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GUIDELINES FOR ALLEVIATION OF SIMULATOR SICKNESS SYMPTOMATOLOGY

R. S. Kennedy*
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M. G. Lilienthal**
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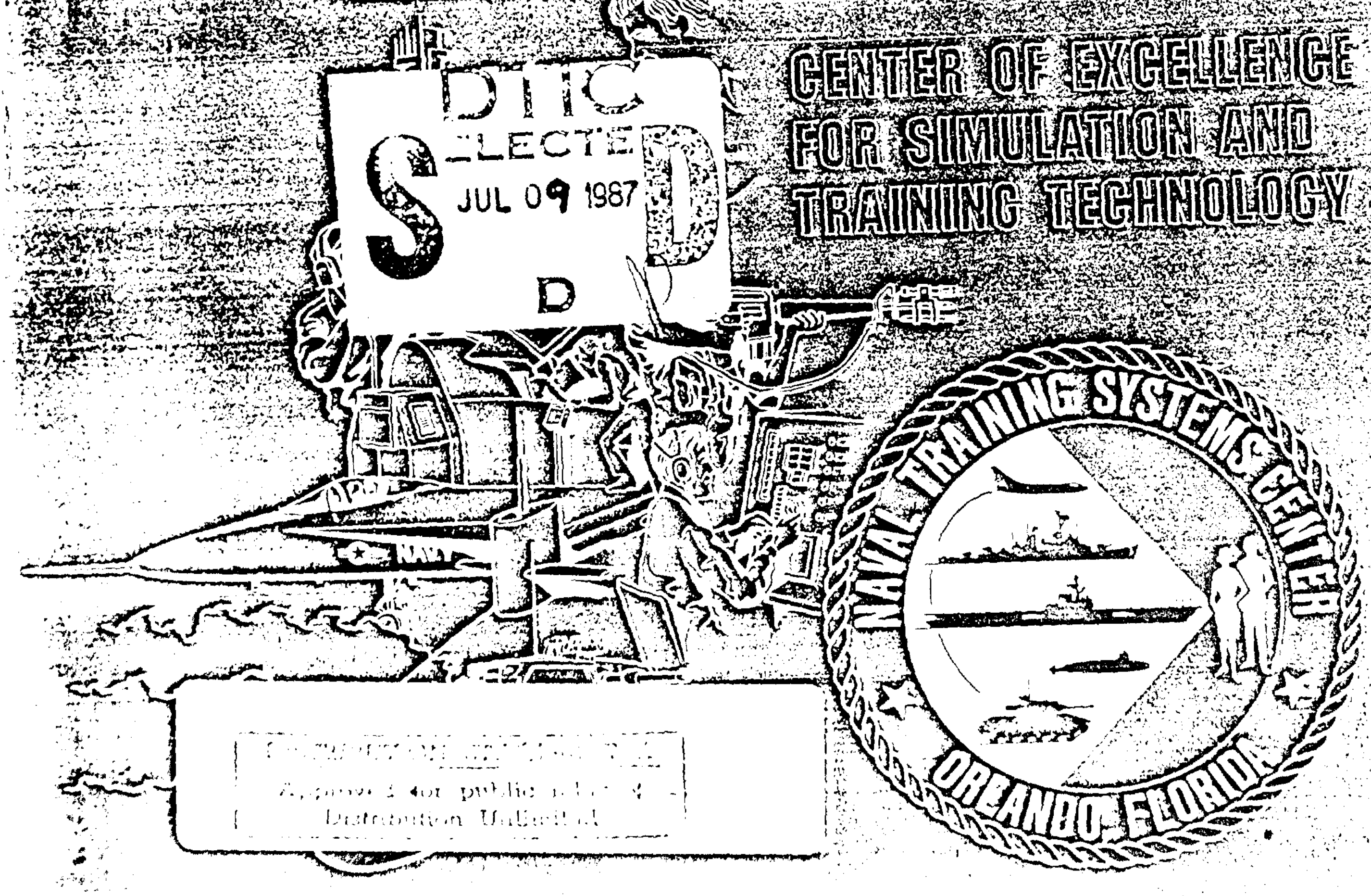

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Ground-based flight simulators train effectively and at a relatively low cost, but simulator sickness may compromise their utility. Within the U.S. Navy, simulator sickness is reported with increasing frequency. Instructors complain that such distress may interfere with simulator use and reduce the effectiveness of training. Operational effectiveness is compromised by flight restrictions subsequent to training in some simulators. Field studies conducted over the last two years at 10 flight simulator sites showed incidence rates ranged from 12%-60% for these simulators. A data base is being assembled to discover whether the incidence of symptoms is related to specific equipment features or syllabus demands that require a variety of motion characteristics (i.e., hover, air combat, jinking). Wide field of view, distortion, cue asynchrony, and very low frequency vibration also appear to be contributing factors. A cross-disciplinary biomedical engineering panel was convened to

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discuss the problem. The present paper describes the recommendations of this panel. Research literature related both to the findings of the data base survey and to the recommendations has been integrated in this report.

FOREWORD

Guidelines and recommendations contained in this report have been from work performed under a number of different projects, and represent contributions from many individuals whose inputs are gratefully acknowledged. Among the contracts whose products have impacted the document are:

N61339-81-C-0105, Work Order No. 0007

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SECTION I

INTRODUCTION

The use of ground-based flight trainers permits training at relatively low cost (Orlansky & String, 1977, 1979). Simulators are as much as 10-30 times more available than aircraft and, in some cases, can be fully amortized in 18 months. While less an issue today, they do not incur fuel costs. They permit practice of tasks such as emergency procedures which cannot be conducted safely, or well, in the aircraft. They provide special training options like playback, freeze, performance measurement, and more formal and immediate feedback in the form of reports and integrated scores.

During the last 10 years, the U.S. Navy has bought many simulators incorporating new technologies, including moving-base, multichannel computer-generated images, wide and very-wide fields of view, high resolution and textured visual scenes. and shaker g-seats. As more advanced systems have become operational, reports of simulator sickness have increased within the U.S. Navy (Kennedy, Merkle, & Lilienthal, 1985; Kennedy, Lilienthal, Dutton, & Ricard, 1984). Instructors have complained that the symptoms interfere with simulator usage and that subsequent flight activities have been limited in some commands (U.S. Navy Message 1980; 1981).

Simulator sickness resembles forms of motion sickness. Vomiting is the cardinal sign, while drowsiness, dizziness, and nausea are its chief symptoms (Kennedy & Graybiel, 1963a, b; Wiker, Kennedy, McCauley, & Pepper, 1979a, b). Less frequently reported, but often present, are postural changes, or ataxia, sometimes referred to as "leans" or "staggers" (Fregly, 1974; Fregly & Kennedy, 1965; Crosby & Kennedy, 1982). Other <u>signs</u> of motion sickness include changes in cardiovascular, respiratory, gastrointestinal, biochemical, and temperature regulation functions (cf., Colehour & Graybiel, 1966; Money, 1970; McClure & Fregly, 1972a, b). Other <u>symptoms</u> include general discomfort, apathy, dejection, headache, stomach awareness, disorientation, lack of appetite, desire for fresh air, weakness, fatigue, confusion and, occasionally, flashbacks and incapacitation. Symptoms which are particularly characteristic of simulator sickness include pallor, sweating, salivation, and eye strain. The visually related disturbances are more prevalent than the neurovegetative. Simulator sickness more resembles disturbances subjects experience when wearing reversing, displacing, or inverting lenses (Welch, 1978) and, but to a lesser extent, astronauts' experiences with the space adaptation syndrome (Homick, 1982; Parker, Reschke, Arrott, Homick, & Lichtenberg, 1985).

RATIONALE FOR A SIMULATION SICKNESS PROGRAM

There are several obvious disadvantages resulting from simulator sickness. If a simulator develops a reputation for producing sickness, aircrew lack of confidence in the training may promote disuse. Furthermore, it may be necessary to limit subsequent flight activities if simulator aftereffects are sufficiently disturbing. This, in turn, may limit overall operational effectiveness. Simulator aftereffects may even place the person directly at risk in other post-training activities (e.g., driving).

We reserve the term simulator sickness for those situations which are nauseogenic in simulators but not in aircraft. If a training device induces sickness when simulating events which also produce sickness aloft, we would not refer to this as simulator sickness. Even though such a simulation is representational, its training value must be narrowly limited. This implies that unless the sickness-evoking conditions have clear-cut training value (yielding high positive transfer), methods should be sought to minimize the sickness. It is probably stating the obvious to indicate that we know of no circumstance where sickness-evoking conditions have been shown to have high training value!

Less obviously, nausea has long been studied in animals as an aversive stimulus (Garcia, Rusinik, & Brett, 1977). Learning has been shown to play an important role in what foods an animal eats or, more to the point, does not eat. "Bait shyness" or "taste aversion" has been observed in rats, mice, cats, monkeys, ferrets, coyotes, fish and reptiles, as well as hamsters, slugs, and chickens (Thompson, 1980). These responses are even more resistant to extinction than most avoidance-learned responses. They are also noteworthy for being learned after long delays between presentation of the stimulus and the internal toxicosis (Revusky & Garcia, 1970). The role of nausea and internal toxicosis as aversive stimuli has also been studied at the human level, but only in relation to food intake. In motion sickness where, of course, it also occurs, surprisingly little attention has been paid to nausea as an aversive stimulus. It clearly influences ticket purchases on carnival devices (Irwin, 1976, 1977), and probably career choices (Jones, Levy, Gardner, Marcsh & Patterson, 1986), and could discourage recreational and other planned uses of space travel (cf. Christensen & Talbot, 1986).

This neglect is all the more surprising since nausea appears to be a consistent accompaniment of "troubleshooting" in the central nervous system occasioned by sensory conflict or perceptual disorganization (Kennedy & Frank, 1986). That is, when sensory information from different sources in the same or different modalities is not in accord with what is expected from perceptual learning or the "neural store" (Reason, 1969; 1978) troubleshooting begins and the subject feels sick. Given the principles of learning and memory, this sequence of events has the consequence that people may avoid doing whatever it was that led to the sensory conflict and subsequent nausea. For example, some pilots avoid using the visual system of a simulator and go on instruments as often as possible to avoid simulator sickness. Nausea as an aversive stimulus may merely assist the pilot to learn not to make responses that lead to either sensory conflict or toxicosis. The implications for skill acquisition, skill maintenance and transfer of training are clear-cut, i.e., nausea may act as both punisher and negative reinforcer in shaping behavior.

APPROACH TO THE PROBLEM

For these reasons, a program was initiated by the U.S. Navy to document, better understand and alleviate the problem of simulator sickness. First, the research literature was integrated and compiled to permit access and review (Casali & Wierwille, 1986a). A series of research efforts are documented in the form of technical reports sponsored through the Naval Training Systems

Center (Kennedy, Dutton, Ricard, & Frank, 1984; Kennedy, Frank, & McCauley, 1984; Kennedy, Lilienthal, Dutton, & Ricard, 1984; Kennedy & Frank, 1986; Kennedy, Merkle, & Lilienthal, 1985; Lilienthal & Merkle, 1986; Casali, 1986; and Casali & Wierwille, 1986a,b).

A conference was also sponsored by the Office of Naval Research which funded the National Research Council's Committee on Human Factors in the Commission on Behavioral and Social Sciences and Education. The committee brought experts from the three military services and the academic community together to identify the initial research requirements for simulator sickness. The conference recommendations (McCauley, 1984) were: (1) to formally survey the occurrence of sickness in the various training devices, (2) to determine what the actual incidence of symptoms is in each case, and (3) to determine whether any equipment features are correlated with disproportionate incidence.

Ten U.S. Navy flight simulators were visited and evaluated (Kennedy, Dutton, Ricard, & Frank, 1984). Preliminary analysis determined that the incidence ranged from 12% to 60% for these simulators. The data currently are being studied in an attempt to relate symptoms to specific equipment features and pilot trainee characteristics (Lilienthal, Redmond, Merkle, Kennedy, & Lane, 1986). For instance, in one simulator, visual system misalignment, distortion, cue asynchrony, and luminance changes (Palmer, 1985) were found which may be causal of simulator sickness. However, in the analyses of the simulator sickness data which have proceeded so far, no single factor has been uncovered which appears to cause illness in all simulators. Some findings have emerged and they are introduced in the report as they are relevant to particular guidelines. These relationships are the subject of a more comprehensive report (Lilienthal, Kennedy, Berbaum & Merkle, in preparation).

In the fall of 1985, a cross-disciplinary biomedical engineering panel was convened to propose immediate, interim solutions to simulator sickness until a research and development program could be undertaken to define improved simulation design criteria. The full transcript of that meeting is under preparation seperately (Kennedy, Berbaum, Dunlap, & Lilienthal, in preparation), and an abbreviated listing of the "guidelines" have been presented elsewhere (Kennedy, Berbaum, Dunlap, Merkle, & Lilienthal, 1986). A Field Manual for use at Navy simulator sites is included in Section IV. The manual is being introduced at several Navy sites to determine its effect on the prevention of sickness.

ORGANIZATION OF THIS REPORT

The purpose of the present report is to present these guidelines for consideration. In Section II the rationale for guidelines is presented, supported by the Pensacola biomedical panel consensus and by previous research findings. Section III presents proposal engineering modifications and research to present simulators and planned simulator acquisitions. This section is the first educated "guess" at engineering fixes to alleviate simulator sickness. Future planned research, both in the laboratory and at field sites, will attempt to more fully define engineering specifications for simulators.

Section IV collates the information from Section III into a field manual for simulator instructors, trainees, and operators. Section V concludes with a list of basic research topics that will help solve the simulator sickness and simulator aftereffects problem.

SECTION II

GUIDELINES FOR ALLEVIATING SIMULATOR SICKNESS

Human factors engineering derives its methodologies and approaches from experimental psychology and engineering. These disciplines adhere to a deterministic model in which human behavior is considered to be an output function of external stimuli or situations. In human engineering, the stimulus may be energy (e.g., lighting changes) or equipment variations (e.g., different cockpit configurations). It is often found that there are group specific responses to stimuli with some variability among individuals, but responses are nevertheless proportional, and monotonically related to, the stimulus. In such a model, one attempts to identify and specify the attributes of stimuli which govern responses. By so doing, we set out to assemble a set of lawful relationships for these stimuli. In the case of simulator sickness, no such lawful relationship between external stimulation and human response has been established. That is, the "exact" equipment and presentation of stimuli which induce simulator sickness have not been determined. In most simulators, less than 30% of the persons exposed become ill, some simulators seem to be nauseogenic for different reasons, and persons who might be considered to be ill do not all exhibit the same symptoms. Simulator sickness (as well as other forms of motion sickness) is polygenic and polysymptomatic. That is, simulator sickness has several causes and affects different people in different ways. This suggests that a different approach would be more appropriate for studying the problem.

The approach taken in clinical investigations in illness studies appear to be a good model to provide understanding and solutions to the simulator sickness problem. In this approach an illness is first identified, named, and the natural history of the disease is described. This includes its symptomatology, its time course, its incidence, the persons or groups that tend to be afflicted, and what happens if left untreated. We believe that simulator sickness is like other illnesses and that solutions to the problem are more likely to be found by following this model. For example, like most diseases, not everyone who comes in contact with the agent gets sick. Not everyone who gets sick will experience the same level of severity. Some people recover more rapidly than others. Some are immune, some allergic. On certain days, one's susceptibility may be higher or lower, sometimes for unknown reasons. Continued and repeated exposure usually results in increased resistance. An individual may be more resistant to some exposures but have low tolerance to others.

The symptomological patterns described above are typical in cases of simulator sickness. Thus far we have followed this model. We believe it suggests courses of action more useful in the study of simulator sickness than those indicated by the experimental model. For example, the intention of the simulator sickness survey was to observe the problem in its natural state (i.e., at operational simulator sites), and then to describe the symptoms as they occurred to determine the particular simulator equipment configurations, environmental conditions, simulation flight regimes, instructional approach, and individual differences that predict simulation sickness in which they occurred. Had we followed an experimental model, our approach would have been to try to induce illness in subjects and then to determine which conditions caused the problem. Because only about 30% of the individuals become ill under even the worst simulator conditions, such a study would make little use of less than one third of the data. Furthermore, at the time we began this work, we were not sufficiently knowledgeable about the characteristics of the problem to undertake a program of research based on the experimental approaches. The Navy survey has provided useful information about the incidence, time course, symptoms and other "natural history" aspects of the problem. Now, based on this survey data, and the subsequent consensus of the biomedical panel, we are in a position to formulate research and development plans to address more fundamental experimental questions which we hope to pursue in the near future. In the meantime, we propose the guidelines found in Section IV. We suggest that they be used to resolve the occurrence of the sickness and when symptoms of simulator sickness present themselves.

Factors that surfaced at the biomedical conference (Kennedy, Berbaum, Dunlap, & Lilienthal, in preparation), which are believed to influence simulator sickness AND can be modified in the near term, are grouped according to whether they entail: a) changes in simulator usage; or b) capitalizing on the awareness of the instructor and adaptability of the operator (see Section IV). Longer-term engineering design changes in simulators are also under consideration, but these require research and development into the aetiology of simulator sickness. Engineering research efforts may include: a) examining whether sustained motion cueing could be substituted for transient motions; b) monitoring the frequency x acceleration cumulative motion profiles of simulator flights to provide warnings of nauseogenic conditions; c) analytic decomposition and determination of the characteristics of the visual imagery necessary for pilot perceived self-motion (i.e., vection); d) division of visual motion into subject and object motion; e) elimination of cue asynchrony; f) avoidance of visual delays and lags. So far, there have been only a few preliminary laboratory studies into the effect of cue asynchrony and visual delays on the incidence of simulator sickness (Uliano, Kennedy, & Lambert, 1986; Frank & Casali, 1986).

The "Guidelines" are listed under major categorical headings and stated in the form of rules. Rationale for each item are provided, in some cases including verbatim comments from the panel member from the Pensacola conference who best described the rule. These guidelines are being field tested via lecture and other training media (Section IV) at Navy simulator sites where incidence is high.

General Rules to Follow

o Pilots should be become aware of the time course of the symptomatology of simulator sickness.

Mild symptoms at first may not have sufficiently pronounced feedback to be noticed unless one is poised to appreciate those symptoms for what they are. Less obvious manifestations (signs) are pallor, sweating, salivation, drowsiness, and postural changes. Other symptoms include general discomfort, apathy, dejection, headache, stomach awareness, disorientation, lack of appetite, desire for fresh air, weakness, fatigue, confusion, decreased spontaneity, carelessness and incoordination, particularly in manual control. Table 1 lists the different categories of symptoms (Kennedy, Dutton, Ricard, & Frank, 1984). On those occasions, one can avoid the subsequent experience of

TABLE 1. MODIFIED DIAGNOSTIC CATEGORIZATION TIME SHEET

PATHOGNOMONIC SYMPTOM

Vomit

MAJOR SYMPTOMS

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

MINOR SYMPTOMS

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

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

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

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

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

"OTHER" SYMPTOMS

Character facies
Increased yawning
Stomach awareness
Anorexia
Burping
Bowel movement desire
Headache
Dizziness
Aerophagia
Vertigo
General fatigue

heavy symptoms by flying straight and level or terminating exposures early. If an operator in a simulator is experiencing difficulties and he is not otherwise actually engaged as a crewmember in the conduct of the flight, he should request nonparticipation thereafter, or alternatively, request control of the aircraft, change seats, etc. Anyone not involved directly in the scenario of the simulator should not remain within the simulator.

o Persons who are new to the simulator, regardless of background, and persons with extensive flight time but little simulator time are at risk.

After long layoffs from simulator flying due to leave, temporary duty, aircraft assignment, or other reasons, the reintroduction to simulator flying should be taken gingerly and operators should consider themselves naive operators of the simulators.

"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, but group functions are manufactured out of individual differences. This averaging is performed in order to obtain general functions. However, even in a careful experiment, individual differences are present. While it is not suggested that the inertial properties of simulators need to be tailored for individuals, it should 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 conflict by others less sensitive with particular constellations of cues that occur during aircraft maneuvers.

The overwhelming evidence for individual differences in response to stimulus intensity suggests that simulator visual and inertial inputs are not phenomenally of the same intensity across all people (Benson & 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 would be furthered by better definition of the frequency response of visual and inertial presentation thresholds for 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, & Young, 1980), simulator sickness (Barrett & Thornton, 1968), perception of velocities and accelerations (Puig, 1970), and exposure history as measured by a motion sickness questionnaire (Reason & 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 the causes of simulator sickness. and also to provide a basis for constructing individual simulator regimens for susceptible persons.

The simulator sickness survey (Lilienthal, Kennedy, Berbaum & Merkle, in preparation) revealed that some individuals rapidly experienced symptoms and others were repeatedly immune. Data examined thus far from the survey indicate that perhaps as much as 80% of the simulator sickness problem may reside in perhaps 20% of the population. This is not to suggest that the solution is to be found in personnel selection. Rather, it is possible that a particular population may be at greater risk for this problem and one of the simpler remediations in the near term would be to have those persons who have a high likelihood of occurrence receive special treatments to alleviate the problem Navy-wide through training and adaptation, as opposed to engineering changes.

The best theory of motion sickness resembles the template matching model of Reason (1978), Oman (1980), and others who posit a cue conflict theory. In this approach, perceptions ordinarily are ordered and are generally in accord with each other. 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 may take place following certain rules providing certain conditions are met. In general, the organism samples over time or past history (neural store) to determine whether phenomena 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).

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 (Fregly, 1974). Data are available to compare ataxia performances from blood alcohol levels and simulator exposure (Fregly, 1974; Crosby & Kennedy, 1982). Because both postural equilibrium and manual control are closed-loop control systems under voluntary control in the cerebral cortex, and involuntary (motor) control in the cerebellum, it is reasonable to hypothesize that if posture is disrupted by exposure to a simulator, so too will be 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 ACMS -- are that even brief exposures (e.g., less than one hour in the simulator) result in long-term fatigue effects.

Drowsiness is reported for nearly all simulators that induce 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 problems associated with motion sickness and, possbily, simulator sickness too. Ryan, Scott, and Browning (1978) found evidence of drowsiness after simulator exposures. It is well known that the pontine reticular formation receives some control from the vestibular nuclei (Yules, Krebs, & Gault, 1966). Moreover, one paper (Allen, Oswald, Lewis, & Tagney, 1972) has shown the effects of distorted visual input on sleep. The association between sleep and vestibular stimulation has a large literature (Pompeiano, 1974) but appears not to be widely known. Conceivably, this effect can occur from exposure to distortion in visual inputs during simulator exposures.

- Simulator sickness may be contagious perhaps due to suggestibility. As symptoms become recognized, the person experiencing them should exit the simulator.

In the studies that were performed by O'Hanlon and McCauley (1974), pairs of subjects were run at the same time. A subject was allowed to leave if he requested such, or became sick. These data were later reanalyzed by Bittner (1976) who showed that the probability of both subjects leaving when the one was sick was much higher than expected by chance. In other words, a susceptible subject was one who probably was paired with another "susceptible" subject.

- Adaptation of the individual is one of the strongest and most potent fixes for simulator sickness.

Fineberg (1977) showed that previous learning with visually displayed information has an effect on subsequent perceptions of velocity. Runeson (1977) 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" (p. 208). When persons were exposed to long periods under rotation (Fregly & Kennedy, 1965) the posteffects were still measurable three and four days after the exposure ceased. And in some cases (Goodenough & Tinker, 1931), an aftereffect can be shown to be retained as long afterwards as two years. Guedry (1965) has shown postadaptation effects of several weeks. Berbaum, Kennedy, Welch, and Brannan (1985) list a case where one has lasted 25 years.

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 was measured in the form of posteffects. 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 postadaptation effects from passive adaptation can still be strong and this has direct relevance to steering an automobile after simulator exposure.

O'Hanlon and McCauley (1974) exposed a small sample of subjects to linear oscillation at nauseogenic frequencies and accelerations about once a week for seven weeks. In general, the results of that experiment indicated very little if any adaptation. Kennedy, Tolhurst, and Graybiel (1965) studied exposure to the Pensacola Slow Rotation Room with either a 2-day or a 30-day hiatus between trials. There was substantial evidence of retained adaptation over the 2-day delay and very little savings 30 days later. Unpublished observations from Kennedy (1965) show that repeated exposures on a daily basis resulted in adaptation and savings in the form of transfer from a static to a dynamic environment in the same Slow Rotation Room. Guedry (1965) showed that following exposure to the Slow Rotation Room nystagmic responses had strong evidence of savings, one, two, and three days later, but that 30 days later there was very little if any savings, and as much as seven days later there was only a moderate amount. Exposure to a Coriolis acceleration increased a person's tolerance to airsickness over previous tolerance levels (Cramer, Graybiel, & Oosterveld, 1976). When 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.

PANEL EXCERPT

DR. EBENHOLTZ: "When you look at it from the point of view of the underlying oculomotor system, you find that the identical antecedent condition that produces adaptation also leads to the motion sickness syndrome. They are identical. If you want to produce one you've got to be ready to treat the other."

DR. KENNEDY: "And when you monitor the adaptation process, the symptomatology disappears as the performance is modified."

- In order for adaptation to be optimized, there should be a minimum of one day between simulator hops, and a maximum of seven days between sessions. A very good goal for simulator hop assignments or scheduling should be one hop every day or every other day. When there are long intervals between hops it is strongly recommended that operators should limit their simulator exposure to shorter hops and initially to gentler maneuvers.

- Simulator flights should not be scheduled on the same day as aircraft flights.

There are cumulative effects of motion reported in the scientific literature whereby weak stimuli (often in an impoverished environment) trigger what appear to be large phenomenal impressions or illusions. These capacitor-like effects have been reported, particularly in connection with Coriolis stimuli, and one might expect that pseudo-Coriolis may behave similarly to Coriolis conditions. In the Coriolis condition, subjects have noticed symptoms which occurred well after they had received their initial stimulus and indeed, in some cases, appeared stronger than the initial stimulus itself. For this reason, and because pseudo-Coriolis is suspected in connection with helicopter training flights in simulators particularly, one needs to be poised to note them. Aftereffects are a consequence of simulated flying, but care should be taken to minimize their influence. The simplest and most effective way known is to limit exposure duration and perhaps to break it up.

PANEL EXCERPT

DR. WHITESIDE: "Was there a time difference between the sensation of the motion to which they were exposed and the onset of the symptoms?"

DR. RESCHKE: "Well, we were doing it daily for several hours a day, and then they would go back to their offices. But the thing is, after they were adapted to the rotating room, it was at that time almost coincident with total adaptation -- they could make as many head movements in there as they wanted to free of symptoms -- that then they would go back to their offices, and in a stationary situation where they had a desk in front of them, and a head movement suddenly causes the desk to start moving, the room to tilt, and the symptoms come on like that."

DR. WHITESIDE: "This is more or less after the experimental session of head movements during rotation, and a trained subject goes back to his desk and within an hour or so he gets sick."

DR. RESCHKE: "He's totally adapted to the actual rotating environment, but now there's a negative transfer to the stationary world."

DR. BERBAUM: "Which occurs sometimes days later?"

DR. RESCHKE: "Yes."

DR. DUNLAP: "So the offset of this pseudo-Coriolis effect is slow relative to the offset of actual spinning and getting sick?"

DR. RESCHKE: "Yes, and I can speak from personal experience on that one."

DR. McCAULEY: "I think that the main problem may be that you're dangerous in the aircraft when you adapt to the simulator. I don't know that. I don't think anyone knows that. But to me, that is the most important question. More so than taking these 20% of the guys and instead of them having the symptoms over their first six hops in the simulator, we are going to back it off to only the first two...."

DR. McCAULEY: "Two incidents reported in the literature frightened most people about this accident possibility. In one of the very first studies in Pensacola in about 1950 by Miller and Goodson, one of their subjects in a helicopter flight simulator had to stop his car, get out, and walk around because he was so disoriented he was afraid he couldn't even drive his car home. What if this guy was flying the aircraft instead of driving his car? The other one was from the Air Force studies, and I still find it a little puzzling, but where Kellogg and Castore were talking about these guys who would lay in their bunks at night and all of a sudden the whole room would appear to go inverted...."

DR. McCAULEY: "Just a little more anecdotal support. This concerns one of the newer helicopter simulators at Cherry Point. It was a fairly new one, and I remember when I was talking to the pilots there I talked to about three of them who said that we definitely feel higher in a simulator than we do in the aircraft. And I was trying to get them to talk about negative transfer training and that's the one thing they came up with. They have a little bit of trouble in landing if they go fly the aircraft later the same day because in a simulator they feel high, and so they have a real hard time landing the simulator. They go down to where they feel like the wheels ought to be touching...."

DR. BERBAUM: "One way to program things to avoid that would be to train on both the simulator and the aircraft at the same time, and to keep those situations as distinct as possible so as to develop simultaneous adaptations to the two situations."

DR. McCAULEY: "I think that would be a good approach, and also I think it's important to inform these people. We have to be concerned that during this period of adaptation in the simulator when he goes flying later that day or the next day that the probability of an accident is not increased."

DR. WELCH: "That's because they haven't learned those two different worlds yet."

DR. McCAULEY: "Eventually, I agree that he'll learn both of them."

DR. WELCH: "That's a dangerous thing; while they are learning to discriminate they may have an accident...."

DR. BERBAUM: "According to your model, will that kind of contingent adaptation occur?"

DR. EBENHOLTZ: "The model doesn't say anything about contingent adaptation. I remain skeptical about it. I would rather think that, for example, the vestibular system is responding and triggering these adaptations. I rather think that when you get into a real airplane that you begin to make different types of movements and that triggers the responses associated with that...."

DR. BERBAUM: "So far as you are concerned then, until proven otherwise, that's going to be a short-term history which is going to determine the current set point?"

DR. EBENHOLTZ: "That sounds correct...."

DR. BERBAUM: "Whether one used a strategy of adaptation as a solution would depend partly on what one thinks about how adaptation works in terms of how the set points are controlled. Is that just based on recent history -- just a recalibration, or are there contingent types of adaptation based on recognition? If recognition played a role, and you might train a person to feel comfortable with the spatial and temporal distortions in the simulator, those adaptations that may be inappropriate for aircraft will be engaged during actual flight."

DR. YOUNG: "We know that there are adaptations that depend on recognition of the state. And the most dramatic one I can think of is in divers. An experienced diver changes his vestibulocular reflex when he puts on his mask. I forget what the magnitude of that, but, you know, the gain I'm talking about is very large. The adaptation appears to take place as soon as the mask goes on. That is a distortion which is every bit as large as the kind we're talking about. At any rate, there is evidence that you can adapt by recognizing a situation. You can adapt using an internal neural program that is appropriate for that situation. I think that may well take place in the simulator. The question is whether it decreases the value of the vestibular input in teaching the flying task...."

DR. WELCH: "The question about whether you could adapt to two or more perceptual worlds: Yes, I think you can. There's no question that the same kind of adaptation as the diver has also occurs in the same kind of situation of going from a simulator to outside of it, into it or out of it, or from a simulator to the airplane and back again. But you have to do that enough times to build up this kind of distinction that they could make. And that might be a way, with repeated experience, of getting them ultimately to be able to be adjusted to both different environments, although even then you'd probably want to do this in gradual increments to, say, the size of the visual field and the simulator and things that have already been suggested on top of this. But I think you could expect if you are moving a person back and forth between these two worlds you would get a building up of a discrimination, and perhaps broader generalization to other tasks like that one."

Habituation vs Adaptation

PANEL EXCERPT

DR. WELCH: "My opinion is that you don't get one modality recalibrated in terms of the other, or some median in the middle situation, so that there wouldn't be adaptation in terms of a resolution of perceptual modification. On the other hand, I really don't know the data on this that would be a very testable question."

"What I would suspect happens is that people simply get used to having a conflict. In other words, the conflict no longer surprises them anymore, so maybe you could say that's no longer a conflict, if you wanted to, but not by my quantitative measure. The conflicts quantitatively would still be there, but they might be now expecting it; that is, it is something they're used to having. It's like people wearing goggles. At the end of wearing them for 25 days the world still looks upside down, but they expect it to look upside down. See? That's the difference."

"And so I use the term habituation. And some of this is stuff that Dr. Ebenholtz has talked about at one point or another."

DR. BERBAUM: "So habituation is a resolution of conflict between the expected and current input?..." You seem to be saying with these conceptual behavioral models that what happens to produce sickness is that you recognize one of these stored entities that somehow doesn't fit, in some small respect."

DR. WHITESIDE: "Yes. So your Conceptual Behavioral Model, your CBM is, in fact, a subset from your data base. It's a subset that has a certain structure and certain pattern and so forth, and you compare that with the behavioral model you're getting from the actual environment you're handling. If they don't match, that's a conflict situation, and if they do match, you're happy. It may not be actually cognitive. It may be something you're not even aware of."

MR. JEX: "If it doesn't match in some respects -- like the motion cues that are incongruent with what you see, there are probably some things that you can tweak to make them match and accept and other things which, no matter what you do, you can't easily tweak. The head tilt is an example where the motion is so disparate that no arrangement that you can easily make in that model is going to explain those effects. In nonlinear systems, it is possible that no matter what you do, getting from here, you can't get to the fact that you require a totally different set of inputs to be accounted for. You've got to start a new model -- certainly the first time. Now, the next time you have a model that allows that particular nonlinearity in its adjustments, you can adjust a little easier."

- Do not schedule simulator hops for greater than two hours for any reason.

There are documented cases of simulator sickness in the Navy's P-3C Operational Flight Trainer (2F87(F)), particularly at the flight engineer's position. Crosby and Kennedy (1982) showed that when operators took breaks midway through their exposure, far fewer symptoms were experienced than when they took the full exposure without a break. Exposure duration and frequency of exposure also appear to be important variables in other environments that produce motion sickness (McCauley & Kennedy, 1976; McCauley, Royal, Wylie, O'Hanlon, & Mackie, 1976). Additionally, studies in the Slow Rotation Room (Graybiel, Kennedy, Knoblock, Guedry, Mertz, McLeod, Colehour, Miller, & Fregley, 1965) show that the persistence of the motion aftereffect is proportional to the exposure duration. Related effects have been reported throughout the perceptual modification literature (cf., Welch, 1978, for a review). Some F-4 pilots, after training in the SAAC at Luke AFB, have reported sensations of climbing and turning while watching television, or experiencing an 180-degree inversion of the visual field while lying down (Kellogg, Castore, & Coward, 1980). Perceptual aftereffects also have potential consequences for disorientation and degraded motor control. Kellogg et al. (1980) suggest 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."

Studies preliminary to the Cinerama demonstration at Epcot (Jex, unpublished observations, 1985) determined that 15 minutes was a useful exposure time to demonstrate the impression of self-motion without attendant motion sickness symptoms (except for extremely susceptible individuals). For this reason, a 15-minute period is used at Epcot and rarely does anyone become ill. Similarly, a 15- to 20-minute period in a simulator may be expected to be well tolerated by most pilots, even one who is susceptible to simulator sickness. It is also likely that some adaptation will occur to repeated, short-duration exposures.

- o. Extensive use of time-outs.

- o In highly nauseogenic hops, shorten exposure periods, take breaks and use time-outs.

Most experts agree that motion sickness accumulates; if the stimulus continues, symptoms increase until an end-point such as vomiting is reached. Weak stimuli, if protracted, could eventually trigger symptoms. Furthermore, the likelihood of posteffects may even be greater. We believe that posteffects produced by weak, protracted stimuli may be more severe and appear with longer latencies than those produced by more short-term stimulation. In this view, if the pilot exits the simulator as soon as symptoms appear while they are still mild, and then return later, symptoms may dissipate prior to onset of severe discomfort, and some adaptation to the stimulus may be achieved. When the pliot returns to the simulator he may be more receptive to training.

An alternative way of looking at this is to consider the various symptoms as having different stimulus energy thresholds such that milder symptoms have lower thresholds. Thus, as stimulus energy increases, the first symptoms to occur are mild, and there is a progression of symptoms from mild to strong as a function of increasing energy. It should be noted that stimulus energy is assumed to increase as a function of time even if stimulus intensity is constant, i.e., the body is assumed to integrate intensity over time (albeit imperfect integration. It is possible that different continued exposure to the physical stimulus below the thresholds of accumulated energy may increase tolerance by adaptation or habituation. When the threshold level is reached for mild symptoms, the pilot should then take a break. This will permit the operator to return after the break, benefit from the training, but never experience the stronger, unpleasant, and discomforting symptoms (Bergstedt, 1965, Reason & Graybiel, 1972). Whiteside (in Kennedy, Berbaum, Dunlap, & Lilienthal, in preparation) advocates a more rapid method for adaptation in which an avalanche of strong symptoms are evoked. Although this is an intriguing notion, the data are insufficient to recommend it as an approach at this time.

- o Do not go in the simulator unless you are in your usual state of fitness. Avoid fatigue or sleep loss, hangover, upset stomach, periods of emotional stress, head colds, upset stomach, ear infection, ear blocks, upper respiratory illness, and medication.

Several reports have shown that the stimuli for emesis can summate, so that with radiation (Cordts, 1982) and the flu (deWit, 1957; Kellogg, Kennedy, & Graybiel, 1965), lowered thresholds are found under the combined stress. 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. 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 lower the simulator sickness incidence. In any case, flight surgeons should probably be cautioned about letting a pilot fly in the simulator if a pilot is grounded for illness.

Simulation Flight Scenario

o Minimize close ground interaction, particularly when turning and/or taxiing or other changes in orientation.

Flying close to simulated ground surfaces increases the angular velocity of edges for any aircraft motions due to the relatively greater rates of change of visual angles subtending the objects which are depicted. It also magnifies any disparities in velocity that may occur from misalignment or distortion of edges. At the same time, shape definition of surfaces in many simulators is poorer close in. Without surface texture or high detail, close surfaces are rendered as patches of color. The only clues to actual distance to a surface may be changes in the shape of the perimeter which is already distorted at extremely oblique angles. Additionally, the simulation tolerances for objects in close are probably tighter, and conversely, those without exactly faithful representations may be more noticeably degraded up close than further away (Chambers, 1985; in Kennedy, Berbaum, Dunlap, & Lilienthal, in preparation). It is possible also that increased attention to realism for purposes of simulating self-motion through rich (many edges) scene content has potentiated the nauseogenic properties of such displays (Andersen, 1986; Andersen & Braunstein, 1985). Therefore, the apposition and resulting conflict between focal and ambient (Leibowitz & Post, 1982) systems may be the visual analogue of Coriolis (Guedry, 1970) and pseudo-Coriolis (Dichgans & Brandt, 1973) which appears so very nauseogenic. Sickness from conflict between depth cues has been speculated upon previously (Kennedy, Berbaum & Frank, 1984), but without the benefit of Andersen's (1986) suggestions.

The visual perspective and inertial equations which approximate reality tend to break down close to surfaces. To the extent that a visual/vestibular conflict is present, increased velocity may equate to increased strength of stimuli and thereby increase the conflict. The potency of pseudo-Coriolis stimuli as contributory factors in simulator sickness is probably greater in the case of objects up close.

PANEL EXCERPT

DR. EBENHOLTZ: "There is another aspect to this. That is, the effect that the speed of the pattern has in terms of modulating these ill effects of exposure. For example, to determine the demand that it makes on the eye, you might want to modulate the velocities of these patterns or at least build up to perhaps what would be a truer representation, but build up to it in several stages. Don't just zap him with very high velocity patterns until he has had time to adapt his system to those."

DR. BERBAUM: "In other words, when you start training him, keep him at high with minimum texture, so that he is not near the ground surface, and so that he is not getting a big vection factor. Then slowly bring him in for more."

DR. YOUNG: "On what Don [Parker] commented upon on earlier, with respect to your question, 'What kind of maneuvers are likely to be the most provocative?' I would also like to suggest that those maneuvers which put the pilot in close contact with the ground are likely to be the ones which are the most provocative for simulator sickness."

MR. CHAMBERS: "When you're in close, there are a lot of things in simulation that become very suspect. For example, scene content and any roll or other movements appear as very large inputs. So, in addition to scene content, the aerodynamics and its validity of replicating the aircraft in that enclosed environment is known not to be as good. You now have a very good reference with which to judge how well the aerodynamics are doing. In the case of helicopters, you have ground effect that sometimes isn't simulated as well as the normal aerodynamics. So, in addition to the visual, it's the basic control simulation validity that needs to be really checked on."

- Minimize rapid gain and loss in altitude. Minimize abrupt and continued roll, porpoising.

If one changes altitude abruptly, particularly in a rotary wing simulation, one is effectively producing greater accelerations. Alternating gain and loss in altitude could be equivalent to a ship motion simulation, and to the extent that the frequency of alternation is in a nauseogenic bandwidth (McCauley & Kennedy, 1976), it is possible that the sickness may be directly related to these motions. Large increases or losses of altitude would be equivalent to increased acceleration. Motion sickness is linearly proportional to the acceleration and curvilinearly proportional to frequency. That is, 0.2 Hz is more nauseogenic than 0.5 Hz. Preliminary findings from studies with careful inertial recordings of man-in-the-loop control of the 2F64C (SH-3 OFT at NAS Jacksonville, FL) helicopter simulator indicate that substantial amounts of energy (acceleration) are presented in the range of .13-.45 Hz (Lilienthal, Allgood, Kennedy & Berbaum, in preparation) in all three planes of motion. This simulator also has very high incidence of simulator sickness.

PANEL EXCERPT

DR. YOUNG: "My belief is that if you look at the problem in a single axis, you are not going to find but a very small incidence of motion sickness, no matter how you place it, and you might go away disappointed from that study. I am basing this on a lot of people's single axis and linear work. I think sickness begins mostly after you start getting into multiple axes."

- Landings are likely to be more nauseogenic at sea if the seastate is high for reasons related to issues covered above and in McCauley and Kennedy (1976). Therefore, shipboard landing with zero seastate is the recommended landing scenario if simulator sickness is to be minimized early in training.

- Avoid situations where freeze can occur during early hops. Instructors should be encouraged to take over and fly out of conditions known to go into freeze. If it is necessary to freeze for any instructional purpose, or to change mission segments or syllabus subject matter, such a freeze should follow recovery of straight-and-level flight.

When the visual stimulus is placed in freeze, this is done in the mistaken belief that such a stimulus is neutral. However, there is a very large literature on motion aftereffects and it is well known that the vestibular system also exhibits an after discharge following angular acceleration and deceleration (Howard & Templeton, 1966). The vestibular stimuli (and perhaps the visual too) should be permitted to "slow down" gradually.

- Do not slew while the operator's visual is on.

The reason that freeze and slewing with the visual on should be avoided is that these conditions provide inappropriate simulation. The same visual cues that are used to simulate flight provide inappropriate impressions of orientation or movement through space in the freeze or slew conditions. Therefore, freeze situations should be avoided when possible and slewing should be done with the visual off. Freezing, even with a blank screen, may bring the visual motion to a stop, but not the vestibular input. Therefore, freezing abruptly while in a turn does not permit the vestibular signal, which was recruited by visual vection (Homick, Reschke, & Vanderploeg, 1984) to dissipate and vestibular aftereffects probably result in cue conflict.

- Turn motion base off.

Reports from the simulators at the U.S. Marine Corps Air Station, New River, North Carolina, indicate that pilots have requested that the motion base of the simulator be turned off when they experienced problems. Whether and to what extent this works is not entirely settled. Although it is argued that some movement of the simulator may be an advantage, turning the motion base off may have a salutory effect in some situations. Occasionally, particularly early in practice, novice pilots are unable to satisfactorily control the simulated aircraft. The decreased control results in increased acceleration, perhaps at particularly nauseogenic frequencies. (McCauley & Kennedy [1976] have argued that 0.2 Hz is particularly nauseogenic.) In such a situation, reducing the acceleration applied to the vestibular system may be more beneficial than the attendant conflict created by a fixed-base with a moving visual field. Although there is no clear-cut experimental evidence for this, there are good theoretical reasons for this recommendation.

PANEL EXCERPT

MR. CHAMBERS: "Yes, I think there's a problem with the cue being enough to make a difference. Just like there can be too much time lag, there can be inadequate amplitude to make any effect. Not that there's a lot of documentation to support these particular numbers. If the motion cue represents perhaps less than 20% of what the aircraft is going to provide in a similar maneuver, it may be of no value to the pilot to be present at all, and if it's late, it will only be harmful."

...: "We found this in some helicopter tests, where we could find no performance effect in helicopter hover ability to hold a precision position, when the motion cues were below 25%. Moreover, when we cranked them up to near 100% of what the aircraft was in that hover position, it had no significant improvement in its performance, compared with no motion."

...: "So if you don't have much of a motion cue to start with, you're probably better off just to turn it off if it's disturbing, in that it's got some cue disparity with something else in it...."

MR. JEX: "In conditions where inertial motion cues are going to be congruent in the real world case like, perhaps, nap-of-earth flying, it's useful to have motion cues that can be severely attenuated but they can't be severely phase distorted, and if the differences are on the order of a tenth of a g in the phase distortion or transient part of it, that will probably be okay too."

...: "Now for other cases, like pulling down on targets, there's no way you can simulate those cues. In fact, the pilot learn to suppress the g cues in that case, and they are operating primarily visually. In fact, what you want to do, I believe, is take away the simulator g cues, in that case. They're wrong in the first place. In the second place, you're trying to teach the pilot to suppress them, so let him focus on the visual cues and that's a better training principle."

...: "The pilots in the dogfight learn to tune those out as control signals, except in a violent dogfight -- we've done some work along those lines -- the pilots are aware of these motions and they're actually suppressing them in terms of discomfort, but they're not using them as motion cues. By using real world motions and various attenuations of them, you can show this. But it turns out that in a violent dogfight type of flying, where you're pursuing a target through the skies, you don't need and you don't want the motion cues in any flight sense. They're just a nuisance because they act to fight you. When you want to roll quickly to follow the other guy, the rate cue of your vestibular sensor is saying

"Hey, don't roll so fast." But when you are flying through inertial space, like rough air, then the motion cues and the visual cues are congruent, and then the motion cues can be and, in fact, are used by the human to offload the visual workload."

Two problems with motion bases need to be avoided. First, the lag in the motion base response should not be longer than 83-125 msec (Ricard & Puig, 1977); otherwise, pilot-induced oscillation may result. Also, no more than a 40 msec asynchrony between inertial and visual cues should exist in a simulator. Some simulators have a variable and time-lag variable asynchrony; during parts of the maneuver you may have one time lag, and in other parts of the maneuver you may have another time lag. In some simulators visual response time is faster than the motion base response time. The ultimate limit for lags and cue asynchrony will be the bandwidth of the motion platform. Shutting off the motion platform in situations where its response time is long or will not match the visual system response time may be a way of alleviating symptoms.

- Decrease the field of view on nauseogenic hops (e.g., initial hops).

PANEL EXCERPT

DR. KENNEDY: "Of course, as your field of view gets bigger, other things being equal, vection is going to increase."

MR. CHAMBERS: "But another thought along that same line, of reducing the input stimulus -- that's what we're talking about -- for those pilots that have a problem or for pilots that have a problem in certain task areas, temporarily reducing the stimulus input which might be reducing the field of view or the amount of time they spend. It could even be a choice that's selectable by the pilot, either based on his prior experience when he goes in, he has to go through certain training procedures, he's going to do it in mode B, which means he will only use the forward window during landing...."

DR. YOUNG: "You asked before a question about the range of things one could look at in a visual system alone to find out about what elements in the visual system are responsible for simulator sickness. This is not the same as saying, 'What would you do to the visual system to fix it?', because you may very well find that the very things that are primarily responsible for creating the simulator sickness are also the ones that make it an effective simulator tool. The extreme example is if you turn off the visual system the problem goes away. But so does the simulation. But the obvious ones are ones that were in your list of suggested topics. Field of view: I believe that the wider the field of view, the more serious the simulator sickness problem is. I also believe the wider the field of view, the better the vection and the more effective the simulation."

MR. JEX: "Our feeling is that the primary sensors involved in those effects are the parafoveal sensors, which are roughly from the limit of fovea, 5 to 10 degrees out, out to maybe 30 to 40 degrees. In this zone the retinal elements are connected strongly in such a way as to extract streamer information about the motion through the visual field. I think this is a highly evolutionary tuned neural system that many running predators have, and it allows you to run over a rough terrain, chasing your prey or escaping your prey, without falling down."

- Go on instruments.

The visual scene may contain distortion, asynchronies, lags, misalignments, flutters, and other combinations of stimuli which are disturbing to the operator. Moreover, there may be characteristics of a wide-angle visual scene which are particularly nauseogenic. Therefore, and particularly in a fixed-base simulator, going on instruments is just like taking a break.

PANEL EXCERPT

DR. YOUNG: "The conflict model for perception of movement basically calculates this conflict at every moment of time and integrates it. As a result of that conflict you're changing the weighting on either the vestibular or the visual input. If the conflict remains small, that may be nauseogenic, but not enough to result in much adaptation. If the conflict remains large, you just turn off one of them. The obvious idea is that if the visual scene is totally at odds with the vestibular input or the passive nonpilot, and it remains that way for some period of time, you turn off the visual input.

- Turn off the scene content from the visual system and turn on the cabin lights during breaks and seat changes. Also, turn scene off and turn interior lights on at the end of each training session before leaving the simulator.

The reason for turning off the scene content from the visual system and turning on the cabin lights during breaks and seat changes is to permit the simulation cues that have been given in the previous few minutes to dissipate. A visual scene, particularly one at an off-angle, frozen on the visual system, may suggest to pilots that they are still at an odd angle. This would be particularly so since the visual scene would have a history over which the pilot would have moved to that position. Turning on the cabin lights replaces that visual scene with a known static environment.

Head Position and Movement

- Minimize head movement, particularly when new, dynamic kinematics are being demonstrated.

The nature of the relationship between simulator sickness and head movement has not been determined. Sinacori (1969) has observed that pilot head movements during moving-base simulations are similar to head movements found in helicopter flight, but head movements during fixed-base simulations were different. Perhaps the head is moved in accord with the inertial inputs. In fixed-base simulation head movements are not in accord with the inertial stimulus and may be a source of cue conflict. For this reason, moving-base helicopter simulators may be less provocative of 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). Head movements increase motion sickness susceptibility in gliders (Johnson, 1952), a Slow Rotation Room (Kennedy & Graybiel, 1965) and in space flight (Homick et al., 1984). There are studies (Parker et al., 1985; Graybiel et al., 1965, p. 735; and Graybiel, Meek, Beischer, & Riopelle, 1960) where the same inertial, conflicting stimulus is better tolerated when the head is fixed on the shoulders, even though the head goes through complex arcs which result in essentially the same stimulus as when the head is free to move. Graybiel, Beischer, Meek, and Riopelle (1960) showed the same result in squirrel monkeys who were moved through Coriolis stimulation, but with heads restricted, and evidenced less sickness than when subjects were free to walk around. Motion sickness may be expected to be reduced in flight simulators if head movements are restricted. However, 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 information must be extracted from noncentral parts of the field, as in air combat maneuvering, then restriction of head movement may not be an option. These issues will be very much in prominence when head- and eye-coupled area-of-interest displays are employed (cf., Berbaum & Kennedy, 1985).

PANEL EXCERPT

DR. CRAMPTON: "The story of the monkeys is an interesting one, and Dr. Reschke has done some of these experiments as well. But it has been shown that if you put a monkey in a box, a plastic box in which they can see the walls and so forth, and rotate them at about 20 RPM, that there is a range of susceptibility, but you get a pretty good sickness rate if you let the animals move around. If, however, you fix the animal so his head can't move, and put him in exactly the same situation, the sickness rate drops enormously. And we have interpreted that as being in large part eliminating Coriolis-like phenomena...."

MR. JEX: "Another thing I can't understand is when you do the head tilts in the dark, you get emesis very quickly. Why is that so very stressing?"

DR. GUEDRY: "It seems to me that head tilt during rotation is almost in the sensory conflict. I think that one phenomenon that led more people to think about conflict than almost anything else, because what's happening is that, say, you tilt your head this way, the canals are signaling that your head has gone one way and the otolith is signaling that it's going another way. It happens in both the dark and the lighted room. Scientists now are referring to the experience with circular vection in the roll plane as paradoxical. Well, you have the same thing, paradoxical motion with a cross-coupled stimulus. Your velocity sensation is definitely not in keeping with your angular displacement sensation. You will have a strong feeling, say, of diving but not getting anywhere or not getting as far as you should for the velocity that you're experiencing. The otolith is signaling that your skull is going one way, the canal is signaling your skull is going another way, and the brain is trying to figure out how to keep the skull together".

In a related report, Dichgans and Brandt (1973) discuss a pseudo-Coriolis effect wherein a rotatory stimulus coupled with incidental head movements produces the same feelings of discomfort that are experienced in a slowly rotating room when the person moves his head. In the Slow Rotation Room (Graybiel et al., 1965) the conflict is between the sensory information originating at the semicircular canals which are responding to the Coriolis accelerations, and the sensory information originating at the otolith organs which are responding to the change in linear position with head tilt. The two stimuli are approximately orthogonal to each other, one giving the impression of a descending, banking turn, and the other a change in position so that the head is now tilted and looking up from the right shoulder. Such impressions are very strong and compelling and occur similarly whether the environment is an optokinetic stimulus used by Dichgans and Brandt (1973) or a slowly rotating room (Guedry, 1970). Pseudo-Coriolis can occur within a helicopter simulator, particularly one with a fixed base. The head movements in the simulator are not unlike those within the real helicopter where the pilot gets an inertial stimulus to which he may have adapted. Therefore, the suppression of Coriolis-like symptoms in actual helicopters may transfer as a conditioned response to the operator's head movements in a ground-based flight trainer where the inertial motions are markedly different.

PANEL EXCERPT

> DR. KENNEDY: "I believe that adaptation to Coriolis stimulation may be the source of the problem in simulators which do not rotate for pilots who have experience in helicopters which do some rotational activities. Whether they be taxiing, or flying, or other operations, these pilots perform a number of head movements incidental to the movement of the cockpit, and in so doing after many hours, they probably adapt to the Coriolis stimuli that they are getting in the course of flying helicopters. When those people go into a simulator, I think that they have a conditioned response of opposite sign, which they now must adapt to and which may not be a problem for novice pilots...."

o Keep head within the design eye spheroid; remain on-axis for all visual displays. The design eye typically is a one-quarter cubic foot of space whereby a person may be on-axis for all of the visual displays that he is supposed to be viewing. Many operators scrunch forward or slump in their seats when making landings and this may take their head outside the design eye in order to improve their view of the display in front of them. This should be discouraged.

Several forms of distortion can occur to a pilot viewing visual displays from a position outside the design eye. Distortions in space perception based on off-axis viewing may lead to distortions in motion perception (and perceived self-motion). Distance and velocity estimation may therefore be affected. Head movements made incidental to distorted motion may exacerbate the problem.

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.

PANEL EXCERPT

> DR. YOUNG: "Sitting forward of the design eye is indeed a problem, and I've had many people comment to me on the fact that when they are in a position in which they are not exactly lined up with their individual appropriate video displays it's upsetting. I've heard comments that they kept looking over at their first officer's display to see what was going on on that side of the runway. That gets some incidence of simulator sickness. That produces some incidence of simulator sickness."

<u>Sickness Prone Individuals</u>

o Those individuals who have experienced symptoms on recent simulator hops should: (a) limit exposure, variety, and intensity of kinematics; (b) turn off one or more visual channels; (c) if symptoms have been extreme also turn off the motion base; (d) after symptom-free performance on several hops, these cues may then be brought back in; (e) for those individuals having difficulty acquiring stick feel, turn motion base off, or until stick feel is acquired. It is better to make night landings before day landings during the syllabus.

PANEL EXCERPT

> DR. KENNEDY: "We have conducted a few repeated-measures observations of people over 10 to 15 hops. When we've done that, we've found that a very effective treatment for simulator sickness is the number of hops. When we have found sickness rates to be high on initial exposures to the simulator, there is not only some adaptation, but the adaptation is large and dramatic. Although it is philosophically not a good idea to advocate adaptation as a cure for bad design, the strength of the improvement, the potency of the adaptation process, and the protection afforded in subsequent hops is such that it looks as though two or three exposures, even for the person with great susceptibility, may be effective."

o In all cases where previous simulator exposures resulted in symptomatology greater than a minimum amount, the recommendations which apply to introductory hops for novice pilots above should be followed.

Persons with extensive aircraft flight time, but little flight trainer time, are more prone to sickness. Such persons on their introductory hops should be very cautious about the application of kinematics and other nauseogenic stimulus conditions. Persons with persistent problems in simulators should attempt to consider IFR (Instrument Flight Rules) training procedures (e.g., restrict the field of view perhaps by using peripheral occluders like those used in cross-country instrument training flights). If symptomatology is experienced or anticipated, then limit simulation scenarios to 10-minute epochs and then come down off motion and turn on the interior cabin lights for one minute before commencing the remainder of the hop.

The evidence for experienced pilots having more difficulty than novice pilots includes a study by Havron and Butler (1957); also reported by Miller and Goodson (1960). In those studies, the persons with the most extensive experience also reported more motion sickness symptoms. This finding was replicated by McGuinness, Bouman, and Forbes (1981) and Kennedy (1981). Two of these studies involved helicopter simulators, one with a moving base and one with a fixed base. The third study involved an air combat maneuvering (fixed-base) simulator.

Nauseogenic Hops

o Some hops/scenarios may be more sickness-producing than others.

The training syllabus of the F-18 Weapon System Trainer (2E7) at the Naval Air Station, Lemoore, contains approximately 30 syllabus hops which vary in kinematics. Flying time in the real aircraft is mixed with simulator hops. The simulator is a fixed-base device. Simulator sickness incidences peak at three periods in the course syllabus: during initial hops, during early familiarization with air combat, and later during heavy concentration of energy management and weapons envelope delivery for air combat. In the first period, the pilot is new to the simulator and is learning to control his aircraft. In the second, he receives dynamic and complex kinematics for the first time. In the third, the visual environment contains optokinesis and vection-producing stimuli that are very strong. Moreover, these stimuli are constantly changing and there is a high workload. The three periods produce different rates of sickness, but they are higher than during other hops. Particular countermeasures covered under the sections on head movements, the duration of the hop, and other factors may reduce symptoms if applied at those points in the syllabus which have higher expected incidences.

PANEL EXCERPT

> MR. CHAMBERS: "Well, the most common or the largest volume of reported incidences of simulator sickness occur in one helicopter where turning and twisting maneuvers are employed. And the next is in air combat maneuvering simulators. Now, of course, in that case there is a lot of head motion involved in addition to the wide vision."

o Persons who have experienced eye strain on previous flights should request schedules to arrange for flights in the A.M. hours. Conversely, if persons have reported "fullness of the head" or persistent headache in previous flights they may consider scheduling theirs for afternoon flying.

This guideline is included because eye strain problems, which may be occasioned by misalignment of displays or other distortions, are very likely due to the requirement for repeated changes in accommodation. In the early hours, when persons are less likely to be fatigued by the day's visual demands, these problems may be better tolerated. Alternatively, fullness of the head can be caused by lack of drainage in the paranasal sinuses after a night spent recumbent and sleeping. This latter is often a problem of the early morning hours and which can disappear by noon.

In the simulator sickness survey (Lilienthal, Kennedy, Berbaum & Merkle, in preparation; Kennedy, Dutton, Ricard, & Frank, 1984; Kennedy, Merkle & Lilienthal, 1985), eye strain and fullness of the head were two of the most persistent responses. It is well known that in situations where the cues for accommodation and convergence do not match, headaches are likely to result (Ebenholtz, 1985, in Kennedy, Berbaum, Dunlap, & Lilienthal, in preparation; deGroot & Kamphuis, 1983; Shahnavaz & Hedman, 1984; Smith, Tanaka & Halperin, 1984). Simulators, of course, also have conditions where accommodation and convergence are not concordant. It is conjectured that pilots are less likely to experience eye fatigue earlier in the workday rather than later. Therefore, if a pilot encounters these symptoms, he should schedule his flights for earlier in the day. The visual effects that have been reported in simulator sickness studies include substantial amounts of eye strain. As might be expected, eye strain seems to be higher with CGI displays than in dome systems (Lilienthal, Kennedy, Berbaum & Merkle, in preparation). This implies that CGI systems are more conducive to eye strain and there suggests that the number of channels is proportional to the number of symptoms. Further study is required to determine whether the difficulties associated with eye strain involve accommodation and displays not imaged at infinity.

There is a possible explanation for the eye fatigue problem which may have some relevance for the reported eye fatigue when viewing visual display terminals (deGroot & Kamphuis, 1983) and to a lesser degree the complaints offered by persons who play video games for long periods of time. A less likely explanation is that there may be a pooling of blood in the extremities, particularly with extended periods of time seated in positions which do not involve a great deal of torso and leg movement. As a result, blood supply to the visual system could be reduced and retinal blood oxygen levels could also be summarily reduced.

Engineering and Maintenance Guidelines

- All of the computer-generated image cameras should be correctly aligned, particularly their virtual distance and with a common-bore sight.

There are two primary reasons for checking the alignment of the computer-generated imagery (CGI) channels. First, misalignment means that there is no design eye for the complete system from which all channels can be viewed simultaneously. Thus, the same sorts of distortions that result from having one's head outside the design eye could occur with misaligned CGI channels. Second, if CGI optical channels had different focuses, then a scene depicted at infinity would require different accommodative distances. The resulting extensive accommodative search could result in fatigue and thereby headaches. There is evidence that this occurs in regular visual display terminal usage (deGroot & Kamphuis, 1983; Shahnavaz & Hedman, 1984; Smith et al., 1984). Simulators which are suspected of being out of alignment should be "griped" and maintenance undertaken.

- Report problems with the simulator such as:
  - changes in stick feel
  - color balance
  - uncommanded motion base actions
  - misalignment of issues between and within displays

Early reports of simulator sickness (Miller & Goodson, 1958) in the 2FH2 helicopter simulator indicated that there were limitations in system fidelity. These included vibration of the visual displays, other vision distortions, and foggy, blurred, and generally out-of-focus presentations. 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. The sickness present was far greater than expected in a similar exposure in flight. In their analysis, Miller and Goodson (1958, pp. 12-18) state:

> "...Three-dimensional objects...appear tremendously distorted." This was particularly true during motion and may have led 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 six feet from his eyes...This difference of about six 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."
>
> "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."

Instructor Guidelines

- Instructors should be aware of the symptoms of simulator sickness in order to observe their students before, during, and after the simulator flight

The instructor is one of the key elements in attenuating the effects of simulator sickness. He can best evaluate if the student is at risk before entering the simulator. The instructor can cancel the lesson, more clearly observe the trainee, or avoid many of the nauseogenic properties of the flight hop. During the hop, the instructor can continue to monitor the trainee for signs of increasing illness. The instructor can introduce more breaks, shorten the length of time in the simulator, and insure that the Guidelines are adhered to by the student. After the flight, the instructor should attend to any simulator aftereffects that could jeopardize the safety of the trainee.

SECTION III

PROPOSED ENGINEERING MODIFICATIONS FOR REMEDIATION OF SIMULATOR SICKNESS SYMPTOMATOLOGY

A series of engineering modifications were recommended at the Pensacola conference which, it is believed, if implemented could provide remediation of simulator sickness symptomatology. However, it is recognized that such changes entail a longer term commitment to research and development.

MOTION BASE

TRANSIENT VS. SUSTAINED. The motion base provides two kinds of cues: acceleration and tilt; one is transient, the other is sustained. The transient is usually followed by the sustained with a "washout" ramp between them. The algorithm used to compute motion has two parts with multipliers for transient and sustained aspects of the simulation. Therefore, the transient or acceleration simulation could be removed easily, leaving the sustained tilt simulation intact. Since otoliths and canals react to the types of stimulation independently, removal should reduce vestibular/vestibular conflict and perhaps visual/vestibular conflict. This simulator fix could be particularly useful if pitch and roll acceleration have high energy values at nauseogenic frequencies (cf. Lilienthal, Allgood, Kennedy & Berbaum, in preparation).

RESONANT FREQUENCIES AND MOTION SICKNESS. Use of accelerometers to determine the physical motion of simulators should be done with student and experienced pilots actually flying the simulator. The power spectrum should then be plotted and the energy at various frequencies evaluated. It is possible that energy at 0.2 Hz is a major variable contributing to simulator sickness. Measuring the stimulus energy presented to the student is the only way to test this hypothesis. If energy at particular frequencies turns out to be a major contributor to sickness, then a monitoring device that would summarize the energy at various frequencies for a particular hop could be read out to the instructor so that he could judge accurately the likelihood of simulator sickness and call for breaks at appropriate times.

Motion sickness due to vertical oscillation has maximum symptomatology occurring at frequencies of about 0.2 Hz (McCauley & Kennedy, 1976; O'Hanlon & McCauley, 1974). This, of course, is for the single frequency case. It would be enlightening to plot the density distributions of various moving-base flight simulators against the acceleration by frequency design criteria of U.S. Military Standard (MILSTD) 1472C (1981). For example, the motion density distribution within simulators may be of the wrong waveform 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 to minimize maintenance problems, may shift the frequency downward in the simulator. Thus, even though the aircraft dynamics being simulated may not be particularly nauseogenic (≃ 1 Hz) (Kennedy, Moroney, Bale, Gregoire, & Smith, 1972), the simulator's resonant frequency may be in a "bad" region (e.g., around 0.2 Hz).

One of the chief problems encountered in the Navy's simulator sickness survey was that it was technically very difficult to measure the stimulus to the human operator. It was not easy to know with confidence the visual and inertial environment impinging on the pilot. Attempts to rectify this problem resulted in program delays. It is absolutely necessary that a simple package be available to measure the physical environment in a reasonable amount of time. Some simulator sickness is probably due to simulators running "out of spec." This should be determined prior to additional work in this area.

Figure 1 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 the most disadvantageous area for very low frequencies is between 0.13 and 0.40 Hz, and for vibration, 3.0 - 8.0 Hz.

Hartman and Hatsell (1976) recorded the vertical motion of the Simulator for Air-to-Air Combat (SAAC) over the course of a typical mission scenario. We have transformed the power spectral density analysis to RMS g and replotted the data in Figure 2 along with the MILSTD 1472C data of Figure 1. 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. It is of more than passing interest that the data on which the military standard are based are the single frequency case. Guignard and McCauley (1982) showed greater sickness when complex waveforms were employed at the same frequency and acceleration. Simulation not only entails complex waveforms, but distributes the energy in g_x and g_y as well as g_z. An additional complication of such a stimulus is that it may exhibit lower thresholds for nausea (Irwin, 1976) in g_x and g^y than for g_z.

If a more relaxed standard of sickness than 10% vomiting were to be used (e.g., dizziness, nausea, drowsiness, sweating, or pallor 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 3 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 and Hatsell (1976) reported incidence rates for 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.

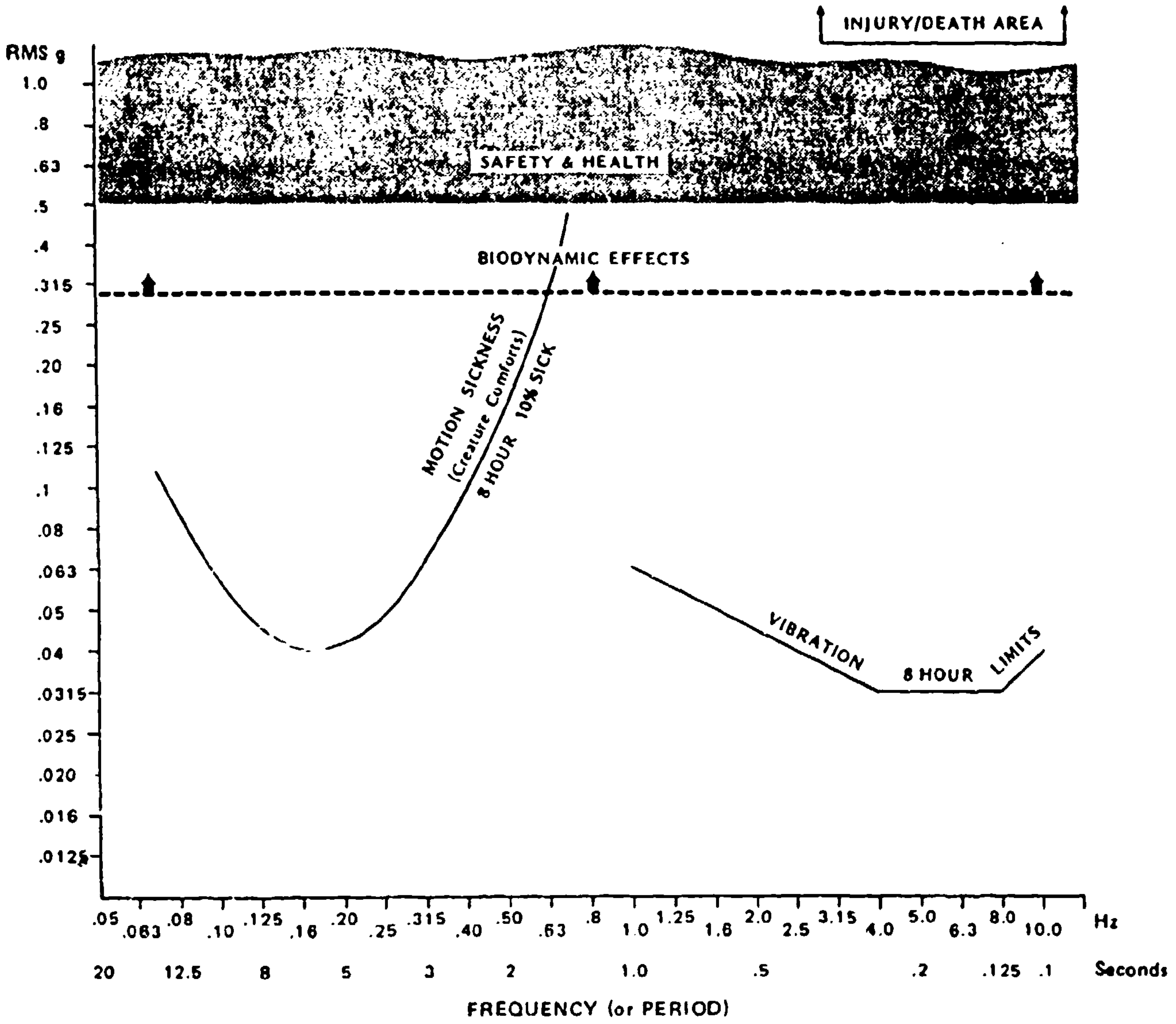

Figure 1. Exposure limits prescribed in U.S. Military Standard 1472C for motion and vibration.

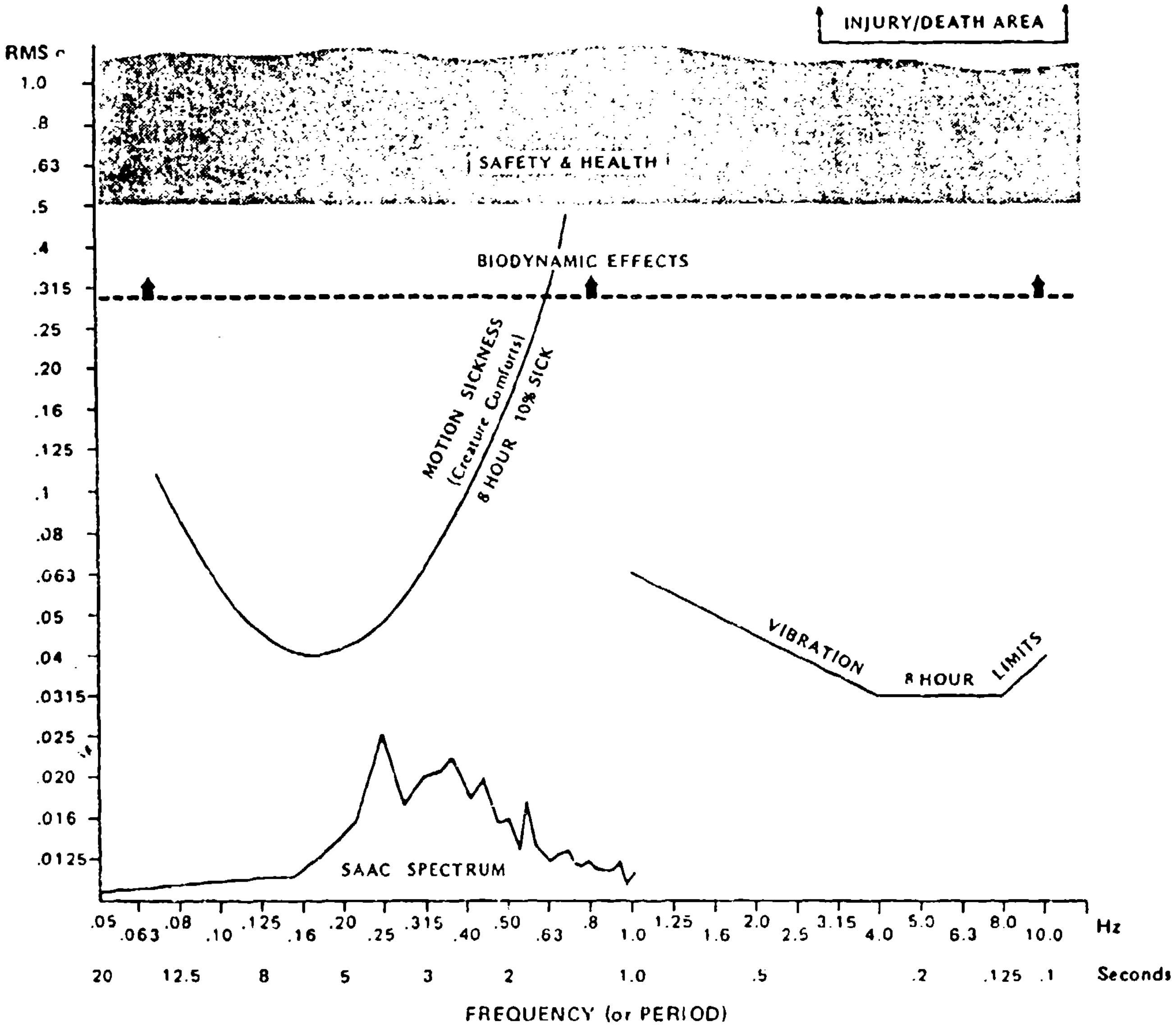

Figure 2. Vertical motion spectrum of Simulator for Air-to-Air Combat (SAAC) added to Figure 1.

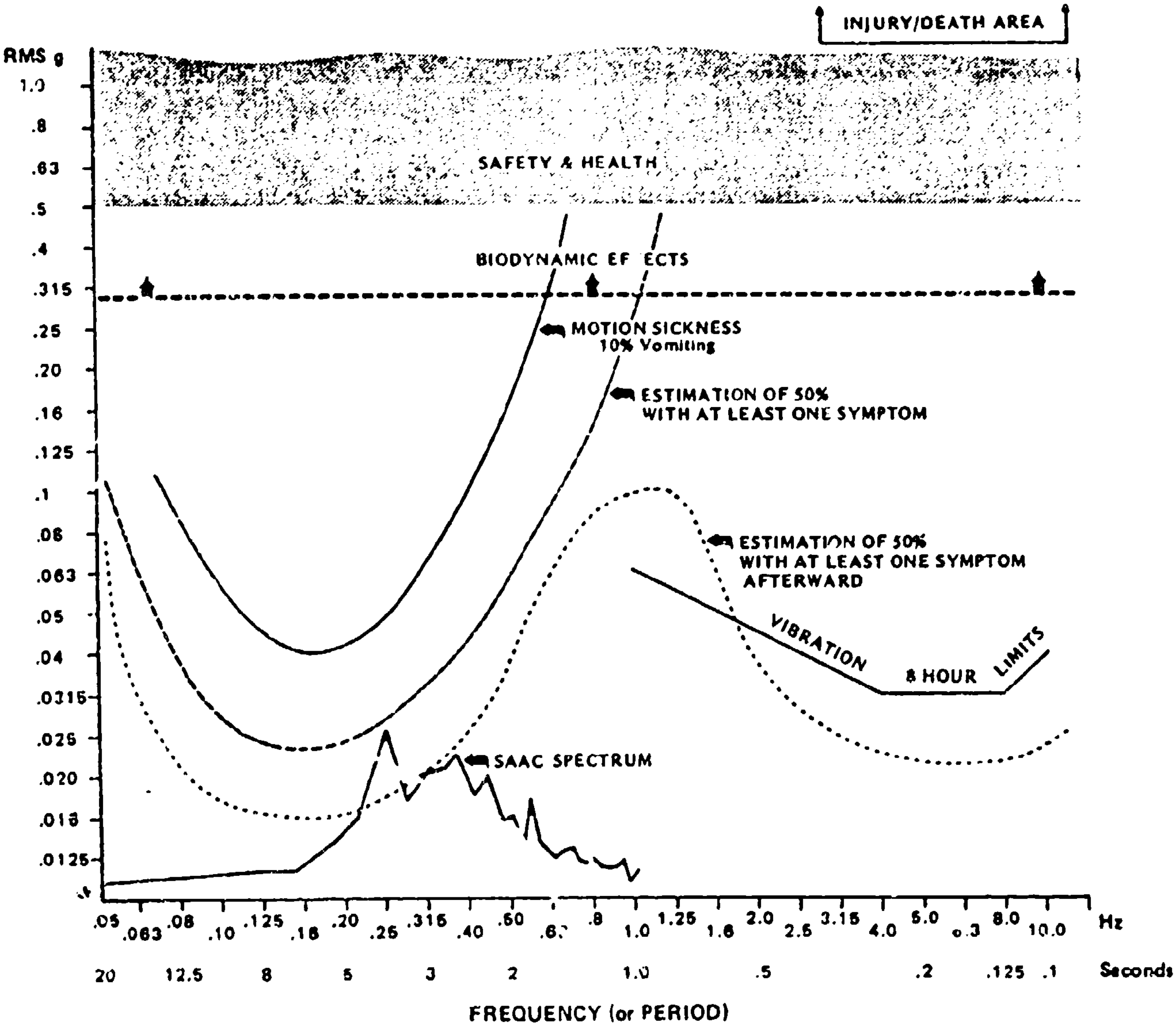

Figure 3. Addition of occurrences of lesser symptomatology.

In Figure 4, the postadaptation 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 that 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 theory and scientific data. It does not, however, 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. Recent evidence (Lilienthal, Allgood, Kennedy, & Berbaum, in preparation) suggest that much of the energy is in this region for a helicopter simulator with a high sickness rate.

It has been reported at some simulator sites that the stick is overly sensitive as compared to the actual aircraft. Studies should begin immediately with experienced pilots to determine whether this is true and have the control corrected accordingly.

VISUAL IMAGERY

DECOMPOSITION OF VISUAL MOTION. The visual stimulus probably should be measured in the same way as the inertial stimulus. However, since the effective stimulus for vection is not simple (Andersen, 1986), it is less certain what factors should be measured. If lawful relationships between stimulation and incidence were uncovered, they could guide a quest for the visual analogues of those stimuli. Some of the attributes of the visual display that could be measured would be difficult or expensive to measure. What follows is the beginning of a plan, but it will require additional study before it can be fully formulated. It is offered here as heuristic. If we assumed that, whatever scene was presented, it provided the same stimulus for vection, and that vection were a postspace constancy phenomenon, then we could simply measure the travel of the design eye through the spaces described by the data base. Of course, we know that such assumptions are incorrect. Measuring the travel of contours x length-of-contours may be a better description of the effective stimulus for vection. In other words, vection may be a peripheral, preconstancy phenomenen. We should begin to relate these things to perceived self-motion, orientation, and simulator sickness incidence, though this may prove less easy than measuring the physical motion.

It is possible that the nauseogenic properties of visually induced motions may be similar to those of inertially presented stimuli. That is, for fixed-base trainers, it is possible that movement of the visual scene at about 0.2 Hz may be particularly distressing. The [illegible] environment could be characterized in the same way that the inerti[illegible]nment was in MILSTD-1472C. Possibly, the two envelopes ov[illegible] spectral analysis of the visual system's response characteristics, si[illegible] to what has been described in MILSTD-1472C for motion sickness, should be prepared (Figure 2). Specifically, the displacement, in visual angle, and frequency of the visual input, which serves as a forcing function for vection, should be determined. Insufficient research is available in this area of optokinetic (vection) stimulation for sinusoidally presented stimuli to render an opinion, but should be studied.

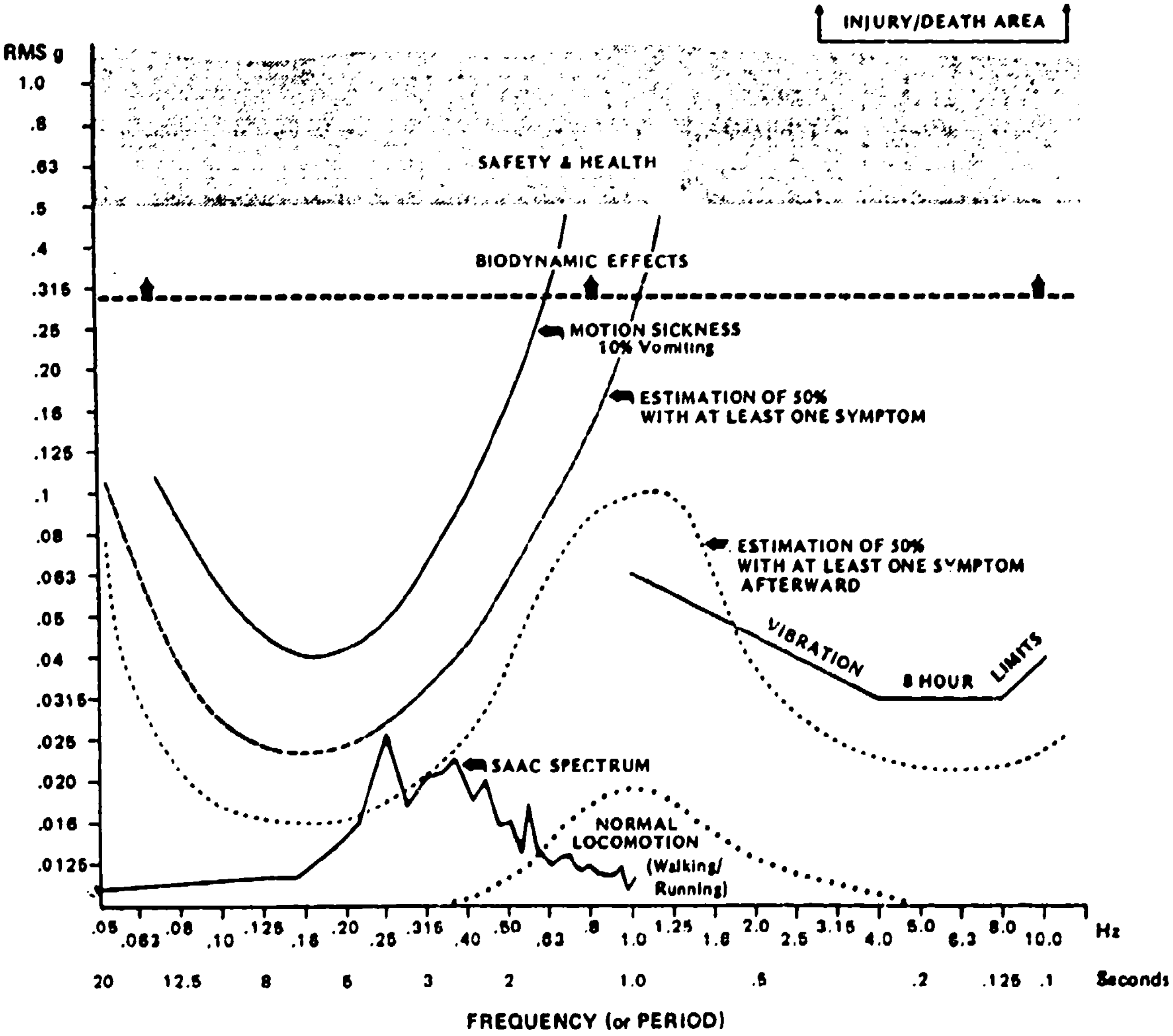

Figure 4. A comparison between MILSTD-1472C vomiting criteria and a projected envelope for lesser symptomatology. (Derived from Kennedy & McCauley, 1982).

The responses of the visual and the vestibular systems to vertical oscillations of various frequencies may or may not coincide. This difference could serve as the measure of the magnitude of cue conflict when the two are not in accord. All cue conflict theories of motion sickness would predict increased incidence with increased conflict, but no objective measures of the magnitude of conflict are available. It would be helpful if we could diagram the frequency response of the visual system for oscillation.

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 (Andersen, 1986). When stationary and moving contrasts were simultaneously present at different distances, self-motion perception was more affected by the stationary or the moving contrasts located in the background. "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." (Brandt et al., 1975, pp. 497-498). Perhaps CGI provides inadequate stimulation of the depth periphery. Andersen and Braunstein (1985) report a related phenomenon.

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). In studies of transformed visual worlds, using displacing and reversing prisms, the primacy of vision over proprioception appears to be clear-cut but not everyone agrees (cf., Benson, 1985, personal communication). In terms of cue conflict theory, visual disruptions are likely to be most distressing because vestibular and proprioceptive disruptions are more liable to be brought into correspondence by central nervous system plasticity. The primacy of the visual system from the standpoint of perceptual rearrangement does not imply that disruption of the vestibular system may not lead to motion discomfort. However, the vestibular system invariably signals self-motion, but visual motion must be perceptually divided into subject-motion and object-motion.

VISUAL-INERTIAL LAGS

DELAYS AND LAGS. Simulators do not always do what the command signals tell them. Evidence for such temporal discrepancies appears in a paper by Seevers and Makinney (1979) where in the SAAC there was a reasonable doubt as to how well the motion system onset cuing scheme contributed to simulator effectiveness. Erroneous onset cues are provided to the pilot, tending to compound further the question of the utility of the motion systems employed on visual system simulators. An evaluation comparing responses of each lag disclosed discrepancies, including excessive lag times and cross-coupling between movements which indicated that errors exist in movement of the platform (Seevers & Makinney, 1979). It also has been reported to one of the authors that a Navy helicopter simulator has been "out of spec" in having visual lags greater than 280 msec. These discrepancies can contribute to simulator sickness. The standard in question is Military Standard 1558, which governs motion platform systems (MILSTD-1558, 1974, Six-Degree-of-Freedom Motion System Requirements for Air Crewmember Training Simulators).

CUE ASYNCHRONY. The lags on some helicopter simulator visual systems range from 177 ± 23 msec. The motion base is just a little faster (perhaps 150 msec). It may be possible to slave the motion response to the visual response so as to eliminate cue asynchrony (which is now 5 to 50 msec). Of course, since cue asynchrony is already at a minimum amount of what is presently technically feasible, and since pilot-induced oscillations (PIO) may result from long lags, particularly in fast-moving or hard-to-control aircraft, it is not certain that this manipulation will help.

PANEL EXCERPT

> MR. CHAMBERS: "There are a number of cue sync[hrony] problems that have been shown to exist in a lot of simulators, and they vary so that in some cases the visual will lag the motion cue, and in other simulators it will be vice versa. In either case, if there becomes a significant difference between them there are usually complaints about problems. Some attempts have been made in simulators to make them match up by delaying the lead-in cue. However, if you exceed a certain amount, then that's perceived as the whole system 'going bad,' so there's a limit to what you can do. Somewhere around 200 milliseconds is the limit; you go beyond that in trying to match cues, and you're destroying the entire simulation dynamics."
>
> DR. MAY: "What sort of asynchrony between the cues can they tolerate?"
>
> MR. CHAMBERS: "I don't know good definitive numbers on that, but rule of thumb numbers are around 40 milliseconds. If you can stay under 40 milliseconds, you're probably not going to get complaints. That's 40 milliseconds between cues. In addition to cue disparity, some simulators have a time lag inconsistency in that there is a variable time lag in the system. It's like living in an accordian world or rubber band time world where during parts of the maneuver you may have one time lag, and in other parts of the maneuver you may have other time lags. We've seen as much as plus or minus 80 milliseconds variation in the time lag because of the way the equipment was implemented, and the effect of that needs to be tested also."

Most modern flight trainers employ CGI visual displays. 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 & Puig, 1977). Indeed, nearly all the information dealing with visual displays in flight simulators is based on performance deficit as a function of delay. Whether certain delays are more or less conducive to simulator sickness has not been taken into account. 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 CGI 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. It should be pointed out that this paper was prompted by the question of PIO, not simulator sickness. A recent study (Uliano et al., 1986) studied three asynchronous visual throughput delays in a fixed-base simulator. The longer and more asynchronous delays showed initally higher incidence rates, but the differences were not significant.

Much of the work of K. U. Smith (1963, and with Sussman, 1969) reports on the effects of lag and perceptual feedback with temporal or space-displaced vision. Although Howard and Templeton (1966) have seriously questioned the results, it is fairly well accepted that lags and spatially displaced feedback impede learning and disrupt performance. Smith (1963) showed that there are difficulties when information is visually delayed. Observed effects of feedback delays indicate that little or no learning occurs in most response systems with feedback delays longer than 0.4 seconds or, if limited learning occurs, it is likely to be unstable (cf., also Held, 1970). These and other findings indicate that every motion system of the body is specialized in terms of the temporal feedback compliances that regulate it. 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.

"SMART" SIMULATORS

It would be desirable if a "smart" simulator could be created whereby instead of freezing a visual scene the computer recognized when it was nearing its design limits or boundaries and took over control from the pilot and flew him out of an excessive condition and brought him back gently to rest.

PANEL EXCERPT

DR. RESCHKE: "What you need is a smarter simulator, maybe not a more realistic simulator, but a smarter one with a good enough feedback that the system knows when the pilot is going to exceed the limits, and at that moment you begin shutting down before it ever reaches that point, because you can't let it come to the point where discordant information is available."

DR. BERBAUM: "It seems like we're coming to a heuristic that says whatever sources of information are available to the pilot, as far as his orientation in space, you have to give him an endpoint interpretation that's consistent and unprovocative."

DR. CRAMPTON: "Just like in a highly stable aircraft, take your hands off and you return to straight and fly level."

MR. CHAMBERS: "Some aspects of the "smart" simulator notion may be easily implemented. If one had a set of 6, 8 or 10 different scenarios, and depending on preconditions, it finds in a look-up table a particular shutdown procedure in that place. It may be possible to empirically identify likely scenarios. At the same time, voice may be useful in telling the pilot "hands off" as though he had a control pilot."

The complexity of the visual field is 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 CGI; 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 ACMS 2E6, may lead to discomfort from disruptions of ambient systems. It is not inconceivable that there are visual/visual conflicts wherein the focal and ambient systems which 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). The nauseogenic properties of depth disruption (Andersen & Braunstein, 1985) may be an example of such a conflict.

In a review paper by Stenger, Zimmerlin, Thomas, and Braunstein (1981), the authors comment that most CGI systems do not produce a strong impression of self-motion. One wonders whether the CGI 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 and point-source projection systems which have "softer" imagery and which may not set off so much apposition between these two visual systems. 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 CGI displays.

The prismatic adaptation which can occur during scotopic and photopic stimulus conditions (Graybiel & 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 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 CGI systems, but this notion may be too speculative for the data.

Leibowitz and Post (1982) have stated "Metamorphosia resulting from 'buckling' of the retina produces an irregular distortion of the retinal image which usually cannot be compensated optically" (viz., Duke-Elder, 1940). 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. Under circumstances where distortion of focal inputs may be a cause of discomfort, blurring may be a useful remedy. This should be explored.

SECTION IV

SIMULATOR SICKNESS FIELD MANUAL (MOD 1)

A survey has been conducted by the Navy into the problem of simulator sickness in 10 different flight simulators. In the analyses of the data which have proceeded so far, no single factor has been uncovered which appears to cause illness in all simulators. However, a good deal is now known about ways to control the problem when it occurs, and these methods have been collected below as a field manual.

SIMULATION SICKNESS

FIELD MANUAL

MOD 1

NAVAL TRAINING SYSTEMS CENTER

HUMAN FACTORS LABORATORY

ORLANDO, FL 32813-7100

NOVEMBER 1986

WHAT IS SIMULATOR SICKNESS?

It is a form of motion sickness that sometimes occurs in simulators. It may be induced by either physical or visual motion, or by some unusual combination of these two sources of motion information. Its symptoms may include fatigue, dizziness, nausea, eye strain and pallor. Occasionally, vomiting may occur.

WHO IS SUSCEPTIBLE TO SIMULATOR SICKNESS?

- Persons who are new to the simulator are most susceptible.

- Persons with extensive flight time, but little simulator time, may be especially susceptible. However, individuals with the same backgrounds may differ greatly in their susceptibility to simulator sickness and some may not experience any symptoms.

- Factors which may contribute to an individual's susceptibility are sleep loss, flu, upper respiratory illness, ear infection, ear blocks, medication, hangover, upset stomach, head cold, and emotional stress.

TO DETERMINE IF SOMEONE IS EXPERIENCING SIMULATOR SICKNESS LOOK FOR THESE SYMPTOMS

PALLOR
DROWSINESS
SWEATING
HEADACHE
FATIGUE
NAUSEA
"LEANS" AND "STAGGERS"
DIZZINESS
BLURRED VISION
CONFUSION
VOMITING

Remember that severity of symptoms may differ from one individual to another. Some persons may be SICK long before they VOMIT. Because sickness deteriorates performance and training effectiveness (and may be contagious due to suggestion), it is important to detect symptoms early before they become acute.

OTHER SYMPTOMS THAT MAY OCCUR

STOMACH DISTRESS
BURPING
LOSS OF APPETITE
FEELINGS OF WARMTH
DIFFICULTY CONCENTRATING
FULLNESS OF HEAD
DEPRESSION OR APATHY
EYE STRAIN
DIFFICULTY FOCUSING EYES
VISUAL FLASHBACKS
DISORIENTATION
VERTIGO

GENERAL RULES TO FOLLOW

1. To facilitate early detection of sickness, all simulator users should be familiar with symptoms and be encouraged to report symptoms immediately.
2. When sickness is detected, the person experiencing symptoms should leave the simulator as soon as possible and should not return until all symptoms have subsided, usually 10 to 12 hours.
3. Brief exposures (short hops with gentle maneuvers) separated by one-day intervals will facilitate adaptation to simulator motion and help prevent sickness, especially during the early stages of simulator training for both novices and experienced pilots with little simulator training.
4. Maximum duration of a simulator flight should not exceed 2 hours, if possible. Take breaks, hydrate yourself, and use time-outs.
5. During initial simulator training sessions or after a long period of not using the simulator, avoid scheduling simulator and aircraft flights on the same day.
6. Good health and fitness, combined with general adaptation, will help to reduce susceptibility to simulator sickness.

GENERAL GUIDELINES FOR PREVENTING SIMULATOR SICKNESS

I. SIMULATOR FLIGHT SCENARIO

If certain simulator flight scenarios tend to produce sickness:

- Minimize changes in orientation when close to the ground, especially when turning.
- Minimize rapid changes in altitude, abrupt rolls, and porpoising.
- Limit shipboard landings to scenarios with zero seastate, especially in early training stages.
- Avoid freeze situations in early training stages, if possible. If not, the freeze should follow recovery of straight-and-level flight.
- Do not slew while the visual scene is turned on. If slew must be used, fly into the clouds and then slew.
- If all else fails, turn off motion base and/or the visual scene and conduct instrument training.
- During breaks, seat changes, and at end of each training session, turn off the visual scene and turn on interior cabin lights before exiting the simulator. If you are not allowed to turn off the visuals, make sure the simulator scenes show 0 degree pitch, 0 degree yaw, and 0 roll attitude before exiting.

II. HEAD POSITION AND MOVEMENT

<u>If head position or movement contributes to the problem:</u>

- Minimize head movement, especially when new, dynamic simulator motions are being trained or being reintroduced.

- Keep head positioned on the proper axis (within the design eye) for viewing visual displays. Do not hunch forward or slump down in seat. Off-axis positioning of the head and eyes may result in distorted visual dynamics.

III. SICKNESS-PRONE INDIVIDUALS

<u>If someone has recently experienced simulator sickness</u>:

- Limit initial duration, variety, and motion intensity of simulator flights.
- Turn off one or more visual channels initially.
- If previous symptoms were acute, also turn off motion base during early training stages.
- After several symptom-free simulator flights, motion and visual cues may be restored.
- Schedule simulator night landing training before day landing training.
- If acquisition of "stick feel" proves difficult, turn off motion base until "stick feel" is learned.
- If "eye strain" occurred in previous simulator flights, schedules should be arranged for morning simulator flights.
- If "fullness in the head" or persistent headache occurred in previous simulator flights, schedules should be arranged for afternoon flights.

ENGINEERING AND MAINTENANCE GUIDELINES

- Make sure computer-generated image cameras are aligned correctly, especially the image virtual distance.

Report problems with the simulator such as:

- changes in stick feel
- color imbalance
- misalignment of issues between and within displays
- uncommanded motion base actions

Set cabin temperature so that it is comfortable throughout the training session.

INSTRUCTOR GUIDELINES

PRE-HOP

- OBSERVE

  Look for signs of illness (e.g., pallor), fatigue, lack of alertness, signs of eyestrain, hangover, cold, and emotional stress in the pilot.

- INQUIRE

  Ask student: Have you ever had vertigo, been sick or had other symptoms in a simulator? Did you have sufficient sleep last night?

- EVALUATE/ACTIONS

  If pilot seems at no risk:

  - Proceed with hop

  If pilot seems a marginal risk:

  - Proceed with hop
  - Stay alert for development of symptoms
  - Encourage pilot to report any symptoms
  - Follow guidelines

  If pilot seems at risk:

  - Consider rescheduling hop
  - Adhere to guidelines strictly
  - Consider terminating hop early

INSTRUCTOR GUIDELINES

DURING HOP

- OBSERVE/INQUIRE

CONTINUE EVALUATION

IF ADVERSE SYMPTOMS OCCUR DURING HOP:

- Follow flight scenario guidelines
- Discontinue hop if necessary
- Shorten duration of simulator flight
- Reschedule aircraft flights no sooner than 24 hours after simulator flight or 12 hours after remission of symptoms, whichever is later

INSTRUCTOR GUIDELINES

POST-HOP

- OBSERVE/INQUIRE

Symptoms may occur immediately after a hop or later. Be alert to any symptoms during simulator flight debrief. If any occur, make sure pilot has time to get over symptoms before letting him leave. Make sure that the pilot is not suffering from vertigo before driving an automobile. Report any severe problems such as vomiting, vertigo, or disorientation to the flight surgeons immediately.

IV. HELP LINES

For additional information, comments, or experiences that may help other pilots please contact:

LCDR Michael Lilienthal
(AV) 791-5130
(FTS) 848-5130
(COMM) 305-646-5130

SECTION V

CONCLUSIONS

This report represents the current state of expert knowledge of simulator sickness symptomatology and aeteology. Two sources of knowledge were drawn upon, namely, research findings reported in the scientific literature over the last 30 years, and the views of a panel of biomedical engineering experts. The objective was to achieve an integration of this knowledge from which could be inferred a set of basic principles that govern simulator sickness incidence, time-course, and susceptibility. These principles have been set forth in this report as guidelines which may be utilized to prevent, or reduce, the incidence of simulator sickness. They are suggested remedies only, "quick fixes" based on the existing need for immediate methods to cope with the growing problem of simulator sickness. The highly tentative nature of the guidelines presented in this report is indicative of the profound need which now exists for a broad program of basic research on the problem of simulator sickness. Given the current, and projected, investment in simulators, and their value as effective training devices, it is imperative that existing knowledge be expended as expeditiously as possible. Among the many categories in need of basic research, the following appear prominently:

- Symptomatology, its time-course and physiology.
- Effect of simulator sickness on performance acquisition and reliability (i.e., training effectiveness).
- Adaptation of sickness symptoms.
- Transfer of sickness adaptation to operational environment.
- Individual differences in susceptibility and adaptation.
- Properties of sickness-inducing stimuli.
- Visual and motion sources of cue conflict (focal vs. peripheral visual systems, canal vs. otolith vestibular systems, visual vs. vestibular-proprioceptive systems).
- Simulator design trade-offs (fidelity vs. transfer-of-training, fidelity vs. sickness, transfer vs. sickness, etc.)

Participants in the 1985 Pensacola Ariola Conference on Simulation Sickness are shown below.

Name	Affiliation
Berbaum, K. S.	Essex Corporation
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REFERENCES

Allen, S. R., Oswald, I., Lewis, S., and Tagney, J. The effects of distorted visual input on sleep. Psychophysiology, 1972, 9(5), 498-504.

Andersen, G. J. Perception of self-motion: Psychophysical and computatational approaches. Psychological Bulletin, 1986, 99(1), 52-65.

Andersen, G. J., and Braunstein, M. L. Induced self-motion in central vision. Journal of Experimental Psychology, Human Perception, and Performance, 1985, 11(2), 122-132.

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

Benson, A. J. and Reason, J. T. Individual differences in aftereffects of apparent motion: Part II. Judgments of exponentially decaying signals, impulsiveness, and motion sickness susceptibility. Farnsborough, Hants, England: Royal Air Force Institute of Aviation Medicine, FPRC Memorandum No. 226-b, 1966.

Berbaum, K. S., & Kennedy, R. S. Plan for evaluation of the training potential of helmet-mounted display and computer-generated synthetic imagery. Orlando, FL: Essex Corporation, Technical Report No. EOTR-85-6, 1985.

Berbaum, K. S., Kennedy, R. S., Welch, R. S., and Brannan, J. K. Space adaptation syndrome: Reducing symptomatology through perceptual training. Houston, TX: Johnson Space Center, National Aeronautics and Space Administration, Final Report No. NAS 9-17278, 1985.

Bergstedt, M. Stepwise adaptation to a velocity of 10 RPM in the Pensacola Slow Rotation Room, paper presented at the 1st Symposium of The Role of the Vestibular Organs on the Exploration of Space, Pensacola, FL: U.S. Naval School of Aviation Medicine, 339-345, 1965.

Bittner, A. C., Jr. Observations on susceptibility of subjects paired with sick subjects. Unpublished. Naval Biodynamics Laboratory, New Orleans, LA: 1976.

Brandt, T., Wist, E. R., and Dichgans, J. Foreground and background in dynamic spatial orientation. Perception & Psychophysics, 1975, 17(5), 497-503.

Casali, J. G. Vehicular simulation-induced sickness, Volume I: An overview. Orlando, FL: Naval Training Systems Center, NTSC-TR-86-010, August 1986. (NTIS No. AD A173-904)

Casali, J. G., and Wierwille, W. W. Vehicular simulator-induced sickness, Volume II: A selected annotated bibliography. Orlando, FL: Naval Training Systems Center, Final Report TR-86-011, August 1986a. (NTIS No. AD A172-990)

Casali, J. G., and Wierwille, W. W. Vehicular simulator-induced sickness, Volume III: Survey of etiological factors and research facility requirements. Orlando, FL: Naval Training Systems Center, Final Report TR-86-012, August 1986b. (NTIS No. AD A173-226)

Christensen, J. M. and Talbot, J. M. A review of the psychological aspects of space flight. Aviation Space & Environmental Medicine, 1986, 57(3), 203-212.

Colehour, J. K., and Graybiel, A. Biochemical changes occurring with adaptation to accelerative forces during rotation. Pensacola, FL: NASA/U.S. Naval Aerospace Institute, Joint Report No. NAMI-959, April 1966.

Cordts, R. E. Animal-model studies of radiation-induced emesis and its control. Brooks Air Force Base, TX: USAF School of Aerospace Medicine, Report SAM-TR-8226, 1982.

Cramer, D. B., Graybiel, A., and Oosterveld, W. J. Successful transfer of adaptation acquired in a Slow Rotation Room motion environments in Navy flight training. In Recent Advances in Space Medicine, AGARD CP-203, C2-1, 1976.

Crosby, T. N. and Kennedy, R. S. Postural disequilibrium and simulator sickness following flights in a P3-C operational flight trainer. Proceedings of the 53rd Annual Scientific Meeting of the Aerospace Medical Association, p. 147-148, Bal Harbor, FL: 1982.

deGroot, J. P., and Kamphuis, A. Eyestrain in VDU users: Physical correlates and long-term effects. Human Factors, 1983, 25(4), 409-413.

deWit, G. Acquired sensitivity to seasickness after an influenza infection. Practicum Oto-Rhino-Laryngologica, 1957, 19, 579-586.

Dichgans, J. and Brandt, T. Optokinetic motion sickness as pseudo-Coriolis effects induced by moving visual stimuli. Acta Otolaryngology, 1973, 76, 339-348.

Duke-Elder, W. S. Textbook of ophthalmology: Volume I. London, England: Kimpton, 1940.

Fineberg, M. L. The effects of previous learning on the visual perception of velocity. Human Factors, 1977, 19(2), 157-162.

Frank, L. H., and Casali, J. G. Simulator sickness: A review of its costs, countermeasures, and prediction. Long Beach, CA: SAE, Engineering Society for Advancing Mobility on Land, Sea, Air and Space, Aerospace Technology Conference and Exposition, Technical Paper No. 861782, October 1986.

Fregly, A. R. Vestibular ataxia and its measurement in man. In H. H. Kornhuber (Ed.). *Handbook of sensory physiology. Volume VI-2: Vestibular system, Part 2: Psychophysics, applied aspects and general interpretations*. Berlin, Germany: Springer-Verlag, 1974.

Fregly, A. R. and Kennedy, R. S. Comparative effects of prolonged rotation at 10 RPM on postural equilibrium in vestibular normal and vestibular defective human subjects. *Aerospace Medicine*, 1965, *36*(12), 1160-1167.

Garcia, J., Rusinik, K. W., and Brett, L. P. Conditioning food-illness aversion in wild animals: Caveant canonics. In H. David and H. M. B. Horwitz (Eds.), *Operant-Pavlovian Interactions*, p. 273-316. Hillsdale, NJ: Lawrence Erlbaum, 1977.

Gibson, J. M. *The perception of the visual world*. Houghton-Mifflin, New York, 1950.

Goodenough, F. L. and Tinker, M. A. The retention of mirror-reading ability after two years. *Journal of Educational Psychology*, 1931, *22*, 503-505.

Graybiel, A. M. Structure elements in the concept of motion sickness. *Aerospace Medicine*, 1969, *40*, 351-367.

Graybiel, A. M. and Held, R. Prismatic adaptation under scotopic and photopic conditions. *Journal of Experimental Psychology*, 1970, *85*(1), 16-22.

Graybiel, A. M., Kennedy, R. S., Knoblock, E. C., Guedry, F. E., Jr., Mertz, W., McLeod, M. E., Colehour, M. S., Miller, E. F., II, and Fregley, A. R. Effects of exposure to a rotating environment (10 RPM) on four aviators for a period of twelve days. *Aerospace Medicine*, 1965, *36*, 733-754.

Graybiel, A. M., Meek, J. C., Beischer, A. S., and Riopelle, A. J. Observations of canal sickness and adaptation in chimpanzees in a "Slow Rotation Room." Pensacola, FL: Naval School of Aviation Medicine, Research Report No. 55, 1960.

Guedry, F. E., Jr. Habituation to complex vestibular stimulation in man: Transfer and retention of effects from twelve days of rotation at 10 RPM. *Perceptual and Motor Skills*, 1965, *21*, 459-481.

Guedry, F. E., Jr. Some vestibular problems related to orientation in space. *Acta Oto-laryngolica*, 1968, *65*, 174-185.

Guedry, F. E., Jr. Conflicting sensory orientation cues as a factor in motion sickness. Pensacola, FL: In *Fifth Symposium of the Role of the Vestibular Organs in Space Exploration*, NASA SP-314, August 1970.

Guignard, J. C., and McCauley, M. E. Motion sickness incidence induced by complex periodic waveforms. *Aviation, Space and Environmental Medicine*, 1982, *53*, 554-563.

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

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

Held, R. Two modes of processing spatially distributed visual stimulation. In F. O. Schmidt (Ed.) The neurosciences: second study program, New York, NY: Rockefeller University Press, 1970.

Henn, V., Cohen, B., and Young, L. R. Visual vestibular interaction in motion perception and the generation of nystagmus. Neurosciences Research Program Bulletin, 18(4), 1980.

Homick, J. L. Space motion sickness. Houston, TX: NASA Johnson Space Center JSC 18681, 1982.

Homick, J. L., Reschke, M. F., and Vanderploeg, J. M. Space adaptation syndrome: Incidence and operational implications for the space transportation system program, paper presented at the AGARD Aerospace Medical Panel Symposium, Williamsburg, VA, 1984.

Howard, I. P. and Templeton, W. B. Human spatial orientation. London, England: John Wiley and Sons, 1966.

Irwin, A. W. "G" can be amusing. paper presented at Human Response to Vibration Conference, Royal Military College of Science, Shrivenham, England, September 1976.

Irwin, A. W. Hill motion and valley vibration. Northampton, United Kingdom: UK Group, Human Response to Vibration, VOP Bostrom, 1977.

Jex, H. R. Observations regarding Epcot's Cinerama. Unpublished. Hawthorne, CA: 1985.

Johnson, W. H. The importance of head movements in the production of motion sickness. CANADA: Defense Research Board, DMRL Project No. 20-1, TIP U22185, 1952. (Abstract in Aviation Medicine Bibliography, 1952).

Jones, D. R., Levy R. A., Gardner, L., Marcsh, R. W. and Patterson, J. C. Self-control of psychophysiological response to motion stress: using biofeedback to treat airsickness. Aviation, Space and Environmental Medicine, 1986, 56(12), 1152-1157.

Kellogg, R. S., Castore, C., and Coward, R. Psychophysiological effects of training in a full vision simulator. Proceedings of the 51st Annual Scientific Meeting of the Aerospace Medical Association, p. 203-204, Anaheim, CA: 1980.

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

Kennedy, R. S. Observations on transfer in the Slow Rotation Room. Unpublished. Pensacola, FL: Naval School of Aviation Medicine, 1965.

Kennedy, R. S. 2F87 (#5) Aircraft operational flight trainer trip report of sickness. New Orleans, LA: Naval Biodynamics Laboratory, Unpublished memorandum, 6 March 1981.

Kennedy, R. S., Berbaum, K. S., Dunlap, W. P., & Lilienthal, M. G. Proceedings of cross-disciplinary biomedical engineering panel concerning methods for alleviating simulator sickness. Meeting held in Pensacola, FL, August 1985, synopsis in preparation.

Kennedy, R. S., Berbaum, K. S., Dunlap, W. P., Merkle, P. J., & Lilienthal, M. G. Guidelines for alleviation of sickness in sumulators. Proceedings of the 30th Annual Human Factors Society, Dayton, OH: September, 1986.

Kennedy, R. S., Berbaum, K. S., and Frank, L. G. Visual distortion: The correlation model. Proceedings of the SAE Aerospace Congress & Exhibition, Long Beach, CA: SAE Technical Paper Series No. 841595, 1984.

Kennedy, R. S., Dutton, B., Ricard, G. L., and Frank, L. H. A survey of flight simulators for the U.S. Navy. Proceedings of the SAE Aerospace Congress & Exhibition. Long Beach, CA. 1984.

Kennedy, R. S., and Frank, L. H. A review of motion sickness with special reference to simulator sickness. Proceedings of the 65th Annual Meeting of the Transportation Research Board, Washington, DC, 1986. Also published as "A review of motion sickness with special reference to simulation sickness. Orlando, FL: Naval Training Equipment Center, NAVTRAEQUIPCEN 81-C-0105-16.

Kennedy, R. S., Frank, L. H., and McCauley, M. E. Simulator sickness: Reaction to a transformed perceptual world. VI. Preliminary site survey, paper presented at the AGARD Aerospace Medical Panel Symposium, Williamsburg, VA: 1984.

Kennedy, R. S., and Graybiel, A. A comparison of the susceptibilities of three groups of naval aviation personnel to symptomatology of motion sickness, paper presented at the American Psychological Association Meetings, Philadelphia, PA, 1963a.

Kennedy, R. S., and Graybiel, A. Pensacola diagnostic categorization worksheet for the evaluation of vestibular sickness. Pensacola, FL: Naval School of Aviation Medicine, NAVSCOL AVNMED Form No. 6500/125, 1963b.

Kennedy, R. S., and Graybiel, A. The Dial test: A standardized procedure for the experimental production of canal sickness symptomatology in a rotating environment. Pensacola, FL: NASA/U.S. Naval School of Aviation Medicine, TR-NSAM-930, June 1965.

Kennedy, R. S., Lilienthal, M., Dutton, B., and Ricard, G. L. Simulator sickness: Incidence of simulator aftereffects in 10 Navy flight trainers. Proceedings of the SAFE Symposium, Las Vegas, NV, 1984.

Kennedy, R. S., & McCauley, M. E. Effects of tension leg platform motions on human performance and physiology, paper prepared for Conoco, Hutton Project, Colliers Wood, Long, England. Orlando, FL: Canyon Research Group, Inc., 1981 (Rev. 1982).

Kennedy, R. S., Merkle, P. J., and Lilienthal, M. G. A comparison of postural equilibrium effects following exposure to different ground-based flight trainers, paper presented at the SAFE Sympsoium, Las Vegas, NV, 1985.

Kennedy, R. S., Moroney, W. F., Bale, R. M., Gregoire, H. G., and Smith, D. B. Motion sickness symptomatology and performance decrements occasioned by hurricane penetrations in C-121, C-130, and P-3 Navy aircraft. Aerospace Medicine, 1972, 43, 1235-1239.

Kennedy, R. S., Tolhurst, G. C., and Graybiel, A. The effects of visual deprivation on adaptation to a rotating environment. Pensacola, FL: Naval School of Aviation Medicine, NSAM-915, NASA Order No. R-93, 1965.

Leibowitz, H. W. and Post, R. B. The two modes of processing concept and some implications. In J. Beck (Ed.) Organization and representation in perception. Hillsdale, NJ: Lawrence Erlbaum Associates, 1982, p. 343-363.

Lilienthal, M. G., Allgood, G. O., Kennedy, R. S. and Berbaum, K. S., The incidence of simulator sickness symptomatology as a function of the profile of inertial motions in two different ground-based flight trainers. Abstract submitted to Annual Meetings of the Aerospace Medical Association, Las Vegas, NV, in preparation.

Lilienthal, M. G., Kennedy, R. S., Berbaum, K. S., and Merkle, P.J., Jr. Simulator sickness in U. S. Navy flight simulators. Orlando, FL. Naval Training Systems Center, NAVTRASYSCEN, in preparation.

Lilienthal, M. G., and Merkle, P. J., Jr. Simulator sickness in flight simulators: A case study. Washington, DC: Proceedings of the 65th Annual Meeting of the Transportation Research Board, p. 81-86, 1986.

Lilienthal, M. G., Redmond, K. J., Merkle, P. J., Kennedy, R. S., and Lane, N. F Design-related factors in simulator sickness: Detailed analysis of 10 flight simulators. Paper presented at Aerospace Medical Association, Knoxville, TN: 1986.

McCauley, M. E. (Ed.). Simulator sickness: Proceedings of a workshop. National Academy of Sciences/National Research Council/National Academy of Sciences, Washington, DC: Committee on Human Factors, 1984.

McCauley, M. E. and Kennedy, R. S. Recommended human exposure limits for very low frequency vibration. Point Mugu, CA: Pacific Missile Test Center, Technical Paper 73-36, 1976.

McCauley, M. E., Royal, J. W., Wylie, C. D., O'Hanlon, J. F., and Mackie, R. R. Motion sickness incidence: Exploratory studies of habituation, pitch and roll, and the refinement of a mathematical model. Arlington, VA: Office of Naval Research, TR No. 1733-2, April 1976.

McClure, J. A., and Fregly, A. R. Effect of environmental temperature on onset during motion sickness. *Aerospace Medicine*, 1972a, *43*(9), 959-967.

McClure, J. A., and Fregly, A. R. Forehead sweating during motion sickness. Pensacola, FL: Naval Aerospace Medical Research Laboratory, NAMRL-1157, February 1972b. (NTIS No. AD A743975)

McGuiness, J., Bouman, J. H., and Forbes, J. M. Simulator sickness occurrences in the 2E6 Air Combat Maneuvering Simulator (ACMS), Orlando, FL: Naval Training Equipment Center, NAVTRAEQUIPCEN 81-C-0315-4500-1, 1981.

Military Standard 1558 (MILSTD-1558). *Six-degree-of-freedom motion system requirements for air crewmember training simulators*. Washington, DC: Department of Defense, 1974.

Military Standard 1472C (MILSTD-1472C). *Human engineering design criteria for military systems, equipment and facilities*. Washington, DC: Department of Defense, 1981.

Miller, J. W. and Goodson, J. E. A note concerning "motion sickness" in the 2FH2 hover trainer. Pensacola, FL: Naval School of Aviation Medicine, Research Project NM 1701-11, Subtask 3, Report 1, 1958.

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

Money, K. E. Motion sickness. *Psychological Reviews*, 1970 *50*(1), 1-39.

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

Oman, C. M. A heuristic mathematical model for the dynamics of sensory conflict in motion sickness. Cambridge, MA: Massachusetts Institute of Technology, MVT-80-1, 1980.

Orlansky, J. and String, J. Cost-effectiveness of flight simulators for military training. Volume II. Estimating costs of training in simulators and aircraft. Arlington, VA; Institute for Defense Analyses, IDA paper P-1275, 1977.

Orlansky, J. and String, J. *Cost-effectiveness of flight simulators for military training*. Orlando, FL: In First Inservice/Industry Training Equipment Conference, NAVTRAEQUIPCEN IH-316, 1979, p. 9-19.

Over, R. Individual differences in figural aftereffects. *Psychological Bulletin*, 1970, *74*(6), 405-410.

Palmer, R. G. Trip report. Unpublished memorandum. Naval Training Systems Center, Orlando, FL. 1985.

Parker, D. E., Reschke, M. F., Arrott, A. P., Homick, J. L., and Lichtenberg, B. K. Otolith tilt-translation reinterpretation following prolonged weightlessness: Implications for preflight training. *Aviation, Space and Environmental Medicine*, 1985, 56, 606-606.

Pompeiano, O. Cerebello-vestibular interrelations. In H. H. Kornhuber (Ed.). *Vestibular system Part I: Basic mechanisms*. New York: Springer-Verlag, pp. 4-17, 1974.

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

Reason, J. T. Relations between motion sickness susceptibility: The spiral aftereffect and loudness estimation. *British Journal of Psychology*, 1968, 59, 385-393.

Reason, J. T. Motion sickness: Some theoretical considerations. *International Journal of Man-Machine Studies*, 1969, 1, 21-38.

Reason, J. T. Motion sickness adaptation: A neural mismatch model. *Journal of the Royal Society of Medicine*, 1978, 71, 819-829.

Reason, J. T. and Graybiel, A. Factors contributing to motion sickness susceptibility: Adaptability and receptivity. In M. P. Lansberg (Ed.). *Proceedings of the AGARD Aerospace Medical Panel Symposium on Predictability of Motion Sickness in the Selection of Pilots*, AGARD DP-109, Glasgow, Scotland, 1972.

Revusky, S., and Garcia, J. Learned associations over long delays. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. IV) (1-84). New York: Academic Press, 1970.

Ricard, G. L., Norman, D. A., and Collyer, S. C. *Compensating for flight simulator CGI system delays*, paper presented at the 9th Interservice/ Industry Conference, Orlando, FL: Naval Training Equipment Center, 1976.

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

Rosinski, R. R. Effect of projective distortions on perception of graphic displays. Pittsburgh, PA: University of Pittsburgh, Office of Sponsored Research, TR 82-1, Contract N00014-77-C-0679, 1982.

Runeson, S. On the possibility of "smart" perceptual mechanisms. *Scandinavian Journal of Psychology*, 1977, 18, 172-179.

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

Seevers, J. A., and Makinney, R. L. Simulator for air-to-air combat motion system investigations. Brooks AFB, TX: Air Force Human Resources Laboratory, AFHRL-TR-79-18, 1979.

Shahnavaz, H., and Hedman, L. Visual accommodation changes in VDU operators related to environmental lighting and screen quality. Ergonomics, 1984, 27(10), 1071-1082.

Sherrington, C. S. The integrative action of the nervous system. Silliman Memorial Lectures. New Haven, CT: Yale University Press, London, England: Constable, 1906.

Shirley, R. S. Motion cues in man-vehicle control. Doctoral dissertation. Cambridge, MA: Massachusetts Institute of Technology, Man-Vehicle Laboratory, Center for Space Research, 1968.

Sinacori, J. B. Validation of ground-based simulation, paper presented at the American Helicopter Society Meeting, Hawthorne, CA: Norair Division, Northrop Corporation, 1969.

Smith, A. B., Tanaka, S., and Halperin, W. Correlates of ocular and somatic symptoms among video display terminal users. Human Factors, 1984, 26(2), 143-156.

Smith, K. U. Special review. Sensory feedback analysis in medical research. I. Delayed sensory feedback in behavior and neural function. American Journal of Physical Medicine, 1963, 42(2), 49-84.

Smith, K. U. and Sussman, H. Cybernetics: Motor learning and memory. In E. A. Bioldeau and I. McD. Bilodeau, Principles of Skill Acquisition, New York, NY: Academic Press, 1969, 103-139.

Stenger, A. J., Zimmerlin, T. A., Thomas, J. P., and Braunstein, M. Advanced computer-image generation techniques exploiting perceptual characteristics. Brooks AFB, TX: Human Resources Laboratory, AFHRL-TR-80-61, 1981.

Taub, E. Prism adaptation: Control of intermanual transfer by distribution of practice. Science, 1973, 180, 755-757.

Teichner, W. H. Reaction time in the cold. Journal of Applied Psychology, 1958, 42, 54-59.

Templeton, W. B., Howard, I. P., & Lowman, A. E. Passively generated adaptation to prismatic distortion. Perceptual and Motor Skills, 1966, 22, 140-142.

Thompson, C. I., Control of Eating, N.Y., Spectrum, 1980.

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

Uliano, K. C., Kennedy, R. S., and Lambert, E. Y. Asynchronous visual delays and the development of simulator sickness. Dayton, OH: Proceedings of the Human Factors Society 30th Annual Meeting, September 1986.

U.S. Navy Message from COMPATWINGSLANT, Brunswick, ME to CNO, Washington, DC. 2F87(F) SER No 5 FE and co-pilot display, April 1980.

U.S. Navy Message from FITRON ONE TWO FOUR to RUWFVAA/COMFIT AEBWWINGPAC, San Diego, CA. F-14 WST 2F 112/WAVS aircrew readjustment, October 1981.

Welch, R. B. Perceptual modification: Adapting to altered sensory environments. New York: Academic Press, 1978.

Wiker, S. F., Kennedy, R. S., McCauley, M. E., and Pepper, R. L. Reliability, validity, and application of an improved scale for assessment of motion sickness severity. Washington, DC: U.S. Coast Guard Office of Research and Development, USCG Technical Report No. CG-D-29-79, 1979a.

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

Young, L. R. Integration of visual and motion cues for flight simulator requirements and ride quality investigation. Cambridge, MA: Massachusetts Institute of Technology, Report No. N77-18740, 1976.

Yules, R. B., Krebs, C. Q., and Gault, F. P. Reticular formation control of vestibular system. Experimental Neurology, 1966, 16(4), 349-358.

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To Whom It May Concern:

Ref: AD A 182 554
"Guidelines for Alleviation of
Simulator Sickness Symptomatology"

We have noticed the omission of the name of one of the participants in the conference reported in the above-cited document. Enclosed is a corrected page 58 and we are requesting that, if possible, this page be inserted in the document that you have.

Your assistance will be greatly appreciated.

Sincerely,

ESSEX CORPORATION

Robert S. Kennedy, Ph.D.
Vice President

Encl.

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