a visual display and a motion system has three primary inputs: visual, kinesthetic, and vestibular.

THE CONTROL TASK

In piloting tasks, visual observation of instrument panel displays, the external environment as seen from the cockpit, and sensations of motion provide the primary cues upon which the pilot bases his motor responses. Variations in the gravitational-inertial forces affect the pilot through the motion sensors of his vestibular system. The pilot's visual function and his sense of orientation are, in turn, affected through these sensors. As a result of the interconnection of the vestibular and oculomotor control systems, effects produced on the pilot's visual system, in turn, influence the response of his vestibular system and his sense of orientation (Peters, 1969). The interplay between these two anatomical systems finally results in the effective, or ineffective, control of the aircraft or flight simulator. It is this interplay between visual and motion cues that makes the simulation problem particularly difficult. In analyzing a specific flight situation, it is important to differentiate between the visually-induced effects and those resulting from motion. Then, it must be known how these cues react in combination. In cases where both visual and motion cues are being presented simultaneously, unless the cues are realistic in both relative intensities and temporal factors, their

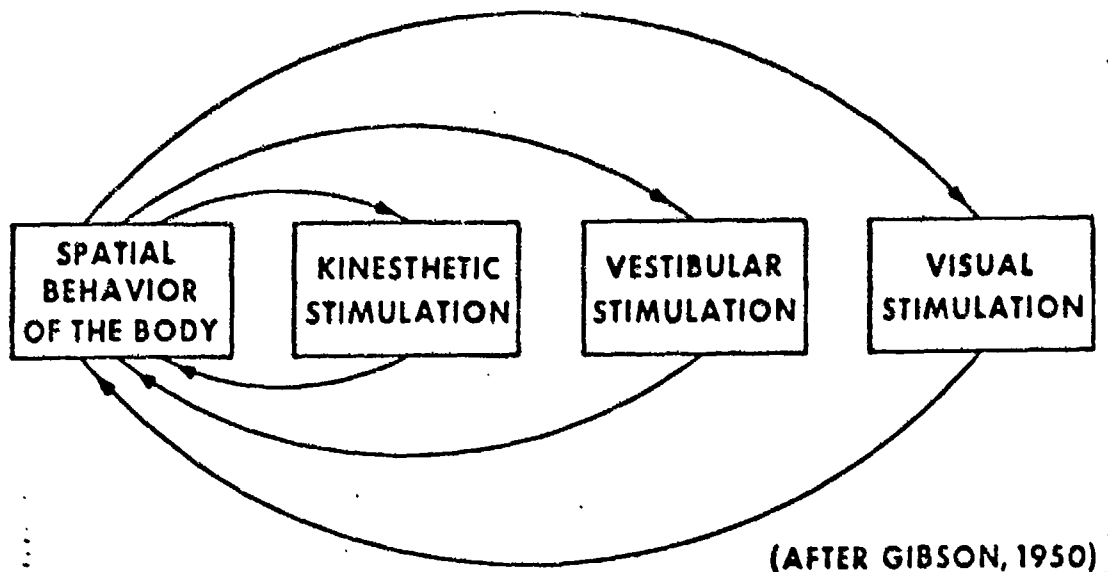


Figure 1. Visual and proprioceptive feedback.

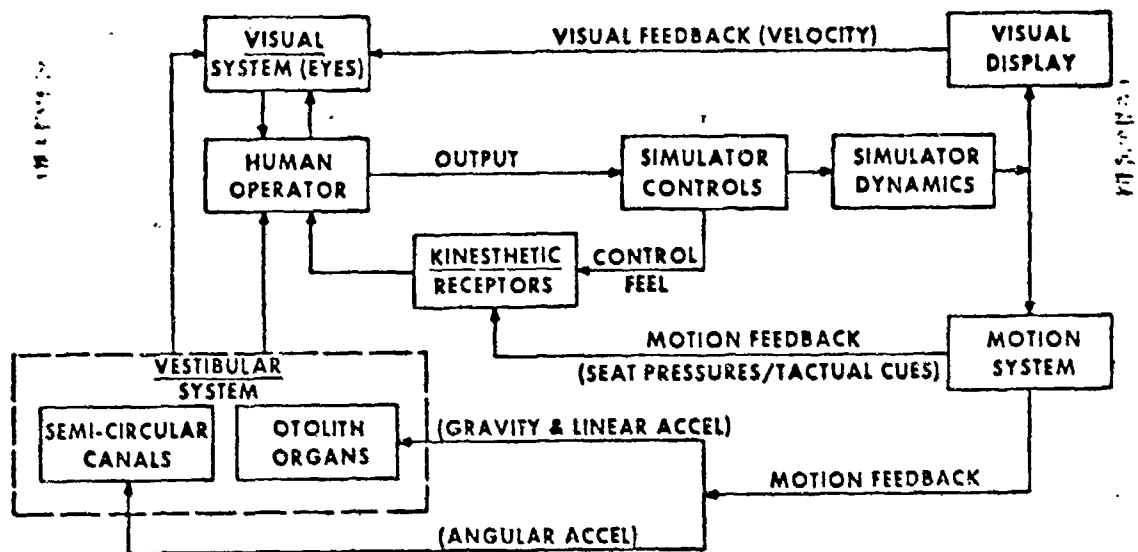


Figure 2. Visual and motion closed-loop system.

interactions may provide contradictory information and/or produce effects which are not representative of the operational situation being simulated.

ILLUSIONS AND SPATIAL DISORIENTATION

The illusions experienced in flight arise primarily from stimulation of the vestibular system and from visual phenomena. Illusions arising from visual phenomena refer to illusory perceptions of orientation or motion resulting from erroneous interpretation of visual information, are distinguished from visual phenomena caused by compensatory eye movements and eye reflexes caused by stimulation of the vestibular system.

Research in vestibular physiology has shown the importance of the vestibule in producing motion sickness and spatial disorientation. An example of this is shown by the fact that those deaf people who show no vestibular sensitivity do not get sick (Wendt, 1951) and are less susceptible to disorientation than normal individuals (James, 1948), (Olive, 1969).

A study correlating physical and medical data from 1,000 aviators over a 20-year period was made by the American Institute of Biosciences (Olive, 1969). An analysis of the data indicated

that disorientation and vertigo are responsible for early problems of failure of flight training, and for many aircraft accidents, and that with increasing age, problems of disorientation and vertigo increase.

Peters (1969) states that although kinesthetic and auditory perceptions are involved in some illusions, they are of secondary importance. The issue is complicated, however. There is evidence to indicate that humans can detect linear motion more accurately by the kinesthetic senses than by the vestibular. Although there is little doubt that the vestibular apparatus provides considerable information on linear acceleration, a simple experiment will show that these are limited in their application. Armstrong (1952) has described the experiment as follows: "If the head is turned on its vertical axis 90 degrees to the left or right and the body subjected to a forward linear acceleration, the labyrinth should be stimulated in such a manner that the motion would be interpreted as being lateral instead of forward. Actually, this does not occur, the body motion being correctly interpreted, and this must arise from somatic sensibilities. This somatic sensing of motion has been recognized for years by pilots who aptly referred to it as 'flying by the seat of the pants'."

Further evidence of how sensory interaction can affect perception has been demonstrated by experimentation. Wapner, Werner, and Chandler

(1951) had subjects align a luminous rod to the gravitational vertical in a dark room. It was found that if a loud tone was presented to one ear or if the chair was tilted approximately 30 degrees from the vertical, the rod was misaligned by several degrees. Apparently, auditory or kinesthetic inputs influence perception of the vertical.

The inability of the mind and body to differentiate clearly between sensations arising from different sensory organs is not necessarily detrimental to simulator design. It can sometimes be helpful in providing illusions of realism. An example is in the use of a dynamic seat, also referred to as a G-seat. This device is designed to produce a feeling of motion by controlled pressure redistributions across the contact surfaces between the body and the seat. The pressure variations can be produced by pneumatic or hydraulic inflation, direct mechanical deflection, or changes in tension of the seat covers. The sequence and magnitude of the pressures can be computer-controlled to simulate the somatic cues experienced during particular maneuvers. As it is introspectively difficult to distinguish vestibular from somesthetic sensations, this approach has been proposed as an inexpensive solution to the problem of simulating motion in a training device.

SPATIAL ORIENTATION TRAINING

A major causal factor of aviation-instrument, weather accidents is spatial disorientation. This generally occurs when the pilot unexpectedly loses visual reference to the ground, horizon, or a cloud layer, and as a result loses control of the aircraft. Some flight situations in which disorientation may occur are listed in table 1.

SIMULATOR SICKNESS

A factor which favors the inclusion of motion as part of a total simulation system is the inhibition of simulator sickness. It has been observed that symptoms resembling motion sickness develop when operating simulators that include a visual system providing apparent motion without accompanying real motion. It has been suggested that the attempt to interpret the visual cues in the absence of corresponding physical motion cues is one source of conflict that produces this effect. This cannot be the case

according to Gibson's (1950) theory, which postulates that the absence of cues does not constitute a conflict of cues. An example in support of this is that the absence of some cues inhibits motion sickness, as shown by the fact (mentioned earlier) that deaf-mutes lacking vestibular perception do not get motion sick. However, we are not really considering the absence of cues. There are inertial stimuli which tell the individual that he is not moving, despite the visual cues which imply motion and/or a change in this vertical reference. This seems to be where the conflict arises. Experience has shown that in that it is not the visual illusion of motion *per se*, but the visual sensation of apparent acceleration and/or change in direction which triggers off the initial feeling of discomfort. Witkin (1949), in a rotating room experiment, indicated that the greatest discomfort occurred at the point of reversal of direction of movement, that is, at the position of greatest angular acceleration. This should not be surprising as the inner ear is extremely sensitive to any force acting on the body (gravity, for example) and to any acceleration of the body, but is not sensitive to uniform motion. One might hypothesize that the cause is related to the increase in neural activity from eye movements following a changing visual scene which is contrasted with the static physiological cues from the proprioceptive system. However, it is generally very difficult to isolate the causes of simulator sickness and it is even possible to develop simulator sickness in a static situation such as in a room tilted from the inertial vertical. According to Steele (1963), in these cases of visually induced symptoms, the cause appears to be over-stimulation of the inner ear.

The following hypotheses are some that have been advanced in an effort to explain simulator sickness:

1. Conflict between the apparent motion seen on the visual display and lack of any corresponding real motion of the simulator.
2. Optical distortion (both static and dynamic) in the visual display, particularly of vertical objects; the synthetic presentation of a visual scene which is a distorted representation of a real environment.
3. Poor resolution.
4. Rapid changes in brightness (flicker).
5. Wide field of view.
6. A highly structured visual field (too much detail).

7. A poorly structured field combined with peripheral flicker.

8. Excessive lag between simulator control and corresponding movement in the visual display.

9. High-frequency vibrations which disrupt accommodation.

10. Projection screen-to-observer distance insufficient for infinity focus of the eyes, producing conflict between actual distance of the display and the apparent distance of the scene.

Items 6 and 7, above, appear somewhat contradictory. This may have resulted from different interpretations of the term "structured field." Benfari (1964) reported that vertigo was most common when there was a combination of a poorly structured field and peripheral flicker. He found that motion and flicker could be integrated in a highly structured field without inducing vertigo. Benfari also found that flicker or poor structure by itself had no apparent effect. In his report, a poorly structured field was defined as: "(a) having a figure-ground contrast ratio of less than 2:1, (b) having poorly-articulated objects in the field, (c) lacking a definite frame-of-reference such as an horizon or vertical border, and (d) having a relatively homogeneous textural gradient."

An important factor in these experiments was that a 165-degree cinedome projection screen was used. This wide-angle screen produced a "compelling illusion of confinement by the boundaries of the visual field. Subjects who stood outside the boundaries of the cinedome were not affected as strongly by the vertigo inducing stimuli" (Benfari, 1964). Items 6 and 7 are, therefore, related to item 5 (wide field of view), and it is apparent that most of the factors listed above are, generally, interrelated.

When a definite frame of reference is missing, it is difficult to distinguish the visual field from what Gibson calls the "visual world." Gibson states that, "In some flying maneuvers, in amusement park devices, in a special type of vertigo, and in a number of experimental situations, the visual world and the visual field cannot be distinguished from one another and some illusory frame of reference—a non-gravitational vertical—may then dominate perception. The experience is disconcerting and unpleasant. It is in these situations that one loses equilibrium."

In two independent studies conducted on the 2FH2 Hover Trainer (Bell Helicopter Simulator) the first investigators (Havron and Butler, 1957)

concluded that the basic problem resulted from a conflict between visual and proprioceptive cues due to a lack of cockpit motion. The second team (Miller and Goodson, 1958) concluded that the basic problem was caused primarily by conflicting visual cues produced by a combination of several optical distortions in the display.

A similar situation was encountered in an automobile driving simulator manufactured by the Goodyear Aerospace Corporation, in use at the Injury Control Research Laboratory, U.S. Public Health Service, in Providence, Rhode Island. Many subjects (40 to 50%) experienced simulator sickness on this device, and the cause was generally attributed to the lack of a motion system. However, it was noticed that the optical pickup and vidicon camera, which were suspended on the end of a movable carriage above an 87:1 (HO gauge) scale terrain model, vibrated as the gantry moved about. This vibration was magnified through the optical relay system and transmitted to the projection screen. Although the picture jitter was not too obvious, the observer's eyes were constantly shifting in an effort to stabilize the scene. It was subsequently believed that this was the cause of the simulator sickness, rather than the lack of real motion. Coincidentally, on the 2FH2 Hover Trainer there was also picture jitter produced when executing a turn or other abruptly changing maneuver. Subjects reported this as a contributing factor to the simulator sickness experienced on this device. However, since picture jitter coincided with the turning or other sudden maneuver, it could have been the illusion of acceleration due to the simulated maneuver, rather than the jitter, which produced the feeling of malaise. It would appear difficult to isolate the cause in this case. Another possibility is that jitter and the apparent acceleration were both contributing factors.

Recently, a new gantry drive mechanism, which virtually eliminated picture jitter, was installed on the Goodyear driving simulator but simulator sickness persists in the device. The Injury Control Research Laboratory plans to incorporate a dynamic seat into the simulator, which will move during acceleration, braking, and turning, in further efforts to eliminate the problem (Lewis, 1969).

An interesting aspect of the 2FH2 Hover Trainer study was that a higher percentage of instructors became sick (60%) than students (12%) (Miller and Goodson, 1958). Three hypotheses were offered to account for this:

RECOMMENDATIONS AND RESEARCH ISSUES

1. Before incorporation of a motion system for the sole purpose of preventing simulator sickness, it must be definitely ruled out that the problem is not strictly a visual one. If it is a discrepancy in the presentation of visual cues (distortion) the addition of motion will not remedy the situation and may only aggravate it. Hall and Parker (1967) reported that in one Air Force, high-performance, tactical aircraft simulator (without a visual display) the motion system was not used often because it was unnecessary for what it taught and it tended to make the students nauseous (motion sick).
2. Experimental studies should be conducted to provide conclusive evidence to support (or reject) some of the hypotheses that have been advanced regarding simulator sickness. A relatively straightforward study which may yield information of practical importance is one which would contrast the effects of a dynamic visual system with and without real motion. It would attempt to show that the sickness produced by the perception of apparent motion on a visual display can be negated by the addition of real motion. Sinacori's (1969) validation study of ground-based simulation attacked this problem as a side issue. Unfortunately, only one subject was used in the primary evaluation, and as the susceptibility to simulator sickness shows wide individual differences, it would appear premature to make generalizations based on the results derived from a small sample. Continuation of this experimental work, using a large sample of both experienced and inexperienced pilots, should be encouraged.
3. A study should be conducted to determine the effects of wide versus narrow field of view displays as a contributing factor to simulator sickness.
4. It may be found that visually-induced (apparent) motion and real motion cannot be "mixed," but that the real motion must accompany the apparent motion synchronously in order to avoid simulator sickness. Visually-induced uniform motion may be an exception.
5. Detailed measurements of pilot head and eye movements during various stages of fixed and moving base simulations should be made and compared with flight data. This type of investigation may provide an explanation of the function of the ocular counter-roll reflex and its relation, if any, to simulator sickness.

6. Pilot instrument training is a known technique for preventing or recovering from spatial disorientation. In addition to instrument training, spatial orientation training should be employed to familiarize the pilot with the causes of the illusions experienced during disorientation, and to train him on countermeasures to prevent or overcome the effects of the misleading cues which cause the phenomenon.

7. Physical training is another area which merits consideration. Vestibular training by Soviet cosmonauts made it possible to raise their vestibular stability. Passive exercises were conducted several times a week alternated with special active exercises as part of general physical training. All cosmonauts showed higher vestibular tolerances to rotation after training (Yuganov, et al., 1966).

SUMMARY

No sensory system is completely isolated from the others. As a result, simultaneous stimulation of several senses will produce an interactive effect. The organization by the nervous system of various sensations into meaningful perceptions is an extremely complex process. It is not strange, therefore, to find that at times there are misinterpretations of cues leading to false perceptions.

The sensations which conflict most frequently with visual perceptions are those originating in the vestibular system of the inner ear. Sensory interactions between the visual and vestibular apparatus are very important to consider in simulator applications which couple a visual display to a motion system.

There are three general types of acceleration: linear, angular, and radial. The vestibular system serves to sense these accelerations in conjunction with the somatic senses. Although the eyes are stabilized by inputs from the vestibular apparatus, the visual system appears to lack proprioceptive feedback of its own. The direction of gaze is known only by reference to what is being looked at. In the presence of a well-structured visual display, therefore, the visual mode will be the primary, overriding input. With a poor visual reference, however, the motion cues will tend to take priority. In situations where the visual and motion inputs are sensed as being equally demanding, they will be reinforcing or

1. Subjects are more prone to become sick when sitting as passengers than when they are actually "flying" the simulator (students had the controls the majority of the time). The fact that vehicle operators rarely become sick and passengers often do can be explained by the conflict of cues hypotheses. As the operator receives direct feedback from the vehicular controls (Barrett and Thornton, 1968), and is also in an optimum position for viewing the outside environment, he can anticipate what is to happen and does not experience conflict. On the other hand, the passenger who does not have these references may become ill.

2. Visual distortion is more apparent to an experienced pilot, who is continually scanning the scene, than to a student who tends to fixate on a particular area of the screen. Yet in order to reduce the tendency to experience vertigo, Sinacori (1967) instructed his simulator pilots to scan the total display frequently and to avoid staring at a particular point on the display. This is but one of the many paradoxes to be found in the literature of simulator sickness.

3. There was probably no cue conflict for the student pilots, since they had not learned the specific motion cues which are characteristic of helicopter operation. Conversely, the instructor pilots experienced cue conflict as a result of the absence of the proprioceptive sensations which they had been highly trained to interpret and respond to. Fitts (1951) found that visual control is very important while an individual is learning a new perceptual-motor task but as performance becomes habitual, proprioceptive feedback or "feel" becomes more important. This is readily apparent in learning to typewrite, to play a musical instrument, and in learning many other skills.

Habituation is also a factor applicable to simulator sickness. In some cases, instructors may find that they adapt to the simulator after gaining experience in operating the device, and subsequently will not suffer any ill effects. As an aid to reducing the effects of simulator sickness in a point light source simulator, Sinacori (1967) recommended the following procedures:

1. Wearing eyeshades which prevent direct light and extraneous reflections from entering the pilot's eyes.

2. Instructing the pilot to close his eyes during startup and shutdown procedures when exaggerated simulator visual motion occurs.

3. Frequent rests.

4. Frequent scanning of the total display and avoidance of staring at a particular point during a precision hover or maneuver.

5. Instill high motivation in the pilot.

A study by Northrop Norair Division (Sinacori, 1969) addressed itself to the issue of simulator sickness as part of an investigation to determine a ground-based simulator's capability to produce data representative of visual flight. A jet-lift V/STOL aircraft simulator using a point light source visual display with a rotational, 3 degree of freedom motion base, was used as the test vehicle. Fixed base operation of this simulator induced pilot nausea and reduced pilot-vehicle performance. Use of the motion system greatly reduced or eliminated the nausea and produced results comparable with flight results.

Another interesting aspect of this study was the attention paid to head movements which were found to be related to vehicle motions. Measurements showed that compensatory head movements occurred during lateral quick-stop maneuvers when peak bank angles exceeded 5 to 6 degrees. The head counter-rolled in order to reduce the total inertial rolling of the head during moving base operation. During fixed base operation, the head movement was reversed; the head tended to follow the visual scene which moved in the opposite direction to what the real motion would have been. The same pattern of head movements shown during moving base operation was observed by Sinacori for five other pilots while they performed the same task during flight in a helicopter.

Head movements may have some bearing on the higher incidence of sickness involved with wide-angle visual displays as compared to displays having narrow fields. However, wide-angle displays usually have more distortion than narrow-field displays, and, possibly more important, the pilot loses all sense of a stable reference in a wide angle system since the edges of the projection screen are not in the immediate field of view. Which of these three factors is the most important—head movements necessary to scan a wide field, distortion, or loss of a stable reference? Or, do they all interact to produce vertigo?

contradictory depending upon whether the cues are in or out of phase.

In conclusion, it may be stated that effective training design requires that the significance of cue interactions be established. Investigators can be misled by trying to extrapolate the results of single-variable experiments to complicated applications where many variables are present. Care must be taken to incorporate into the training device not only the stimuli required for training in specific tasks, but the essential combinations of stimuli as well. In addition, it is important that the perceived pattern of cue combinations actually represent those of the operational environment.

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Mr. JOSEPH A. PUIG

Research Psychologist, Human Factors Laboratory, Naval Training Device Center

Mr. Puig received his B.A. and M.S. degrees from New York University and an M.A. in Experimental Psychology from St. John's University.

In 1950 he joined the Grumman Aircraft Engineering Corporation where he participated in the Lunar Module Program as Group Leader, Visibility and Optics Section. This assignment involved human factors research as applied to spacecraft controls and displays, lighting, and visibility.

After 10 years with Grumman, he joined the NAVTRADEVCEEN in 1968 where he was assigned to the Training Effectiveness Division. His major duties here involve the evaluation of training systems, and studies in the application of human factors principles to simulation.

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(i)

ABSTRACT

Fifteen women and sixteen men were given a 10-minute 'ride' in a fixed-base car simulator with a moving visual display (Sim-L-Car). These exposures were standardised, and included a considerable amount of implied (but not actual) vestibular stimulation. Approximately one half of the subjects wore 'blinkers' which restricted their field of view to the dynamic visual display. The principal findings were:

(1) Some measurable decline in well-being was reported by 28 of the 31 subjects; (2) Women were significantly more susceptible than men; (3) Both previous passenger and car driving experience correlated positively with the degree of disturbance produced by the simulator; but driving experience appeared to exert the greatest influence upon susceptibility; and (4) Exclusion of the static features of the field of view appeared to have no effect upon susceptibility. These results were interpreted in the light of the 'sensory rearrangement' theory of motion sickness.

Motion sickness susceptibility; simulator sickness susceptibility;
sensory conflict.

INTRODUCTION

It is now well established that a form of motion sickness, sometimes called 'simulator sickness', can be produced by the operation of fixed-base vehicle simulators incorporating an appropriately moving visual scene (Miller & Goodson, 1960; Sinacori, 1968; Barrett & Thornton, 1968). One explanation for this phenomenon has been provided by the 'sensory rearrangement' theory of motion sickness (Reason, 1970; Reason & Diaz, 1970) which argues that the essential provocation comes from a mismatch between the total pattern of information being signalled by the basic orientation senses - the eyes, the vestibular system, and the non-vestibular proprioceptors - and that held in store from previous stimulus exposures. Thus, motion sickness is thought to be triggered by a conflict between the prevailing inputs from the spatial senses and those expected on the basis of prior experience; with the all-important proviso that the current sensory influx must include a changing velocity stimulus of the sort normally detected by the vestibular system.

Within the terms of this theory, simulator sickness is presumed to arise from the absence of vestibular signals in the presence of visual information which, in conditions of actual vehicle motion, would be accompanied by corroborating signals from the semicircular canals or otoliths as well as from the non-vestibular proprioceptors. The basic assumption that simulator sickness is due to the unfulfilled expectations of a vestibular input created by the seen motion is partially borne out by the experimental finding (Miller & Goodson, op cit) that experienced vehicle operators are considerably more susceptible to this disorder than trainees, or those with little or no previous experience of real vehicle motion. This is presumably because the expectations of the former are more firmly entrenched than those of the latter, and hence conflict more drastically with the 'rearranged' sensory inputs encountered in the simulator.

The present investigation differed from previous studies of simulator sickness in that it employed passive rather than active observers. The car simulator used in this experiment was controlled by the investigator while the subject, seated beside him, passively observed the dynamic visual display through the 'windscreen'. The question which interested us was: 'How much does the absence of active vehicle control influence susceptibility to simulator sickness?' If a relatively high incidence of symptoms were observed in this passive mode, then it would be reasonable to assume that the sense of involvement created by actually handling the controls was not essential, or even particularly influential, in producing sickness. And on theoretical grounds, there was no reason to suppose that 'passengers' would be any the less susceptible than 'drivers', provided that they paid close attention to the moving visual scene (cf. 'Cinerama sickness').

In addition to studying the incidence of simulator sickness in passive observers, this investigation also considered the effects of three variables which, on a priori grounds, were likely to influence susceptibility. These were:

- a. Sex. There is a wealth of evidence (see Reason, 1968) to show that women are generally more prone to most conventional forms of motion sickness than men, and it was expected that similar sex differences in susceptibility would be revealed in the present experiment.
- b. Restriction of vision. Approximately half of the subjects wore 'blinkers' which restricted their field of view to the screen displaying the moving visual scene. It was thought that eliminating the 'unrealistic' aspects of the environment - such as the stationary surroundings - might enhance susceptibility.

c. Previous car experience. The subjects' prior experience as both car passengers and drivers was measured. From previous findings, it was expected that the degree of both kinds of experience would be positively related to the amount of disturbance created by the simulator session; although it was of theoretical interest to discover which of these two forms of experience, passenger or driver, would have the greater influence.

METHOD

Subjects

Fifteen female and sixteen male undergraduates and technical staff were used as subjects. Their ages ranged from 17-23 years, the modal age being 19. The majority of the subjects were volunteers from a first year Psychology degree course, the remainder being junior technicians. All the subjects were asked to complete a Motion Sickness Questionnaire (MSQ) at the completion of the experiment (see Reason, 1968, for details of the MSQ and scoring procedures). The mean MSQ score for the women was 53.4, and for the men, 44.9.

Subjects were also asked to estimate how many hours per week, on average, they spent as car passengers and car drivers. Comparative mean experiences for women and men were:

- a. Women as passengers: 4.1 hours a week
range 0-14 hours a week.
- b. Women as drivers: 1.5 hours a week
range 0-12 hours a week.
- c. Men as passengers: 3.5 hours a week
range 0-10 hours a week.
- d. Men as drivers: 2.0 hours a week
range 0-10 hours a week.

Simulator

The driving simulator was the Sim-L-Car, a point light source device manufactured by General Precision Systems of Aylesbury, Bucks. It was a closed loop system which relied for its visual display on a point light source projection system. The body of the simulator was made up of A-40 components and fascia. It was instrumented with standard car controls: steering wheel, gear lever, clutch, accelerator, brake pedals, handbrake, and key-operated ignition. Two seats were situated side by side in the car body 'mock-up'. The simulator was also equipped with a sound source which, when turned down to its lowest volume, provided a fairly convincing background noise and 'tickover'.

The visual display was presented to the occupants of the car on a 6 x 12 ft rear projection screen located just ahead of the bonnet at a distance of 6 ft from the driver and subject. The display consisted of the refracted image produced when the illumination from a high intensity point source of light passed through a transparent, circular 'Plexiglass' disc. A roadway network, comprising a winding perimeter road with intersecting transverse roads, was painted on to the surface of the disc. Added 'realism' was provided by trees (fashioned from cotton wool and wire), perspex buildings, and a stationary toy bus. The impression of vehicle movement was created by the controlled motion of the road disc beneath the stationary light source; the motion of this disc was governed by the speed and direction controls of the car in a realistic fashion.

The overall effect was that of driving on the perimeter track and intersecting roads of a deserted airfield. The optics were such that the car always appeared to be driving into a wintry sunset. From the investigator's point of view, the greatest realism was achieved with a combination of low, 'twilight', illumination and fairly high apparent speeds. In addition, the display characteristics were most satisfactory on a lefthand (anti-clockwise) circuit of the perimeter track. However, right turns were made at junctions on the transverse roads.

Procedure

Subjects sat in the passenger seat of the simulator, and were told that this experiment was part of general investigation designed to evaluate the simulator as a training device. They were informed that it could, on occasions, produce mild symptoms of travel sickness such as dizziness, queasiness, and nausea. The purpose of this particular experiment, they were told, was to find out how many people were affected and to what extent. To this end they were asked to keep their eyes fixed on the screen ahead and to ignore any distractions in the room around them.

Each subject was then driven over a standard course for a period of 10 minutes. The course was chosen both to maximise the realistic features of the device (i.e. high average speed and lefthand circuits when on the perimeter road) and to include a large amount of implied vestibular stimulation (i.e. sharp cornering at speed, rapid acceleration and braking, stopping and starting). During the run, the only source of illumination was that from the visual display itself.

At the end of the run, subjects were asked to rate their general state of well-being (at that time), to describe their symptoms (if any), and to rate the realism of the car simulator. Details of the rating scales and symptom scores are given in a separate section below.

Restriction of Vision

As mentioned earlier, approximately one-half of the subjects were provided with 'blinkers' to screen out all but the moving display from the field of view. The 'blinkers' consisted of an oval rubber tube which was held by the subject over his eyes. One end of the tube was moulded to fit the nose and forehead. Subjects were instructed to adjust the shape of the tube so that it excluded all but the projection screen from the visual scene. To avoid unnecessary eye-strain or pressure headache, they were instructed to hold the 'blinkers' very lightly against the face.

Experimental Measures

The principal dependent measures were the Well-being Scale (Reason & Graybiel, 1970; Reason & Diaz, 1970), and a Symptom Score derived from a standardised symptom check-list. The well-being estimates were made on the basis of an eleven-point category scale, ranging from 0 - 'I feel fine' to 10 - 'I feel awful, just like I'm about to vomit'. To obtain the Symptom Score, subjects were asked whether they had experienced any of the following symptoms either during or immediately after the run: dizziness, bodily warmth, headache, increased salivation, stomach awareness, and nausea. Two further symptoms were mentioned by subjects during the post-run interview: dry mouth and drowsiness. In addition, the presence and degree of pallor and cold sweating were assessed by the investigator. To achieve the overall Symptom Score, the presence of any of these signs or symptoms was categorised as 'mild', 'moderate', and 'severe'. A score of 1 was given to all reactions classified as 'mild', 2 to those classified as 'moderate', and 3 to 'severe' reactions. The final Symptom Score for each subject was obtained by summing these individual weightings.

In addition, the subjects were asked to rate the realism of the Sim-L-Car on a 10-point scale from 0 - 'Not at all like a real car', to 10 - 'Just like a real car'. At the completion of the interview, subjects were asked to fill in the MSQ.

RESULTS

Incidence

In three subjects only did both the Well-being Rating and the Symptom Score indicate a complete absence of any ill-effects. The remaining 28 subjects reported varying degrees of disturbance ranging from mild dizziness to the presence of all listed reactions including severe nausea. One subject gave a well-being rating of 10 and asked

for the run to be stopped after 9 minutes because she felt close to fainting. A percentage breakdown of the proportion of subjects reporting each kind of reaction is shown in Table 1.

Table 1

Percentage of Women, Men, and Total Sample Reporting each Sign or Symptom.

	(N=15)	(N=16)	(N=31)
Signs and Symptoms	% Women	% Men	% Total
Dizziness	73	69	71
Bodily warmth	47	50	48
Headache	53	38	45
Stomach awareness	53	31	42
Nausea	60	25	42
Pallor	53	6	29
Sweat	33	25	29
Increased salivation	13	25	19
Dry mouth	13	0	6
Drowsiness	7	0	3

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From Table 1, it is clear that the most frequently occurring symptom was dizziness, and this was true for both men and women. The next most frequent symptoms were bodily warmth, headache, stomach awareness, and nausea. The only really marked discrepancy between the sexes was in the presence of pallor, something that was detected far more often in women than in men.

It is also clear from Table 1 that all but one symptom, increased salivation, occurred more frequently among the women, a discrepancy that was predicted on the basis of known sex differences in susceptibility. A more detailed analysis of these sex differences is given below.

Sex differences

Table 2 shows the mean Well-being Ratings and Symptom Scores for men and women. Mann-Whitney 'U' tests calculated for both measures indicated that women were considerably more disturbed by the simulator than the men; W-B Ratings, $U=48.5$; $p<.01$ (one-tailed test); Symptom Scores, $U=65.5$; $p<.025$ (one-tailed test).

Table 2

Mean Well-Being Ratings and Symptom Scores for Men and Women

	<u>Women</u>		<u>Men</u>	
	Mean	Range	Mean	Range
Well-Being Rating	4.7*	0-10	1.7	0-5
Symptom Score	6.6	0-18	3.1	0-7

*The higher the Well-Being Rating, the more severe the disturbance. The same is true of the Symptom Score.

In view of their marked differences in susceptibility, men and women were treated separately in all subsequent analyses.

The Effect of 'Blinkers'

Table 3 shows the mean Well-Being Ratings and Symptom Scores for female and male subjects with and without blinkers. For neither sex did the restriction of vision make any significant difference to the degree of disturbance produced by the simulator ride. In view of this, the presence or absence of blinkers was ignored in subsequent analyses.

Table 3

Mean Values for Subjects with and without 'Blinkers'

	<u>With (N=7)</u>	<u>Without (N=8)</u>
<u>Women</u>		
Well-Being Rating	4.4	4.8
Symptom Score	6.8	6.5
	<u>With (N=8)</u>	<u>Without (N=8)</u>
<u>Men</u>		
Well-Being Rating	1.1	1.8
Symptom Score	3.0	3.5

The Effects of Previous Car Experience

Spearman rank order correlation coefficients were computed between the two sickness measures and the average time per week spent as a car driver and passenger. This was done for men and women separately, and the results are summarized in Table 4.

Table 4Relations between Degree of Sickness and Previous Car ExperienceWomen N=15

	<u>rho</u>
Well-Being Rating/Driving experience	+0.51*
Well Being Rating/Passenger experience	+0.22
Symptom Score/Driving experience	+0.50*
Symptom Score/Passenger experience	+0.45*

Men N=16

	<u>rho</u>
Well-Being Rating/Driving experience	+0.32
Well-Being Rating/Passenger experience	+0.05
Symptom Score/Driving experience	+0.43*
Symptom Score/Passenger experience	-0.12

(*indicates $p < .05$)Realism Ratings

For women, the mean realism rating was 5.8, the modal value 6, and the range 2-9. The pattern for men was very similar: a mean of 5.6, a modal value of 7, and a range from 2-8.

Casual inspection of the data suggested that there was a negative relationship between the realism ratings and the two measures of sickness. To check this, rank order correlation coefficients were computed, and are set out in Table 5.

Table 5

Relations between the Degree of Sickness and the Realism Rating

<u>Women</u>	
	<u>rho</u>
Well-Being Rating/Realism Rating	-0.31
Symptom Score/Realism Rating	+0.01
<u>Men</u>	
	<u>rho</u>
Well-Being Rating/Realism Rating	-0.46*
Symptom Score/Realism Rating	-0.34

Predictive Value of MSQ

To assess the value of the MSQ for predicting individual differences in susceptibility to simulator sickness, rank order correlations were computed between the total MSQ score and the two measures of simulator sickness. The resulting coefficients are shown in Table 6.

Table 6

Relations between the Degree of Sickness and MSQ Score

<u>Women</u>	
	<u>rho</u>
MSQ/Well-Being Rating	+0.10
MSQ/Symptom Score	+0.15

view obtained from the front of a laterally stable train moving at constant speed along a perfectly straight track. In this investigation, it was certainly true that manoeuvres such as cornering at speed, travelling fast along a winding stretch of road, and sudden braking were the ones most frequently cited as responsible for loss of well-being.

The rather surprising finding that the presence of the 'blinkers' had no effect upon susceptibility to simulator sickness is of particular interest since it suggests that cognitive factors, such as the knowledge derived from seeing the stationary surrounds, play little or no part in the production of symptoms. Evidently, the presence of incompatible elements in the visual scene does not appreciably reduce the nauseogenic properties of the dynamic visual display.

Both this and the demonstration that passive observers are equally prone to sickness point to the involvement of a fairly low-order central mechanism: one that is more attuned to signals from the relatively primitive orientation senses than to subtle nuances of cognition. Such a conception is very much in accord with the 'sensory rearrangement' theory of motion sickness in which psychogenic factors are considered to be of secondary importance only. The essence of this theory is that symptoms are triggered (exactly how is not understood) by inconsistencies between the prevailing influx from the spatial senses and stored traces from comparable exposures in the past. If the brain centre concerned with integrating spatial inputs has come to 'expect' (on the basis of prior experience, that is, through the process of perceptual adaptation) that a particular movement of the visual scene will be correlated with specific vestibular inputs, then the absence of these vestibular signals on a subsequent presentation of the same visual stimulus will evoke the symptoms of motion sickness. Why these reactions should take the particular form that they do, and what functional purpose they serve, is not understood; but there seems little doubt that unfulfilled 'vestibular expectations' are the primary cause.

Two factors that clearly did influence susceptibility were sex and previous car travel experience. That women were more disturbed by the simulator than men was not surprising considering that women are known to succumb more readily to most forms of motion sickness. But this finding does not bring us any nearer to understanding why these sex differences exist. Are women simply more liable to present the nausea syndrome than men? Is it linked in some way to their hormonal make-up? Or do the differences in susceptibility originate from the spatial integrating centre itself? These important questions remain unanswered.

Equally predictable, though perhaps less difficult to understand, is that susceptibility to simulator sickness, both for men and women, was positively related to the amount of previous experience with car travel, both as passengers and as drivers. This general relationship can be explained, as stated earlier, by suggesting that, in experienced travellers, the stored stimulus traces are more firmly consolidated in the 'spatial memory store'. However, on the basis of this argument it would be expected that driver experience should count for more than passenger experience because, like the subject in the present experiment, the car driver is forced to maintain the 'eyes-forward' mode of looking; whereas the passenger is not constrained in quite the same way, i.e. some of the time he will be looking out at the road ahead, but at other times he will be glancing out of the side windows or within the car. By comparison, therefore, the car driver has a much better opportunity of building up stimulus traces appropriate to the simulator situation, and so should be more disturbed by the rearranged sensory inputs in the simulator. Do the present findings support these predictions? Examination of the correlation coefficients displayed in Table 4 shows that, for both men and women, the relationships between the two measures of simulator sickness and driver experience were better than those with passenger experience; although, except in one instance, these were also positive. The small samples used in this experiment, and the relatively limited range of driving experience of the subjects, mean that a great deal of reliance cannot be placed on these particular data; but they do conform with the

arguments set out above. If such a finding were replicated using larger numbers and a wider range of driving experience, it would provide very strong support for the 'unfulfilled expectation' aspect of the sensory rearrangement theory.

Two other findings are worthy of brief comment. First, the rather curious fact that those subjects who were most disturbed by the simulator ride tended to rate the device as being less realistic than those who were relatively unaffected. Were they 'punishing' the simulator (or the investigators) for making them sick? Or was it that they were not normally car sick so that the presence of unfamiliar reactions like dizziness and nausea rendered the simulator less like the real thing? It is hard to say. But whatever the cause, it casts some doubt on the validity of the realism ratings per se.

Secondly, it is clear from the coefficients displayed in Table 6 that the MSQ (a personal history inventory) would not have been particularly successful in predicting the degree of simulator sickness. However, the relationships were much higher for men than women; and for both sexes, they were higher with the Symptom Score than the Well-Being Ratings. Considering the very imprecise nature of the measures, correlations of this order are perhaps the best that can be expected. At best, the MSQ is a very blunt instrument, and its greatest usefulness is in screening out highly susceptible individuals. It is known to be far less effective in discriminating between individuals of moderate susceptibility (Reason, 1968).

Finally, what are the practical implications of these findings? So long as fixed-base simulators incorporating dynamic visual displays continue to be used extensively for training, information that throws some light on the origins of the distressing and time-wasting condition of 'simulator sickness' can always be put to good use. But, perhaps more importantly, these results reveal a little more of the general mechanisms involved in the production of the motion sickness phenomenon, and it is only from a clear understanding of these underlying processes that effective preventive measures can be formulated.

PRINCIPAL FINDINGS

1. Some decline in well-being was reported by 28 of the 31 unselected subjects passively exposed to a 10-minute ride in a closed-loop car simulator.
2. Women were significantly more susceptible than men.
3. Previous car experience, both as passenger and driver, correlated positively with the degree of disturbance produced by the simulated ride. However, there was some evidence to suggest that driver experience exerted a more powerful influence upon susceptibility to simulator sickness.
4. 'Blinkers' which excluded the static features of the surroundings appeared to have no effect upon susceptibility.

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TAEG Report No. 63

THE EFFECTS OF SIMULATOR LANDING PRACTICE AND THE
CONTRIBUTION OF MOTION SIMULATION TO P-3 PILOT TRAINING

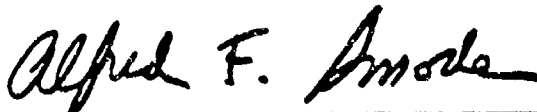
Leonard E. Ryan
Paul G. Scott
Robert F. Browning

Training Analysis and Evaluation Group

September 1978

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ALFRED F. SMODE, Ph.D., Director,
Training Analysis and Evaluation Group



WORTH SCANLAND, Ph.D.
Assistant Chief of Staff
Research and Program Development
Chief of Naval Education and Training

The TER⁷ value indicates the aircraft landing trials saved for every landing trial in the simulator.

TER examples 1 and 2 show that the value of one landing trial in the simulator ranges from 1.18 to .79 landing trials in the P-3 aircraft. These different TER values are most likely the result of a combination of the variables listed below:

1. C-1 training was conducted using a block syllabus; C-2 used an integrated syllabus.
2. A more stringent criterion was imposed on C-2.
3. C-2 had several poor performers who increased the group average.

Despite the differences, however, the data show that transfer of landing practice in the simulator is high.

A comparison of the landing trials of the C-3 and E groups (TER example 3 above) indicates the value of landing pattern airwork. Under training conditions which did not permit flare or touchdown practice in the simulator, a training benefit did occur. In this example one landing trial in the simulator saved .57 landing trials in the aircraft.

The study results indicate that simulator practice in landing pattern airwork and the final phase of landing transfers positively to the aircraft. This transfer occurs even though VP-30 instructor and student pilots universally agreed that the 2F87F does not "handle" like the aircraft during the final phase of landing. The question of greater training effectiveness as a function of improved fidelity was not addressed in this study. It is a topic worthy of further investigation.

EFFECT OF LIMITED FIELD OF VIEW ON LANDING PERFORMANCE. A major concern of pilots is the limited field of view of the rigid model board. They suspect this reduces the training value of landing practice in the simulator since visual cues in the periphery are absent. However, the belief that a wide angle visual capability is required for effective training is not supported by the data in the present study nor by a number of other studies. For example, Armstrong⁸ employed a Varsity aircraft configured such that the field of view of the pilot was limited to 50°. Armstrong reported that landing performance in the aircraft was almost unaffected by loss of peripheral vision, even

⁷ The reader is cautioned not to interpret the TER as a constant; it is not necessarily linear with increased training, and it varies as a function of previous practice.

⁸ B. D. Armstrong. Flight Trials to Discover Whether Peripheral Vision is Needed for Landing. Royal Aircraft Establishment Technical Report 70205. 1970. Ministry of Aviation Supply, Farnborough Hants.

under poor visibility conditions. Roscoe⁹ configured a Cessna T-50 such that the windshield of the airplane was replaced by an aluminum sheet through which a periscope was installed. An image was projected from the periscope to an 8 inch screen with a field of view from the pilot's eye of a maximum of 30 degrees horizontally and vertically. Roscoe found that both experienced and inexperienced pilots could make safe takeoffs and landings by periscope using a variety of techniques and under a variety of conditions. Based on these aircraft data and the data from this study, it is reasonable to conclude that high fidelity simulators do not require "wide" angle visual systems to provide effective landing training.

SUMMARY OF FINDINGS

The findings of this study are summarized below:

1. The E group who received no flare or touchdown practice during simulator landing trials required significantly more landing trials in the aircraft to attain proficiency than did the C-1 and C-2 groups who received full landing training in the simulator (37, 17, and 28 landings, respectively).
2. The group that received no simulator training, C-3 (the fly only group), required significantly more landing trials in the aircraft to attain proficiency than did the E group. Practicing landing pattern airwork in the simulator contributes positively to landing performance in the P-3 aircraft.
3. The C-1 group required fewer total simulator and aircraft landings to attain proficiency than did the aircraft-only trained group (C-3). This suggests that the task learned in the simulator transfers significantly to subsequent aircraft landing performance.
4. The TERs computed from the landing data show that landing practice in the simulator provides a training benefit under the three different training conditions examined.

For ✓

⁹ S. N. Roscoe, S. G. Hasler, and D. G. Dougherty. "Flight by Periscope: Making Takeoffs and Landings; The Influence of Image Magnification, Practice, and Various Conditions of Flight." Human Factors. 8. 1. February 1966. pp. 13-40.

SECTION IV

CONFLICT OF VISUAL AND MOTION CUES

The addition of visual simulation to high fidelity flight simulators has produced instances of physiological discomfort during and immediately after training in the device. This has presumably resulted from cue conflict when visual motion cues are present in the absence of cockpit motion cues. This is particularly so with wide-angle visual systems. During the series of TAEG studies evaluating the 2F87F simulator, several VP-30 instructors reported nausea and general disorientation when the visual system was operative while the cockpit motion system was off. Consequently, the issue of motion sickness relating to simulator training was examined as a part of the second study in this report. *af/*

QUESTIONNAIRE ASSESSMENT

To assess the prevalence of motion sickness with the cockpit motion system off and the visual system on, a motion sickness questionnaire (MSQ) used by the Naval Aerospace Medical Research Laboratory (NAMRL) was submitted to instructor pilots and pilot trainees. This questionnaire is reproduced in appendix A.¹⁰

The questionnaire was administered to students and instructors of classes 7803 and 7805. Class 7803 received simulator training without cockpit motion; class 7805 received simulator training with cockpit motion.

The data from these two groups were compared with published data on student Naval flight officers¹¹ and with data on a group of college males.¹² Comparisons among these groups are shown in tables 8, 9, and 10.

The data in table 8 are compiled from sections A and B of the motion sickness questionnaire. Appendix B provides the scoring procedures used for sections A and B of the MSQ.

¹⁰ The MSQ was modified for this study by Dr. F. E. Guedry of NAMRL. In addition, Dr. F. E. Guedry and Dr. J. M. Lentz conducted a computer analysis of the MSQ data collected during this study.

¹¹ J. M. Lentz, G. L. Holtzman, W. C. Hixon, and F. E. Guedry, Jr. Normative Data for Two Short Tests of Motion Reactivity. NAMRL-1243. 1977. Naval Aerospace Medical Research Laboratory, Pensacola, FL.

¹² J. T. Reason. An Investigation of Some Factors Contributing to Individual Variation in Motion Sickness Susceptibility. FPRC Report 1277. 1968. Ministry of Defense (Air Force Dept), London.

While there are statistical differences between the C and E groups, the practical differences are small. Simulator training time was the same for all students. For both groups, the average was about 12 hours per student as first pilot. A comparison of the C and E groups' average trials to proficiency for each task shows the largest differences to occur in Aborts, Holding, TACAN/VOR, and Normal Landings. Of these, Aborts and Holding appear to have the only true differences. TACAN/VOR and Normal Landings trials for the C group would be essentially the same as for the E group if all the C students had been trained to proficiency.

Based on these data, it appears that the lack of simulator cockpit motion may have a slight adverse effect on training in Three and Four Engine Aborts. The differences in the Holding task are difficult to explain particularly in terms of motion as a training variable.

EFFECTS OF NO-MOTION SIMULATOR TRAINING ON SUBSEQUENT AIRCRAFT PERFORMANCE. The effect of training in the simulator without cockpit motion on later student performance was examined. In the initial planning only those tasks were selected in which performance presumably would be affected by the variables of motion. The following analysis considers only those tasks. An analysis of variance (F test) with repeated measures was used. The measure employed was Aircraft Trials to Proficiency for the following tasks:

1. Abort Four Engine
2. Abort Three Engine
3. Instrument Tasks
 - a. Holding
 - b. Non-Prec App TACAN
 - c. VOR
 - d. NDB
 - e. LOC
 - f. Prec App GCA
 - g. ILS
 - h. Inst Procedures
4. Landings
 - a. Normal Landings
 - b. Approach Flap Landings
 - c. Three-Engine Landings
5. Engine Failure After Refusal

As shown in table 7, no significant differences obtained between training methods ($F=3.21$), and no significant interaction effect occurred between training method and task ($F=.91$). Trials to Proficiency were affected more by variance of students within groups than by training method. The only statistically significant finding was that certain tasks require more aircraft training trials than do others ($F=201.43$). This, however, is obvious.

TABLE 8. DATA COMPILED FROM SECTIONS A AND B OF THE MOTION SICKNESS QUESTIONNAIRE (RESULTS RELATE TO HISTORY OF MOTION SICKNESS)

	Class 7803	Class 7805	NFO Group	College Group
Number of Students	26	21	552	150
Mean Motion Sickness Susceptibility Score	20.80	12.80	15.99	28.00
Standard Deviation	17.10	15.80	18.78	20.00

Table 8 shows the no-motion group (Class 7803) to be average in terms of motion sickness susceptibility as determined by MSQ methods. The scores for this group indicate less susceptibility than those of college males but more susceptibility than those of the NFO and class 7805 groups. The mean of the no-motion group was increased slightly by one student who had a score of 73.7 (highly susceptible to motion sickness).

Table 9 presents data compiled from section C of the questionnaire. For ease in interpretation, each question is stated followed by the appropriate data from classes 7803 and 7805. Question 5 also includes published data of Lentz and Collins for comparison with the VP-30 data.¹³

Responses to questions 2 and 3 suggest that the no-motion group is about average for military aviation in that the percent of individuals indicating some degree of airsickness under provocative flight conditions is average to above average. This finding is consistent with previous studies. Question 4 indicates about 10 percent of the group experience dizziness episodes in everyday life. Again, this is average or slightly above average for military aviators.

Question 5, percent taking antmotion sickness medication, is average compared with a college group. Considering the extensive exposure to motion of class 7803, this percentage is below expectations. However, the percentage for class 7805 is even lower.

Questions 6 and 7 are based upon items used by Hutchins and Kennedy.¹⁴ The items are regarded as good predictors of airsickness. Their report, however, does not give percent of individuals replying in each answer category. A common sense look at the responses from classes 7803 and 7805 suggests that some students regard themselves as "poor risks" in motion sickness studies. Several individuals admitted experiencing sickness feelings when viewing

¹³ J. M. Lentz and W. E. Collins. "Motion Sickness Susceptibility and Related Behavioral Characteristics in Men and Women." Aviation Space Environmental Medicine. 48, 4, pp. 316-322, 1977.

¹⁴ C. W. Hutchins and R. S. Kennedy. "Relationship Between Past History of Motion Sickness and Attrition from Flight Training." Aerospace Medicine. 36, pp. 984-987, 1965.

wide-screen movies involving external views from within moving vehicles (see question 8). Overall, both groups seem about average for pilots in regard to susceptibility to motion sickness. Sections A, B, and C indicate that class 7803 contains enough individuals with some history of motion sickness to serve as a reasonable test group for testing the prevalence of motion sickness with the cockpit motion system off and the visual system operating.

Table 10 presents data compiled from section D of the motion sickness questionnaire. Table 10, part A, presents (1) grouped responses of class 7803 for the six questions of part A, (2) the scoring procedure for part A, and (3) comparisons of motion sickness symptoms for class 7803, class 7805, and two groups of student Naval flight officers from a study by Lentz, et al.¹⁶ Lentz collected normative data for these Naval flight officers on two tests of motion reactivity. These two tests were the brief vestibular disorientation test (BVDT) and the visual vestibular interaction test (VVIT).

Section D, part A, indicates that the simulator exposure produced little evidence of motion sickness either during or after simulator training. Most of the affirmative answers were in reference to tiredness or drowsiness. This may be a sign of motion sickness, but it may also be attributable to (1) prolonged simulator sessions or (2) time of day of the session. Of the symptoms that could be related to motion or the lack of it, three students reported headache and five reported mild unsteadiness.

The mean of the no-motion group is considerably lower than the mean of the BVDT and VVIT comparison groups who were exposed to "provocative stimulation." Thus, the no-motion students and instructors rated their 4-hour simulator exposure as less physiologically disturbing than the comparison groups rated their 10-minute exposure to the VVIT or their 6-minute exposure to the LVDT.

Section D, part B, which asked each individual to give his opinion of the simulator, may be the best set of questions in the questionnaire because they directly address the point of interest. If the responses from section B are converted to a four point rating scale where 1 = Not At All, 2 = Somewhat, 3 = Moderately, 4 = Very Much So, the mean for question B1 for class 7803 is 2.96 closest to "Moderately." Question B1 for class 7805 is 3.7 closest to "Very Much So." For Question B2, the mean for class 7803 was 1.77 closest to "Somewhat." The mean for class 7805 was 1.14 closest to "Not At All." For question B3 the mean for class 7803 was 3.2 closest to "Moderately." Class 7805 was not scored on question B3 since they did not fly the simulator without motion.

Based on student and instructor responses on the Pensacola Motion Sickness Questionnaire, simulator training with and without cockpit motion produced little evidence of motion sickness either during or after simulator flights. From the present results, it appears that the students and instructors both strongly favor having the motion cues available.

¹⁶ Lentz, Holtzman, Hixon, and Guedry, op. cit.

Sinacori, J. B. V/STOL ground-based simulation techniques
(USAAVLABS Technical Report 67-55). Hawthorne, CA: Norair Div.,
Northrop Corp., November 1967.

USAAVLABS TECHNICAL REPORT 67-55

V/STOL GROUND-BASED SIMULATION TECHNIQUES

By

J. B. Sinacori

November 1967

**U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA**

**CONTRACT DA 44-177-AMC-462(T)
NORTHROP CORPORATION
NOPAIR DIVISION
HAWTHORNE, CALIFORNIA**

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SINACORI, J. B. V/STOL Ground-based Simulation Techniques. Prepared by Northrop Corp., Norair Division, Hawthorne, CA for U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, USAAVLABS Technical Report 67-55, Nov. 1967.

Summary: A study of various kinds of simulators has been made to determine their capability to produce data representative of visual flight. Four simulations of a jet-lift V/STOL aircraft were conducted using the same pilot. Control characteristics and airframe parameters were maintained constant (as closely as possible), and the same tasks were used by the pilot in each evaluation. The resulting data were compared with flight results from the same aircraft. The simulators used different displays, motion modes, and instrumentation, and the results are discussed in the light of the characteristics of each simulator.

The results show clearly that in order to produce quantitative data representative of flight results, the display must have a quality level compatible with the task being performed. Specifically, a precision hovering task requires a high resolution display, while a translation (or transition task) can be performed with a display of much less resolution. The display content is important, particularly for the precision hovering task where height holding is required. For flight simulation of large translational movements, cockpit motion did not appear to affect the results, however, for precision hover and small, quick position changes, cockpit motion appears to be important in that it assists the pilot in detecting small drift and improves his ability to control vehicle attitude. The absence of cockpit motion when using a point source visual display for the presentation of visual information can cause vertigo and loss of performance.

The study shows that valid V/STOL flight simulation can be accomplished and that quantitative and subjective data which closely compare with flight results can be obtained.

- f. Pilot vertigo was induced as the time duration of a particular flight increased. Vertigo was especially annoying to the pilot during attitude reversals or hovering. The pilot felt he could do better with cockpit motion cues.
- g. The pilot felt that he could not perceive small drift motions and therefore down-rated the controllability accordingly.
- h. Power spectral and probability density distributions of the pilot's stick inputs are presented in Figures 6 and 7. Note that they are lower than the flight values except during attempted hover where the energy at 0.6 Hz in the simulated flight is larger than flight.

Critique

- 1. The unacceptability of the attitude control is the result of the pilot's not being able to bring the vehicle to an acceptable hover either at high or at low altitude. At high altitude, hover is difficult anyway; but at low altitude, the realism of the display was destroyed by the excitation of the transparencies' natural frequencies and the loss of resolution. The large relative position thresholds which exist at this scale also prevent an acceptable hover. If a hover cannot be achieved, then a lateral maneuver is not possible.
- 2. The control is acceptable for large translations away from the ground because the errors generated during attempted hover are not serious when applied to a large translation maneuver such as translating down the runway at an altitude of 100 feet. This is because the longitudinal plane assumes importance during the maneuver and the lateral excursions resulting from poor roll control are small compared to the large longitudinal motion. In other words, sideslip angles are maintained within acceptable limits.
- 3. The reduced pilot activity (see Table I) is caused by the inability of the pilot to perceive small motions, thereby causing him to adapt a "loose" control technique. In other words, he sees little and therefore does little.
- 4. Pilot vertigo may be caused by the conflict between the sometimes "fair" visual cues acquired during attempted hover and the highly trained kinesthetic sensations which are expected but not felt because the cockpit is fixed. Inadvertent pilot head motions were observed frequently.

3. The power spectral density of the pilot's lateral stick deflection verifies this point, as the attitude closure was being effected at frequencies of 1.0 Hz. The closures for flight occur at frequencies of 0.5 Hz, while the various other simulators' closures are between these values but closer to the lower one.

GENERAL CRITIQUE

Effect of Motion

It has been observed that overcontrol tendencies exist with the fixed-base simulators, while for all other quantities constant, this does not occur in the moving-base simulators or flight. The visual display frequency response of the fixed-base simulators is sufficiently high that this is not a factor in the overcontrol problem (see Appendix I). The onset of vertigo for the fixed-base simulators using the point light source type of display is established. The indications are, therefore, that significant pilot lead can be generated through the rotary motion cues. This is illustrated in Figure 16, which contains several root loci of pilot attitude closures. A pilot model consisting of lead and a time delay represented by a first-order Pade' approximation (reference 4) is included. Note that varying pilot gain can produce closed loop roots which may vary considerably in damping ratio at nearly the same frequency and pilot gain. The observations from the fixed-base simulation indicate that closed loop roots exist at frequencies of 3.5 radians per second with a damping ratio of 0.1 to 0.3. Such a closure would be represented by the dark crosses on Figure 16. The root locus shows, however, that the complex roots may be moved to the left if the pilot lead time constant T_L is increased to 0.4 second at constant pilot gain. The resulting damping ratio is then 0.5. This is approximately what is observed in flight. Compare the time histories of Figures 11, 15, and 17. The same absence of motion which results in decreased pilot lead could cause the conflict between the visual and kinesthetic cues which can cause vertigo (reference 5). Note that in all the simulators with motion, no overcontrol or vertigo tendencies have existed.

Figure 18 serves to illustrate the effect of introducing another closure. In this figure, the effective closed loop transfer function of the pilot-attitude controller is combined with the additional airframe transfer function relating side position and bank angle. Pilot attitude gain $K_{p\phi}$

and lead time constant are fixed, and the locus is plotted for various values of the linear pilot gain K_{p_y} .

Closed loop roots are shown for a particular pilot linear gain. Note that the position closure is lightly damped and of low frequency. This root location may be improved if the attitude closure roots were more heavily damped.

An examination of a power spectral density distribution for the lateral stick (Figures 3, 4, 6, 7, 9, 10, 13, and 14) shows dominant resonances at frequencies of 0.1 to 0.3 Hz and 0.5 to 1.0 Hz which correspond to the root locus just described. A comparison of power spectral density from flight or a moving-base simulator with those from a fixed-based simulator shows that a more dominant peak occurs at frequencies of 0.5 Hz for the fixed-base simulators, verifying that the attitude closure is lightly damped. It is probable also that cues working on the involuntary aspects of the perceptive/reactive system can be used by a highly skilled VTOL pilot. The latency time for the detection of linear accelerations is below the period of the position loop roots. This suggests that a highly skilled pilot could use linear acceleration cues supplied by his vestibular system. For the VTOL aircraft near hover, a linear acceleration is very nearly equal to attitude change times the acceleration of gravity. Therefore, this cue may be used as a sensitive attitude cue.

Effect of Display

It has been shown how the display can cause position holding performance to decrease. An examination of the power spectral density distribution of a simulator with a poor display reveals that the levels are generally lower than in flight. [This points to the hypothesis that a correct attitude closure is not possible unless sufficient position cues exist. This is because, without correct position information, it is not necessary to control attitude accurately and the "drifting" kind of performance is observed. The position cues, therefore, are important both in content and in dynamics.] They not only must provide the pilot with excellent information regarding his position and attitude in space, but also must provide him with the correct derivatives of his spatial coordinates. This means that the thresholds must be considerably less than the expected R.M.S. levels of these coordinates and below the pilot's visual threshold.

Nearby vertical towers with markings enhance a pilot's ability to perceive vertical motion. Familiar objects and known grid lines also help. The three-dimensional aspect of the point light type of visual display not only serves to give the pilot more information due to the wide field, but also allows him to scan for the most rapidly changing coordinate. Pilot scan rate was found to be high for the visual hovering task. Target fixation during precision hovering attempts often led to degraded performance which could be restored by briefly scanning once more.

Overcontrol tendencies in roll and overshoot in lateral position during maneuvering were observed. Inadvertent head motions were also observed. The vertigo tendency was nearly suppressed by both pilots. This was accomplished by introducing several factors:

1. The wearing of eyeshades which prevented the direct light from the transparency from entering the pilot's eyes and which also shut out the extraneous surface reflections of the transparency.
2. The adoption of a procedure where large simulator visual motion such as that occurring during startup and shutdown was not observed by the pilot simply by instructing him to close his eyes during those times.
3. Frequent rests.
4. The frequent scanning by the pilots of the total display and the avoidance of staring at a particular point during a precision hover or maneuver.
5. Pilot motivation.

Control Utilization

Control moment utilization was studied to provide additional data on which to base conclusions. Also, this parameter is of fundamental importance for designers of V/STOL vehicles. It can reveal information regarding pilot control inputs, since it represents the final output of essentially a filter which receives the pilot control motions.

Since the X-14A vehicle is nearly neutral, it has nearly zero rotary damping on all axes, and the rolling moment of the reaction control system divided by the roll moment of inertia $\left(\frac{L_{RC}}{I_X}\right)$ is nearly equal to the rolling acceleration \dot{p} . The error is small and therefore these quantities are used interchangeably throughout this section in units of acceleration, radians per second squared.

Table I contains the measured R. M. S. values of \dot{p} for all simulators and flight test. Note that the ratios of the R. M. S. values of \dot{p} to δ_{SR} during hover are nearly constant. However, these ratios for Simulator D (all motion) and flight test are different from the ratios for all other simulations. The results clearly show that the measured ratio of

U. S. Navy Message from COMPATWINGSLANT, Brunswick, ME, to CNO,
Washington, DC. 2F87(F) SER NO 5 FE and co-pilot display.
April 1980.

ROUTINE

R 031859Z APR 80

FM COMPATWINGSLANT BRUNSWICK ME

SUBJ: 2F87(F) SER NO 5 FE AND CO-PILOT DISPLAY

TO CNO WASHINGTON DC

INFO COMNAVAIRSYSCOM WASHINGTON DC — COMNAVAIRLANT NORFOLK VA
COMPATWINGSPAC MOFFETT FIELD CA COMPATWING FIVE BRUNSWICK ME
FASOTRAGRULANT DET BRUNSWICK ME

UNCLAS //NO1551//

CNO FOR OP 594, NAVAIR FOR AIR 4133, AIRLANT FOR 31181
SUBJ: 2F87(F) SER NO 5 FE AND CO-PILOT DISPLAY

A. PHONCON CNO CAPT FUNDERBURK/CPWL CAPT BISHOP OF 1 APR 80

1. DURING THE INSPECTION OF 2F87F #5 AT SINGER/LINK BINGHAMTON NEW YORK, CHANGES TO THE PROPOSED CGI VISUAL DISPLAY WERE NOTED, AND IDENTIFIED BY THE FLEET PROJECT TEAM AS POSSIBLE WEAKNESSES IN THE NEW TRAINING DEVICE. THESE DEFICIENCIES WHICH PRECLUDE MINIMALLY ACCEPTABLE FLEET TRAINING ARE: A LACK OF A VISUAL DISPLAY FOR THE FLIGHT ENGINEER AND A LACK OF A FORWARD QUARTER WINDOW DISPLAY FOR THE CO-PILOT.
2. IN VIEW OF THE DIFFERENT REQUIREMENTS OF THE FLEET COMPARED TO THE FRS AND THE ASSOCIATED IMPACT ON ISD AND PQS, THE FOLLOWING TRAINING NEEDS AND REQUIREMENTS ARE SUBMITTED:
 - A. TRAINING NEEDS:
 - (1) THE CO-PILOT'S SIDE WINDOW DISPLAY IS CONSIDERED ESSENTIAL FOR FLEET CO-PILOT TRAINING, PATRON PLANE COMMANDER RIGHT SEAT WORK, AND INSTRUCTOR PILOT TRAINING. THE PPC AND INSTRUCTOR RIGHT SEAT WORK ARE CONSIDERED THE MOST DIFFICULT TRAINING EVOLUTIONS THE P-3 COMMUNITY ENCOUNTERS.
 - (2) FROM A PSYCHO/PHYSIOLOGICAL STANDPOINT, THE FLIGHT ENGINEER'S CENTER WINDOW IS ESSENTIAL TO THE FLEET NEEDS TO ENHANCE THE TRAINING ENVIRONMENT FOR THE FLIGHT ENGINEER, AT THE PRESENT,

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U N C L A S S I F I E D U

2F87 1 THRU 4 HAVE A VISUAL DISPLAY FOR THE FLIGHT ENGINEER, SO NO DOCUMENTED CASES OF DEGRADED TRAINING OR MOTION SICKNESS EXISTS. DURING THE IN-PLANT INSPECTION AND INFORMAL USAGE ON-SITE, EVERY ENGINEER HAS COMMENTED ON THE FEELING OF DIS-ORIENTATION BEGINNING AS SOON AS ONE HALF HOUR AFTER TAKING HIS PLACE IN THE COCKPIT. THIS IS CRITICAL, IN THAT NORMAL TRAINING PERIODS WILL BE OF 3 TO 4 HOUR DURATION.

B. TRAINING REQUIREMENT:

- (1) IN THE PRESENT 2F87(F) TRAINERS, THE PILOT AND THE CO-PILOT HAVE A FORWARD DISPLAY ONLY. TAEG REPORTS GENERATED SINCE ACCEPTANCE OF THE FIRST 2F87(F) HAVE POINTED TO THE PROBLEM OF LACK OF PERIPHERAL VISION IN THE LANDING PHASE. THIS WAS IMPORTANT IN THE FRS DUE TO THEIR TRAINING OF REPLACEMENT PILOTS LANDING FROM THE LEFT SEAT. THE PROBLEM ENCOUNTERED IN THE FLEET IS THE TRAINING OF PILOTS FOR RIGHT SEAT LANDINGS AND RUNWAY WORK. THE REQUIREMENT TO ACCOMPLISH THIS TRAINING IS CONTAINED IN THE CURRENT PILOT PQS FOR PATROL PLANE SECOND PILOT, PATROL PLANE COMMANDER, AND INSTRUCTOR PILOT. THE ABILITY OR LACK OF ABILITY TO HANDLE THE AIRCRAFT FROM THE RIGHT SEAT HAS BEEN THE SUBJECT OF NUMEROUS SAFETY REPORTS SUBMITTED BY THE P3 COMMUNITY. THESE REPORTS COVER EVERYTHING FROM MINOR INCIDENTS TO MAJOR ACCIDENTS.
- (2) IN ORDER FOR THE P3 FLIGHT STATION TO WORK AS A TEAM, EACH MEMBER MUST BE ABLE TO GIVE HIS TOTAL ATTENTION TO THE TASK AT HAND. IN THE CASE OF THE FLIGHT ENGINEER, THIS MEANS TO MONITOR HIS INSTRUMENTS AND ASSIST THE PILOT IN ANY TASK THAT REQUIRES HIS ACTIONS. IT IS FELT THAT THE POTENTIAL DISORIENTATION CAUSED BY THE INCOMPLETE VISUAL DISPLAY, COMBINED WITH THE MOTION CHARACTERISTICS OF THE TRAINER, WILL PLACE UNNECESSARY DISTRACTIONS AND FATIGUE UPON THE FLIGHT ENGINEER, DEGRADING HIS CONTRIBUTION TO THE TEAM EFFORT, AS WELL AS HIS INDIVIDUAL TRAINING. WITH THE PRESENT AND FORECAST SHORTAGE OF FLIGHT ENGINEERS, IT IS IMPERATIVE THAT THE ENGINEERS WE DO HAVE ARE TRAINED TO THE MAXIMUM, IN THE BEST ENVIRONMENT POSSIBLE. IN 2F87(F) #5, THIS ENVIRONMENT DOES NOT EXIST. IN ORDER TO PLACE THE ENGINEER IN A REDUCED FATIGUE SITUATION IT IS ESSENTIAL THAT HE BE ALLOWED TO TRAIN IN A DEVICE THAT DOES NOT INCREASE THE CHANCES OF SPATIAL DISORIENTATION. THIS CAN BE ACCOMPLISHED BY ADDING A VISUAL DISPLAY AT THE FORWARD CENTER WINDOW.

C. CAPABILITIES REQUIRED:

- (1) FORWARD QUARTERS CO-PILOT WINDOW TO ALLOW THE CO-PILOT, PPC, IP TO GAIN THE PERIPHERAL VISION REQUIRED TO PROPERLY OPERATE THE AIRCRAFT IN THE LANDING PHASE.
- (2) CENTER FORWARD VISUAL DISPLAY - TO HELP RESOLVE THE INADEQUACIES DISCUSSED ABOVE.

D. QUANTITIES AND COST:

- (1) THESE FIGURES HAVE BEEN SUBMITTED BY THE CONTRACTOR, AND ARE HELD BY NAVAIRSYSCOM.

E. INITIAL TRAINING CAPABILITY:

(1) IT IS REQUESTED THAT THE IMPROVEMENTS BE MADE PRIOR TO FULL TIME FLEET USE WHICH IS PROPOSED TO BE NOVEMBER 1980.

F. ONGOING/RELATED EFFORTS: NONE

3. CPWL POC: CAPT BISHOP (CF) AV 476-2598

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U U N C L A S S I F I E D U

U. S. Navy Message from FITRON ONE TWO FOUR to RUWFVAA/
COMFITAEEWINGPAC, San Diego, CA. F-14 WST 2F 112/WAVS
aircrew readjustment. October 1981.

ROUTINE

* U N C L A S S I F I E D *

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RTTUZYUW RUWFSGG5090 2970032-UUUU-RUCLMFA.

ZNR UUUUU

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FM FITRON ONE TWO FOUR

TO RUWFVAA/COMFITAEEWINGPAC SAN DIEGO CA

INFO RUWFAAB/COMNAVIAIRPAC SAN DIEGO CA

RUCLMFA/NAVTRAEQUIPCEN ORLANDO FL

UNCLAS //NO3750//

SUBJ: F-14 WST 2F112/WAVS AIRCREW READJUSTMENT

A. COMFITAEEWINGPACNOTE 3750/3750 CH-1 OF 11 JUN 81/27 AUG 81

1. REF A PROMULGATES GUIDELINES FOR AIRCREW READJUSTMENT PERIODS AFTER USE OF F-14 WST 2F112/WAVS. F14 FLEET PROJECT TEAM (FPT) AND OTHER INPUTS WHICH RESULTED IN RESTRICTIONS IN REF A WERE BASED UPON LIMITED EXPERIENCE WITH 2F112/WAVS AND SEVERAL PRELIMINARY PHYSIOLOGICAL STUDIES CONCERNING FIXED-BASE, FULL VISUAL FLIGHT SIMULATORS. 2. INDIVIDUAL DEBRIEFS OF ALL FITAEEWINGPAC 2F112 USERS HAVE BEEN CONDUCTED ON THE WHOLE RANGE OF DEVICE FIDELITY, UTILIZATION, TRAINING USES, AND PHYSIOLOGICAL EFFECTS. BASED UPON COMMENTS OF A LARGE USER SAMPLE SPACE AND INFORMAL FPT LIAISON WITH AUTHORS OF STUDIES CITED ABOVE, RECOMMEND RESTRICTIONS REF A BE MODIFIED AS FOLLOWS:

(1) DISCUSSION: SOME AIRCREWS HAVE EXPERIENCED SENSORIMOTOR

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DIFFICULTIES AND SICKNESS AFTER "FLIGHT" IN THE 2F112/WAVS. SYMPTOMS CAN BE WIDE RANGING AND VARY SIGNIFICANTLY BETWEEN INDIVIDUALS. AVIATION PHYSIOLOGISTS AND NAVAL AEROSPACE MEDICAL RESEARCH PERSONNEL CLASSIFY THIS PHENOMENON AS REVERSE SENSORY CONFLICT. EFFECTS ARE MOST PREVALENT ON THE FIRST EXPOSURE TO THE VISUAL SYSTEM.

(2) ACTION: THE FOLLOWING GUIDELINES ARE SET FORTH:

(A) AFTER "FLYING" THE 2F112/WAVS FOR THE FIRST TIME, AN AIRCREWMAN WILL NOT FLY IN ACTUAL AIRCRAFT AS A CREWMEMBER FOR A PERIOD OF TWELVE (12) HOURS. THIS PERIOD SHOULD INCLUDE A GOOD NIGHT'S SLEEP.

(B) ON SUBSEQUENT "FLIGHTS" IN THE 2F112/WAVS, INDIVIDUAL AIRCREW JUDGEMENT SHALL BE EXERCISED PRIOR TO ACTUAL FLIGHT REGARDING ADEQUATE READJUSTMENT. A MINIMUM OF TWO (2) HOURS SHALL BE OBSERVED BETWEEN EXITING 2F112/WAVS AND ACTUAL FLIGHT.

(C) THE DEVICE WILL BE STARTED AND STOPPED (FROZEN) IN A WINGS-LEVEL, NOSE-ON - HORIZON (EARTH HORIZONTAL) ATTITUDE. IN ADDITION, THE VISUAL SYSTEM WILL BE SECURED AND WHITE DOME LIGHTS

ROUTINE

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WILL BE TURNED ON BEFORE CREWMEN EXIT THE COCKPITS.

(D) A MINIMUM OF TORSO HARNESS AND ANTI-G SUIT WILL BE

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WORN. FULL FLIGHT GEAR MAY BE WORN.

3. AT PRESENT, REF A RESTRICTS DEVICE UTILIZATION. USERS ARE
HESITANT TO LET AIRCREWMEN FLY THE DEVICE AND NOT BE ABLE TO
SCHEDULE THEM FOR FLIGHTS THAT NIGHT. HOWEVER, ABOVE RECOMMENDATIONS
ARE BASED UPON A CONSIDERED EVALUATION OF ACTUAL AIRCREW READJUST-
MENT REQUIRED FOR SAFETY. SUCH ACTION SHOULD INCIDENTALLY IMPROVE
DEVICE UTILIZATION.

BT

#5090

NNNN

Wenger, J. E. Motion sickness in the P-3C Fleet Readiness Trainer at Naval Air Station, Brunswick, ME (Memorandum NBDL:60:jah;6500). New Orleans, LA: Naval Biodynamics Laboratory, 14 January 1980.

From: Commanding Officer, Naval Biodynamics Laboratory
To: Commander, Naval Air Systems Command (AIR-413), Washington, DC 20361
Subj: Motion Sickness in the P-3C Fleet Readiness Trainer at Naval Air Station, Brunswick, Maine
Ref: (a) Phonecon between CDR Ashburn, Naval Air Systems Command (AIR-413) and CDR Kennedy, Naval Biodynamics Laboratory, (Code-60) of 4 Dec 1980
(b) COMPATWINGSILANT Brunswick, ME, MSG 031859Z APR 80 to CNO
(c) Phonecon between Dr. Robert Kellogg, ACM Simulator staff, Williams AFB and CDR Kennedy, Naval Biodynamics Laboratory (Code-60) of 1 Feb 1980
(d) DCIEM Technical Communication No. 80-C-44 Defence and Civil Institute of Environmental Medicine, Downsview, Ontario, Canada
(e) Naval Air Development Center Report No. NADC-77274-50, 30 Sept 1977
(f) Chapter by Conrad Kraft (pp. 363-385) in Psychology from Research to Practice Ed. by M. L. Pick, Jr., H. W. Leibowitz, J. E. Singer, A. Steinschneider, and H. W. Stevenson, Plenum Press: 1978

1. Reference (a) requested Naval Biodynamics Laboratory (NBDL) to investigate the P-3C Fleet Readiness Trainer (FRT) at Naval Air Station, Brunswick, Maine and to recommend ways to alleviate simulator sickness in that system. Simulator sickness in the Brunswick FRT is experienced by virtually all flight engineers but not by the pilots and copilots. Reference (b) initially called attention to this problem. In order to better assess the Brunswick FRT, CDR Kennedy, LCDR Carter, and Dr. Bittner, members of the NBDL staff, first visited the P-3C FRT at NAS Jacksonville, which is virtually identical to the one at Brunswick but has a model board visual display whereas the Brunswick FRT has computer generated imagery (CGI). The Jacksonville FRT does not produce appreciable motion sickness. They also witnessed a demonstration of an S-3 FRT at Cecil Field which has a version of CGI, but also produces negligible motion sickness.

2. The simulator sickness experienced by flight engineers in the Brunswick P-3C FRT is of classic form and resembles simulator sickness experienced in other training devices e.g., references (c) and (d). These flight engineers experience and react to the optically induced distortions and illusion which after a latent period of about 30 minutes give rise to the following effects: dizziness, yawning, burping, confusion and headache, salivation, stomach awareness, extreme unsteadiness, and nausea. Moving the head appears to aggravate the problem. Training missions are routinely aborted after flight times of only 40 minutes. The postural disequilibrium results in safety risks when exiting the trainer. Moreover, immediately after a training session flight engineers suffer spots before the eyes, headache and feelings of disorientation. There is the suggestion of longer range (hours) effects so that flying and driving may be contraindicated up to 48 hours.

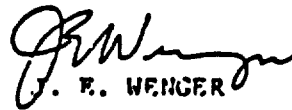
1. The cause(s) of these symptoms should be eliminated for the following reasons. The flight engineers are at risk when walking on the ladders at the exit of the simulator following training because of extreme unsteadiness induced by the simulator. The students become reluctant to take more training after this experience. Additionally, the symptoms of simulator sickness reduce the effectiveness of the flight engineers and hence jeopardize the flight crew in real flights that follow the training on the same day. Training is probably less effective because the flight engineers attend to their malaise rather than to the flight being simulated. Scheduling problems due to illness result in lost crew time on the simulator following aborts.

4. It is proposed the following FKT stimuli lead to the flight engineers' simulator sickness. The most obvious cause of the sickness is the CGI viewed off-axis. This conclusion was reached for the following reasons: (1) sickness occurs even without simulator motion at Brunswick; (2) sickness is not prevalent in an identical simulator without CGI (with or without motion) at Jacksonville, and (3) sickness is not experienced by the pilot and copilot who view the CGI on-axis. Off-axis viewing (the flight engineers' view) of the CGI includes the following characteristics. The scene is optically compressed inboard and expanded outboard. This kind of distortion of the visual scene is known to produce disorientation and nausea. Furthermore, only the flight engineer sees the outer edges of the two CGI's. The CGI edges appear to be outside of the windscreen (hence they seem far away), yet the edges seem to move in the opposite direction of any head movement (hence they seem to be nearby). This kind of perceptual conflict is also known to produce disorientation and nausea. Finally, during a turn the horizon appears from the flight engineer's seat to break and rise faster on the side with the elevated wing. A broken horizon is truly a distressing perception which can only exacerbate nausea and disorientation. Note that only the CGI in front of the pilot and copilot are involved in these nauseating perceptions. The CGI on the sides of the flight deck are veridical and appear reassuring for all the crew.

5. It may prove necessary to undertake an R&D program to attain a deeper understanding of simulator sickness and how it can be avoided. The following are recommended as "quick" and "intermediate" solutions to the immediate problem at Brunswick. a.) The first is to occlude the flight engineer's view of the pilot and copilot's CGI. This has been shown to reduce but not eliminate the simulator sickness according to reference (b). In our opinion, the same effect can be obtained with "Light Control Film" manufactured by the Industrial optics Division of the 3M Company (Product Information, (612) 733-5555). Other countermeasures may include minimizing head movement, recognition of early signs of motion sickness (burping, salivation, yawning, sweating), increased mental concentration by flight engineers on the task at hand, and use of the simulator in a fixed base mode for flight engineers with minimal flight hours. c.) The intermediate fix would be to install a third CGI in front of the flight engineer. This should not be visible to the pilot and copilot.

6. In part, it is the separateness of the displays which gives rise to the problems cited herein. The separate displays provide conflicting signals to the peripheral vision of flight engineers. Perhaps a television projection of CGI images on an approximately curved screen would combine the advantages of CGI (low maintenance cost, geographic versatility) and model-board visual simulations (a continuous wide-screen perspective), reference (c).

7. Two other shortcomings of the CGI (which are considered to be of minor importance in the present simulation) became apparent during the investigations and deserve comment. First, the visual CGI movement and the platform movement are initiated by the same electronic signal which is implemented immediately on the CGI display but is implemented with delay in the platform movement due to the dynamics of hydraulic systems. Hence the platform movement tends to lag the visual scene movement. This kind of stimulus lag is not present in the real P-3C so that trainees may be learning to expect inappropriate combinations of visual movement stimuli. This problem can be solved by using feedback from actual movement at the simulator to initiate movement of the CGI's. A second problem is that the CGI produces very definite cues that the images are only a few feet away, although the CGI are simulating objects thousands of feet away. These depth cues are due to binocular vision. This can be verified by viewing the CGI with one eye open and the other eye closed, then opening the closed eye and closing the initially opened one. When this is done the CGI appear to jump, as do all nearby objects. Objects that are really thousands of feet away do not jump. The effects of this misleading cue in the simulation are difficult to surmise, but the effect may be important when transition to actual flight is considered (reference (f)). Perhaps these two errors of simulation should be investigated further. It is the recommendation of NNDL staff members that first priority be given to solutions of the serious simulator sickness problem of flight engineers in the P-3C FRT at Brunswick. This is especially true because the Brunswick simulator is a prototype, so timely action will avoid the simulator sickness problem in other P-3C FRT's that are yet undelivered.


J. E. WENGER

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CHURCH (NED 3-C)
CO AIRDC

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SUGGESTIONS FOR FURTHER READING

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