FLIGHT SAFETY FOUNDATION
HUMAN FACTORS & AVIATION MEDICINE
Vol. 38 No. 4 *For Everyone Concerned with the Safety of Flight* July/August 1991

SIS — The Ultimate Realism in Simulators

The new breed of high-tech simulators are so realistic they have spawned a new ailment — Simulator Induced Syndrome.

by
Melchor J. Antuñano, M.D., M.S.
Research Scientist
Krug Life Sciences, U.S. Air Force School of Aerospace Medicine

The use of flight simulators for training aircrews has gained great acceptance and popularity among military and civil aeronautical communities worldwide. Flight simulators have several advantages over aircraft trainers including lower equipment cost, lower operational and maintenance costs, increased availability, unsurpassed safety to train aircrews on emergency procedures and a greater capability for immediate feedback on training proficiency. New developments in computer technology, both in hardware and software, have led to the creation of sophisticated simulators that produce a more realistic simulation of flight than previous generations.

However, the widespread use of the new flight simulators has also led to an increased number of reports of simulator sickness, more properly termed simulator induced syndrome (SIS), among both experienced and inexperienced aircrews [3,10]. The term simulator sickness was first used in 1957 by Havron and Butler to describe the occurrence of motion sickness in a flight simulator [9].

The occurrence of simulator sickness (as well as any other type of motion sickness) should be regarded as a normal response of a healthy individual (without organic or functional disorder) when exposed to an unfamiliar motion. Therefore, individuals who experience this unpleasant condition should not be considered abnormal or diseased. In fact, experiencing motion sickness symptoms indicates the integrity of the neuro-vestibular system (inner ear motion sensors).

Also, the use of the term simulator sickness can be misleading because it has the connotation of an illness. Consequently, it is preferable to use the term simulator induced syndrome to describe those signs and symptoms that appear among some air crew members during their training on flight simulators.

Signs and symptoms of SIS include vomiting, retching, nausea, cold sweating, drowsiness, increased salivation and swallowing, skin pallor, difficulty concentrating, mental confusion, difficulty focusing, visual flashbacks, eye strain, blurred vision, sensation of fullness of the head, apathy, lethargy, increased yawning, stomach awareness, anorexia (loss of appetite), burping, increased need for bowel movement, headache, dizziness, vertigo, postural instability and increased fatigue [5, 7, 11, 14, 21]. However, the most commonly reported symptoms of SIS are distinctly visual in nature (eyestrain, blurred vision, difficulty focusing, visual flashbacks, headache, difficulty concentrating) [13].

The immediate onset of SIS is the most common occurrence; however, post-flight (delayed) signs and symptoms have also been reported frequently [1, 4, 10, 12, 13, 20, 22]. Most of the available data on SIS has been obtained from studies conducted by the U.S. military. Table 1 summarizes the data from several studies on the incidence of SIS among military pilots. The occurrence of this reaction ranged from 10 percent to 88 percent, and involved both fixed-wing and rotary-wing flight simulators. It is unfortunate that there has not been a study on the incidence of this phenomenon among civilian commercial air crews during their simulator training. However, there are some anecdotal reports indicating the occurrence of SIS among this pilot population.

Sleep deprivation, general fatigue, alcohol consumption, emotional instability, excessive rigidity in personal behavior, neurotic reactions, anxiety, fear, and insecurity are all factors that can increase susceptibility to motion sickness of any type (including SIS). Females have been shown to be more susceptible to motion sickness than males of any age. In addition, reduced mental activity (low mental workload) during exposure to an unfamiliar motion has been implicated as a predisposing factor for motion sickness. A pilot who concentrates on mental tasks will be less likely to become motion sick because his attention is diverted from seeking orientational clues.

Susceptibility Increases with Experience

A possible explanation for the occurrence of SIS is provided by the neural mismatch theory, also known as cue conflict theory, sensory rearrangement theory or perceptual conflict theory [6, 18, 19]. This theory indicates that SIS may be the result of a conflict between the sensory cues (visual, vestibular, proprioceptive — those activated by stimuli produced by movements or tension within tissues) produced by the flight simulator and the pilot's expectations of what should be, based on his or her past flight experience. In other words, when the actual sensory input transmitted by the eyes, the vestibular system and the proprioceptive receptors does not agree with the expected sensory input derived from past flight experience, a sensory mismatch occurs.

This mismatch may also occur when there is a conflict or incongruity between the several types of information transmitted by the visual, vestibular and proprioceptive receptors. Such a sensory mismatch leads to neurovegetative responses that represent the signs and symptoms of SIS. The longer and more intense the exposure to a sensory mismatch is, the higher the probability of experiencing SIS. However, the repetitive exposures to the unfamiliar motion conditions produced by a particular flight simulator can result in adaptation and increased tolerance. Unfortunately, adaptation of a pilot to a particular simulator is not the ideal solution because upon return to the motion conditions encountered during real flight, a sensory mismatch can occur again, and this time it could result in airsickness.

It would be reasonable to expect that pilots who do not experience airsickness during real flight should not experience SIS, if the quality of the flight simulator was almost identical to real flight. However, the occurrence of SIS among aircrews can be regarded as evidence of the limitations of current equipment to simulate real flight [13]. An inadequate flight simulation exposes a pilot to an unfamiliar motion environment to which he is not adapted and can result in SIS. Imperfections in flight simulation are better perceived by pilots with extensive flight experience, because they have learned to expect certain orientational clues to occur in response to certain control inputs. These observations explain why highly experienced pilots are more likely to develop SIS than less experienced pilots [4,11].

There are several factors related to the design and operation of modern flight simulators that can be involved in the occurrence of SIS, including:

- Flat screens and computer-generated imagery systems for simulated "outside views" through the windshields can produce optical distortion, inadequate image resolution and annoying flicker.

- Multiple, wide-field-of-view screens can result in abnormal stimulation of peripheral vision.

Table 1. The Incidence of Simulator Induced Syndrome Among Military Pilots

Author and Ref. No.	Type of Simulator	No. of Subjects Participating	% of Cases of SIS
Baltzley (1)	Fixed Wing (P-3C)	51	22
Baltzley (1)	Fixed Wing (E-3C)	13	62
Baltzley (1)	Fixed Wing (2E-6)	10	30
Baltzley (1)	Fixed Wing (F/A-18)	45	56
Baltzley (1)	Fixed Wing (F/A-18)	22	45
Crosby (3)	Fixed Wing (P-3C)	20	50
Frank (5)	Fixed WIng (E-2C)	21	48
Hamilton (7)	Fixed Wing (CP-140)	16	50
Hartman (8)	Fixed Wing (SAAC)	114	52
Kellogg (10)	Fixed Wing (SAAC)	48	88
Kennedy (13)	Fixed Wing (F/A-18)	94	31
Kennedy (13)	Fixed Wing (F/A-18)	26	27
Kennedy (13)	Fixed Wing (F-14)	52	10
Kennedy (13)	Fixed Wing (E-2C)	55	47
Kennedy (13)	Fixed Wing (P-3C)	66	39
Magee (16)	Fixed Wing (C-130H)	42	83
Money (17)	Fixed Wing (CP-140)	114	43
Baltzley (1)	Rotary Wing (CH-46)	176	48
Baltzley (1)	Rotary Wing (AH-64)	130	50
Baltzley (1)	Rotary Wing (CH-53)	121	55
Baltzley (1)	Rotary Wing (SH-3)	98	57
Havron (9)	Rotary Wing (FH-2)	36	78
Kennedy (13)	Rotary Wing (SH-3)	223	60
Kennedy (13)	Rotary Wing (CH-46)	281	26
Kennedy (13)	Rotary Wing (CH-53D)	159	36
Kennedy (13)	Rotary Wing (CH-53E)	230	33

- Inadequate screen illumination, inadequate viewing distance and off-axis viewing can all produce visual fatigue, and result in parallax and distorted visual perception.

- Presence of visual and inertial lags inherent in the equipment can cause desynchronization between the display of visual information and the actual motion of the simulator. This can result in conflicting sensory stimulation.

- Indiscriminate use of the situational freeze mode or the reset function by the instructor can be very disorientating for air crew members.

Overall, SIS is more frequent among aircrews training in simulators with six-degrees-of-freedom and in simulators with computer-generated imagery systems [3, 10, 21].

Consequences Addressed

There are a number of results that can be attributed to SIS:

- A possible decrease may occur in the voluntary use of flight simulators to avoid the unpleasant symptoms (immediate and post-flight).

- Aircrews may experience distrust or lack of confidence in the received training, due to the unfavorable conditions under which practice in the flight simulator took place. Therefore, it is reasonable to assume that SIS may prevent air crews from achieving the full training potential of flight simulators.

- Post-flight symptoms can result in impaired psychomotor performance which may interfere with the safe operation of motor vehicles (aircraft, automobiles, motorcycles, etc.).

- Occurrence of delayed symptoms of SIS upon return to normal flight duties may represent a potential risk for the safe operation of the aircraft.

Among SIS defense and prevention mechanisms are the following:

- Pilots who have experienced SIS in the past should be aware that prolonged or intense exposure to the simulator on subsequent training flights may again result in SIS.

- Simulator training should be avoided when pilots are diseased, ill or physiologically impaired due to self-imposed stress (fatigue, sleep deprivation, use of non-prescription medications, alcohol consumption within 24 hours).

- If a pilot experiences motion sickness during training, he should be instructed to immobilize his head against the headrest and the flight should be terminated as soon as possible. The pilot should be assisted out of the simulator (due to possible postural instability), and instructed to adopt a supine position, close his eyes, and relax. The remaining simulator training should be re-scheduled for at least 24 hours later.

- Pilots involved in simulator training (especially those who have experienced SIS) should be instructed to sleep adequately and to avoid self-imposed stresses before they return to their normal flying duties.

- At the discretion of the company's physician, anti-motion sickness drugs could be used prior to simulator training to prevent the onset of symptoms. This allows air crews to cope with the training to prevent the onset of symptoms and promotes an adequate learning environment. Scopolamine 0.3 to 0.6 mg, taken orally 30 minutes to one hour before training could be used for an effective preventative measure. The only inconveniences with the use of scopolamine are its side effects including drowsiness, dry mouth, pupillary dilation and impaired visual accommodation. An alternative is to use an oral combination of 0.3 to 0.6 mg of scopolamine and 5 to 10 mg of dextroamaphetamine. This combination is more effective than scopolamine alone, and eliminates the drowsiness. Another effective oral combination is 25 mg of promethazine and 25 mg of ephedrine taken one hour prior to the training. It is very important to make sure that the effects of any of these drugs disappear completely before air crew members are allowed to return to normal flying duties.

Ideally, the solution to the problem of SIS would be to improve the design of current flight simulators to make them as realistic in relation to actual flight as possible. Unfortunately, any improvement in flight simulation fidelity (especially at the upper limits) is expensive. In addition, a greater level of fidelity does not always result in better training effectiveness. Research has shown that even though a good return in training transfer is obtained from a moderate level of realism fidelity, only minor improvements in training transfer can be attained at greater levels of realism. Therefore, in order to maintain a balance between cost and training effectiveness, careful thought must always be given to specify the requirements for fidelity in any given flight simulator.

References

1. Baltzley, D.R., Kennedy, R.S., Berbaum K.S., Lilienthal,

M.G., and Gower D.W. "The time course of post flight simulator sickness symptoms." *Aviation, Space and Environmental Medicine.* 60:1043-1048, 1989.

2. Chappelow, J.W. "Simulator sickness in the Royal Air Force: a survey." *Technical Report No. NTIS-N89-12171/9.* Institute of Aviation Medicine, Royal Air Force, Farnborough, England, 1988.
3. Crosby, T.N., and R.S. Kennedy. "Postural disequilibrium and simulator sickness following flights in a P3-C operational flight trainer." In: Preprints of the 53rd Meeting of the Aerospace Medical Association. Aerospace Medical Association. 147-148, 1982.
4. Crowley, J.S. "Simulator Sickness: A problem for Army aviation." *Aviation Space and Environmental Medicine* 58:355-357, 1987.
5. Frank, L. H., R.S. Kennedy, R.S. Kellogg, and M.E. McCauley. "Simulator sickness: reaction to a transformed perceptual world. I. Scope of the problem." *Technical Report No. NAVTRAQUIPCEN TN-65.* Naval Training Equipment Center, Orlando, FL, 1983.
6. Guedry, F.E. Jr. "Conflicting sensory orientation cues as a factor in motion sickness." *Technical Report No. NASA SP-314.* Fifth Symposium on the Role of the Vestibular Organs in Space Exploration. Pensacola, FL, 19-21 August 1970.
7. Hamilton, K., L. Kantor, R. Heslegrave, L. Magee and K. Hendry. "Simulator induced sickness in the CP-140 (Aurora) flight deck simulator." *Technical Report No. DCIEM-89-RR-32.* Defense and Civil Institute of Environmental Medicine, Downsview, Ontario. 1989.
8. Hartman, B.O., and C. Hatsell. *Field Study: SAAC simulator.* USAF School of Aerospace Medicine, Brooks AFB, San Antonio, TX 1976.
9. Havron, M.D., and L.F. Butler. "Evaluation of training effectiveness of the 2FH2 helicopter flight trainer research tool." *Technical Report No. NAVTRADEVCEN 1915-00-2.* Port Washington, NY, Naval Training Device Center, 1957.
10. Kellogg, R.S., C. Castore, and R.E. Coward. "Psychophysiological effects of training in a full simulator." In: Preprints of the 51st Annual Scientific Meeting of the Aerospace Medical Association. 203-204, 1980.
11. Kennedy, R. S., and L. H. Frank. "A review of motion sickness with special reference to simulator sickness." Workshop on Simulator Sickness, National Academy of Sciences/National Research Council, Washington, D.C., 1983.
12. Kennedy, R. S., and Lilienthal, M.G. "Simulator sickness: Incidence of simulator aftereffects in Navy Trainers." Paper presented at the Annual SAFE Meeting, Las Vegas, Nevada, 1984.
13. Kennedy, R.S., M.G. Lilienthal, K.S. Berbaum, D.R. Baltzley, and M.E. McCauley. "Simulator sickness in U.S. Navy flight simulators. " Aviation, *Space and Environmental Medicine.* 60:10-16, 1989.
14. Kennedy, R.S., M.E. McCauley, R.W. Root, L.H. Frank, A.C. Bittner, Jr., and T.A. Binks. "Simulator sickness: Reaction to a transformed perceptual world, VI. Preliminary site surveys." *AGAR Conference Proceedings No. 372:34.1-34.11*, Motion Sickness: Mechanisms, Prevention and Treatment. NASA Langley Research Center, Hampton, VA, 1984.
15. Kroll, J.D. "Control of simulator sickness in an AH-64 aviator." *Aviation, Space and Environmental Medicine.* 60:1202-1203, 1989.
16. Magee, L.E., L. Kantor, and D.M.C. Sweeney. "Simulator induced sickness among Hercules aircrew." *Technical Report No. NTIS-N89-12141/9.* Defense & Civil Institute of Environmental Medicine, Downsview, Ontario. 1989.
17. Money, K.E. "Flight simulator sickness in the Aurora CP 140 FDS." *Technical Communication No. DCIEM-80-C-44.* Defense and Civil Institute of Environmental Medicine. Downsview, Ontario. 1980.
18. Reason, J.T., "Motion Sickness: A Special Case of sensory rearrangement." Advance Science 26:386-393, 1970.
19. Reason, J.T., and J.J. Brand. "Motion sickness adaptation: a neural mismatch model." *Journal of the Royal Society of Medicine.* 71:189-829, 1978.
20. Ungs, T.J. "Simulator induced syndrome: evidence for long-term aftereffects." *Aviation, Space and Environmental Medicine.* 60:252-255, 1989.
21. Ungs, T.J. "Simulator induced syndrome in Coast Guard aviators." *Aviation, Space and Environmental Medicine.* 59:267-272, 1988.
22. Chappelow J.W. "The incidence of simulator-induced sickness among RAF aircrew." Paper presented at the 64th Aerospace Medical Panel Meeting/Symposium on Motion Cues in Flight Simulation and Simulator Induced Sickness. Conference Proceedings No. 433 Neuilly-sur-Seine, France: NATO-AGARD, 1987.

About the Author

Melchor J. Antuñano is a physician specializing in aerospace medicine. He is a research scientist for Krug Life Sciences at the U.S. Air Force School of Aerospace Medicine, and studies the physiological and psychological effects of human exposure to environmental and operational stress.

Dr. Antuñano is chief editor of the Bulletin of the Iberoamerican Association of Aerospace Medicine, *and associate editor of the* Bulletin of the Aerospace Human Factors Association.

What's Your Input?

Flight Safety Foundation welcomes articles and papers for publication. If you have an article proposal, a completed manuscript or a technical paper that may be appropriate for *Human Factors and Aviation Medicine* please contact the editor. Submitted materials are evaluated for suitability and a cash stipend is paid upon publication. Request a copy of "Editorial Guidelines for Flight Safety Foundation Writers."

HUMAN FACTORS AND AVIATION MEDICINE

Copyright © 1991 FLIGHT SAFETY FOUNDATION INC. ISSN 0898-5723

Please send two copies of reprinted material to the editor. Suggestions and opinions expressed in this publication belong to the author(s) and are not necessarily endorsed by Flight Safety Foundation. Content is not intended to take the place of information in company policy handbooks and equipment manuals, or to supersede government regulations. • Manuscripts must be accompanied by stamped and addressed return envelopes if authors want material returned. Reasonable care will be taken in handling manuscripts, but Flight Safety Foundation assumes no responsibility for material submitted. • Subscriptions : $50 U.S. (U.S. - Canada - Mexico), $55 Air Mail (all other countries), six issues yearly. • Staff: Roger Rozelle, director of publications; Arthur H. Sanfelici, senior editor; Ashton Alvis, production coordinator; Sandra Mitchell, editorial assistant • Request address changes by mail and include old and new addresses. • Flight Safety Foundation, 2200 Wilson Boulevard, Suite 500, Arlington, Virginia 22201-3306 U.S. • telephone: (703) 522-8300 • telex: 901176 FSF INC AGTN • fax: (703) 525-6047