AEROSPACE

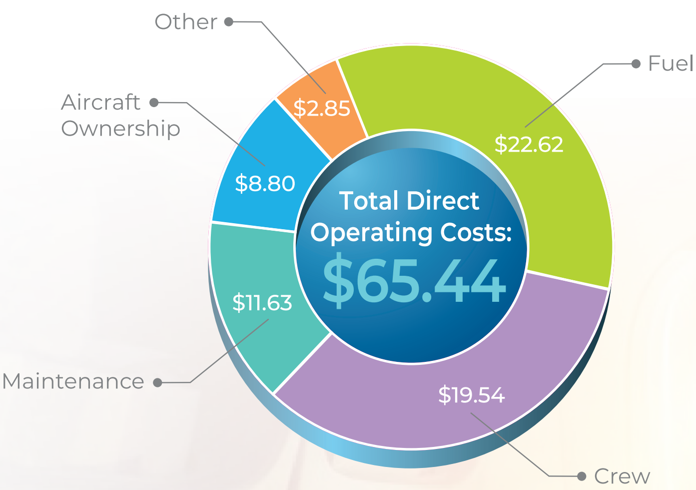
Technical White Paper

Advanced Cabin Air Filtration: How advanced air filters improve the cabin environment, reduce delays and enhance safety

High quality HEPA filters are now a common feature on passenger aircraft. Whilst HEPA filtration effectively prevents the spread of infectious agents throughout the cabin, they do not remove certain gaseous contaminants. Many airlines now use HEPA filters with an additional activated carbon stage to rapidly remove additional contaminants and unpleasant odours from the cabin.

Time is money for any business, but few sectors run on margins tight enough to demand a breakdown of costs to the minute. Airlines are among those to track the price of delays in such granular detail, and with good reason: In 2007 the FAA calculated that delays cost U.S. carriers $8.3 billion – almost $3 billion more than their net profit for the year:

Direct Aircraft Operating Cost Per Block Minute



Naturally, not all hold-ups are avoidable. Disruptive weather is a reality and air traffic management contains inefficiencies, but according to the U.S. Bureau of Transportation Statistics, about a third of delays are due to events within an airline's control.

Airline-attributable delays include so-called 'fume events', characterised by unpleasant odours detected in the cockpit or passenger cabin. A 2021 report from The Association of Flight Attendants reviewed and categorised over 12,000 fume event reports submitted to the FAA between 2002 and 2011. The two major sources were electrical faults (37%) and bleed air related engine oil/hydraulic fluid ingestion (26%). Small quantities of decomposed engine oil or hydraulic fluid can generate extremely bad odours. Any bleed air related compounds can enter the cabin before being removed by the filters.

In a 2013 edition of Airbus' technical magazine, FAST, the aircraft manufacturer pointed out that "a noticeable cabin odor can be generated from ingesting only a very small amount of oil". Bad smells worry passengers, and crews may delay take-off until these dissipate. The longer the odor lingers, the longer the delay. In the worst cases, a flight will be cancelled or, if already airborne, diverted, which can cost an airline north of $200,000. Fume events can be disruptive because identifying a smell is time consuming and crew members are not always able to detect its source. Despite the rarity of such incidents, they do occur frequently enough to concern airlines: In 2010 the FAA published a bulletin related to fume events that equates to 0.9 events per 10,000 flights. In 2013 an International Air Transport Association (IATA) study reported a fume event rate of 1 event per 10,000 flights. A 2015 FAA funded study of US based airlines reported an average fume event rate of 2 events per 10,000 flights. They also reported a "substantial variation" by aircraft type with a maximum of 8 events per 10,000 flights.

Introduction of Cabin Air Filtration

Commercial aircraft have had air filters incorporated for many decades, but until the early 1990s the principal use of these filters was to protect equipment from dust and dirt. The major proportion of the cabin air was fresh air: however, as it became apparent that reducing the proportion of outside air could generate substantial fuel savings, recirculation rates of up to 50% of the cabin air was introduced. In turn this led to concerns about the possibility of the spread pathogens from infectious passengers within the cabin and high levels of cross infection throughout the cabin.

The solution to this problem was to install High Efficiency Particulate Air (HEPA) filters. Replacing the coarse filters designed to protect fans and ducting from dust with HEPA filters not only continues to keep aircraft equipment dust free, but also protects the passengers from the potential spread of microbial contamination in the recirculation air.

Most commercial aircraft now incorporate HEPA filters, which have demonstrated a minimum efficiency of 99.993% in tests with bacterial and viral challenges. Typical airborne microbial contamination experienced in aircraft can be in the range of 0.02 µm to 5 µm. To put this in perspective, a human hair is approximately 75 µm thick and pollen can span 8 to 100 µm.

How HEPA works

Aircraft HEPA filters are most commonly manufactured using glass fibre filter medium. HEPA filters remove particles in three main ways:

1. Direct Interception. This mechanism is analogous to sieving: particles such as dust, sprays and pollen that are greater than 10 µm are too large to penetrate the pores of HEPA filter medium.
2. Inertial Impaction. Particles such as some bacteria, dusts and carbon soot that are between 0.2 µm and 10 µm in size, can penetrate the surface pores of the HEPA medium but quickly impact on the surface of the glass fibres where they are captured.
3. Diffusional Interaction. Virus and other particles, such as exhaust emissions, smaller than 0.1 µm move through the air with an erratic path caused by collisions with air molecules and other particles. This behaviour is known as Brownian Motion. The smaller the particle, the more erratic the path and therefore the higher the probability the particle will impact a glass fibre and become trapped. It is this mechanism that results in the very high removal efficiency of particles that are less than 0.1 µm.

The combination of these filtration mechanisms provides the aircrew and passengers with an extremely high level of protection from the entire range of particles encountered in recirculated air systems. Every HEPA filter installed on almost every type of large commercial aircraft, demonstrates a minimum efficiency of 99.97% with 0.3 µm particles. Further testing with 0.023 µm MS2 Coliphage virus, and with bacteria between 0.3 µm and 0.6 µm demonstrated a minimum microbial removal efficiency of 99.993%.

Each of these particle removal mechanisms contribute to the filtration characteristic known as The Most Penetrating Particle Size, or MPPS. This characteristic describes the particle size that is most likely to pass through a particular filter. In the case of HEPA filters for aircraft it occurs between 0.1 and 0.2 microns.

Activated Carbon Supplement:

As their name implies, HEPA filters are designed to trap particles. They do not remove vapours and Volatile Organic Compounds (VOCs) that can be the cause of unpleasant odours in the cabin. VOCs originate from either the outside air source or from within the cabin. Sources of VOCs from outside of the cabin include exhaust fumes from the airport environment, jet fuel fumes and hydraulic fluid and engine oil decomposition products. Within the cabin, VOCs may originate from personal care products, in-flight catering, internal furnishings and from the passengers themselves. Fume events are usually characterised by high VOC concentrations, but the cabin will always experience a fluctuating VOC level from various sources.

Relative to its weight, activated carbon is among the most adsorbent materials in the world. Often processed from coal or coconut shells, it is incredibly porous, which means just 1g of the substance can provide up to a staggering 1,500 square metres of surface area. Pall Aerospace uses activated carbon manufactured using a proprietary process from polymer beads, which has enabled an adsorbent optimised for cabin air filtration and providing at least a 25% increase of surface area compared with typical coconut shell carbon materials.

The effectiveness of the activated carbon in each filter can be improved further if the carbon medium is evenly dispersed in a foam pad rather than concentrated in a corrugated flat medium. Pall's A-CAF (Advanced Cabin Air Filter), for example, places a HEPA filter on top of such a foam pad as part of an integrated unit that is installed into standard filter housings.

While activated carbon adds filtering capabilities, it is not an absolute filter in the manner that HEPA filters remove particulates, viruses and microbes. So, instead of acting as an insurmountable barrier, activated carbon is designed to adsorb enough VOCs to limit detectable odours during periods of elevated concentrations, such as fume events.

Figure 1 illustrates the effectiveness of the Pall A-CAF in reducing odours and VOCs from a cabin. With it's installation, a fume or odour present in the cabin will be reduced to non-detectable levels within 3 minutes after onset (Time 0).

Without an odour filter in place, the event can take over 10 minutes to dissipate to an acceptable level:

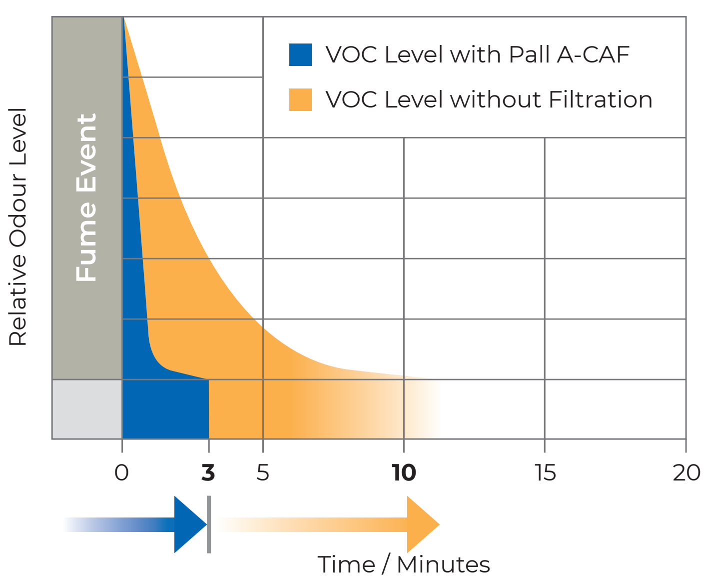


Figure 1: VOC/Odour Removal Characteristic

It should also be noted that commercial aircraft environmental control systems are designed with air filters – HEPA and activated carbon – in the cabin recirculation system only, and therefore VOCs entering the cabin from outside air sources need to pass through the cabin once before they can be removed. The volume of air in a typical passenger cabin is replenished approximately once every three minutes.

Lifecycle Costs

As smoking on aircraft was progressively outlawed through the 1990s, filter manufacturers noticed a dramatic improvement in the longevity of their products. HEPA and carbon filters no longer needed replacement every year, and some were still offering acceptable performance after 6,000 hours and longer. With improvements in materials, manufacturing techniques and the elimination of smoking, combined HEPA and carbon filters have a lifespan well in excess of estimates when they were first introduced. On-wing life is now comparable to that of the original HEPA-only filters. As a result, the recommended change interval is typically 20-24 months, or at an exchange interval similar to that of the current HEPA filter. Better service life combined with greater awareness of the impact of fume events and their impact on schedules meant more interest in VOC and odour protection from airlines. Pall introduced the first activated carbon solution in the late 1990s. Since then better service life combined with greater awareness of the impact of fume events has drawn progressively more interest in VOC and odour protection from airlines.

Regulatory Environment

There is little regulation surrounding cabin air quality. Federal Aviation Regulation (FAR) 121.219 mandates that passenger and crew compartments be "suitably ventilated"; that carbon monoxide not exceed a certain level; and that fuel fumes not be present. FAR 28.831, an aircraft certification standard, stipulates that each passenger and crew member receive 0.55lb of fresh air per minute, and that the cabin "be free from harmful or hazardous concentrations of gases or vapors". However, beyond setting limits for carbon monoxide, carbon dioxide and ozone concentrations, the regulation does not define what is harmful or hazardous.

Increased awareness of the effects of fumes events on both airline operational efficiency and the effects of passengers and crew has led to numerous studies of cabin air quality, the constituent compounds that characterise it and its possible short- and long-term effects. The airline industry, the airframe and systems manufacturers and many independent experts collaborate on research projects and producing documents to advise best practices for the management of fume events. Many standard committees such as SAE, BSI, CEN and ASHRAE have all produced guidance documents which are continuously reviewed and updated as new information becomes available.

What Could The Future Bring

It is not only the airline industry that is now more concerned with air quality: There is increasing regulation from national and international health authorities that impacts all sectors, including air transport.

The European Union Directive 2008/50/EC regulates the annual concentrations of pollutant in ambient air, including particulates, nitrogen oxides, sulphur oxides, carbon monoxide and ozone to name a few. Control of these compounds will affect how we develop new and manage current technologies. Systems will be developed to reduce pollution at its source and help improve ambient air quality and subsequently cabin air quality. This includes how aircraft are operated at the airport. For instance, many airports limit the use of the Auxiliary Power Unit (APU) whilst on the ground and also require aircraft to taxi using one engine only in an effort to reduce exhaust emissions.

A number of cities are also starting to restrict the areas accessible by diesel cars. If these regulations extend to other industries, hydrocarbon particulate levels in the workspace, including aircraft cabins could be subject to stricter control.

Thankfully, technology already exists to meet tighter control and monitoring of fumes in the aircraft cabin. Installation of HEPA and carbon filters in the main ducts coming from the bleed air source would address fume events prior to the air entering the cabin. This would ensure the aircraft could be operated and maintained to meet the tighter standards. Sensing technology would also allow more proactive maintenance on the sources of fumes before they became a problem for passengers, pilots and crew.

Rather than incremental improvement, the history of cabin air filtration has been defined by a series of short, sharp leaps. The next one - that eliminates disruptive fume events completely - might be just around the corner.

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