Development of the Universal Waste Management System

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The Universal Waste Management System (UWMS) is the next-generation space toilet destined for the International Space Station (ISS) and the Orion Multi-purpose crew vehicle. It is a configurable design that is largely similar for both vehicles, is not limited to a fixed mission duration, and can be extended to future space exploration missions. Working with the Advanced Exploration Systems program at the National Aeronautics and Space Administration (NASA) headquarters, the Orion Program, and the ISS Program, Collins Aerospace has designed the UWMS to be lighter, smaller, more efficient, more easily maintained, and with a greater emphasis on human interfaces than previous space toilets. The first two UWMS units are scheduled for installation on the Orion vehicle and launch to the ISS in 2020. This paper will examine the advancements in space waste management that are realized in the UWMS design.

Nomenclature

DFS	=	Dual Fan Separator
FOD	=	Flight Operations Directorate
ISS	=	International Space Station
NASA	=	National Aeronautics and Space Administration
URA	=	Urine Receptacle Assembly
UWMS	=	Universal Waste Management System
WCS	=	Waste Collector Subsystem

I. Introduction

Since the beginning of human presence in space, there has been a need for capturing and/or managing biological waste generated by the crew in microgravity. Typical waste products for the purposes of this paper include: urine, feces, menses, and vomit/emesis. Each type of waste, historically and largely still today, has its own collection methods and systems. The types of systems used have varied over time to achieve certain mission or program specific goals. This paper examines the latest iteration of the microgravity toilet developed and the improvements it is meant to achieve.

II. Early Waste Collection Systems

Early missions like Mercury were fully comprised of crew members within a pressurized garment. During these missions all waste management had to be accomplished from within the pressurized garment which drove its own unique application and solutions that won't be discussed in this paper. Later, in addition to the in-suit collection system, Gemini utilized the first cabin microgravity collection systems. The first unit included an inflatable roll on male cuff and an extendable bellows to generate negative pressure (i.e. suction). While the system was small and simple, it proved difficult to use and typically required assistance to operate. In later Gemini missions the bellows was replaced with an 800 mL collection bag and a check valve was added to the inflatable cuff to stop back flow. During some extended Gemini missions feces collection became necessary via a flexible plastic bag where the opening had a sticky interface used to seal the bag to the crew's body during use. Separate vomit/emesis containers were also provided for the crew.[1] These systems remained relatively unchanged until Apollo 12 when the Urine Receptacle Assembly (URA) became the primary urine system. The URA consisted of a cylindrical can in which the crew could direct their urine stream into the can and the urine could simultaneously be pulled/transported through a honeycomb

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filter, then a hose, and finally vented overboard to space vacuum.[2,3] Female specific collection for urine and menses were not addressed as there were not female American astronauts until the Space Shuttle missions.

III. Modern Waste Collection Systems

Modern waste collection systems on spacecraft (1980s to current) took far more the form of a toilet as one might expect to see on earth's surface with chair like interfaces in which crew members could float over in a squatting position to release and collect their waste. However instead of gravity to aid in collection airflow is used. These systems offer quicker, easier collection as well as the capability of simple simultaneous urination and defecation collection. The first primary example was a prototype used on Skylab.[4] A few years later a similar system would be implemented and used for decades (1981-2011) by the Space Shuttle program and was known as the Shuttle Waste Collector Subsystem (WCS). The Shuttle WCS is shown in Figure 1. The latest example is a Russian built toilet shown in Figure 2 which is currently in use aboard the International Space Station (ISS) today.[4,8]

Figure 1. Shuttle WCS (NASA Photo Archives)[4,8]

Figure 2. ISS Toilet (NASA Photo Archives)[4,8]

All the modern waste collection systems use independent interfaces and air paths to collect both urine and feces simultaneously but separately. In the commode interface, feces is typically directed into air permeable bags, then sealed and stored in containers.[4,8] In the case of the ISS, the filled containers are sent with other trash to be burned up in atmospheric reentry. Other missions plan to store the filled containers indefinitely. Additionally in the urine interface, urine is directed into a spinning separator in which the liquid is separated from the air flow and sent to intermediate storage vessels.[4,8] The use of air flow in this application allows urine capture for both male and female crew members without intimate or gender specific interfaces. The ISS recycles a large portion of the urine collected and turns it into drinking water. Other vehicles have opted to dump the urine overboard similar to Apollo and Shuttle missions. Both air flow paths are then passed through a carbon based filter to entrap odors and trace contaminants before returning to the cabin.[4,8] The ISS has special filters added to the urine side collection to capture menses as needed prior to the liquid separator.[4,8] Aside from the basic functionality provided above, the modern waste collections systems vary greatly in the following ways: human interfaces, size, weight, level of redundancy, efficiency, and maintainability. Previous ICES papers have done a thorough comparison of modern waste collection systems (ref. 4).

IV. Goal of the Universal Waste Management System

While humans have maintained a constant presence in space aboard the ISS for almost the past 20 years, little has changed for the ISS waste management system. A major part of NASA's long term goals, in conjunction with other international space partners, is to continuously innovate and improve technology, increase the amount of science and knowledge, improve crew comfort, and increase the accessibility of space. One such platform of improvement in recent years is the new toilet known as the Universal Waste Management System or UWMS.[4] The UWMS development was a partnership of the Advanced Exploration Systems program at NASA headquarters, the Orion Program, the ISS Program, and Collins Aerospace. Some of the primary objectives of the new toilet were to be lighter, smaller, more efficient, more easily maintained, and provide a greater emphasis on human interfaces than previous microgravity toilets. Additionally, the toilet could be moderately configurable in order to be used across multiple vehicles or platforms thereby reducing the need for future development programs like deep space missions.

V. Development of the Universal Waste Management System

Preliminary work on the packaging of the UWMS goes back to the mid/late 2000s[8]. However, the official UWMS program did not begin until November 2015 with the initiation of the UWMS Program contract[7]. In order to significantly reduce size and weight for programs like the multi-purpose crew vehicle Orion, the toilet is largely zero-fault-tolerant to operation. This change would provide large reductions in both envelope and mass as other systems similar to the Shuttle WCS had fully redundant motors, fans, and urine separators. Fitting something similar in size to the Shuttle WCS or ISS toilet into the Orion hygiene bay was just not practical from a physical space or mass standpoint.

The UWMS uses airflow from the Dual Fan Separator to entrain both feces and urine. Separate air flow paths collect feces and urine.

- Feces, vomit, and menses products are collected by an air-permeable Fecal Bag while the air passes through on its way to the Dual Fan Separator. The Fecal Bags are single-use items. After each use, the Fecal Bag is sealed and disposed in the Fecal Canister. The Fecal Canister is changed out when full.
- The UWMS collects urine via a funnel/hose arrangement using airflow from the Dual Fan Separator to aid in directing the urine flow into the separator. The Dual Fan Separator separates air from the urine and distributes the treated urine to downstream systems.
- The flow of pretreated urine out of the UWMS is controlled via pressure sensors, a solenoid valve, and the Controller. The pressure generated by the Dual Fan Separator must be above the threshold pressure before urine is pumped out of the UWMS.
- Power conditioning, control, failure detection & notification, and data processing are performed by a single Controller. There is a RS-422 serial interface which transmits UWMS health and status data.

The fluid and component schematic for the UWMS (in the configuration to be used on ISS) is shown in Figure 3.

Further changes were targeted at increases in efficiency. For example, power is closely managed on space vehicles and the UWMS would require new limits on both peak and average power draw during operation. In addition bounds were placed on gas entrainment of the urine leaving the separator, as well as the overall weight of daily consumable items used by the crew. Two of the largest focuses of improvements were maintainability and human interfaces.

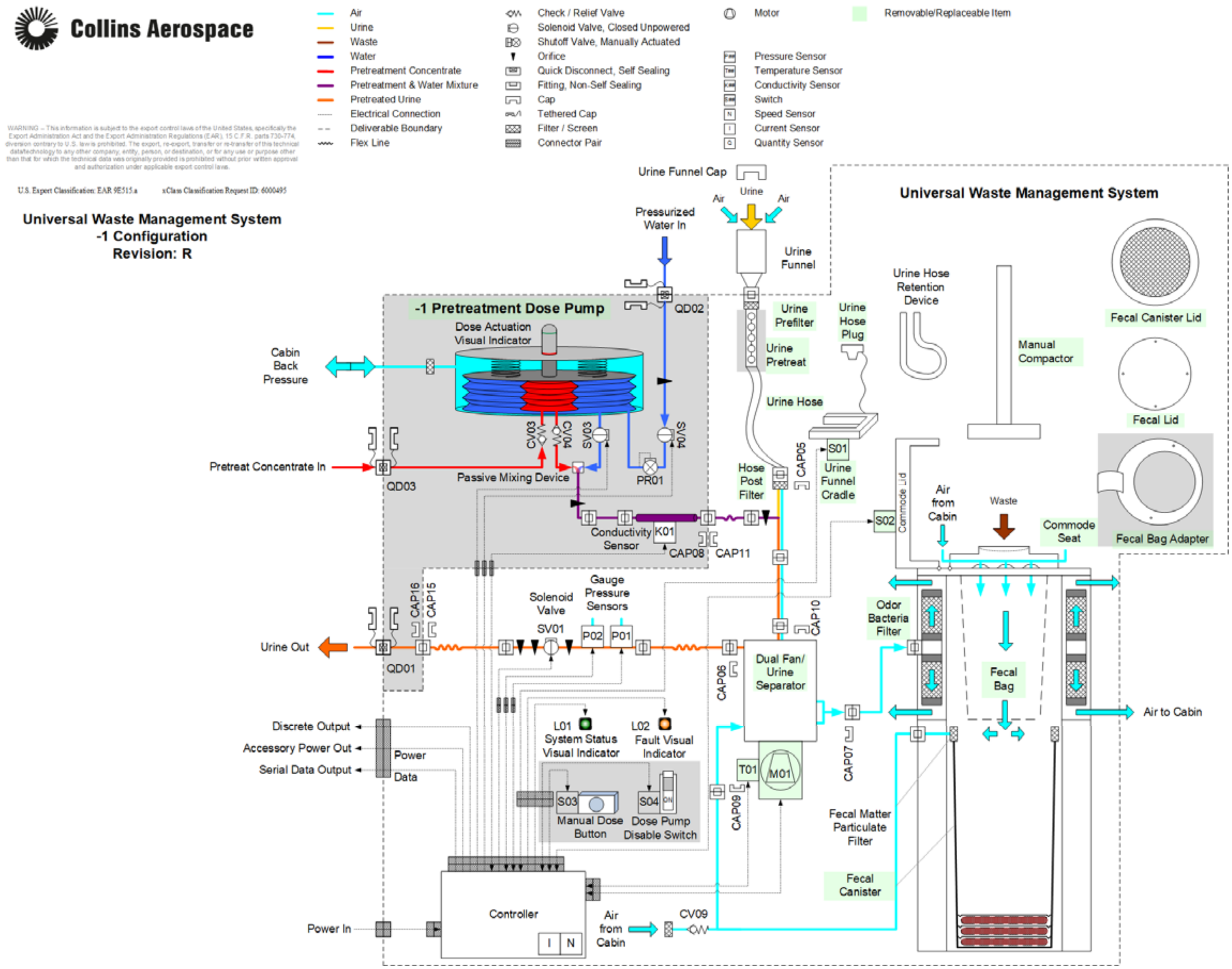

Figure 3. ISS UWMS Fluid Schematic

A. Size and Weight

The as-built UWMS for both ISS and Orion weigh less than 115 lbs. This does not include ancillary hardware or vehicle integration hardware like the toilet power box, data recorder, foot restraints, ISS pretreat dosing assembly, urine bellows, etc. Contrast that with Shuttle WCS which came in at 165 lbs shows a significant reduction in mass[4]. However it should be noted that the WCS did include its own foot restraints and some additional ancillary hardware. In addition to the notable change in mass, the UWMS takes up a volume of less than 5 cubic feet. Shuttle WCS took up more than two times that space at 12 cubic feet[4]. Alternately, while the ISS toilet looks relatively small in crew photos, in reality it takes up a large amount of space in the racks behind the wall of the commode coming in around 26 cubic feet of space[4]. By contrast, the UWMS is fully contained on the commode structure itself and does not require racks or additional space outside of the commode envelope which is similar in size to a 13 gallon trash bin. Figure 4 shows the Orion configuration UWMS model within the approximate Shuttle WCS volume (depicted as a box with

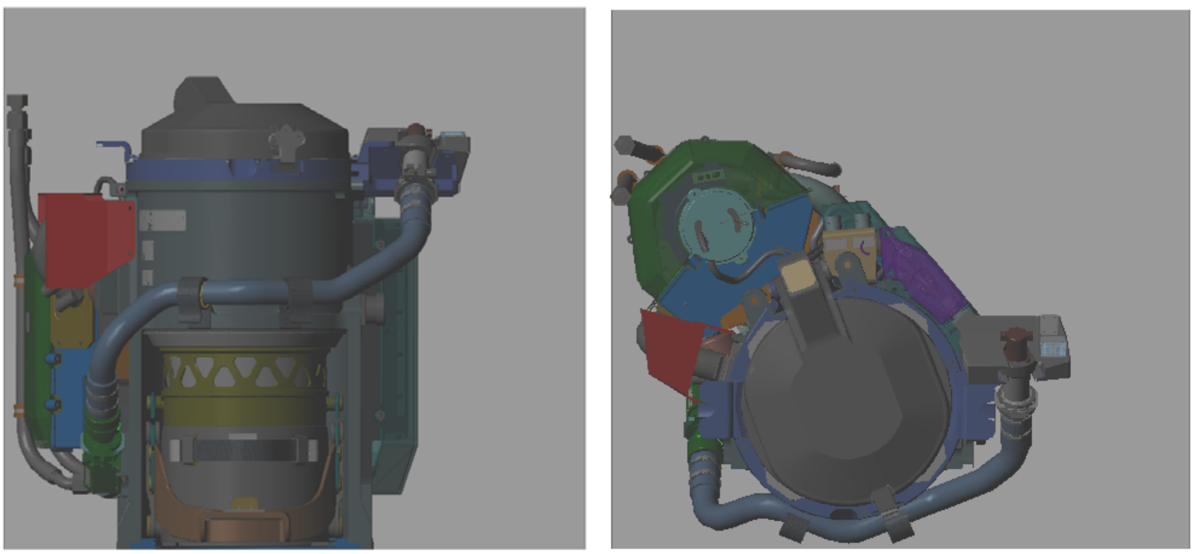

Figure 4. Orion UWMS Model as compared to Shuttle WCS volume

dimensions 27x27x29 inches).

Consumable items are used and replaced regularly with toilet operation which means either storing the supply for an entire mission or continually launching resupply missions. Both cases mean mass and space. Analysis of the UWMS consumables (which includes: Fecal bags, Fecal compaction Plates, Fecal Canisters, Fecal Canister Lids, Urine Pretreatment, Urine Filters, and Menses Filters) estimates a usage rate of just under 0.5 lbm of consumable items per person per day of operation for an indefinite mission duration.

B. Efficiency and Performance

An early design constraint was placed on power consumption in order to accommodate usage on exploration vehicles. Significant effort was thus spent reducing frictional losses in rotating equipment and in improving efficiency of the fans within the Dual Fan Separator. These efforts were successful in achieving the power consumption targets of 274 watts for steady-state operation and 380 watts for peak power. Ground testing has confirmed that the UWMS steady-state power consumption during operation is less than 270 watts in worst-case conditions and short duration transients (6 seconds or less) are limited to 305 watts, while power consumption in standby mode between uses is less than 10 watts. The profile of power consumption during a representative use is shown in Figure 5.

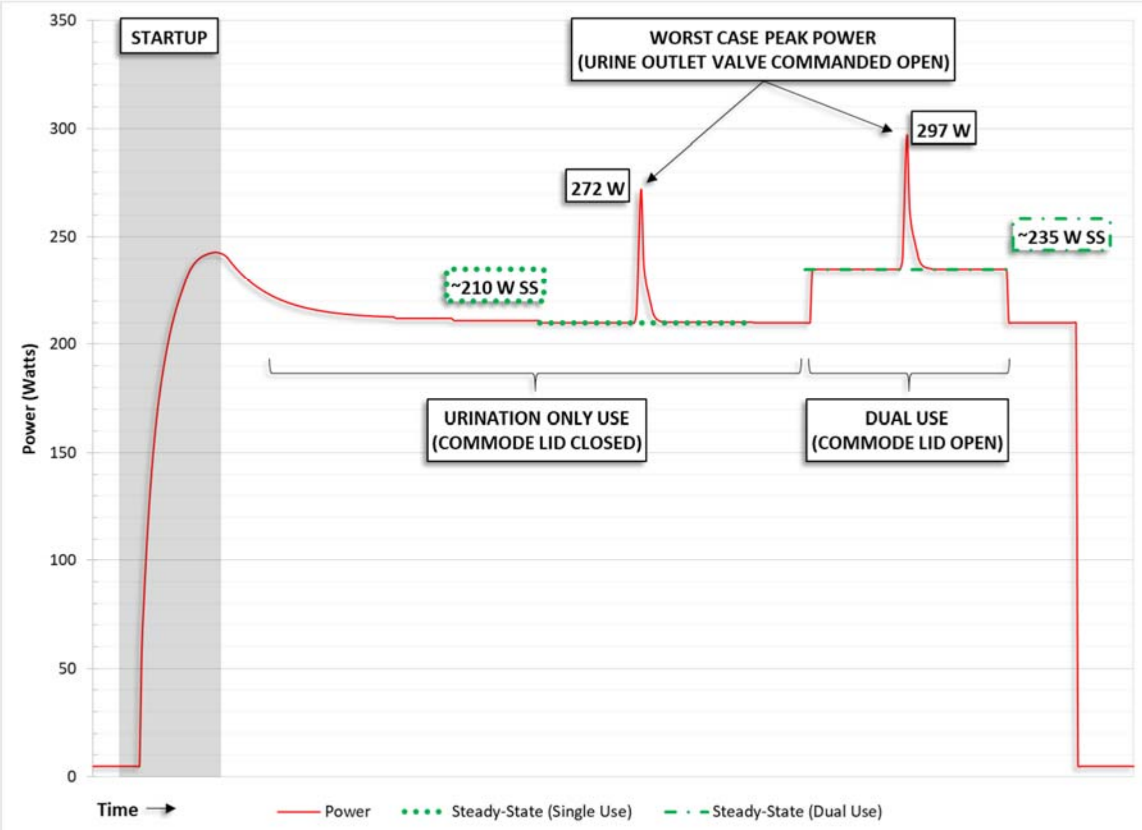

Figure 5. UWMS Peak and Steady State Power

Moreover, with regards to separation capability, the Shuttle WCS only placed a 10% air entrainment requirement on the urine separator.[5] The UWMS requirement is less than 2% average air entrainment, and flight acceptance testing for both ISS and Orion configurations in a 1g environment has verified the actual air entrainment is less than 0.5%. Testing was a cumulative average of various micturition profiles and then summed based on 6 micturitions per crew per day assuming a standard variance of 1 small profile, 4 medium profiles, and 1 large profile. The current ISS toilet air entrainment is unknown; however it is also believed to be less than 2% in order for the Urine Processing Assembly on ISS to properly function.

Another performance improvement targeted at crew comfort was noise reduction. Moving air by fans creates pressure waves. These pressure waves reverberate in small enclosed spaces and can become uncomfortable if crew members are exposed to loud enough noises for extended periods of time. A notable drop in total noise has been a continual improvement comment of astronauts for all modern toilets. The target requirement of the UWMS was to be under 68 dB when A-weighted for an operational time which last up to 1 hour. The UWMS acoustic verification testing at NASA showed the flight ISS configuration recorded an A-weighted equivalent noise of under 73 dB while the flight Orion configuration came in higher at just under 76 dB. In comparison, the Shuttle WCS requirements were split by octave bands. However, the A-weighted log sum of the octave bands was 74 dB.[5] Significant improvements in this area were not realized by the new design and are in a similar historical range.

C. Maintainability

From the start of the program the UWMS was desired to be easily maintainable. The concern stemmed from issues and regular maintenance associated with the current toilet used on ISS. For that reason some major subsystems of the UWMS were designed to be replaceable in microgravity. In addition to the regularly replaced consumable items, some of these replaceable components/subsystems include:

- The Flexible Urine Hose
- The Odor Bacteria Filter
- The Dual Fan Separator
- The Dosing Assembly (ISS specific)
- Both Pressure Sensors
- Urine Outlet Solenoid Valve
- The Controller
- The Autostart Cradle
- The Toilet Seats
- The Fecal Bag Adapter Kit

To show the magnitude of possible maintenance Figure 6 highlights the schematic items that are replaceable or considered a consumable. Being able to replace components or subsystems means in the event of an issue or failure, replacement and/or modifications can be made and implemented in a quicker time period than building a new toilet. It also means fewer parts, reduced testing, reduced flight mass and volume, and reduced cost. The UWMS maintenance plan includes scheduled replacement times for various components that are life limited like the consumables as well as detailed removal/installation instructions for swapping out all the replaceable items listed.

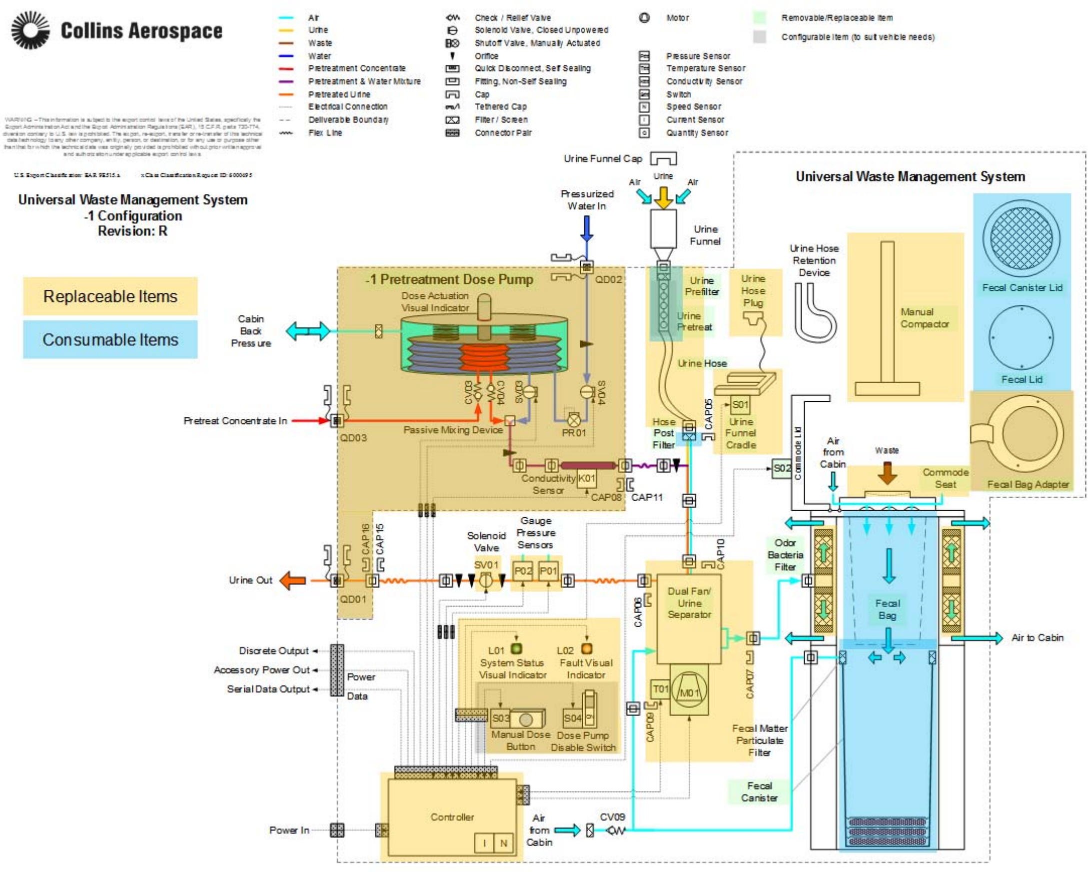

Figure 6. Replaceable and Consumable Components of the UWMS

D. Crew Interfaces

Another major impact of UWMS development was the focus on crew interfaces. Prior to the start of the official UWMS Program in late 2015, the Engineering Directorate at NASA's Johnson Space Center had already conducted extensive crew evaluations on the commode seat and the urine funnel. The conclusions of those studies informed the UWMS requirements and preliminary designs. The toilet seat has two different configurations based on this crew feedback, and NASA provided the design files for the seats to be used in the UWMS. NASA is providing the funnels as Government Furnished Equipment for both the ISS and Orion missions.

While these items are excluded from the replaceable items listed, they are interchangeable and allow crew to choose their interfaces to the toilet. The purpose is a continued focus on crew comfort and preference. Each crew member is given their own funnel for purposes of cleanliness and the Urine funnels can be interchanged by crew in a matter of seconds. At the time of this writing, the general shape is essentially finalized; however various options exist to provide slightly different air flow paths. It is not known whether multiple types of funnels will be launched for crew assessment. Two seat options also exist (shown in Figure 7), one taller with a larger opening, and one shorter with a smaller opening. Both seats will be launched, and the seats are also interchangeable in a matter of moments.

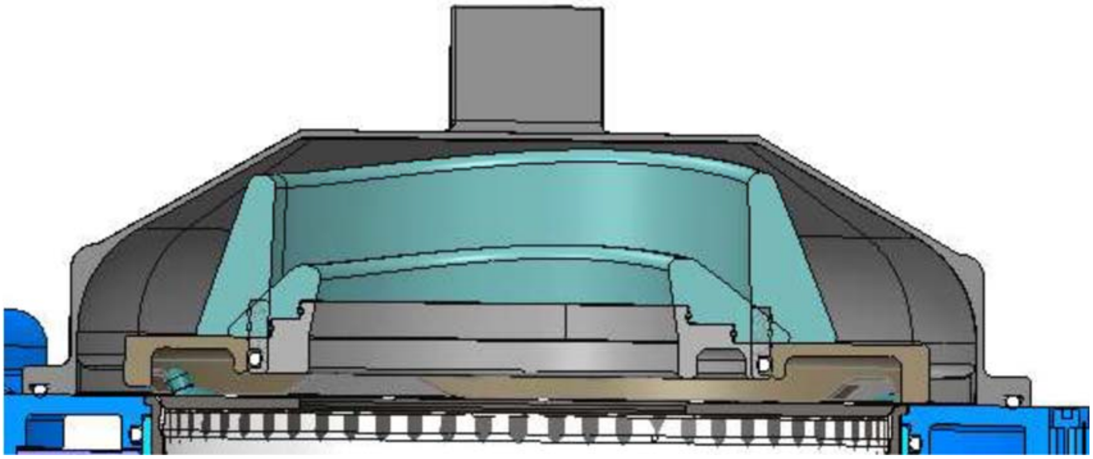

Figure 7. UWMS with both seat configurations overlaid

After preliminary design of the toilet, prototypes of various aspects of the design were created and delivered to NASA for human interface assessment by a group of astronauts, the Crew Office, and the Flight Operations Directorate (FOD). From the assessment in the summer of 2016, a comprehensive list of comments were documented and delivered to Collins Aerospace. Collins made updates to the UWMS design based on this feedback:

- Improved the replaceability of the fecal matter filter
- Redesigned the method of compacting fecal deposits for volume efficiency
- Changed status and fault indications to provide clearer indication of system status
- Tapered the fecal canisters, improving launch and storage packaging efficiency (Figure 8)
- Optimized startup time to reduce time crew must wait until UWMS is ready for use

The Crew and Thermal Systems Division at NASA's Johnson Space Center has designed and provided additional equipment to make the UWMS a complete toilet system. This equipment includes functional hardware such as a power box to condition the incoming power supply, a tank of urine pretreatment, a data recorder, and interconnecting hoses & cables; it also includes crew provisions for usability and privacy such as stall walls and doors, mounting hardware, and foot restraints that can be configured by the crew to provide optimal restraint and lower-body positioning.

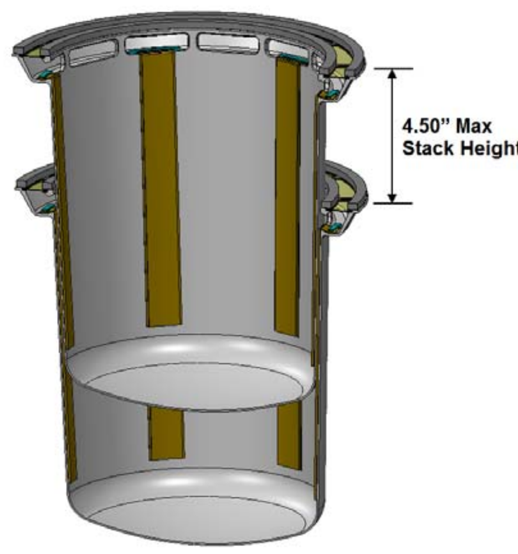

Figure 8. Fecal Canister stackability after tapering design

E. Configurability

Details of future missions and vehicles may not be known, but the UWMS includes several features which allow vehicle or mission specific configuration based on some key controls. One control is the method of urine pretreatment. There are multiple methods of managing biological growth of urine or maintaining solids from breaking down and precipitating out of solution should it be required. The two configurations of the UWMS allow use of either a solid pretreat being dissolved during each urination event or direct injection of a liquid pretreat at predetermined times of use. At this phase the proposed deep space solution used by Orion is the solid pretreat as it does not require additional liquid injection hardware which is not part of the base UWMS. Another control is the vehicle urine output interface, specifically the connection type and system flow and pressure requirements. Vehicle connection locations and type are easily changed as required, but the UWMS also includes selectable or customizable orifices in the urine flow path to regulate flow and pressure to meet any requirements for vehicle specific urine collection systems.

VI. Conclusion

The UWMS has targeted significant strides in advancing waste management systems for future missions either in low earth orbit or deep space. The UWMS is the smallest and lightest microgravity toilet that generates its own airflow and provides simultaneous collection assistance. It also requires less power to perform those tasks than previous toilets. The user interfaces have been studied, designed, and reviewed to be simple to understand, safe, and are easy to operate. The physical interfaces have been designed in conjunction with the NASA crew office to be comfortable and ergonomic for 95th percentile males and females. The UWMS as a system also meets new maintainability goals by providing replaceability of various sensors, subsystems, and/or individual components. All combined, these improvements could potentially prove highly beneficial to many future space programs by lowering waste management budgets, shortening vehicle specific development schedules, decreasing launch mass/volume, improving crew comfort and happiness, as well as reducing failures and time to resolution. The Orion configuration (Figure 9) and ISS configuration (Figure 10) of the UWMS were delivered to NASA in December 2019 and June 2020.

Figure 9. Orion configuration of the UWMS (JSC Imagery Online)

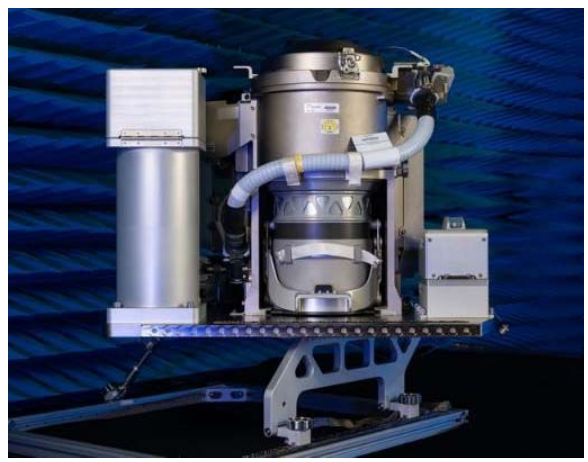

Figure 10. ISS configuration of the UWMS (JSC Imagery Online)

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