Medical Problems in Testing High Altitude Pressure Suit

CAPTAINS CHARLES L. WILSON AND MYRON B. ZINN, USAF, MC

DURING a ten-month period ending April 24, 1959, the Aerospace Medical Laboratory completed an intensive study of the medical problems encountered in pressure suit testing in the low pressure chamber. It is important to distinguish between the results of routine suit indoctrinations and experimental suit testing. Routine indoctrinations connote the use of standardized items of personal protective equipment and standard profile chamber tests. In experimental pressure suit testing, new and unproved suit types are used. It means that these suits are tested for much longer time intervals and at extremely low barometric pressures, such as 100,000 feet. This series of unfamiliar variables existing in research and development renders experimental suit testing more hazardous in theory and in fact.

STANDARD CHAMBER TEST PROCEDURE

Preparation of a subject for a routine or experimental pressure suit test requires nearly ten manhours of work. The actual execution of the test requires eight to sixteen additional manhours of labor. Officers and airmen of the Aerospace Medical Laboratory act as subjects. The subject dresses in long cotton underwear which partially protects the skin from suit pinching and absorbs perspiration. He sits at a console which provides 100 per cent oxygen and denitrogenates for the following required period:

Two hours denitrogenation if ambient pressure is to be above 25,000 feet 15 minutes or more.

One hour denitrogenation if ambient pressure is to be above 25,000 feet 5-15 minutes.

Thirty minutes denitrogenation if ambient pressure is to be above 25,000 feet less than 5 minutes.

With this schedule, no instances of the "bends" occurred. The denitrogenation may be accomplished with the A-13A mask; then the breath is held and the helmet is slipped on. This eliminates the fatigue of wearing the helmet during the two hours of denitrogenation. The subject is then assisted in donning the pressure suit and gloves. The feet do not require formal pressurization by bladder socks unless the test profile is to be in excess of 65,000 feet for more than one hour. However, a snug shoe such as ordinary oxfords is required. When a loose sneaker is worn, there is excessive room for foot swelling. Prolonged non-pressurization of the foot subsequently causes tissue edema and ultimately arterial occlusion from high extraluminal pressure. The symptoms are ischemia and the associated tingling, numbness and pain. Chamber repressurization and concomitant suit depressurization causes immediate re-

---

From Aerospace Medical Laboratory, Wright-Patterson Air Force Base, Ohio. Dr. Wilson is now at 10 Dietz Court, Hyde Park 36, Massachusetts.

Presented on April 27, 1959, at the 30th annual meeting of the Aero Medical Association, Los Angeles, California.

active hyperemia and relief of symptoms of arterial occlusion.

The subject enters the chamber, is seated, and the following connections are made: microphone and earphone, electrocardiogram, blood pressure, bladder and capstan pressure, heat source to facepiece, lap belt, shoulder harness and parachute. A "press-to-test" device on the seat-kit inflates the suit to check bladder and capstan pressures. The chamber is equipped with a 16-mm camera and flood lights to record subject performance during tests. The camera is triggered at the medical monitor's station. A crystal pickup has been developed and is now being tested to record blood pressures at low barometric pressures. Since evacuating a chamber also evacuates the stethoscope, a substitute device was needed to convey the Korotkov sounds. The crystal pickup voltages are amplified and fed into a speaker mounted near the medical monitor. The chamber is evacuated to 40,000 feet. The outside lock (which contains an emergency crewmember) is evacuated to 25,000 feet where he remains for the test period. The subject chamber is then evacuated to 100,000 feet to check out suit pressures and then returned to 30,000 feet. Next a two and one-half second decompression is accomplished to the highest possible altitude (which is 65,000 feet with the accumulator in this laboratory). The individual test profile continues from this point.

We employ a "count-down" for all decompressions. The subject is directed as follows: "On the count of 'three', take in your normal volume of breath —don't take in a deep breath. By the count of 'two' breathe out half of this volume, and by the count of 'one' exhale the remaining volume, at which time the decompression will occur." (The subject is cautioned never to hold his breath.) Once this count-down is described to the subject, a dry run count-down is performed, during which time the observers listen to and watch his breath excursions to ascertain that he understands and follows the instructions explicitly. Then the actual decompression count-down is performed. Once a slow or two and one-half second decompression has been successfully completed, the subject sustains a rapid or one and one-half second decompression from 30,000 to 65,000 feet. We have never encountered mediastinal emphysema in our chamber subjects as a result of rapid decompression. The only incident caused by a rapid decompression is described in this paper as Case 3.

ROUTINE PRESSURE SUIT INDOCTRINATIONS

The Aerospace Medical Laboratory offers pressure suit support to several projects in the U. S. Air Force, the U. S. Navy, and the National Aeronautics and Space Administration (NASA).

During the development of the X-15 research aircraft by a joint effort of NASA, the Navy, and the Air Force, it became apparent that a full pressure suit would be needed to protect the pilot in the event of cabin depressurization. Through research and development efforts in this laboratory, a new and greatly improved full pressure suit, the MC-2 (Fig. 1) has been produced. A full pressure suit is any combination of garments which delivers equal pressures to the whole surface of the body. These pressures must be adequate to prevent tissue fluid vaporization and at the same time deliver an adequate pO_2 to the alveolar gas mixture. Current full pressure suit pressures deliver between 150 and 200 mm. Hg. pressure to the body when suit and man are exposed to a vacuum. Partial pressure suits are those which were originally designed to deliver pressures to all parts of the body except the arms and legs. As the state-of-the-art of partial pressure suits became more refined, arm and leg protection was added to increase time-altitude protection capabilities. At present, the hands are pressurized above 55,000 feet, but the feet are not pressurized until above 65,000 feet. Currently, all the pilots who are scheduled to fly in the X-15 are being fitted at the manufacturer's plant, and subsequently indoctrinated. It surpasses the performance of the MC-3A and MC-4 partial pressure suits, and adequately protects a human at 100,000 feet for long periods of time.

The "Man High" research project of the Air Force Missile Development Center, Holloman Air Force Base, New Mexico, and the Office of Naval Research "Stratolab" project both consist of human subjects being carried in capsules into the stratosphere by gigantic balloons filled with helium. One of the multitude of protective measures afforded the subjects is an MC-3A partial pressure suit ensemble.

There have been many Air Force research flights of aircraft to altitudes above 50,000 feet. Pressure suits are required to be worn during such flights. Examples of these missions are F-101, F-102, and F-104 "zoom" flights to extreme high altitudes to study relight of "flame-outs."

Fig. 1. The MC-2 full pressure suit.

There is another small group of subjects who have received pressure suit indoctrinations in physiological training units and demonstrated symptoms of near syncope during indoctrination. These subjects are referred to this laboratory for evaluation and recommendation. The usual complaint has been difficulty in breathing when the suit is inflated. After a few minutes of suit pressurization, the subject notes that he is "lightheaded," the field of vision constricts, and the chamber observers note a moderate to intense cyanosis of the face (the only visible part of the body when dressed in a pressure suit). If this situation is permitted to progress, the subject faints. Retesting these subjects in the same pressure suits has resulted in identically poor responses. The cause in all four cases observed has been a tight suit and neck seal fit. (See Table I).

TABLE I. EXPERIMENTAL AND ROUTINE TESTING WITH PARTIAL PRESSURE SUITS

Conditions	Experimental Tests MC-1 Suit (65,000 Feet for One Hour)	Routine Indoctrinations MC-3, 3A, 4 Suits (65,000 to 100,000 Feet for Five or More Minutes)	
		Selected Data Prior to July 1, 1958	Ten-Month Period of Controlled Observation
Total attempted tests	56	34	59
Number of tests completed	33	33	54
Number of tests aborted	23	1	5
Causes for abortion			
Unconsciousness	2	0	1*
Pre-syncope	5	0	1
Tachycardia (over 160)	3	0	0
Claustrophobia	1	1	0
Hyperventilation with apprehension	2	0	0
Poor ventilation	1	0	0
Improper suit fit	2	0	0
Suit failure (zipper broke)	2	0	1
Gas pains	1	0	1
Bends	0	0	0
Miscellaneous	4	0	2
Number of decompressions		35	45
Successful		35	45
Unsuccessful		0	0

*Case 2 in text

TABLE II. EXPERIMENTAL DATA FROM TESTS OF POSITIVE PRESSURE BREATHING AND PARTIAL PRESSURE SUITS

Conditions	Positive Pressure MA-2 Helmet 30 mm Hg at 40,000 Feet	Breathing A-13 Mask 30 mm Hg at 50,000 Feet	Suit Fit Problems Investigated*	Long Duration Tests with MC-3A or MC-4A at 100,000 Feet (without pressurized feet)
Number of tests	8	4	4	6
Duration of test (minutes)	15	10	20	160
Cause of termination				
Unconsciousness	1	1	0	0
Pre-syncope	0	0	4	0
Foot Ischemia	—	—	—	5
Fatigue	0	0	0	1
Tachycardia (above 160)	0	1	0	0
Arbitrary	7	2	0	0

*In all cases, after refitting, subject withstood two hours at 100,000 feet without incident.

Case 1.—A jet pilot with 1,000 hours, had a size 15 neck. His original helmet neck seal was a very tight size 12, causing obvious facial plethora when worn at ground level. His uninflated pressure suit restricted his maximum thoracic inspiratory circumference by 30 per cent. The torso length of his original suit was too short, causing him to hunch forward markedly. This torso-length misfit caused excessive pressure on the venous return from the neck when the suit was inflated. The suit-neck circumference also was too small, increasing the neck tourniquet effect. Finally, the legs and arms were too tight, causing increased capillary fill time and plethora. The compounded effect of all of these improper fittings produced a vascular engorgement of the head and extremities and restricted ventilation. When the subject was properly fitted, he remarked on the comfort of the new suit and passed his indoctrination test satisfactorily without any of the previous symptoms (Table II).

During routine indoctrination-type flights, two additional incidents occurred.

Case 2.—The subject was a twenty-three-year-old man. He wore an MA-2 helmet and an MC-4A suit with pressurized gloves (Fig. 2). Following two hours of denitrogenation, he was positioned in the low pressure chamber and it was evacuated to 100,000 feet. The bladder and helmet pressure were 145 mm. Hg. and the capstan was 15 psi, both of which are normal. After three minutes at this altitude, a sudden "hiss" of gas was heard through the intercommunication system. It became apparent that an open exhalation valve was not the cause of the sound because of its steady, unchanging character and lower frequency. The chamber was immediately "dumped" (a term used for extremely fast repressurization). The total time that elapsed before an emergency was recognized and recompression begun is unknown, but it was no more than ten to twenty seconds. During the rapid descent, the subject became cyanotic, slumped unconscious and convulsed. The chamber was dumped from 100,000 feet to 30,000 feet in about five seconds. At 30,000 feet, emergency oxygen was administered by mask. His color returned to normal and he promptly regained consciousness. A complete physical and ambulatory observation during the next fourteen days revealed no signs or symptoms of any remaining effects. The pressure loss occurred because the rubber face seal had become worn where it was rubbed by the plastic of the facepiece. This worn area suddenly perforated at high helmet pressures (Fig. 3). As a result of this experience, all field units, as well as this facility, check these gaskets carefully before each test.

Case 3.—The subject was a thirty-six-year-old man. He was wearing equipment identical to that in Figure 2, an MA-2 helmet and MC-4A pressure suit and gloves. The chamber was evacuated to 100,000 feet to check all pressures and related equipment.

Fig. 2. The subject is wearing the MC-4 partial pressure suit, MA-2 helmet, and parachute, and is seated in an ejection seat.

The chamber was returned to 30,000 feet and a two and one-half second decompression to 65,000 feet was accomplished without incident. The chamber was repressurized to 30,000 feet a second time in preparation for the rapid or one and one-half second decompression. The subject briefly opened his facepiece with the approval of the physician, equalized the tympanic membrane pressures, and closed his facepiece. The three observers and the subject, who is very well experienced, judged that all was normal. The second decompression to 65,000 feet was summarily accomplished. As the suit and helmet inflated, the subject as well as the observers immediately realized that the helmet was leaking dangerously. The subject actually placed his hands over the visor in an attempt to seal in the escaping gas pressures. Although the subject became

Fig. 3. Tear in rubber face seal in MA-2 helmet (Case 2).

cyanotic and lightheaded, the chamber was returned to a safe pressure before the subject became unconscious. Inspection of the helmet revealed that the wide rubber gasket around the facepiece was on the outside of the plastic visor. Before the subject closed his visor, the rubber face gasket flopped outside the helmet (Fig. 4). Thus pressures could not be contained in the helmet and bladder system. As a result of this accident, it was recommended that after a subject opens and closes his facepiece in flight, he push his "press-to-test"* to insure that the pressures hold in his suit and helmet.

EXPERIMENTAL PRESSURE SUIT TESTING

The Aerospace Medical Laboratory is responsible for developing better types of pressure suits to meet the demands of new weapon systems. Such a program requires a detailed knowledge of the various Air Force mission requirements and practical flight problems. The equipment must be comfortable to be acceptable to the pilot. An integral part of this responsibility is a continual sharing of information with the Navy and the numerous government contractors.

Fig. 4. The subject is wearing the MA-2 helmet incorrectly with rubber gasket on outside of face mask.

Physiologic Evaluation of Pressure Suits.—Such evaluation includes cardio-pulmonary, electrocardiographic, and gaseous tensions measurements. Of utmost importance are the practical considerations of ease and speed of donning, suit comfort, field of vision while wearing a helmet, problems of maintenance of equipment, reliability with repeated testing, and mobility during suit pressurization. This lab-

*Button on seat-kit to inflate suit for check of pressurization.

oratory not only evaluates Air Force contractor's suits, but also those of the Navy.

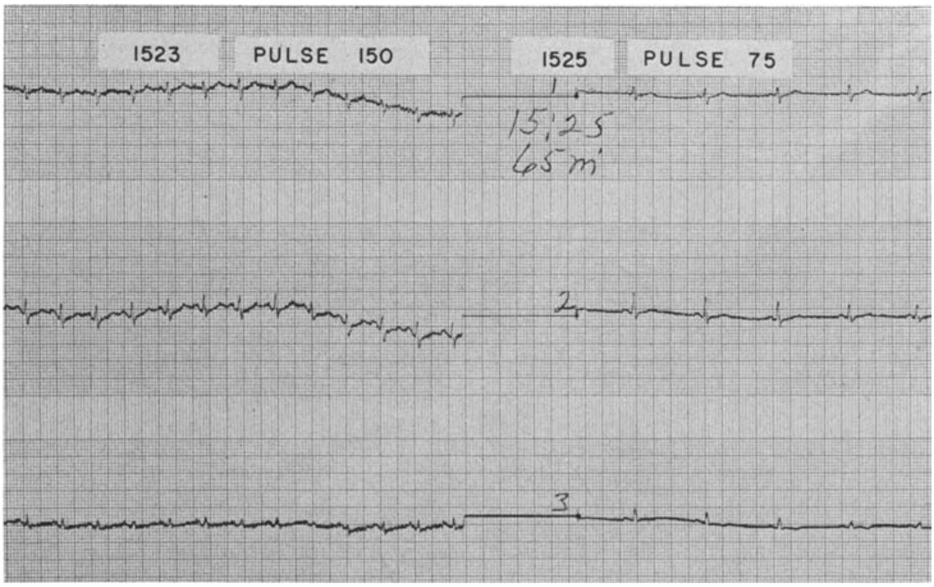

Fig. 5. Electrocardiogram of subject in MC-1 suit at 65,000 feet, showing sudden onset of bradycardia. Recorder turned off for two minutes between tracings.

Crew Selection Development Program.—The Aero Medical Laboratory has been engaged in developing a battery of physiologic and psychologic tests to assist in the selection of crew members for astronautical operations. This series of tests was employed in the psycho-physiologic evaluation and selection of all of the project Mercury astronauts.

One of the physiologic tests employs an early model partial pressure suit, the MC-1, which has only a small anterior chest and abdomen bladder. This bladder does not offer adequate counterpressurization on the outside of the chest to equalize the high intrathoracic pressure. In effect, pressure breathing obtains. The MC-1 pressure suit is employed as a research tool. The test profile is to expose the subject to 65,000 feet for one hour. Remarkable physiologic changes occur. Tachycardia is frequent while the subject is at 65,000 feet, usually ranging from 110-130. The rate has been as high as 160, at which time the test was aborted.

The most important physiologic response to the MC-1 pressure suit test is the alarming frequency of sudden pre-syncope. The pattern leading up to syncope is fairly uniform. The subject is exposed to 65,000 feet. Suddenly, he breaks into moderate diaphoresis on his entire body. He discerns this easily on his arms and legs where the sweat evaporates through permeable fabric. The effect is a cold sensation such as evaporating ether or other highly volatile organic liquids. Concomitantly, there is a definite hypotension and a relative bradycardia. True bradycardia implies the pulse is below 60 per minute. However, in the MC-1 suit during the test, a sudden drop in pulse from 150 to 75 (Fig. 5) is a relative bradycardia. With the sudden hypotension and bradycardia, one may infer that there has been a dramatic decrease in the cardiac output. Emergency repressurization of the chamber from 65,000 to 40,000 feet will deflate the suit in four to six seconds. Return to consciousness occurs in another four to six seconds. The pallor, clammy skin, hypotension, and bradycardia often persist for one to two hours after cessation of the test. The lapse of time from the first symptoms until syncope varies from a few seconds to two minutes. As soon as the first symptoms appear, the test is immediately terminated to avoid unconsciousness.† Table I summarizes the experience of the authors with this severe psycho-physiological test.

Windblast Studies.—To determine the protective capabilities of the pressure suit and helmet during ejection, windblast effects were studied. Eleven subjects were firmly strapped in a steel-beam reinforced ejection seat. A hydraulic-lift steel deflector drops, allowing a terrific windblast to act on the subject's head and chest. Air speeds of 350 miles per hour at 80° F. at sea level for ten seconds resulted in no injury from helmet or cable pulley. This demonstrated the excellent windblast protection of the pressure suit and helmet.

Emergency Protection. — A final project of intense interest employs the A-13A positive pressure mask and D-2 regulator. It was the intention of the Aerospace Medical Laboratory to determine if this mask gave emergency physiologic protection when worn at the ambient altitude of 50,000 feet for ten minutes. If the mask afforded adequate emergency protection, then it could be safely worn during aircraft descent from 50,000 feet in the event of cabin decompression. The preliminary results indicate that it is unsafe to wear the A-13A mask above 45,000 feet for more than one or two minutes. Of four subjects who were exposed to 50,000 feet, one became unconscious and convulsed in twenty seconds. A second subject had premature ventricular contractions, but the test was completed because of the rarity of the ectopic beats. The third subject had a pulse of 167 at which time the physician terminated the test. Only one subject performed uneventfully for ten minutes at 50,000 feet.

Table II summarizes the experience of some of our recent suit and pressure breathing tests. It demonstrates that experimental testing is hazardous. The dangers arise from new designs, untested items, extreme vacuums, and unconventional use of existing equipment. It also demonstrates that an excessively tight-fitting pressure suit will render the pilot ineffective.

†It is possible that this pressure breathing presyncope is caused by stimulation of lung stretch receptors. If so, complete atropinization should prevent the development of presyncope in subjects.

ACKNOWLEDGMENT

The authors wish to express their appreciation to Miss Beverly Bruns, who prepared the manuscript, to the Technical Photographic Division for its expert assistance in preparing the photographs, to the Altitude Chamber Crew for its interest and initiative, and to the subjects without whom this study could not have been made.