



AEROSPACE INFORMATION REPORT

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Guide for Evaluating Combustion Hazards in Aircraft Oxygen Systems

RATIONALE

AIR825/13 has been reaffirmed to comply with the SAE Five-Year Review policy.

FOREWORD

This document is one of a set of related documents. These documents comprehensively address the "Introduction to Oxygen Equipment for Aircraft," and are referred to as slash (/) documents, rather than chapters. The documents may be obtained as a set or individually. As the field of oxygen systems for aircraft has evolved, it became cumbersome for one document to cover the full range of subject matter. The reader who is seeking overall familiarity with oxygen systems for aircraft should read all of these documents that combine to form a general reference to oxygen systems. The reader who is familiar with oxygen systems for aircraft may want to obtain only the slash documents that pertain to topics that are of specific interest.

The document set is written as an introductory level, suitable for anyone who would like to understand the basics of oxygen systems in aircraft and specifically for the engineer who has just recently been assigned to aircraft oxygen systems. Many of these documents point the reader toward more detailed treatments located in other SAE documents.

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Documents

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1. SCOPE:

This guide is intended to promote safe designs, operations and maintenance on aircraft and ground support oxygen systems. This is also a summary of some work by the ASTM G 4 Committee related to oxygen fire investigations and design concerns to reduce the risk of an oxygen fire. There have been many recent technological advances and additional test data is available for evaluating and controlling combustion hazards in oxygen equipment. Standards that use this new information are rapidly evolving. A guide is needed to assist organizations and persons not completely familiar with this process to provide oxygen systems with minimum risks of combustion. This guide does not necessarily address all the detailed issues and provide all data that will be needed. For a complete analysis, supplemental publications need to be consulted. This guide does discuss the basics of oxygen systems fire hazards. The hazard analysis process is discussed and a simple example to explain this process. Also, this guide does not address the overall system safety issues normally evaluated in aircraft programs. This guide does provide some important background and observations about combustion in oxygen systems. Information is given describing how to accomplish a hazard analysis. Furthermore, background is provided to explain critical locations in oxygen systems that need to be evaluated and other locations that do not require hazard analysis.

It is important to note that any effort that requires a comprehensive and effective hazard analysis should use the complete information in the documents referenced herein. In general, the need for a hazard analysis applies primarily to gaseous oxygen equipment at 50 psi and higher pressures. LOX equipment does have hazards concerns as well and is usually treated similarly to GOX equipment at 500 psi. It should be noted that there are other phenomena associated with LOX equipment that must be considered. An example is that LOX can combine with hydrocarbons to form a gel, which explodes under impact. On the other hand, since LOX is a very cold liquid it tends to quench most possible ignition sources that could cause promoted ignition. When examining oxygen equipment at lower pressures the primary concern is the increased ignition and fire concern with combustible non-metals.

1.1 Purpose:

This document is intended to provide a guide for minimizing the risk of combustion hazards associated with the design, installation, and maintenance of aircraft oxygen systems. This guide also discusses a process of planning and organizing a project assisting someone who wishes to evaluate an oxygen system(s) such that combustion risks are minimized. The use of this guide and supporting documentation in part or whole is entirely elective.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AIR1169	Bibliography of References Pertaining to the Effects of Oxygen on Ignition and Combustion of Materials
ARP1176	Oxygen System and Component Cleaning and Packaging
AIR4071	Lubricants for Oxygen Use

2.1.2 ASTM Publications: Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D 2863	Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index)
ASTM G 63	Guide for Evaluating Nonmetallic Materials for Oxygen Service
ASTM G 88	Guide for Designing Systems for Oxygen Service
ASTM G 93	Practice for Cleaning Methods for Material and Equipment Used in Oxygen-Enriched Environments
ASTM G 94	Guide for Evaluating Metals for Oxygen Service
ASTM G 128	Standard Guide for the Control of Hazards and Risks in Oxygen Systems

2.1.3 Other Applicable References:

Dees, J., and R. F. Poe, Test Plan: Guide for Oxygen Hazards Analyses on Components and Systems, TP-WSTF-713, NASA Johnson Space Center, White Sands Test Facility, Las Cruces, NM July 7, 1993

Bamford, L. B., and M. A. Rucker, Guide for Oxygen Component Qualification Tests, TP-WSTF-712, NASA Johnson Space Center, White Sands Test Facility, Las Cruces, NM 1992

2.2 Definitions:

CRES: Corrosion RESistant Stainless (CRES) Steel.

Component: On any oxygen equipment item such as a regulator the components are subgroups of function equipment that make up the whole item. For example, the servicing or fill valve, the pressure relief valve, the pressure gauge, the outlet flow regulating device, and the supply vessel.

Flammable: Possible to burn, combustible, capable of being ignited.

Stress Risers: Elements that cause increased stress or a tendency to increase the risk of ignition and combustion.

Thermal compensator: Special device in a mechanical design carrying a gas such as oxygen that absorbs heat energy and carry away the heat energy from mechanical parts which are at risk of ignition. The temperature is more rapidly conducted away to the ambient to keep the oxygen temperature inside the tubing minimized. The device can also shut down oxygen flow if a maximum limit is reached.

3. BACKGROUND:

3.1 What Factors Cause Fires:

Oxygen system fires and explosions are a result of numerous factors that are complex in their interaction and not easily understood. This guide will assist someone not familiar with these phenomena to better understand and analyze any oxygen system hazards. It is always best that an expert be consulted who has years of background with oxygen systems combustion issues when it is important to minimize these risks.

Any person thinking about investigating these issues to reduce risks must dispense with all biases concerning what is known about normal fires in the earth's atmosphere, which is approximately 21% oxygen, 78% nitrogen and 1% inert gases at 101.3 kPa (14.7 psi) at sea level.

Fires and fire hazards are most often conceptualized in an environment that is found at ground level. An increase in the partial pressure of oxygen increases the potential for combustion in terms of both initiation and severity. Combustion in 100% oxygen with increased pressure will occur more readily and spread more rapidly. Most persons are not familiar with oxygen fed fires and therefore more information is provided herein to explain how this phenomenon is different. Normal fires at ground level occur in a low concentration of oxygen with a relatively low pressure. The partial pressure of oxygen at sea level is 21.27 kPa (3.087 psi) which is determined by $0.21 \times 101.3 \text{ kPa}$ (14.7 psi). There is 21% oxygen in the earth's atmosphere at all altitude levels. The magnitude of the oxygen pressure can be thought of as a stress riser. Figure 1 shows a comparison of stress risers in low and high-pressure oxygen equipment as compared to the partial pressure of oxygen in air at sea level.

A stress riser is also any of a number of key parameters that have been found to make ignition more likely. Stress risers in oxygen systems include:

1. pressure
2. oxygen concentration
3. other included gases
4. temperature
5. phase (liquid versus gaseous oxygen)
6. mechanical failure
7. higher oxygen velocities
8. time and age

A thorough discussion of stress risers is available in ASTM G 128-95.

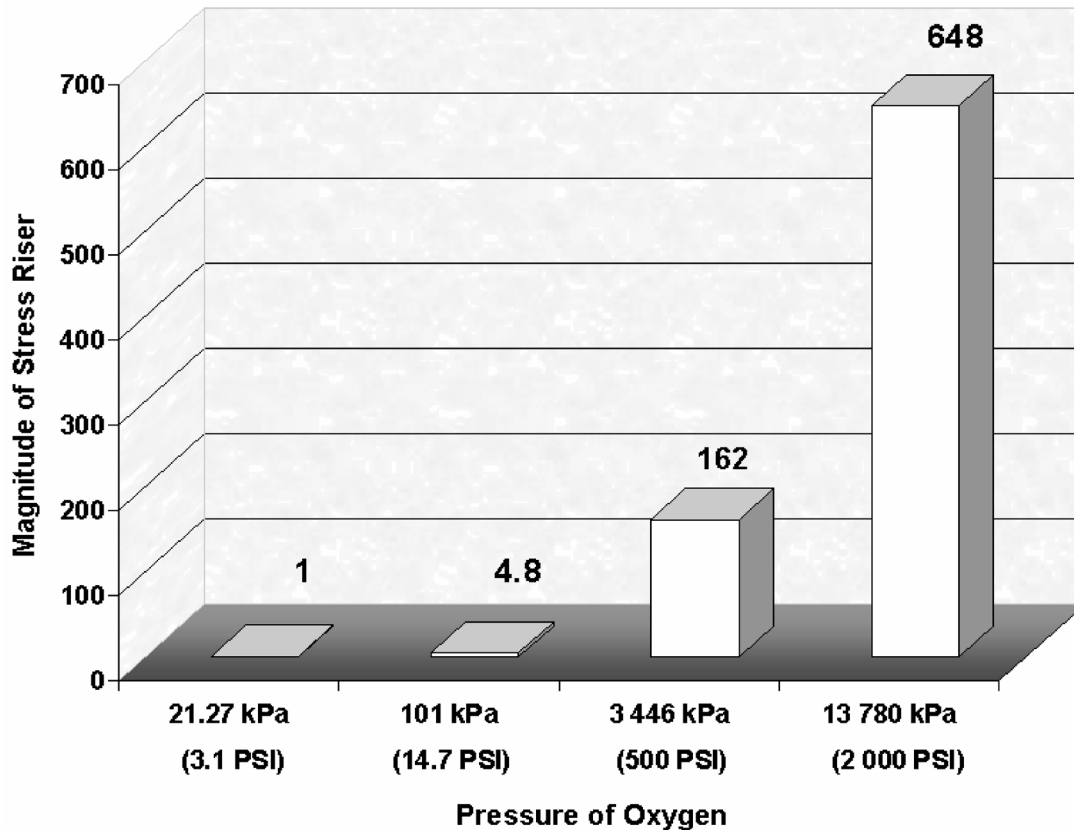


FIGURE 1 - Oxygen Pressure Stress Riser Comparisons for Low and High Pressure Oxygen Equipment

3.1 (Continued):

Dalton's Law states that the total pressure of a mixture of gases is equal to the sum of the partial pressures of each gas in the mixture. In the earth's atmosphere the following relationship describes the gas pressures.

Total Pressure at Sea Level = Partial Pressure Oxygen + Partial Pressure Nitrogen + Partial Pressure Inert Gases

Any combustion in an oxygen system occurs at an increased oxygen partial pressure and usually 100% oxygen. There will also be the additional pressure used in the supply and dispensing equipment. Normal supply equipment used in aircraft oxygen systems is typically 12,400 to 14,820 kPa (1800 to 2150 psig). Experience and test data show that combustion in pressurized oxygen equipment occur very rapidly and with much violence. Such fires are thought of as explosions by the observer, but high-speed film shows that these so called explosions are actually oxygen fed fires. Technically speaking, explosions are really detonations. Metal fires are the most violent and should be the greatest cause for concern to an oxygen systems designer.

3.1 (Continued):

What are the chains of events that lead to combustion in oxygen equipment and any equipment that is nearby? It is helpful to think of a "fire and explosion triangle." See Figure 2. One side of the triangle is the oxygen, another side is the fuel and the other side is the ignition mechanism. Take away any side of the triangle and the combustion (fire and explosion) can not occur. The problem is that one cannot take away any side of the triangle with oxygen equipment.

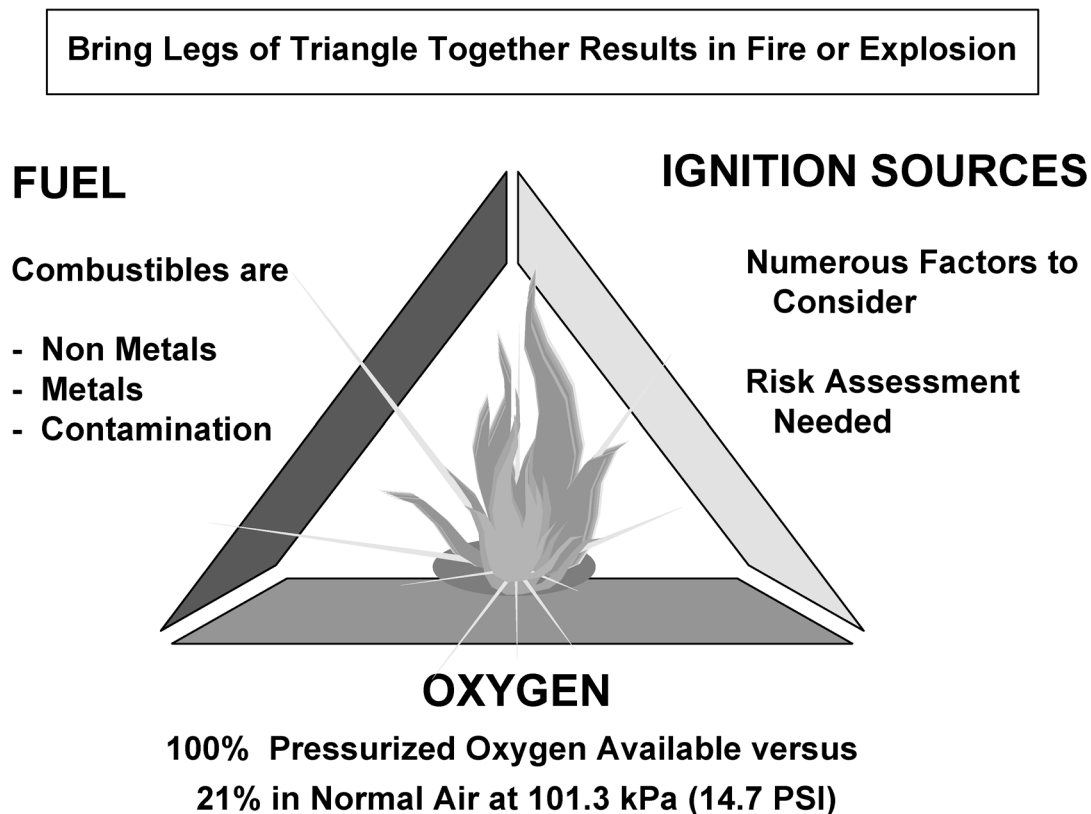


FIGURE 2 - Fire and Explosion Triangle

The oxygen is always present as it is stored and dispensed.

The fuel source is always present, as the container for oxygen and the dispensing equipment are metals and nonmetals, which can all combust in 100% oxygen. For example, the equipment will consist of pressurized cylinders, regulators, valves, tubing and fittings that are all made of metals and nonmetals. All of these materials can combust with 100% pressurized oxygen.

3.1 (Continued):

The ignition side of the triangle is a more difficult issue to understand. It can be explained that it is a function of a number of factors that are always present to some degree in oxygen equipment. Experience shows us that the risk of ignition from all factors should be assessed and kept as low as possible. The risk must be kept within acceptable limits. An oxygen technical expert should be consulted to determine the level of risk. Ignition can come from a number of sources. More details are provided herein to explain this. For example, moving metal particles can cause ignition. As oxygen gas is supplied from a higher pressure to a lower pressure location and the gas encounters a restriction such as a fill valve, a temperature rise is associated with the compression of oxygen in this location. This occurs when filling pressure vessels or cylinders on the aircraft. The compression occurs at the first restriction to flow usually at the fill valve on the aircraft. Temperature rises are also associated with restrictions on other valves such as the pressure regulator or reducer on the aircraft pressure vessel. Experience with servicing oxygen cylinders and the resulting fires have shown that this is a likely cause of fires in much oxygen equipment occurring more frequently than is considered acceptable. Contamination, which is readily combustible, may be inadvertently introduced into the system. A risk assessment is advised to determine what may be done to minimize hazards associated with ignition.

3.2 Causes of Fires and Explosions:

The primary causes of oxygen systems fire and explosions that may be considered are:

- Improper design and manufacturing.
- Improper materials both metals and nonmetals used in equipment and assembly.
 - Examples of non-metals are soft goods used for seals, seats and diaphragms; lubricants; anti-seize compounds; and anti corrosion treatments.
- Improper cleanliness methods and lack of adequate verification of cleanliness.
- Improper operational procedures.
- Improper or poor maintenance methods and procedures.

See ASTM G 128-95 and ASTM G 88 for information on primary causes of oxygen fires and explosions. SAE AIR1169 gives a listing of references concerning the effects of oxygen on ignition and combustion of materials.

3.2 (Continued):

As the number of stress risers associated with given oxygen system increases, the risk of a fire and/or explosion becomes greater. There will always be some degree of risk involved! Our goal should be to keep these risks as low as possible or within acceptable limits. One method to understand or visualize this is to remember each cause of combustion has a level of risk (stress riser) associated with it. Usually as all these causes are put into the equation, they become additive in nature. The extent to which these causes are additive is not an exact science. Each cause can have a different weight and associated level. Even more perplexing is that the ignition potential is not usually repeatable. For example, a series of tests accomplished under the same potential conditions does not provide repeatable results. This illustrates the need to run a number of test points at any given condition to determine the relevance of the data. In addition, to further confound the issue the severity of the combustion (fire and explosion) is not repeatable. It helps to keep these issues in mind when examining the risks for combustion per the illustration in Figure 3.

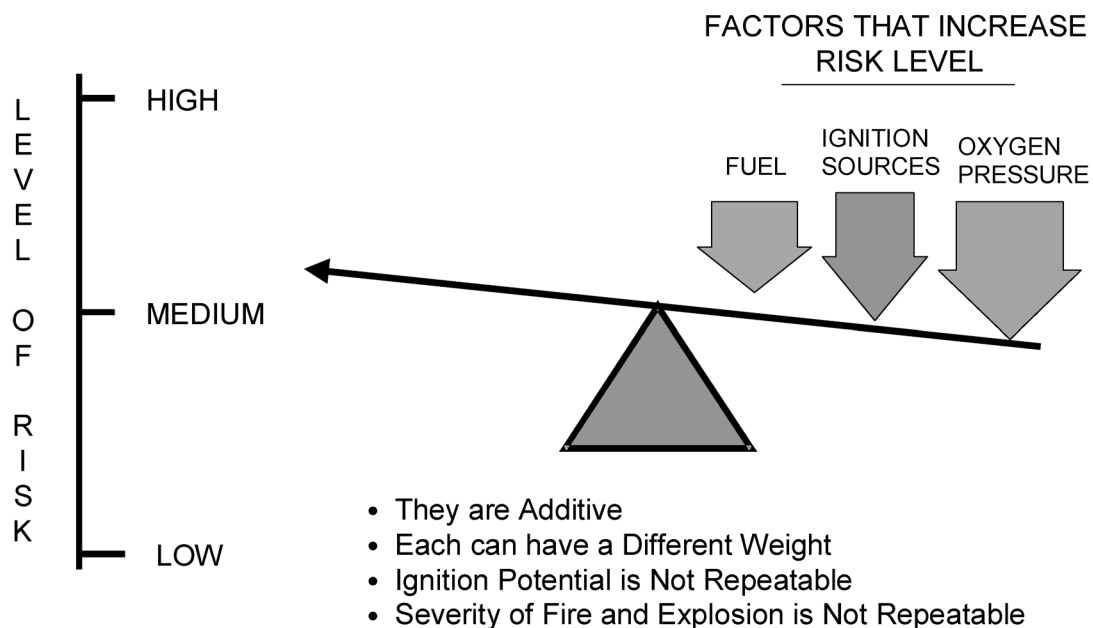


FIGURE 3 - How Fuel, Oxygen Pressure and Ignition Sources Contribute to the Risk of a Fire and Explosion