NASA Orion Exploration Toilet on Artemis-II

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The Orion unit of the Universal Waste Management System (UWMS) was delivered to Kennedy Space Center in December 2019 and installed in the Artemis-2 vehicle in 2021. This paper discusses the details of the design and how they are tailored to the Orion architecture and mission. Changes and updates made based on limited use of the sister unit on the International Space Station (ISS) are provided. Consumables and mass decisions based on the requirements, both internal to the project and those provided by the program and other stakeholders stakeholder are detailed. Updates to the hardware components and vehicle installation for ease of installation, noise reduction, damage suffered after installation, and crew feedback are discussed. This includes use of adapter plates, an acoustic cover, replacement of the urine hose, an updated seat and fecal bag design, and design and installation of an odor bacteria filter particulate barrier (OBFPB). Configurations to launch the new seat stowed and install the Odor Bacteria Filter (OBF) and OBFPB as close to launch as possible are discussed. Finally, data from the on-orbit performance and crew feedback including fecal canister capacity information is included. Implications for future Artemis missions complete the paper.

Acronyms and Nomenclature

ACY = Russian Waste Collection System
COTS = Commercial Off The Shelf
CCU = Collapsible Contingency Urinal
DAN = Domain Adapter Node
DFS = Dual Fan Separator
EMI = Electromagnetic Interference
HFC = Hard-sided Fecal Canister
ISS = International Space Station
JSC = Johnson Space Center
MER = Mission Evaluation Room
MCO = Mars Campaign Office
NASA = National Aeronautics and Space Administration
OBF = Odor Bacteria Filter
OBFPB = Odor Bacteria Filter Particulate Barrier
RTV = Room-Temperature Vulcanizing silicone
TAC = Toilet Acoustic Cover
UWMS = Universal Waste Management System
WHC = Waste and Hygiene Compartment
WMS = Waste Management System

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I. Introduction

THE Universal Waste Management System (UWMS), operational nomenclature 'Toilet', project delivered two units in preparation for exploration missions and were designed by Collins Aerospace. [1] One unit is flying on Orion's Artemis-2 mission (Figure 1) and a second unit (Figure 2) performed a limited checkout on the International Space Station (ISS) to demonstrate the functionality of the system which included the Dual Fan Separator (DFS). [2] The two units are functionally very similar but have some key differences. That is, they are like sisters, not twins. Differences in the configurations are seen from designs that are driven by distinctly different interfaces between the two vehicles and the methodology of treating the urine for disposal or recycling; changes made for optimization for mass and volume of consumables; and updates made based on crew feedback and functional performance from the ISS demonstration.



Figure 1. Orion UWMS installed in Artemis-II vehicle.

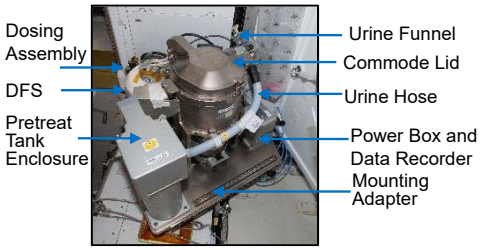


Figure 2. ISS UWMS with Toilet Integration Hardware in ISS Node 3.

II. Design Configurations

A. Vehicle Interfaces

Although there are certainly similar constraints for mass and volume for ISS and Orion, it is obvious that Orion's vehicle is much smaller than ISS and even the available space for the installation of the Toilet Hardware is similarly constrained. On ISS, the Toilet is installed in Node 3, adjacent to the currently in-use Russian designed Waste and Hygiene Compartment's (WHC) ACY. Orion's Toilet is in a Hygiene Bay as well but it is a smaller volume than the Toilet Stall on ISS and much less accessible for entry. That said, the essential "footprint" of both UWMS units is the same excluding the Toilet Integration Hardware needed on ISS. There are eight fasteners at the base for connection to the vehicle. A Mounting Adapter is used on ISS to connect to the Seat Track in Node 3. Mounting Adapter plates were designed for connection to the Orion vehicle backbone. This was needed because there was not sufficient clearance to access the fasteners (protected with windowed openings) with the torque wrench needed for the installation. The Adapter Plate assembly seen in Figure 3 is comprised of two plates; one attaches to the vehicle and

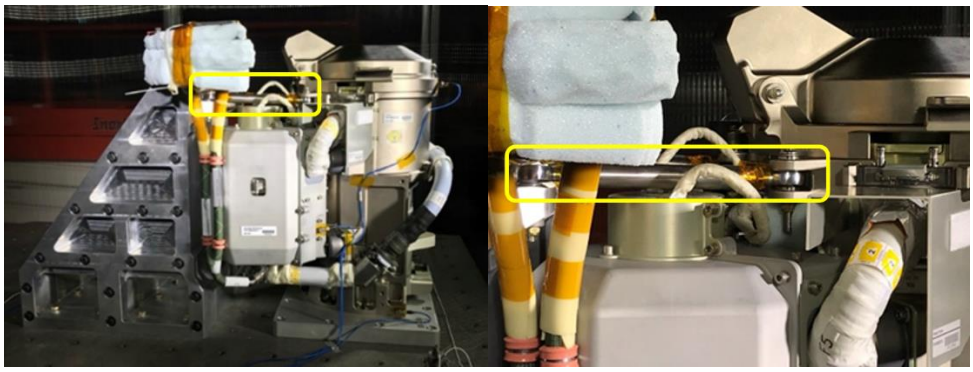


(a.) (b.) (c.)

Figure 3. Upper Adapter plate, (a.) UWMS with upper Adapter Plate during fit check, (b.) detail of bolt attachment access, (c.) model showing connection of plates and vehicle with cutaway view of UWMS.

the second to UWMS with connections between the two.

The main commode structure of UWMS, the commode housing, was designed to withstand the Orion intense launch/abort/landing loads. Because the units were meant to be as functionally similar as possible, this configuration is used on the ISS unit as well although that unit was soft stowed with much less stringent launch loads. The connections at the base are all that are provided for the ISS unit, however, the Orion unit requires the addition of two stiffening struts at the rear of the unit that attach directly to the Orion vehicle. See Figure 4 for locations of struts



(a.) (b.)

Figure 4. Orion UWMS during vibration testing at JSC. (a.) Struts connecting to vibration testing fixture. (b.) Struts in close view (yellow box).

(shown in yellow box) during vibration testing at Johnson Space Center (JSC.)

There are also slight differences in the acoustic cover of the dual fan separator (DFS) seen in Figure 5. The Orion cover has a prism-like shape to accommodate interface restrictions in the very crowded and small Orion Hygiene Bay while the ISS cover has a smooth exterior. The cover is seen on the left of the unit in Figure 5.



Figure 5. Orion UWMS unit during Electromagnetic Interference (EMI) testing at JSC. DFS acoustic cover is seen on the left of the unit with flexhoses (yellow box).

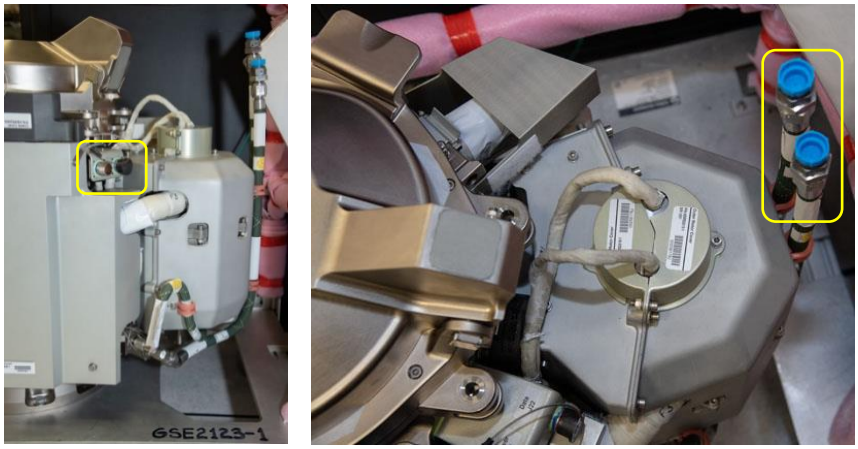
The Orion unit interfaces with the vehicle for power. A power connector on the right rear of the unit (seen below in Figure 6 (a.) in yellow box) connects to a vehicle supplied power cable. And although data is generated by the unit, there is no data connection to the vehicle and no data is recorded or displayed and cannot be retrieved. There is current input available but no telemetry from UWMS is collected. The ISS unit does distribute data to the ISS vehicle via a Data Recorder and a Domain Adapter Node (DAN) box which is displayed in the ISS Mission Evaluation Room (MER).

B. Urine Treatment

Another significant difference between the "sister" units is how urine is managed. The ISS has the added complexity of supplying liquid urine pretreatment to condition the urine for entry into the sensitive ISS water recycling systems. The supply of filtered water from the ISS potable water system and pretreat concentrate from a tank means additional hardware including the Dosing Assembly, Pretreat Tank and Pretreat Tank Enclosure, three hoses (Pretreat concentrate supply (a phosphochromic acid), water supply and Pretreated urine delivery), a conductivity sensor to assure the dosing is correctly applied, and electrical cables for power and data. Of course, ISS performs much more complex operations because the station is continuously operated and recycling water is key to a sustainable operation. This is being demonstrated on ISS for long duration exploration missions as well.

Orion's Artemis missions are intended to be shorter missions. Artemis-2 is 10.5 days and thus the plan is to vent the collected urine overboard similarly to the previous programs Shuttle and Apollo. The Orion UWMS design

includes two flexlines that are connected to vehicle systems; one is a urine delivery line which empties the Toilet into a temporary holding tank for venting and a vent line to equalize the systems. These flexlines are supported by structural connections on the DFS Acoustic Cover (capped in blue) and seen in Figure 6 (b) yellow box.



(a.) **(b.)**

Figure 6. Connections of flexlines to the DFS Acoustic Cover, (a.) Power connector shown uncapped, (b.) flexhoses shown with blue caps

Urine is treated with Oxone instead of the liquid pretreat solution as on the ISS unit. The oxone provides stabilization for the shorter duration period that the urine is stored. It is fabricated into solid tablets that are contained in a sock-like assembly. This assembly holding 8 Oxone tablets is attached to the bottom of the pre-filter below the urine funnel in the urine hose, see Figure 7. The Oxone is dispensed by dissolution as the urine flows over the tablets.



Figure 7. Urine Pretreat Assembly with filter and holding 8 Oxone tablets.

This method was used on Shuttle missions which were short in duration similar to the Orion missions.

As Orion's Artemis-2 prepared for launch during 2025, an issue with the packaging of the urine treatment assemblies containing oxone was discovered as part of the packing for stowage process. To maintain the one-year shelf life of the oxone tablets, the assemblies were heat-sealed in evacuated and gaseous nitrogen filled combi-therm packaging and stored in evacuated and gaseous nitrogen filled glass jars. When the assemblies were removed from the glass jars, multiple units were noted to be "deflated", that is, they appeared to have lost the nitrogen pressure pad. It appeared that the heat seal of the assembly package was not intact, although because of the storage in glass jars and the recent delivery, the oxone was still useful. Because of the loss of pressure, the packaged units were placed in a drink package and vacuum sealed with nitrogen, see Figure 8. This provided a sealed enclosure for the assemblies. Investigation into the root cause is planned for 2026.



(a.) (b.)

Figure 8. Urine Pretreat Assemblies (a.) Original deflated packaging, (b.) Packaged in drink bag for stowage.

III. Consumables Manifest for Optimization of Mass and Volume

C. Quantities

A key objective of the demonstration on ISS was to evaluate the quantities of consumables needed for the Artemis-2 and future missions. Again, mass and volume are always of keen interest in spacecraft design and there was intense interest in the needed allocation for consumables related to metabolic waste hygiene. Crewmembers are remarkably resilient regarding the restrictions imposed by space travel; however, it is a primary goal to make it easy, clean and comfortable to perform these very frequently needed hygiene tasks. This is for the crewmember's health and comfort but also to optimize the time needed for cleanup.

As part of the limited checkout on ISS, a canister used to collect fecal deposits, the Hard-sided Fecal Canister (HFC), was filled and returned to the project team for evaluation. [2] Key findings included the actual capacity of the canister. Ground testing with ersatz fecal material predicted 20 deposits including fecal bags, dry and wet wipes, gloves and four compaction plates. The evaluation of the contents revealed that there were 13 deposits and fecal bags with various quantities of dry/wet wipes and gloves and six compaction plates. The canister contents were fully compacted and the canister was filled to capacity. There are numerous variables which affect the number of deposits that can fit into a canister. Obviously, the size of the fecal deposits varies from person to person and affects the available space. Number of wipes and gloves used by the individual crew member (personal preference) and how much the fecal bag is "bundled" also affect the number of deposits that can fit into the can. Data from the ISS demonstration provided information on actual use with UWMS in a micro-gravity environment that cannot be simulated completely on the ground. The data is invaluable for planning for future missions and provides a guideline, however; this information is refined as additional canisters are used and returned for evaluation. The data collected impacted Orion in two ways.

First, the dry wipes found in the ISS returned HFC were not those supplied by NASA but were supplied by the Russian International Partner. It was assumed and confirmed that these wipes were preferred by the crew. The NASA supplied wipes were compared to "wiping peanut butter off the counter with wax paper." The Russian supplied wipes are not available for manifest on Orion so an alternative was found. The legacy NASA dry wipes were replaced with a commercial off the shelf (COTS) provided toilet paper. A demonstration of the available toilet paper options was done on ISS using ACY and the results used for the Orion Artemis-2 manifested quantities.

Second, because the quantities for the deposits found were less than assumed (13 vs. the predicted 20), this affected the manifested quantities for use with each HFC, the lids associated with the HFC canisters, the number of fecal bags and the number of compaction plates. Although this resulted in an increase in mass, it was assessed as well worth the avoidance of the risk of not providing adequate needed items to collect the fecal waste and having crew experience an issue with storage of fecal material. Cleanliness and comfort for the crew are always considered in these decisions.

Contingency supplies are provided as well. In the event that UWMS does not operate nominally, the crew will use the unpowered UWMS and consumables for fecal operations and will urinate into the Collapsible Contingency Urinals (CCU) [3]. Additional fecal bags, compaction plates and Ziplock bags for containment are being flown.

Current quantities on-board are shown in Table 1 below. Assumptions are shown below.

Table 1. UWMS Consumables for Artemis-2 and Assumptions

Total On-Board*		
	Nominal	**Contingency**
Fecal Canisters	8	
Fecal Bags	104	24
Compaction Plates	48	6
Urine Prefilter Assemblies (oxone)	12	
Secondary Urine Filter	1	
Supplemental Urine Filter	42	
Urine Hose	1	
Odor Bacteria Filter	1	

*Assumptions
4 crew for 10.5 day mission
2 fecal deposits per day
13 deposits per canister,
1 fecal bag per deposit
Landing canister can be full, empty or partially filled.
6 compaction plates per canister
Urine prefilter/Oxone changed daily plus one
Secondary urine filter good for 30 days
1 female crew member / mission with 7 day menstrual cycle and 6 urinations per day
Urine hose not changed during mission
OBF filter good for 42 crew days

IV. Crew Feedback

Detailed feedback from the ISS crewmembers who used UWMS on ISS was collected both by questionnaires completed on-orbit as well as in-person interviews. Valuable information was shared on usage, issues and quantities of consumables as discussed above. There were three major concerns from the crewmembers. The amount of air flow, size and placement of the commode seat and fecal bags, and acoustic levels generated by the DFS. [2]

Crew members commented that air flow seemed less than adequate based on how it felt during operation and although there was a concern for ability to entrain the fecal matter (urine was judged to have adequate air flow), no escapes were noted. Review of the designed air flow quantities indicated that the volumetric air flow was greater than or equal to both the WHC system and Shuttle era systems, the opening for the 5" commode seat is larger than the ACY which reduced the velocity at the point of capture.

Crew also noted that the fecal bag diameter was too large. Intuitively, it would seem that a bigger opening would be easier to target, however, crewmembers noted that the fecal bag material aided in "capture" of the fecal material. Because there is no gravity during space travel bathroom use, the fecal waste doesn't fall away from the body. At the targeted area where the waste touches, it will connect at that point and allow the crewmember to detach the bolus from the body. With a wider diameter, the bolus has a further distance to reach an adherence point and the likelihood of an escape or connection outside the target area increases.

Crew commented that a smaller diameter seat and fecal bag would increase velocity and also aid in adherence of the fecal material. The ACY system is used with the seat lifted away because of small air holes that are hard to clean and that configuration means the body is in contact directly with the fecal bag material (called an ACY Insert.) Crewmembers liked that configuration. Because of these concerns, the commode seat was redesigned with a 4" opening, a lower profile and a configuration that allowed the fecal bag to cover the seat for direct contact. The fecal bag closure was improved with a drawstring mechanism also similar to the WHC option. In addition, a directional tube was added to the bottom of the seat to help direct air flow and further improve the velocity. [4] See Figure 9.



(a.) (b.) (c.) (d.)

Figure 9. Seat and Fecal Bag updated design, (a.) 4" Seat Removed from UWMS (original NASA designed seat provided with UWMS by Collins Aerospace), (b.) Soft-Stowed 4" Grooved Seat with Tube (updated NASA design), (c.) Updated Fecal Bag, (d.) Fecal Bag installed over 4" Grooved Seat with Tube

The configuration of air flow changed from entering under the seat to entering thru the top of the seat so an evaluation was done on ISS to see the impact on air flow. Crewmembers noted improved air flow and capture using a wadded up tissue to simulate a fecal bolus during a demonstration on ISS. See Figure 10 for original configuration



(a.) (b.)

Figure 10. Original UWMS designed seat and fecal bag during air flow demonstration on ISS.

and Figure 11 for updated seat and fecal bag configuration.

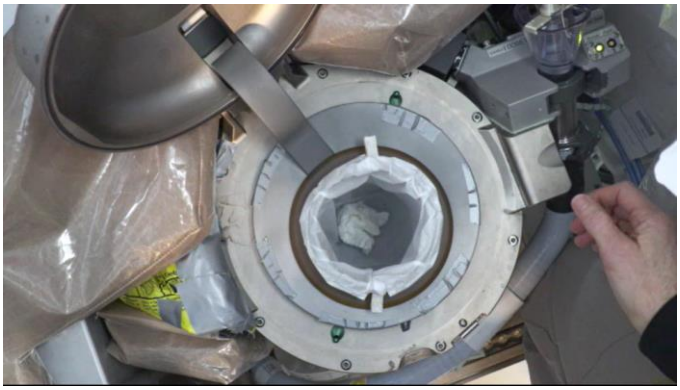
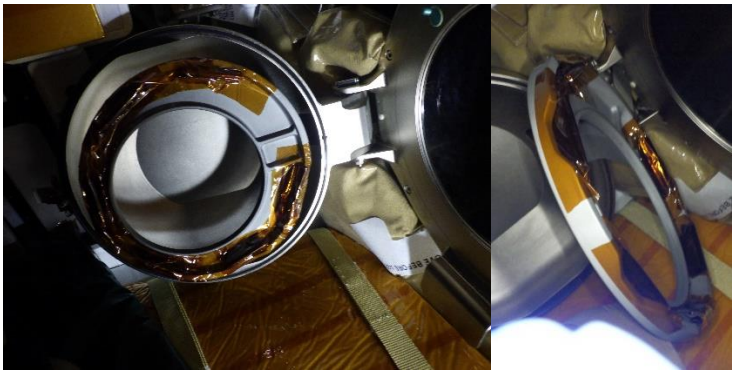


Figure 11. Updated UWMS 4" Grooved Seat with Tube and updated Fecal Bag during air flow comparison test on ISS with taped openings.

The updated design with the 4" grooved seat with tube that allowed the fecal bag to be installed over the seat was selected by crewmembers for use on Orion's Artemis-2 mission based on the air flow demonstration done on ISS. This seat is manifested as a stowed item and will be installed before the first use of the Toilet. [5]

To direct airflow through the top of the seat rather than as designed under the seat, castellated openings in the seat carrier were taped over with Kapton tape, see Figure 12 on the UWMS in the Artemis-2 vehicle for use on the flight. This matches the configuration used in the testing on ISS>



(a.) **(b.)**

Figure 12. Kapton tape installed on Seat Carrier, (a.) under-side of Seat Carrier, (b.) Side view showing taped over openings.

Air flow and velocity have a direct impact on acoustic levels. During environmental testing, there were two components of the acoustic levels emanating from UWMS. The first is the "case radiated" element that comes directly from the source of the noise, that is, the fan. A second element is "duct borne" and is the noise the air makes traveling down the urine hose, entering/exiting the commode and exiting thru the Odor Bacteria Filter (OBF.) Based on crew comments, hearing protection is recommended during use. Upgrades were made to the Orion Hygiene Bay to reduce the case radiated element. A Toilet Acoustic Cover (TAC) was designed, built and tested on ISS which essentially placed a barrier between the source of the noise and the crewmember. A custom designed cover for the Orion UWMS configuration was provided and a reduction of approximately 3 decibels was seen.

Detailed fit checks were done in the Artemis-2 vehicle to assure the cover was properly fitted to block the case radiated noise. A final check was done during installation of the flight unit.

Additionally, acoustic blankets were fabricated for the walls of the Orion Hygiene Bay. These panels use Soundfoam and Kapton to absorb the noise resulting in a reduction of 5.7 db. See Figure 13 for Toilet Acoustic Cover in light brown and wall panels in orange. Future upgrades are in work including a modification to the gearbox, impeller, and potentially an air muffling device for future missions. Final acoustic readings were done by the crew on Artemis-2 and will be provided in a future paper.



Figure 13. Orion UWMS in Artemis-2 Hygiene Bay with Toilet Acoustic Cover in light brown and wall panels in

V. Functional Performance on ISS

A. Odor Bacteria Filter (OBF) Particulate Barrier (OBFPB)

During installation of the ISS UWMS OBF (used for odor control during use and while unattended), particles of the media were noted in the packaging. See Figure 14, for details of the OBF installation on ISS. [3]

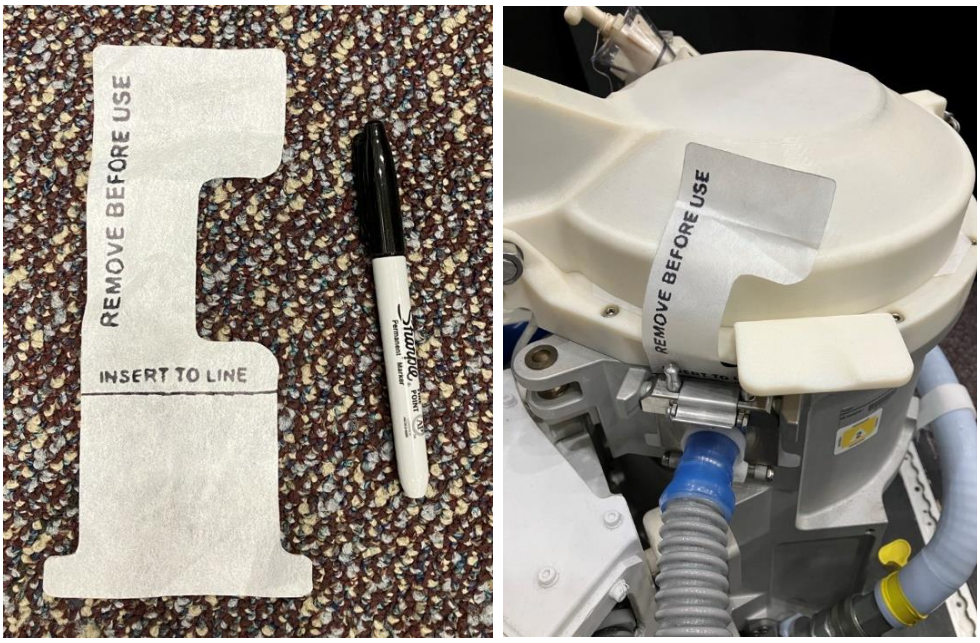


(a.) **(b.)** **(c.)**

Figure 14. (a.) Odor Bacteria Filter for UWMS, (b.) Crewmember installing OBF on ISS. UWMS Toilet has the top removed and the concentric location for the OBF can be seen, (c.) OBF in original packaging where particles were noted.

It was known that the particles could migrate from the inlet while stored in the packaging and a plug was added to the hardware for delivery and transport of the items. The particles noted on ISS were from the outlet side of the unit which was not expected. The ISS unit was launched without an OBF in place. But Orion's Artemis-2 UWMS would be launched with the OBF in place to reduce the crew time needed before first use (this is the only Toilet on the vehicle which is different than ISS so availability after launch should be as soon as possible.) Installation of the OBF in the UWMS involves removal of the top of the commode as well as the auto-start cradle. Both are secured with captive fasteners. The orientation of the UWMS in the Hygiene bay is horizontal when in the launch attitude. The inlet for the OBF is facing down and is directly over the outlet for the DFS. This could mean that particles could fall from the OBF into the DFS during launch and impact operation.

A barrier was designed to protect the DFS from particles during launch and will be installed prior to launch. This barrier is made of a Teflon coated membrane that is air permeable but will not allow the particles to pass. The barrier will be removed prior to first use and discarded. Figure 15 shows the particulate barrier and fit check with UWMS trainer at JSC. No ground testing for launch loads was done with the barrier installed in UWMS because the unit was installed in the Artemis-2 vehicle in 2021 before the barrier was completed.

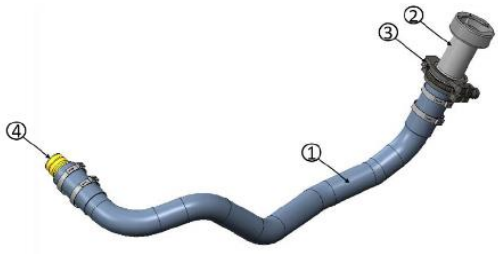


(a.) (b.)

Figure 15. Particulate Barrier for the Orion UWMS (a) prototype unit, (b) fit check with UWMS trainer at JSC's SVMF.

VI. Other Hardware Changes

The Orion UWMS was delivered to Kennedy Space Center (KSC) in December 2019 and was installed in the vehicle in early 2021. After installation and during other work in the Hygiene Bay, damage was noted to the urine



No.	Description
①	Urine Hose
②	Urine Funnel Interface
③	Filter Assembly
④	Urine Hose Outlet QD

Figure 16. Urine hose configuration

hose which is located on the front of the unit and is not protected from contact. The urine hose is fabricated on a rotisserie by building up layers of Room-Temperature Vulcanizing silicone (RTV) over a coil. Configuration is shown in Figure 16.

The final layer showed delamination and was flaking off. Investigation showed that the final layer was not well-adhered. The urine hose was replaced with a new assembly and protected with a bag covering it in the vehicle until close to the launch period. Figure 17 shows these views.



(a.) (b.) (c.)

Figure 17. Orion UWMS (a) with urine hose prior to delivery, (b) delamination of hose surface, (c) replacement hose with temporary cover in Artemis-2 vehicle.

Installed in the urine hose is a dummy urine pretreat assembly for launch. The prefilter itself allows closure of the urine hose at the installation point, however oxone is not needed until first use. Crewmember will remove the dummy assembly and insert a fresh Urine Pretreat Assembly with oxone prior to the first urination. The assembly is shown above in Figure 7. The prefilter is on the left side of the assembly in the picture and is made of RTV.

A foot restraint will be installed in the Hygiene Bay as part of the pre-first use preparations. To better accommodate crew members of varying heights, a Foot Strap (seen in Figure 18) was added to the bay as well. This can be seen in Figure 18 with the Orion UWMS in the Artemis-2 vehicle during final updates prior to launch.



Figure 18. UWMS in Orion's Artemis-2 while final updates are made before launch.

VII. On-Orbit Performance

Because there is no data to evaluate from the Orion UWMS other than power draw, crew feedback will be very valuable to inform operational or hardware updates for future missions as well as consumable use and preference. Debriefs with crewmembers are planned for after the mission. Shown in Figure 18 above is the Orion UWMS in the Artemis-2 vehicle during final updates prior to launch.

UWMS performed nominally during the Artemis-2 mission. Defecations were successful and crew reported good performance with the updated seat and fecal bags. The returned fecal canisters will be evaluated similarly to the returned ISS HFC for quantities used on Artemis-2 for future mission manifesting decisions. These additional details on quantities used for fecal canisters, compaction plates, wipes and gloves will be provided in a future paper.

Crew reported successful urinations with UWMS early in the mission; however, the number of urinations that could be input using UWMS were limited for a significant portion of the mission duration because of issues with the overall Waste Management System (WMS). The primary vent system downstream of UWMS experienced problems and resulted in very slow vented flow rate of urine. Urinations were performed with UMWS when possible based on

this reduced flow rate. Crew members also used the CCU's which collect urine and then connect to the secondary vent urine system for venting.

More details on the use of UWMS on the Artemis-2 mission along with specific crew feedback, performance details, and relevant comments will also be provided in a future paper.

VIII. Conclusion

The Orion UWMS is different from the ISS UWMS in several ways. Some of the differences are based on the vehicle integration needs and configuration, some were driven by the urine treatment design differences, hardware was added at crew request and hardware was changed out due to the lengthy period between delivery and the launch schedule. Others resulted from crew feedback. The Orion UWMS benefitted greatly from the demonstration on ISS even though it was shorter than hoped. Changes have been made based on crew feedback from that demonstration. Conversely, the lessons learned on Orion will also be used to improve performance and usability on the ISS unit. Because the design and implementation of toilet hardware for use in space continues to evolve, the Artemis-2 mission and the UWMS used there will continue the process started with Gemini and Apollo and improve the experience for all future space travelers.

Acknowledgments

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