

DOT/FAA/AM-00/6

Office of Aviation Medicine  
Washington, D.C. 20591

# Testing the Structural Integrity of the Air Force's Emergency Passenger Oxygen System at Altitude

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February 2000

Final Report

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U.S. Department  
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**Federal Aviation  
Administration**

## N O T I C E

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1. Report No. DOT/FAA/AM-00/6		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Testing the Structural Integrity of the Air Force's Emergency Passenger Oxygen System at Altitude				5. Report Date February 2000	
				6. Performing Organization Code	
7. Author(s) Garner, R.P. <sup>1</sup> , Murphy, R.E. <sup>1</sup> , Donnelley, S.S. <sup>2</sup> , Thompson, K.E. <sup>3</sup> , and Geiwitz, K.L. <sup>3</sup>				8. Performing Organization Report No.	
9. Performing Organization Name and Address <sup>1</sup> FAA Civil Aeromedical Institute, P.O. Box 25082, Oklahoma City, OK 73125 <sup>2</sup> Soldier Systems, U.S. Army Aberdeen Test Center <sup>3</sup> Automotive Instrumentation Team, U.S. Army Aberdeen Test Center Aberdeen Proving Ground, MD 21005-5059				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Agency name and Address Office of Aviation Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20591				13. Type of Report and Period Covered	
				14. Sponsoring Agency Code	
15. Supplemental Notes					
16. Abstract <p>The chemical bond attaching the elastic neck seal to the body of the protective breathing equipment (PBE) procured by the U.S. Air Force as an emergency passenger oxygen System (EPOS) was alleged to be inadequate to allow the PBE to perform as intended at altitude. To test this possibility, EPOS units were collected from Air Force Bases and systematically tested at altitude. The Civil Aeromedical Institute was requested to participate in the testing through the FAA Office of the Inspector General and the U.S. Air Force's Office of Special Investigations due to the Institute's longstanding expertise in the area of PBE. Eighty-four of the EPOS units collected were divided into four groups of 21. Since the PBE in question were of relatively recent manufacture, three of the four groups were artificially aged. Altitude testing was conducted in a hypobaric chamber at a simulated altitude of 40,000 feet above sea level. An EPOS unit from each of the "aged" groups was placed on one of the four mannequin heads that were instrumented for monitoring pressure, temperature, and atmospheric gas concentrations. The EPOS units were activated at altitude with the primary data collection continuing for a minimum of five minutes after activation. The neck seal/hood interface did not fail on any of the 84 devices during altitude exposure. A destructive test series conducted on an additional 16 EPOS units indicated that an internal pressure approximately six times that observed at altitude was required to result in structural failure of the EPOS units. Based on the data collected in the performance of these tests, the neck seal/hood body interface bond utilized in the construction of these devices is sufficient to allow the PBE to perform as intended at altitude.</p>					
17. Key Words Protective Breathing Equipment, Emergency Passenger Oxygen System, High-Altitude Destructive Testing				18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 11	22. Price



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# TESTING THE STRUCTURAL INTEGRITY OF THE AIR FORCE'S EMERGENCY PASSENGER OXYGEN SYSTEM AT ALTITUDE

## INTRODUCTION

An emergency aboard an aircraft can require individual protection from hypoxia, smoke, and fumes. Generally, this type of protection can be offered through the availability of protective breathing equipment (PBE), commonly referred to as a "smoke hood." PBE devices have been designed for both aircraft passengers and crew. It is recognized that crewmembers require the protection offered by PBE to successfully complete their assigned tasks in emergency situations. Performance standards for crewmember PBE call for specific functional capabilities and have been relatively well defined (1, 2, 3, 4). The net safety benefits in providing PBE to passengers aboard commercial transport category aircraft are a subject of debate (5). Although some guidelines have been created (6), no governing body currently mandates or regulates "smoke hood" type devices for transport category aircraft passengers. However, due to the potential benefits of the devices in certain circumstances, many private and military organizations have made the decision to equip their aircraft with PBE for passengers.

The United States Air Force Air Mobility Command recognized the need for a readily accessible, portable, passenger protective system to supply passengers with oxygen and protect them from the effects of smoke and toxic fumes. After an extensive evaluation and testing of available devices suited for passenger protection, a "smoke hood" type of device was chosen by the Air Force. The device is manufactured by the Essex PB&R Corporation. The United States Air Force calls the device the Emergency Passenger Oxygen System (EPOS). During the delivery cycle for the devices ordered by the Air Force, the production facility was relocated from Elkton, Maryland, to Edwardsville, Illinois. The quality of the construction of the EPOS came into question after the relocation of the manufacturing facility in terms of a Qui Tam lawsuit filed on behalf of the government.

It was hypothesized that the relocation of the manufacturing from the original production facility (OPF) to a new production facility (NPF) resulted in flaws in the assembly process. Specifically, the hypothesis holds that the attachment between the neck seal and hood body of the units from the NPF are not able to withstand the forces generated if the Victim Rescue Units (VRU) were activated in a manner, and at an altitude, consistent with its intended use. To examine this possibility, VRU units from both the OPF and NPF were tested. The Civil Aeromedical Institute was requested to participate in the testing through the FAA Office of the Inspector General and the U.S. Air Force's Office of Special Investigations due to their longstanding expertise in the area of PBE.

The purpose of the testing was to evaluate the capabilities of a PBE neck seal and hood shell attachment. The goal was to address a very specific aspect of the VRU design and the associated manufacturing processes. Emphasis was placed on the investigation of the influence of aging on the device's capabilities to provide adequate protection during an emergency involving altitude exposure. The devices tested were the Essex VRU provided to the Air Force as a Passenger Smoke and Fume Protective Device (PSFPD), designated herein as the EPOS.

## METHODS

### **Emergency Passenger Oxygen System:**

The 84 EPOS tested at altitude had been previously distributed to United States Air Force bases. The Air Force's Office of Special Investigations had collected the test devices from Charleston AFB in South Carolina, Travis AFB in California, Dover AFB in Delaware, and McGuire AFB in New Jersey. The experimental design of the tests was balanced, in that each test group contained equal numbers of EPOS units from the bases and manufacturing

locations. Only those EPOS units that had not been removed from the original packaging were used for the tests making up this study.

**Artificial Aging:** The EPOS devices in question were manufactured relatively recently. It is possible that the neck seal bonds in the new systems are functional but might deteriorate with age. Therefore an attempt was made to artificially age them. A higher incidence of failures among the aged devices would indicate that the neck seal bond was insufficient.

Three groups of EPOS units were artificially aged. Aging consisted of placing each group in an environmental chamber for a period of one week at temperatures of 50°C, 65°C, and 80°C. These groups were designated Aged1, Aged2, and Aged3, correspondent with the temperature range. The relative humidity of the environmental chamber was maintained at 25%. A fourth group served as a non-aged control.

**Altitude Testing:** Altitude testing was conducted in a hypobaric chamber at a simulated altitude of approximately 40,000 feet above sea level. A total of 84 EPOS units were tested.

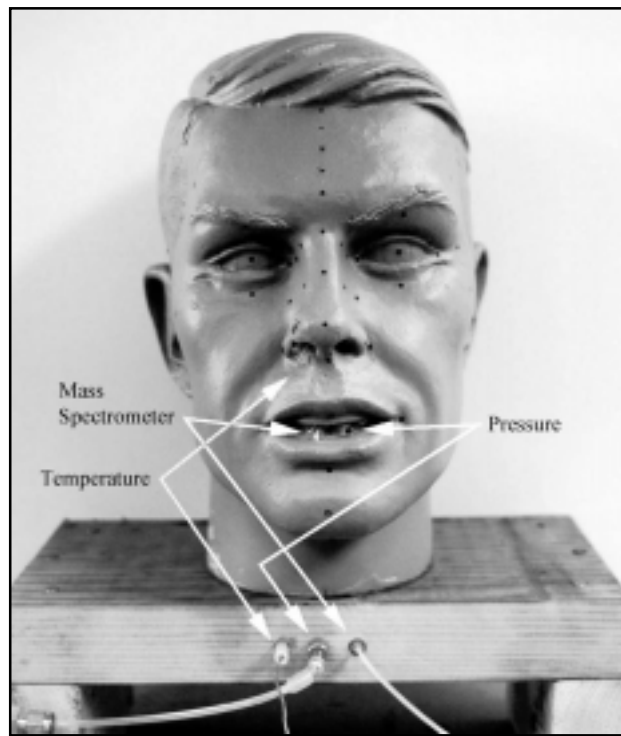
The test setup consisted of a mannequin head mounted on a wooden stand. The interior of the head was hollow. Three polypropylene tubes were channeled through the mannequin base and the interior of the head emerging in the area of the mouth and nose for data collection purposes. This setup allowed data collection from inside the EPOS without the risk of compromising its structural integrity. Figure 1 shows the mannequin head setup.

A metal disk screwed to the wood of the base sealed the interior of the mannequin head from the ambient environment. A pressure relief valve that opened at 25 mmHg was mounted in the metal disk. A test rack was built that held four mannequin heads outfitted in this manner. The arrangement allowed four EPOS devices to be tested during each hypobaric chamber decompression. An EPOS from each of the “aged” groups was tested during each of the 21 decompressions, and test items from each group were rotated onto the different mannequin heads during the tests.

Testing consisted of opening the EPOS immediately prior to the altitude test. Care was taken not to activate the oxygen system. Activation of the oxygen system normally consists of the neck of the hood being pulled open so the EPOS can be placed over the user’s head. A small clip seals the oxygen canister

before activation. The clip is attached via a string to a plastic bulb on the side of the EPOS opposite the oxygen canister. When the user pulls open the neck of the EPOS for donning, the clip is pulled away from the oxygen canister, allowing the flow of oxygen. The tests required the EPOS to be activated at altitude. Therefore, the plastic bulb of the string system normally used to activate the oxygen canister was carefully removed. The EPOS was then placed on one of the four mannequin heads. A cord running from outside the chamber was tied to the string that normally activated the oxygen flow when pulled. This arrangement allowed the EPOS to be activated from outside the chamber once the desired pressure level was achieved.

Once the four EPOS test units were in place, the chamber was closed and evacuated to a simulated altitude of approximately 42,000 feet at a rate of 5,000 feet per minute. The oxygen system was activated after two minutes at the maximum altitude obtained. A 15-second interval was allowed between activation of each device. Changes in gas concentrations were collected in 15-second segments using a mass spectrometer (Perkin-Elmer, MGA-1100). A rise in oxygen concentration indicates that oxygen



**Figure 1.** Mannequin head and base setup used for testing EPOS at altitude.

was being released into the EPOS. Of primary interest was the pressure change within the EPOS after activation at altitude. It was hypothesized that the expansion of ambient air trapped in the EPOS hood coupled with activation of the oxygen system at altitude, would result in failure of the chemical bond between the neck seal and the hood body.

Pressure changes were measured using OMEGA PX-140 pressure transducers. Temperature changes in the EPOS were monitored using thermocouples. Gas concentrations were followed for a total of 5 minutes at altitude. The chamber was then held at altitude for an additional 2 minutes before being returned to ground level. Upon return to ground level, the EPOS were removed from the mannequin heads and carefully checked for any structural failure, particularly in the area of the neck seal and hood body. After the spent hoods were removed and checked, the next set of four EPOS units was tested.

Data signals from the measurement transducers were collected using an Advanced On-Board Computer System (ADOCS). The ADOCS is a computer-based data acquisition system developed by the Aberdeen Test Center for applications at Aberdeen Proving Grounds. The data were saved as a text file and later analyzed using either a computer spreadsheet (Microsoft Excel™) or the LabVIEW™ data acquisition and analysis software (National Instruments).

**Destructive Tests:** Two sets of tests were performed at ground level. These were conducted in the Protection and Survival Laboratory at the Civil Aeromedical Institute. The first set consisted of activating a subset of four EPOS units and monitoring pressure changes at ground level for comparison with values observed after activation at altitude. In the second set of tests, an air compressor was used to distend the EPOS until the unit failed structurally. These tests were anticipated to indicate the pressure and failure pattern of the units when stressed beyond their structural capacity.

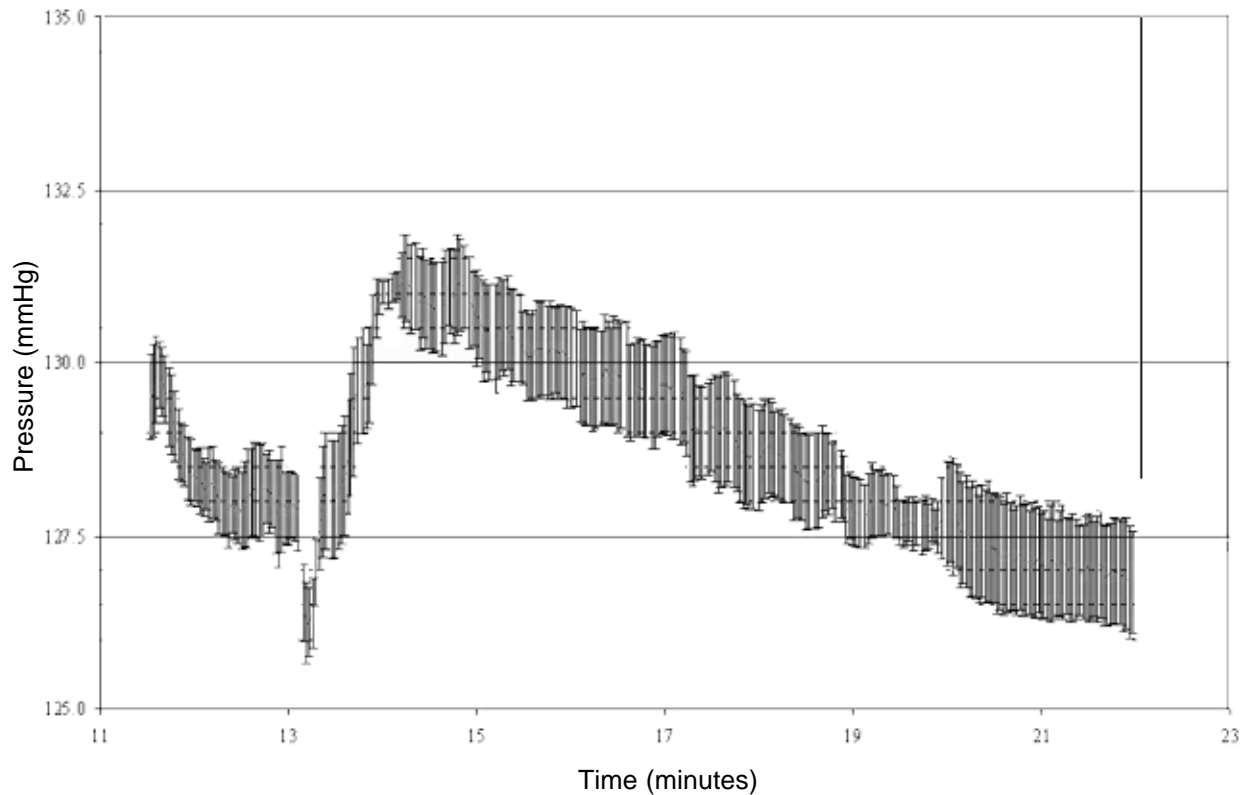
## RESULTS

There is no way to specifically determine the extent that the aging process conducted in this study was effective. Care was taken in administering the process to mimic conditions in the laboratory that are used in equipment specifically designed for aging (7). However, none of the vacuum seals of the EPOS packaging were disrupted by the attempt at artificial aging. Therefore, the influence of airflow and humidity on the EPOS itself must be considered minimal. The elevated heat in the environmental chamber must be considered the primary determinant of artificial aging of the materials and manufacturing processes.

Eight-four devices were tested at an altitude of approximately 40,000 feet above sea level. There was not a failure of the neck seal/hood interface in any of the tests. The pressure level inside the hood after activation at altitude increased, on average, 3.5 mmHg (i). It took approximately 1 minute for this value to be reached. This increase is less than would be anticipated based on release of gas into a fixed volume. The test setup could lose oxygen through leakage from around the neck of the mannequin, sampling by the mass spectrometer, and diffusion through any small leaks in the test configuration. Another contributing factor is that the pressure increase in the EPOS attenuates flow rate of oxygen out of the cylinder. Oxygen concentration did rise in the EPOS in all of the tests (Figure 3). Nitrogen levels within the devices fell, consistent with the increase in oxygen concentration. The level of nitrogen remaining in the EPOS suggests that the flow was sufficiently restricted to prevent the total washout of nitrogen by the oxygen from the storage canister.

Pressure changes within the EPOS (n=4) activated at ground level are presented in Figure 4. The average pressure change observed was 1.6 mmHg and occurred approximately 2.5 minutes after activation. As expected, PBE activation at altitude resulted in greater internal pressure. The pressure change at altitude

### Average Internal Pressure Change After Mask Activation at Altitude



**Figure 2.** Summary of pressure changes associated with activation of passenger emergency oxygen system at approximately 40,000 feet simulated altitude. The values represent the mean  $\pm$  standard deviation for a sample of 4 devices.

developed more quickly than when EPOS devices were activated at ground level. A subset of four devices from each aged group was tested in the destructive test series. The average pressure required to rupture the PBE was  $17.8 \pm 1.3$  mmHg with no statistically significant differences existing among the four groups (Figure 5). This pressure level is approximately six times the change observed at altitude. No consistent pattern was observed in the failures.

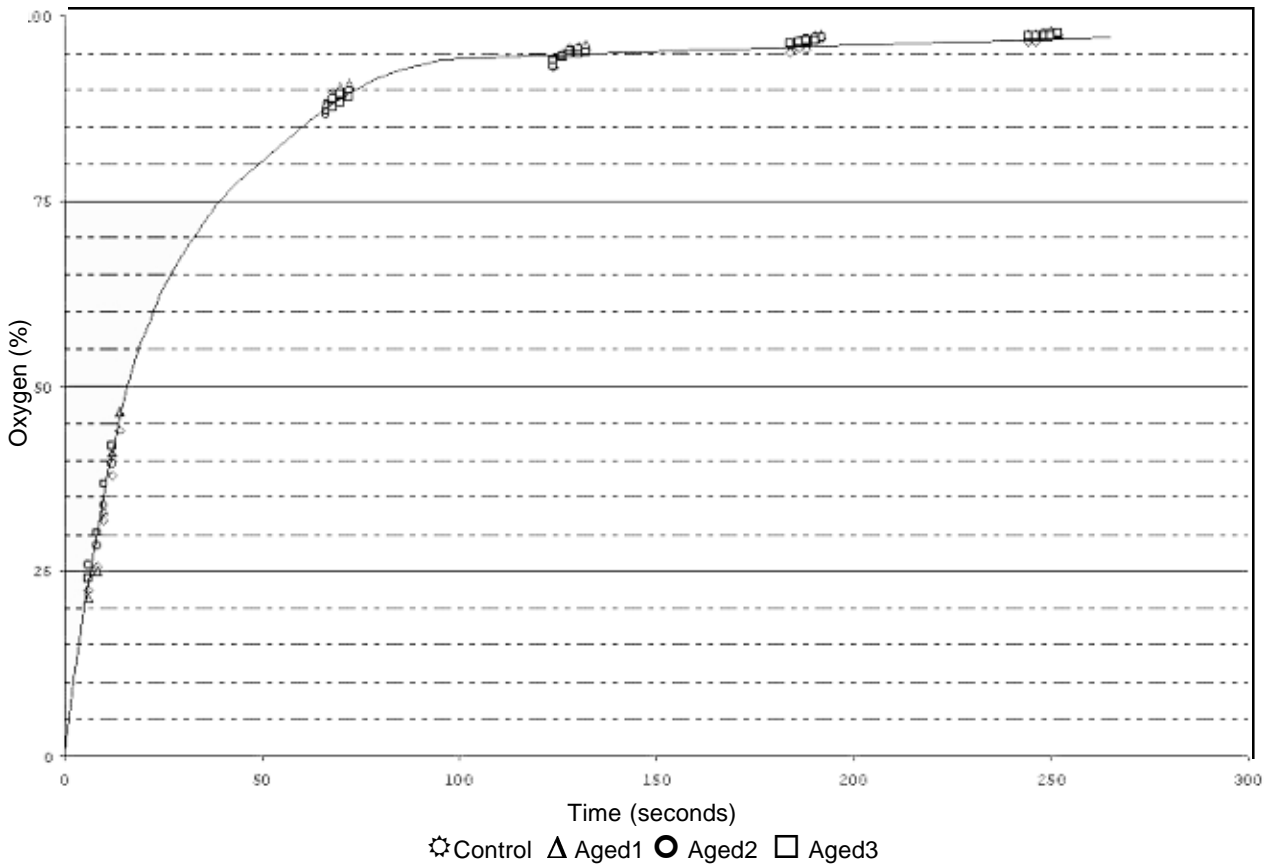
### DISCUSSION

A key component in conducting these tests was the attempt to artificially age the EPOS. Accurately conducting an artificial aging test is a complex task (8, 9). Although studies related to artificial aging of materials have become more plentiful in recent years, the variety of materials from which the EPOS is

constructed does not allow a definitive analysis of aging. The approach used in this study was to use an aging protocol that would allow treatment differences to be identified, even though a specific time value could not be reliably placed on the treatments.

Aging is commonly recognized as the changes occurring in an entity over a period of time. Accelerated or artificial aging is a procedure that is designed to indicate in a relatively short period of time what will happen to materials over a period of years in storage. There have been numerous studies investigating factors that make artificial aging most consistent with the normal aging process. Most of the test methods are ultimately based on van't Hoff's principle, which describes the effect of temperature on the rate of chemical reaction (10). It has been found that the effect of heat is similar to that of natural aging under average conditions. Other factors such as





**Figure 3.** Changes in oxygen concentration inside the EPOS after activation at altitude. The last 5 data points collected (10 seconds) of each 15-second collection interval are presented. Each data point in the graph represents the average of the 21 EPOS units making up the “aged” group.

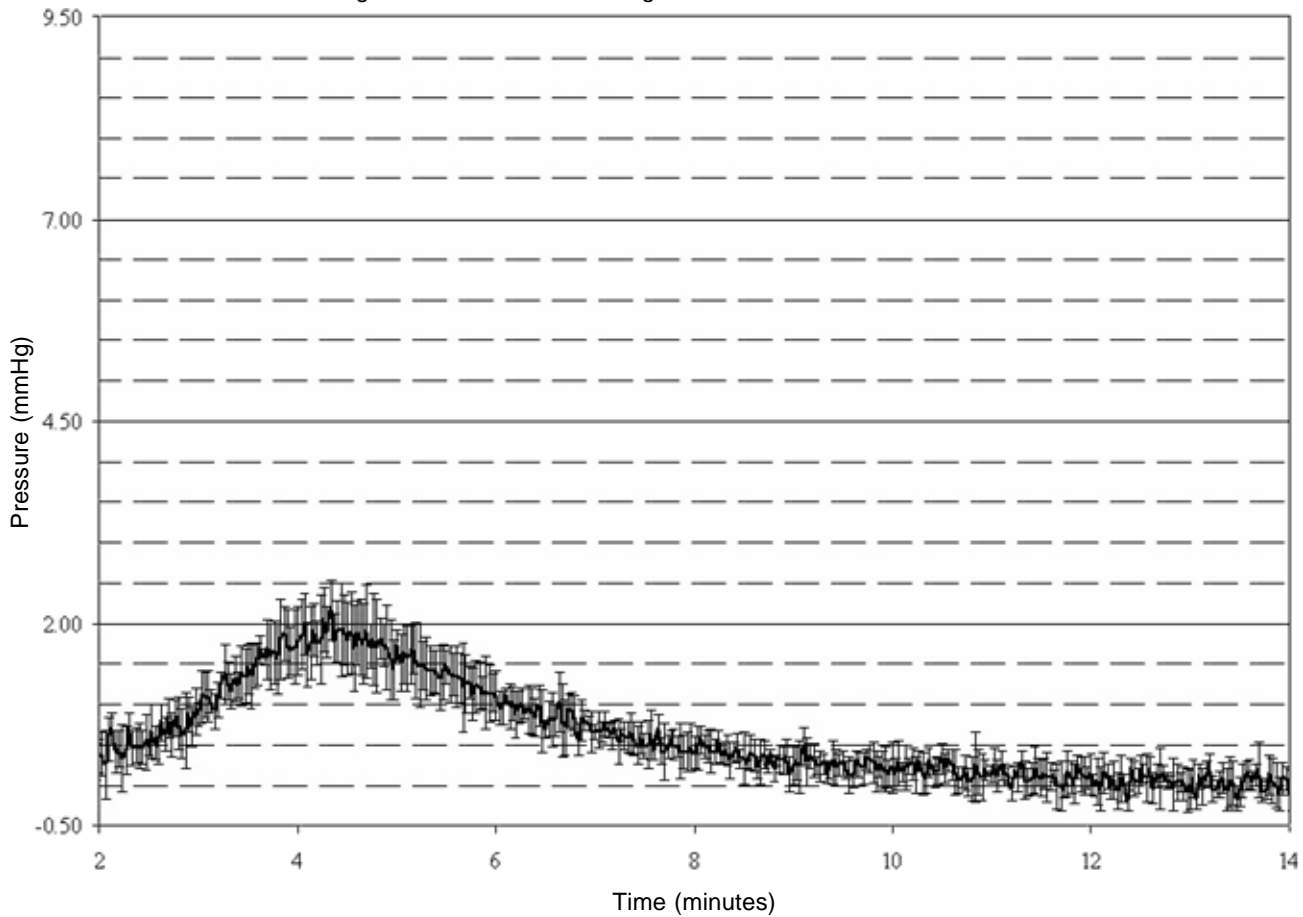
humidity and airflow can also influence the artificial aging process (7). The challenge in the process is matching appropriate changes in environmental conditions to bring about changes consistent with the natural process in the material(s) being tested.

Due to the vacuum packaging, heat was the only variable that could have characteristically aged the EPOS. The complexity of the materials and adhesives in manufacturing the devices does not allow assignment of specific time periods to the aging exposures used in this study. However, it is assumed that the temperature differences among the three artificial aging scenarios were sufficient to make the test characteristically different from each other. It appears that two alternatives need to be considered since none of the bonds failed during the altitude tests. The chemical bond between the neck seal and hood body did not deteriorate as a result of the heat increases. If

that were the case, natural aging would not be anticipated to significantly alter the bond during the lifespan of the device. The other explanation is that the artificial aging did not last long enough to have an effect on the hood body/neck seal bond.

However, this position must be considered in the context of recognized approaches to artificial aging. The Food and Drug Administration and others have accepted a 14-day exposure to 55°C and 70-90% relative humidity as being roughly equivalent to 1 year of ambient real-time aging (11). Based on this estimate, the 80°C treatment used in this study may represent natural aging of 4 to 6 years. It could be more or less than this due to the dependence of heat aging on both the materials and the nature of the chemical bond (9). The complexity of these interactions makes a definitive time equivalent impossible to achieve.

Average Internal Pressure Change After Mask Activation at Ground Level

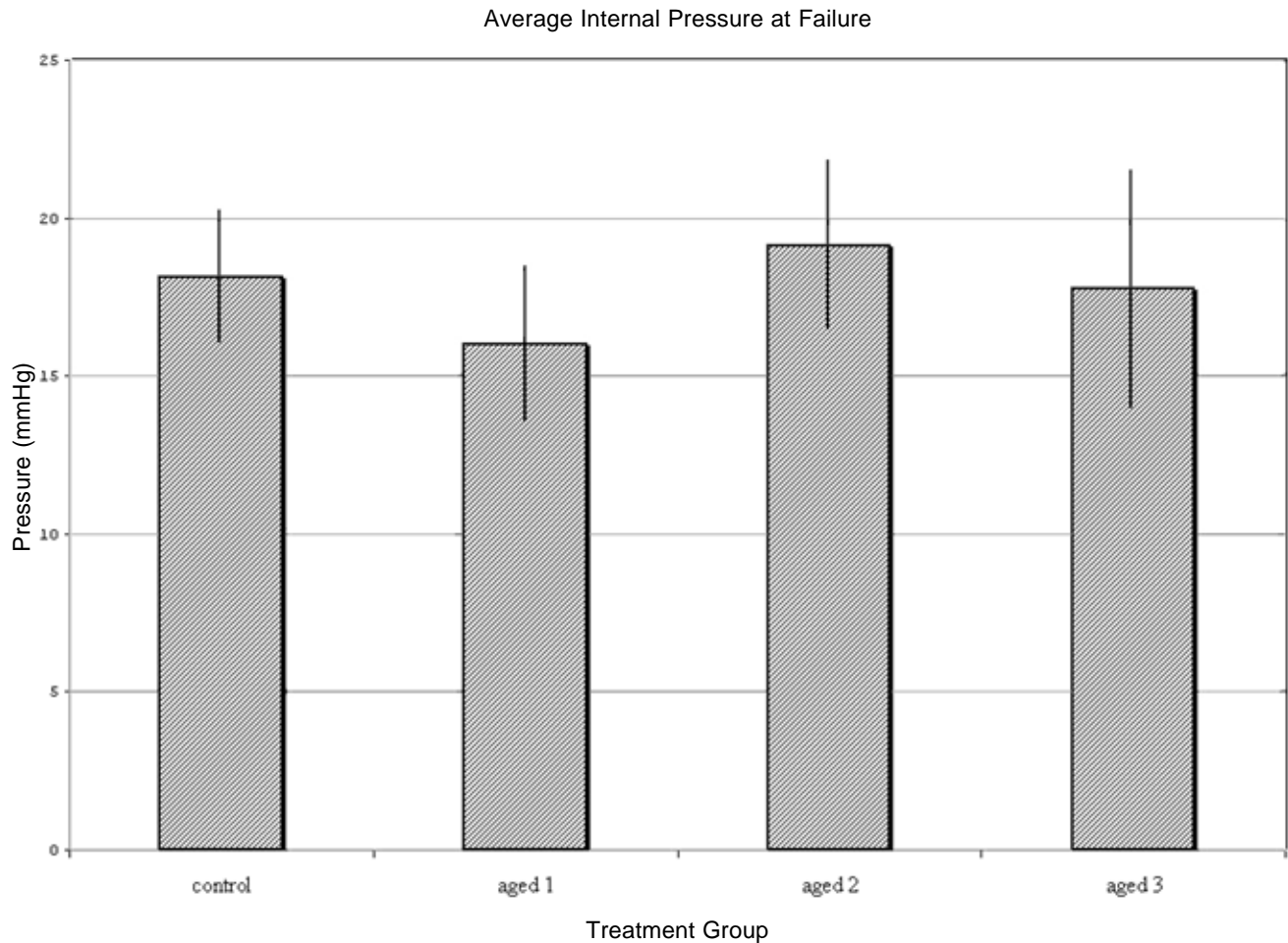


**Figure 4.** Summary of pressure changes associated with activation of passenger emergency oxygen system at ground level. The values represent the mean  $\pm$  standard deviation for a sample of 4 devices.

There are valid arguments on both sides of the debate over aircraft passenger use of equipment designed to provide protection from smoke and fumes in addition to hypoxia protection. Based on experiences and circumstances anticipated on Air Force aircraft, the decision was made to provide protective breathing equipment as a means of smoke protection for the passengers. The minimum acceptable performance requirements the Air Force set forth were high. They wanted a device that could be donned in 20 seconds. It could not interfere with hearing and vision or the physical mobility of the wearer. The ability to evacuate the aircraft or perform emergency duties must be maintained. Fire protection was required for the head and neck. Inflight, the Air Force wanted 15 minutes of smoke and fume protection coupled with hypoxia protection equivalent to the

“Dixie cup” style of continuous flow passenger oxygen mask commonly found aboard civilian airliners. All of these features were to be contained in a package that fit the existing storage space aboard aircraft, weighed less than 2 pounds, and cost under \$200.00. A Sources Sought Synopsis regarding the anticipated off-the-shelf procurement of a EPOS and meeting announcement for all interested vendors was published in the Commerce Business Daily on February 24, 1993.

The Air Force used numerous resources in evaluating the PSFPD submitted for consideration. There was an extensive evaluation of all of the devices. Both positive and negative aspects of each were weighed in the context of Air Force requirements. The decision was made to procure the PSFPD manufactured by Essex PB&R Corporation. The production facilities



**Figure 5.** Average pressure increase immediately prior to structural failure in a subset of devices from each of the aged treatment groups. The mean  $\pm$  standard deviation is represented. The pressure level results in distension of the elastic neck seal material to a diameter of 2.5 to 3.5 feet, which extends the hood body well above the head of the wearer.

for the device were moved after the contract had been signed with the Air Force. If quality was maintained, it does not appear that a change in manufacturing point within the continental United States is of significance. However, the competence of the NPF was challenged in the courts. This action may have been a function of problems with the bond between the hood shell and neck seal of units that were original manufacturer DuPont, or there may have been other factors involved. Regardless of the basis of the complaint, the decision was made to investigate the performance of the hood body/neck seal bond.

Results from the tests conducted on the devices that had been previously delivered to the Air Force indicated that the neck seal/hood interface would remain bonded, consistent with the intended use of

the EPOS. Furthermore, destructive testing on a subgroup of devices indicated that it only took a small percentage of the internal pressure resulting in structural failure to distend the rubber neck seal to an extent that the EPOS became functionally useless due to visual obstruction. Improvements in protective capabilities, donning, and design may some day make passenger protective breathing equipment consistent with the safety goals of organizations throughout the world of aviation. Performance, comfort, and other characteristics of the EPOS tested in this study could be improved. However, the results of the tests strongly suggest that the structural integrity of the device exceed any functional demands placed on it by the wearer.

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