SAE Aerospace
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AEROSPACE INFORMATION REPORT

SAE AIR5648

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Fuel Versus Oxygen: Evaluations and Considerations

RATIONALE

AIR5648 has been reaffirmed to comply with the SAE five-year review policy.

1. SCOPE

Specific Federal Aviation Regulations (FAR) define oxygen system requirements for an in-flight decompression incident. This AIR addresses the oxygen system requirements for a decompression incident that may occur at any point during a long-range flight, with an emphasis for a decompression at the equal time point (ETP). This AIR identifies fuel and oxygen management contingencies, and presents a possible solution for the most efficient, safe, and optimum flight continuation.

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 JAR Publications

Available from www.jaa.nl/jar/jars_toc.html

JAR-OPS 1.245 Critical Fuel Reserve Planning

2.1.2 FAA Publications

Available from www.faa.gov/avr/AFS/FARS/far_index.htm

FAA Advisory Circular 120-42A Critical Fuel Reserves

2.2 Definitions

AFM: Aircraft Flight Manual.

CFM: Company Flight Manual. An airplane operating manual based on the manufacturer's AFM, but revised specifically to the company's operations.

DCS: Decompression Sickness. Physiological effects brought on by exposure to reduced atmospheric pressure, dependent upon the actual pressure and the duration of exposure.

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SAE values your input. To provide feedback on this Technical Report, please visit http://www.sae.org/technical/standards/AIR5648

ETE: Estimated Time En route. Distance divided by the TAS or GS, expressed in time.

ETOPS: Extended Twin Operations. Operations intended to be, or actually conducted by a twin-engine aircraft over a route that contains a point further than one hour's flying time (in still air) at the normal one-engine-inoperative cruise speed from an adequate alternative airport.

ETP: Equal Time Point. The point reached on an intended route where the time required to continue flight to the destination (or a specified suitable airport ahead) is equal to that required to return to the point of departure (or a suitable airport behind). Fuel and oxygen supplies must be sufficient to cover the distances defined by the ETE.

FAA: Federal Aviation Administration.

FAR: Federal Aviation Regulation.

FL: Flight Level. A level of constant atmospheric pressure related to a reference datum of 29.92 inches of mercury. Each is stated in three digits that represent hundreds of feet. For example, flight level 250 represents a barometric altimeter indication of 25,000 feet; flight level 255, an indication of 25,500 feet (US FAR 1-6). Flight levels are referenced above a certain altitude determined by the appropriate regulatory authority.

FUEL DURATION: Fuel available divided by fuel flow, expressed in time.

FF: Fuel Flow

FOB: Fuel On Board.

GS: Ground speed. True airspeed plus a wind factor.

ISA: International Standard Atmosphere.

JAA: Joint Aviation Authorities.

LROPS: Long Range Operations. Proposed regulatory concept which addresses all aircraft, irrespective of the number of engines.

NTPD: Normal Temperature and Pressure Dry (21°C and 760 mm Hg).

OEM: Original Equipment Manufacturer.

OXYGEN DURATION: The amount of oxygen available expressed in time.

OPA: Oxygen Planning Analysis.

RANGE: Fuel available divided by fuel flow, multiplied by the TAS or GS, expressed in distance.

REGULATORY OXYGEN: Refers to the oxygen requirement for a pilot to be breathing supplemental oxygen above a certain altitude, dependent upon which FAR part number that pilot is operating under (e.g., FAR part 91, 121, 135).

SR: Specific Range. Pounds of fuel per nautical mile.

STC: Supplemental Type Certificate. A Type Certificate issued by an aviation authority for an aircraft that has been modified from its original design.

TAS: True Airspeed. The indicated airspeed corrected for temperature and altitude. Also referred to as "corrected airspeed."

TC: Type Certificate.

3. BACKGROUND AND PROBLEM DEFINITION

Differences regarding fuel and oxygen planning have developed over time due to technological advances in modern aircraft designs. In the past, oxygen requirements focused on the design and operation of the oxygen system. The oxygen system is designed by the Original Equipment Manufacturer (OEM). The potential design basis should include an emergency descent from cruise altitude, the fuel remaining at the ETP, or some other variable(s).

As aviation technology has progressed, procedures for preflight oxygen planning have remained the same. The technology available today allows for an improved method of calculating and analyzing oxygen duration. This data will allow a comparison of both fuel and oxygen supplies. Several older designs also did not consider additional oxygen requirements such as continuous supplemental oxygen for an ailing passenger.

One of the flight crew's responsibilities is making decisions that affect the safety and well being of the aircraft occupants. The essential data for both fuel and oxygen, which the flight crew must address in assessing potentially life-threatening situations during preflight planning or while en route, must be readily available as outlined in FAR 23.1441.c/25.1441.c. Pressure is currently the most common means to indicate bottled oxygen quantity to the flight crew. The flight crew must have the ability to determine a useable oxygen duration at all times in order to make sound, accurate decisions during an emergency requiring extended use of supplemental oxygen.

On every flight there are three important elements that should be assessed prior to departure. First, the flight crew must define the flight route based on winds, weather, and any extenuating circumstances. Second, the flight duration must be known as it dictates the minimum amount of fuel required at takeoff. Finally, the fuel remaining at the ETP must be estimated because it will determine the minimum altitude at which the aircraft can proceed from the ETP to an alternate airport. If this minimum altitude is higher than 10,000 feet, and more fuel cannot be added, supplemental oxygen will be required to safely complete the flight. Defining each of these elements will allow the flight to continue while preventing exposure to wet foot print (ditching) or landing short of the intended alternate airport. Note that a useful common denominator for these three factors is time.

An example of how this problem could realistically occur would be when an aircraft does not stop for fuel prior to flying over water or uninhabited terrain. Some aircraft oxygen systems are tailored for a worst-case scenario, such as a decompression during a flight between San Francisco and Honolulu. If this same aircraft had a flight route from Denver to Honolulu, and the flight crew over flies San Francisco without stopping for fuel, there may not be enough oxygen on board to address a decompression incident.

It should be expected that the oxygen system is designed in agreement with the fuel system. Flying at a lower altitude requires more fuel and less oxygen. Flying at higher altitudes requires less fuel but more oxygen. Oxygen systems are often certified based on both fuel and oxygen being full at the departure airport, but this assumption may not be valid for every flight. Therefore, the oxygen fuel analysis should be performed consistently with the existing operational parameters.

The problem of presenting oxygen duration to the flight crew in a useful manner is complicated because a wide variety of units of measurement have been used during oxygen system certifications. These units carry over into cockpit presentations of oxygen quantity. Often these units are not easily converted into a duration of the current oxygen supply. These different approaches could lead to confusion. Also contributing to the complexity is that the conversion of bottle pressure to liters of oxygen, the foundation for flow rate, has not been consistently presented throughout the industry. The information necessary to develop a system/methodology to determine oxygen duration should be available, and conveyed to the aircraft operator/owner as part of the oxygen system approval. Clear documentation would provide the opportunity for the flight crew to determine if the oxygen duration required for the safe conduct of flight has been met.

The current FARs that mandate oxygen requirements mainly address the oxygen required to cope with a cabin decompression and flight thereafter. However, there are other factors that can impact the oxygen supply such as therapeutic, first aid, and regulatory oxygen (for flights above FL 350 FAR part 135 operations, for FL 410 FAR 91/121 operations). For example, on a long-range flight, these other factors could consume a considerable percentage of the oxygen supply before a decompression may occur.

This document suggests a means of calculating the duration, based on time, of an aircraft's oxygen supply prior to flight or while en route. This method would provide an improved means for preflight planning of an aircraft's oxygen supply to be more consistent with modern aircraft. The calculations for this process can be performed either manually or through electronic processing. Either method allows comparison of the flight duration against both on board fuel and oxygen supplies, and can be outlined as follows:

1. Time is the basis for the calculations and the solution.

2. Construct oxygen and fuel duration tables in a manner that allows oxygen and fuel contingencies to be determined easily, efficiently, and accurately for pre-flight planning and any in-flight scenario, while remaining in compliance with current regulations.

3. Include this information in the TC or STC.

4. Maintain the goal of allowing this type of planning to be easier and to provide the flight crew with real time solutions for any point along the flight route.

4. AIRCRAFT PERFORMANCE

The Aircraft Performance Graph (Figure 1) for this Oxygen Planning Analysis (OPA) provides performance values at selected altitudes for the respective aircraft. The X-axis is the geographic distance scale, specified in nautical miles. The left hand Y-axis (referred to as the Primary Y-axis) displays the fuel needed to travel the required distance specified in thousands of pounds. The required amount of reserve fuel should also be included. The right hand Y-axis (referred to as the Secondary Y-axis) is the ETE to travel the required distance, given in hours and minutes, and becomes the basis for oxygen duration necessary at the divert altitude. Various wind components are presented in the upper hand legend to provide greater accuracy.

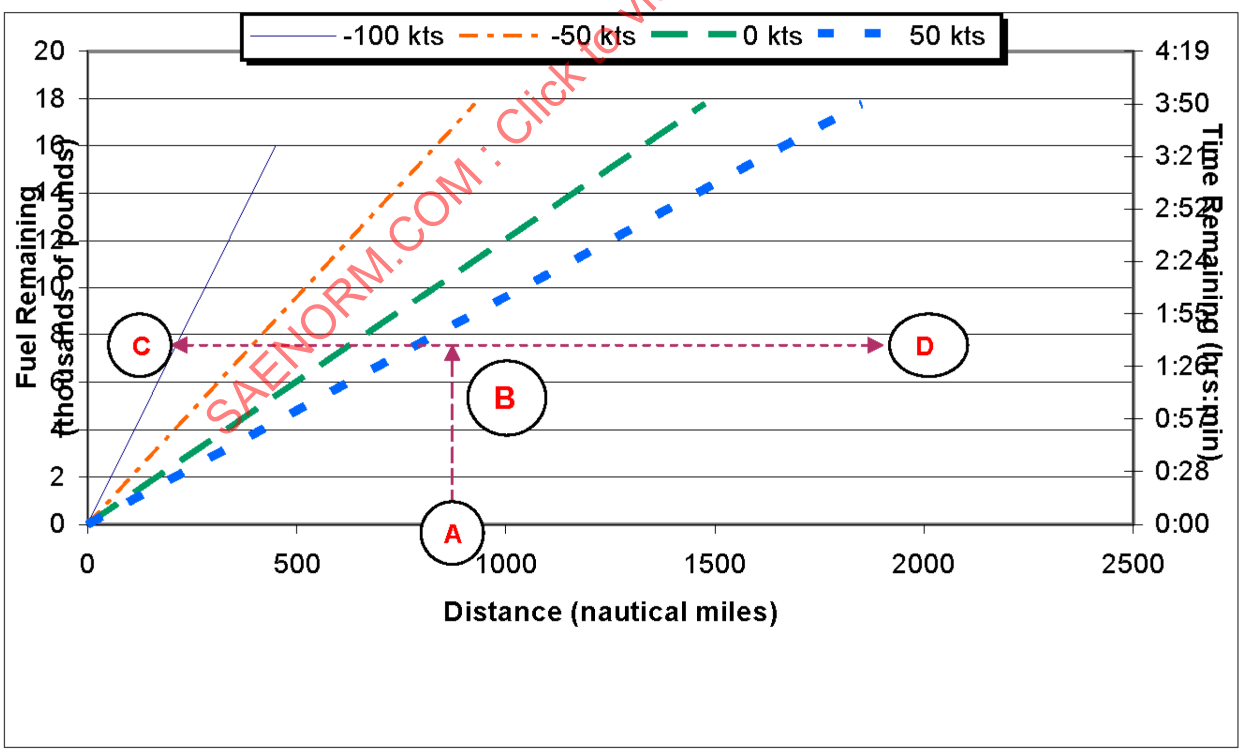


FIGURE 1 - AIRCRAFT PERFORMANCE GRAPH
(SHOWN AT FLIGHT LEVEL 200)

Aircraft Performance Graphs must be produced for each individual aircraft type considered for this OPA. These graphs should be consistent with the altitude profiles for each aircraft type to which they are certified. These graphs can be utilized for establishing the time to travel from any point (i.e., ETP) to an alternate airport. The lowest altitude that allows fuel conservation consistent with reaching the selected alternate airport can then be determined. Sufficient performance data is readily available from each aircraft manufacturer to produce these graphs.

5. OXYGEN DURATION

The second part of the OPA is the tabulated Oxygen Duration Table (Figure 2). This table is arranged so that the number of passengers and crew are displayed across the X-axis, and the indicated oxygen bottle pressure, specified in psi, is displayed along the Y-axis. Note that the pressure must be considered for all oxygen bottles available for the oxygen supply. Where these two values intersect is the resultant oxygen duration for that particular flight condition. The oxygen duration is calculated by converting the cubic feet of oxygen at bottle pressure to liters of oxygen, divided by the applicable flow rates.

Pressure* (psi)	Volume (liters)	Oxygen Duration (hrs : min)									
1850	4393	9:30	6:39	5:07	4:09	3:30	3:01	2:39	2:22	2:08	1:57
1800	4274	9:15	6:28	4:58	4:02	3:24	2:56	2:35	2:18	2:05	1:54
1700	4037	8:44	6:06	4:42	3:49	3:13	2:46	2:26	2:11	1:58	1:47
1600	3799	8:13	5:45	4:25	3:35	3:01	2:36	2:18	2:03	1:51	1:41
1500	3562	7:42	5:23	4:09	3:22	2:50	2:27	2:09	1:55	1:44	1:35
1400	3324	7:11	5:02	3:52	3:08	2:39	2:17	2:00	1:47	1:37	1:28
1300	3087	6:40	4:40	3:35	2:55	2:27	2:07	1:52	1:40	1:30	1:22
1200	2849	6:10	4:19	3:19	2:41	2:16	1:57	1:43	1:32	1:23	1:16
1100	2612	5:39	3:57	3:02	2:28	2:04	1:47	1:34	1:24	1:16	1:09
1000	2374	5:08	3:35	2:46	2:14	1:53	1:38	1:26	1:17	1:09	1:03
900	2137	4:37	3:14	2:29	2:01	1:42	1:28	1:17	1:09	1:02	0:57
800	1900	4:06	2:52	2:12	1:47	1:30	1:18	1:09	1:01	0:55	0:50
700	1662	3:35	2:31	1:56	1:34	1:19	1:08	1:00	0:53	0:48	0:44
600	1425	3:05	2:09	1:39	1:20	1:08	0:58	0:51	0:46	0:41	0:38
500	1187	2:34	1:47	1:23	1:07	0:56	0:49	0:43	0:38	0:34	0:31
400	950	2:03	1:26	1:06	0:53	0:45	0:39	0:34	0:30	0:27	0:25
300	712	1:32	1:04	0:49	0:40	0:34	0:29	0:25	0:23	0:20	0:19
200	475	1:01	0:43	0:33	0:26	0:22	0:19	0:17	0:15	0:13	0:12
Number of Passengers		1	2	3	4	5	6	7	8	9	10

* Oxygen bottle pressure based on NTPD conditions.

FIGURE 2 - OXYGEN DURATION TABLE
(SHOWN AT FLIGHT LEVEL 200)

Other valuable information is available to the flight crew by means of other sources. Examples include the matrix of FAA approved Aircraft Flight Manual (AFM) or Company Flight Manual (CFM) performance data for the aircraft. This includes the True Air Speed (TAS), Fuel Flow (FF), and Specific Range (SR) for the weight, altitude, and temperature conditions anticipated or experienced while en route.

This OPA provides the flight crew with the necessary information to determine if the planned flight can be safely conducted. This OPA also provides all of the necessary information in a readily accessible form to successfully manage any oxygen contingency, and continue the flight in the safest manner possible. If an emergency descent was required due to a decompression, the amount of oxygen expended by crew and passengers during the descent must be accounted for. In order to calculate the current oxygen duration, the initial oxygen duration should be reduced by the amount of oxygen expended during the descent.

Temperature versus pressure adjustments are also a consideration when developing an OPA. The location of each oxygen bottle will determine the extent that temperature and pressure will affect the system, whether on the ground or in-flight. Given that each oxygen system design is unique to each aircraft, this factor should be addressed by the operator after carefully establishing the conditions.

6. HOW TO USE THE FIGURES

This OPA can be used as a preflight planning tool that allows the flight crew to determine adequate quantities of both fuel and oxygen. It can also be used dynamically in-flight to evaluate oxygen contingencies involving a loss of cabin pressure.

In preparing for a worst-case scenario during preflight planning, the starting point for the OPA would be the fuel remaining at the ETP. Information pertaining to fuel remaining at the ETP, and the distance to each waypoint, is available by means of a flight plan. All high altitude jet aircraft are certified and equipped with sufficient oxygen to comply with emergency descent requirements. However, the focus of this document is concerned with extended flights above 10,000 feet after a decompression, as this will necessitate oxygen use (example: FAR 121.329). If the aircraft has a sufficient fuel supply to continue to the alternate airport and land, after descending to 10,000 feet, then no other supplemental oxygen planning is required. If there is not a sufficient amount of fuel on board to continue to the alternate airport, the range of the aircraft must be extended by climbing to a higher altitude. Extended Twin Operations (ETOPS) flights are the most demanding and will be referenced in this example, however, fuel and oxygen planning is not limited to only ETOPS flights.

To begin the planning process, first determine the fuel remaining at the ETP and the distance to land at the closest available alternate airport. The first performance graph to reference is for an altitude of 10,000 feet, keeping in mind that if there is sufficient fuel to land at the alternate airport while maintaining this altitude, the oxygen preflight planning is ostensibly over. If there is insufficient fuel to continue to the alternate airport at 10,000 feet (FL 100), additional fuel should be added until the requirement is met or the tank capacity is maximized. If enough fuel cannot be added prior to takeoff, due to insufficient fuel tank capacity, the next higher altitude should be checked. This process will continue until a suitable altitude is determined with sufficient fuel to reach the alternate airport.

For simplicity, the example graphs used in this OPA consider four altitudes: 10,000, 15,000, 20,000, and 25,000 feet. The example graphs also display theoretical, yet practical, data to demonstrate how the graphs are used. The assumed data used for this example, which would be given in a theoretical flight plan, include a distance of 1000 nautical miles, 10,000 lbs of fuel remaining, and a tail wind of 50 knots.

The example performance and oxygen graphs shown (Figures 1 and 2) are given at an altitude of 20,000 feet (FL 200). As previously stated, the user should always begin at FL 100, but for this example it will be assumed that there is not sufficient fuel at FL 100 to reach an alternate airport from the ETP. FL 200 will be used as it demonstrates preflight planning for both fuel and oxygen.

The Aircraft Performance Graph (Figure 1) allows the user to begin from any one of the three axis (Distance, Fuel Remaining, and Time Remaining). Applying one of these variables and a wind factor to the graph will provide values for the other two variables.

Since the theoretical flight plan provides a distance of 1000 nautical miles from the ETP to an alternate airport, the first step is to locate this value along the X-axis (Point A in Figure 1). The next step is to project vertically from this point until the given wind component is intersected (Point B). To determine the amount of fuel remaining, move horizontally to the left from Point B until intersecting the Primary Y-axis (Point C). To determine the ETE, move horizontally to the right (from Points B or C) until it intersects the Secondary Y-axis (Point D). For this hypothetical example, in order to fly a distance of 1000 nautical miles, with a tail wind of 50 knots, the fuel requirement is approximately 9500 lb (Point C) and the ETE is approximately 2 hours (Point D). Since the flight plan specifies that there will be 10,000 lb of fuel remaining at the ETP, and the requirement is 9500 lb, this portion of the preflight planning is complete.

The next step is to address the oxygen requirements at the altitude previously determined by the Aircraft Performance Graphs. The Oxygen Duration Table (Figure 2) is used to determine the duration of oxygen available based on altitude, flow rates, number of passengers (including crew), and oxygen cylinder size and pressure. To begin using this table, two items of information are required: the number of passengers, and the oxygen system pressure (psi) prior to flight. To determine the oxygen duration, move vertically up the respective column for the number of passengers, and horizontally right for the respective row for the oxygen cylinder pressure. The point of intersection (“intersecting cell”) is the oxygen duration available for the given conditions. The oxygen duration must be equal to or greater than the ETE previously determined from the Aircraft Performance Graph. If it is not, more oxygen must be added until the requirement is met at the specified altitude.

The example continues with further theoretical values of five passengers and an oxygen cylinder pressure of 1500 psi. Given these values, and using FL 200 previously determined, the intersecting cell is 2:50. This provides an oxygen duration of 2 hours and 50 minutes, which is greater than the previously estimated ETE of 2 hours. Therefore, there is an adequate supply of oxygen for this theoretical flight. If there is not enough oxygen on board to meet the ETE from the ETP to the alternate airport, and enough oxygen cannot be added prior to takeoff, then the flight should either not depart, or an intermediate fuel stop must be considered.

All potential oxygen use must be considered during preflight planning. Any normal drain on oxygen duration that may occur between charging the system and reaching the ETP should be included. This may be represented by requirements where one pilot must continuously breathe 100% oxygen. If medical oxygen is taken from the oxygen system, it must be considered in the preflight plan as well.

Once the aircraft is in flight, this OPA can be used dynamically in determining the oxygen duration at any point. Interpreting the OPA in-flight will be slightly different than the given example, and will most likely be needed in the event of cabin pressure loss at some point other than the ETP. In this case the flight crew wants to know how much oxygen duration is on board at this particular time. Simply enter the table for the respective altitude with the current bottle pressure (psi), and then locate the cell that intersects with the number of passengers on board. This cell provides the time remaining for oxygen at that particular altitude.

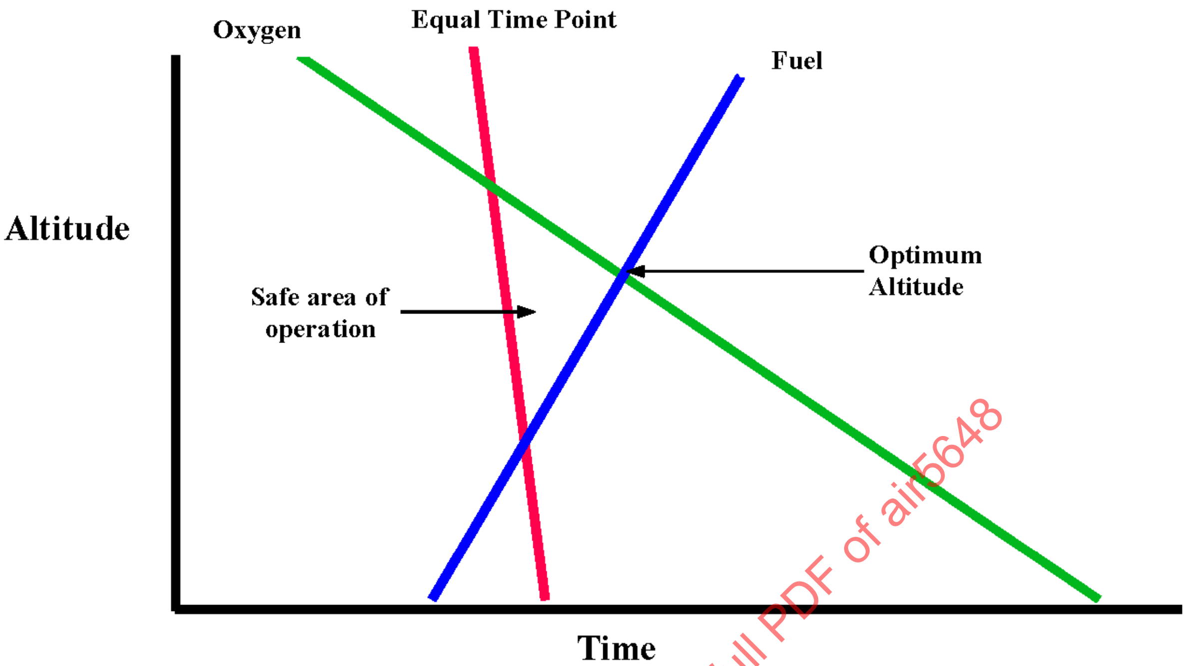
Given that there was a sufficient fuel and oxygen supply for a depressurization at the ETP (the worst case), there will always be an altitude at which the closest alternate airport can be reached, for any point along the route of flight. At worst, this will be the altitude planned for the ETP.

The flight crew should always be cognizant of the amount of fuel and oxygen on board at any time. An OPA provides the necessary information to cope with emergency contingencies and continue the flight as safely as possible. This OPA provides this fundamental information in a tangible form, time. Currently, the primary indication for bottled oxygen is pressure, which does not provide direct, useable information during an in-flight oxygen contingency. Because some operators must comply with regulatory requirements related to this OPA, an efficient method for evaluating potential flight scenarios is of obvious benefit.

The lowest permissible altitude should always be used for these calculations in order to minimize the probability of physiological harm, such as decompression sickness (DCS). DCS is one example of a risk that becomes greater as altitude increases. Note that 10,000 feet is the highest and most fuel-efficient altitude where oxygen is not required, and 25,000 feet is the typical limitation for most aircraft for extended flight following a decompression.

7. AUTOMATED OXYGEN PLANNING ANALYSIS

An efficient means of depicting this OPA can be achieved using microprocessor-based electronics. Using common graphics capabilities, this approach allows complex calculations to be summarized and conveyed very efficiently. The Oxygen Planning Analysis Graph (Figure 3) provides an example of one such format. The depiction is similar to an aircraft flight management computer display that conveys other tabulated data. Another advantage to automating the OPA process is that the calculations are computed rapidly, therefore allowing the flight crew to quickly evaluate numerous in-flight scenarios.



Oxygen line: Displays oxygen duration in time versus altitude.

Fuel line: Displays fuel duration in time versus altitude.

Equal time Point Line: Displays the time required for each of the five ETPs that are calculated for the flight. This becomes the reference line for the fuel and oxygen requirements. Any resource that falls in front of the line (right) indicates that there is enough of that resource to complete that flight safely.

Safe Area of Operation: This area indicates you have adequate resources to complete this particular flight.

Optimum Altitude: This is the altitude where both fuel and oxygen are equal in duration.

FIGURE 3 - OXYGEN PLANNING ANALYSIS GRAPH

When applying this approach, a number of general factors become evident for the flight to be safely managed. One factor is that the range must always be longer than the ETP distance, or in other words the fuel remaining at the ETP must always exceed the fuel required to continue or return to the ETP alternate airport, plus reserves.

Another factor is that the oxygen duration must always be equal to or greater than the ETE to an alternate airport at any given point and altitude. Hence it is essential that there is ample fuel and oxygen on board the aircraft prior to reaching the ETP. It must be recognized that the ETE is a dynamic quantity - a “proverbial” moving target. Anything affecting the aircraft TAS or GS changes the ETE. For example:

1. Aircraft gross weight
2. Altitude
3. Temperature
4. Wind component
5. An increase in aerodynamic drag profile