THE NASA FIREFIGHTER'S BREATHING SYSTEM PROGRAM: A STATUS REPORT

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INTRODUCTION

The National Aeronautics and Space Administration (NASA), through its Technology Utilization Program, has been making its advanced technology developments available to the public. This has coincided in recent years with a growing demand within the fire service for improved protective equipment. A better breathing system for firefighters has been one of the more immediate needs identified by the firefighting organizations. The Johnson Space Center (JSC), because of their experience in providing life support systems for space flight, was asked to determine the feasibility of providing an improved breathing system for firefighters. Such a system was determined to be well within the current state-of-the-art, and the Center is now completing a development program for an improved system. This report outlines the overall objectives of this program, progress to date, and future planned activities.

NASA QUALIFICATIONS AND EXPERIENCE

The Crew Systems Division at JSC was responsible for the development of the life support system for the lunar exploration missions. The major components of this system are shown in Figure 1. They are:

1. The pressure garment assembly (PGA) more commonly referred to as the space suit. This protects the crewman from exposure to space vacuum and the temperature extremes of the lunar surface while providing the crewman with the mobility to perform lunar exploration.

2. The portable life support system (PLSS). This is a back mounted life support system which provides breathing oxygen for the astronaut, pressurization for the suit, removes carbon dioxide, and provides cooling and communications.
3. The oxygen purge system (OPS). This is mounted on top of the PLSS and supplies backup oxygen for 30 minutes in the event of primary system failure.

The Crew Systems Division has also been responsible for the development of extravehicular life support systems for the Gemini and Skylab Programs. This has required the ability to determine the physiological needs of persons working in extremely hostile environments, to develop the lightweight systems to satisfy these needs, and to operate them successfully on actual missions. The development of the firefighter's breathing system (FBS) requires a parallel systems engineering approach.

PROGRAM OBJECTIVE AND PLAN

The basic objective of the FBS Program, as shown in Figure 2, is to develop an improved system which will satisfy the operational requirements of fire departments while remaining within their cost constraints.
To achieve this, NASA contacted fire departments throughout the country both to determine deficiencies of present systems and to establish general requirements for an improved system. This investigation revealed that the primary areas of concern to firefighters were: system weight, system bulk, operating duration, human factors, and component performance. Hence, the FBS must offer significant improvement in each of these areas while remaining within a cost range acceptable

to most fire departments. To accomplish this the program is being conducted in three phases: Concept selection, system development (which includes design, fabrication and testing) and field evaluation.

The end products of the program will be prototype breathing systems, development reports, guideline procurement specifications and a final program report all of which will be made available to potential manufacturers and users. Throughout the program, contact has been maintained with the appropriate government regulatory agencies such as The National Institute for Occupational Safety and Health (NIOSH) and The Department of Transportation (DOT). In addition, fire service organizations such as The National Fire Protection Association, The International Association of Fire Chiefs and The International Association of Firefighters periodically reviewed the program.

SYSTEM DEFINITION

The first, and perhaps most important, step in any system development program is the selection of the optimum system concept to fulfill the needs of the user. This was accomplished during the concept selection phase. Based on the information obtained from fire departments, design goals were set for system weight, configuration and a true 30 minute system operating duration. Although current systems are rated as 30 minute systems, they generally experience a shorter duration in actual firefighting. An extensive engineering study was conducted to determine the optimum system concept for this application. A systems approach which considered the user and the FBS as an integrated man/machine system was utilized. Physiological requirements of working firefighters were defined. These included such parameters as oxygen consumption and carbon dioxide generation rates, breathing flow requirements, and quantity of breathing gas required. These then became system requirements against which each of the candidate system concepts were evaluated.

All self-contained breathing system concepts fall within either of two broad categories; open loop systems or closed loop systems. The open loop systems which are shown schematically in Figure 3 consist of a breathing gas supply such as compressed air, a control element such as a pressure regulator or flow control valve, and a face mask. The exhaled breath is discharged to the surroundings through a check valve in the face mask. This is the system concept most commonly used by fire departments today. Advantages of this type of system are low cost (initial and recharge), simple maintenance and recharge, use of air rather than pure oxygen, uneffected by low temperature environments, shut down and restart capability and a reliable depletion warning system. The disadvantages are that it is not the minimum weight or bulk system and it requires a high pressure air source for recharging. The optimum open loop system is a demand type system using high pressure compressed air contained in a lightweight pressure vessel.

The alternate system concept is the closed loop system as shown in Figure 4. With these systems the user 'rebreathes' his own exhaled breath after carbon dioxide and water vapor have been removed and oxygen has been replenished. Carbon dioxide removal is usually effected by use of a chemical 'scrubber' which absorbs carbon dioxide. Heat added to the gas stream by the carbon dioxide removal process and the wearer's respiration should be removed by a gas cooler to avoid uncomfortablely high temperatures. The gas cooler is also desirable to accomplish removal of water vapor from the exhaled breath. The oxygen consumed is replaced by an oxygen supply which may be either compressed gas, liquified gas, or chemical. The advantages of a closed loop system are minimum weight and a flatter external profile. The principal disadvantages are higher initial and recharge cost, the use of pure oxygen, decreased efficiency in low temperature environments, some inability to restart after shutdown, more complex maintenance and recharge and lack of an acceptable warning system.

Comparison of the advantages and disadvantages of both systems resulted in the selection of the open loop demand type system. This is clearly superior to the closed loop system in all areas except weight and profile, and although not the minimum weight system, its weight is acceptable. The weight of the NASA developed system is considerably lower than that of currently available breathing systems of similar duration.

A lightweight pressure vessel is the key component for reducing weight of the FBS. The pressure vessel is cylindrical in shape and is designed to store air at a pressure of 4500 PSI as opposed to the 2200 PSI pressure in currently used pressure vessels. Other shapes such as spherical, toroidal and coiled tubing were considered as was the possibility of using two or more small pressure vessels instead of one large vessel. These ideas were rejected, however, mainly because of cost considerations.

The 4500 PSIG pressure vessel level was chosen as optimum for reducing the system bulk yet not exceeding regulator technology and commercially available charging compressor capability. Several pressure vessel materials and construction methods were considered; and a composite vessel made up of a metal liner and a glass filament overwrap was selected as the best approach based on cost, durability, and safety. Figure 5 illustrates this type of construction. It has a one piece aluminum liner and is overwrapped with resin-impregnated glass fibers. The stresses are carried by multiple layers of glass fibers wrapped in both the hoop and polar directions. These materials and fabrication techniques result in a bottle weight of approximately one-half that of comparable all metal vessels.

To satisfy our design goal of a true 30 minute duration, an air storage capacity of 60 standard cubic feet (SCF) was selected. Of course, it must be recognized that exact duration is dependent on work rate and individual physiological factors. When the potential weight savings which could be realized by using filament wound pressure vessels became apparent, fire department representatives indicated a smaller capacity vessel would also be desirable to satisfy their varied requirements. The smaller vessel would be approximately the size of the vessels used on current short duration 'sling paks' but would offer longer breathing duration and reduced weight. Hence, it was decided to develop two different sizes of pressure vessels, 60 SCF and 40 SCF, either of which would be interchangeable with the FBS.

In addition to the already stated goals of reduced weight and envelope, and increased operating duration, another major objective was to design an FBS which is considerably improved in human factors over currently available systems. The system should be more comfortable, easier to donn and doff, provide less encumbrance to the working fireman, provide an effective depletion warning system, and reduce breathing resistance by providing a regulator with increased flow capacity. A comparison between the existing system and the NASA FBS will show the NASA approach for obtaining these objectives. Figure 6 illustrates a typical currently available breathing system. The existing harness design results in most of the weight being carried by the shoulders. Also the harness often is difficult to donn due to multiple straps and adjustments. The existing systems have a harness mounted regulator which is located in front or on the side and a bulky breathing hose from the regulator to the mask. These items complicate donning problems and are generally an encumbrance to the firefighter. Helmet interference is frequently a problem with the existing mask and head straps.

Figure 7 and 8 illustrates the NASA developed FBS. The support harness distributes the load on the hips by making use of a wide waist belt and frame which conforms to the lower back. Studies have indicated that hip-carried loads are more comfortable and less potentially injurious to the back than shoulder carried loads. The FBS support harness concept provides adequate stability with only a single shoulder strap in addition to the load carrying waist belt. Therefore, it is considerably easier and quicker to donn. The FBS has a two stage regulator. The first (or pressure reducing) stage is mounted on the back frame while the second (or demand) stage, which is very light, is mounted on the face mask. There is nothing mounted on the chest or side to interfere with the firefighters movement. As a further improvement, the mask mounted demand regulator is easily detachable from the face mask by actuating a release lever. With the regulator detached, the user can breathe through a hole in the face mask. The detached demand regulator is stowed in a pouch on the belt.

The face mask is also an area of significant improvement as is illustrated in Figure 9. The bubble type facepiece is held in place by a nylon net and a single adjustable strap. The net concept offers a quick donn capability and reduces the problem of helmet/mask interference. The total size of the mask is reduced and interference problems with the helmet in the forehead area are eliminated. The smaller size and fewer straps of the advanced FBS face mask allow this mask to be considerably lighter than currently available face masks. The mask contains an oral-nasal deflector which aids in reducing visor fogging during exhalation. Also, the demand regulator incorporates a spray bar which channels the inlet flow over the visor during inhalation to clear away any slight visor fogging which may occur. A considerable reduction in inward leakage has been achieved by this mask.

Figure 10 is a schematic of the FBS operation. Breathing air stored inthe pressure vessel flows through the cylinder valve, the frame mounted pressure reducer assembly, the mask mounted demand regulator, and into the mask. Each of these components is described as follows:

1. The cylinder valve assembly provides an on/off control of gas flow. It contains a pressure gage, a thermally sensitive rupture disc, and a shock absorbing bumper.
2. The frame mounted pressure reducer assembly reduces pressure from the 4500 PSI supply to an intermediate pressure of approximately 100 PSI. This assembly contains two pressure reducing valves in parallel and two automatic actuators which control the operation of the reducers. Should the primary reducer fail or should supply pressure fall below 800 PSIG the actuators will automatically open the secondary pressure reducer. The secondary reducer output pressure which is slightly higher than that of the primary reducer, triggers the warning device in the demand regulator assembly.
3. The mask mounted demand regulator provides flow to the face mask upon sensing the slight negative pressure in the mask caused by the wearer's inhalation. The flow automatically shuts off during exhalation and exhaled breath exits the mask via a check valve in the diaphragm of the demand regulator. A manually operated bypass valve is provided to allow the user to purge the mask of contaminants or, in the event of regulator failure, to provide bypass flow.
4. The depletion warning device is integral with the mask mounted demand regulator. The warning device senses demand regulator inlet pressure which rises slightly upon impending air cylinder

depletion or upon failure of the primary reducer in the pressure reducer assembly. Either of these conditions diverts a small amount of air flow through the mask mounted whistle. The whistle sounds only upon inhalation and the exhaust gas from the whistle is inhaled by the wearer; thus, conserving the air supply.

The most significant improvement in the FBS is the increase in operating duration and reduction in system weight as compared to the existing breathing systems. Figure 11 provides a comparison of weight, nominal duration, and cylinder dimensions. If the 60 SCF capacity pressure vessel is used the system weight is 26 pounds. This compares to 33 pounds for the current 45 SCF system. Thus, a weight reduction and duration increase is provided. If the 40 SCF capacity pressure vessel is used, system weight is 20 pounds. This compares favorably to the present 'sling pak' system which has only 25 SCF gas capacity and weighs 24 pounds. In tests of the NASA FBS, the test subjects have indicated a lower air consumption rate than from the existing systems. This will, of course, allow additional duration from a given quantity of stored gas. This lower relative consumption rate is attributed to reduced weight and breathing resistance and improved comfort. The durations presented in Figure 11 should be considered for comparative purposes only since the tests were conducted on trained test subjects at only moderate work rates in a nonstress environment. In actual firefighting conditions consumption rates in the range of 2 SCF/minute may be experienced resulting in shorter actual durations. The additional design improvements are also summarized in this figure.

CURRENT PROGRAM STATUS AND SCHEDULE

The Firefighter's Breathing System has completed the concept selection, design, qualification tests and prototype fabrication phases. Contracts have been completed by Martin Marietta for development of the 40 SCF capacity lightweight pressure vessel and by Structural Composites Industries for the 60 SCF pressure vessels. The pressure vessels exceeded all performance requirements during an extensive test series which included pressure cycling, low/high temperature thermal cycling, high temperature exposure, water exposure and impact resistance. The pressure vessels have been approved by the Department of Transportation (Special Permit 6747) and the Bureau of Explosives has approved the safety relief device.

The contract has been completed by Scott Aviation for the complete FBS using the lightweight pressure vessels. The FBS has completed an extensive test series which included environmental exposure such as low/high temperature, humidity, impact tests and operational tests including regulator flow performance and mask leakage. The FBS has also undergone the previously mentioned NASA manned testing and a series of fire department evaluations in nonfirefighting environments. The FBS design concept was coordinated with NIOSH (National Institute for Occupational Safety and Health) and a FBS has recently been submitted to NIOSH for their evaluation.

The selection of the higher air supply pressure for the FBS has necessitated that NASA define requirements of a high pressure (5000 PSI) air charging station suitable for fire department use. NASA has accepted delivery of such a station designed by the American Instrument Company. The station includes a compressor of the oil free diaphragm type, an air purification system for removal of water and other contaminants, air storage reservoirs of the cascade type and FBS pressure vessel charging fixtures. This type of system could serve as a prototype for fire department procurement. The oil free compressor is especially recommended for the higher pressure breathing air.

The FBS field evaluation is scheduled to begin in mid 1974. During the field evaluation phase, the FBS will be used by several fire departments in actual firefighting service over approximately a six-month period. NASA will monitor the system performance during this period and will provide training, maintenance support and, if required, design modifications. Upon completion of the field evaluation, the program will be concluded with the issuance of a final report and system specifications. These specifications may then be used by fire departments as a guide for their FBS procurement. Manufacturers are currently establishing the capability to commercially produce improved breathing systems based on the NASA FBS. These improved systems should be available for delivery to fire departments by mid 1975.

CONCLUSION

Perhaps the most difficult hurdle to face in the FBS Program is not the solution of technical problems, but rather the achievement of widespread fire department acceptance of the system. This acceptance depends, of course, upon there being sufficient demand by fire departments to justify commercial manufacture of large quantities of these systems. Cost analysis to date indicates that if adequate demand exists for the FBS, costs will only slightly exceed that of existing systems. Thus, it is imperative that those in the fire service who need improved breathing systems convey their needs to those responsible for equipment procurement and to companies who may be potential manufacturers of advanced firefighter's breathing systems. If this is done, and if the demand is sufficient, implementation of the FBS into widespread use in the fire service will be successful. Firefighters will have a breathing system that, because of its substantial advantages in the areas of weight, duration and human factors, will provide greater safety for the firefighter and permit him to work more effectively.

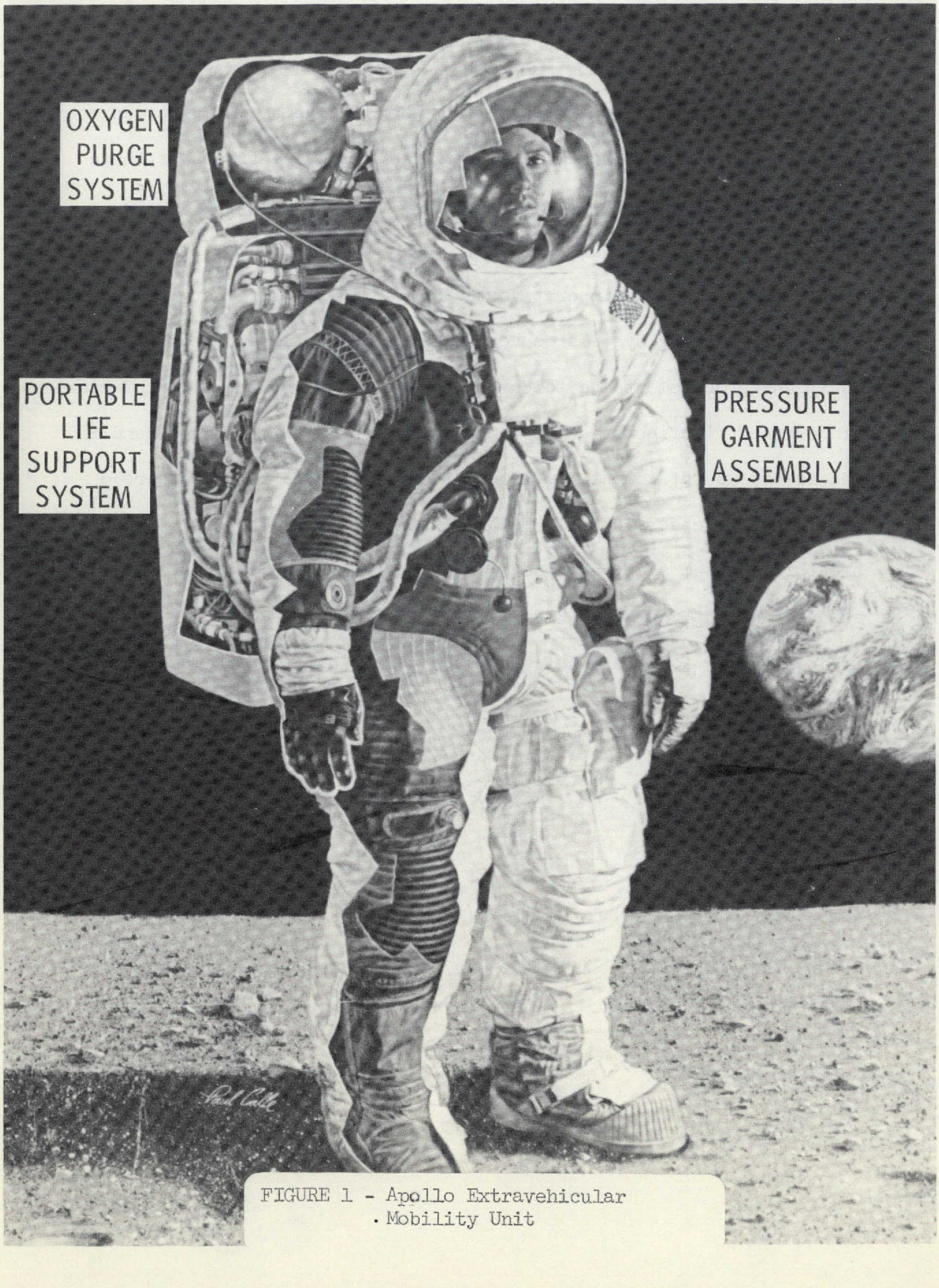

FIGURE 1 - Apollo Extravehicular Mobility Unit

OBJECTIVE

DEVELOP AN IMPROVED FBS (FIREFIGHTER'S BREATHING SYSTEM) SUITABLE FOR WIDE-SPREAD FIRE DEPARTMENT ACCEPTANCE IN TERMS OF COST AND OPERATIONAL CHARACTERISITCS

ASSIST IN THE ACCEPTANCE AND IMPLEMENTATION OF THE IMPROVED FBS BY COORDINATING REGULATORY AGENCY APPROVAL AND CONDUCTING A FIELD EVALUATION PROGRAM

APPROACH

REQUIREMENT DEFINITION BY FIRE DEPARTMENT ADVISORY COMMITTEE

- DEFICIENCIES OF PRESENT SYSTEM
- DESIRED IMPROVEMENTS (REDUCED WEIGHT AND BULK, INCREASED DURATION, IMPROVED HUMAN FACTORS)

PROGRAM PLAN

- CONCEPT SELECTION
- SYSTEM DEVELOPMENT (DESIGN, FABRICATION, TEST)
- REGULATORY AGENCY COORDINATION
- FIELD EVALUATION

END PRODUCTS

FULLY QUALIFIED PRESSURE VESSEL AND FBS AS DEMONSTRATED BY A FIELD EVALUATION IN FIREFIGHTING CONDITIONS

REGULATORY AGENCY APPROVAL

DOCUMENTATION TO ASSIST FIRE DEPARTMENTS AND POTENTIAL MANUFACTURERS

COMMERCIALIZATION OF THE FBS CONCEPT BY MANUFACTURERS

FIGURE 2 - The NASA Firefighter's Breathing System Program

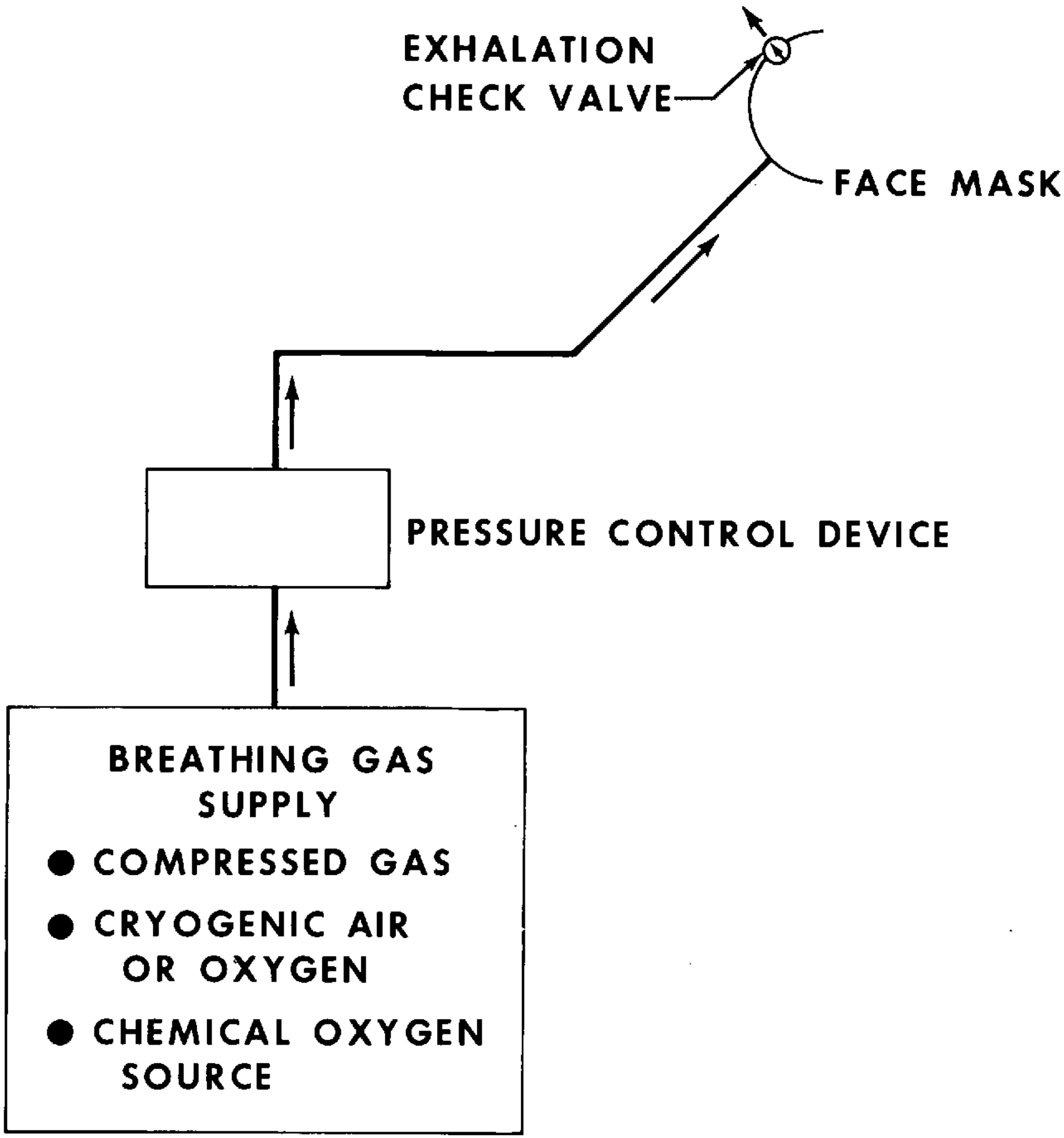

FIGURE 3 - Open Loop System

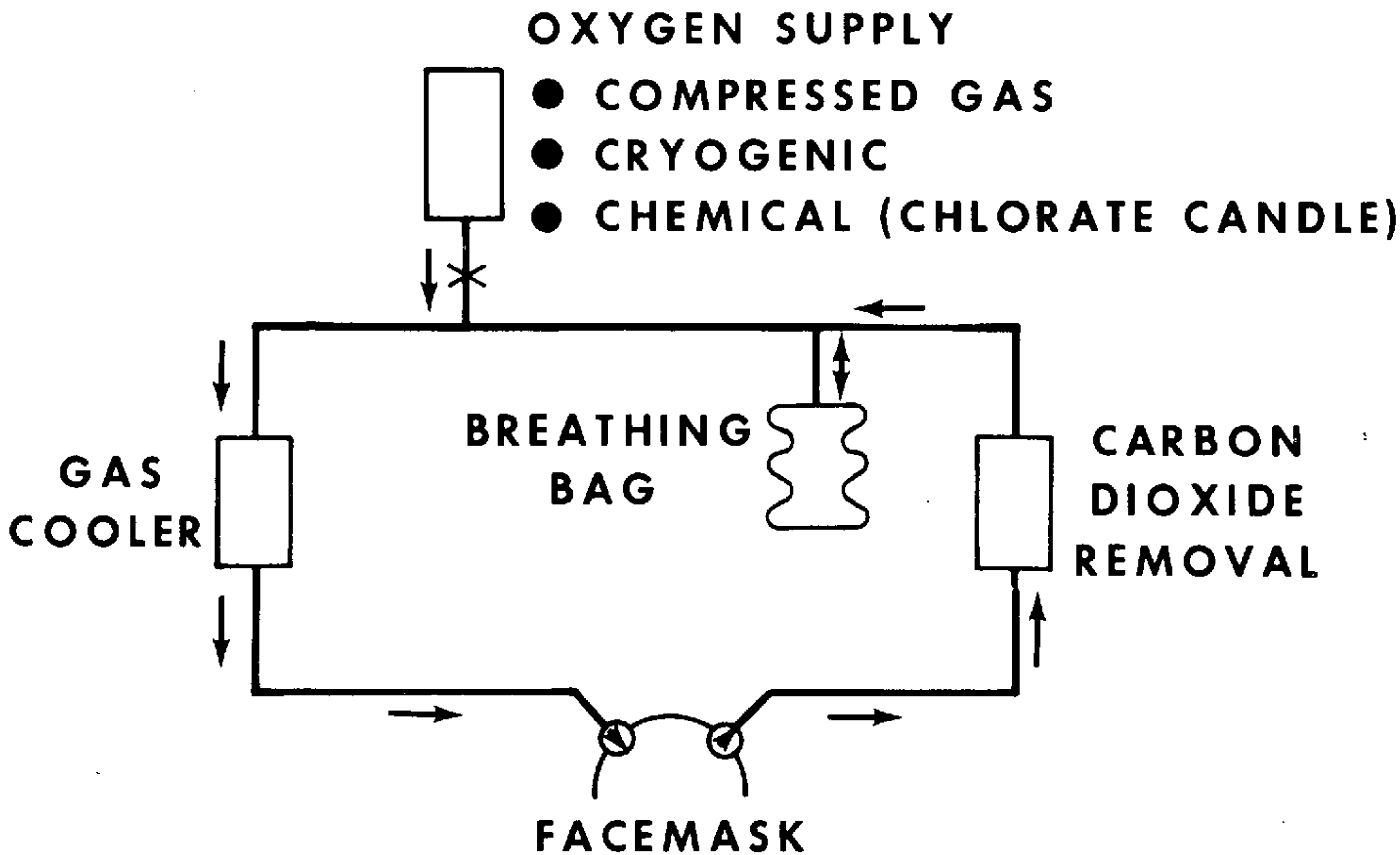

FIGURE 4 - Closed Loop System

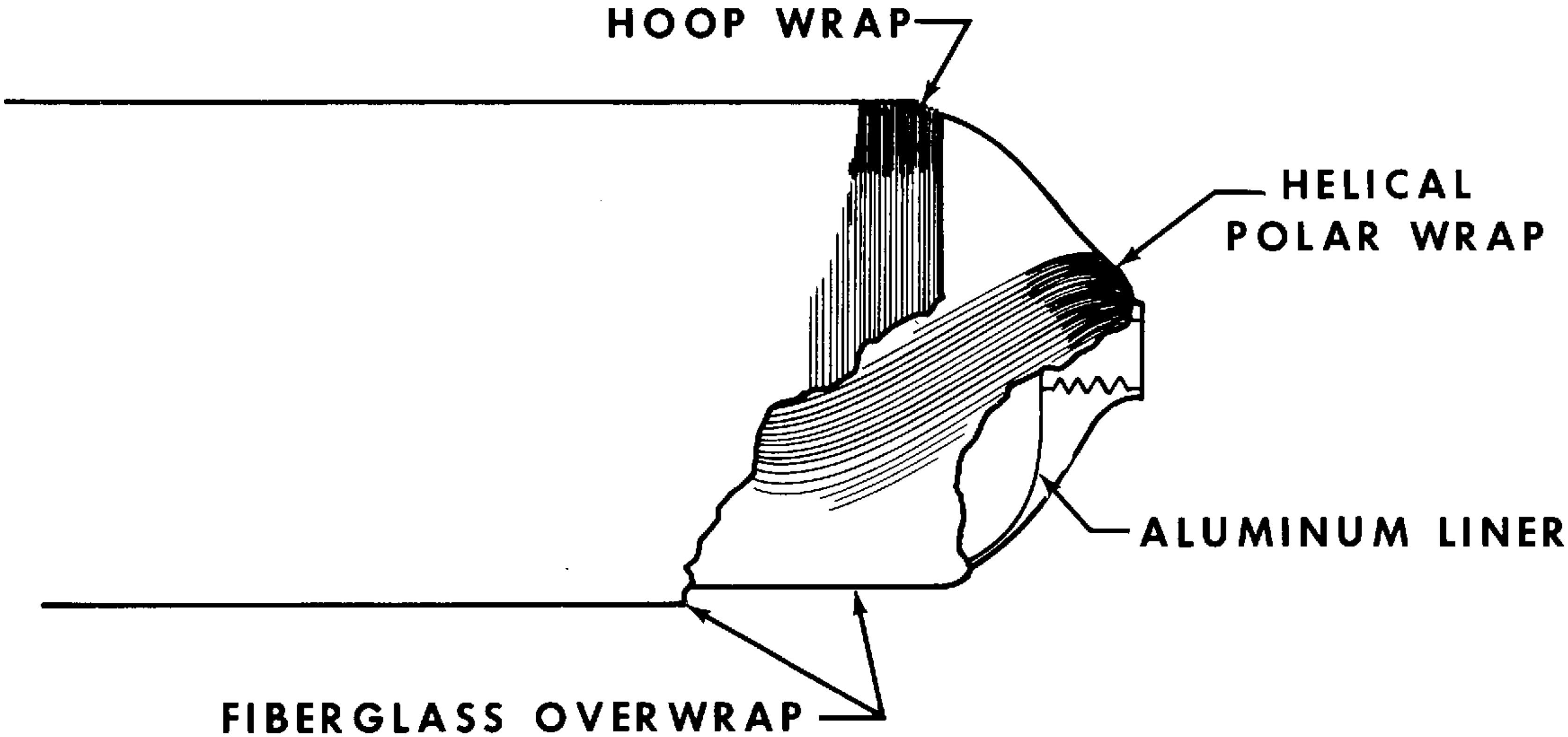

FIGURE 5 - Filament Wound Pressure Vessel

FIGURE 6 - Typical Existing Breathing Apparatus

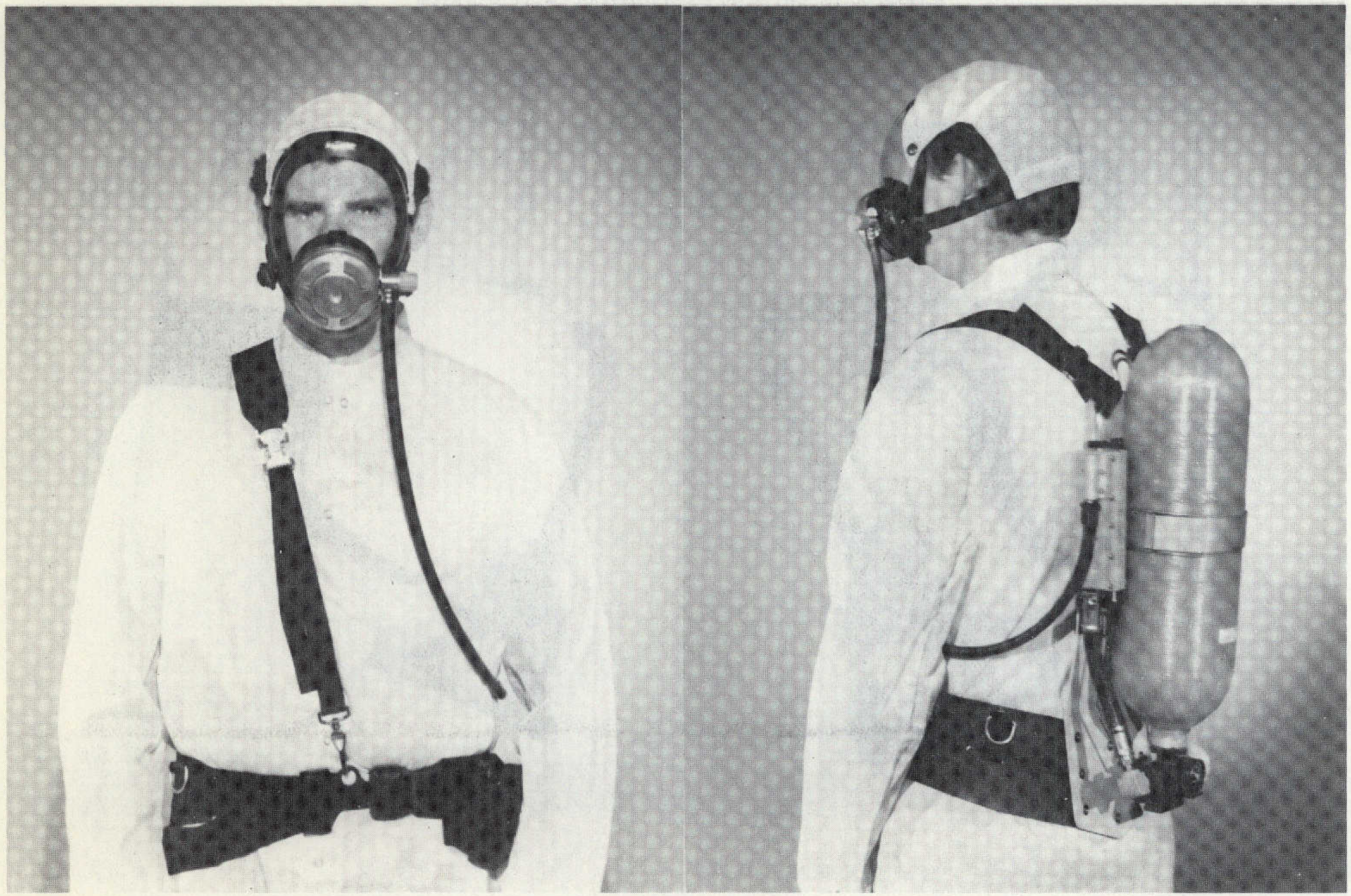

FIGURE 7 - NASA Firefighter's Breathing System
(Single strap configuration in left photo)

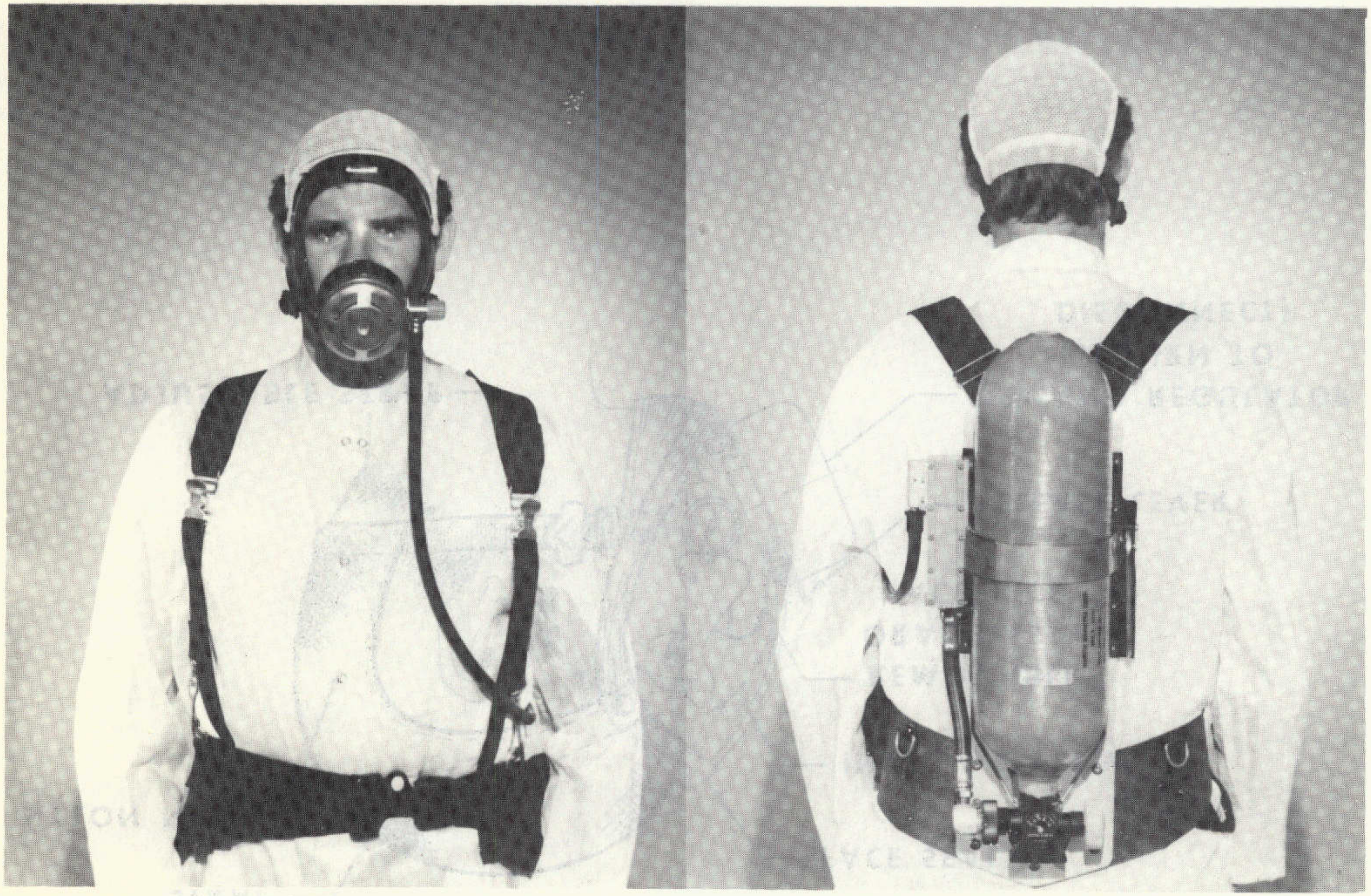

FIGURE 8 - NASA Firefighter's Breathing System

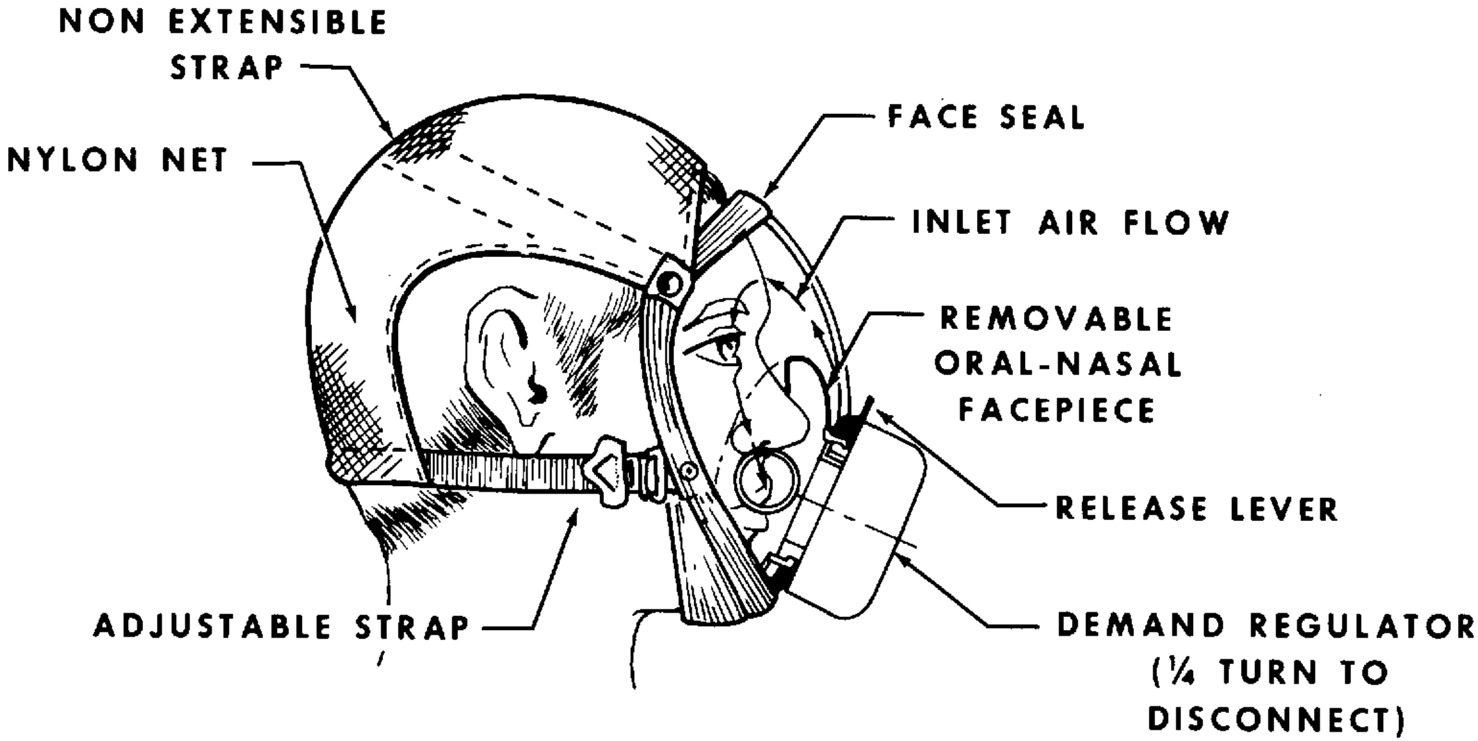

FIGURE 9 - NASA Firefighter's Breathing System Facemask and Demand Regulator

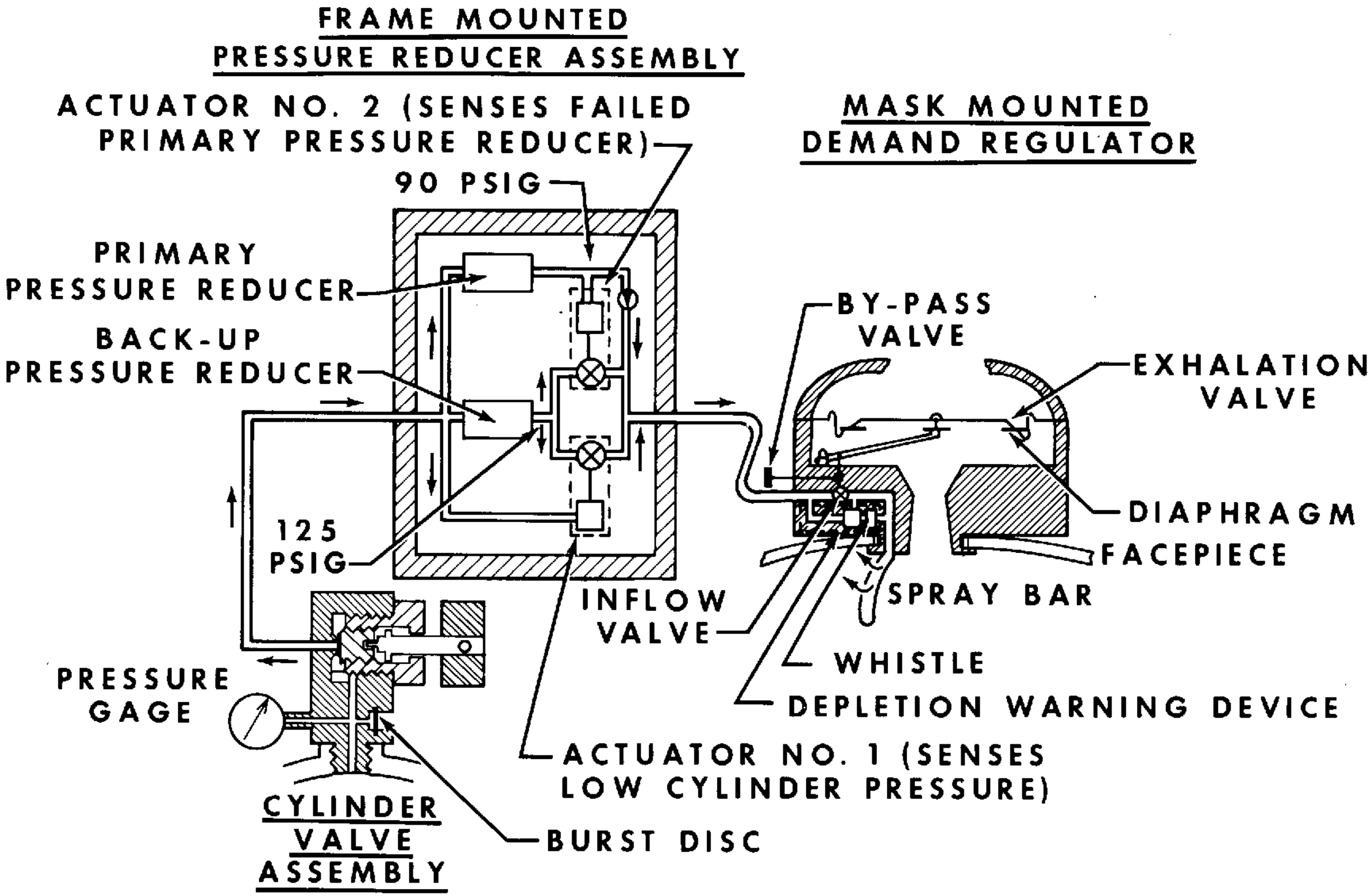

FIGURE 10 - NASA Firefighter's Breathing
System Schematic

FEATURES	EXISTING SYSTEMS	NASA FBS	NASA FBS
STORED GAS CAPACITY (STANDARD CUBIC FEET OF AIR)	45 SCF	40 SCF	60 SCF
OPERATING PRESSURE (POUNDS PER SQUARE INCH)	2200 PSI	4000 PSI	4000 PSI
TEST DURATION* (MINUTES)	36 MIN*	40 MIN*	56 MIN*
TOTAL CHARGED WEIGHT (POUNDS)	33 LBS	20 LBS	26 LBS
CYLINDER DIMENSIONS (INCHES)	6.8 IN. DIAM x 19.5 IN. LONG	5.6 IN. DIAM x 18.6 IN. LONG	6.5 IN. DIAM x 19.7 IN. LONG

*DURATION BASED ON AVERAGE ACTUAL TIMES OF TRAINED SUBJECTS TESTING ON A TREADMILL AT 3.5 MPH AND 3 DEGREE SLOPE. ACTUAL DURATION IN HIGHER STRESS CONDITIONS IS EXPECTED TO BE LESS.

DESIGN IMPROVEMENTS:

- REDUCED WEIGHT/INCREASED DURATION
- SIMPLIFIED HARNESS WITH WEIGHT CARRIED ON HIPS
- REDUCED BREATHING RESISTANCE
- IMPROVED REGULATOR CONFIGURATION
- IMPROVED MASK HARNESS
- REDUCED MASK LEAKAGE

NASA-JSC

FIGURE 11 - Existing Systems vs. NASA Firefighter's Breathing System