Fast Actuating Rectum Transfer Exit Device (FARTED)

NASA's Lunar Loo Challenge

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Chapter 1

Introduction

As NASA prepares to return to the Moon, innumerable activities to equip, shelter, and otherwise support future astronauts are underway. These astronauts will be eating and drinking, and subsequently urinating and defecating in microgravity and lunar gravity. While astronauts are in the cabin and out of their spacesuits, they will need a toilet that has all the same capabilities as ones here on Earth. NASA is calling on the global community for their novel design concepts for compact toilets that can operate in both microgravity and lunar gravity. These designs may be adapted for use in the Artemis lunar landers that take us back to the Moon. Although space toilets already exist and are in use (at the International Space Station, for example), they are designed for microgravity only. NASA's Human Landing System Program is looking for a next-generation device that is smaller, more efficient, and capable of working in both microgravity and lunar gravity. This challenge includes a Technical category and Junior category.

It is in this calling of this unique challenge that we wish to provide a solution that is both functional and innovative. This document will provide our design rationale, the functionality of the product, and how this design has innovated prior designs.

1.1 Overview of Space Waste Collection Systems

Space Waste Collection Systems(WCS) are the implementation of Earth toilets in a microgravity environment. However, easier said than done while in microgravity there poses a challenge of transporting and storing human waste. While in microgravity, fluids are pulled together through its surface tension causing the mundane task of transporting anything through a fluid system a non-trivial task. As a result of this non-trivial task, this seemingly simple task on Earth becomes a very intensive engineering project that cannot be overlooked.

1.1.1 Apollo Waste Collection System

During the age of Apollo, minimal work went into designing an effective waste collection system resulting from the difficulty of even obtaining a low Earth orbit. As a result the astronauts on-board would collect and dump urine overboard instead of storing the urine.

However, collecting urination from the astronauts was simple enough, collecting fecal matter is what proved to be most difficult. In order to avoid the troubles of defecating in space, many astronauts while in space would eat less of their rations to avoid the troubles of defecating in microgravity.

> In the absence of a system providing positive means for the removal of feces from the body, an extremely basic system had to be relied upon for inflight fecal collection. The device used was a plastic bag which was taped to the buttocks to capture feces. After defecation, the crew member was required to seal the bag and knead it in order to mix a liquid bactericide with the contents to provide the desired degree of feces stabilization. Because this task was distasteful and required an inordinate amount of time, low residue foods and laxatives were generally used prior to launch. During flight, in addition to low residue foods, some use was also made of drugs to reduce intestinal motility.[6]

Figure 1.1: Apollo urine transfer system.

Above in Figure 1.1 in which it had two main purposes: 1) dumping during time of voiding, and 2) dumping subsequent to voiding. This was a simple design but was only suitable for those with male appendices, thus this method is not suitable for the Lunar Loo Challenge.

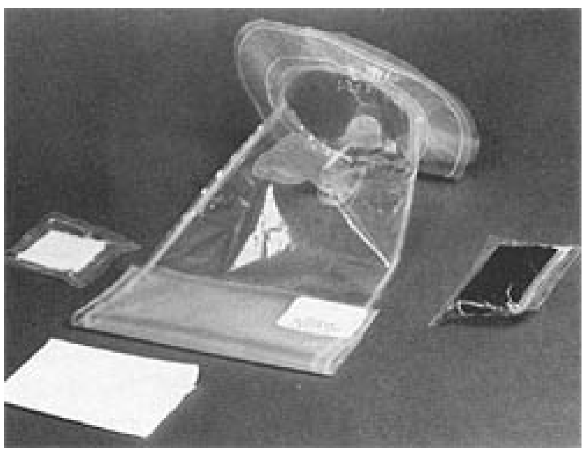

Figure 1.2: Apollo fecal bag for defecating in microgravity.

As shown above in Figure 1.2, the bag used to collect astronaut defecation's was rudimentary in design resulting in many of the astronauts being in great discomfort when defecating. This bag was placed over the anus of the astronaut, and would be sealed after use to prevent the spread of bacteria and pathogens. Again, like before this is not a suitable design for the Lunar Loo Challenge as this design is not reusable and may result in unwanted transfer of pathogens.

1.1.2 NASA's Skylab Waste Collection System

After the Apollo Era, attention in space was shifted to more long duration missions. These missions where based on Skylab, essentially the first manned space station in which many microgravity experiments took place and studies were conducted on the effects on the human body.

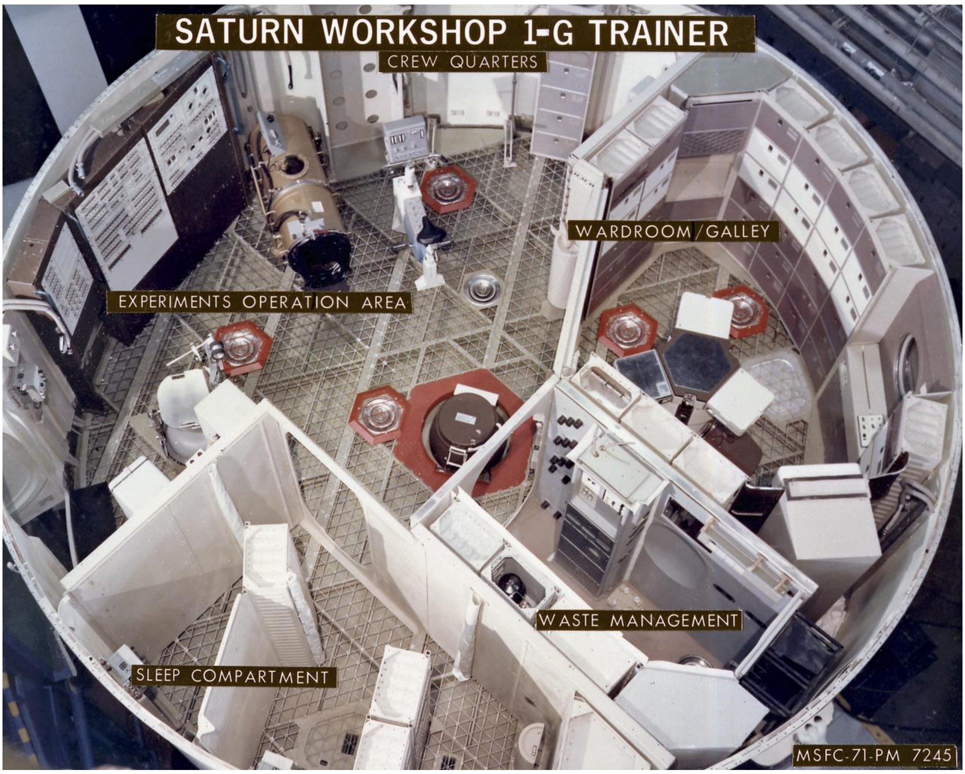

Figure 1.3: Overview of NASA's Skylab trainer crew quarters.

Above in Figure 1.3 is the layout of Skylab workshop 1-G trainer crew quarters. The section labeled "WASTE MANAGEMENT" was the first implementation of a space waste management system instead of the more "manual" methods first demonstrated during Apollo.

Essentially the space toilet was a small hole in the wall with a fan to direct airflow to pull in any urine and fecal matter. After defecating, Skylab would vacuum-dry their feces with heat to kill any pathogens and then be dumped into a waste tank or be studied for scientific purposes.[2]

1.1.3 Space Shuttle's Waste Collection System

The toilet on the space shuttle was the first implementation of a space toilet and as such it was not easy to use. The opening was less than 4 inches wide, which is significantly smaller than a toilet on Earth.

Figure 1.4: Space Shuttle's waste collection system.

As shown above in Figure 1.4, this design was inspired by western style toilets but had its appropriate variations. This toilet was outfitted with fasteners to hold down the astronauts to prevent them from floating off while using the toilet. Then a vacuum-cleaner-like machine (not pictured) would suck up the wastes from the astronauts where the waste would later be vacuum dried before storing.

Again, this was the first implementation of a space toilet, so there remained several key issues that needed improving such as.[4]

1. No paper was allowed in the toilet, and had to be thrown out separately
2. Astronauts had to be "toilet trained" on Earth, this training device included a camera to perfect their aim

1.1.4 Soyuz Waste Collection System

The Soyuz waste collection system is fairly simple in design taking a rather small form factor while remaining relatively functional. This design implements a vacuum suction to gently pull urine or fecal matter to the waiting filters to the storage containers.

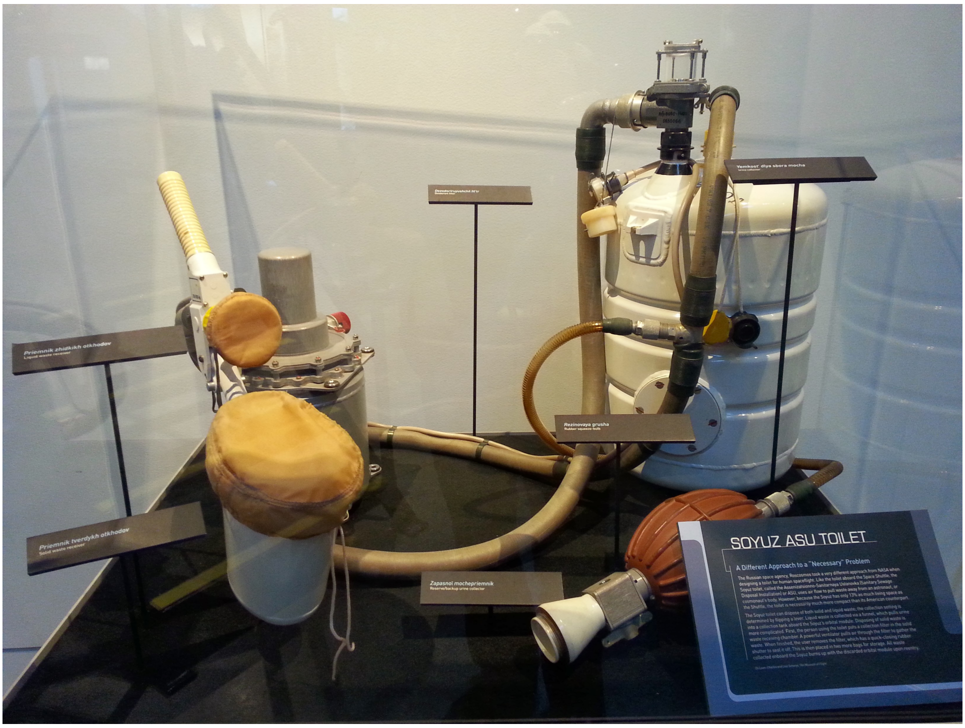

Figure 1.5: Soyuz waste collection system.

Shown above in Figure 1.5, is the Soyuz implementation of a waste collection system that is extremely space efficient. This simple system has a small funnel that can aid in defecating and a small "urinal" for when urinating. However, as with all the other designs this design falls short when considering the compatibility between men and women.[1]

1.1.5 International Space Station Waste Collection System

Figure 1.6: ISS waste management and water recovery system.

More advancements were made from the space shuttle and this resulted in the waste and hygiene compartment. This system would allow the unit to separately channel liquids and solid waste and store each separately. The solid waste would go to a holding tank whereas the urine would go to a recycling program to turn the crew members' urine into drinkable water. [5]

As shown to the left in Figure 1.6, the toilet had simplified in design and was interfaced with a water recovery system to allow for reclamation of waste water. This is an essential service for space travel since water is dense such that transporting it to space is costly and cost-analysis shows that reclamation is more cost effective long term.

Again, like the other waste collection systems, this system is based around vacuum suction to direct the waste to storage. However, where this design falls short is that it has separate attachments for men and women when absorbing urine. [3] In this case the Lunar Loo Challenge would like one design that accommodates both men and women without the need of external attachments.

References

[1] Clayton C. Anderson. "Where do Astronauts go to the Toilet in the Soyuz". In: (2017).

[2] Hillary Brueck. "A Brief History of How Astronauts Have Gone to the Bathroom in Space for 58 Years". In: (2019).

[3] Rebecca Harrington. "How Astronauts go to the Bathroom in Space". In: (2016).

[4] JAXA Japan Aerospace Exploration Agency. "How do toilets work in space?" In: (2003).

[5] Cheryl L. Mansfield. "Behind The Scences". In: *International Space Station* (2008).

[6] Richard L. Sauer. "SP-368 Biomedical Results of Apollo". In: Lyndon B. Johnson Space Center, 1975. Chap. 2, pp. 469–484.

Chapter 2

Lunar Loo Challenge

Artemis is NASA's program to land the first woman and the next man on the Moon by 2024. Humanity is going back to the Moon to establish a presence that will enable eventual crewed journeys to Mars. As we prepare for our return to the Moon, innumerable activities to equip, shelter, and otherwise support future astronauts are underway. These astronauts will be eating and drinking, and subsequently urinating and defecating in microgravity and lunar gravity. While astronauts are in the cabin and out of their spacesuits, they will need a toilet that has all the same capabilities as ones here on Earth.

This challenge seeks to radically change current lunar space toilets to reflect the technological advances that NASA wishes to achieve throughout Artemis's mission timeline.

2.1 Challenge Overview

Figure 2.1: NASA's Lunar Loo challenge, hosted by a collaboration between hero^x and NASA Tournament Lab (NTL)

NASA is calling on the global community for their novel design concepts for compact toilets that can operate in both microgravity and lunar gravity. These designs may be adapted for use in the Artemis lunar landers that take us back to the Moon. Although space toilets already exist and are in use (at the International Space Station, for example), they are designed for microgravity only. NASA is looking for a next-generation device that is smaller, more efficient, and capable of working in both microgravity and lunar gravity. Getting back to the Moon by 2024 is an ambitious goal, and NASA is already working on approaches to miniaturize and streamline the existing toilets. But they are also inviting ideas from the global community, knowing that they will approach the problem with a mindset different from traditional aerospace engineering. This challenge hopes to attract radically new and different approaches to the problem of human waste capture and containment.

2.2 Lunar Loo Requirements

Driving new technological advances often times result from system requirements and the Lunar Loo challenge is no exception. Thought to be a trivial task, designing a toilet that offers services accommodating to many while in microgravity does indeed require attention to detail and knowledge of the microgravity environment.

2.2.1 Toilet Design Specifications

The specifications listed below represent the maximum allowed values. Proposed designs should at least meet them and will preferentially be lower than them. The toilet design should:

- Function in both microgravity and lunar gravity
- Have a mass of less than 15 Kg in Earth's gravity
- Occupy a volume no greater than 0.12 m^3
- Consume less than 70 Watts of power
- Operate with a noise level less than 60 dB (an average bathroom fan)
- Accommodate both female and male users
- Accommodate users ranging from 58 to 77 inches tall and 107 to 290 lbs in weight

2.2.2 Toilet Performance Specifications

We are looking for a design that captures all the functionality of a toilet on Earth. At a minimum, crew using lunar toilets should not be exposed to vacuum during use, and toilet designs should be able to:

- Accommodate simultaneous urination and defecation
- Collect up to 1 liter of urine per use, with an average of 6 uses per crew per day
- Accommodate 500g of fecal matter per defecation, with an average of 2 uses per crew per day
- Accommodate 500g of diarrhea per event
- Accommodate an average of 114g of female menses, per crew per day
- Stabilize urine to avoid the generation of gas and particulates
- Accommodate crew use of toilet hygiene products, like toilet paper, wipes, and gloves
- Be clear of previous user's urine and feces in preparation for the next use
- Allow for transfer of collected waste to storage and/or provide for external vehicle disposal. Minimal Lander volume requires regularly minimizing waste storage or removing it from the vehicle
- Allow for easy cleaning and maintenance, with 5 minute turnaround time or less between uses

Additionally, in the event of system failure, the design will ensure that:

- All waste materials collected remain safely stored
- The crew is not exposed to urine, feces, or other collected materials
- The crew is not exposed to vacuum

Chapter 3

Fast Actuating Rectum Transfer Exit Device (FARTED)

Short description of design

3.1 Overview of Waste Collection System

3.1.1 Working in Microgravity

Please discuss in detail how your design will work in both microgravity and lunar gravity

3.1.2 Implementation for All Genders

Please discuss in detail how your design will accommodate female and male crew

3.1.3 Design Versatility

Please discuss in detail how your design be easy to use and maintain, with low noise

3.1.4 Transferring Collected Waste to Storage

Please discuss in detail how your design allow for transfer of collected waste to storage or external vehicle disposal

3.2 Accommodations of Waste Collection System

3.2.1 Waste Containment

Please discuss in detail how your design will capture and contain urine, feces, vomit, diarrhea, and menses,

3.2.2 Stabilizing Urination

Please discuss in detail how your design will Stabilize urine

3.2.3 Functionality of Waste Containment System

Please discuss in detail how your design will accommodate simultaneous urination and defecation,

3.2.4 Lifetime

Please discuss in detail how your design will accommodate the needs of 2 crew members for 14 days,

3.2.5 Integration with Hygiene Products

Please discuss in detail how your design will accommodates the use of toilet hygiene products,

3.2.6 Time of Turn Around

Please discuss in detail how your design will clears previous waste content prior to next use,

3.2.7 Mission Lifetime

Please discuss in detail how your design will defines how often the collections system must be replaced or disposed of in the mission

3.3 Safety Measures of Design

3.3.1 Minimizing Contact with Waste

Please discuss the safety measures in place to ensure that during nominal use or in the event of a system failure crew handling of waste materials during maintenance or system use is minimized

3.3.2 Isolating System from Vacuum

Please discuss the safety measures in place to ensure that during nominal use or in the event of a system failure crew members are not exposed to vacuum

3.4 Technical Maturity

Please discuss the technical maturity of your proposed toilet design. What TRL would you assign it? Please provide a supporting rationale and/or evidence for this rating. Why do you believe this could be developed and integrated into a lunar rover in the next 2-3 years?

3.5 Technical Judging

- Proposal Quality Quality of proposal: clear, concise writing; thoughtful and complete explanations of how the proposed toilet design concept meets the specifications listed; accompanying CAD file (or other file format) is clear and complete. [10 pts]
- Capabilities - Usage
  Overall technical feasibility of the proposal toilet design.
  Compatible for use by both female and male crew members.
  How well does the design address issues like ease of use, odor control, noise, and turnaround time.
  Likelihood that it will function in both microgravity and lunar gravity when prototyped.
  How easy will it be to adapt the design for integration into a lunar rover. [20 pts]
- Capabilities - Capacity Likelihood that it can successfully meet the performance specifications when prototyped, capturing:
  - Urine (and stabilizing it)
  - Feces (accommodating simultaneous urination and defecation)
  - Diarrhea
  - Vomit
  - Menses

  Likelihood that it can accommodate the needs of 2 crew members for 14 days.
  Defines how often the collections system must be replaced or disposed of in the mission [20 pts]
- Technical Maturity The likelihood that proposed toilet design can be developed and integrated in the next 2-3 years.
  Quality of the explanation and supporting evidence for why a solution is designated at a particular maturity level. [20 pts]
- Safety Confidence that proposed design will minimize the crew handling of crew waste during maintenance or system use in all mission environments, and will not expose crew to vacuum in the event of a system failure. [20 pts]
- Innovation Novelty or creativity of proposed approach.
  Elegance of design.
  Describe how the innovation overcomes limitations and constraints of existing technologies or commercial products. [10 pts]