SAFETY ASPECTS IN AVIATION PHYSIOLOGICAL TRAINING DEVICES

MR. HANS W. WINDMUELLER
Land/Sea Trainers Modification Division
Naval Training Device Center

INTRODUCTION

This topic has been selected for discussion because of the rather unique problems associated with safety, when dealing with a group of devices, which we commonly refer to as Physiological Trainers. Safety, of course, is a subject that is written, shown, talked, and even preached about by virtually every segment of our society. However, in these trainers safety becomes the primary design criteria with all required hardware acting to support this one goal.

In this paper, it is intended to discuss this "safety as a design goal" by first briefly discussing Physiological Trainers and their training objectives, and then give a summary of a few of the more "notorious accidents" which bear directly on engineering design as applied or, in these instances, misapplied to physiological training environments.

PHYSIOLOGICAL TRAINERS AND THEIR TRAINING OBJECTIVES

Physiology, as defined in Webster's dictionary, is a branch of biology dealing with the processes, activities, and phenomena incidental to and characteristic of life or of living organisms. A physiological training device is, therefore, best described as a device associated with or causing the disorganization of physiological functions of a student. Aviation Physiological Training strives to teach the individual aviation-oriented student the "art," for lack of a better word, of survival when placed in an environment which is abnormal and potentially hazardous to him. In order to accomplish this a necessary part of the training must, in fact, cause a disorganization of physiological functions of the student. This is accomplished under controlled conditions, but unfortunately in some devices, in potentially hazardous personnel environments.

Typical of these devices are the Device 9U44 series, Dilbert Dunkers; Device 6EQ2 series, Ejection Seat Trainers; and probably the most complex and hazardous physiological device, the 9A/9U49 series, Low Pressure Chambers.

The training objective of the first of these devices, the Dilbert Dunker Ditching Trainer, is to train and expose a student to the methods and procedures required to escape from an aircraft which has somehow managed to become "water-borne" vice "air-borne"; that is, he has gotten his wings wet because he was over water and his propeller did not want to rotate any longer, or he got a "cold-cat" shot from the deck of a carrier in the case of a jet or propeller aircraft. In order to expose the student to this situation, we place him in a carriage at a height of approximately 25 feet mounted to rails which angle at approximately 40^{o} to a water surface. The student is fully strapped into an operational aircraft seat after which the carriage, with student attached, is released. The ensuing events can best be described as the world's wildest roller coaster ride in that the carriage impacts the water at a considerable speed and almost immediately inverts and sinks to a depth which totally submerges the trainee. The trainee, at this point, finds himself upside down, firmly strapped and held by a number of belts and fittings to a seat, and submerged under water in a disoriented condition. His proper procedure is then to coolly and calmly release himself from the seat's restraining harness and swim out. Should he panic, and have to be extricated by safety divers, he has it all to look forward to again.

The second of these devices, the Ejection Seat Trainer, has the objective of training personnel to escape from an aircraft which, in its simplest sense, is anticipated to stop flying in the very immediate future. With the advent of relatively fast maneuverable and high altitude aircraft, which includes most post-World War II military aircraft, it is virtually impossible to open a canopy, climb out a cockpit and jump, thereafter opening a parachute. As a result, the ejection seat was invented and over the years considerably improved. The various ejection seat trainers we use are fitted with different operational ejection seats at various military stations, in such a manner, as to permit a Naval aviator to undergo ejection seat training on a seat identical to that used in the particular type aircraft he is flying. In order to accomplish this training the student is placed in an ejection seat, which is at rest, in a semi-enclosed area dimensionally similar to an aircraft cockpit. The seat is attached to a sled, which is mounted to rails, and is affixed at an angle of approximately 75^{o} to the horizontal. The student is given the proper ejection sequence and body position and, thereafter, is told to fire the seat using the appropriate activation method. Upon student activation, a pyrotechnic charge is fired causing the sled, with seat and student affixed, to very rapidly travel up the rails to a height of approximately 10 to 12 feet.

The third of these devices, the High Altitude Low Pressure Chamber, has the objective of teaching the student or, in this instance, a group of students the use of high altitude life support equipment. This includes all the various types of personal oxygen supply masks and protective helmets as well as aircraft oxygen supply regulators as appropriate to the particular aircraft to be flown by the trainee. To the extent possible, the student uses his own personal issue survival equipment in the chamber, which serves the dual purpose of training the aviator, and gives him the assurance that the equipment will actually work, should he need it in his aircraft. Along with the operation of equipment, the trainee is extensively briefed on the physiological effects of high altitude or low atmospheric pressure on his body. Demonstrations are conducted to demonstrate hypoxia, which is a lack of oxygen to the bran and pressure breathing requiring the trainee to work to exhale, and a number of other rather insidious things, which a pilot may expect to be confronted with, when flying at altitudes above 10,000 feet without cabin pressurization. The device, in which this training occurs, is a rather substantially large compartmentalized steel rectangular box,which is attached by piping to a rather substantial vacuum pump. Through the use of controlling mechanisms, the pump is allowed to evacuate a compartment or compartments of the chamber which thereby places the student in a reduced atmospheric pressure environment identical to that experienced at high altitude.

In addition to the group training accomplished in all of the 9A/9U series Low Pressure Chambers, certain of these devices; specifically, the 9A9s and the 9U49B, have the capability of rapid or explosive decompression, which is used in conjunction with full pressure suit work. The full pressure suit is a rather complex garment which has the purpose of fully enclosing the human body and insuring that an atmospheric pressure is maintained on the body which sustains life (3.5 psia). This type suit has probably been seen by almost everyone in the world in that it was shown very impressively by Mr. Neil Armstrong on July 20, 1969, when he stepped on the surface of the moon. While Mr. Armstrong's suit was definitely of the very latest design it, in fact, served the same purpose as a military-type full pressure suit. In fact, if the life support back pack were removed from the NASA suit and the color was changed from white to our rather notorious olive drab, it would be difficult to distinguish an astronaut from an F-4 Phantom pilot, flying at 60,000 feet. Since all Naval aviators are required to wear this type suit, when operating at altitudes above 50,000 feet MSL, they must also be trained in the application, operation and mobility limiting factors resulting from its use.

The Decompression Chamber variety of Low Pressure Chambers is used for this type training. In this chamber there are three locks or compartments. The main compartment is approximately 18 feet long by 8 feet wide and 8 feet high. In a full pressure suit run this compartment is evacuated to a pressure equivalent to that at 100,000 feet MSL altitude (0.16 psia). The student, in his full pressure suit, is placed in the adjacent lock or compartment, which is called the intermediate lock. This lock is then evacuated to an equivalent pressure to that found at 35,000 feet MSL (3.47 psia). Then, by activating a large electro-pneumatically operated valve, air is allowed to pass from the intermediate compartment into the accumulator compartment. This action is rather impressive to watch since the end result is that the trainee, or more properly the full pressure suit, is exposed to a change in pressure equivalent to flying from 35,000 feet MSL (3.47 psia) to 65,000 feet MSL (0.74 psia) in something under three quarters of one second (the device is actually capable of performing this in 0.25 seconds). The effect on the student is that his suit "inflates" (actually the suit is maintaining existing 35,000 feet pressure and, since less air is around it, it appears to inflate), and the student meanwhile realizes that he has a mobility-restricting appurtenance around him. He will also probably note a beaker of water at approximately 98.6^{o}F, which is placed in the chamber for demonstration purposes, boiling away as though the temperature has been raised to 213^{o} F. This gives him a real appreciation of his full pressure suit, since he has been told, and now realizes that if his body were exposed to an altitude in excess of 62,000 feet MSL (0.89 psia), his blood would be boiling exactly like the water in the beaker.

This training, therefore, demonstrates the use, application and requirement for the full pressure suit in high altitude aircraft operations, since if an aircraft should lose cabin pressure at these altitudes, as a result of hostile action, failure of some cabin surface, or any number of reasons, there just would not be enough time to take remedial action. This incidentally, from all available information, is unfortunately an exact analogy of the situation the three Soyuz 11 Cosmonauts were exposed to in their fateful attempt to return to Earth after a completely successful orbiting space lab mission in late June of this year.

With this rather brief description of three of our physiology-type trainers, you can probably begin to appreciate the difference between a physiology device, and say, an operational flight and weapon system trainer (OF/WST). In the OF/WST the student is essentially taught to reason out and react appropriately as a result of audio-visual type information. In physiological aviation survival training you might say we go a little deeper. In the Dilbert Dunker we strap him in, run him down rails, flip him upside down, and put him under water; in the Ejection Seat we put an explosive charge under his rear, tell him to fire it, while reminding him that if he doesn't hold his back straight he could suffer a fractured spine; and in the Low Pressure Chamber we take his oxygen away and tell him he will not survive unless he uses his equipment properly. This then explains why physiology is different and also the extraordinary part safety must play in this type of device.

PHYSIOLOGICAL ENVIRONMENTS AND ACCIDENT HISTORY

From the preceding discussion, it would appear quite obvious that subjecting human beings to the "exhilerating experiences" of a physiological device must, by necessity, sooner or later result in an injury and, in fact, a good argument can be made for this position. On the other hand, the student or trainee is at a point in life when he could readily be considered in ideal physical condition. The average trainee has been pumped full of health-assuring vaccines, examined from head to foot, has no heart, liver, lung or kidney problems, and probably cannot even exhibit a decent hemorrhoid. The fact is, that, the trainee is probably at the peak of physical condition and at an age where his body can withstand punishment and abuse better than at any time in his life.

What, then, is the reason that accidents happen in a physiological training environment? My experience, over the past nine years, has been that one factor always stands out in every accident. This factor is the total underestimation of the crossing of sciences and fields of technology involved in design, fabrication, maintenance, and utilization of any of the physiological training devices. After all, these devices certainly do not appear to have nearly the complexity of any self-respecting computer. The truth of this situation is, however, quite different. While the computer designer must have an excellent knowledge of state-of-the-art electrical engineering, the engineer working in physiology has almost daily need for, at least, a basic knowledge of electrical engineering, mechanical and structural engineering, including hydraulics and pneumatics, chemistry, physics and in the case of altitude chambers, high altitude physics. Then, to further complicate the situation he must understand how each of these fields affects a living organism. The effect on living organisms is, needless to say, the worst stickler in this requirement. Unfortunately, the engineer or technically oriented man tends to "think at right angles" to the physiologist or medical individual. As a result, a lack of communication is quickly established and the two go their separate ways with no follow-up on the part of the engineer. The engineer complains that no one appreciates his technological breakthrough and the user, in this case the physiologist, thinks it is not esthetically pleasing and something is wrong, but he does not know how to explain it. Meanwhile, the engineer does not follow-up on the device's operation or utilization since he will not be appreciated. Then "bingo" a disaster occurs. This cycle seemingly occurs over and over again to the consternation of everyone, especially the accident victim. That is to say, the one truth in this rather unusual training device field is "Murphy's Law" (anything that can go wrong will go wrong) will prevail.

As an example, take the case of the gentleman who is now considered the father of aviation physiology. During the early 1800's he was concerned with the physiological aspects of high altitudes on living organisms. Not being certain what would happen to a human, ascending from the surface of the earth, he wisely chose one goat and one duck to be put into a gondola below a hot air balloon. The balloon was released and subsequently ascended with the goat and duck. An hour or so later the balloon descended back to earth and the goat was found to be in excellent condition, thereby, proving that a living animal and, in all probability, a human could exist at what was then considered a high altitude. Unfortunately, however, the thought of restraining the goat within the gondola had not been properly considered and the goat had, in fact, not appreciated the experience of being the first goat in free flight. As a result, while the experiment was in all aspects a scientific success, the duck was found dead in the gondola, trampled to death by the goat and, thereby, proving conclusively that "Murphy's Law" existed before the twentieth century, at least for ducks. Since that time there have been a number of similar situations in a physiology training or physiology environment. Some are comical, but unfortunately, many are sad.

On the Device 6EQ2 Ejection Seat Trainer a situation occurred where a young Naval aviator, an Ensign, found that the ejection seat went further up the rails than anticipated. In fact, the seat went all the way to the top of the rails and was teetering back and forth in the breeze balanced precariously by only two of its four restraining mechanisms. Fortunately, the Ensign had a strong heart and no injury resulted. The cause of the incident was probably too much black powder in the cartridge used in an overheated barrel assembly on a very hot day. Shortly, thereafter, a modification was made to the ejection seat firing barrels employing a relief port, which activiated if overpressure from a charge occurred. In the 1960's, a number of accidents have occurred on ejection seat trainers, such as broken toes, when a student's foot hit the simulated instrument panel of the cockpit section of the trainer as the seat moved up the rails, or bruised elbows, when the student's arms hit the side of the cockpit. We even had a barrel assembly explode at a Naval Air Station in our own state of Florida. In each instance,modifications were quickly made and fortunately only one man was seriously injured.

On the Dilbert Dunker, no injury of any consequence is known to have occurred until early last year when we were informed that a Marine pilot at a Marine Corps Air Station sustained fractures of the 6th and 7th cervical vertebra, as well as a badly cut mouth. The history of this accident is a typical "Murphy's Law" situation. In other words, a long series of circumstances just waiting for an accident to happen. The device had been in operation for many years without any apparent problem. At the time, the device had not received any type of quality assurance and inspection, and because of its long history of good operation, had not received any priority for an inspection. The Marines, by their very nature of being good fighting men, did not really have their hearts in water survival training and consequently did not properly perform even routine maintenance on the device. They also had determined that the inertia reel on the ejection seat was too much trouble to pull against each time a student was strapped into the device. As a result, they had pulled the seat shoulder straps out and locked the inertia reel by wedging something in the teeth of the reel. This of course allowed the student to move his upper torso freely in the seat, since his shoulder straps no longer restrained him back into the seat. In addition to this, the two catch assemblies, which are supposed to prevent the cockpit from inverting until being released just before reaching the water, were in such condition that one catch was totally inoperative, and the other so rusty that the Marines admitted having to jump up and down on the cockpit to make it engage, when the carriage was retrieved back to the top of the rails after a ditching run. Add to this a particular day when the usual operating crew were not available and a new crew took over. The result was that the cockpit was not locked down in the carriage, when the student got into the device. After strapping the student in, the carriage was released and almost immediately started to invert. At this point the cable drum operator slammed on the brake abruptly stopping the cable drum, cable and cockpit carriage. This naturally gave the cockpit, which incidentally had reached approximately 90° of its full 180° inverted position, a tremendous jerk, thereby, giving the student what can only be called one of the most confirmed cases of whip lash in history. In this accident everyone was actually lucky. Why lucky? Because if the carriage had continued down the rails in the inverted position, the major part of the cockpit would have cleared the edge of the pool and, along with the section of the student's body from the neck down, gone into the water. But the top of the seat, and from the neck up, the student would have stayed on dry land. Needless to say, immediate "Murphy" proof modifications were initiated and a quality assurance inspection procedure was established. Since that time, several additional safety oriented, but unrelated modifications have been made on this series of devices.

The 9A/9U49 series of Low Pressure Chambers, in the area of safety, present by far the greatest challenge of any physiology training device. To date, we in the Naval aviator training have been extremely fortunate. We have not experienced a single known serious accident in any low pressure training chamber. It might be added, in retrospect, that knowing the scope and purpose of numerous modifications, directives, and procedures, which have been instituted since 1965, would amaze any rational person in that "Murphy's Law" never caused a group fatality in one of these devices. Unfortunately, our counterparts in both NASA and the Air Force were not that lucky. The NASA incident occurred on January 27, 1967, when LCOL Virgil I. Grisom, LCOL Edward H. White II, and LCDR Roger B. Chaffee were burned alive in a physiology environment, resulting from a flash fire aboard Apollo I, during a launch pad test. This fire was ultimately attributed to electrical arcing in a wiring harness within the capsule. Just four days later, on January 31, 1967, at Brooks Air Force Base, Texas, two airmen met a similar fate. In order to better appreciate the hazards of a fire in a closed compartment, housing personnel in an altitude simulating physiological environment, and specifically in these cases, as in our chambers, an oxygen enriched atmosphere, let me briefly go over the situation that occurred at Brooks.

At about 8:18 AM, on the morning of January 31, 1967, two airmen entered a low pressure chamber for the purpose of conducting tests in the chamber, at an equivalent pressure of 18,000 feet MSL (7.3 psia), in a high oxygen content environment. After about twenty minutes the outer lock in which they were standing had reached the 18,000 foot altitude, and the door was opened between the outer lock and adjacent main lock, which was already at 18,000 feet. The two airmen then entered the main lock to attend to some animals on which the testing was being performed. A few minutes later the crew chief, who was sitting at an instrument panel outside, heard a noise, which to him sounded like an animal cage being dropped inside. He then went to a porthole where he saw fire in the chamber. Immediately, he sounded an alarm and the fire department arrived in two minutes, and two doctors were ready to give aid in approximately two and a half minutes. However, the firemen and doctors were all to no avail. The casualty list--sixteen rabbits, about fifty mice, and two young airmen.

The resulting investigation indicated that the fire had probably been started by one of the airmen stepping on a teflon covered power cord attached to a goose neck lamp which was plugged into a standard 110 vac utility outlet inside the chamber. As a result of stepping on the cord, the cord shorted to the steel to the steel deck with the arc igniting the bottom of the airman's trousers. Experiments have shown that once ignited the airman would have been completely engulfed in flame in a matter of mili-seconds and, assuming combustible materials within the chamber, the entire chamber would have been engulfed in flame within two seconds. What went wrong? In my opinion, somewhere there are some engineers and technicians now spending some sleepless nights because they installed 110 vac utility outlets in a chamber housing combustible materials totally neglecting "Murphy's Law." Truly—an accident waiting to happen.

CONCLUSION — A CHALLENGE OF SAFETY

In conclusion, I would like to summarize this topic by saying--physiological training devices and physiological training environments are different. We deal directly with the human body—not just with replaceable hardware. I would also like to give you the following six tenets of "Murphy's Law":

1. IN ANY FIELD OF SCIENTIFIC ENDEAVOR, ANYTHING THAT CAN GO WRONG, WILL GO WRONG.