

NASA Universal Waste Management System and Toilet Integration Hardware Operations on ISS – Issues, Modifications and Accomplishments

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The Universal Waste Management System (UWMS), which has the ISS operational nomenclature "Toilet", was initially installed on the International Space Station (ISS) in 2020 with final installation completed in 2021. Although technical issues were encountered that delayed installation and operations, progress was made towards the objectives of the project. Technical issue work-arounds resulted in operation of the Toilet with use by male and female crew members in a controlled extended checkout. This paper will summarize operations of the Toilet and Toilet Integration Hardware in this limited configuration, problems encountered during installation and checkout, the modifications made to allow further usage on ISS, and the future modifications planned for nominal use. It will also describe the portions of the technology demonstration that were completed and the benefits from that work and how that knowledge informs the Orion-installed UWMS unit and future manifesting of consumables for both Orion and ISS.

Nomenclature

AES = Advanced Exploration Systems
ARED = Advanced Resistive Exercise Device
COTS = Commercial-Off-The-Shelf
DFS = Dual Fan Separator
ECLS = Environmental Control and Life Support
ECLSS = Environmental Control and Life Support System
EDU = Engineering Development Unit
FY = Fiscal Year
ISS = International Space Station
JSC = Johnson Space Center
LED = Light Emitting Diode
LR = Logistics Reduction
NCR = Non-conformance Report
NASA = National Aeronautics and Space Administration
OBF = Odor Bacteria Filter
SpX = Space X

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TIH = Toilet Integration Hardware
TD = Technical Demonstration
UPA = Urine Processor Assembly
UWMS = Universal Waste Management System
WHC = Waste and Hygiene Compartment

I. Introduction

NASA contracted Collins Aerospace to develop an updated toilet for use in exploration missions. It is desirable to have a common core hardware assembly that only required modest modifications for adaption to multiple exploration microgravity mission elements. The goal of the new system is to reduce mass and volume, both of which are key objectives of successful hardware used for long range missions. Additionally, the new toilet has the goal of improving usability for female crewmembers. The Universal Waste Management System project builds on previous toilet designs and delivered a toilet for ISS and the first crewed Orion mission. Delivery of the Orion toilet (seen in Fig. 1) was in December 2019 and the unit was installed into the Artemis-2 vehicle in March 2021 for launch in 2023. The ISS unit, seen in Fig. 2 along with the Toilet Integration Hardware, launched to ISS in October 2020. The ISS unit is awaiting final installation and nominal operations on ISS in Node 3. A limited checkout was performed in October/November 2021.

Fig. 1. Orion UWMS installed in Artemis-II Vehicle.

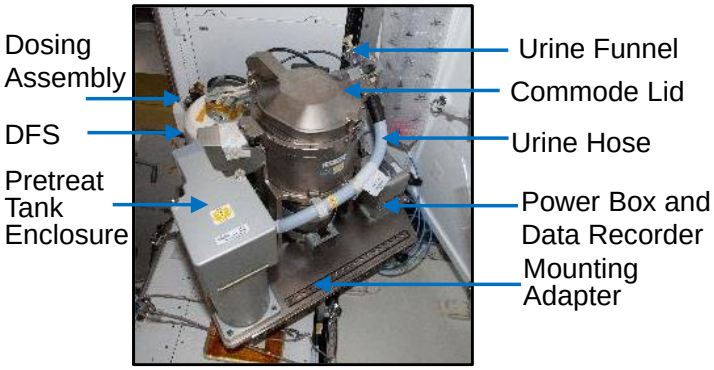

Fig. 2. ISS UWMS with Toilet Integration Hardware in Node 3, ISS.

II. Hardware Overview

The UWMS project's two toilet units have key goals for a reduction in mass and volume over previous toilets used in space vehicles. The ISS UWMS (Toilet) is 65% smaller and 40% lighter than the current ISS toilet used by US crew in the Waste and Hygiene Compartment (WHC.) The Orion UWMS (WMS is 61% smaller than the toilet used on Shuttle missions. Air flow to aid in the collection of urine and fecal material is provided by a dual fan separator (DFS) which also serves to remove air from the urine/pretreat stream. Combining the two fans used in previous toilet designs into a motor arrangement with a single fan housing (separate impellers) provided much of the resultant reduction in mass and volume. The unit provides a simple startup operation with no need for an external panel that initiating the unit either with removal of the urine funnel or lifting the commode lid. Pretreatment of the urine is performed in both units to stabilize the urine for processing on ISS or venting on Orion. A Conductivity Sensor provides measurement of the concentration of pretreat dispensed for the ISS unit. Fecal deposits and consumables such as wipes, and gloves are contained in a hard-sided fecal canister. More details can be found in a previous paper [1].

III. On-orbit Start-up and Issues

UWMS launched to ISS on NG-14 in October 2020 as two assemblies, the Toilet, and the Dosing Assembly. The Dosing Assembly includes Dose Pump and Conductivity Sensor. Installation began in December 2020. During

installation, an issue was discovered with the fittings on the conductivity sensor which attach the Dosing Assembly to the Toilet[2]. During ground investigation and testing of the spare units, the function of the spare sensors was found to be problematic. The testing was initiated during the process to replace the on-orbit unit with a spare. Issues with the conductivity sensor impacted completion of the on-orbit demonstration. Completion of the root cause analysis and an updated design are in work at the time of this paper.

Proceeding with start-up despite issues with the sensor, the Dual Fan Separator (DFS) failed to spin. Indications from crew were there was no sound of start up and no air flow data noted. A "locked rotor" fault was seen in the on-orbit data. Efforts to remove power and restart were not successful. Crew attempted to dislodge the impeller by removing the hose on the inlet side of the DFS and forcing air with an on-board vacuum cleaner into the hose and to the impeller of the DFS. See Fig. 3 Ground testing with the spare DFS showed that air did allow the DFS to spin, and the on-orbit testing provided details on whether the separator was mechanically stuck or did not have power to spin.

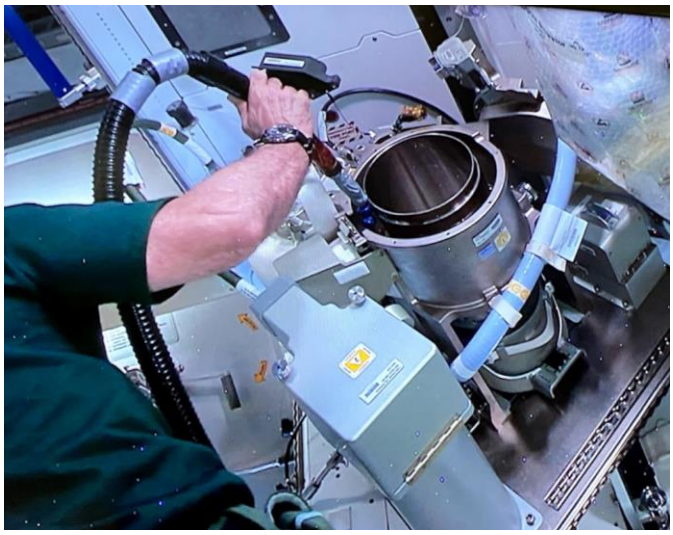

Fig. 3. Attempt to free DFS with vacuum on-orbit (ISS)

Once power was reapplied to UWMS, there was no indication that the DFS was operating, and the data continued to indicate a "locked rotor" fault. The ISS program procured and flew spare components for UWMS including a spare DFS unit. The decision was made to remove the failed DFS from UWMS and replace it with the spare DFS available on ISS. The replacement unit was found to be fully operational, confirming that the issue was with the originally installed DFS and not another issue within the system. Fig. 4 shows ground testing of DFS prior to launch and Fig. 5 shows the on-orbit unit.

Fig. 4. DFS during ground testing

Fig. 5. DFS with cover removed on-orbit (ISS)

After confirmation that the DFS was operational, the conductivity sensor fittings were connected, and a leak test performed. The leak test verified no leaks were present at any of the system fittings including the fittings on the conductivity sensor discussed above. However, the conductivity sensor did not function as expected and continued to show low conductivity after multiple dose pump dispenses. The readings were seen to be at the bottom end of the range much as was seen with the ground spare units. The UWMS was now operational for air flow but did not have an operational sensor to validate pretreat concentration and confirm urine was being pretreated to protect the downstream ISS recycling hardware systems. A key component of the toilet system is the validation of a good pretreat dose. This function allows for the balance between the risks of too little pretreat which may allow a buildup of microbial growth and potential failure of the Urine Processor Assembly (UPA) and too much pretreat which can cause corrosion and is a waste of the valuable consumable of pretreat solution.

A sample of the pretreat remaining in the lines of UWMS was obtained by the crew and returned on SpX-23 in September 2021 (see Fig. 6.) The sample showed the expected orange-red color of the phosphochromic acid solution and was analyzed by the support labs at JSC. A sample containing only water would be clear with no color at all. Varying degrees of pretreat would show a deepening orange-red color. The sample clearly showed the presence of pretreat solution, however, the sample appeared to be concentrated during the return and was higher than expected. Because the sample was not in a sealed container, it appeared that evaporation during return, concentrated the pretreat to a level likely not seen before return. The site for obtaining the sample was at the base of the urine hose and a flexible syringe was used to draw the sample from the cavity in the urine block after removal of the hose. The hose is a replaceable unit, however, access to the cavity was difficult due to the angle needed and the available sample volume small. Additional access to allow sample availability may provide better insight to on-orbit operations with minimal interruption in service of the system.

Fig. 6. Pretreat solution on-orbit sample returned for analysis

A plan was developed to use a combination of available on-orbit data to predict the presence and relative concentration of the pretreat solution. This evaluation used the pressure sensor which provided the basis for opening the outlet solenoid valve and the pressure of the ISS water bus. The separator bowl pressures show a distinct difference between a water solution and a pretreat/water solution due to the difference in specific gravity. This data was validated with ground test data as well as that seen on-orbit. Also, the water bus indicates how much water is drawn by the dose pump and because of the design of the dose pump, a corresponding volume of pretreat can be assumed. These two factors along with the returned sample color and analysis allowed a plan to go forward for approval of a Limited Checkout of the UWMS on ISS. Completion of the checkout of UWMS and the planned technology demonstration is planned to provide valuable data for the Orion Artemis-2 mission, the first exploration mission use of UWMS. Information on use by multiple crewmembers for multiple days to simulate the Orion missions will provide confidence in the system prior to Artemis-II as well as informing packing quantities for consumables such as fecal canisters and lids, fecal bags, wipes, gloves and both air and urine filters. Completion of this tech demo is evaluated based on the available configuration and is balanced with the risk to the UPA. The proposed plan to reduce risk to UPA included operational changes to collect and evaluate the pretreated urine in a tank before processing and to do real time monitoring of pressures as outlined above to allow insight into the amount of pretreat being dispensed.

IV. Limited Checkout Summary and Issues

A Limited Checkout allowed operation of UWMS with no immediate risk to downstream systems by delivering the urine/pretreat solution to an interim tank for later evaluation and processing and using the pressure data however, this did increase the use of pretreat solution as additional dose were needed. The configuration is not the nominal setup through the Urine Transfer System (UTS) but allows the urine to be collected at UWMS and delivered to a stand alone tank for future processing and delivery to the Urine Processor Assembly (UPA.) The Limited Checkout also limited the number of crew members using UWMS to minimize the number of stand alone tanks needed for this off-nominal configuration, see Fig. 7 and 8.

Fig. 7. Stall configured for UWMS use

Fig. 8. UWMS ready for use in Stall

A decision was made to have only a single crewmember at a time use UWMS for 1 week. A male and female crewmember each used UWMS for one week with a third (male) crewmember using UWMS for 2+ days in addition to the originally planned 14 days. The checkout allowed use of the functions of UWMS including urine and fecal collection, compaction of fecal deposits, urine funnel evalution[1], seal/fecal bag evaluation, acoustics evaluation, and fit/function of Stall and Toilet Integration Hardware (TIH.)

The Limited Checkout was extended due to crew handover and a third crewmember (male) used UWMS in the third week, see Fig. 9. During use for urination on Day 16 of the Limited Checkout, the UWMS shut down showing a Pressure Sensor Fault. The UWMS operation is a zero-fault tolerant design and fails safe to protect the crewmember and the hardware. Review of the pressure sensor data showed unexpected data trends which are still in review, but no anomalies attributed to the sensors themselves. There are two (redundant) sensors, and both tracked identical data readings which indicates that the sensors are functioning correctly and assessing a pressure condition as the data shows. This leads to the fault tree analysis indicating the cause to be an occlusion of the pitot in the bowl of the DFS causing irregularities in the pressure readings which were not expected. Additional testing of the on-orbit hardware is needed to confirm this evaluation. During the evaluation of the pressure sensor shut down fault, the UWMS was placed into a dormant configuration. The UWMS hardware and all downstream hoses and connections were flushed with water and then coated with pretreat solution to prevent microbial growth of the UWMS and TIH during the non-use period.

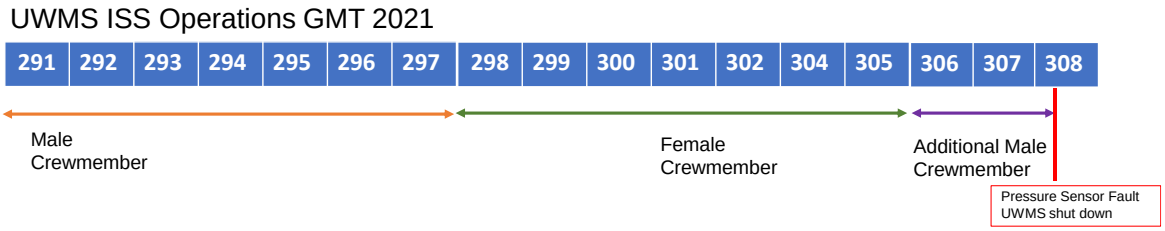

Fig. 9. Timeline of UWMS Limited Checkout on ISS

V. Accomplishments and Remaining Objectives

Although the TD has yet to be completed, valuable information was obtained for the use of the UWMS for exploration missions as well as continued use on ISS. Checkout of the components of the UWMS and TIH was completed. The UWMS performed successful fecal and urine collection functions. An ease-of-use evaluation was obtained from the crew as well as an evaluation of key crew interface components like the seat and urine funnels. Fecal deposits were made into a fecal canister, compacted using the provided compactor, and then capped after final use. Feedback from the crew (male and female) provided valuable information for the Orion missions on crew use and preference of seat and funnel options. The pretreated urine collected into the stand alone tank was processed successfully although additional processing time and crew operations were needed.

The Limited Checkout did not meet all of the planned technology demonstration objectives. The configuration of the hardware necessitated use of only a single crew member at a time. Daily use by three crewmembers (or more) for concurrent days is needed to evaluate crew use and nominal system performance in an actual mission scenario. Additional evaluation of the body-interfacing components is desired to obtain as much crew feedback as possible to inform future use and any needed design update and operational changes.

Another key evaluation that is significant for the Orion missions is the capacity of the Odor Bacteria Filter (OBF.) During ground acceptance testing, OBF did not pass the verification of the requirement of an 84 crew-day capacity for odor control. The 84-crew-day requirement is based on the Artemis-3 mission of 4 crewmembers for 21 days (4 crew members x 21 days = 84 crew days.) The testing failed between 50 and 75% due to odor breakthrough for breakthrough of odors. An on-orbit evaluation is needed for manifesting adequate numbers of OBF units for Artemis missions. Crew did report that UWMS was smelly during the Limited Checkout, however, the OBF installed in UWMS had been installed since the May startup attempt and was at an unknown status for capacity depletion. It was noted later that the seals were not in nominal position during installation which could have contributed to the smells from UWSM as well. An additional evaluation is needed with a fresh OBF installed just prior to use and with multiple crew members to assess a mission scenario more accurately that will inform OBF manifesting plans Artemis missions. Fig. 10 shows the on-orbit replacement of the OBF.

Fig. 10. UWMS with new OBF for installation.

Replacement schedule of the urine pre and post filters is an additional evaluation that is needed with multiple crew members and a longer operation. No degrading of these filters was noted by the crewmembers during the Limited Checkout. Consumables usage by multiple crewmembers for a longer duration is also needed for both manifesting for Artemis missions as well as the future manifesting strategy for ISS.

Validation of an operational conductivity sensor with the dose pump is needed to provide evaluation of the dosing assembly and the overall impact to the ISS systems. A working sensor is needed to perform these functions.

VI. Crew Feedback

Crew provided feedback to the project team using a daily questionnaire to provide details on usage, consumables, and experience as well as a more detailed weekly questionnaire. These questionnaires are key to the evaluation of the hardware for the Orion needs and future ISS use, for engineering insight into design adequacy and for evaluation for contract payment milestones.

Overall, the crew noted that the UWMS was easy to use, and it works. They did, however, note various areas for improvement. Chief among the comments from two crewmembers who provided input was that the system was too loud. The acceptance acoustics testing performed prior to delivery, showed an exceedance of the requirements. The requirement for UWMS as a source was less than 68 dba. Values measured during acceptance testing prior to delivery averaged 72.9 dba. On-orbit readings measured during the on-orbit Limited Checkout measured 78.5, however, this includes the surrounding Stall hardware and other Node 3 acoustic levels. An acoustics evaluation of the on-orbit hardware showed a slight reduction from predicted levels, but the noise levels prompted the crew to use hearing protection during UWMS operations. Updates to the UWMS hardware as well as acoustic blanketing in the surrounding Stall volume are being investigated. A cover for the area behind UWMS is on-orbit and an updated acoustic survey to assess effectiveness of the cover will be performed during UWMS operations, see Fig. 11.

Fig. 11. ISS Acoustic Cover Prototype fit-check with UWMS Trainer in JSC's Space Vehicle Mockup Facility (SVMF), building 9

Seat and Fecal Bag size were noted to be too large and not ideally located for use. Both crewmembers made the current configuration work; however, updates were requested.

For the UWMS, three funnel designs were developed and provided on ISS for use and evaluation.[2] The feedback received indicated overall that the urine funnels work with the UWMS. The male crewmember had no preference. The female crew member preferred the notch option but also noted a potential issue with the interface between Plug and Funnel. After multiple cycles (removal from the Urine Funnel), the plug appeared to indicate some material degradation on the clip interface that snaps onto the top of the funnel when installed. The degradation was seen with a color change of the printed part which could indicate fatigue. The project will use this feedback to investigate a future redesign to improve the integrity of this interface. See Fig. 12 for funnel details as well as referenced paper.[2]

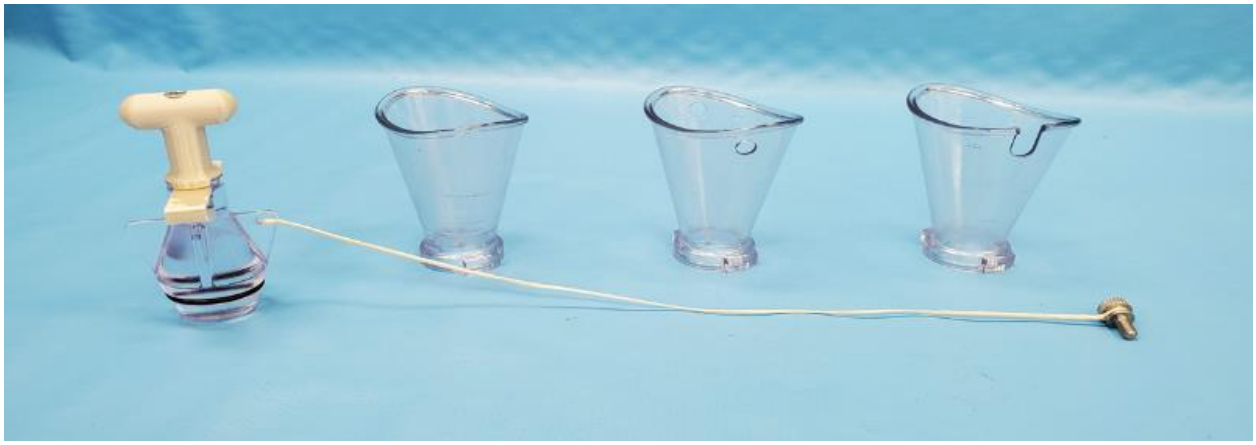

Fig. 12. UWMS Urine Funnels: Urine Funnel Plug, Urine Funnel, Urine Funnel (Hole), Urine Funnel (Plug)

UWMS air flow was noted to be less than experienced on WHC; but the amount of air flow was not noted as an issue for entrainment and retention of waste and no waste releases were noted. The concern was for verification of air flow on startup to validate the DFS operation. It appears that this observation is related to the size of the opening as volumetric air flow is equal or greater than that on WHC. The speed of the air at the interface point should be considered as well as the volumetric flow rate. Air flow is used for odor control and entrainment of waste. See Table 1 for details of the flow rate. Crew noted air flow as an area for improvement.

Toilet Air Flow Rates in CFM				
	Shuttle	**Shutttle EDO**	**WHC/ACY**	**UWMS**
Urine	9.9	13.5	8.8	**14**
Fecal	16	15	14	**16**

Table 1. Toilet Air Flow Rates in CFM.

VII. Forward Plan

The UWMS is currently in dormancy to allow the team to evaluate data and recommend an operational path as well as allow hardware updates for operations of the conductivity sensor and acoustics. A proposed additional checkout is in consideration. Completion of a working conductivity sensor as well as acoustics modifications are currently in work. The conductivity sensor will likely impact a return to nominal operations as well as mitigations for acoustic levels. This work likely will push the schedule of operations for completion of the tech demo into 2023, however, additional checkout operations may occur late in 2022.

VIII. Conclusion

Completion of the technology demonstration of the UWMS on ISS is paramount to informing explorations missions including Orion program milestones. The demonstration will provide details of consumables usage, ability of the crew to perform simultaneous urination and defecation operations, and overall information on use of a compact toilet in micro-gravity. Scheduling this work using available data and further learning of the operational performance is advantageous while also pursuing component modifications.

Acknowledgments

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