



AEROSPACE INFORMATION REPORT

Society of Automotive Engineers, Inc.
TWO PENNSYLVANIA PLAZA, NEW YORK, N.Y. 10001

AIR 1103

Issued 11-16-70
Revised

INTRODUCTION TO PRESSURE SUIT ASSEMBLIES

PREFACE - This introductory treatment of the characteristics of Pressure Suit Assemblies (PSAs), supporting subsystems and the interface areas to be resolved in applying them to aeronautical and space systems, was compiled to convey the major differences in varied types of pressure suits and to convey an understanding of the problems and limitations associated with PSA applications.

1. PURPOSE

The information presented here was compiled to provide aerospace system and environmental control system engineers a ready reference to general information and application guidelines to be considered when designing a vehicle which is expected to expose operators to reduced pressure levels.

2. BACKGROUND

Pressure suits have evolved in many styles, and are usually adapted to fit a particular mission. In general, they consist of a helmet, coveralls and gloves, with boots worn over airtight foot coverings or laced onto the coveralls. The primary purpose of providing redundant pressure protection must not be allowed to overshadow the equally important needs of the crew for comfort, unhampered task performance and protection from flight and survival stresses. The application of PSAs imposes many complications including preflight checkout, support equipment, comfort conditioning, feeding, waste removal, survival, cleaning, maintenance, and storage. Originally, PSA applications began in conjunction with high altitude flight record attempts, continued into military aviation and flight test programs, and finally into space explorations.

3. PHYSIOLOGICAL REQUIREMENTS

- 3.1 **Oxygen Needs:** Dry air contains almost 21% oxygen by volume. At sea level pressure, (760 torr) it would seem to provide an oxygen partial pressure (pO_2) of 159 torr; however, this value is reduced a small amount since water vapor is present as a diluent gas. Similarly any gas mixture being breathed is heated to 98.6 F and saturated with water vapor before reaching the alveoli where gas exchange occurs. The resultant incoming pO_2 for air then is reduced to 150 torr. This unavoidable and essential presence of water vapor has an even greater effect upon the pO_2 as it becomes a larger proportion of the total pressure. At an altitude of 33,700 feet where the nominal total pressure is 190 torr, breathing 100% oxygen results in a pO_2 of only 143 torr entering the alveoli for gas exchange. Other diluent gases, such as nitrogen, helium, and carbon dioxide can occupy a part of the total pressure and also reduce the pO_2 . Accepted equivalent values for adequate oxygen are:

Air at 760 torr equals 100% oxygen at 190 torr
Air at 632 torr equals 100% oxygen at 166 torr
Air at 523 torr equals 100% oxygen at 144 torr

SAE Technical Board rules provide that: "All technical reports, including standards approved and practices recommended, are advisory only. Their use by anyone engaged in industry or trade is entirely voluntary. There is no agreement to adhere to any SAE standard or recommended practice, and no commitment to conform to or be guided by any technical report. In formulating and approving technical reports, the Board and its Committees will not investigate or consider patents which may apply to the subject matter. Prospective users of the report are responsible for protecting themselves against liability for infringement of patents."

At 632 torr (5,000 feet altitude) air contains the minimum pO_2 essential to retain normal periods for completely adapting the eyes for night vision. Military fighter pilots are instructed to use oxygen with air dilution for all night flying. Air at 523 torr (10,000 feet) contains the minimum pO_2 essential for normal unimpaired performance; however, hard work or exposures for hours will show physiological symptoms of oxygen deficiency (hypoxia). In situations where less than 100 torr of pO_2 is available in the gas entering the alveoli, an unacclimatized subject will be hypoxic. To the opposite extreme, one cannot breathe gas containing very high pO_2 for extended periods without developing oxygen toxicity. In general, toxicity to oxygen does not develop with pure oxygen at one half atmosphere - but will develop within a few minutes at two or more atmospheres.*

*(Reference Flight Surgeons Manual AFM 160-5)

- 3.2 Respiratory Needs: Depending upon level of work, physical and metabolic variations and psychological stresses, man breathes gas at a respiratory minute volume (RMV) ranging from 5 to 55 liters per minute BTPS (body temperature, pressure, saturated). Peak instantaneous flow rates may reach 3 times the respiratory minute volume. The volume of breathing gas required to be furnished by the vehicle system can be calculated for a selected RMV from the following relation using absolute pressure in torr and absolute temperatures. A typical RMV selected to cover 99% of the pilot population flying high performance fighters was 25 liters per minute BTPS.

$$V \text{ std equals } RMV \times \frac{\text{body press} - 47}{\text{std pressure}} \times \frac{\text{std temp}}{\text{body temp}} \times \text{time in minutes.}$$

The maximum metabolic oxygen consumption for the adult, healthy male is near three liters per minute at standard conditions of temperature and pressure (STP). This limit value establishes a maximum aerobic (without oxygen debt) metabolic rate of 15 kilocalories per minute or 3,600 Btu per hour. Conditioned athletes can maintain this rate of work perhaps for one half hour. Routine average pilot activity probably requires about 0.5 liters of oxygen per minute BTPS. Of course this would not be adequate for a significant portion of the adult male population and would not provide for work and stress.

Reference "Handbook of Respiratory Data in Aviation Medicine" 1944
and WADDTR 60-166 "Usage Rates of Aircraft Oxygen", 1960.

- 3.3 Respiratory Limits: Man's respiratory passageways establish an anatomical dead space which cannot participate directly in the gas exchange process. Oxygen masks and pressure suits add equipment dead space to the anatomical dead space and increase the rebreathed gas volume. Unless this rebreathed gas volume is minimized it will cause an increase in inspired carbon dioxide which leads to a compensatory increase in respiratory minute volume. Inspired CO_2 should ideally be kept below 4 torr; however, the effect of 8 torr pCO_2 causes only a 5 to 15% increase in respiratory minute volume. Subjective awareness will probably not be produced until the respiratory minute volume is increased by at least 50%, as a result of breathing about 20 torr pCO_2 . Other factors including exercise, hypoxia, cold and excitement would increase the respiratory response to a given CO_2 content in the inspired gas.
- 3.4 Barometric Changes: Although gradual pressure changes in PSAs are desirable as in cabins, extraordinarily rapid decompressions can be tolerated with little difficulty if the airway passages are unobstructed. AF Manual 160-5 shows explosive decompressions from 8,000 to 35,000 feet (7.4 psi) in less than 0.1 second have been tolerated by human subjects. Critical lung pressures and traumatic aeroembolism will occur if the glottis happens to be closed at the moment of decompression, either due to voluntary breath holding or to swallowing. A conservative decompression limit for pressure suited crewmen would be 1 psi per second realizing that between 5 and 3.5 psia the usual PSA will cease venting and prevent further decompression. Compression must be at a slower rate. About 0.1 psi per second should be suitable; however, the system should include an override to allow interruption of compression at will, to prevent ear or sinus trauma. Large reductions in pressure cause dysbarism - a term applied to all of the physiological effects independent of hypoxia. Dysbarism symptoms include the effects of evolved gases in tissues of the body (bends, chokes and neurological disorders) as well as effects of expansion of trapped gases. The incidence of dysbarism increases with the rate of ascent, altitude, duration of exposure, activity and cold. The incidence decreases with increased time of denitrogenation prior to the reduction in pressure. Exercise not only increases the incidence of symptoms at a given altitude, but lowers the threshold altitude for the occurrence. Dysbarism ordinarily does not occur below 30,000 feet (226 torr), but symptoms

can be induced at 22,000 feet (321 torr) by strenuous exercise.

Breathing pure oxygen for 1 hour before exposure to 180 torr, a typical pressure for aviator's PSAs, is usually effective in preventing dysbarism. Decompression to less than half the original absolute pressure can be expected to produce bends - unless inert gases such as helium or nitrogen were excluded from the breath for some time prior to the event.

- 3.5 Thermal Considerations: Thermal comfort depends upon level of activity, the ambient situation, radiation, insulation, permeability of clothing and provisions for controlling some of these conditions. Forced ventilation of PSAs with conditioned dry gas is effective up to about 16 cu. ft per min. for metabolic rates up to 300 kilocalories (1200 Btu) per hour - but the period is limited by body water loss. Athletes are capable of 1,500 K cal (6000 Btu) per hour for a few minutes - but very high ventilation flows do not produce high cooling rates because convective film and evaporation coefficients are relatively poor. Cooling at high rates can be accomplished effectively using water to supplement a breathing gas flow of about 100 liters per minute. A cooling garment circulating about 2 liters of "cold" water per minute has an excellent cooling capacity and is physiologically desirable since it removes sensible heat from the body by conduction directly from the skin rather than by the latent heat of evaporating perspiration. Another method of cooling by conduction which is equally effective utilizes thin water charged patches on the surface of the body which function as water boilers when the interior is vented to vacuum. The water functions as an expendable refrigerant by boiling under very low pressure at low temperatures.
- 3.6 Efficiency of the Human Body: The metabolism of man rises above the level to sustain basic living processes whenever he does work. This work requires a metabolic energy increase of 4 to 5 times the useful work equivalent. If a pressurized garment is being worn, the external work required for man to do the task could double and thereby cause an increase in metabolism of 8 to 10 times the energy equivalent of the work done.
- 3.7 Other Stresses: Ejection seats, parachutes and high performance vehicles impose potentially hazardous accelerations of the impact, buffet and vibration varieties. Space missions may also include exposure to specular and ionizing radiations, as well as a significant probability of meteoroid collision.

4. TYPES OF ASSEMBLIES

Pressure suits have been produced in several styles for varied applications since no one garment is "best" in all cases. Designers consider the system requirements and these needs establish the acceptable PSA characteristics. Past experience has shown that most significantly different missions establish different protection requirements for the crew. Examples include the U-2 aircraft, the X-15 research rocket craft, DynaSoar, YF-12, Mercury, Gemini and Apollo. Even applications in the U. S. Navy differ with respect to tactics, mission duration and preflight support when compared to the U. S. Air Force.

- 4.1 Partial Pressure Suits: For applications requiring only short periods of exposure at altitudes up to 70,000 feet (34 torr), incomplete pressurization particularly of the hands and feet can be tolerated. The partial pressure suit pressurizes the torso fairly evenly in most designs but leaves the hands protected only by snug fitting gloves and the feet confined in the flight boots. It is possible to extend the active pressure system to include hands and feet, but in so doing the simplicity is compromised. This class of garment is easier to don and doff and allows some normal convective cooling but still may require forced ventilation if large body surfaces are covered with impervious layers. They are tight and restrictive, particularly when pressurized, so that mobility of the wearer can be seriously inhibited. Air Force Manual 11-1 defines Pressure Suit, Partial, as "A skin tight suit which does not completely enclose the body but which is capable of exerting pressure on the major portion of the body in order to counteract an increased intrapulmonary oxygen pressure."
- A. The original partial pressure suits utilized expanding pneumatic capstan systems to tighten the coveralls on the man. Suits of this type were used in aircraft to around 65,000 feet with descent to 42,000 feet necessary within about 10 minutes. Rapid decompressions cause severe unbalances between breathing pressure and pressure on the body unless a special regulator interlock and dump valve precludes the condition.

- B. Locating bladders over parts of the chest, groin, and back increased the altitude tolerance and restored breathing mechanics to near normal. Finally, the bladders extended over the entire torso and provided easy breathing with excellent altitude tolerance. Such a garment was worn in a chamber at about 2 torr and was routinely used to 70,000 feet for several hours. This model precludes natural ventilation to a large extent. Pressure maintained at 145 torr, equivalent to 39,500 feet, makes bends almost certain unless most of the dissolved inert gas in the body has previously been washed out by breathing pure oxygen for several hours.
- C. Partial pressure suits also are fabricated without capstan systems. This simplifies the pressure regulation system since it no longer is required to establish two different pressures in response to change in barometric pressure and maintain a specific gage pressure ratio between them. Garments of this type are the British Jerkin - G Suit combination, the U. S. Air Force designed full bladder suit (Type CSU-4/P) and the French Air Force EFA-30. Each of these vary in time at altitude exposure capability.
- D. One design approach employs strips of folded bladders which should greatly improve comfort for routine wear. When sealed containing a small quantity of air, these bladder strips pressurize by expansion according to Boyle's Law. If suitably confined with a restraint layer containing simple mobility joints, it can develop pressure over the body. Problems remain to assure balance between helmet and body pressure, to achieve isobaric body pressure and to provide ease of breathing. The strip bladder approach can also be used with the bladders interconnected to the helmet pressure rather than sealed, thereby avoiding these problems.
- E. All of the above require integration with helmet, gloves, boots, oxygen system, and the usual escape and survival equipment. Helmets can be obtained with breathing regulators and respiratory valves mounted on or within them. In most cases the oxygen regulator is located in the survival seat kit. Mounting the regulator on the helmet adds to head suspended weight but it does minimize required hose connections, reduce their size and decrease the complexity of the disconnect.
- F. Helmets for partial pressure suits usually employ a soft up-turned rubber neck seal to prevent loss of oxygen from the helmet. The neck piece extends down under the collar of the suit to pressurize all the neck shoulder area. In addition to the oxygen services, respiratory valves and communications head set, some means must be included to limit respiratory dead space. Most types use a low positive pressure to inflate this helmet sealing liner and prevent collapse during inhalation. "Pumping" of this layer is physiologically intolerable. British/Canadian helmets are of a unique style in that they contain an oral-nasal mask to minimize re-breathed volume and to allow the visor to remain open during routine flight. In the event of decompression, the visor closes automatically and the head area behind the face is pressurized by a bladder. The face area is pressurized directly by the gas which also fills the head pressure bladder. Helmet rise is prevented by leaving an area approximately the same as the neck cross section on top of the skull unpressurized.
- G. All helmets of the type which are worn with visor closed must have provisions for internal fogging control. Most effective fog prevention is obtained from direct heating with imbedded electrical resistance wire circuits, although limited fog control is possible using oxygen wash over the visor interior. Thermo panes and conductive coatings have been used with some success; the principal drawbacks are weight, intensified reflections, light transmission loss, and fragility. Visors have been fabricated with heater wires laminated between two layers of tempered glass, but they are quite heavy. Polycarbonate visors are being used for their outstanding impact resistance but they afford poor scratch resistance. Acrylic plastic visors are widely used for their scratch and impact resistance, excellent visible light transmittance, good optical quality and relative ease of fabrication.