Nonwoven Fabric Uses and Prospects in Human Space Flight

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General:

The US space shuttle fleet has been flying for over 20 years. Although the shuttle operates in a unique exterior environment, the interior is intentionally made to be as close to the "normal" human environment as possible. The filtration needs of the shuttle are not substantially different from those of a large mobile home or camper, supporting the needs of a family of seven for up to two weeks. Therefore, most of the materials that are used to filter the air, water, and other fluids on the Shuttle are similar or identical to those employed in other sectors of the transportation industry.

The only significantly different feature of the space environment is the unique "three phase" nature of the air (with suspended liquids and solids ranging in size from aerosol droplets to binoculars). Such suspended debris contributes to the air filtration and waste management problem. Careful flow management and cleanliness practices help to mitigate the effect of debris, and liquid spills are rare, seldom making it to the filters. (It has been common on all spacecraft to look first for lost items on the air intake filters, since all objects ultimately migrate there in the flow. Liquids tend to seep rather than "spill", and so tend to aggregate in a ball near the source.)

In addition to the basic fluids of the interior environment (water and water wastes, air, & its constituent supply gasses) the shuttle also has unfiltered fluid systems for Freon, hydrogen, helium, ammonia, hydraulic fluid, and propellants. Only the propellant system, owing to its uncommon chemistry, represents a fluid system that is not typical of household or medical applications. Careful external filtration prior to flight assures the cleanliness in these closed systems.

Material Selection:

NASA is primarily interested in the reliability and proven track record of the materials and components that it chooses. Weight reduction is a secondary objective, especially for small items whose weight is negligible compared to the 110-ton vehicle. The commercial market is a powerful engine for Darwinian selection of the most appropriate materials for common problems. The quality control associated with large production usually dominates the selection rationale, compared to the potential weight benefit of a "higher-tech" solution for any small set of components. NASA's fundamental design practice is to include fault tolerant, redundant systems for any life-critical function, so increased reliability of any single component (such as a filter) is not usually a driver in modifications to existing designs, unless they are presently prone to failure or are excessively heavy. Terrestrial fluid filtering systems are very highly reliable and lightweight, and are therefore not typically candidates for space-specific improvements.

Therefore, common commercial products are employed wherever possible, unless there is a significant program-wide benefit to be gained from investment in new materials or techniques. The *packaging* of the filters (and other components) is required to withstand extremes of shock and acceleration, and unique part numbers have been required to create shuttle components that fit its ductwork, but otherwise the materials used in such routine functions are common with their earth-based equivalents.

By contrast, even a few percent weight savings in larger (or multiple) structures can be of huge benefit. NASA has invested in numerous upgrades to the Shuttle including composite secondary structures for the interior, ultra lightweight seats, bag stowage systems (versus hard structure), and even new alloys for the 38 ton external tank. The advantages of nonwoven fabrics for light weight, strength, and formability in the general transportation industry are particularly useful in the structures and surfaces of the space flight environment.

Features that might prevent a terrestrial material from being selected for spaceflight are related to flammability or toxicity, due to the crew's need to survive (even after a part's failure) within a closed environment. Materials are carefully screened for their outgassing (the "new car smell" of unreacted volatile constituents, typical of most plastics) and offgassing (volatile products arising from age, heat, or other reaction with the environment). This is true both inside and outside the spacecraft, since many external coatings have unique surface properties (to survive the extremes of space) that do not abide contamination. Recently, significant work has been conducted to explore the colonies of microbial life that grow in space, on everything from fabric to titanium. As a result, numerous porous and woven materials have been restricted, since the pocketed geometry of these materials makes disinfection and total cleaning difficult.

The Onboard Environment:

The shuttle operates with a "semi closed" environment. Gasses and liquids are vented overboard as needed to maintain desired pressures, to evacuate the airlock, or to purge unwanted wastes. Cabin air is replaced from gaseous nitrogen and cryogenic oxygen supplies. The liquid oxygen is heated to gaseous phase by passing it through coils which surround pipes of the main spacecraft temperature control loops. This has the added benefit of removing waste heat from the thermal loops.

Water is a natural byproduct of the hydrogen-oxygen fuel cells that produce the shuttle's power. A large surplus of water is produced as a result of meeting the power demands of each mission. Therefore, most of the water is transferred to the Space Station, vented overboard, or both. (Note that the Space Station derives benefit from the regular influx of water, since total recycling of its own water would deprive its payloads of needed electrical power). Condensate from the temperature & humidity control system is also vented as needed, and to a lesser extent (on the shuttle only), urine and wet trash wastes are vented. Space Station urine and wet trash is treated and stored for de-orbit aboard Progress spacecraft, which are destroyed upon atmospheric re-entry.

On all shuttles, Lithium Hydroxide (LiOH) canisters remove carbon dioxide and other trace contaminants. One shuttle shuttle, (Columbia) has in the past been outfitted with a Regenerable Carbon Dioxide Removal System (RCRS), which consists of beds of solid amine resin. These redundant beds are alternately placed in the airflow for CO2 removal, and then vented to vacuum to regenerate them. This system is heavy, and is complicated compared to LiOH. However, the system is important for long duration missions (up to 17 days) where necessary LiOH supplies would be prohibitively bulky. When needed, the system can be reinstalled at some cost. Different molecular sieve systems remove CO2 and other trace contaminants on the Russian and American segments of the Space Station. Both ISS systems use layers of silica gel and packed beds of differing Zeolites in their sieves.

Filtration in the Major Fluid Loops

Air:

The shuttle controls the environment for the crew cabin and for any pressurized volumes in its payload bay. A common plenum of air supports all compartments, and forced exchange via supply ducts assures complete mixing. (This is a particular problem in the space environment, where natural convection is nonexistent. Without thorough forced convection, dangerous pockets of oxygen or of CO2 could build up with catastrophic effects). On all spacecraft, air travels through open hatchways for the return leg. While the shuttle is docked to the Space Station, air is still forced in a steady exchange between the two spacecraft, because each vehicle supports only its share of the total life support needs of the merged crews.

Air is the primary cooling medium for the avionics in the shuttle and its habitable payload bay volumes. Separate air loops control the temperature and humidity in the avionics region and the crew compartment. Pressurized payloads have separate avionics air cooling loops that exchange heat with dedicated heat exchangers in the payload bay. In avionics cooling, lesser heat loads are exposed to the general flow of the air, and several high-heat systems have their own internal fans. Each such fan must have its own filter, since in the weightless environment it is possible (and routine) for floating debris to be swept into the electronics by the airflow. Small metal shavings from improperly cleaned hardware have been a troublesome source of notebook computer malfunctions.

The orbiter's cabin air filters are located on the duct intakes of the cabin and avionics bay circulation systems, and on the main air-cooled critical system: the Inertial Measurement Units (IMU's). The majority of air filters are a 50 x 250 mesh made of 304 stainless steel wire. The 50 x 250 mesh cloth has a 40-micron nominal and a 70-micron absolute debris capture rating. The material is manufactured by the Crosswire Cloth Manufacturing Company. In addition, the Orbiter Cabin Air Cleaner (OCAC) is located in the starboard hatchway that connects the mid deck with the flight deck. The OCAC has a filter rating of 38.5 microns. All debris filters are vacuumed in place every time the shuttle lands, and are removed for ultrasonic cleaning at the Palmdale California plant when the orbiters return there for overhaul every few years. While the shuttle is in orbit, the crew cleans all accessible filters every three days (blue Velcro® "fuzz" is the dominant debris).

As on earth, air conditioning equipment in orbit dehumidifies air, with a byproduct of liquid water. While the shuttle uses centrifugal motion to separate the condensate from the chilled air, the Space Station uses a layered filter of alternating nonwoven hydrophobic and hydrophilic media to wick the two phases apart.

Water:

A redundant pair of closed water loops provides the heat sink for the temperature & humidity control of the air. In addition, supply water is generated from the fuel cells, and diverted into one of four tanks (A, B, C, D) which are used as the supplies to redundant flash evaporator (cooling) systems during ascent and entry. Tank "A" additionally serves as the potable water tank. In the line to this tank only, silver-palladium tubes are used to remove excess hydrogen gas from the water before a microbial filter assures potability, and assures that there is no backflow of biological material upstream. Note that the water is hydrogen-rich because maximum efficiency of the fuel cell operation results in excess hydrogen in the water output. This has the undesired effect of producing flatulence in the crew, if not removed.

In-line filters assure the smooth operation of the closed cooling loops against possible pump impeller debris. However, the water supply line has no filters, with the exception of the one mentioned microbial filter. This system is pressure driven by the gaseous Nitrogen, and thus has no moving parts that could necessitate a filter..

Wastes:

Waste Management is the biggest challenge to the onboard filters. Up to seven crew use a common toilet for missions exceeding two weeks. Several techniques have been used for human waste management: The toilet operates on the principle of forced air convection, with a combination of centrifugal motion and filtration to separate solids, liquids, and odorous gasses. The current technology employs airflow to move the wastes, and has separate systems for urine and for fecal matter. There is centrifugal separation of urine from its dedicated air transport, and paper filters to capture solid wastes in an air stream, much like a vacuum cleaner bag. Once full, the waste filter is compacted and stacked in a sealed canister. Again, waste fluids are vented from the shuttle, and are treated and stored for de-orbit aboard the Space Station. Future interplanetary missions will ultimately require that such wastes be recycled.

Summary:

In summary, the US Space Shuttle is a miraculous vehicle built of largely familiar technologies. Where absolutely necessary, materials science has been challenged to create special components, including the astounding thermal protection system and special coatings. However, in the fields of human life support and of basic fluids engineering, NASA's selection criteria for filtration products are common with those of the more traditional segments of the transportation industry. The market for these products will follow mankind as we push forward in our permanent occupation of the cosmos.