Evolution of the Next Exploration Toilet through Human-in-the-Loop (HITL) Testing

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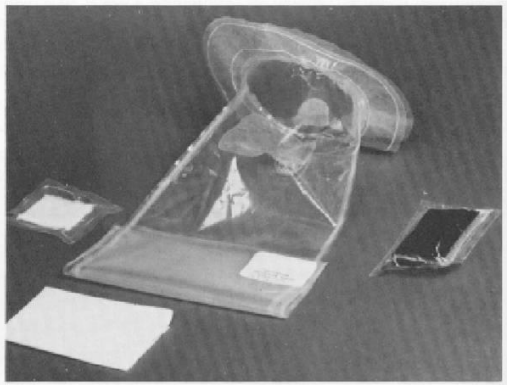
Introduction

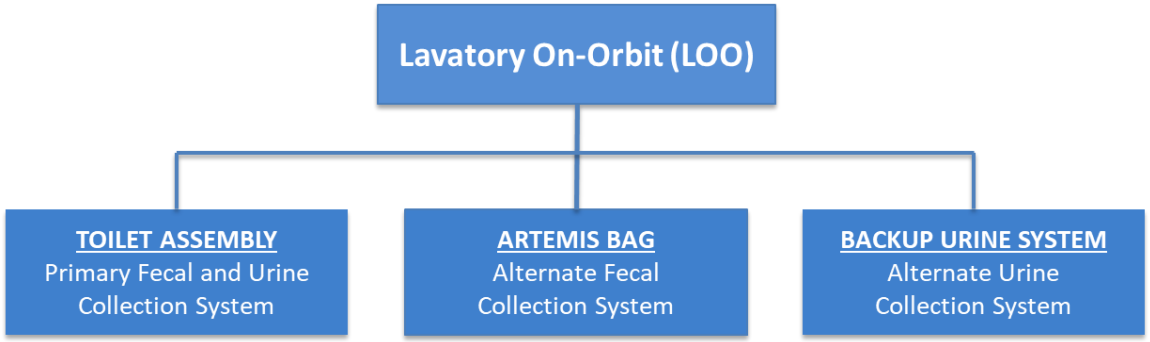
- Waste management is a crucial function to the success of human spaceflight
  - Early systems were simple and supported male crew only
    - Waste collected in single-use bags (intimate body contact, no odor control)
    - Generally unfavorable with the crew (waste escapes, odorous, unhygienic)
  - More recent systems improved upon waste capture, hygiene, and accommodating male and female crew
    - Introduction of airflow to assist with waste capture/separation and odor control
    - Crew interfaces to accommodate different anatomy (male/female)
  - UWMS – most recent system developed for longer duration missions
    - Focus on reducing overall mass and volume and improving on crew hygiene and interfaces
- Space toilets are complex systems
  - Crew interfaces pose a unique challenge in their design since every user could use or interface to the system differently
    - Goal: To design systems that can accommodate as many users as possible
- Human-in-the-Loop (HITL) testing is an effective method for obtaining design feedback from end users
  - Consistent and unbiased method for collecting data
  - Establishing a repeatable process is key



Apollo Bag for fecal collection

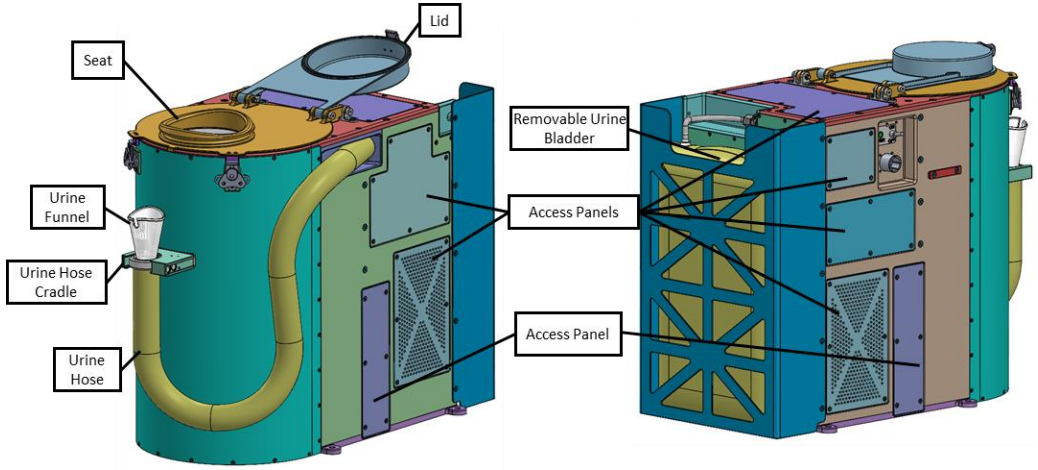
Lavatory On-Orbit (LOO)

- Project started July 2020 to develop a toilet for the Human Landing System (HLS) program
- LOO provides accommodations for collection, containment, and disposal of body waste (urine, feces, diarrhea, menses, and vomit)
- Key Driving Requirements
  - Operate in microgravity and partial gravity (will be used during lunar surface stay)
  - Provide crew interfaces for both male and female crewmembers
  - Support simultaneous operations ("simo ops" - urination and defecation at the same time)
  - Compatible with environmental conditions (lunar dust, higher oxygen, and vacuum exposure)
  - Minimize overall mass, volume and noise levels
- Three major elements for waste collection: Toilet Assembly, Artemis Bag, and Backup Urine System (BUS)



Lavatory On-Orbit (LOO) – Toilet Assembly

- Toilet Assembly is the primary system for both urine and fecal collection
- Urine is collected via a urine hose and funnel
  - The urine travels through the hose into a separator that expels any air and allows only urine to be collected in a bladder
- Feces is collected in a fecal bag attached to a seat
  - Each fecal bag is single-use and has elastic at the top to secure it to the seat while in use
  - The bag is closed with a drawstring after use and pushed down into a larger bag that holds multiple deposits
- A fan provides airflow for both collection paths to aid in waste capture and odor control



Toilet Assembly preliminary CAD model showing exterior features and primary crew interfaces

Lavatory On-Orbit (LOO) – Backup Systems

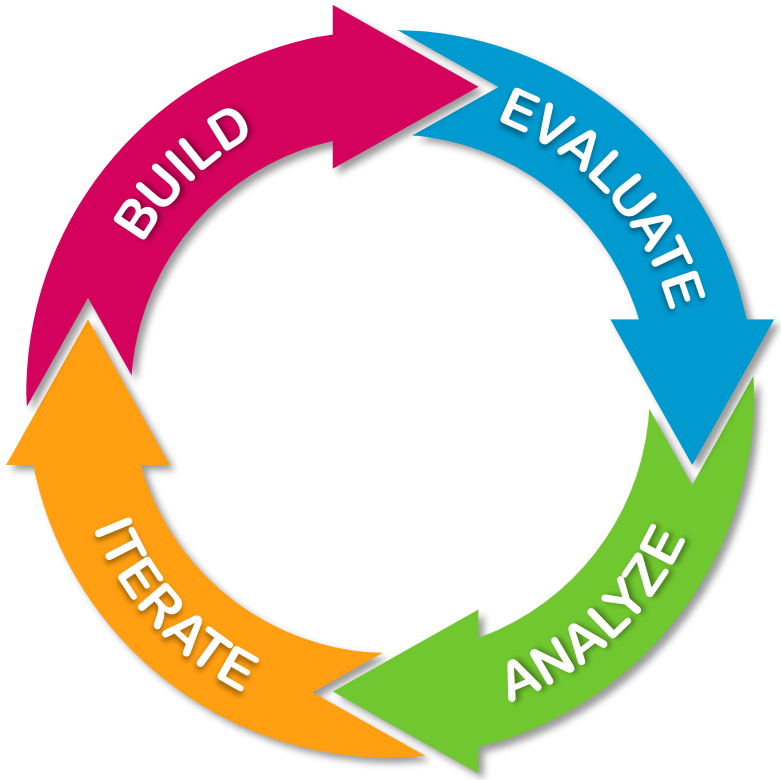
- Artemis Bag – passive fecal collection system based on the Apollo Bag with improvements (odor control, containment and crew interfaces)
  - Seat interface with a single-use bag that attaches over the seat (reduce fouling)
  - Reusable seat with hand-holds to assist in positioning
  - Bag includes “aid” to assist with initial fecal separation
  - Once used, bag is removed from seat, closed (drawstring) and stored
- Backup Urine System (BUS) – passive urine collection system
  - Based on the Orion-developed Collapsible Contingency Urinal (CCU)
    - Demonstrated on ISS to determine functionality and overall performance
  - Hand-held device with a crew interface (male and female) and bag to collect urine; one-time use bag for HLS
  - Relies on capillary action to draw urine away from the body and down to the bottom of the bag
    - Hydrophobic and hydrophilic materials also aid in urine collection
- Artemis Bag and BUS will be used in the event of a primary system failure

Artemis Bag with “wipe” feature to aid in initial fecal separation

High-fidelity prototype of the Collapsible Contingency Urinal (CCU) hardware (with male interface)

Human-in-the-Loop (HITL) Testing Process

- Establish a standard process
  - Consistent data collection and analysis
  - Maintains test subject privacy
  - Removes any potential bias from test subject to test subject
- The LOO project developed a ***Crew Evaluation Process Memo***
  - Documents all the steps to complete each evaluation
    - How to request test subject participation (specific to NASA-JSC)
    - Process and approvals for safety-related reviews
    - How to conduct evaluations, and
    - Data collection, analysis and documentation



Standardized HITL Process → Consistent & Valuable Feedback → Successful Design Iterations

Human-in-the-Loop (HITL) Testing Process

Hardware is ready for evaluation…
What is the next step?

Data Capture

- *Develop Questionnaire:*
  - Standardizes data collected
  - ***Ask "What are you trying to learn?" → Criteria***
- *Four types of data:*
  - Criteria Rating: Likert Scale (1-5)
  - Criteria Importance: How important for overall use
  - Criteria Rankings: If multiple design are evaluated
  - Open Comments/Feedback

HITL Testing
(a.k.a. Crew Evaluations)

- *Conduct "Mock" Evaluation (project team):*
  - HW familiarization & Questionnaire review
  - Conduct evals the same (overview, questions, and feedback)
- *Prior to first evaluation:*
  - *Safety walk-through (facility and HW)*
  - *Final dry-run (1-2 days before first eval)*

Final step → Conduct Evaluations!

Data Analysis

- *Criteria Ratings – Averaged and weighted across test subjects*
  - *Determines if design is an acceptable solution*
- *Criteria Rankings – Tallied to determine overall best design*
- *Open Comments/Feedback* → ***Most Valuable data to project***
- *Evaluation Summary Memo:*
  - *Used to determine next iteration*
  - *Includes:*
    - *Tabulated/analyzed data*
    - *Initial findings/interpretation*
    - *Comments collected during evaluations*

Iterate Design

Use data analysis/results to identify design updates

Crew Evaluation Overview

- Project has completed four crew evaluations since 2020
- Total of 38 evaluations completed
  - Many test subjects were repeat evaluators; provides continuity throughout design iteration
  - Male and female test subjects (with varying space flight experience)
  - Evaluation #1: February 2021
    - 14 test subjects
    - Objective: Evaluate initial LOO hardware designs for Toilet Assembly and Artemis Bag (low-fidelity)
  - Evaluation #2: February 2022
    - 8 test subjects
    - Objective: Evaluate Artemis Bag concepts
  - Evaluation #3: June 2022
    - 10 test subjects
    - Objective: Evaluate preliminary Toilet Assembly design
  - Evaluation #4: September 2022
    - 6 test subjects
    - Objective: Evaluate 1) updated Artemis Bag design, 2) BUS hardware 3) simo ops with backup systems

Crew Evaluation #1 Results

- Toilet Assembly
  - Prototypes for 2 toilet structures and 3 seat options were evaluated
- Primary design features evaluated:
  - Overall seat shape and comfort
  - Fecal bag interface and placement
  - Restraint types
- Results/Preferences
  - Smallest seat opening size with a saddle shape
  - Fecal Bag attached over the seat
  - Elastic as the method for bag closure and interface to seat
  - Access to both foot and hand restraints
  - *Emphasis on "making all components easy to clean"*

Example of Questionnaire Criteria and Likert Rating Scale (including Criteria Importance)

Rate the design on following criteria:

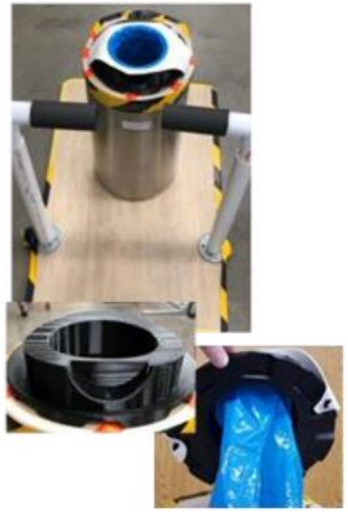
Completely Unacceptable 1 — 2 — 3 Neutral — 4 — 5 Completely Acceptable

Importance scale: (N)ot Important -> (S)omewhat Important -> (I)mportant -> (V)ery Important

Criteria	Design 1	Notes / Importance of this criteria
Interface:		
Ability to align to body		N S I V

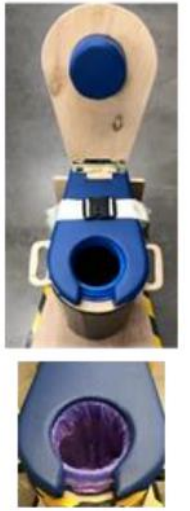
Evaluation #1 - Toilet Assembly low-fidelity prototypes

Toilet/Seat/Bag Design 1



Toilet/Seat/Bag Design 2

Toilet/Seat/Bag Design 3



Crew Evaluation #1 - Results

- Artemis Bag
  - 4 concepts were evaluated
- Primary design features evaluated:
  - Mounting method/interface
  - Restraint types
  - Closure Method
  - Method for initial waste separation (from body)
- Results/Preferences
  - Options for attaching bag to body in different ways
  - Waist restraint for securing to body
  - Drawstring for bag closure
  - Method to manually wipe/squeeze from outside of bag for initial separation

Evaluation #1 - Artemis Bag low-fidelity prototypes (4 designs)

Crew Evaluation #2 - Results

- Artemis Bag - 3 concepts evaluated (2nd design iteration)
  - "Mix-&-match" features for a final design
- Primary design features evaluated:
  - Ability to align and secure HW during ops
  - Effective waste separation
  - Ability to enclose waste and ease of cleanup after use
  - Restraint types
- Results/Preferences
  - Elastic for closure method
  - Hand "cot" (like Apollo Bag finger "cot") for initial separation
  - Access to foot restraints
  - Minimize features that would be difficult to clean

Evaluation #2 – Artemis Bag prototypes (3 designs)

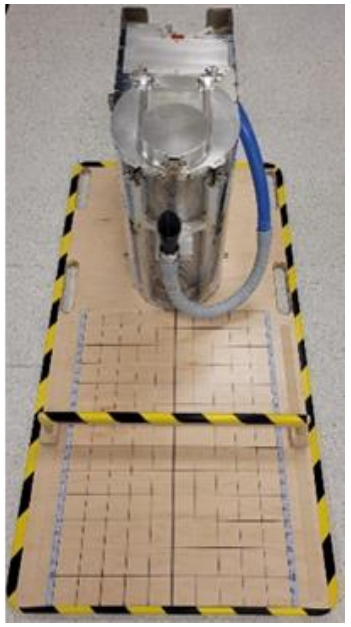
Based on these results, 2 Artemis Bag designs were taken forward as potential solutions

Evaluation #2 – Design feature summary table

Features		AB Design #1	AB Design #2	Not Moving Forward
Bag Features	Primary Closure	Elastic	Drawstring	Twist and Secure
	Secondary Closure	Fold and Secure	Peel and Stick	Ziploc

Crew Evaluation #3 - Results

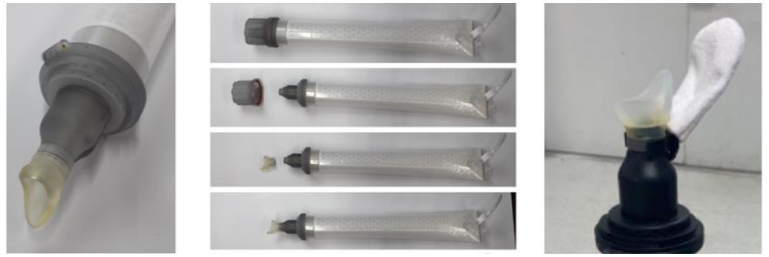
- Second design iteration for the Toilet Assembly was evaluated
  - Low-to-medium fidelity prototypes for components
- Primary design features evaluated:
  - Seat features (shape/width, comfort)
  - Fecal bag closure
  - Urine hose length
  - General component layout
  - Ease of cleanup
- Results/Preferences
  - General acceptance of seat shape/placement to support simo ops
  - Fecal bag drawstring closure was acceptable
  - Acceptable hose length, although some comments on making it longer
  - Several comments on improving overall cleanliness (reducing crevices)
  - *In general, comments were mostly positive for the overall design*



Evaluation #3 – Toilet Assembly prototype

Crew Evaluation #4 - Results

- In evaluation #4, test subjects evaluated 2 Artemis Bag design concepts and the BUS concept
- Primary design features evaluated:
  - For BUS, subjects provided general feedback on the menses collection device and simo ops with Artemis Bag
  - Artemis Bag
    - Bag operations (attachment, removal and closure)
    - Ability to align to body and maintain control
    - Fecal separation aid
    - Ease of cleanup
- Results/Preferences
  - Overall acceptance of BUS concept (based on Orion CCU)
  - Elastic drawstring for closure
  - Wipe for fecal separation
  - General acceptance of hand-held seat
    - Preference for wall-mounted option to support simo ops



Backup Urine System prototypes (female interface)

AB Design 2

AB Design 1

Secondary/Odor Bag

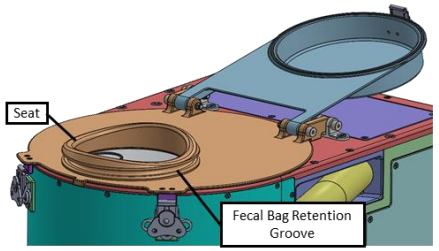
AB Seat

Artemis Bag prototypes - 2 designs including hand-held and wall-mounted seat

AB Seat Wall Mount

Project Status and Conclusions

LOO Seat and Fecal Bag interface (in development for ISS UWMS)



- In January 2023, the LOO project was put on hold
  - Completed preliminary design phase
  - Current work
    - Seat and fecal bag mods for the ISS UWMS (based on LOO HW)
    - Perform a technology demonstration for feedback on usability and system performance
    - If successful, will build hardware for Orion Artemis-2 UWMS
- HITL testing has been vital to the successful development of the LOO design
  - 38 evaluations completed over the 4 evaluation periods (many repeat evaluators)
    - Repeat evaluators provide continuity throughout design iteration
    - Test subjects see the results of their participation and feedback
- Space toilets are not easy; every person will use it slightly different
  - Solicit input often and early in every design phase
  - Utilize the end user as test subjects when possible → provided invaluable data on how system will be used
- Establishing a standard process is key for successful HITL testing

Questions/Feedback

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