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# The Manufacturing Techniques of Micro-Hole Filters and Protection Against Viruses

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A commercial aircraft consists of 3-4 Million parts depending on its type. It is noteworthy that freighter conversions would have significantly fewer parts than the full passenger versions. Components and systems are made up of parts. Assemblies are made up of components. The aircraft, itself is the top assembly which consists of parts, Commercial Off-the-Shelf (COTS), loose-items, standard parts such as fasteners and consumables. The systems such as hydraulic, pneumatic, wire-harness, Environmental Control System (ECS), and others are crucial members of the aircraft. These systems have many interfaces in the cockpit, cabin, or cargo bay. For example, the passenger overhead panel is one of them that is an outlet of the ECS for conditioned airflow and wire-harness for illuminating. As shown in Figure 1 below there are some buttons on this panel which is an interface between complicated systems and passengers.

When we get deep into the ECS system, we see that this system is responsible for performing a great number of tasks, including pressurizing and ventilating the cabin, controlling the pressure, and temperature on board. Overall, it can be stated that the ECS mainly provides air to the anti-ice system and Passenger Air Conditioner (PACK) and regulates cabin temperature, pressure (T, P), and humidity. It is worth emphasizing that the ECS is a vital system not only for aircraft but also for submarines and spacecraft. The ECS basically concentrates on the inside of the aircraft, whereas the outer side environmental control is usually called the Environmental Protection System (EPS). As depicted in Figure 2, the ECS includes components consisting of filters, air pumps, humidifiers, driers, valves etc.

Generally the ECS air conditioning also includes;

- Window defogging,
- Fire protection,
- Water and sanitation,
- Fuel tank inertization,
- Cabin furniture ergonomics,
- Cabin entertainment systems,
- Lighting etc.

Another issue is pressurization control. The air inside the cabin is compressed by the air pumps. The whole aircraft is pressurized by bleed air with 250 kPa from the engine compressor, upstream of the combustion chambers. This air is supplied to the conditioning packs at approximately 180 0C through a Pre-Cooler. Cabin pressure is controlled by outflow valves to maintain the cabin pressure above 75 kPa which simulates that the aircraft flies at 7,800 feet. This level is accepted as the comfort level for passengers and crew. The pressurization control system is equipped with highly reliable pneumatic members. Any sudden change requires an emergency procedural activity.

On the other hand, the EPS is used against high temperatures, high wind and turbulence, water and ice deposition, radiation, electrical shock and biological attacks, ranging from micro-organisms to birds.

The aircraft, itself is a closed container and the cabin air conditioning should provide comfort conditions such as 22±2 0C, 90±10 kPa, 60±10 % Relative Humidity (RH). During flight and taxi, these values are directly in relation to the outside conditions such as, -60/+50 0C, 10:100 kPa, 0:100 %RH, ozone, etc. The ECS should provide ventilation, pressurization, cooling, heating, humidification, dehumidification, demisting, and disinfection. As shown in Figure 3, the conditioned air enters the cabin and cockpit from distribution manifolds via wall-floor, ceiling grills, and directional outlets in the overhead panel and goes out through the collection ducts under the seats.

For example, a Boeing 747-400 approximately has Vair=886 m3 of air. The air in the Boeing

747-400 is circulated roughly every 350 seconds. About half of this amount is exhausted from the aircraft through an outflow valve located under seats and the other half is drawn by fans through special High-Efficiency Particulate Arresting (HEPA) filters to filter microscopic particles. Most of the micro-organisms and particles do not pass through the HEPA filter. However, the aerosol particles around 0.3 µm (300 nanometers) in size cannot be completely removed by the filter because the HEPA filter limitation is about that size. As the “removal efficiency” of filters gradually decreases during operation, the filters no longer meet the requirements of the HEPA filter, and they need to be replaced. To protect the workers, the public, and the environment at reasonable costs and with acceptable waste generated, it is important to evaluate the removal efficiency of aerosols and determine the frequencies of replacement (Min-Ho Lee, 2019).  For this reason, with some maintenance intervals, the filters are changed dependent upon flight hour (FH) and flight cycle (FC) parameters. Protecting the soldiers from warfare aerosols was an essential issue for both operational headquarters and field troops. The only solution was the gas masks which was not practical for all. The US Army Chemical Corps then developed a combination of a purifier unit and a mechanical blower that is called as "collective protector". Since comparatively large airflows were required, the filter, incorporating the same cellulose-asbestos paper used in the service gas mask, was fabricated into a deeply-pleated form with spacers between the pleats to keep them apart and serve as air passages (First, 1998). It was the predecessor of the HEPA filters which are widely used at present in many places such as commercial aircraft, hospital intensive care units, operating rooms, and industrial clean rooms.HEPA filters are designed to control the particles that enter a clean area by filtration. These filters were created and developed during World War II as part of atomic bomb research for containment of radioactive aerosols.

HEPA filters function through a combination of three important aspects. First, there are one or more outer filters that work like “sieves” to stop the larger particles of dirt, dust, pollens, and other droppings from creatures, such as dander or hair. Inside these filters, there is a concertina, which is a mat of very dense fibers, that traps smaller particles. These pre-filters are designed to stop 90% of particles from the incoming air. The inner part of the filter uses three different methods to catch particles as they pass through with the moving airstream. . At high airspeeds, some particles are caught and trapped as they smash directly into the fibers, while others are caught by the fibers as the air moves past. A particle that enters into the flow field that is surrounding the fiber must follow the curved path of the streamlines if it is to pass around the fiber. When a particle possesses sufficient inertia, because of its higher momentum relative to that of the conveying gas molecules, it resists for following the curvature of the air stream and gets in contact with the fiber. The effect becomes greater as aerodynamic equivalent diameter extends and as the speed of the air approaching the fiber increases. However, when the suspended particles are very small, it is observed that they tend to follow the curved streamlines closely. In this scenario, the particles have little inertia however they are strong in Brownian motion. As it is shown in Figure 4, Brownian motion pattern is used for describing the random motion of particles suspended in a fluid that can be a liquid or a gas resulting from their collision with the fast-moving molecules in the fluid. This pattern of motion typically consists of random fluctuations in a particle`s position inside the tank fulfilled with gas or other liquids. A few examples of the countless diffusion processes that are studied in terms of Brownian motion include transport processes that are affected by larger currents, the diffusion of pollutants through the atmosphere, and the diffusion of calcium through bone tissue in living organisms. Examples also include the motion of pollen grains on still water. Movement of dust motes in a room although largely affected by air currents.

At high airspeeds, some particles are caught and trapped as they smash directly into the fibers, while others are caught by the fibers as the air moves past. At lower airspeeds, particles tend to wander about more randomly through the filter (via Brownian motion) and may stick to the fibers as they do so. Together, these three mechanisms allow HEPA filters to catch particles, which are both larger and smaller than a certain target size. There are different grades of HEPA filters, based on their ‘efficiency ratings’. One of the most commonly used HEPA filters is the H14 filter, which is designed to remove almost 99.997% of particles from the air (Sandle, 2013).

In Figure 5 illustrates that particles around 0.3 µm can be filtered by HEPA filters.

Ultra-Low Particulate Air (ULPA) is also a filter which has finer holes than HEPA. As provided in Table 1, an ULPA filter can remove from the air at least 99.999% of dust, pollen, mold, bacteria and any airborne particles with a minimum particle penetration size of 0.1 µm (100 nanometers).

There are some standards for categorizing the filters such as EN 1822, ASHRAE 52.1, etc. shown in Table 1 the classification of HEPA and ULPA is given in accordance with EN 1822:1998 standards.

It is noteworthy to mention that these filtering values reflect the number of the particles not the size of the particles.

In Figure 6 shown below, the fibers in the HEPA filters are denote as the orange bars, trapping dust and dirt particles in three ways. Some particles crash into filter fibers and are absorbed by the impact. Some are caught as they flow along in the moving airstream and when they get too close to the filter fibers they are trapped by interception. At lower airspeeds, some are trapped by diffusion. The interception occurs when randomly moving dust and air particles crash into one another and some are pushed into the filter fibers.

The biological aerosols such as fungi, bacteria, and viruses are called bio-aerosols. The bio-aerosols could cause unwanted health impacts such as infectious, toxigenic, and allergic situations. At present, in many laboratories, many researchers are focused on the bio-aerosols. By the mentioned researchers, many papers have been published regarding the prevention and treatment of respiratory infection outbreaks originated from lethal viruses such as swine-origin influenza A (H1N1), Middle East Respiratory Syndrome (MERS), severe acute respiratory syndrome coronavirus and finally novel coronavirus (2019-nCoV). It is not difficult to claim that especially the filters are the mainly focused laboratory studies (Park, Joe, Piri, An, & Hwang, 2020). Although, many studies with a wider scope are still being performed to increase the performance of the filters, the processability and producibility still have some constraints in terms of manufacturing techniques. So far HEPA filters have been manufactured with legacy technologies such as plastic injection, fiber manufacturing technologies, etc. Many of the designs made possible through additive manufacturing are "impossible or too difficult" using traditional manufacturing technologies. With legacy production, the more geometrically complex a part or component becomes the more expensive it is to manufacture, and at a particular level, it becomes impossible to manufacture. Additive Manufacturing works in the opposite way, the more geometrically complex the part is, the more convenient it is for additive manufacturing (Olaf Diegel, 2019). Additive manufacturing has some limitations such as hole diameter. In some cases, the hole diameter can be as small as

80 µm (Solakoğlu, 2016). The Ti6Al4V is the most common alloy used in the aviation and medical industry (Shunyu Liu, 2018). As a lightweight and yet strong alloy, Ti6Al4V saves weight and is hence extremely suitable for jet engines, gas turbines, and many airframe components. This alloy`s biocompatibility also attracts many experts in the medical field for prosthesis applications (Cen Chen, 2019). It is possible to produce membranes that have 0.1 µm or smaller holes thanks to the Saracyakupoglu Manufacturing Technique ©which depends on the philosophy of overlapping the additively manufactured smallest holes. This technique uses an approach of layer-by-layer manufacturing with calculated non-axial holes. Because of the complexity of this system, it would be impossible to handle these small-sized holes with the usage of legacy manufacturing technologies. As future work, it will be possible to manufacture anti-viral filters with the help of novel technologies. For sure, those filters will have a deep capability of banning the angstrom-sized particles, bacteria, and viruses