Cosmic-ray Induced Aerosol Particle Charging, Implications for Exposure to Children and Pregnant Women in Aircraft

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Summary

A number of epidemiological studies have reported an increased risk of acute myeloid cancer and other cancers in commercial airline personnel. Increased exposure to cosmic radiation at such altitudes has been postulated as a possible cause or factor, especially during solar flare events. Aircraft occupants are also exposed to a variety of potential airborne carcinogens in addition to ionising radiation. A case exists for the implication of cosmic rays and airborne carcinogens as co-factors in carcinogenesis, by charge enhanced deposition of aerosols within the human lung. The plausibility of this mechanism can be tested through the measurement of ion number concentrations onboard commercial aircraft, using a Programmable Ion Mobility Spectrometer (PIMS), developed at the University of Reading. The feasibility for using this instrument in such a campaign is discussed.

Introduction

Natural sources of ‘fair weather’ tropospheric ionisation are dominated by terrestrial radioactivity and cosmic rays. The contribution from cosmic rays increases with altitude and dominates above the boundary layer (3-4 km). At the continental surface the ionisation rate (q) is ~ 10 ion pairs cm\(^{-3}\) s\(^{-1}\) and is dominated by airborne radon isotopes. Over the oceans, cosmic rays provide the sole contribution to q, which drops to ~ 2 ion pairs cm\(^{-3}\) s\(^{-1}\) at sea level, rising to a maximum of ~ 40 ion pairs cm\(^{-3}\) s\(^{-1}\) at an altitude of ~ 15 km (Gringel et al., 1986).

Commercial aircraft generally cruise at altitudes of between 10 and 18 km. The implied elevated exposure to ionising radiation at such altitudes has raised concerns over the health implications for cabin personnel (Boice et al., 2000). Furthermore, an increasing number of passengers are being exposed to elevated doses of radiation as a result of more frequent long-distance and budget flights. Several epidemiological studies have highlighted increased cancer incidence and mortality among commercial airline personnel, including occurrence of acute myeloid leukaemia (Band et al., 1996; Gundestrup & Storm, 1999 and Pukkala et al., 1995). While the increase in radiation exposure at aircraft altitude is generally small, significant increases in dose may occur during solar flare events, such as during the extreme burst of solar activity that occurred during October/November 2003. The possible implications for leukaemia risk resulting from in utero or childhood exposure on long-haul flights should be examined.

In addition to increased direct exposure to cosmic radiation, airline personnel are also exposed to a variety of potential carcinogens, notably engine fumes and onboard pesticides (Blettner et al., 2002). Furthermore, aerosol populations in environments of enhanced ionisation generally possess modified charge distributions (Clement & Harrison, 1992). Charge enhanced nanometre-sized aerosols have been shown to deposit with a greater efficiency in the lung (for example, Cohen et al., 1998), thus providing a mechanism of increasing dose to pollutant
aerosols. This enhancement in deposition results from the electrical image forces created between the charged aerosols and the conducting lining of the human airways.

Characterisation of small ion and aerosol number concentrations in cabin air is fundamental to making an assessment of charge-mediated increase in exposure to toxic aerosol. The development of an instrument for measuring bipolar small ions at the University of Reading, convenient for transportation on aircraft is discussed.

Materials and Methods

The proposed instrument for making small ion measurements onboard aircraft is a Programmable Ion Mobility Spectrometer (PIMS). The PIMS mechanical design, calibration and components have already been described in detail in the scientific literature (Aplin & Harrison, 2000, 2002 and Harrison & Aplin, 2000a, 2000b). It is an air-aspirated cylindrical capacitor (Gerdien condenser) and is capable of measuring bipolar atmospheric small ions of radius < 3 nm, up to concentrations of about 10 000 cm\(^{-3}\). It is computer controlled to enable self-calibration and error checking. Figure 1 shows a photo of the PIMS with the different components indicated.

Several PIMS have previously been deployed in their picoammeter measurement mode, on the University of Reading field site and at Weybourne, Norfolk.

![Figure 1. Photograph of PIMS3 instrument including connections.](image_url)

In this operational mode a polar conductivity \(\sigma_{\pm}\) is derived as:

\[
\sigma_{\pm} = \frac{i e_0}{CV_{PB}} \quad \text{equation 1}
\]

where \(i\) is the measured ion current generated by atmospheric ions impacting onto the inner electrode, \(C\) the capacitance of the condenser and \(V_{PB}\) the polarising bias voltage applied to the outer electrode. Current was logged onto a portable laptop computer using sampling frequencies of between 0.2 and 1 Hz for periods of between a few hours and fourteen days. Conductivity can be converted to ion number concentration \(N\), if the critical mobility \(\mu_c\) for the instrument is known, which is a function of air flow velocity and bias voltage:
Current measurements can be compensated for leakages and offsets prior to calculating ion concentration.

The response of the PIMS to variations in ion production rate has been demonstrated by making simultaneous measurements of small ions and radioactivity. Background radioactivity measurements from α, β and γ sources were made using three ZP1401 Geiger-Müller tubes. Two of the tubes were co-located with the PIMS measurements, with the third situated at a distance of 20 m away. Each tube was operated within the plateau of its sensitivity curve with a dead time of 90 ms at a bias voltage of 500 V. All instruments were fixed at a height of 1 m above the ground.

**Results**

Figures 2(a) and (b) illustrate the linear response of the PIMS multi-mode electrometer calibration in its picoammeter mode and of the Digital to Analogue Converter (DAC) respectively. The picoammeter mode calibration is achieved by generating a range of bipolar reference femtoampere currents using a precision voltage ramp and capacitor system, as described in Harrison & Aplin (2000b). Ion mobility spectra are constructed by making current measurements over a range of bias voltages, adjusted by programming the DAC via a microcontroller. A $V_b$ range of ±25 V is currently achievable, however, it is possible to modify the PIMS so that it may operate at higher bias voltages to permit the detection of “intermediate ions”, of radii up to 30 nm.

![Figure 2](image.png)

**Figure 2.** Calibration of the PIMS multi-mode electrometer in picoammeter mode. (a) Electrometer output voltage over a range of input currents. (b) Generated bias voltage over a range of DAC programme codes.

The effect of an increasing background radioactivity on positive air conductivity over a three-hour period of data acquisition is illustrated in figure 3(a). A positive correlation between conductivity and Geiger-Müller tube count rate is evident. On this particular occasion, both conductivity and count rate increase concurrently with temperature throughout the majority of the measurement period (figure 3(b)). It is likely that this effect was attributable to increasing emanation and exhalation rates of radioactive isotopes from the soil as the ground thawed, following a frost the previous night.
Figure 3. (a) Positive conductivity plotted as a function of Geiger-Müller count rate. (b) Variations in temperature, Geiger-Müller count rate and positive conductivity, on 28 November 2003.

Conclusion

This presentation proposes a campaign of ion measurements to be made onboard commercial airlines in an attempt to assess the electrical properties of the ambient nanometre-sized aerosol populations. This can be achieved using a Programmable Ion Mobility Spectrometer (PIMS) recently developed at the University of Reading. The instrument measures bipolar small ions of < 3 nm (up to ~30 nm with a minor modification) and is capable of responding to variations in ionisation rates on a timescale of minutes. It is also highly portable and therefore suitable for transportation on aircraft cabins. The motivation for this study is to assess the risk of an increase in exposure to pollutant nanometre-sized aerosols as a result of cosmic ray mediated, charge enhanced lung deposition.

References