

# *EFFECTS OF COMBINED EXPOSURE TO VAPOURS AND OILS MISTS AT ALTITUDE*

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Proceedings of the Colloque International Poussieres, Fumees et Brouillards sur les Lieux de Travail: Risques et Prevention ISSA, Toulouse, France, 11-13 June 2001.

## *Introduction*

Aircraft materials such as jet-fuel, de-icing fluids, engine oil, hydraulic fluids, and so on, contain a range of ingredients, some of which are toxic (such as tricresyl phosphate). These materials can contaminate airplane cabin air, and these can lead to exposure to vapours and aerosols. The range of bleed air contaminants and their concentrations, which may be found during in-cabin contamination events during flight, can be extensive. Significant contaminants include: aldehydes; aromatic hydrocarbons; aliphatic hydrocarbons; chlorinated, fluorinated, methylated, phosphate, nitrogen compounds; esters; oxides; and combusted or pyrolysed products such as carbon monoxide, carbon dioxide, smoke particles of unknown constitution. These may be in gas or vapour form, or as oil mists of partially combusted particles. Gases and vapours may also be adsorbed onto aerosol particles.

## *Issues that can Impact on Exposure to Contaminants on Airplanes*

### *The Impact of Altitude*

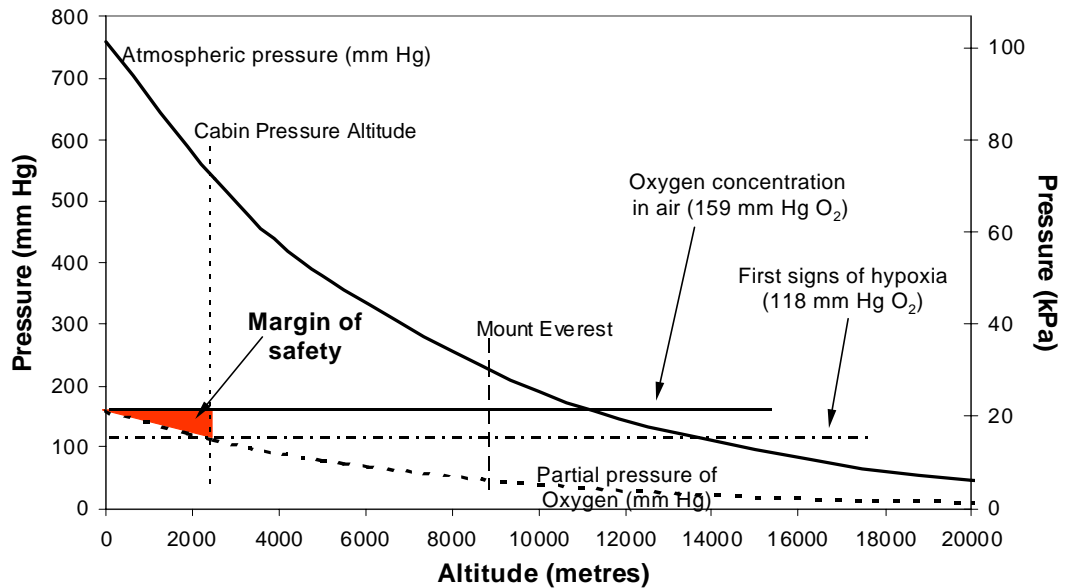
The concentration of oxygen at increasing altitude remains constant, at 20.9%. This suggests that oxygen levels are unchanged. This is not true. Basically, as altitude increases, the atmospheric pressure declines. While the proportion of oxygen in air remains unchanged, the actual amount of oxygen in air decreases.

Atmospheric pressure at sea level is 760 mm Hg, with the corresponding partial pressure of oxygen in air is 159 mm Hg (20.9% or 760 mm Hg). The minimum O<sub>2</sub> concentration for work is considered to be about 136 mm Hg (18 kPa or 18%) O<sub>2</sub> in air at sea level. A minimum oxygen partial pressure of 118 mm Hg (equivalent to an altitude of 2438 m/8000 ft) is required to prevent hypoxic cabin air in commercial aircraft during normal operations. This partial pressure is maintained by the cabin pressure system (a second requirement for release of oxygen dispensing units at 4572 m/15,000 ft is recommended).

The altitude at which the partial pressure of 136 mm Hg is reached is also quite close to the pressure at which airplane cabins are pressurised (118 mm Hg). There is little margin of safety in people working at altitude, and in many cases, such workers may be beginning to become hypoxic. This shown in the Figure below, where the area bounded by the dashed partial pressure of Oxygen in Air curve, and the dotted line representing the minimum physiological demand line represents the margin of safety at which workers can be considered to have sufficient oxygen to work safely). Further, the position of the cabin pressurisation line shows

that in some cases, workers at altitude may not be obtaining enough oxygen for their physiological requirements.

**Figure: Pressures and Oxygen Concentrations at Altitude**



**Assumptions:**

- Atmospheric pressure: 101 kPa (760 mm Hg) at sea level
- Proportional concentration of O<sub>2</sub> in air: 20.9% (21 kPa or 159 mm Hg) at sea level)
- Aircraft Pressurisation Pressure: Equivalent to an altitude of 2500 m (about 8000 ft).

Other problems with lowered oxygen concentrations include changes in sensitivity to toxic exposures (for example, the toxicity of carbon monoxide is 50% higher at 8000 ft than at sea level), and the possibility that incipient hypoxia may lead to higher respiratory rates and therefore increased exposure.

Other factors due to the manner in which air is circulated in planes, may also have an effect, such as humidity, temperature, or contaminants such as carbon dioxide, carbon monoxide, ozone and particulates.

**Issues Related to Vapours and Particulates**

Airborne contaminants are generally divided into two types: gas/vapour and particulates.

**Gases/Vapours:** A gas is those molecules of a chemical that exist in a gaseous phase. Where all the molecules of a chemical are in the gaseous phase, the chemical is considered a gas. A vapour is the gas phase of a liquid at room temperature. Therefore, a vapour is that amount of liquid that evaporates into air (or dissolves into air). Gases and vapours form true solutions in air. The amount of evaporation is dependent on the individual vapour pressure of the contaminant. Where vapour pressure is low, only a small amount of the contaminant will evaporate. Generally, vapour pressure increases with temperature.

Where volatile organic chemicals (VOCs) have high vapour pressures, they will be present in air in high concentrations, are more likely to reach toxic concentrations and are amenable to sample collection and analysis using sorbent or gas collection methods. Where semi-volatile or poorly volatile chemicals have low vapour pressures, they are less likely to reach toxic

concentrations unless they are highly toxic, and sorbent or gas collection methods are less useful for sample collection.

**Particulates:** These are materials that are suspended, not dissolved, in air, and include fumes, smoke, mists, aerosols, dusts, fibres and so on. Particulates may be in liquid phase (such as mists), solid phase (smokes, fumes and dusts) or mixed phases (aerosols). Precise criteria for these terms exist based on particle size and phase, but are unnecessary for the present discussion.

Where a particulate is present in air and contains a volatile component, the volatile components will evaporate at a rate dependent on individual vapour pressures. However, depending on the amount of particulate present in air, it is possible to exceed the vapour pressure of an individual contaminant. Where a contaminant has a low vapour pressure, particulate exposure is more important than exposure to vapour.

Therefore, particulates containing a large proportion of volatile components will evaporate quickly (sometimes even before settling), indicating that the vapour phase of the contaminant is more important. Particulates containing poorly volatile components will stay in particulate form for a long time, until gravity or turbulence causes them to settle. Once settled, particles coalesce onto or adhere to surfaces, and any remaining volatile components become subject to evaporation through their vapour pressures. Where evaporative pressures are low, long term, low-level contamination leading to residual exposures will occur.

Further, because particulates can settle on exposed skin and be subject to absorption through skin, sometimes after airborne exposure has ceased, it is important to consider both the inhalational and skin routes when estimating exposure.

Particulates are not amenable to the same sampling and collection methods that are required for gases and vapours. They require specialised sampling, usually by filtration or gravimetric methods. Further, because particulates can exist in different sizes and diameters, an estimate of that fraction of the particulate that is taken into the respiratory system may be more critical than an estimation of the total concentration of particulate. Consideration of the type of airborne contaminants, whether in vapour, particulate or mixed phases is quite critical for the success and relevance of a monitoring program.

### ***Issues Related to Combustion and Pyrolysis***

Any chemical or chemical mixture is subject to degradation processes, such as oxidation or reduction. Over time, these can cause substantial loss of original chemical structures and properties. This process occurs more rapidly at higher temperatures and pressures, in accordance with the laws of thermodynamics.

However other breakdown processes are possible, such as, a material subject to a source of heat energy can burn. This is called thermal degradation, or thermolysis. The process of thermal degradation is a chemical process in which oxygen and energy are used to transform the original chemical into its oxidised form. For example, carbon containing materials will, in the presence of energy and oxygen, produce the two oxides of carbon: Carbon dioxide (CO<sub>2</sub>) and Carbon monoxide (CO). The first of these (CO<sub>2</sub>) is produced in the presence of an abundance of oxygen, the second (CO), where stoichiometric concentrations of oxygen are lacking (usually in conditions of incomplete combustion). Both of these oxides are gases, one (Carbon monoxide) is indeed toxic even at low concentrations, causing toxic asphyxiation. Single or

short term exposure to CO insufficient to cause asphyxiation produces headache, dizziness, and nausea; long term exposure can cause, among other effects, memory defects and central nervous system damage.

Where oxygen is completely lacking, the process of thermal degradation can still proceed, but this time, any carbon in a material, will be reduced from the chemical form it is located, to molecules containing proportionally more carbon (and proportionally less volatile components) and ultimately, carbon atoms. This process is called pyrolysis. Both oxides of carbon are gases, but elemental carbon is a solid (usually seen as smoke or soot). Further, the process of reducing carbon containing materials to carbon depends on the chemical nature of the source material, and will produce different pyrolysis products as the reaction process proceeds. Pyrolysis products may be fairly pure in carbon content, but are more usually found with other organic or inorganic breakdown products. The processes inherent in pyrolytic degradation are very complex, and vary depending on the source materials, the temperature and duration of combustion, and the progressive combustion of pyrolysis products that occur in the thermal degradation process.

Many combustion and pyrolysis products are toxic. The toxic asphyxiants, such as carbon monoxide or hydrogen cyanide were discussed above. Some thermal degradation products, such as acrolein and formaldehyde are highly irritating. Others, such as oxides of nitrogen and phosgene, can produce delayed effects. Still others, such as particulate matter (for example, soot) can carry adsorbed gases deep into the respiratory tract where they may provoke a local reaction or be absorbed to produce systemic effects.

Of course, in a situation where a fire occurs, all three processes can occur. Where there is no oxygen, pyrolysis products (such as smoke) will be formed, where there is incomplete combustion carbon monoxide will form, and where there is complete combustion, carbon dioxide is formed. Further, these process may proceed sequentially, as oxygen becomes available to the burning material.

Therefore, as well as particulate and gas/vapour phases, consideration of the type of airborne contaminants, whether in unchanged, degraded, combusted or pyrolysed forms is also critical for the success and relevance of a monitoring program.

### ***Issues related to Exposure in an Airplane***

If an airplane engine leaks in flight, and leaking engine oils contaminate air flowing to the flight deck or passenger cabin. There are two possible exposure scenarios:

- exposure to the oil;
- exposure to a thermally degraded oil and its by-products.

In such circumstances, exposed crew and passengers are exposed to airborne contaminants that are leaking directly into air, and they are unaware of the toxicity of the contaminants they are inhaling. There is little control of exposure.

If exposure is to an oil, it will be at least partially in a particulate (mist) form, where it can attain higher airborne concentrations than might be predicted from vapour pressures (even at elevated, but rapidly cooling, temperatures). Also, the potential for skin exposure is greatly increased, as the mist can settle onto exposed skin, where it will then be available for dermal absorption.

Further, the emission of oil vapours/smoke/mists into the passenger cabin would produce contamination of the cabin. Particulates would settle out onto surfaces (such as ducting, cabin walls, furniture and equipment), which would thereafter slowly vapourise, the rate of evaporation being dependent on individual contaminant vapour pressures. This residual contamination would continue until cleaned off or until it had evaporated.

While the toxicity of some aircraft fluids has been established, little is known about the possible transformations that may have occurred in an oil while in operation. A leak of such an oil from an engine operating at altitude would see most of the oil pyrolyse once it leaves the confined conditions of temperature and pressure operating in the engine. While it seems reasonable that any ingredients with suitable autoignition or degradation properties that allow such a transformation after release from the engine could be radically transformed, it is possible to speculate in only general terms about the cocktail of chemicals that could form.

Presumably this would include:

- combustion gases such as carbon dioxide and carbon monoxide;
- other irritating gases, such as oxides of nitrogen;
- partially burnt hydrocarbons (including irritating and toxic by-products, such as acrolein and other aldehydes); and
- any specific toxic contaminant such as Tricresyl phosphate that are fairly stable at high temperatures or thermal degradation products, such as highly toxic oxides of carbon, nitrogen or phosphorus.

These contaminants will be in gas, vapour, mist and particulate forms.

If the exposure is to a thermally degraded oil then as well as any exposure to the oil mist (as outlined above), exposure can also include particulates such as soots; thermally degraded chemicals such as acrolein, and combustion gases such as carbon monoxide.

Chemicals used in Aviation are commercially useful products. They are known to contain toxic ingredients. While the continued use of toxic materials is always a matter requiring caution and forethought, a full deliberation of risks and benefits may overcome such considerations.

An increasing number of oil leaks in the 1990's around the world and the increase in a number of flight attendants and flight crew reporting signs of toxicity after such events suggests the toxicity of the jet oils should be reconsidered:

- Firstly, the exposure scenario at altitude is utterly different from conventional exposures to the such products while using them in maintenance situations. Exposed individuals do not know to what they are being exposed, exposure by inhalational and dermal exposures can occur, the possibility of escape is absent, the possibility of cleaning or decontamination is absent).
- Secondly, options for the control of exposure are all but absent. Switching off an engine or bleed air system may offer some assistance, but is less useful if an entire ventilation system is contaminated.
- Thirdly, the exposure may be not only to gases and vapours, but also to particulates (such as oil mists or soots) that can be in proportionally greater concentrations than they would be for vapours.

- Fourthly, the exposure may vary from unchanged oil mists, or to combusted or pyrolysed contaminants. The chemical make up of such a mixture would be difficult to deduce; the toxicity of exposure to such a mixture would be difficult to predict.

However, these contaminants could not be classified as being of low toxicity. The interactions of such effects with a specific toxic exposure is not known, but not presumed to be benign. The possible problems that might arise from exposure to such a cocktail cannot be dismissed without proper consideration.

## *Effects of exposure*

Studies of exposures in airplanes where cabin contamination occurs show common symptoms of irritancy and toxicity. The range of symptoms in these studies is quite broad, affecting many body systems. These include:

- **neurotoxic symptoms:** blurred or tunnel vision, nystagmus, disorientation, shaking and tremors, loss of balance and vertigo, seizures, loss of consciousness, parathesias, numbness (fingers, lips, limbs), parathesias;
- **neuropsychological symptoms:** memory impairment, light-headedness, dizziness, confusion and feeling intoxicated, forgetfulness, lack of co-ordination, severe headaches, sleep disorders;
- **gastro-intestinal symptoms:** nausea, vomiting, salivation, diarrhoea;
- **respiratory symptoms:** cough, breathing difficulties (shortness of breath), tightness in chest, respiratory failure requiring oxygen, susceptibility to upper respiratory tract infections;
- **skin symptoms:** skin itching and rashes, skin blisters (on uncovered body parts), hair loss;
- **cardiovascular symptoms:** chest pain, increased heart rate and palpitations;
- **irritation** of eyes, nose and upper airways;
- **sensitivity:** signs of immunosuppression, food and alcohol intolerances, chemical sensitivity leading to acquired or multiple chemical sensitivity
- **general:** weakness and fatigue (leading to chronic fatigue), exhaustion, hot flashes, joint pain, muscle weakness and pain.

Some of these effects are transient, others appear more permanent. A preponderance of these symptoms are related to exposure to irritants. However, the presence on symptoms related to central nervous system dysfunction, hair loss, muscular and gastrointestinal problems, suggests the possibility of a component of systemic toxicity. Neurotoxicity is a major flight safety concern, especially where exposures are intense. The exacerbation of pre-existing health problems by toxic exposures is also highly probable.

Many of the signs and symptoms of exposure being reported by exposed flight crew (and to a lesser extent, passengers) appear consistent with the toxicity of some of the ingredients of the oils. These include hydrocarbon neurotoxicity from exposure to organic chemicals, COPIND from organophosphate exposure, or long term low level toxicity from exposure to carbon monoxide. These health problems need to be evaluated with more care than is apparent in the aviation industry at present.

This is a hidden issue. These health effects present significant issues with regard to the health of pilots, cabin crew and passengers, but most notably with regard to air safety if pilots are incapacitated and cabin crew cannot supervise cabin evacuations during emergencies.