The Space Congress® Proceedings | 1999 (36th) Countdown to the Millennium

Apr 27th, 2:00 PM - 5:00 PM

Paper Session I-D - A Study of Alternative Technologies to Compressed Air Self-Contained Breathing Apparatus

J. Timothy Moore
Fire Chief Cape Canaveral Air Station/Kennedy Space Center Fire Rescue Services

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Executive Development

By: J. Timothy Moore
Fire Chief
Cape Canaveral Air Station/Kennedy Space Center Fire Rescue Services
Mail Code: SGS-322/E-Mail: Moore-1, Tim/Location: K6-1198/Phone: 867-4258/FAX: 861-6789
Kennedy Space Center, Florida

Paper Session Topic - Science: Global Benefits From Space

Abstract

The Kennedy Space Center Fire Department is tasked with the rescue of flight crew members of the United States Space Shuttle fleet for launch and landing at the Kennedy Space Center and two transatlantic emergency landing sites. This research project addresses the problem of how conventional compressed air technology used in self-contained breathing apparatus SCBA limits the Firefighters at Kennedy Space Center in performing their mission of astronaut rescue.

The purpose of this research project is to examine alternative technologies to compressed air SCBA in hopes of ensuring that the Astronaut Rescue Team members are equipped with an SCBA that best meets their needs.

A literature review was conducted to research available literature pertaining to alternative technologies to compressed air. The methodology used for this research project was that of descriptive. The research questions explored the limitations of compressed air SCBA when used for long duration, high workload, activities such as astronaut rescue, what technologies were currently available to resolve the problems identified with compressed air SCBA, and what draw backs existed with the alternative technologies. This survey was developed to examine thoughts and feelings on the ergodynamics of different SCBA that could be used by rescue team members. This survey was a deliberate attempt to focus on the end users' needs rather than bioengineering laboratory evaluations on what the next generation of SCBA should be for the Astronaut Rescue team.

The results of the research disclosed that the compressed air SCBA technology simply fell short in meeting the long duration requirements and was too large and heavy to ensure entry into the space shuttle emergency entry points. The research also revealed that of the two primary alternative SCBA technologies, the liquid air pack was shown to better meet the needs of the Astronaut Rescue team at Kennedy Space Center.

Additional research is recommended to verify this author's results and to explore how the liquid air pack SCBA might be utilized by other fire departments.

Introduction

On April 12, 1981, the space shuttle Columbia, space transportation system STS-1, was launched from the Kennedy Space Center, Florida. Columbia was the United States' first reusable spaceship that could return to earth and land on a runway. It became very apparent that the respiratory protection apparatus used for the Apollo Space Program would not meet the needs of the Space Shuttle Program.

The Apollo Astronaut Rescue Team Firefighters were only tasked with removing the astronaut flight crew from the command module at the launch pad, so the usage of small compressed air D cylinders worked well for the confined space of the crew module. (Doerr and Martin, 1991). The space shuttle program changed the nature and scope of the astronaut rescue. The flight crew number went from three to seven. The major change was the addition of developing a rescue team to perform on and off runway rescue in the areas around the Kennedy Space Center. Rivers, swamps, woodlands, and pine forest make up the 25 mile radius around Kennedy Space Center, thus presenting a real challenge in finding an SCBA that will work in all types of environments.

The immediately dangerous to life and health (IDLH) atmosphere around a crash site produced by highly toxic rocket propellants require the need of an SCBA to exceed the one hour rating.

Problem

The weight, size, and maximum one hour rating of air supply of compressed air technology for self-contained breathing apparatus severely limits the Firefighters at the Kennedy Space Center from performing a rescue of the flight crew from the space shuttle.

Purpose

The purpose of this research was to examine alternative technologies to compressed air SCBA for the Astronaut Rescue Program at the Kennedy Space Center.

Research Method

The descriptive research method was used. Research consisted of literature analysis and a survey which required the respondents to rate five different kinds of SCBAs using six different criteria. Also, nine questions were asked addressing the focus of the next generation of SCBA for flight crew rescue usage at Kennedy Space Center. The survey was distributed to 30 Astronaut Rescue Team members representing the 15 member Pad Rescue Team and the 15 member Search and Rescue (SAR) Team. All 30 members responded to the survey.

Research Questions

The following questions were asked for this research project:

1. What are the limitations of compressed air SCBA when used for astronaut rescue at Kennedy Space Center?

2. What is needed by the Kennedy Space Center Fire Department for the next generation SCBA for flight crew rescue?

3. How does the end user rate technologies that could be utilized to resolve the limitations identified with compressed air SCBA?

4. Are there disadvantages of the alternative technologies to compressed air SCBA?

Background And Significance

As part of the National Fire Academy's Executive Development Course, critical attention is given to creativity and innovation. A logical course is to examine one's own organization for areas of creativity and innovations that may not be found anywhere else, and that may be of benefit to others. This research project analyzes current technology for self-contained breathing apparatus other than industry standard for compressed air or rebreather units. Thus, this relates well to the stated objective of the Creativity and Innovation unit.

Kennedy Space Center Fire Department is made up of 150 paid professional Firefighters. It is a full service fire department providing suppression, EMS, and Haz Mat response, and is also tasked with the rescue of astronaut flight crew from the space shuttle. The compressed air technology used in self-contained breathing apparatus used by the fire service today simply does not meet the needs of the Astronaut Rescue Team at the Kennedy Space Center Fire Department.

This research paper examines alternative technologies to compressed air for self-contained breathing apparatus. This research is important for the following reasons:

By presenting alternative technologies to the compressed air SCBA, it may help other chief fire officers step outside the paradigm of what an SCBA is or should be.

Identifies which SCBA best meets the needs for the Kennedy Space Center Astronaut Rescue Team and what Astronaut Team members are seeking in the next generation of SCBA to be for flight crew rescue.

In addition, the research identifies NASA technology that may provide for a safer SCBA which could be used for all fire departments.

Literature Review

Initial literature search was conducted through the United States Fire Administration Learning Center (LRC), but was limited in subject area of self-contained breathing apparatus. The purpose of the research was to examine alternative technologies to compressed air SCBA for the astronaut rescue for the space shuttle transportation system.

Steven (1981) examined the two types of closed circuit breathing technology used to date. This author provides evidence as to the physiological benefits of positive pressure closed circuit breathing apparatus as well as its disadvantages of breathing high concentrations of oxygen that this type of SCBA technology produces. The author's conclusion is that National Institute of Occupational Safety and Health (NIOSH) should proceed with creation of design and test criteria for positive pressure closed circuit breathing apparatus.

Doerr (1988) reviewed cryogenic air technology and compared commercially available closed circuit SCBA unit known as rebreather and compressed air SCBA. It is the author's view that the closed circuit and compressed air SCBAs are not suitable for the rescue forces at the Kennedy Space Center.

Doerr attempted to perform the NIOSH protocol in the testing of the liquid air pack and found that NIOSH criteria does not specifically address liquid air. The tests did reveal a shortcoming with the liquid air pack.

But overall, the liquid air SCBA was shown to be superior to any other known SCBA in regards to air supply, weight, comfort, duration and safety by the author's field studies.

In the journal International Fire Chief, (Campbell, 1978) presented an article that explored National Institute of Occupational Safety and Health (NIOSH) and Mining Enforcement and Safety Administration (MESA) regulations for firefighter SCBA. Overall safety was addressed regarding such things as compressed air bottles and flame retardancy of straps/harnesses. The author states that current compressed air SCBA are "inadequate for the job" that we are asking fire rescue personnel to perform.

In Firehouse, (Ornberg, 1991) states the liquid air pack (LAP) can provide fire rescue personnel up to three hours of air. Such an SCBA would be of tremendous value not only for the Kennedy Space Center Fire Rescue but also for all operations involving high rise, haz mat, confined space, subway and mining emergencies.

He goes on to state that the use of liquid air is safer due to the fact that liquid air may be -317° Fahrenheit but is only stored at 150 pounds per square inch (PSI) as compared to compressed air which is stored at pressures up to 4,500 PSI.

(Elliot, 1989) writing in IAFC on Scene, cites the cost of a LAP, if commercially available, would be around $2,000 each. He did not provide any technical information costing out a LAP. He states that making liquid air is simple and is not an insurmountable problem by using hospitals as suppliers of liquid oxygen and nitrogen. All that would be needed would be some type of mixing device to meter and mix the two cryogens together to make liquid air.

(Doerr and Martin, 1992) presents an article in Journal of International Society of Respiratory Protection. The authors examine the logistics of liquid air. The specifications for liquid air used at KSC allows for an oxygen content of 20 to 25 percent. This allows for normal oxygen enrichment resulting from the higher boiloff rate of nitrogen.

The making of liquid air for use in the LAP is done by the usage of a simple "Y" fixture with the oxygen side approximately half the size as the nitrogen side of the "Y" which can flow blended at a rate of approximately 100 gallons/380 liters per minute at a cost of approximately $1.35 per 210 gallons/795 liters. It is also noted that there is about 10 percent boiloff loss when transferring and an average daily boiloff of one to two percent of storage tank capacities. The authors state that supplying long duration SCBA providing high flow, cool, breathing air appears to be only with the usage of liquid air, compressed air could not provide the same long duration.

(Carlson, 1991) explores why the LAP cannot use compressed air technology to determine the mass or volume of air available in the LAP/SCBA. A compressed air SCBA uses a pressure gauge to show the drop in compressed air as the SCBA is nearing the end of service life. The pressure in a liquid air pack remains constant (at 150 PSI) throughout the service life.

The author offers a solution to the problem of how to determine the mass or volume of air still available to the user of the LAP/SCBA.

(Weinstein, 1989) authored an article in Industrial Fire World on the technology used in the closed circuit rebreather SCBA is superior to that of open circuit compressed air SCBA. The sole advantage is that of extended duration of breathing air supply.

(Shaffer, 1984) examines the SCBA technology of using a liquid fluorocarbon that is actually breathed into one's lungs, i.e., liquid ventilation. This system would control one's body core temperature and would provide for prolonged periods of usage, as well as overcoming the need to decompression from deep water diving.

The literature review assisted the author of this research in the understanding of technology other than that of compressed air for SCBAs. However, it did not address the question of what should be the basis of the next generation of SCBA for the Astronaut Rescue Team at the Kennedy Space Center.

Procedures

The research process for this project initially centered with the Learning Resource Center, located at the United States Fire Administration, Emmitsburg, Maryland. A very limited information base was available which included video tape interviews, some published literature and related topics. A supplemental source was found through contacts within NASA at the Kennedy Space Center, Florida. Descriptive research criteria was used to investigate current availability of other technology to compressed air used in self-contained breathing apparatus (SCBA) for the Astronaut Flight Crew Rescue Teams at Kennedy Space Center.

A closed format survey was developed using questions that would require the respondent to identify answers which best represented their personal point of view concerning: alternative technologies to compressed air SCBA for the Astronaut Rescue Program at Kennedy Space Center. In order not to bias the survey, a total of five different SCBAs were surveyed. The following three use compressed air: 30 minute standard ISI Ranger Open Circuit, European AGA Divator; ARAP Astronaut Rescue Air Pack - approximately 20 minutes. The non-compressed air

SCBAs are as follows: Liquid Air Pack (LAP) and Rebreather. A copy of the survey form used is located in Appendix A.

The surveys were given to all members of both Astronaut Rescue Teams: Launch Pad and Search and Rescue. Thus the total population surveyed was 30. Included in the population were 15 members of the Launch Pad Rescue Team and 15 members of the Search and Rescue Team. The data collection consisted of a one page survey completed at the end of a departmental training sessions. (See Appendix A)

The method of statistical analysis of the survey results involved tabulation of the individual answers for questions one through five. There are six parts that must be answered placing a number ranging from one to five, one by the best and five by the worst. Also, if the respondent had no opinion it could be noted. For question six through 14, the respondent had to answer yes or no. The answers were tabulated by respective question for comparative analysis. (See Appendix A)

Definition of Terms

1. **Human interface**: How well a device meets the need of the user
2. **Bioengineering**: The application of engineering principles in regards to medicine and biology.
3. **Alternative technologies**: In regards to this research any other type of technologies other than the standard compressed air used by most fire departments.
4. **Liquid air**: Air that has been compressed until it has changed from a gas to liquid (-317° F).
5. **Rebreather**: A closed circuit SCBA that the uses exhalation breath and removes the carbon dioxide and adds 100% oxygen.

Limitations

This research is subject to a variety of limitations. The Kennedy Space Center Astronaut Rescue Team is the only fire service in the USA that is using a working prototype of the liquid air pack. The subjects surveyed were limited to the current Astronaut Rescue Team members at Kennedy Space Center.

The survey sought to determine the response of the Astronaut Rescue Team members regarding the use of alternative technologies to compressed air self-contained breathing apparatus. Thus, the survey protocol is not based on bioengineering laboratory evaluations. Rather the survey protocol is based on the end user's thoughts and feelings on the ergodynamics of the different self-contained breathing apparatus. The data collected was tabulated into categories correlating to the survey questions and placed in chart form. (See Appendix B through D) The data regarding the next generation SCBA was then summarized. (See Appendix E)

Results

A total of 30 Astronaut Rescue personnel were contacted, of this sample, 100 percent responded. The results are presented in Appendix B through D. The next generation of SCBA is summarized in Appendix E. The results to the specific research questions are as follows:

1. **What are the limitations of compressed air SCBA used for Astronaut Rescue at Kennedy Space Center?**

The space shuttle scenario involves rescue of up to seven crew members in an atmosphere contaminated with toxic propellants (Doerr and Webber, 1987). The space shuttle systems are extremely complex requiring the rescue personnel to work in immediately dangerous to life and health (IDLH) environments for timeframes that may well exceed 60 minutes. The standard open circuit compressed air SCBA requires large heavy cylinders, containing as much as 90 cubic feet of air, in order to reach a 60 minute duration (Doerr, 1994). The standard 60 minute compressed air SCBA may be rated at 60 minutes but the physiological requirements of Firefighters performing the rescue may only allow for a 40 minute service life. Also, the top hatch of the space shuttle is only 20 inches square. Therefore, the size of this type SCBA would not allow rescue personnel to make entry into the top window to effect a rescue of the flight crew. An additional concern is that of the dangers of compressed air cylinders being damaged when team members are deployed to off-site remote locations by "fast roping" out of H-60 helicopters (D. Doerr, Personal communication, September 11, 1994).

2. **What is needed by Kennedy Space Center Fire Department for the next generation of SCBA for flight crew rescue?**

The results of the survey indicate that the main focus of the next generation of SCBA should be in making it smaller and lighter with longer service life duration and comfort being a close second. (See Appendix E for a detailed breakout of survey)

3. **How does the end user rate the technologies that could be utilized to resolve the limitations identified compressed air SCBA?**

The results of the survey suggests that the liquid air pack (LAP) SCBA was rated by the end users to be superior to compressed air technologies SCBA in the overall safety of the unit; lighter in weight; better human interface; smaller in size so as to allow for shuttle top hatch entry; and the duration of air supply showed vastly superior to the compressed air SCBA units. The LAP also has an added physiological benefit to the user. It will deliver the service life of air supply at a constant 65 degrees Fahrenheit no matter how hot the environment (Ornberg, 1991).

4. As for the closed circuit rebreather SCBA, the data indicated that it was the least preferred of the SCBA units (Doerr 1993). The closed circuit rebreather SCBA may provide 60 minutes of air supply but the elevated temperatures as high as 135° F delivered to its user may have adverse effects to rescue personnel in the hot and humid Florida environment, thereby contributing to heat stress hazard. In addition, the rebreather SCBA will not work well in a water environment. (See Appendix B through D)

5. **Are there disadvantage of the alternative technologies to compressed air SCBA?**

The results of the survey revealed that even though the LAP SCBA is rated by the end users to be superior to all other SCBAs surveyed, it fell short in one area of the survey, reliability. (See Appendix B) This may be due to the fact that the LAP SCBA can only hold its air supply for 13 hours even when not in use. (Doerr and Martin, 1992)

6. As to the closed circuit rebreather, the survey showed it fell short in all areas surveyed. (See Appendix B through D).

Discussion

The author's purpose in conducting this research was to examine alternative technologies to compressed air SCBA for the Kennedy Space Center Astronaut Rescue Program. Through both the review of the literature and the survey of the Astronaut Rescue Team members it was identified that there was a definite relationship between the results of this research and the finding of others. It was found that there are only two technologies which can meet the requirements needed for the space shuttle rescue program that are currently available. The first is closed circuit rebreather SCBA which is commercially available and meets NIOSH certification standards for the provision of a long duration air supply. The other is the liquid air pack (LAP) which meets NASA requirements for the space shuttle rescue program, but doesn't meet all NIOSH standards, and is not yet commercially available. (Doerr and Martin, 1992, pg 2-4)

The author's interpretation of this research is that the cryogenic liquid air technology has the following draw backs: not NIOSH approved, 13 hour storage life of breathing air, cryogenic air is not readily available, not commercially available, end of service life of unit is difficult to measure. When comparing the LAP to commercially available closed circuit rebreather units, which is the only other practical non-compressed air SCBA technology, the LAP cryogenic air technology out performs the rebreather units on all categories surveyed. (See Appendix B)

Specific organizational implications became apparent to this author in the analyzing of the survey data. These implications are:

Liquid air SCBA technology is accepted by the end user as a superior technology to compressed air and rebreather technologies for an SCBA.

Even though the LAP SCBA is smallest and lightest in weight of the long duration SCBA, the end users still feel it should still be smaller and lighter.

Development should proceed on the refinement of the LAP SCBA so that its usage could be expanded into everyday fire/rescue activity such as firefighting, haz mat and confined space rescue.

The Kennedy Space Center Fire Department has not done a good job in promoting the LAP SCBA as NASA's technology transfer program directs more exposure of the LAP SCBA is needed in the fire service community. But on a positive note the Life Support engineering office is interfacing better with the Fire Chief's office in regards to the development of the next generation of SCBA to be used at Kennedy Space Center. This should assist in the design and refinement of the next generation of SCBA.

Recommendations

The author's research found severe limits to the usage of compressed air technology SCBA for Astronaut Flight Crew Rescue. (See Appendix B through D for rescue teams' rating of their preference of the five different types of SCBA). The author used descriptive research to apply new technology breakthroughs regarding non-compressed air SCBAs addressed in this research. It is recommended that the main focus of future research be given to the refinement of liquid air SCBA technology so that it may provide the same benefits to all other fire departments who require an SCBA for longer duration needs on a day to day basis. In addition, a national standard should be developed by NIOSH for the testing and certification of the liquid air pack. Consideration should also be given to researching the technology that is pushing the envelope of science like the Werner (1990) artificial gill that would allow humans to breathe in a liquid environment in the same manner as in a normal air environment, and the Shaffer (1989) liquid breathing SCBA that uses oxygenated fluorocarbon for prolonged SCBA usage. By pushing the limits of technology and simply not accepting that compressed air SCBA is the best technology, the fire service needs to provide the safest SCBA to its members using alternative technologies.

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