Microgravity diaper- Space diaper for Astronauts

Behavioural research | Industrial design | UX design | prototyping

Company Human Space Flight Center, HSFC- ISRO, Bengaluru

Duration 4 months (Feb'24 - July'24)

My Role Design researcher and Industrial designer, Individual project

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Mentor Sunil Kumar, Dy Biomedical department head | Dr. EVS Kiran Kumar Donthu, Assistant Professor, IIT (BHU), Varanasi

Background
Indian Space Research Organization (ISRO) is India's national space agency and Human Space Flight Center (HSFC) is a branch responsible for the implementation of Gaganyaan Project, India's first manned space mission. HSFC looks after end-to-end mission planning, development of Engineering systems for crew survival, crew selection & training and also pursue activities for sustained human space flight missions.

The Gaganyaan is a orbital spacecraft designed to carry a 3-member crew to an orbit of 400 km for a duration of 3 days and safely return to the Earth, by landing in Indian sea waters.

The Problem
What is often overlooked in the glamour of space mission is unglamorous bodily waste management systems. This happened during the early NASA missions- Gemini, Apollo. Neglecting these essential functions affected mission success and astronaut performance directly. Failure to completely and effectively capture waste can result in not only unhygienic or unpleasant conditions but also result in the spread of substantial quantities of bacterial contamination, noxious odour problems.

Goal
To design a diaper, by studying the journey of the Astronauts and addressing the pain points to minimize difficulty of use.

Design Brief provided-
HSFC was looking to redesign configuration of a wearable toilet (diaper) for astronauts which is easy to remove and put on, in a microgravity conditions without spilling the waste.

Project Timeline and deliverables

(18 + 1 weeks)

12th Feb		16th June	July 1st week
Secondary research • Studied evolution of space wearable toilet devices • Product archetype- Diaper • Product benchmarking • Material interaction study • Human factors study	**Generative Research and Research Analysis** • Scenario storyboarding • Emotion mapping • Pain points • User needs **Primary Research** • Behavioural mapping • Iteration • System level solution	**Ideation, Iteration, prototyping** • Sketches • Rapid prototyping • Testing	**Final Design Development** • Final prototype making **(Final Output Delivered)**	**Post Project completion development** • System intervention
4 weeks	**3 weeks**	**9 weeks**	**2 weeks**	**1 week**

Design Process

I started by studying three areas parallelly- the product (diaper), the place (spacecraft) and the person (astronaut). Then interaction of all three.

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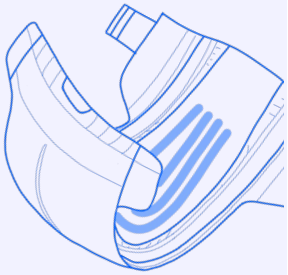
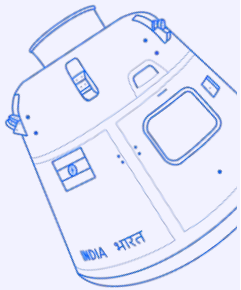
1. Diapers and Wearable Space Toilets



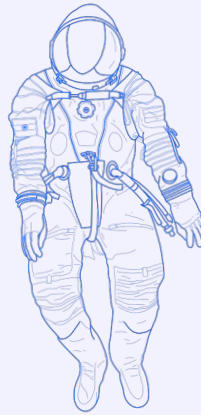
- Deconstruction of a diaper- Material and layering
- Working principle- capillary action
- Types and usage
- Adult and baby diapers market research and benchmarking
- Evolution of wearable space toilets
- Understanding existing space diaper

2. Spacecraft



- Interior of gaganyaan spacecraft
- Material behaviour and interaction study- liquids, solids, and gases

3. Astronauts



- Studying the IVA (inter vehicular activity) space suit
- Interaction with the suit- method of wearing and removing
- Human factors data- Physiological data, anatomical measurements

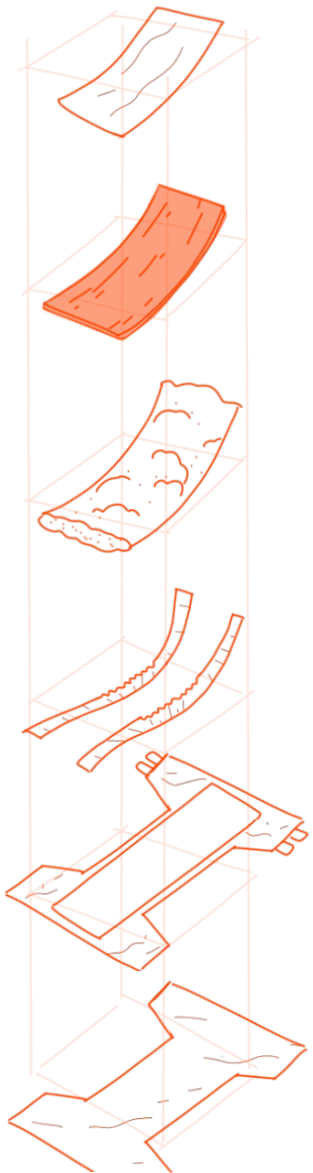
Interaction of all three

Case studies from Apollo and Gemini missions to understand the challenges faced while using the existing waste management products

1. Diapers

I looked at the past and present of commercial as well as space diaper. Also studied their usage.

Deconstruction of a diaper
Purpose- To understand Materials and layering



The hydrophobic top-sheet
Large cavities to quickly soak up liquid and wick it away from the users skin

The surge layer/ A&D layer
Smaller cavities that absorb the liquid and distribute it evely

Core absorbent
layer made of paper or wood pulp and SAP, that absorbs the liquid and converts it into solid gel

Leg Cuffs
Along the edge of the diaper is elasticized leg cuffs, that contain the solid waste from spilling from the sides

Back sheet
It is the liquid barrier

Microfibre outer layer
The outermost layer feels just like a cloth for the comfort of the users.

Evolution of wearable toilets
Purpose- understand history

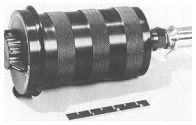
1960s

Urine collection assembly, UCA

Urine transfer assembly, UTA

Faecal collection assembly, FCA

Faecal containment system, FCS

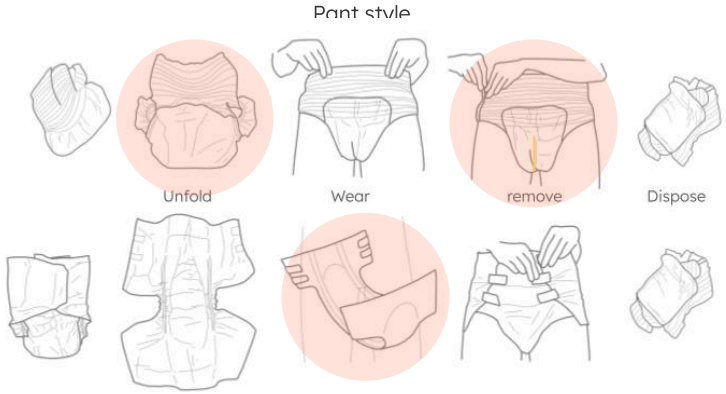


Urine receptacle assembly, URA

1990s

Maximum absorbency garment, MAG (First diaper ever made)

Usage of diaper (Highlighted- Ease of use)
Purpose- Understand pain points and opportunities



Summary-

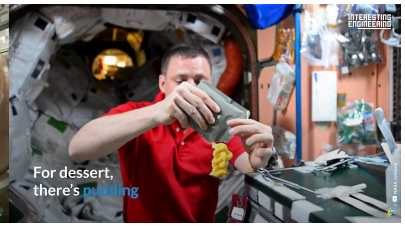
- Diapers utilize capillary action by engineering the pore sizes and layering them in the order of large at top and small at the bottom that creates a one way channel for liquid
- Baby Diapers have more variety in padding structure and top sheet texture, while adult diapers have good absorbency capacity of up to 1.2 litres while being discreet
- Out of 6 space wearable toilets studied, only 2 are compatible with IVA suit- MAG, UCTA and only MAG collects both types of waste, is user friendly and gender inclusive

2- Spacecraft

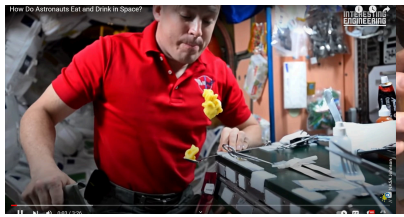
Study of the spacecraft focused on the clearance space around the astronauts to perform activities, and understanding material behaviour in micro-gravity.

Numerous YouTube videos of astronauts were watched for these material behaviour insights.

Water sticks to any surface it comes in contact with and form blogs around it, displaying jello like behaviour. When disturbed tiny droplets scatter and fly in all directions.



The semi- solid material tends to stack onto itself creating a tower.



Gases tend to linger for longer duration

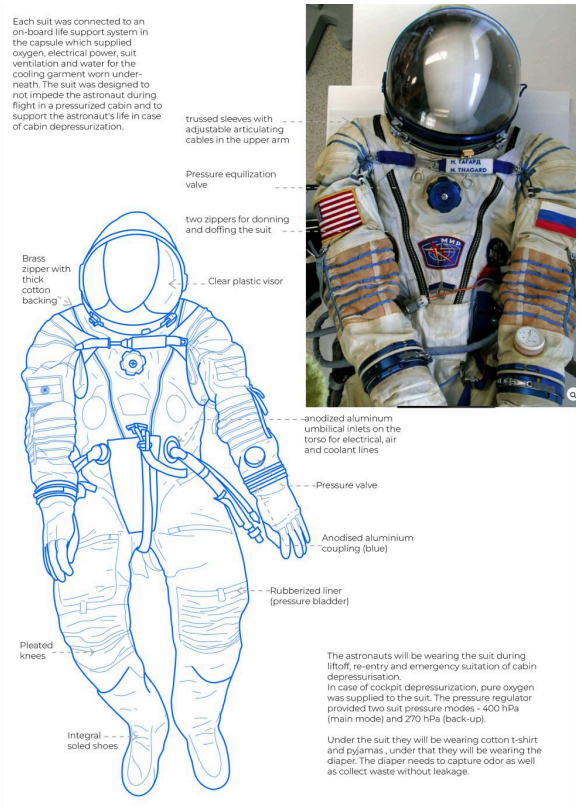
The semi- solid material like honey is impossible to remove from a surface. it acts like slime.

The material interaction study highlighted some key behaviours that the material demonstrated in microgravity. These behaviours further helped in designing features for the end product.

3- Astronaut

This involved study of the space suit to understand diaper interaction with it, ergonomic and technical considerations. Also studies the human factor data- anatomical, physiological.

To better understand the diaper's interaction with the suit astronauts will be wearing, this study focused on the suit's layering and openings for donning/doffing and the human body and bodily waste- Anatomical and physiological data



Anatomical data

Anatomy	Description	Dimension Range (Male)	Dimension Range (Female)
A	Lateral separation of ischial tuberosity	10 - 14 cm	11 - 16 cm
B	Width of perineal furrow	7.5 - 9 cm	7.5 - 9 cm
C	Anterior and posterior separation between tuberosities and exterior urethral opening	13 - 27 cm	6 - 9 cm
D	Anterior and posterior separation between anus and external urethral opening	15 - 30.5 cm	9 - 11.5 cm

Physiological data

Waste Type	Average Per Event	Maximum Per Event	Duration/Frequency
Faeces	Vol : 150 mL Mass : 150 g Length : 4-23 cm	Vol : 500 mL Mass : 500 g Length : 33 cm	Average of 2 events per day
Diarrhea	Vol : 500 mL Mass : 500 g	Vol : 1500 mL Mass : 1500 g	8 events per day for up to two days
Urine	Vol : 100-500 mL Flow rate : 10-35 mL/S Mass : 100.7-513.8 g	Vol : 1000 mL Flow Rate : 50 mL/s Mass : 1027.6 g	Average of 6 events per day
Vomitus	Vol : 500 mL Mass : Varies depending on stomach content	Vol : 1000 mL Mass : Varies depending on stomach content	8 event per day for up to three days in-flight and post-landing
Menses per cycle	Vol : 30- 50 mL Mass : see footnote	Vol : 114 mL Mass : see footnote	Approx. 80% released within the first 3-4 days

Source-
NASA STD 3001 VOL2

Suit and human factor data study gave specifications for designing the diaper.

Interaction of all three

Use case 1 (Fecal collection assembly)

"Give me a napkin quick, there's a turd floating through the air."- Astronaut Tom Stafford

Problem- Solid waste escaping the collection bag

Touch points of escape-

1. Improper adhesion to the body
2. Escaping the collection bag while detaching it from the body
3. Waste matter stuck to body
4. Improper disposal bag seal

Identified Pain points-

- Improper fit
- Inadequate capturing of the waste during and post activity
- No means of post activity inspection

Use case 2 (Fecal collection assembly)

"The task of manually manoeuvring the waste was so distasteful that astronauts would avoid defecating all together"- One of the Apollo astronauts

Problem- Undesirable manual manoeuvring of the waste to slow down the process of off-gassing

Touch points of escape-

1. Kneading of waste with germicide

Identified Pain points-

- Undesirable manual manoeuvring of the waste
- Disinfecting waste manually
- Continuous presence of odour

Use case 3 (Urine collection and transfer assembly)

"Urine spills were quite frequent and roll on cuff had to be dried and frequently replaced to prevent disease like UTI. This created a new challenge for a product that was supposed to be used hands free and suited."- One of the Apollo astronauts

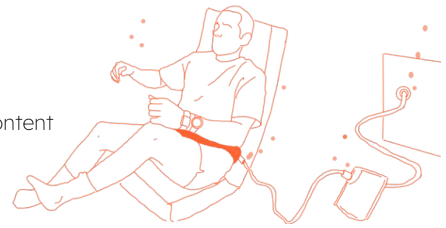
Problem- Urine containment and leakage
Intimate contact with the device

Touch points of escape-

1. Multiple quick fittings
2. Non reliable roll on cuffs that damage easily

Identified Pain points-

- Leakage from multiple quick fittings
- Odor and potential contamination from leaked urine content
- Infection risk from intimate contact with the device
- Lack of Replacement indicator
- Multiple issues preventing hands free use



This phase of the project required studying different scenarios from users pov through reports, videos, books, news articles and speaking with the astronauts. 5 main use cases were identified for the use of diaper and pain points where listed.

Primary research

After a long discussion with Astronaut Prasanth Nair (Group Captain), K. Kumar (ISRO Associate Director), a few other department heads from HSFC and ISRO, two more use cases were created from the training experience of the Astronauts. These use cases emphasized on psychological discomfort and highlighted issues like Privacy.

Use case 4

Problem- Soiling diaper and changing it while being in the seat, next to the other astronauts

Touch Points-

- Soiling while seated without visual privacy next to another astronaut.
- Close proximity increases cross-contamination risks.
- Giving a heads-up for privacy during and after the activity.
- Odour and sound during the process.
- Securing a comfortable position and accessible surface to minimize mess and speed up replacement.
- Distance to disposal bin from all seats.

Pain Points-

- Lack of privacy barriers around seats.
- Discomfort in giving heads-up for privacy.
- Embarrassment and psychological barriers due to odour and sound.
- Need for restraints and a surface to keep items organized.
- Inaccessible disposal bin for all crew members

Space waste management system pain points

Faeces collection related issues	**Inadequate capturing of faeces-** There is a risk of faeces escaping the collection system during, or after the process. This could lead to contamination of the spacecraft (FCS)	**Intimate contact with faeces-** Being in intimate contact with the faecal waste can cause infection and skin irritation. (MAG)	**Ensuring proper clean up-** Often the faeces would soil the cabin surfaces, the crew and their clothing, leading to unsanitary living space. (FCS)	**Off-gassing-** The bacteria in the waste would produce gases and might cause leaks. To slow down the process waste need to be disinfected with germicide. (FCS)
Urine collection related issues	**Leakage-** Collecting and containing urine has been challenging, spills cause odour and contamination. (UCTA)	**Infection-** Wearing a urine soaked product in close contact with the skin can cause UTI. (UCTA, roll on cuff)	**Non gender inclusive-** To prevent frequent changing personalised UCTA device was designed, only for men	
Time related issues	**Multiple waste processing step-** Defecation might require a long time, if astronauts are to manually manoeuvrer stuff, this also impacts crew's performance (FCS)	**Extreme case scenario-** In an extreme case scenario, the astronauts can't rely on diapers incase they need to spend all three days in the IVA suit. (MAG)	**Frequent replacements-** Low capacity or damage from wearing might require frequent replacements (UCTA)	
Unpleasant experience	**Constant odour-** Devices often did not absorb odour and hence the shuttle would smell bad most of the day due to off-gassing (FCS and UCTA)	**Manual manoeuvring of the waste-** The astronauts did not like it when they had to manually mix germicide with the faecal waste (FCS)	**Unintuitive use-** Bad ergonomic fit with multiple fitting of a device cause an overall bad experience (FCS and UCTA)	**Suited use-** Devices that can only be used unsuited required waiting for 'use time intervals' causing discomfort. (FCS)

Adult diaper use pain points

Physical discomfort and health issues	**Skin irritation-** Prolonged contact with the moisture and friction can cause rashes and infections	**Uneven liquid distribution-** Gravity pools urine in the centre of a diaper, making it bulky	**Discomfort-** Non breathable materials of the diaper traps heat and causes discomfort
Hygiene and maintenance	**Odour-** Odour containment becomes challenging in hot and humid climate and need frequent changing	**Leakage due to compression-** As the diaper gets saturated compression causes it to leak	
Functionality	**Positioning-** Tape style diapers are difficult to position and wear individually	**Side and back leakage-** The leg cuffs only prevent solid waste from spilling and not the liquid waste	
Emotional experience	**Low self esteem-** People experience embarrassment and social stigma from wearing diapers causing them to feel self conscious all the time	**Psychological discomfort-** Discomfort from being in contact with the waste	

User needs for a space bodily waste management diaper

Faeces collection requirements	Adequate capturing of the waste	Minimal contact to avoid discomfort and infection	Ensuring proper cleanup post activity					
Urine collection requirements	Leakproof from side, back	Even distribution of urine	Quick wicking of urine away to prevent UTI					
Time requirements	Minimal waste processing and disposal steps	Avoid frequent replacement	If needed to be used for extreme case scenario, must withstand	Ease of process				
Experience requirements	Odour absorbent	Minimal manual manoeuvring	Intuitive use and easy to position	Breathable material, comfortable to wear	Privacy- visual, olfactory, and sound	Physical and mental reassurance at each step	Adaptability- works in gravity and microgravity both	Communication and support- to ask for privacy without embarrassment

Research Analysis and insights

Different tools like journey mapping, emotional mapping combined with behavioural mapping tools- COM B were used to bring out actionable insights.

Use case 5

Problem- Venting (liquid waste) in close proximity of other astronauts
Touch Points:

- Leakage during the venting process.
- Behaviour of liquid changes pre-liftoff and post-orbit entry.

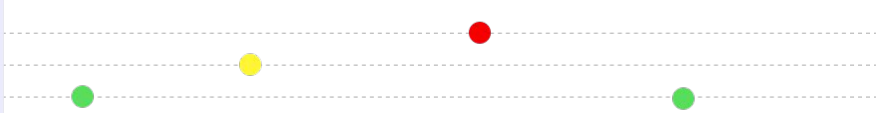
Pain Points:

- Seats and suits must account for potential leakage.
- Varying solutions needed to manage leakage pre-liftoff versus in orbit

This analysis not only revealed the need for product-specific interventions but also highlighted opportunities to address the problem at various stages of the journey, requiring a system-level intervention.

"It's hard to talk about it openly, but we know how much it affects our performance during the mission"- Astronaut Captain Prasanth Nair

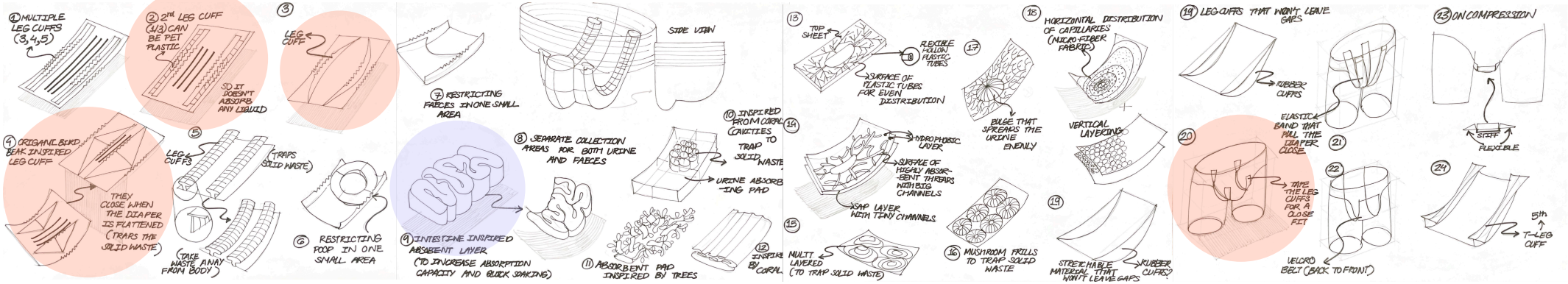
Scenario 5: Venting in close proximity of other astronauts, pre-liftoff
Target behaviour: Astronauts should be able to use diaper without anxiety

	Pre- activity		During activity	Post- activity
Actions level 1	The astronaut is seated with the rest of the crew	The astronaut feels ths urge to urinate	When he feels that other are not noticing, he slowly starts venting	When he is done, he checks around the suit, for visual leakage cues or touches nad makes sure that nothing has leaked
Actions level 2	He is performing pre-launch checks and communicating with the mission control	The astronaut tries to distract other by starting a small talk	He becomes still and silent	He get back to work
Actions level 3		He wiggles a little in his chair to maintain comfort		
Emotional Friction				
Capability (Can the behaviour be accomplished)	Managing Cognitive overload	Attention and attention control, of yourself and others	Skill development against social anxiety	Dexterity and default bias (to go back to what you were doing without lingering anxiety)
Motivation (Is there motivation for the behaviour to occur)	Anticipation(Habitual readiness to manage bodily functions during critical operations)	Professional confidence (Support from the team in maintaining a professional environment)	Self- esteem (Instinctive actions to use the diaper discreetly)	Loss Aversion (Concern about the potential negative consequences of leakage)
Opportunity (Is there opportunity for the behaviour to occur)		Positive reinforcement from peers and trainers about the use of the diaper	Changing Social norms	Reciprocity
Intervention Strategy Idea		Having DND (Do not disturb) mode, conversing non-verbally	Having visual, auditory and olfactory barriers. between the seats or behind the seat, provide privacy	Provide reassurance

The behavioural mapping template used in this analysis was developed by Robert Meza, a behavioural analyst and founder of Aim for Behaviour organisation.

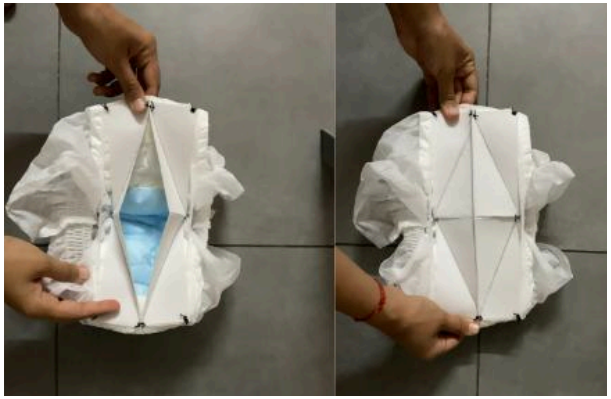
Ideation, prototyping and iteration

Ideas were sketched and quick mocks were made using material from commercial diapers. A part of the final concept was directly taken from the existing diapers while rest was tweaked and joined to it.



Concepts picked for prototyping Final Concept

Multiple leg cuffs
To prevent side leakage, this concept includes multiple leg cuffs. A pair of polypropylene leg cuffs is supplemented with an additional PE and elastic leg cuff in between them.



Origami inspired leg cuff V1
Taking inspiration from the origami square fold, the leg cuffs have been designed such that they remain open while wearing the diaper (bend position) and close while removing (flat position). The idea is to capture the solid waste to avoid spillage.

Origami inspired leg cuff V2
Replicating the origami folding leg cuff mechanism using the elements of an existing diaper. By repositioning the leg cuff stitches, a similar flap closing-opening mechanism can be achieved.

Adjustable leg cuff
Making the leg cuffs adjustable, by providing access on the outside to prevent side leakage and diaper sagging. The tabs can be pulled and taped for a close fit.

Outcome

The Product

Drawing inspiration from the convoluted kidney nephron structure, I designed a padding structure that has more surface area than the regular pads. It helps in faster absorption of liquid, even distribution and prevention of leakage. Moreover it has a separate pocket for collecting solid waste, that helps minimize the contact and reduces chances of infections. **(Project under NDA)**

Diaper that absorbs 3 times the liquid absorbed by regular diapers using the same amount of raw materials.

Evaluation

Faeces collection requirements	Adequate capturing of the waste	Minimal contact to avoid discomfort and infection	Ensuring proper cleanup post activity					
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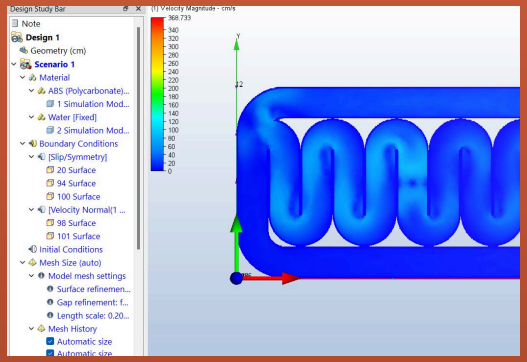
The user needs checklist score indicated that 12 out of 18 criteria were met through the design. Meeting the remaining criteria was not possible solely by working on the product; instead, it required an integrated approach that considered user experience and interaction with the product throughout the entire activity.

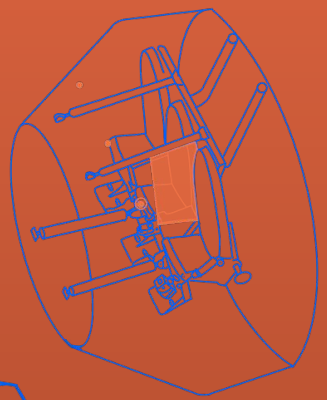
Simulation testing



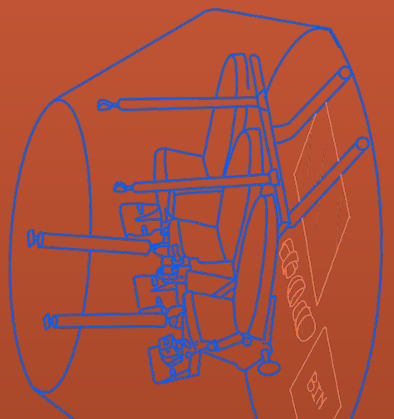
Computer fluid dynamics (CFD) tests-
These tests analysed the liquid distribution through the pad by applying material, fluid temperature, velocity, pressure, and gravity constraints.
Result- This design significantly improved liquid distribution and reduced fluid pressure in the pad.

One step beyond

I proposed systemic interventions for the spacecraft interiors to support the activity.



Physical barriers between the seats and lighting control to increase privacy



Additions such as a mirror for checking oneself during clean-up, a surface for holding necessary items, and accessibility to the common waste collection unit will significantly improve the user experience.