The occurrence of smoke and/or toxic fumes in the aircraft cockpit or cabin is more common than is generally realised, and it is a hazard which endangers the health and lives of aircrew and may limit their capability to deal with the source of the problem.

The Extent of the Problem

The reported incidence of in-flight smoke and fumes in ADF aircraft was calculated by reviewing the number of Aviation Safety Occurrence Reports (ASORs) raised for such incidents in last five years, and also determining the quantum of flying undertaken during that period. It turns out that for every 2000 hours of flying operations conducted in the ADF, one incident of in-flight smoke/fumes is being reported (0.5 per 1000 hrs). The incidence is very similar in the Air Force and the Navy, but is almost half in the Army (Table 1 below). The incidence varies significantly from one aircraft type to the other, as seen in Table 2, page 11.

<table>
<thead>
<tr>
<th>Service</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>All ADF</td>
<td>0.523</td>
</tr>
<tr>
<td>Royal Australian Air Force</td>
<td>0.582</td>
</tr>
<tr>
<td>Australian Army</td>
<td>0.288</td>
</tr>
<tr>
<td>Royal Australian Navy</td>
<td>0.665</td>
</tr>
</tbody>
</table>

Table 1: Incidence (ASOR’s) of Smoke & Fumes per 1,000 flying hours
Source of Smoke and Fumes

The smoke or fumes can originate from a variety of sources. The immediate cause is usually a leakage, over-heating, or burning of various materials. Some common sources are:

- aircraft materials (insulations, cables, composites etc)
- batteries
- radioactive substances
- ordnance
- fuels
- hydraulic fluids
- lubricants
- fire extinguishing agents
- de-icing fluids
- oxygen system impurities
- ozone

In-flight smoke/fumes may contain a variety of toxic substances. Some potential contaminants and their concentrations that a smoke protection equipment is required to protect against are listed in the table below.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Potential Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide (CO&lt;sub&gt;2&lt;/sub&gt;)</td>
<td>35,000 ppm (3.5%)</td>
</tr>
<tr>
<td>Carbon Monoxide (CO)</td>
<td>10,000 ppm (1.0%)</td>
</tr>
<tr>
<td>Hydrogen Chloride (HCL)</td>
<td>1,000 ppm (0.1%)</td>
</tr>
<tr>
<td>Hydrogen Fluoride (HF)</td>
<td>1,000 ppm (0.1%)</td>
</tr>
<tr>
<td>Hydrogen Cyanide (HCN)</td>
<td>400 ppm (0.04%)</td>
</tr>
<tr>
<td>Oxides of Nitrogen (NO)</td>
<td>200 ppm (0.02%)</td>
</tr>
<tr>
<td>Acrolein</td>
<td>50 ppm (0.005%)</td>
</tr>
<tr>
<td>Ammonia (NH&lt;sub&gt;3&lt;/sub&gt;)</td>
<td>1,000 ppm (0.1%)</td>
</tr>
<tr>
<td>Hydrogen Bromide</td>
<td>1,000 ppm (0.1%)</td>
</tr>
<tr>
<td>Total Hydrocarbons</td>
<td>5,000 ppm (0.5%)</td>
</tr>
<tr>
<td>Sulphur Dioxide</td>
<td>100 ppm (0.01%)</td>
</tr>
<tr>
<td>Particulates (0.5-10 micron)</td>
<td>3.5 mg/Litre</td>
</tr>
</tbody>
</table>

Table 3: Potential Contaminants and Their Concentrations

Effects of Toxic Substances

Most of the contaminants enter the body through inhalation and many are highly toxic, even in extremely small amounts. Short-term exposure may cause irritation of the respiratory passage, cough, shortness of breath, light-headedness, dizziness, and confusion. Skin irritation, nausea, abdominal cramps, and vomiting may also occur.

There is some evidence that continued exposure to small amounts of certain contaminants may produce chronic, long term, and irreversible damage to humans. Blood disorders, and damage to lungs, liver and kidney may occur. Some toxins may be potentially carcinogenic, i.e., cancer causing. Unfortunately, specific information relating to such effects is very limited, since by its very nature, no human research is possible due to ethical consideration. Animal research has its limitations when extrapolated to humans. Consequently, most of the evidence is presumptive.

The aircraft cockpit and cabin are unique workplaces that cannot be compared with industrial and other workplaces on the ground. Aircrew members are required to perform complex tasks requiring high level cognitive skills, which may be much more sensitive to insult by hazardous contaminants in the smoke/fumes, such as Tri-Cresyl Phosphate (TCP). Therefore, the maximum permissible limits for
safe exposure recommended by the Occupational Safety and Health Administration (OSHA) of USA, and American Council of Governmental Industrial Hygienists (ACGIH) for industrial workers cannot be applied to aviation.

Various ADF agencies charged with that role are constantly working to eliminate, or minimise to the extent possible, exposure to all hazardous contaminants at the workplace.

**Aircrew Protective Systems**

A system is required which can provide protection to aircrew while combating the emergency (of in-flight smoke/fumes), and performing other essential duties at the same time. The requirement is for a device, or a system, to keep the contaminant(s) out of the breathing system, and also protect the eyes from exposure to toxic substances. Ideally, such a system would consist of a full-face mask to protect the eyes, the mouth, and the nose, and a closed-loop breathing system to prevent the inhalation of contaminated cabin air.

In addition, in all cases of in-flight smoke and fumes, it is highly desirable that the cabin is flushed out to get rid of the contaminant(s) and avoid continued exposure, which means depressurising the aircraft if flying at altitude. If the incident occurs at an altitude of more than 10,000 feet, depressurising the aircraft will also bring in the problem of hypoxia, which will require supplemental oxygen for the aircrew. Therefore, unless the problem of smoke and fumes occurs at an altitude of less than 10,000 feet, provision of supplemental oxygen must form a necessary part of the solution.

Most national and international regulations mandate that 100% oxygen should be available for all aircrew for a period of 15–25 minutes. This is based on the time required to descend to a safe altitude of about 10,000 feet. However, the time required to descend may sometimes be much longer due to geographic or operational considerations, in which case a larger amount of oxygen will need to be made available. The cockpit crew will generally have a plumbed oxygen system, and the amount of oxygen is not a constraint. However, the backend and mobile aircrew need to carry a portable oxygen system, which limits the maximum amount of oxygen that can be provided. Detailed requirements for smoke protection breathing equipment for mobile aircrew have been specified by the Allied Nations interoperability agency, the Air Standards Coordinating Committee (ASCCC), in Air Standard 61/101/15 (see box).

It is important not to confuse a smoke/fumes situation with incidents of loss of cabin pressure, wherein there is no need for a closed-loop oxygen system, and the aircrew can breathe a mixture of oxygen and air by selecting ‘airmix’ on the regulator. Breathing on ‘airmix’ increases the endurance of the oxygen system many-fold.

The only practical method of providing oxygen in a portable system is to carry gaseous oxygen under high pressure in metallic cylinders. Steel cylinders are heavier, but can withstand higher pressures than most cylinders made of lighter materials. As a result, one is able to carry greater amounts of oxygen in steel cylinders.

Oxygen hoods are commonly used in aviation. These devices provide oxygen from a small cylinder into a transparent hood sealed at the neck. The oxygen is re-breathed continuously from the hood, while a chemical scrubber absorbs the exhaled carbon dioxide. The major disadvantages of such a system are that it is incompatible with the aircraft communication systems, degrades the visibility, and produces heat around the neck (from CO₂ scrubbers) that may become intolerable at high workloads. Most importantly, the endurance of an oxygen hood is only a few minutes, especially at high workloads when it may last for not more than five minutes. However, oxygen hoods are useful for sedentary passengers waiting to be rescued.

Chemical oxygen generators are unsuitable for aircrew, as they cannot be switched off once they are activated, and they also generate heat when in operation.

Liquid oxygen and on-board oxygen generators (OBOGS, molecular sieve) are too complex and cumbersome for use in a portable system.

Air filters used by earth-bound fire fighters have a very limited role, if any, in the air. The number of potential contaminants in the air is large and varied, making it impossible to find a filter that will eliminate all contaminants.

Unfortunately, none of the portable oxygen systems currently available for mobile aircrew to deal with an in-flight smoke/fumes situation is fully satisfactory. In such a situation, some compromises may have to be made, and a robust risk management plan needs to be put in place, based on the specific requirements and threat perceptions of each operation.

**Management of Smoke/Fumes Incident in the Air**

Flying units need to have their own Standing Instructions for dealing with incidents of smoke/fumes in the air. The strategy should be to immediately commence breathing 100% oxygen with the toggle down to prevent inboard leakage of cabin air into the mask and then investigate the problem. If the problem persists, the aircraft should be descended to safe altitude as soon as possible and depressurised to ventilate the cabin,
followed by a return to base or landing at the nearest suitable airfield, if warranted. Each case needs to be evaluated on its merit and decisions taken after considering all the factors, including operational imperatives, flight safety, and OH&S guidelines.

Aircrew members who may have had a significant exposure to smoke or fumes need to consult a doctor for observation and further investigations. The determination as to whether the exposure is significant or not should be based on commonsense and on factors such as the period of exposure and symptoms experienced. When in doubt, an exposure should be assumed, and medical/AVMED consulted. The protocol recommended by the RAAF Institute of Aviation Medicine (AVMED) for the medical management of exposure to smoke and fumes is provided on this page. Further work is in progress to develop this policy.

DFS Comment

This excellent article by Dr Singh encapsulates the hazards associated with smoke and fumes in aircraft—and their management, as well as describing the various protection systems currently available in ADF aircraft.

It is important to note that Aviation Safety Occurrence Reports (ASORs) are required to be submitted (amongst many others) for:

- any occurrence resulting in injury;
- any occurrence resulting in hypoxia or hypobaric trauma; and
- any occurrence resulting in any exposure to smoke and/or fumes or radiation.

ASORs are despatched to Comcare upon receipt at DFS-ADF and thus Comcare do not require notification in addition to the ASOR. However, the Defence Safety Management Agency (DSMA) has a standing requirement for all dangerous occurrences and injuries to be reported via an AC563. DFS-ADF is liaising with DSMA to endeavour to have the ASOR form accepted as sufficient notification to DSMA of a dangerous occurrence. In the meantime, the above occurrences require submission of both an ASOR and an AC563.

For these occurrences, appropriate medical attention should be sought for affected personnel as soon as possible and an AC563 submitted to DSMA within 24 hours. Further guidance on AC563 reporting is in contained in the DASM Chapter 9 paragraph 22 and Annex D at: http://defweb.cbr.defence.gov.au/home/documents/departmental/manuals/safetymanv3.htm and from the DSMA website at: http://dsma.dcb.defence.gov.au

Any occurrences listed above requiring the completion of an AC563 and medical review must (through agreement with Comcare) be classed as at least an Incident, with an investigation carried out and actions/recommendations determined to prevent a recurrence. The wording in Chapter 9 of the DASM will be amended in AL1 to be more specific in stating that for any occurrence involving injury, hypoxia/hypobaric trauma or exposure to smoke/fumes/radiation, the classification Event cannot be used.

Royal Australian Air Force Institute of Aviation Medicine

GUIDELINES FOR THE MEDICAL MANAGEMENT OF AIRCREW EXPOSED TO SMOKE AND FUMES

Aircrew presents to medical section after a smoke & fumes incident.

1 IF patient is Asymptomatic THEN
   - Observe for 20 minutes
   - Go to Step 3 or 4.

2 IF patient is Symptomatic THEN
   - Place patient on 100% oxygen for 20 minutes
   - Obtain a brief history of the patient and the incident
   - Perform a Clinical assessment
   - Obtain Spirometry reading
   - Determine blood oxygen saturation
   - Complete Physiological Incident Report
   - Go to Step 5 or 6.

3 IF patient is Asymptomatic THEN
   - Return to flying duties.

4 IF patient becomes Symptomatic THEN
   - Go to Step 2.

5 IF patient becomes Asymptomatic AND the tests are normal THEN
   - Return to flying duties.

6 IF patient remains Symptomatic OR the tests are abnormal THEN
   - Perform a Clinical Review
   - Admit patient for Observation
   - Perform a Chest X-Ray
   - Perform FBC, LFT, and Biochemistry tests
   - Proceed to Step 7 or 8.

7 IF patient becomes Asymptomatic AND the tests are normal THEN
   - Return to flying duties.

8 IF patient remains Symptomatic OR the tests are abnormal THEN
   - Declare the patient TMUFF
   - Consult AVMED for further disposition of the case.

NOTE: In ALL cases, a full record of all actions must be kept in the treating clinic and copies sent for the member’s medical file.