

AEROSPACE INFORMATION REPORT

AIR6829™

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Oxygen Considerations for High Elevation Airport Operations (HEAO)

RATIONALE

The number of high elevation airports (greater than 8000 feet MSL) being constructed worldwide is increasing, and there is a need to provide additional guidance on oxygen use for flight operations which are covered in various documents and manuals (AFM, FCOM, SMS) as approved by national authorities. This document intends to address oxygen considerations at high altitude airports. This AIR will provide safe guidance based on physiological requirements and list best operating procedures/practices intended to prevent subtle hypoxia. This will ensure the safety of flight is not compromised due to oxygen deficiencies that may arise in this unfamiliar area of flight operations. This document will address physiology, system, equipment operations/limitations, and flight operations to provide a broad body of information to aid in adhering to current regulations. In some cases, there will be operational issues without an obvious link to oxygen requirements, but which could have indirect consequences. This document will attempt to identify these issues in an SMS construct. Nothing herein takes precedence over an aircraft OEM or an approved AFM/POH.

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1. SCOPE

This document covers information concerning the use of oxygen when flying into and out of high elevation airports for both pressurized and non-pressurized aircraft. Oxygen requirements for pressurized aircraft operating at high altitudes have for decades emphasized the potential failures that could lead to a loss of cabin pressurization coupled with the potential severe hypoxic hazard that decompressions represent. This document is intended to address the case where the relationship between cabin and ambient pressures are complicated by operations at high terrestrial altitudes. Operators who fly into these high-altitude airports should address the issues related to this environment because it carries the potential for insidious hypoxia and other conditions which can affect safety. It provides information to consider in developing operational procedures to address hypoxia concerns consistent with regulatory mandates. In some sections, procedures are discussed that may mitigate the deleterious effects of hypoxia in a non-flight regime yet still have the potential to represent risk factors associated with flight operations. All the information is provided as a framework for potential oxygen management and other procedures to facilitate responsible practices and facilitate compliance with existing regulatory requirements.

This document cannot address every type aircraft pressurization system, oxygen system or operational condition the flight may encounter. Any threat or hazard not discussed in AIR6829 should be brought to the attention of the OEM, the regulatory authority and the flight operations department for proper guidance.

1.1 Purpose

The purpose of this document is to identify hazards that can occur at high terrestrial altitude locations currently being developed as airports. It provides concepts and perspectives on how oxygen might be utilized to mitigate the potential risks of hypoxia and related issues. As an AIR, the information does not represent requirements and should never be interpreted as a mandate as to how any of these issues must be addressed. The goal is to provide a pertinent list of topics that can be considered in support of an operation's specific situation and always in context of applicable regulations. In some cases, some circumstances may not be addressed by authoritative mandates. This document is intended to provide information to consider issues that fall outside the dictates of specific rules but may have the potential to impact on safety when developing procedures for HEAOs. Much like a decompression scenario, there is tremendous variability involved in a given scenario, including variability in human responses, related to exposures at ground elevations of 10000 to 15000 feet. The document presents issues to consider for landing, takeoff, and potential interim challenges at associated terrestrial altitudes. It is provided as an informational reference for an operator to consider in deciding the most applicable approach to their situation.

1.2 Limitations

Operators who intend to fly into these airports will ultimately be responsible for addressing their particular circumstances consistent with existing regulations and specific operational requirements. This document should help identify and mitigate potential risks through an SMS construct but certainly cannot cover every operational nuance related to high elevation airports.

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 International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR822 Oxygen Systems for General Aviation

AIR825/14 Basic Aircraft Oxygen Systems Design

AIR1389B Regulatory Requirements Covering the Use of Breathing Oxygen in Aircraft



Documents

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AIR5648	Fuel Versus Oxygen: Evaluations and Considerations
ARP1532	Aircraft Oxygen System Lines, Fabrication, Test, and Installation
AS8059	Carry on Portable Oxygen Concentrators

2.1.2 Airworthiness Publications

14 CFR Part 5	Safety Management Systems
14 CFR Part 23	Airworthiness Standards: Normal Category Airplanes (FAA)
14 CFR Part 25	Airworthiness Standards Transport Category Airplanes (FAA)
14 CFR 91.211	Supplemental Oxygen
14 CFR 121.161	Airplane Limitations: Type of Route
14 CFR 121.193	Airplanes: Turbine Powered: en-route limitations: two engines inoperative
14 CFR 121.329	Supplemental Oxygen for Sustenance: Turbine Engine Powered Airplanes
14 CFR 121.331	Supplemental Oxygen Req. for Pressurized Cabin Airplanes: Reciprocating Engine Powered Airplanes
14 CFR 121.333	Supplemental Oxygen for Emergency Descent and for First Aid: Turbine Engine Powered Airplanes
14 CFR 135.89	Pilot Requirements: Use of Oxygen
14 CFR 135.157	Oxygen Equipment Requirements
14 CFR 121.565	Engine Inoperative: Landing: Reporting
14 CFR 121.646	Fuel Supply: Turbine-engine powered Airplanes, Flag and Supplemental Operations
AC 61-107B	Aircraft operations at altitudes above 25000 feet MSL or Mach numbers greater than .75
AC 120-92b	FAA Advisory Circular - Safety Management Systems for Aviation Service Providers
AWM Chapter 525	Airworthiness Manual Chapter 525, Transport Category Airplanes
CAR 605.31	Oxygen Equipment and Supply: Canadian Airworthiness Regulation
CAR 605.32	Use of Oxygen: Canadian Airworthiness Regulation
CAT.IDE.A.235	Supplemental Oxygen - Pressurized Aeroplanes
CAT.OP.MPA.285	Use of Supplemental Oxygen
CHINESE AC 121-21	HEAO regulation for Air Carriers: CAAC Flight Standards Department
CS 25	European Aviation Safety Agency (EASA) Certification Specifications for Large Airplanes

2.1.3 Other Publications

Altitude Acclimatization and Illness Management: Department of United States Army, published on September 30th, 2010.
Available from http://www.usariem.army.mil/assets/docs/publications/articles/2010/tb_med_505_sept_2010.pdf

Hudgins, C.B. (1997) Submaximal exercise and cognitive function testing at altitude to determine the impact of different levels of hypobaric hypoxia. Master's Science Thesis, University of Oklahoma, Norman.
<https://apps.dtic.mil/dtic/tr/fulltext/u2/a350775.pdf>.

Hudgins, C.B., Garner, R.P., Mandella, J.G., and Murphy, R.E. Cognitive performance changes as a result of exposure to various levels of low altitude hypoxia. *Aviat. Space. Environ. Med.* 69:238, 1998.

High Altitude Cerebral Edema. *Neurosurgery* 19:841-849, Volume 19, Issue 5 1986. Hamilton, A.J., Cymerman, A., and Black, P.

High Altitude Medicine & Biology - Mary Ann Liebert, Mary Ann Liebert, Inc., publishers available from <http://www.liebertpub.com/overview/high-altitude-medicine-and-biology/65/>.

High Altitude Medicine and Physiology. 1989 Michael P. Ward, James S. Milledge, John B. West, Arnold London, Oxford University Press, New York.

2.2 Abbreviations

14 CFR	Title 14 Code of Federal Regulations
AC	Advisory Circular
AFM	Airplane Flight Manual
AGL	Above Ground Level
AMS	Acute Mountain Sickness
APU	Auxiliary Power Unit
AWM	Airworthiness Manual (TCCA)
CAAC	Civil Aviation Administration of China
CAR	Canadian Aviation Regulation (TCCA)
COG	Chemical Oxygen Generator
DCS	Decompression Sickness
EASA	European Aviation Safety Agency
ELOS	Equivalent Level of Safety
ETOPS	Extended Range Operations
ETP	Equal Time Point
FAA	Federal Aviation Administration
FCOM	Flight Crew Operating Manual
FLNNN	Flight Level NNN; Aircraft's Altitude (NNN) at Standard Air Pressure, Expressed in Hundreds of Feet
HAAO	High Altitude Airport Operations
HACE	High-Altitude Cerebral Edema

HAPE	High-Altitude Pulmonary Edema
HARH	High Altitude Retinal Hemorrhages
HEAO	High Elevation Airport Operations
MEL	Minimum Equipment List
MEA	Minimum Enroute Altitude
MOCA	Minimum Obstruction Clearance Altitude
MORA	Minimum Off Route Altitude
MSL	Mean Sea Level
OAT	Outside Ambient Temperature
OEM	Original Equipment Manufacturer
PHC	Portable Hyperbaric Chamber
POB	Portable Oxygen Bottle
POCA	Portable Oxygen Concentrator Assembly
POH	Pilot Operating Handbook
QNH	Q Code (Query: Nautical Height) Indicating the Atmospheric Pressure Adjusted to Sea Level
SMS	Safety Management System
SOP	Standard Operating Procedure
SRM	Safety Risk Management
TA	Transition Altitude
TCCA	Transport Canada Civil Aviation
WAT	Weight, Altitude, Temperature

2.3 Definitions

ABSOLUTE ALTITUDE: The physical distance above the terrain.

ACCLIMATIZED: Refers to individuals who have physiologically adjusted to a different terrestrial altitude.

ACUTE MOUNTAIN SICKNESS: Is physical distress caused by the body's inability to rapidly adjust to lower oxygen pressure at high altitude.

ALKALOSIS: Is excessive blood alkalinity caused by an overabundance of bicarbonate in the blood or a loss of acid from the blood (metabolic alkalosis), or by a low level of carbon dioxide in the blood that results from rapid or deep breathing (respiratory alkalosis).

CRITICAL FUEL SCENARIO: As defined in 14 CFR 121.646: "An airplane should have enough fuel on board, assuming combinations of an engine failure and a rapid decompression at the most critical point of the route, to land at an adequate airport with enough additional fuel to hold for 15 minutes at 1500 feet above field elevation."

EQUAL TIME POINT: A point along a route where the “time” to continue to a diversion airport is equal to the time to return.

FLIGHT CREW MEMBER: Qualified pilot on type aircraft flown.

GRID MORA: Provides a reference point clearance within a section outlined by latitude and longitude line on a map. MORA values clear all reference points by 1000 feet in areas where the highest reference points are 5000 MSL or lower. On reference points higher than 5000 MSL, MORA values clear all reference points by 2000 feet.

HIGH ELEVATION AIRPORT: For the purposes of this document, high elevation airports are considered to have elevations in excess of 8000 feet above sea level.

LOW ELEVATION AIRPORT: Airports whose elevations above sea level are typically equal or lower than 8000 feet MSL.

MEDICAL OXYGEN SUPPLY: An oxygen supply, made available prior to and during flight, specifically for a passenger needing an enriched oxygen supply during the course of the entire flight. Oxygen quantity and usage or flow is specified by prescription from the passenger’s physician.

QNH: QNH stands for Question Nil Height - is sea-level pressure. It is used to cause the altimeter to register height above sea level. When sitting on the ground at an airport, dialing QNH into the altimeter will cause it to display the airport’s altitude above mean sea level.

QNE: QNE stands for Question Nil Elevation - which refers to the altimeter setting that will cause the altimeter to read the height above a specific aerodrome or ground level, and therefore read zero on landing.

PaO2: Is the partial pressure of oxygen measurement. Partial pressure is the dynamic that explains why oxygen moves from the alveoli into the blood and why carbon dioxide moves from the blood into the alveoli. Because the partial pressure of oxygen is higher in the alveoli than the adjacent capillaries, it flows into the capillaries.

PORTABLE OXYGEN BOTTLE: A gaseous oxygen cylinder and mask assembly to be used as a mobile supplement to the aircraft oxygen supply for first aid and decompression events.

PORTABLE OXYGEN CONCENTRATOR ASSEMBLY: Is a portable electrically powered device that creates a concentrated source of oxygen from ambient air. For purposes of this document this definition should not be confused with a portable oxygen cylinder assembly normally associated with a gaseous system.

REGULATORY OXYGEN REQUIREMENTS: This refers to supplemental oxygen usage requirements that are dependent on a flight altitude. For example, under 14 CFR 91.211, 121.333, and 135.89 oxygen may be required to be used whenever one pilot leaves his/her seat above certain altitudes.

SAFE ALTITUDE: An altitude where fuel, oxygen, terrain, and weather are considered and will not affect the safety of the flight.

SAFETY MANAGEMENT SYSTEMS: Is a comprehensive management system designed to manage safety elements in the workplace.

TERRESTRIAL ALTITUDE: A term commonly used in mountaineering when describing acclimatization. This refers to the altitude above mean sea level in terms of barometric altitude, and not an altitude based on the distance (height) above the ground.

THERAPEUTIC OXYGEN SUPPLY: An optional oxygen supply made available to passengers upon request and typically administered by the cabin crew.

TRANSITION ALTITUDE: Published height above sea level at which pilots climbing to their cruising level change their barometric altimeter datum from the regional pressure setting to the common international standard setting of 1013.2 hPa.

UN-ACCLIMATIZED: Refers to individuals that have not physiologically adjusted to a different higher terrestrial altitude.

USABLE OXYGEN: It is oxygen that is available for consumption from a certified aircraft supply.

UNUSABLE OXYGEN: Is oxygen from a certified aircraft supply that is not available for consumption but is part of the total oxygen inventory. Often referred to as residual oxygen, it is determined by low pressure at the regulator connected to the high pressure cylinder. When the pressure in the high pressure cylinder decreases to a low enough pressure at the regulator the regulator will shut off not allowing the remaining low pressure gas in the cylinder to escape. This remaining pressure then becomes unusable oxygen since the gas can no longer be accessed. Refer to AIR825/14.

VO2 MAX: VO2 max (also maximal oxygen consumption, maximal oxygen uptake, peak oxygen uptake or maximal aerobic capacity) is the maximum rate of oxygen consumption as measured during incremental exercise.

WAT LIMITED: Aircraft performance is limited due either Weight, Altitude, Temperature, or any combination thereof.

3. HAAO VERSUS HEAO

As far as high altitude operations are concerned, there are two different terms often utilized: High Altitude Airport Operations (HAAO) and High Elevation Airport Operations (HEAO). Each of these terms has a different meaning so the differences should be understood as they apply to this document.

The very basic difference between the two is that HAAO is a general term referencing pressure altitude as it pertains to aircraft operations and its systems. This is a function of barometric pressure as it applies to altitude. HEAO on the other hand is a general term referring the airport as a function of elevation either above ground level (AGL) or mean sea level (MSL). This term is used more by pilots for flight operations. For the purposes of this document, airports with elevations at or near 8000 feet above sea level such that the barometric pressure altitude at the airport can exceed 8000 feet are considered to be high. It is important that the reader has a basic understanding what each term means and how it is applied throughout this document.

HAAO is important when understanding the operation and functionality of the physical aircraft oxygen system and design. Since system designs often use aneroid type devices which activate based on atmospheric pressure, it is essential that the pilot is aware of the effects of atmospheric pressure and how it will affect the oxygen system functionality.

This is critical when it comes to altitude warnings, mask deployment, oxygen flow reset values for some passenger oxygen regulators. For example, the pilot would need to know if the warning received was a normal anticipated event or if in fact it was a real warning requiring some form of pilot action. Consider the management of a high-altitude warning horn in an aircraft NOT equipped with a device to mitigate or silence this warning. The important issue to understand is the aircraft oxygen system generally operates as a function of pressure altitude. The pressure altitude is dynamic and will vary from location to location as an aircraft flies through the atmosphere. Although this is a good equipment design it is impractical to use for low altitude flight operations because although the pressure will vary coincidental with different weather patterns landmasses do not. As an aircraft gets closer to terrain using absolute values such as height above the terrain regardless of pressure altitude must be observed. This transition is always a part of any flight and is normally managed through the use of a local altimeter setting. Flight crews should be clear as to the difference between these two metrics to prevent any confusion on the flight deck. Confusion could arise if the pilot is unprepared for a warning not normally received at a low altitude close to the terrain. For example, aircraft have a warning horn which activates anytime the cabin altitudes exceeds 10000 feet and the horn can be silenced. When the cabin altitude exceeds 14000 feet $\pm$ a certain value the warning horn will activate and cannot be silenced. Flight operations into high elevation airports reduces these tolerances and high-pressure weather systems may produce unexpected warnings that can confuse the flight crew if not trained for or anticipated for HEAO. Flight crews should know what to expect and these risks should be properly mitigated in advance for HEAO flight. Examples of this are provided in a risk assessment worksheet at the end of each major section. Managing this early in the descent is preferred in the best interest of safety thru time management. A conversion table can be found in Appendix I, which shows the change in pressure altitude as it relates to changes to the altimeter setting in inches of mercury (typically referred as QNH). This chart could be used to determine how close the tolerances might be on a particular HEAO flight to help mitigate any risks discussed above.

Typically, when the aircraft is operating at high pressure altitudes (i.e., above Transition Altitude (TA)) references are made using pressure altitude, and as the aircraft begins to descend, those references will begin to change over to HEAO as it descends lower to the earth's surface. At this point absolute height above the ground will govern aircraft altitude without regard to pressure, even though from a physiological point of view, the human body will still be "following" pressure altitude.

Conversely from an aircraft operational perspective, HEAO is based on an absolute altitude above sea level (true altitude) NOT affected by atmospheric pressure and is equally as important for terrain clearance and regulator use of oxygen.

For altimeter settings greater than 31.00 hPa, increase the absolute landing field elevation by 1500 feet for added safety. See Appendix I.

4.1 Safety Risk Management

```

graph TD
    subgraph SRM_Trigger [SRM]
        PC[Planned Changes SRM Trigger]
    end
    subgraph Description_Context [Description & Context]
        SA[System Analysis]
        SO[System Operation]
    end
    subgraph Specific_Information [Specific Information]
        IH[Identify Hazards]
        DAP[Data Acquisition & Process]
    end
    subgraph Analysis [Analysis]
        ASR[Analyze Safety Risk]
        DA[Data Analysis]
    end
    subgraph Assessment [Assessment]
        ASR_Diamond{Assess Safety Risk}
        SA_Diamond{System Assessment}
    end
    subgraph Action_Problem_Resolution [Action: Problem Resolution]
        CSR[Control Safety Risk]
        CA[Corrective Action]
    end

    PC --> SA
    SO --> DAP
    SA --> IH
    IH --> ASR
    ASR --> ASR_Diamond
    ASR_Diamond -- "Risk Accepted" --> SA
    ASR_Diamond -- "Risk Not Accepted" --> EPC[Evaluate Proposed Controls]
    EPC --> SA
    ASR_Diamond --> CSR
    SO --> DAP --> DA
    DA --> SA_Diamond
    SA_Diamond -- "Conformance" --> SO
    SA_Diamond -- "Non-conformance" --> CA
    CA --> SO
  
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Documents
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For the purposes of harmonizing and aligning it with SMS standards, this document identifies possible threats and hazards associated with flying into high altitude airports and then suggest ways to mitigate those hazards and threats supported by empirical science and technology. Very little is written concerning this subject (threats and hazards of HEAO flying) and so it will be a challenge to mitigate the various risks associated with these types of operations.

4.2 Threats and Hazards Identification

At first, it is necessary to identify the most common threats and hazards to provide a foundation to start evaluating how to mitigate these risks. There are some threats and hazards that are commonly known and apply to all operations; and will therefore be included in this document. However, this document cannot identify every threat for every type of aircraft in existence. Therefore, this document represents a starting point for specific scenarios addressed on a case-by-case basis consistent with the rule and concept of SMS and included as part of that operator's application.

4.3 Threats and Hazards Assessment

Figure 2 contains a list of potential hazards, potential consequences and risk mitigations categorized into four sections consistent with the main areas being addressed in this document, which are Physiology, Equipment, Flight Operations, and Oxygen Management.

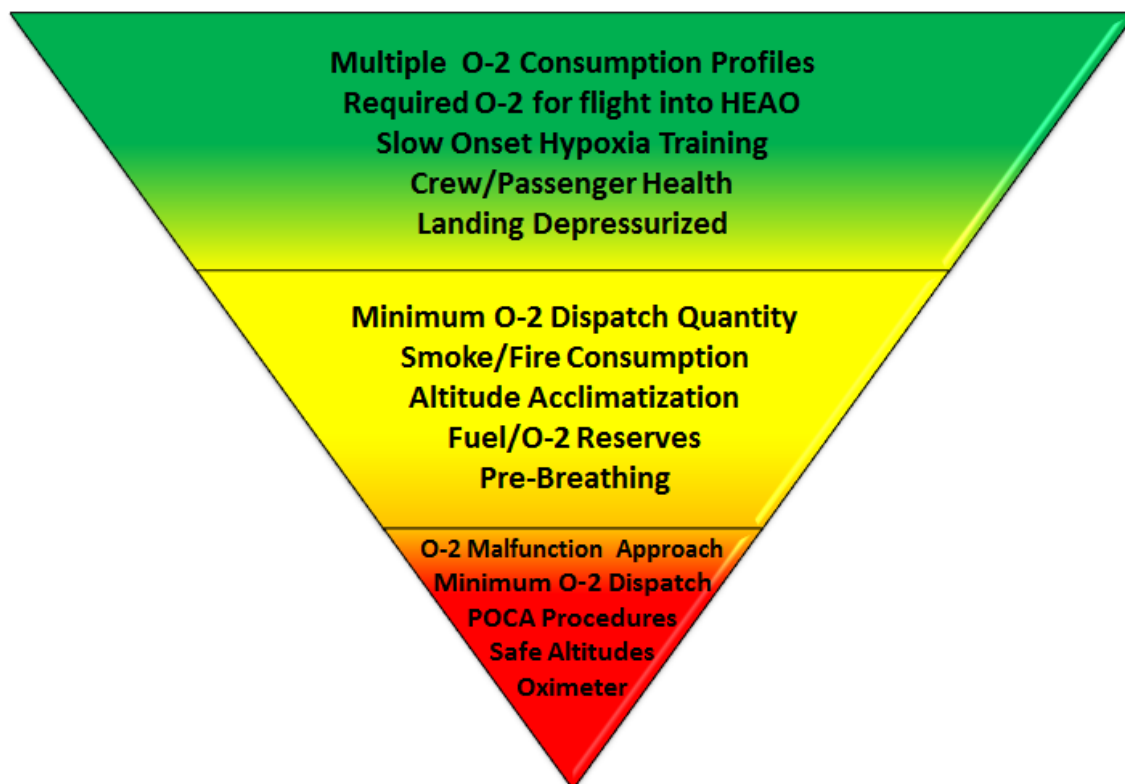


Figure 2 - Typical risk assessment matrix; identified (commonly known) threats and hazards

5. PHYSIOLOGY: PHYSIOLOGICAL VARIABLES IN RELATION TO CHANGES IN ALTITUDE

5.1 Hypobaric Hypoxia: Basic Changes in Gas Composition

Even transitioning to altitudes between 10000 and 20000 feet has the potential of a significant impact on the body as a function of the decrease in atmospheric pressure. The partial pressure of oxygen drops which translates to less oxygen being available for use by the body. That is most readily expressed by a decrease in blood oxygen saturation (S_pO_2). A basic summary of the changes at selected altitudes compared to ground level are presented in Table 1:

Table 1 - Typical blood oxygen saturation at altitudes

Altitude Feet	Pressure mm Hg	% of Sea Level	O ₂ Pressure mm Hg	S _p O ₂ %
0	760.0	100.0%	159.1	96-99
10000	522.6	68.8%	109.4	87-92
12500	473.8	62.3%	99.2	85-90
14000	446.4	58.7%	93.4	83-87
18000	379.4	49.9%	79.4	78-85
20000	349.1	45.9%	73.1	70-80

Physiologically, the body attempts to adapt with an immediate response to the decreased oxygen level by a relatively proportional increase in ventilation and heart rate. The extent of the initial compensation is highly variable among individuals up to roughly half an atmosphere (~18000 feet) above which the two responses fit more of a generic pattern but can still express rather large differences. Individual responses, as demonstrated by hypoxic symptoms and the S_pO₂ numbers in the table can be influenced by fatigue, gender, alcohol, activity, physical conditioning, and a host of other factors. Maybe most important are the physiological control systems. Though ultimately very conceptually similar they are not identical from person to person.

This is particularly relevant in that regulatory materials provide few if any mandates for oxygen management in situations not involving flight. Ground level ambient atmospheric pressure at many high-altitude airports represents equivalent oxygen pressures that would often require the use of supplemental oxygen if experienced in flight. Preflight, post flight, and other ground operations are not addressed yet can represent hypoxic challenges for both air and ground crew that have the potential to compromise safety. Therefore, the complexity of the environment and the responses must be kept in mind in managing operations.

5.1.1 Oxygen Status Monitoring

The signs and symptoms of hypoxia can vary among individuals in terms of what is expressed, the onset, and severity. Historically, aviation physiological training has included a hypobaric exposure in an effort to familiarize individuals with the symptoms they predominantly express. These individual symptoms may be helpful in facilitating crewmembers to determine the presence of hypoxia, but the subjective recognition is far less than quantitative. Therefore, use of a pulse oximeter to monitor S_pO₂ levels may be advisable.

A pulse oximeter permits crewmembers to check for the presence of hypoxia and the potential need for supplemental oxygen quickly and easily. It is a non-invasive measurement based on changes in the optical characteristics of red blood cells that occur as a function of the oxygen level. In aviation, fingertip devices are most often used. Considering the potential risk of hypoxia and the simplicity of oximeter use it seems reasonable that pulse oximeters be part of any operational approach.

Furthermore, ground operations in a low-oxygen environment, such as fueling, catering, de-icing, loading bags, and even climbing aircraft stairs represents physical exertion which may result in meaningful arterial desaturation. Consistently monitoring oxygenation levels during those activities will facilitate the recognition of hypoxia. Consideration should be given to establishing lower limits for the use supplemental oxygen for all personnel. The level may vary as a function of airport elevation, operational tasks, and other factors but a S_pO₂ reading below 88 to 89% seems sufficient to warrant some type of corrective response.

5.1.2 Physiological Changes

In the primary scenario addressed in this document, the circumstances are further complicated by the oxygen pressure decreasing as a function of descent and landing. In most arrival scenarios the plane descends from a maximum cabin altitude of up to 8000 feet to an altitude below 2000 or 3000 feet resulting in an increase in oxygen pressure. Figure 3 presents changes in the primary variables of interest as a function of a short flight into a mountainous region from sea level. Naturally, the arterial oxygen pressure (P_aO₂) tracks the flight profile exactly being a function of the atmospheric pressure. Many of the compensatory mechanisms related to such exposures have insufficient time to fully express themselves upon landing. Therefore, anticipated hypoxic responses may be exaggerated and other potential challenges associated with altitude exposure more likely to be expressed. Again, this emphasizes the need for effective management and coordination of the complex, and somewhat divergent, set of issues that are involved.

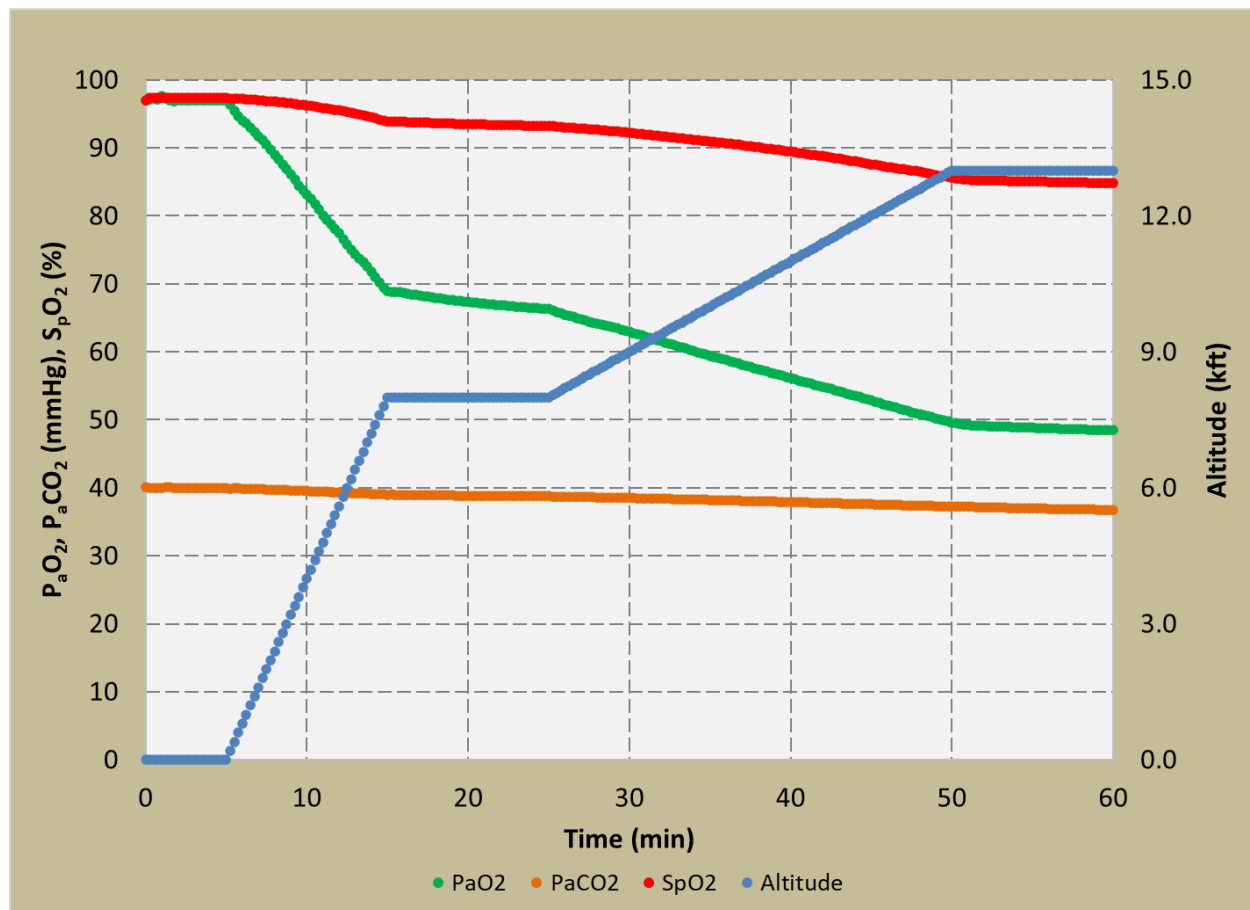


Figure 3 - Changes related to descent into a high elevation airport

NOTE: A maximum 8000 feet cabin altitude is assumed (15 to 25 minutes) with descent and landing at 13000 feet. Calculations performed using a mathematical model for respiration at altitude. Annals of Biomedical Engineering, 35(11), 2007.

5.2 Maladies Related to High Altitude Exposure

In general, the best remedy for any of the following maladies is returning to a lower altitude as soon as possible. The potential feasibility of that approach should be considered by any operator going in and out of airports at high altitude. In describing each affliction, a basic definition will be provided followed with a general description of why the problem occurs at altitude. Potential approaches to prevention are provided and general approaches to treatment beyond descending are briefly discussed as applicable.

Much of the information and approach to minimizing the impact of altitude exposure comes from mountaineering experience. It has been discovered that the best approaches to preventing altitude based afflictions is to ascend slowly maybe spending the first night at 8000 feet or below and to sleep for the night 1000 m (3000 feet) under the maximum altitude reached for the day before. Obviously, this is not an option for aircrew. This increases the risk for individuals post flight as well as their potential for service over the next day or two. Depending on the circumstances at any given altitude, airport transport carriers and other operators should be aware of the risk of the different types of altitude afflictions. There needs to be an action plan for both treatment and any impact it may have on crew availability. An example might be extending the flight time through remaining at a cabin pressure equivalent of 4000 to 8000 feet for longer duration. This might give the body a better chance to adapt to the drop in pressure associated with descent and arrival.

5.3 Acute Mountain Sickness (AMS)

This is a relatively common set of symptoms that occur upon ascent to altitude. Many of these are often experienced by downhill skiers or mountaineers who quickly ascend to their recreational altitudes. It is most often characterized by some combination of headache, fatigue, insomnia, loss of appetite, dizziness, palpitations, and nausea. In most cases, the symptom severity usually dissipates if not completely disappearing after a day or two at altitude. Non-steroidal anti-inflammatory agents (NSAID) may help in attenuating the headache before or after ascent. The drug most commonly used to prevent symptoms is acetazolamide. This drug works to stimulate ventilation. Personnel that find they are particularly susceptible to AMS may want to pursue securing a prescription but should not do so indiscriminately since there are untoward side effects. If you are a pilot consult your aviation medical examiner (AME). Other drugs have been tried with some success but are not often used. AMS symptoms should not be trivialized particularly if they get progressively worse. It is possible for AMS to progress to cerebral or pulmonary edema which can be life threatening. Operational personnel should be aware of the symptoms and the necessity of keeping a mental check on the severity if they occur.

5.4 High Altitude Cerebral Edema (HACE)

Cerebral edema is an excess accumulation of fluid in the cellular spaces of the brain. In the case of high-altitude exposure, it is brought on by the effects of hypoxia on the cells of the blood brain barrier though increases in blood flow and pressure may be contributing factors. It does not occur very often but can be fatal if not properly treated. In terms of an initial personal diagnosis, the situation is complicated since early symptoms are similar to AMS. As it progresses HACE is characterized by pronounced degradation of normal postural and mental aptitudes that may or may not be readily perceived by those afflicted. Usually, HACE is associated with rapid ascent to altitude with the majority of cases occurring above 12000 feet. There is no known approach to preventing HACE other than the general recommendations for proper nutrition and hydration. If it develops, the best treatment is to descend to a lower altitude. Generally speaking, the lower the better. However, there is evidence that the person needs to return to an altitude below 8000 feet to best resolve the problem. (Hamilton, A.J., Cymerman, A., and Black, P., High Altitude Cerebral Edema. Neurosurgery 19:841-849, 1986.) Providing pure oxygen may be of benefit and there are some pharmacological interventions that may be beneficial, but nothing is a substitute for going to a lower altitude. Options for facilitating such an evacuation should be considered in operational planning particularly at airports above 12000 feet. Another method available to re-establish a pressure altitude less than 8000 feet can be achieved through recompression in some type of device.

5.5 High Altitude Pulmonary Edema (HAPE)

Pulmonary edema is fluid accumulation in the lungs. The excess of fluid makes it difficult to breathe since it impairs gas transport (diffusion) down pressure gradients. It leads to impaired gas exchange and may cause respiratory failure. HAPE tends to occur in the first few days after ascent to altitude. It is considered to be caused by an increase in pulmonary artery pressure which damages lung capillary walls. Young adult men seem to be particularly susceptible. Distinguishing features are an extreme shortness of breath and cough which sometimes produces a pink frothy fluid. To lower the risk of HAPE, strenuous activity should be avoided for the first day or two at altitude. Rest and oxygen may sufficiently benefit mild cases, but more significant impairment requires descent to lower altitude. There are pharmacological approaches that are useful in the interim. Generally, the approach is to reduce the bodies' fluid level via some type of diuresis and thereby arterial pressure, but such an approach must be medically considered in terms of the overall hydration status.

5.6 High Altitude Retinal Hemorrhages (HARH)

Simply defined a hemorrhage is bleeding. In general, small hemorrhages are characterized by size and the level of those occurring as a function of altitude are usually associated with capillary (very small blood vessels) in certain areas of the body. In the eye, they often occur but are usually not noticeable and are of little consequence. The exception is when there is a hemorrhage in the macula which can lead to visual defects. At the time of this writing, there is no reports defining the relationship between retinal hemorrhages and the impact of hypoxia on night vision.

5.7 Generalized Peripheral Edema

Edema generally describes the collection of fluid in part of the body. Some people retain water as a function of travelling to altitude. The extra fluid may cause slight swelling predominantly in the face and upper arms and weight gain. There is no correlation among those who exhibit this response to altitude and AMS, HAPE, or HACE. The water retention reverses itself upon return to lower altitudes but can be treated with diuretics. Again, this needs to be considered in context of overall hydration status.

5.8 Disorders of Coagulation

Transit to altitude impacts on the risk of cardiovascular problems. The probability of venous thrombosis, pulmonary embolus, and stroke increase. These problems are associated with a number of hypoxia induced blood clotting abnormalities coupled with other changes occurring in the process of the body trying to adapt to a change in altitude.

5.9 Technological Medical Equipment

There are portable hyperbaric chambers designed to be used for emergency treatment of severe cases of AMS, HAPE, and HACE. The mechanism of action is a rapid pressurization of the patient which representatively simulates a descent of about 1500 to 2500 m. This may be adequate treatment until arrangements can be made to move the person to a lower altitude. Having such a device available at high elevation airports represents a prudent safety precaution.

5.10 Acclimatization

In considering flight operations into mountains regions, questions related to altitude acclimatization may arise. Though some may believe that such adaptations, whether adaptive or indigenous, should be grounds for not having to address many of the SMS considerations contained herein, it is a predominantly false narrative.

True acclimatization takes a relatively long amount of time to develop. The start of the chronic responses that offer protection from hypoxia beyond the acute compensatory adjustments that address exposures normally seen in aviation take days to start to develop. One to three-day turnarounds would not allow an aircrew enough time to sufficiently adapt even if the same group were making weekly sojourns. Of course, the level of any adaptation that did occur would be a function of the exposure (altitude) which certainly would vary with the destination.

This complex situation is further complicated by the fact that there is no readily available definitive test for acclimatization. If one wanted to determine a given individual's status, invasive medical estimates would have to be made on a regular basis. The adaptations to altitude are lost relatively quickly upon return to sea level. Even if one is hypothetically acclimatized to a given altitude or even to a specific level of physiological criteria, it does not mean they would inherently be protected at higher altitudes. For example, in mountaineering many have adapted to base camp conditions over a period of weeks only to suffer problems when progressing to higher altitudes.

People indigenous to high altitude, particularly over generations, certainly have adaptations that are advantageous in coping with hypobaric hypoxia. However, these are also susceptible to loss upon living at sea level. Therefore, criterion would still have to be established for determining the "acclimatized" status in consideration of the aforementioned limitations relating to ever increasing altitude. There might be rationale for a waiver of subsequent testing if an acclimatized person lived at altitude and only exception being travel as a crewmember to lower altitudes temporarily as a function of flights.

In balance, demonstrating and monitoring for an acceptable level of acclimatization in the range of 7500 to 15000 feet seems like a monumental task that would provide results that could never be unequivocally definitive. It would seem complicated and expensive in comparison to the relatively simplistic potential steps covered in this document to circumvent the risks present as a function of high elevation airports.

Therefore, this document does not provide or suggest means of determining whether people are acclimatized or not but acknowledges this situation as an alternative state of being. People who are deemed acclimatized may not need the same amount of supplemental oxygen at a high elevation airport as a person that is not acclimatized. As a result, operators may want to consider acclimatization of some personnel when developing oxygen usage procedures while at a high elevation airport. It must be recognized that tangible criteria must be developed to serve as the basis for such an approach.

5.11 Risk Assessment Worksheet Physiology

Table 2 - Physiology risk assessment worksheet

PHYSIOLOGY		
Potential Risks	Potential Consequence	Risk Mitigation
If no health evaluation for flight crew and passengers by health care professionals.	Health complications caused by high altitude exposure.	Early determination of conditions that have the potential to compromise an individual's ability to adjust to altitude. Potential Health issues as described in the physiology section of this document will increase the safety for crew and passengers into a HEAO.
Inadvertent use of supplemental oxygen on the ground if acclimatized.	Unnecessary upload of a non-renewable oxygen source.	Establish oxygen planning procedures to remove this amount normally planned for unacclimatized planning calculations.
Insufficient supplemental oxygen supply on the ground if un-acclimatized.	Inadequate oxygen supply for ground operation resulting in hypoxia.	Development of ground procedures to determine supplemental ground oxygen requirements.
Improper use of a pulse oximeter.	Can indicate a false low SPO2 and unnecessary use of oxygen.	Proper training of oximeter will improve operational Oxygen efficiencies to ensure use only when needed.
If portable oxygen concentrator is used incorrectly for ground use.	Hypoxia due insufficient oxygen.	Proper training and use of portable oxygen concentrators being utilized.
Excessive use of gaseous oxygen supply for ground operations.	Inefficient use or depletion of gaseous oxygen supply.	Use of oxygen concentrator to supplement gaseous oxygen supply.

6. EQUIPMENT

6.1 Aircraft Oxygen System

The general purpose of the oxygen system is to prevent the effects of hypobaric hypoxia that is associated with altitude. The predominate approaches of accomplishing this are briefly provided below with subsequent sections on considerations of existing regulations and concepts for the most efficient management of the oxygen supply as a resource.

The use of the oxygen system is relatively straight forward, the designs having evolved over the years to permit quick and effective implementation in case of an emergency. However, the underlying performance considerations are quite complex. The performance today must be implementable on a diverse market of aircraft that fly higher and farther than in the past. The entire globe is regularly covered including extended periods over oceans and desolate terrain.

There are existing design and operational regulations applicable for extended operations (ETOPS: 14 CFR 121.646 and AIR5648) which allow routes to be flown at low altitudes where oxygen is not required considering a decompression event at the equal time point (ETP). Flights that do not have enough fuel reserves to safely land at a diversion airport may utilize supplemental oxygen to fly at a higher more fuel efficient altitude forcing greater dependency on the use of oxygen system to extend the range of the aircraft. Although these events are rare, planning is required for every flight. Similarly, this document deals directly with flying into high elevation airports where supplemental oxygen may also be needed and should be treated as a continuation of this type of planning.

Although HEAO operations may rarely be flown, oxygen requirements should be considered for HEAO and oxygen total requirements should be managed appropriately.

During HEAO, there should be a simple method available for the flight crew to manage the various complex oxygen systems. Regardless of the type of oxygen equipment utilized, the operator should have a method that can readily allow the flight crew to determine the quantity of oxygen available in each oxygen supply source.

This document, also supported by AIR5648, proposes a common metric such as time remaining or duration to provide the pilot with a solution. For example, 14 CFR 91.211, 121.329, 121.333, 121.646, AC 61-107A, and AC 25-20 all generally describe oxygen usage as a function of time at specific altitudes for compliance. The emphasis is time as a common denominator in which fuel and oxygen durations can be analyzed and efficiently managed by flight crews to determine the duration of available oxygen.

6.2 Basic Oxygen System Factors

6.2.1 Capacity

The deployment and use of both crew and passenger masks are dependent on the applicable regulations and specific aircraft AFM requirements but crews should be reminded to use oxygen equipment anytime symptoms of hypoxia may be recognized.

SAE document AIR1389B should be consulted to define what requirements may need to be considered for a particular flight and the effect on the oxygen reserve capacity.

Each oxygen system design allows for oxygen delivery at a rate that varies as a function of aircraft cabin altitude. Some system designs control the oxygen flow mechanically and others are electrically controlled. If the aircraft uses an electrical source, it will be important when developing an SMS that there is a procedure or back up plan should there be an interruption of the electrical signal to the oxygen system in total.

Oxygen flow rates are typically based on system pressure and oxygen flow through an orifice. Some systems can control the size of the orifice by mechanical means and therefore vary the oxygen flow rate as a function of altitude. Other systems control the oxygen flow rate electronically. Most crew masks used today use a mechanically controlled mask mounted regulator.

It is important to note that simply having the oxygen stores filled to capacity to support a descent to below 10000 feet following a decompression may not be adequate to satisfy SMS requirements for HEAO. Precision and accuracy are key to implementing adequate procedures and use of a single metric that the flight crew could use to determine there is a sufficient oxygen supply.

6.2.2 Typical Oxygen Quantity Indications Currently Available

Different aircraft systems often utilize different metrics to determine the quantity available in the supply source (e.g., 14 CFR 25.1441(c)) or the quantity being used as per the AFM. For example, fuel usage is often specified in pounds, kilograms, or gallons per hour. Oxygen consumption is typically specified in liters per minute. However, the oxygen quantity available in the supply source may be displayed in a variety of ways such as PSI, man hours remaining, liters or percentage of full. Pilots rarely need to determine how long the oxygen systems will last. As a result, making conversions between oxygen consumption and oxygen quantity available in the supply source is often not readily understood.

During HEAO, there are many variables that affect potential oxygen usage. As such, it is important to analyze the oxygen equipment being used during HEAO to determine what the delivery rate is at specific altitudes. Then, the duration of oxygen supply can be determined by dividing the delivery rate into total available capacity. For example, if the available oxygen capacity is 1000 liters and the delivery is 10 liters per minute (LPM), the duration or time remaining in the oxygen system is 100 minutes or 1 hour and 40 minutes. Since oxygen is serviced using PSI and consumed in LPM there is an additional calculation the pilot must perform to determine the available oxygen quantity. Developing a simple solution to derive the time available in the supply will help ensure a sufficient oxygen supply is available for HEAO.

6.2.3 Obstacles to Develop Time Remaining (Oxygen Duration)

There are several factors that should be considered when calculating an accurate value for oxygen duration. Initially, the volume of oxygen in the supply source should be expressed in the appropriate units. Secondly, the flow rates for all oxygen masks associated with the supply source should be determined for a range of cabin altitudes. Oxygen supply units, presumably in liters, can be corrected for temperature and converted to pounds per square inch (psi) for servicing of the system. It may also be converted into another tailored OEM metric so the time remaining can be calculated. In order to calculate an accurate value for oxygen duration during HEAO, a thorough understanding of the oxygen equipment on board a specified aircraft is required. This information is available from the aircraft OEMs and may be found in the aircraft operating manual or aircraft specific flight crew training materials .

The oxygen remaining should be expressed in time remaining or duration. It is important to analyze the oxygen equipment to determine the delivery rate is at specific altitudes. The duration of oxygen supply can be determined by dividing the delivery rate into total available capacity. Once the time remaining parameter is calculated for each aircraft oxygen system, the pilot should have a useful tool to meet all existing regulatory requirements. Compliance with regulations in context of an SMS construct is suggested in this AIR.

6.2.4 Types of Oxygen Equipment

6.2.5 Chemical Oxygen Generators (COGs)

COGs are single use devices used primarily for supplemental passenger oxygen in the event of a decompression that provide a supply specific flow of oxygen over a designated time course. Using a COG during HEAO would not seem financially feasible since it would require replacement of the generator after each use. Most COGs produce a supply of oxygen typically intended to meet regulatory requirements following a decompression event. The oxygen flow profile is normally matched to a specific descent profile anticipated for the airframe after a loss of pressure at maximum flight altitude. That being the case, use of such a device is not very well matched to the needs existing for HEAO. It may be possible to use chemical oxygen generators as a supplemental oxygen supply source for HEAO provided the flows rates used during COG certification are greater than the flowrates needed for operation into a specific high elevation airport. Using a single use COG or oxygen supply source that can be replenished after use is a business decision that is outside the scope of this document. However, either source may be permissible provided it meets the required flow rate and duration required to fulfill HEAO requirements and meet SMS protocols.

The altitudes anticipated and type of operation (which 14 CFR applies) for the aircraft should be reviewed and adjustments made, as necessary. As an example, consider a commercial aircraft operating under 14 CFR Part 121 into a high-altitude airport whose elevation is 12000 feet. Some operating regulations, such as 14 CFR 121.329(c), allow for 30 minutes with cabin pressures up to 14000 feet before supplemental oxygen use is required for passengers. In this case, an aircraft equipped with chemical oxygen generators for the passengers may be rationally allowed to operate into such an airport without requiring the use of supplemental oxygen.

6.2.6 Gaseous Oxygen Systems

A gaseous oxygen system provides oxygen from a supply reservoir. Usually this is a cylinder containing the compressed gas. The anticipated demand and associated flows are calculated for the various aircraft occupants as part of aircraft certification. Consistent with a passenger COG, gaseous systems normally are designed to support decompression scenarios. However, unlike a COG, each gaseous oxygen system design results in an oxygen flow that varies as a function of actual cabin pressure altitude. Some system designs control the flow mechanically and others electronically. If an aircraft uses an electrical source, it will be important to the SMS process that there is a procedure to address an interruption of the electrical signal to the oxygen system. Since gaseous oxygen systems are generally only limited by their storage capacity, gaseous systems may be more advantageous for HEAO since they would not typically require a unique design for each high elevation airport.

6.3 Oxygen Delivery

6.3.1 Passenger Oxygen Masks

Typically, passenger oxygen masks are deployed from a storage compartment in case of a drop in cabin pressure below a certain level. They are normally only used during a decompression event so stowage and deployment of these masks are generally relegated to maintenance personnel. Pilots operating into HEAO should be familiar with the operation of the passenger system.

Many aircraft OEMs obtain an equivalent level of safety (ELOS) or an exemption to the applicable airworthiness standards to temporarily increase the maximum cabin pressure altitude, raise the altitude for warning horns, or raise the altitude for oxygen mask deployment to allow for operations into and out of high elevation airports. Each operator should contact the OEM or consult the aircraft AFM or AOM to see if there have been special certification considerations for a specific aircraft to accommodate HEAO. Such special certification considerations may require unique operational procedures or equipment installed specifically for operations into high elevation airports.