14 CFR 91.211 - Associated Risks Due to Compliance

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A white paper reviewing risks induced by pilots' routine usage of supplemental oxygen masks during high altitude, long range flights.

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Often cited as the most common rule violation in aviation is FAR 91.211, particularly the lack of oxygen mask use by pilots while cruising at high altitude. The question that comes to mind is; why are otherwise disciplined, compliant, professional pilots choosing to disregard this regulation. There must be compelling reasons for this behavior.

This white paper explores the reasoning behind the widespread choice of ignoring FAR 91.211. In addition, hazards introduced by compliance with FAR 91.211 and possible ways to mitigate the risk associated with identified hazards are discussed.

Background

14 CFR 91.211

Federal Aviation Regulation 91.211 mandates supplemental oxygen requirements for civil aircraft of United States registry. The bulk of known non-compliance is the regulation as it applies to pressurized aircraft. (Shaver, 2010) Although there are similar, or more restrictive, supplemental oxygen rules for airline and charter operations, this discussion will focus on the rules for U.S. general aviation operators under FAR part 91.

The federal supplemental oxygen regulation mandates if one pilot of a pressurized aircraft leaves his/her station while the aircraft is above flight level 350, the other pilot must wear and use an oxygen mask that is secured and sealed and supplies oxygen at all times, or automatically supplies oxygen whenever the cabin altitude exceeds 14,000 feet. Also, while flying above flight level 410, one pilot must always wear and use the oxygen mask. (14 CFR 91, 2013)

EU-OPS 1

The European Union flight regulations do not stipulate using supplemental oxygen at any aircraft altitude, nor if a pilot leaves his/her station. It mandates that crew operating pressurized aircraft with a service ceiling above 25,000 feet will have quick-donning masks within immediate reach and oxygen will be in use when the cabin altitude exceeds 10,000 ft. for more than 30 minutes or the entire time above a cabin altitude of 13,000 feet. (EU-OPS 1.770)

EASA-OPS Draft

EASA-OPS will soon replace EU-OPS. The published draft states the pilot-in-command shall ensure that he/she and flight crew members engaged in performing duties essential to the safe operation of an aircraft in flight use supplemental oxygen continuously whenever the cabin altitude exceeds 10 000 ft for a period of more than 30 minutes and whenever the cabin altitude exceeds 13 000 ft. (European Aviation Safety Agency, 2012)

ICAO Annex 6
The guidance published in ICAO Annex 6 specifies the amount of oxygen required for various flight altitudes based on hectopascals of atmospheric pressure. It also specifies a requirement for quick-donning masks for pressurized aircraft capable of operations above 25,000 feet and the same use requirements for the crew as EU-OPS 1. In other words, the usage of oxygen is based on cabin altitude, not aircraft altitude. (ICAO Annex 6, Chapter 3,4, 2013)

The Hazard

The entire span of physiological hazards associated with high-altitude flight is beyond the scope of this paper. The focus of this discussion is on the hazard associated with sudden exposure to depressurization and the resultant effects of hypoxic hypoxia. The rate of depressurization may be slow, rapid or explosive.

Explosive decompression is defined as a change in cabin pressure faster than the lungs can decompress. Most authorities consider any decompression that occurs in less than 0.5 seconds as explosive and potentially dangerous. (AC 61-107B, 2013) During high altitude flight, this type of decompression will most likely result in debilitating lung damage, as well as other catastrophic body injury. A large breach in the aircraft pressure vessel is necessary for this type of decompression.

Rapid decompression is a change in cabin pressure where the lungs can decompress faster than the cabin. (AC 61-107B, 2013) If a rapid decompression were to occur during high altitude flight, the crew would likely experience hypoxic hypoxia. Several factors will determine the degree of hypoxia experienced by the crew and thus the amount of time the crew is capable of taking protective and corrective action. The period of time between the exposure to an oxygen-poor environment, and the point at which a pilot is no longer capable of flying an aircraft is referred to as Effective Performance Time (EPT). (John D. Odegard School of Aerospace Sciences, 2013) Several factors can cause the EPT to vary. The rate of cabin ascent, physical activity and health will all have an effect. However, there is a generally accepted EPT for most persons.

CABIN ALTITUDE	**EPT**
35000 ft	.5 – 1 minute
40,000 ft	15 – 20 seconds
43,000 ft	9 – 12 seconds
50,000 ft	9 – 12 seconds

(John D. Odegard School of Aerospace Sciences, 2013)

The reason that the EPT does not change above 43,000 feet is that 9 to 12 seconds is the average time it takes for oxygenated blood to flow from the lungs to the brain. After that time, the partial pressure of oxygen is so low that the lungs cannot oxygenate blood enough to keep the brain functioning at a level that could illicit any useful action. It is also important to understand that a rapid decompression to, or above 30,000 feet will reduce the EPT by 30 – 50%. This happens because the rapid expansion of gas being forced from the lungs creates an immediate onset of acute hypoxia. (John D. Odegard School of Aerospace Sciences, 2013)

The insidious nature of a slow decompression can be the most dangerous. The possibility of unrecognized onset of hypoxia during a slow decompression is much more likely to happen than a dramatic, rapid decompression. (AC 61-107B, 2013) Of all documented cases of depressurization, (other than those caused by bombs or aircraft collision) the cases involving a fatal outcome were predominately those caused by slow decompression. (Cipova, 2014) Slow decompression can result from leaking seals, airframe failures, mechanical system failure, or human failure. (NTSB, 2000)

Non-Compliance

Why are otherwise compliant professional pilots choosing to ignore FAR 91.211?
Why are the compliant pilots frustrated with the current regulation?
Why aren't the FAA and NTSB addressing this situation?
These are all questions that should be discussed.

Usually, the intentional non-compliance of an FAA regulation is founded in poor discipline or a lapse in judgment. One may debate if non-compliance of 91.211 defines a pilot as undisciplined. However, we are dealing with a majority of professional corporate pilots who are knowingly ignoring this one rule. They may be making a well thought out decision, or a decision based on the gut feeling that it is the right thing to do.

Tony Kern's well respected book, "Redefining Airmanship", consistently emphasizes the importance of unwavering flight discipline. It is the primary bedrock principle of his airmanship model. (Kern, 1997) It's safe to say, an attitude that allows for choosing not to follow a specific regulation is unanimously labelled as unacceptable in all airmanship and ADM books and articles. The conundrum with FAR 91.211 is that we have a population of the most highly respected professional pilots doing exactly what is labelled as poor airmanship. Who are these pilots? They are test pilots, OEM demo pilots, military pilots, senior captains flying for major corporations, and the FAA.

One hypothesis is that a pilot's decision to ignore FAR 91.211 is based upon a personal assessment of risk. Not wearing the mask is a simple way of mitigating the hazards associated with compliance.

The Risk Assessment

Within an aviation organization, safety is promulgated through the concepts of culture, training, procedures and an appropriate Safety Management System (SMS). A vital part of the SMS is the proactive identification of hazards and assessing the consequences of not mitigating them. A risk analysis tool is useful in determining the need for additional or new mitigation. A typical risk analysis will recognize the hazard, identify the risk and determine the severity and likelihood if the identified hazard should cause an event involving physical injury and/or damage. Using a predetermined risk matrix, the operator can determine if the probability and severity of risk is acceptable, acceptable with mitigation, or completely unacceptable.

A risk analysis of FAR 91.211 compliance was performed in accordance with an IS-BAO Stage III audited Safety Management System (SMS). (Major Corporation, 2014) (see attachment) The hazard is identified as a loss of aircraft control due to hypoxia induced pilot incapacitation because of depressurization. The current mitigation of risk is FAR 91.211.

The severity is categorized as catastrophic since an unmitigated depressurization event can easily result in loss of life or property. The risk analysis procedure identifies a catastrophic level of risk as category A.

The likelihood of a depressurization event in a corporate aircraft is categorized as unlikely or highly unlikely. The highly unlikely label was used for the possibility of an explosive or rapid decompression event. Reviewing the last ten years of accident reports and the Aviation Safety Reporting System (ASRS) supports the designation choices. This risk analysis procedure assigns likelihoods of unlikely and highly unlikely with designations of 4 and 5.

The severity and likelihood categories of A4 and A5 are both acceptable in the Company's Risk Matrix. A4 is considered acceptable with mitigation.

The attached risk analysis report explores the hazards introduced by the current mitigation of complying with FAR 91.211. Eight hazards are identified in the report as a byproduct of compliance. The induced hazards may be categorized as fatigue, CRM interference, vision interference, oxygen depletion, oxygen toxicity, unsanitary health risks, untimely wear and quick-donning feature negated.

The final section of the risk analysis explores four alternative mitigation options.

Hazards Caused by FAR 91.211 Compliance

Fatigue

The oxygen masks currently installed on corporate aircraft are designed for emergency use. Little consideration appears to be made to accommodate long period usage during routine high altitude flight operations. The masks come in one size and are fitted with non-adjustable bands that secure the mask very tightly to the users face. Although there is a comfort setting on the mask designed to relieve pressure on a users face, this feature is a marginal improvement and is seldom operable. There is nothing specific in determining the operability of the comfort setting. It is a completely subjective determination that often causes conflict between the user and the maintainer.

CRM Interference

When one pilot is wearing the oxygen mask, the crew has to cope with impaired crew communication. The current design of the oxygen mask system installed on corporate aircraft is not conducive to routine interphone and radio communication. The hot mic is constantly broadcasting breathing noise over the interphone. This is both annoying and interferes with normal communication. Most crews will cope with this by turning off the mask microphone and having the pilot not wearing the mask handle all radio calls. This isolates the pilot who is wearing an oxygen mask from normal CRM.

Vision Interference

Pilots who wear glasses have a difficult time with the current oxygen masks installed on corporate aircraft. The mask fits over the bridge of the nose where a person’s glasses normally sit. This results in raising the glasses much higher than they normally fit and interferes with the pilot’s vision. Some masks are fitted with attached smoke goggles, which adds to the challenge.

Oxygen Depletion

Even if a user selects the Normal setting, some oxygen is used when the mask is worn. On a long-range flight, the amount of oxygen used can only be known by a reduction in tank pressure. It is very difficult to constantly equate a reducing pressure reading to the amount of time available if oxygen is needed in an emergency. Therefore, most operators have no idea how much time of oxygen use they have, once they begin using the oxygen system to comply with FAR 91.211. The only sure thing is, there isn’t as much oxygen available for use in a real emergency due to consumption of oxygen during routine cruise flight.

After an extended high altitude flight, the oxygen supply must be replenished. Remote destinations frequented by corporate aircraft may not have the capability to replenish the oxygen system. This will either cause an operator to avoid those destinations or forego servicing the oxygen system. There are locations that have questionable oxygen sources and the operator must deal with the risk of contaminating the aircraft's oxygen system. There are also locations, such as China, where the only way to service the oxygen system is to have the tanks removed from the aircraft first. This adds even more unnecessary risk to the operation.

Oxygen Toxicity

Prolonged breathing of 100% oxygen may compromise a pilot's health with symptoms such as disorientation, breathing problems and vision changes, such as myopia. This was not considered a problem in corporate aircraft until ultra long-range aircraft entered the scene. High altitude legs of 10 or more hours are now considered normal and pilots are now exposed to 100% oxygen for extended periods of time. Scientists state the exposure limit for breathing 100% oxygen under normal pressure, as four hours. (Beehler, 1964)

In order to avoid oxygen toxicity and still comply with FAR 91.211, one might select the Normal setting on the diluter-demand oxygen mask. This would allow the mask user to breath ambient air with a small amount of added oxygen. At issue is the effectiveness of not breathing 100% oxygen prior to a decompression event and still maintain the level of performance needed to fly the aircraft. It has been scientifically shown that there will be a severe decrement in performance for a person exposed to decompression from 8000 feet to 41,000 feet without breathing 100% oxygen prior to the decompression. (Billings, 1974) Therefore, the only effective way to mitigate an explosive decompression event, utilizing the current regulation, is to risk oxygen toxicity by continuously breathing 100% oxygen during high altitude cruise flight.

Unsanitary Health Risks

Since the pilots must share the installed oxygen masks, they are potentially exposed to bacterial or viral organisms. Despite cleaning with recommended alcoholic agents, there are areas on the mask left unclean. The head straps are covered with a fabric material that is not cleanable and is in contact with the mask during stowage. The hose connected to the oxygen mask is also not cleanable between usages and can harbor infectious organisms. The risk of exposure is dependant upon the user's ability to thoroughly clean the mask and the health of co-workers who share the mask.

Untimely Wear

The oxygen mask systems installed on corporate jet aircraft are designed primarily to cope with emergency situations. They do not appear to be built for repeated deployment and stowage. The wear on units that are used by crews compliant with FAR 91.211 is evidenced by frayed headbands and decayed seals.

Quick-donning Feature Negated

Quick-donning masks (rapid fitment) are oxygen masks that a pilot can place on the face with one hand from the ready position within 5 seconds, supplying oxygen and properly secured and sealed (14 CFR 91, 2013). The quick-donning feature must be demonstrated from the stowed position in its container, or suspension device (TSO-C78a, 2008).

Most pilots are unlikely to correctly re-stow oxygen masks after use. When a mask is not stowed correctly in its container, the amount of time needed to don the mask is unknown.

Some pilots believe that holding the mask on their lap will reduce the time needed to don the mask. This technique ignores the possibility that a chaotic cockpit environment may occur during certain emergencies, including decompression. An unsecured mask that is needed during a real emergency has a high likelihood of taking longer than 5 seconds to don.

Mitigation Options

Since the risk assessment clearly defines several induced hazards, it is prudent to explore alternative mitigation choices. They are as follows.

Ignore FAR 91.211

This is the mitigation method of choice for the majority of corporate jet operators in the United States. It does eliminate the hazards induced by compliance with FAR 91.211. However, it comes with a price. Selectively choosing which regulations to follow is a dangerous attitude and clearly demonstrates poor airmanship. (Kern, 1997) Chief Pilots and/or Aviation Directors who choose to endorse or ignore this behavior will likely face many other airmanship deficiencies with potential catastrophic outcomes.

Change FAR 91.211

This is an extremely challenging choice, as FAA and NTSB officials do not appear to be concerned with the current situation. Even though the rampant non-compliance with this rule has been published in several magazine and journals, there has been no official response from our regulating agencies. Getting the FAA to take notice that change is needed will only happen if a large and powerful group of operators, pilots, manufacturers and organizations present a common desire and need for change.

What change will be effective? On the surface, a rule change that mimics ICAO Annex 6 supplemental oxygen requirements would be very desirable. This is a common sense course of action. If taken, it is important to include the mitigated hazards with this proposal, as there is a requirement that any rule change will need to clearly show an increased level in safety and be in the public's best interest.

One idea is to include an additional training and equipment requirements with a rule modification. Much like what was done with the alternate night currency regulations, a revised supplemental oxygen regulation might include a requirement for additional training, such as altitude chamber training, with an approved training provider. Also, having an automated descent system is a substantial equipment improvement that adds a new level of safety. This could be a prerequisite for an operator to be qualified to comply with a modified rule.

Modification of the Oxygen System

Several of the hazards induced by FAR 91.211 are caused by the design of the system. Military fighter pilots have worn oxygen masks for years without adding to their list of hazards. Their masks are fitted and are only worn by the individual user. Another consideration would be to design a system that provides an oxygen supply for routine use independent of the emergency system.

Petition for Exemption

Before 1985 there were several exemptions to supplemental oxygen regulations. A denial of exemption filed by the acting Director, Flight Standards Service, changed how the FAA viewed exemption requests for relief of supplemental oxygen rules. (Federal Aviation Administration, 1986)

The concerns expressed by certain commenters opposed to the Proposed amendments contained in Notice No. 82-11 prompted the FAA to reconsider the proposed amendments and the supporting rationale included therein and also stated in previous grants of exemption. Particular attention was directed at the potentially severe physiological consequences resulting from high altitude depressurization in both large and small cabin volume aircraft that possibly would incapacitate the flightcrew and result in an accident. That reconsideration led the FAA to conclusions different from those expressed in Notice No. 82-11 and previous grants of exemption. The FAA determined that further grants of exemption should be discontinued and the notice withdrawn.

Thirty-two companies lost their exemption as a result of his decision.

Bombardier unsuccessfully attempted to get an exemption for the Global Express in 1995. They based their petition primarily on the reliability and redundancy that was built into the Global Express and its improved systems. They also cited the engineering challenge of increasing the oxygen volume to compensate for routine usage. What they failed to do was address physiological issues as the FAA pointed out in their refusal of the petition. (Federal Aviation Administration, 1995)

A review of the Federal Register and the denials of petitions for exemption from supplemental oxygen use requirements reveal a common reason for denial. All petitioners failed to show that exemptions to the rule will improve safety and are in the public's best interest.

The FAA has not entertained an exemption petition for relief from supplemental oxygen regulation since 2005.

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Risk Analysis of FAR 91.211

The Hazard:
Loss of aircraft control due to hypoxia induced pilot incapacitation because of depressurization.

The Risk:
Loss of life and aircraft.

Severity and Likelihood: A4 or A5
Severity – (A) Catastrophic
Likelihood – (4) Unlikely or (5) Highly unlikely – There is virtually no chance of an explosive or rapid depressurization in modern aircraft. There is a more likely chance of a depressurization of less than 7000 fpm due to a malfunction in the pressurization system or door seal failure.

A4 is in the acceptable with mitigation risk category in the Merck Safety Risk Matrix.
A5 is in the acceptable risk category in the Merck Safety Risk Matrix

Current Mitigation:
FAR 91.211

– One pilot will wear and use an oxygen mask while flying above 41,000 feet.
– One pilot will wear and use an oxygen mask while flying above 35,000 feet when the other pilot has left the cockpit.

Hazards Introduced by Current Mitigation:

1. Increased pilot fatigue due to wearing a mask designed for emergencies during long periods of time. The mask is not fit to individual pilots' faces. The mask is very tight on the head and is not adjustable. Breathing dry oxygen for an extended period of time also contributes to fatigue.
2. Interference with CRM. Wearing the mask interferes with normal crew communication. The design of the emergency oxygen mask is not conducive to normal, routine interphone and radio communication.
3. Interference with the performance. The design of the emergency oxygen mask does not allow pilots to wear their glasses in a normal position.
4. Depletion of oxygen. Using the oxygen system during extended long range cruise depletes the supplemental oxygen supply. Oxygen that is depleted by using the system during cruise is not available should a real emergency occur. The moment that the crew begins using supplemental oxygen, they no longer have accurate knowledge of how much oxygen is available for emergency use. Additional problems occur when oxygen must be replenished at a foreign location. Oxygen quality may be questionable and some locations have requirements, such as removing the oxygen tank, which add more hazards to aircraft operations.
5. Oxygen toxicity. This was not a problem before ultra-long range aircraft. Now flying these aircraft on longer legs may expose the crew to 100% oxygen for 10-

12 hours at a time. Extended use of 100% oxygen can have a toxic effect on the human body. Prolonged breathing of 100% oxygen may cause symptoms that include disorientation, breathing problems, and vision changes such as myopia. Prolonged exposure to above-normal oxygen partial pressures can cause oxidative damage to cell membranes, the collapse of the alveoli in the lungs, retinal detachment, and seizure. Less severe symptoms due to bronchial irritation are common.

6. Health risks are introduced during repeated use of the masks during cruise. Although pilots use disinfectant swabs to clean the masks, the cleaning process may not be as thorough as is necessary to prevent the spread of sickness. The design of the system reintroduces contamination in that the face mask is in contact with the head bands during stowage.
7. Unplanned wear on the mask system. The system does not seem to be designed for multiple deployment and stowage by pilots on each flight. The bands fray and the seals decay from all the usage and cleaning.
8. Pilots usually do not re-stow, or incorrectly stow the masks after use. Compliance with the quick-donning requirement is only demonstrated with a properly stowed mask.

New Mitigation Options:

1. Ignore FAR 91.211.
   This option introduces a serious cultural hazard. Choosing to not comply with FAR's demonstrates poor discipline. Endorsing this attitude will likely introduce other hazards that have a likely result of serious consequences.
2. Work with the FAA to change 91.211 to reflect the ICAO Annex 6 recommended rules for use of oxygen by crewmembers. The ICAO rule mitigates risk associated with likely depressurization events, without introducing more hazards. Including FAA approved aviation physiology training and mandatory aircraft equipment would complement this mitigation choice.
3. Modification of the supplemental oxygen system to alleviate the hazards introduced by the current design. A design improvement would include an oxygen system that is independent of the emergency oxygen supply and not introduce additional hazards to the crew.
4. Petition the FAA for an exemption from FAR 91.211 for independent flight departments and/or aircraft models. The FAA is currently not entertaining exemption requests for any relief from 91.211.