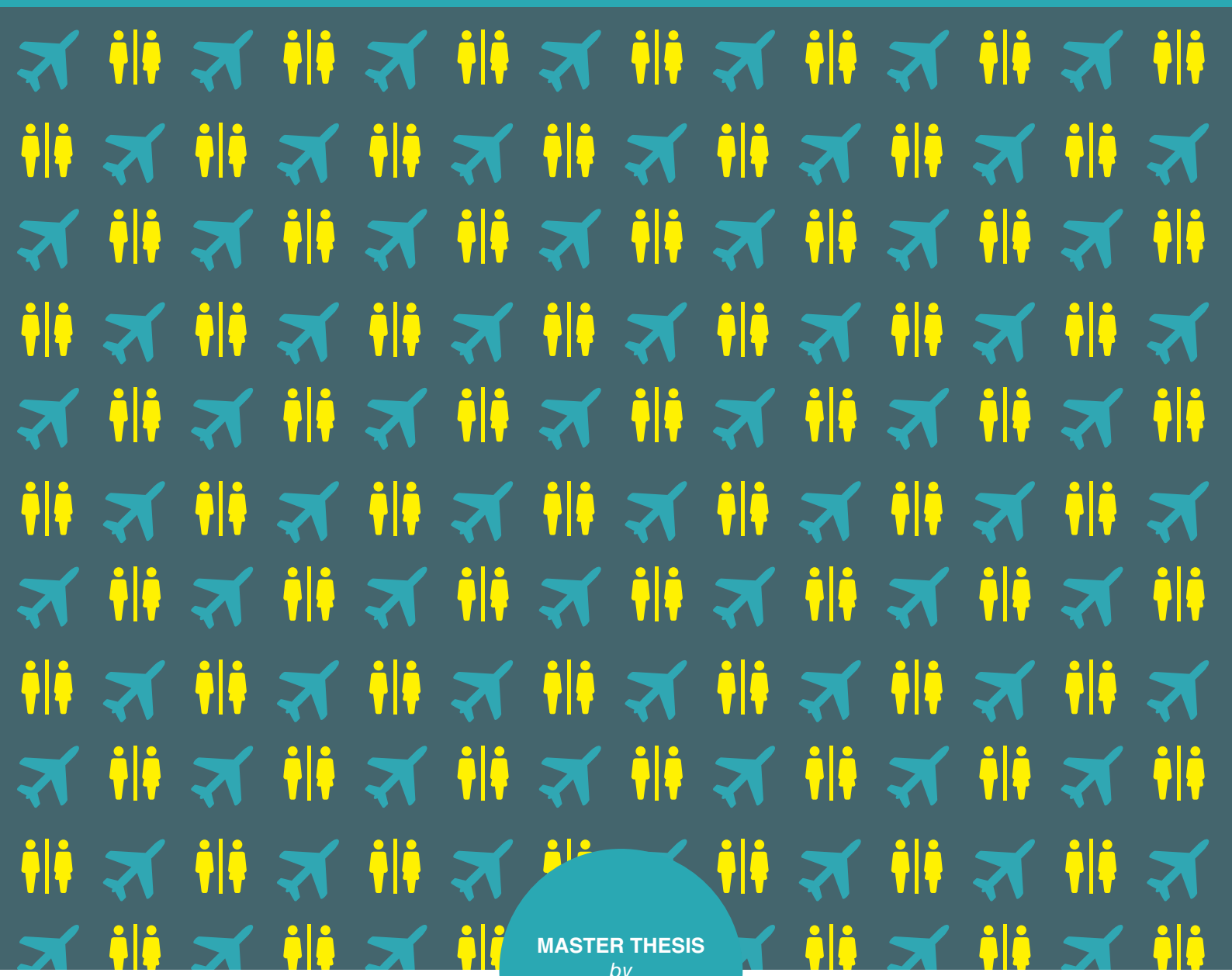
CLEAN AIRCRAFT LAVATORY

"The design of a new concept to improve passenger hygiene on long haul flights"



MASTER THESIS
by
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TU Delft

ZODIAC AEROSPACE

Design of a Clean Aircraft Lavatory

Master Graduation Thesis

Integrated Product Design
July 2018

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Report
Preface

This report is a descriptive outline of my master thesis project completed at the faculty of industrial design engineering at TU Delft, in cooperation with Zodiac Aerospace.

The project was commissioned by Ad Eikelenboom, vice president of Research and Technology at Zodiac Aerospace, Alkmaar. Ad initially presented the problem based on his own experience flying and the general dissatisfaction he felt surrounded the aircraft lavatory.

During my time at TU Delft I was fortunate to work on several aircraft interior design based projects and wanted to graduate on a similar project. The challenges faced by companies in this industry require a high level of competition and cooperation to overcome and it was a thrill to be a part of the process.

I was drawn to this project because it seemed like a very straight forward and universal problem. While this proved to be the case, it also provided a complex and compelling journey towards interesting new solutions. As a design student I'm interested in exploring complex problems which have not yet been solved and this project has given me the opportunity to do so.

The challenge of designing a new product for hygiene was new to me and I've noticed that it has influenced my daily practices and habits for the better. Human hygiene directly relates to the well-being of users and can often be overlooked as a design requirement since it is difficult to quantify or is perhaps not as vital a product requirement as safety or longevity, for example.

I am pleased to say that I'm proud of the result of the project and I hope that Zodiac and TU Delft are as well. It would be gratifying to see my design or parts of it taken further by Zodiac in the future in one of their designs. Staff at Zodiac were pleasant and motivation to work with and I would hope to work with them again some day.

David Randles,

Delft, July 2018

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Executive Summary

0.1

The subject of this thesis report is a new concept design recommendation for aircraft lavatories with respect to better hygiene and cleanliness during long haul flights.

An integrated design research approach is taken to solve the issue of bad hygienic behaviour in the lavatory. Time is taken in the beginning phase of the project to identify and understand the problems in aircraft lavatories This includes an analysis of the current standards and practices surrounding aircraft lavatories, a review of existing products, an analysis of relevant stakeholders, observational research onboard active flights and visit to Zodiacs design and manufacturing facilities in California.

A concept is designed which satisfies the requirements of standard lavatory design and goes a step further to create a new product vision. This achieved using new and existing lavatory design principles and technologies. The design of the product is largely based on fact finding and analysis of the current state of the art, however, user research is also utilised to produce a result which is well rounded and beneficial to multiple stakeholders.

Research indicates that the small form factor of the lavatory makes it challenging for passengers to behave in a hygienic manner. The new design emulates the cubicle based layout of public restrooms, where wash basins are shared. Each lavatory increases in size by removing their wash basins and situating them in the cabin, where they are shared by passengers. Provision of separate lavatories for men and women enables the use of urinals for men and additional space for women and passengers with reduced mobility.

Aircraft lavatories can be kept clean on long haul flights by creating new lavatory services and layouts which expand the space within the lavatory. Airlines can improve passenger hygiene and therefore satisfaction by providing lavatories which are larger and cater to more specific needs, such as standing and sitting urination.

The new design is also of benefit to the process of manufacture and maintenance as it simplifies the existing product significantly and reduces the time it takes to clean and disinfect the aircraft between flights.

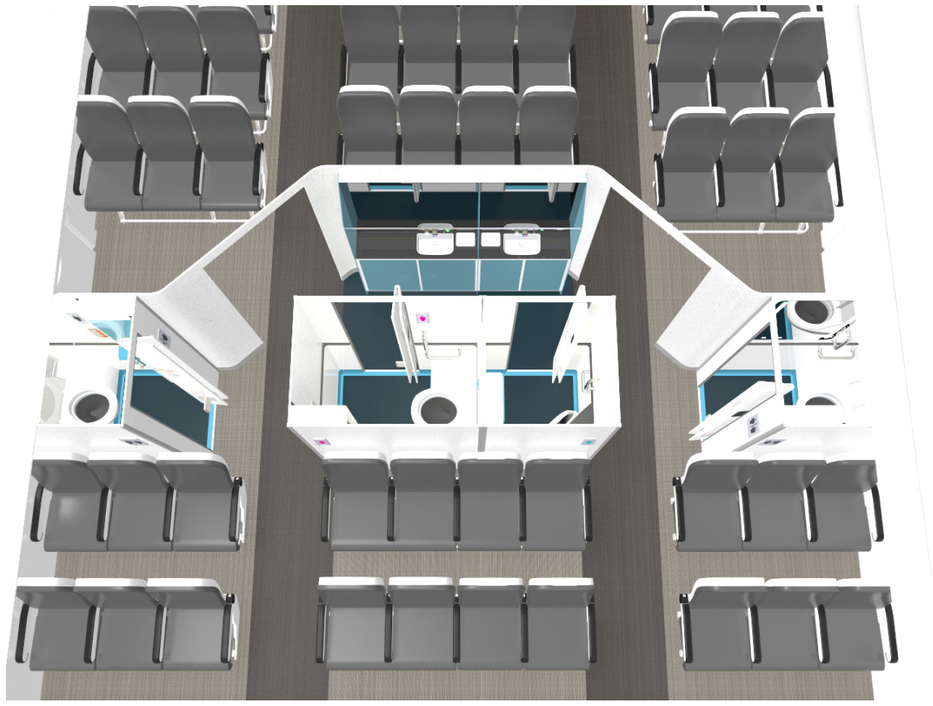

Fig.0.01 The proposed aircraft cabin layout using the Z-Lavs.
Featured are a female and male cubicle with shared sink basins in the cabin and two uni-sex lavatories to either side.

Unisex Z-Lav

Male urinal Z-Lav

Female Z-Lav

Fig.0.2

These are Z-Lavs, minimal aircraft washrooms which feature a modestly sized cubicle in which passengers can go to the toilet and check their appearance in the mirror.

Separation based on gender and a shared hand washing station enables passengers to use the onboard lavatories like they would use any other public restroom.

Chapter 1:
Introduction

In this Chapter...

... the project is introduced. Welcome to this report on Aircraft Lavatory hygiene and cleanliness. In this opening chapter, an overview of the design project overview is given.

This includes the subject background of this assignment, an overview of how the project was completed, the challenges that must be addressed and the methodology applied to do so.

Next an overview is given of company with whom the project was undertaken, Zodiac Aerospace. This includes background information about the company and their products, followed by an analysis of the current aircraft lavatory market and the major competitors.

Finally there is a description of some of the latest innovations from the biggest companies in the industry, much of which serves as inspiration for the new design.

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Assignment Overview

Project Overview 1.1

Introduction

Zodiac Aerospace are a major international player in aero-safety, aircraft systems, galleys, cabins and seats. The galley segment of the business includes the aircraft lavatory, a passenger service area on the aircraft where passengers can use the toilet and wash their hands and face. The main features are a special vacuum toilet, sink, disposable hand towels and a waste bin. Also included are soaps, sanitary products, a table to change a baby and a mirror.

As the focus for the project, the lavatory will be analysed and explored through the first three chapters of this report. In this section a background of the problem is given and the assignment is formulated.

Problem Background

Virtually all commercial airlines now provide passengers a lavatory to ensure that passengers can have a comfortable flight. Though a well intentioned gesture, the reality is far from ideal. Public restrooms are infamously unhygienic and those on-board aircraft are no exception. Passengers worldwide take up a negative stance against these onboard service areas. In this report we will investigate why that is, as well as what can be done to make change.

An aircraft lavatory is a unisex public restroom on an airplane which boasts the highest limitations on space and weight compared to other public provision, due to fuel economy. Space in a plane is limited, with all other services competing for that space. Airlines fit as many lavatories as they can within the aircraft to ensure that passengers don't have to wait too long for a working restroom, but a new trend is seeing airlines opting for smaller lavatory designs which free up space for more seats.

Repeated use quickly leads to the deterioration of hygiene conditions in the lavatory. Passengers may not be inclined to clean up after themselves if they feel as thought it is not their responsibility. The small space also makes it challenging to act in a hygienic manner. Perhaps the greatest challenge with designing an aircraft lavatory is providing a space which is not only clean and hygienic, but dignified and inclusive as possible for its users.

Airlines and original equipment manufacturers (OEM's) would like to devote more time and resources to improved passenger experience to increase brand image and revenue. However, in reality user experience is just one of many design aspects for products in the cabin and is less essential than, for example, safety, cost and weight reduction.

A single lavatory unit may be used 20-30 times an hour by different passengers, leaving it in a perpetual state of deterioration. The lavatories are cleaned between flights when the planes are grounded, including a deep clean which takes place during overnight stops. This does not, however, account for the use during flight.

Problem Statement

It has been observed that by the end of a long-haul flight, the lavatory is objectively dirty and in a state of disarray. More specifically the floor are surfaces are wet and littered with paper waste and gaps and corners look spotted and grimy. Lavatories have a foul odour due to the small space and limited possibility for ventilation, i.e. opening a window.

As a result, passengers leave the aircraft having had an unsatisfactory experience. A certain standard is expected from lavatories and washrooms in all private and public spaces and a lavatory left in an untidy state is not preferable to use. This negatively affects the overall flying experience.

Efforts are made by manufacturers and airlines to provide cleaner lavatories but the deeper issue of poor hygiene behaviour on-board aircraft is often not addressed. Hygienic design is not just about how much bacteria a surface collects, there is also a psychological aspect which influences behaviour. This investigation builds on the knowledge that sanitary conditions must improve in order for the perception of lavatory hygiene to improve.

In chapter 4, Problem Definition, the problem will be explored in greater detail.

Assignment

"Lavatories should be hygienic, as well as have a tidy and clean appearance."

The purpose of this assignment is to create novel concept(s) for a clean aircraft lavatory. The new ideas will aim to improve the passive cleanliness of the space and also improve passengers' perceptions of how clean and tidy the space is during the flight.

Research into industry innovation and new hygienic technologies provide a path towards solutions. The lavatory should include both altered and added features which primarily aim to benefit passenger hygiene and reduce the potential for disorder in the lavatory without neglecting the basic functionalities of a standard lavatory.

The planned project outcome is a concept design and input for a further prototyping phase which has been discussed in detail with the company (see appendix XX). The goal is to create a strong base for a new product development process. This includes a plan for further research and the embodiment of a full prototype.

Fig.1.01

Zodiacs Lavatory Design

Project Goal & Scope

Project Overview 1.1

Project scope

It has been expressed by the company that the proposed lavatory design must also follow the guidelines set by the aviation authorities (FAA and EASA). A pragmatic solution is preferable, one which is not a complete re-imagining of the product but rather a design which Zodiac is both capable of producing and interested in pursuing from a business perspective.

The scope is limited to the design of a lavatory monument and does not include the design of a new cabin, galley, or toilet vacuum system. Included in the scope are all other features and components within the lavatory monument as well as the position in the aircraft.

Economy and premium economy class will be the focus of the new design. Business class, first class or other luxury options are not included as these classes have much wider variance and more freedom to invest in luxurious components. It was determined that the declining sanitary conditions in economy classes are more severe due to the higher passenger density. Furthermore, what works in economy can invariably be scaled up to work in premium classes and not the other way around.

Lavatory dimensions vary depending on the size of the aircraft and the location of the lavatory in the cabin. For this reason the project scope is not limited to one specific size of lavatory. Rather an adaptable solution which has considered a range of configurations is preferable. This also potentially strengthens the business case of the design as it gives Zodiac the opportunity to change the design to suit their needs and style to suit of the customer, airlines.

Fig.1.02 Lavatory Monument exterior

Initial research probes

The starting point for the project is an exploratory desk research. This is a general research which includes four probes into the context surrounding aircraft lavatories, which are based on the following

- The Aircraft Context
- Human ergonomics (needs of the individual)
- New materials and technology
- Cultural factors (needs of society).

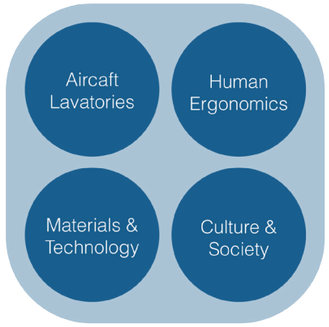


Fig.1.03 Pillars of initial research

Secondary research topics include sustainability, economic viability, product design and manufacture.

Internet research and interviews with experts were the primary means of collecting this information. Each topic is explored in greater detail throughout the report. The following is a brief summary of the four topics examined and their impact on the concept design.

Aircraft Context

Aircraft differ from other public places in many ways. It is first important to understand the history of the product, the current state of the art and the limitations set by the industry and environment it is in. For example there are strict safety regulations set by aviation authorities which must be met. Further limitations include weight and space as the buying potential of such a product is highest when it meets all safety regulations and has reduced weight and is compact to allow space for additional seats.

Ergonomics

The lavatory encapsulates its user. In this respect it is both a product and a space. How the user interacts within the space and with each of the individual components within are a focus for this project. This also extends into cognitive and behavioural ergonomics, which entail the study of patterns of behaviour and driving desired behaviours during use. Multiple user analyses are performed throughout the project to ascertain what passengers and crews need and how the end product will be used.

Technology

Modern lavatories feature advanced technology, much of which is not noticed by the user; high powered vacuum toilet system, clean air circulation and lightweight antimicrobial materials. A lot of effort goes into making these components work together to achieve the primary function of hygienic waste disposal.

A focus for the project is to integrate advanced technology at a user level. For example, touchless controls which are gesture or voice controlled, personalised lighting and advanced material compositions. The goal is to use technological enablers to reduce error and enhance the users' perceptions of hygiene. This probe gathers details on technology which is currently in use as well as generative ideation on possible new technologies.

Culture

By its very nature, air travel links two geographic locations together, often meaning that cultures onboard aircraft are varied. Toilet culture is vastly different around the world, meaning that people do not always behave the same way or exhibit the same attitudes towards it. Understanding and accommodating a range of cultural values with respect to lavatory use and cleanliness is examined and considered in the concept design.

Project goal

The project goals are established following the initial research. The primary goal is;

- *To propose a redesign of the Zodiacs current lavatory offerings in economy and premium economy class by enhancing cleanliness while maintaining adequate usability, structural integrity, weight, build-ability and repair-ability."*

The project seeks to address the real problems which occur in lavatories and to create a solution which is realistic and possible to achieve.

The goal is intended to be achieved in the following ways:

- Gain intimate familiarity with aircraft lavatories, how they work and how they are designed.
- Understands the needs of the stakeholders (passengers, crews, manufacturers and airlines).
- Collect a information on technology which can improve human hygiene and evaluate them for aircraft suitability.

Design vision

The following vision was created following the problem definition stage of the project. It give a general impression of the aim for the new concept design.

"Passengers should feel like they can trust the lavatory to be clean and tidy before they enter. The experience should not be that one enters with caution, expecting a mess or the potential to encounter harmful pathogens."

Lavatory provision should include components and surfaces which are designed to remain clean with minimum effort and also reinforce good behaviour with respect to individual hygiene."

Flight crew and ground crew will likely still be required to clean the space, however their tasks should be minimised, allowing them to focus on other tasks in the cabin. This can potentially lead to reduced turnaround time and improved working conditions."

The design should seek to not complicate the procedure of manufacture and assembly or hinder the process of maintenance. It should reduce the complexity of the lavatory, rather than add to it."

Project Overview

Project Methodology 1.2

This page details the process applied to achieve the assignment goal. The methods and techniques used are primarily based on methods used at the IDE faculty and reflect the teachings in the IPD master course, in particular the *Advanced Concept Design* course. The project largely follows the basic design cycle.

The assignment is completed in three phases; *research problem analysis and concept design*. The aim of the research phase is to collect information and insights in relation to the unknowns in aircraft lavatory hygiene. The aim of problem analysis phase is to give structure and meaning to the information gathered. The aim of the design phase is to apply the knowledge gained to create new ideas and evaluate these ideas with the stakeholder groups.

This project is structured using double diamond technique for converging and diverging multiple times. The four phases in this process are *discover, define, develop and deliver*. This method makes it possible to manage the complexity of the assignment while maintaining a focus on the most important information at key moments.

Exploratory Research

With little initial information to begin with, the project kicked off with examination of the hygiene and sanitation practices currently in place on long-haul commercial aircraft. An analysis of human behaviour within this context was also carried out to understand how the space is used and how the needs of each stakeholder differ. Products and technologies which are both used and not used in aircraft are gathered and evaluated based on their suitability for use in aircraft.

Insights from these analyses are used to create a strong base for problem analysis. A large emphasis is place on understanding the problems as they happen. With that in mind, the research and analysis of the context and problem accounted for the entire first half of the project.

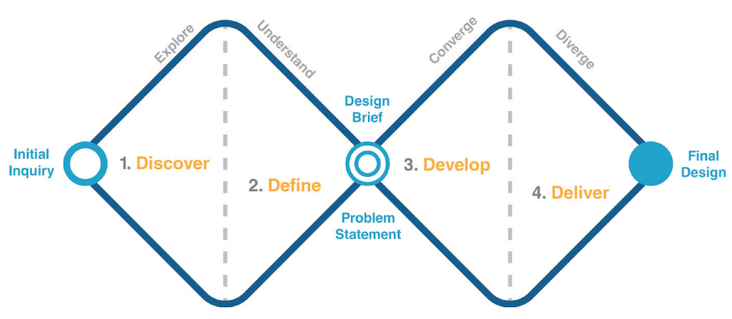


Fig.1.04
Double diamond method

Four project phases use convergence and divergence of information and ideas to create a new product concept

Research Methodology

The research phase of the project begins with a problem definition based on insights gained from the initial probe. A detailed understanding of the design and manufacture of aircraft lavatories and needs of the end users are the goal of this phase.

Members of the passenger community are asked about their flying experience via interviews, online forums and surveys. The goal of these questionnaires is to understand a range of user opinions and problems.

The real world aircraft context is examined by undertaking field research onboard active flights. A total of 6 active flights were investigated, four short haul and two long haul. On the flights the lavatories were intermittently inspected and rated based on aspects of tidiness. Flight crew were also questioned during the flights.

Two of Zodiacs lavatory design and manufacturing facilities in the USA were visited in order to gain an understanding of the development process and present design requirements. A maintenance hangar in Schipol airport was visited to gain information about the cleaning crews and their process.

Each field objectives also include various user observations and interviews with passengers, flight crew and maintenance crews. A more detailed account of the research performed is given on the next page.

Design methodology

Problem definition is completed using creative idea generation sessions. The goal was to ascertain what is causing the core problems in the aircraft lavatory. A sub group of users - experienced flyer's - consisting of two males and two females was used to discuss and refine the problems to identify the design requirements.

In the concept development phase, relevant technologies for hygiene were gathered and evaluated for aircraft lavatory suitability. Morphological charts are used to map all of the known solutions. Ideas are then combined in various ways to create a range of possible concepts.

Selection criteria is devised based on research and discussed with user groups and with Zodiac. Following iterative ideation rounds, ideas are prototyped in Solidworks. The core concept is illustrated in a variety of configurations and layouts using the software

Design Evaluation

The concept is validated based on the list of requirements. Market research is conducted at the aircraft interiors expo in Hamburg in April 2018. A patent search is carried out to ensure that the final solutions are novel. Concept boards are created to illustrate the final design and presented to Zodiac at the projects conclusion.

The final result of the project is a concept design and set of recommendations for further research and development. Building a full scale prototyping for user testing in context is the primary recommendation.

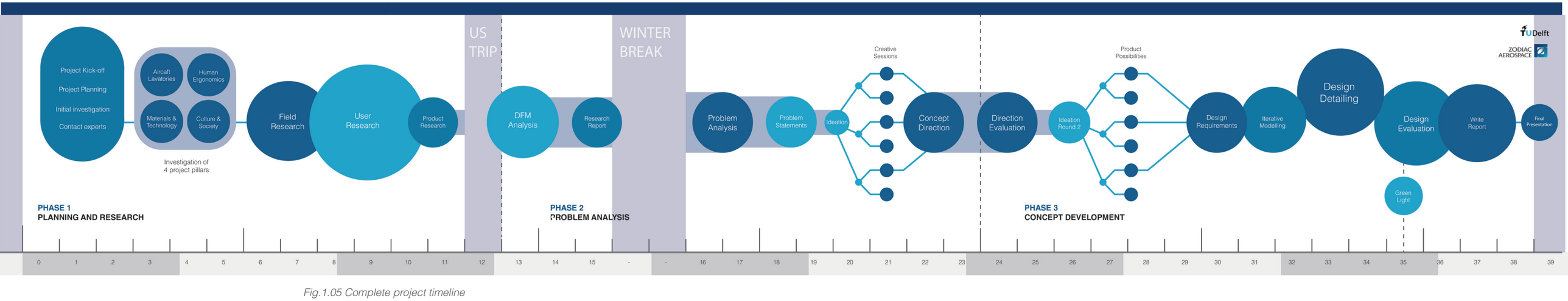


Fig.1.05 Complete project timeline

Research Overview

Project Methodology 1.2

There is no publicly available research on aircraft lavatory hygiene. Some general principles of public toilet design are transferable, for example the ergonomics involved in urination and the hygiene products in use; toilet, sink and disposable paper. Therefore self research within the aircraft context is necessary.

Specific details and accounts of each of the research investigations can be found in *Appendix 1.* The following is a set of general conclusions derived from the investigations.

Research questions

Following the initial research probe, a deeper scope for research was established. The following are questions which

Aircraft lavatory market and industry
- What are the current challenges in the industry and what does the future look like?
- Who are the main competitors, what are they doing?
- What are new opportunities for Zodiac?

Aircraft lavatory design and manufacture
- What are the current design challenges in the industry?
- How is the unit built and how is it designed?
- What other technologies are available and how can they be used in the aircraft setting?

Aircraft lavatory operation and use
- Who are the most important stakeholders?
- How do people use/want to use the product?
- What is best in terms of health of users and society.

This approach entails considering all aspects associated with the production and use of an aircraft lavatory. However, since the priority will be cleanliness in the aircraft context, a primary research question is used:

"How can lavatories be kept clean during a long haul flight?"

A number of design research based investigations were undertaken to answer this question. The following is a more detailed list of questions which arose following the initial problem analysis:

- Aircraft lavatories are **generally disliked**. Which aspects of the design lead to a **negative** passenger experience?
- What are the **defining characteristics** of a clean and tidy lavatory?
- What are the **root causes** of lavatories becoming unclean and untidy?
- What are the **limitations and barriers** for better lavatory design and maintenance?
- In what way can **technology enhance** the user experience? What are the technologies?

Research investigations

A number of locations were visited to learn more about aircraft lavatory production and usage. Interviews and observations provided insights to address the research questions.

An online questionnaire and open forum discussion were used to ascertain more specific user concerns and wishes. The result of this research is a set of answers to the questions in the previous paragraph.

Expert interviews

A number of interviews were conducted with industry professionals during the research phase of the project. Speaking with experts provided the project with direction based on knowledge already established in the industry and helped build a framework for further research.

1. ***Marian Loth;*** *Hygienic NS train toilet designer, TU Delft.* Interviewed on the details and reasoning behind her succesful train toilet design.
2. ***Johan Molenbroek:*** *Hygienic NS train toilet designer, TU Delft.* Provided information on the resaerch and literature which lead to the train design.
3. ***Ian Scoley;*** Head of industrial design at ZEO studio, California. Gave a detailed presentation on Zodiacs DMS architecture and Durinal concept.
4. ***Rasmik Boodaghians;*** *Research and technology manager at Zodiac water and waste, California.* Gave detailed information about the cleanliness problems experienced with the waste systems.
5. ***George Stachowski:*** *Director of Business Management at Zodiac water and waste, California*. Background of some of the larger problems with lavatory design.
6. ***Donough McCrann;*** *Irish architect, Limerick*. Gave a guided tour of restrooms in his home and offered insights about how he designed them.
7. ***JeanMarc Obadia;*** *Hygienic aircraft materials expert at Zodiac Aerospace, Plaisir*. Provided information on how Zodiac uses researches hygienic materials and products.

Questionnaire

Passenger satisfaction was examined using a sample of 50 participants. Participants were found on an online frequent flyer forum and a travel page on Facebook. This survey provided a basic indication of problems which may be experienced by different passenger groups with regard to aircraft lavatories.

The participants were divided on their flight experience, age and gender. The two target groups (frequent flyers and non frequent flyers) were asked a number of questions in an online form regarding their satisfaction with the product. The responses were mostly negative. Passengers in the sample were generally dissatisfied with their experience, particularly in economy class but also in premium economy and business class.

Respondents were also asked to give opinions about the specific problems they experienced in the lavatory. Among the most common answers were limited space, urine on the floor, foul smell and having to queue in the aisle.

Forums

A number of people remarked at being uncomfortable discussing their habits during or immediately following the flight. Furthermore, when asked face to face about toileting, self reporting is known to be unreliable (Althubaiti, 2016).

Online forums are an ideal place for individuals to honestly discuss their problems and opinions honestly. In the absence of quality user insight in context, a number of questions were posed on two frequent flyer forums. Valuable user insights were gathered this way and provided an open forum for further discussion of ideas.

This investigation provided a list of user concerns and wishes. This list can be found in *Appendix 1*.

Observations

Locations which deal directly with the hygiene of aircraft lavatories were visited and observed to gather information about production and maintenance practices. During these visits staff were also interviewed briefly and in some cases users of the facilities gave information about their experiences.

Onboard flights

Habitual behaviour is best captured by observation or following self-reflection with a high degree of anonymity. Direct observation of people is not possible as the breach of privacy also changes behaviour, but the condition in which the facility is left can be observed. A total of six active flights were investigated throughout the course of the project; 4 short haul and 2 long haul. During these flights the lavatories were visited frequently and inspected for hygiene. Flight attendants and passengers were selectively questioned about their experience during and after the flight.

Schipol Airport

Airport maintenance crews operate out of large hangers on the auxiliary of most airports. Aircraft are stored here temporarily for cleaning, refitting, painting and for routine inspections. Within the hangar are a number of crews working to clean, repair and maintain the various elements of the aircraft. A toilet cleaning crew was visited and shadowed for an afternoon. The process of removing the shroud and cleaning the toilet bowl was demonstrated in great detail.

Zodiac Aerospace - California

Zodiac have an office in Huntington beach California specialising in the design and production of their aircraft lavatories. This facility was visited with the goal of integrating the design and manufacture principles in Zodiacs current designs in the new product. The visit included a guided tour of the design studio (ZEO) and of the factory floor.

Zodiac Water and Waste - California

A second Zodiac facility was visited during the trip to California to gain information about the systems working behind the user layer of the lavatory. Beneath the surface there multiple pumps, buffer tanks, liquid transfer systems and heat exchangers which come with their own set of design challenges.

AIX Hamburg

The yearly aircraft cabin interior event was attended in Hamburg in April 2018. The purpose of the visit was to speak to industry professionals and witness the latest innovations the industry has to offer.

Semi-structured interviews

Members from each stakeholder group were interviewed throughout the course of the project. Interviews were most often completed in combination with observational research. For example flight attendants were questioned during flights while the lavatories were under inspection, Zodiac staff were questioned during a guided tour of the manufacturing facility and maintenance workers gave details of their process during the tour at Schipol.

Results of research

These investigations provided the knowledge which lead to the analyses in *Chapter 2; Product Analysis* and *Chapter 3; User Analysis*. Detials about how the research was performed can be found in *Appendix 1*.

The remainder of this chapter will further examine the background of the assignment, including a look at the company, Zodiac Aerospace, their competitors and the latest industry innovations.

Zodiac Aerospace

Company Background 1.3

The following information is taken from the company's website: www.zodiacaerospace.com

Mission

Zodiac Aerospace develops and manufactures state-of-the-art solutions to improve on-board comfort and living conditions, as well as high-technology systems that boost aircraft performance and enhance flight safety. Zodiac Aerospace provides them with worldwide assistance via a comprehensive service designed to meet the complex challenges of the aviation industry.

Zodiac Aerospace aims to anticipate and support the needs of its clients by responding to the new challenges of the market. The Group is increasingly involved as a full systems integrator to certification, enhancing its products and services in various areas, such as:

- Reducing the weight and bulk of on-board equipment and systems to improve aircraft performance;
- Developing ergonomic, modular concepts to improve maintenance and productivity;
- Expanding its range of after-sales services for airline companies;
- Introducing new functions and designs, as well as comprehensive and integrated cabin solutions that make a real difference in the marketplace for airlines and improve passengers experience;
- Developing new safety systems that contribute to improving the safety of air travel.

History

Founded in 1896 by Maurice Mallet, the company Zodiac contributed to the development of aeronautics by designing and manufacturing airships and airplanes. True to its pioneering and innovative spirit, Zodiac invented the concept of the inflatable boat at the end of the 1930s. This concept is leading the company to an international expansion in the 1970s. This period also marked a turning point for the company with its gradual redeployment into aerospace. In 2007, the Group refocused its core business, sold its Marine businesses and takes the name of Zodiac Aerospace.

Strategy

Based on an internal and external growth strategy, Zodiac Aerospace is continuing its development to ensure constant advances in its businesses. Zodiac Aerospace's technological expertise is based on two core business lines: Aircraft Interiors that gathers Cabin and Seats segments, and the Systems activity composed of the Aerosystems segment. These segments develop solutions for aircraft on-board comfort, on-board systems, and safety on-ground and in-flight, supplemented by the dedicated after-sales business of Zodiac Aerospace Services.

Altogether, the Zodiac Aerospace businesses employ 35,000 people worldwide and work with clients throughout the world, offering a comprehensive range of products and services.

Business sectors

Zodiac Aerosystems designs high-technology equipment and systems for critical aircraft functions and in-flight and on-ground safety. The segment proposes safety systems (evacuation slides, emergency arresting systems, oxygen masks…), electrical systems (electrical power system, lighting…), control systems (fuel management, telemetry…) as well as water and waste systems.

Zodiac Aerospace Services offers a global distribution network of spare parts and components, maintenance of equipment manufactured by the Zodiac Aerospace Group, customized support services for airline operators and dedicated technical support.

The Business Group Cabin provides all elements of a seamlessly integrated cabin, from the overhead bins, lavatories and galleys, to the IFE and actuation systems, either as independent world class products or as a fully integrated cabin. Zodiac Cabin's mission is to design, certify, manufacture, and support the world's most innovative aircraft cabin interiors, providing airlines and OEM customers with distinctive aircraft branding, and their passengers with the safest, most comfortable, and enjoyable flying experience.

Zodiac Seats designs, certifies and assembles innovative, personalised and high-added-value products. In providing its expertise to all market customers, the Division draws on a strong international presence.

Future

In February 2018, Zodiac Aerospace became a part of Safran Group, a French aerospace company. Safran is the #3 leader in Aerospace and Zodiac is the #2 leader in Aerospace equipment. The merger in March 2018 resulted in the combined sales of $21bn and a personnel of 92,000 in over 62 different countries worldwide. The future is bright for the newly minted aerospace behemoth as the company now has a presence in all key programs in aerospace.

Fig.6 Zodiac logo banner
Fig.7 Zodiac tradeshow booth
Fig.8 Zodiac cabin interior
Fig.9 Safran engineer insalling an engine

Fig.1.6

Fig.1.7

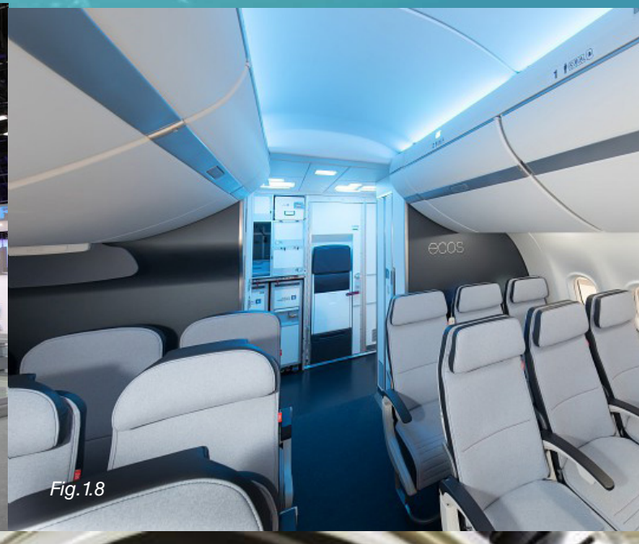


Fig.1.8

Fig.1.9

Zodiac Lavatories

Company Background 1.3

Zodiac Cabin has business units all over the world which focus on a key product. For example, the facility in Alkmaar, Netherlands is the home of AirCatering Equipment. Here the trolley carts, which get pushed up and down the aisle by flight attendants, are designed and optimised. The lavatory is primarily designed and built in California. ZEO Design studio is located in Huntington Beach, CA, where the latest lavatory designs were created. Zodiac Water and Waste is located close by in Carson. Here the systems which supply and circulate liquid and solid material around the aircraft are designed and optimised. All three of these facilities were visited throughout the project for information ans advice on Zodiacs current and future projects.

Although Zodiac Cabin has a broad and diverse product range, lavatories are the focus of this project. The following are the lavatory designs which Zodiac produces;

A330/A340 Lavatory

Zodiacs primary lavatory offering is the SmartLav, purpose built for the Airbus A330 and A340, (see fig.1.10 and 1.11). This lavatory is designed for retrofit into existing aircraft which are close to 10 years old. There is also a variant for the Airbus A350 (see fig.1.13)

The lavatory includes the following features as standard:

- PSU with self-contained gaseous oxygen system
- LED fixtures for wash, mirror, floor and spot lighting
- Mirror module with signs and call button
- Toiletry cabinet with dispensers and drawer
- Scratch resistant composite countertop with back splash, stone/solid color appearance and waste flap
- Temperature control faucet and soap dispenser
- Stainless steel undermount sink bowl with drain stop
- Removable vanity door (for maintenance access) with dual roll toilet paper holder and splash covers
- Hinged vanity door with large removable waste can
- Concealed latches for restricted yet easy access
- Toilet shroud, nearby assist handle and floor pan
- Vacuum flush system and palletized water system
- Full height plastic mirror
- Blade door with coat hook and ash trays

Durinal

This recently unveiled urinal-only lavatory for men gained industry attention by winning the 2018 Crystal Cabin Award. The lavatory has no toilet or hand wash basin, just a single male urinal, disinfectant paper dispenser and trash bin (see fig.1.12 and 1.1.14). The goal is to reduce queuing times in the aisle by diverting men who only intend to urinate. This has the added benefit of a cleaner lavatory for women given that fewer men will use the full lavatory, significantly reducing the amount of urine landing on the floor. The challenge that this concept faces is that Airbus will be required to purchase two separate lavatory options from Zodiac. It is more economic to produce one standard lavatory in 2-3 cabin configurations. There was also some public backlash to the concept as it effectively doubles provision for men needing to urinate while not addressing where they will defecate.

Space Flex Cabin

Widebodied aircraft are required by law to include a facility which is accessible for disabled people. The lavatory at the rear of the cabin is usually larger and features a curved floor profile to accommodate the shape of the planes tail. This is the ideal location for an accessible lavatory.

In collaboration with Airbus, Zodiac created the space flex cabin (see fig.1.15). It includes two lavatories instead of one, which can be joined together making a single, much larger lavatory. The goal of this design is to give passengers with reduced mobility more access than before, while still providing two standard sized lavatories for other passengers to use.

Revolution Toilet

The waterless vacuum toilet system has become the industry standard in next generation aircraft; boasting reduced odor retention, weight and operational costs versus the previous liquid circulation system that circulated the now infamous blue liquid to flush waste. At only 9.5lbs, Zodiacs toilet bowl is one of the lightest and quickest to repair on the market. The revolution toilet uses composite materials to further reduce weight and reliability. It is sure to be the cornerstone of all future lavatory designs (see fig.1.16). Zodiac also won a Crystal Cabin Award for this design.

ISIS Lavatory

Zodiacs ISIS space saving lavatory solutions are a new range of lavatories which use a modular component architecture in order to utilise mass-production techniques, reducing cost and lowering part tolerance (see fig.1.17, 1.18 and 1.19). Lower part tolerance in the lavatory leads to tighter gaps and better control of water spills and dirt buildup. The modular interface also speeds up maintenance and handling and allows the company to create a wider range of configurations.

Analysis

Zodiac designs lavatories to have clean and simple appearance compared to some of their competitors, whose designs will be looked at in the coming pages. There is an emphasis on compact space design and a fundamentalist approach to amenity provision. Zodiac have identified the trend of lavatories getting smaller and aim to strengthen their market presence by designing for simplicity, modularity and upgradability.


Fig.1.10


Fig.1.11


Fig.1.12


Fig.1.13


Fig.1.14


Fig.1.15

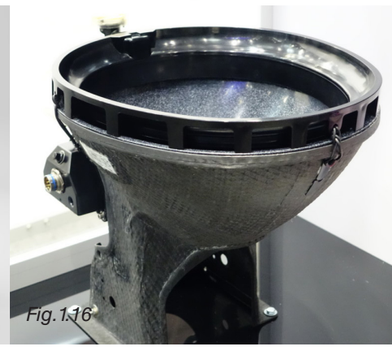


Fig.1.16


Fig.1.17


Fig.1.18


Fig.1.19

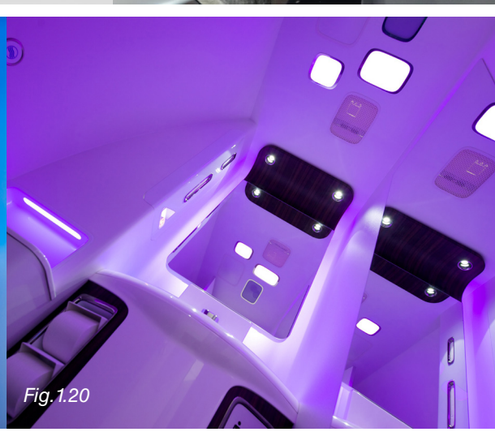


Fig.1.20

Lavatory Market

Market Review 1.3

The production and operation of commercial aircraft is now a multi-billion dollar industry which continues to grow. Airlines and manufacturers are gradually improving products and services to increase profitability and market presence. In this section, a basic overview is given on how the global aircraft lavatory market works and Zodiacs place in it.

Original equipment manufacturers

American Boeing and European Airbus effectively have a duopoly on the market of commercial aircraft worldwide. The rival companies produce aircraft for over x airlines worldwide. Other OEM's such as Bombardier and Embraer generally make smaller commercial aircraft which may only require the provision of a single lavatory or none at all.

Sometimes displeased with delays, Boeing and Airbus now also design cabin interiors to shorten lead times and further cement their hold in the market. However for now they still rely heavily on equipment manufacturers to make interiors. Zodiac has produced after-market lavatories for A330/40, A350 XMB, 737 Max, 747 and 767.

Lavatory system manufacturers

The cabin interior business is large and competitive. Zodiac Aerospace, Rockwell Collins, Jamco Corp., Diehl Aerosystems, Yokohama Aerospace America, The Nordam Group, Geven, AeroCare and Haeco, are among the biggest names in aircraft lavatory production. Each of these companies competes each year to win contracts on new orders from airlines. These orders can either be to build a new fleet aircraft or to retrofit an existing fleet with after market products and services.

These companies will then enlist the expertise of design agencies or in-house teams to focus on innovation in a specific business unit, depending on the size of the order. To give some perspective, Boeing filled 4,363 orders for narrow-body aircraft and 1,357 orders for wide-body aircraft in 2016.

Market Share

Market share is distributed worldwide, with North America leading the industry with a 35% market share according to marketsandmarkets.com. Unfortunately, market statistics for the aerospace industry are not available to the public without purchase. In the absence of quality data regarding the size and growth of the industry, data is taken from Zodiacs annual report.

Lavatories are in comparatively low demand when compared to other interior products such as seats. When Emirates decides to expand its fleet and puts in a order for 100 new Boeing 777 dreamliners they will require the manufacture of over 260,000 seats and only 1800 lavatories. This is why there are more companies producing seats than lavatories.

Market Growth

Key statistics in relation to the market share of each specific company are not available without purchase from a market analysis firm. With the lack of detailed information it was not possible within the scope of this project to predict the best route for Zodiac to take from a business perspective. The analysis does, however, provide details on possible avenues for innovation from a market perspective.

According to *prnewswire.com*, the global aerospace lavatory market is expected to grow 5.2% CGAR during the forecast period of 2016 to 2021 with increasing aircraft deliveries and fleet size being the key drivers. In a growth industry with a rising need for the refitting of older aircraft and changing needs and desires from customers, the lavatory market will continue to expand and grow.

According to *stratviewresearch.com*, Flight programs such as the A320 and 737 are the largest growing (see *fig.1.23*). This is likely due to the explosion of budget air travel in recent years. The 787 dreamliner is growing because its newest aircraft on the market and is lauded as the most luxurious yet.

While low-cost carriers represent the largest amount of growth, experts believe that legacy airlines will soon need to fill orders for retrofit. Zodiacs place in the market is still small. JAMCO corporation is the key supplier for Boeing 737 aircraft and Rockwell Collins recently beat Zodiac for the exclusive contract for the 737 and newer 737 MAX. This is unlikely to change within the next few years.

From this brief analysis, the following conclusion are made about the global aircraft lavatory market;

- The market is growing and it is highly competitive
- Zodiac do not currently have a large presence in this market but they do in other key sectors, such as seating.
- Companies with the greatest market presence such as JAMCO are more likely to secure bigger orders on new aircraft.
- The retrofit market may soon become larger as more and more airlines need equipment renewals.
- Retrofitting requires adaptable and upgradeable designs and technology.
- The desires of airlines, which come from the needs of passengers, drives the market.
- Innovation and positive media attention may help companies to stay in league with their competition while other business sectors keep them profitable.

Jamco AEROCARE DIEHL HAECO

AIRBUS BOEING Rockwell Collins

YOKOHAMA Geven CIRCOR NORDAM

Fig.1.21 Various companies competing for market share

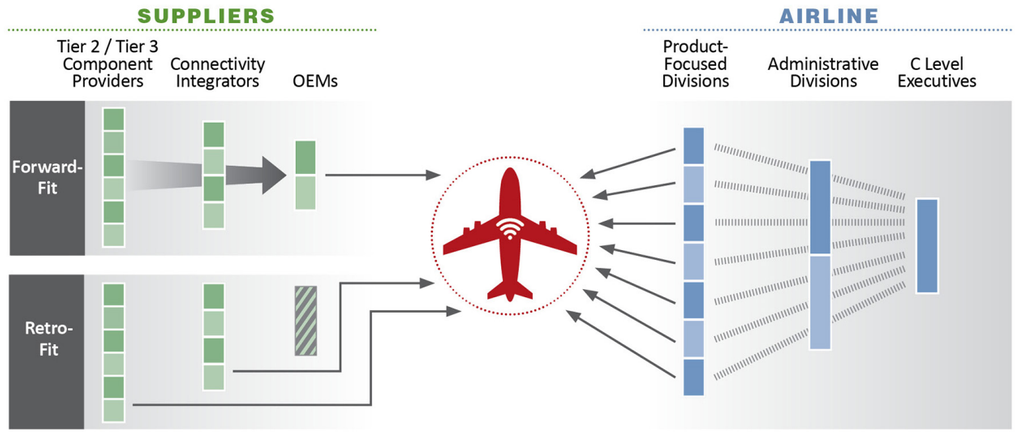


Fig.1.22 Aircraft product supply chain

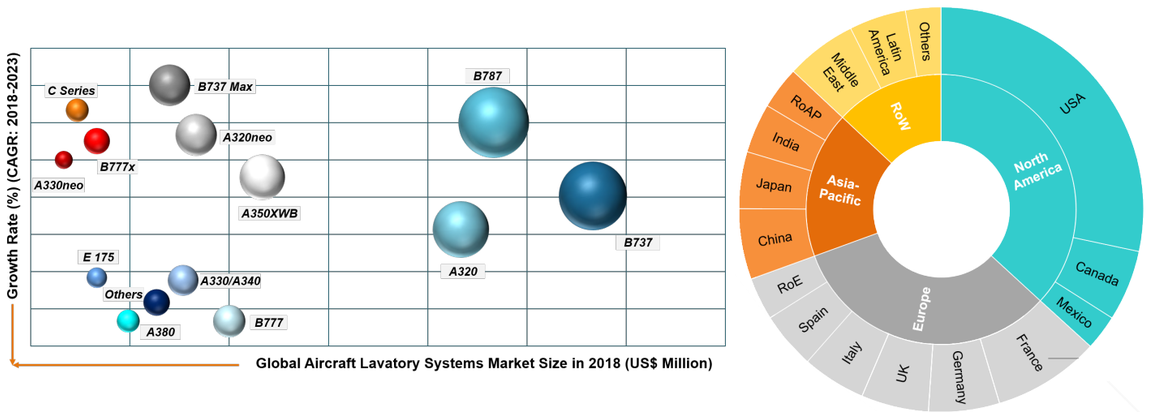


Fig.1.23 Aircraft industry market share by program (left) and region (right)

Latest Innovations

Airlines must fit the maximum number of passengers in economy class to create revenue, necessitating smaller lavatories. Luxury aircraft such as first class on the Airbus A380 have more space and therefore can often result in more ambitious designs. In both cases, hygiene is a major concern. Innovation in aerospace is driven by fuel-efficient design. Weight reduction, space saving and passenger experience are the goal of each of these new innovations.

Events such as AIX Hamburg, home of the Crystal Cabin award, showcase the years best attempts at industry disruption. Here are a few examples from leading companies in lavatory design and hygiene.

Boeing

In March 2016, Boeing unveiled this concept for a self-cleaning lavatory. The concept featured a basic economy class lavatory with a full touchless control interface and far UV-Light disinfection to clean surfaces between each visit (see *Fig.1.24)*. The concept received industry attention, but has not yet been put into use. A possible reason is that while the far-UV light is safe for human skin, it still contributed too heavily to the degradation of surfaces in the lavatory. This is merely speculation, but it demonstrates how difficult it is to innovate when there are so many product requirements to consider.

Boeing recently unveiled another concept for a dry and germ-free floor (see *Fig.1.25)*. The concept collects water in a sub-floor level basin and evacuates it between each use. Boeing promises that this new concept will reduce the flight attendant cleaning task significantly and provide a better smelling lavatory.

Airbus

In collaboration with Zodiac, Airbus created a new class of lavatory which uses space optimisation and creates a design language which enhances the perceivable space in the lavatory, making the passenger feel like they have as much room as possible. It is called the SmartLav (see fig *Fig.1.27)*. The Airbus modular cabin is a concept in development which would fundamentally change how aircraft cabins are designed, manufactured and used (see fig *Fig.1.26)*. Modules containing different sections of cabin are swapped out to suit the needs of the airline between changing flight missions.

Rockwell Collins

Following their acquisition of BE Aerospace last year, Rcokewell Collins caused a stir among the public when they announced a premium lavatory option which intelligently suppresses redundant space inside the lavatory in order to make room for an additional row of seats (see fig *Fig.1.28 and 1.29)*. The lavatory is one of the smallest ever designed and is strictly in functionality.


Fig.1.24


Fig.1.25


Fig.1.26


Fig.1.27


Fig.1.28


Fig.1.29

JAMCO

With over 50 percent of the market share in first class and business, JAMCO are steadily improving their product line to include touchless faucets and bidets as standard. JAMCO are also attempting to introduce hand dryers as an alternative to paper towels in an effort to minimise waste. Their high quality design and styling makes them a front-runner in innovative lavatory solutions (see fig *Fig.1.30)*.

DIEHL Systems

A lavatory which is seamless and sterile in appearance with a fluid looking touchless control interface (see fig *Fig.1.31)*. This high concept and futuristic offering features an unorthodox sink and faucet shape. Again, this design seeks to minimise the visual bulk of the components in lavatory and utilises high quality industrial design for style.

müller|romca

This German industrial design studio creates beautiful first class lavatory designs which exemplify luxury in their use of space and practical features. Their design for the Lufthansa A380 (see fig *Fig.1.32)* lavatory with a urinal and extra large shroud for the toilet. This design demonstrates how well a lavatory can be designed when space is not as limited in first class on high class flight missions.

Other

Smaller companies often introduce new innovative technology which catches the eye of aircraft manufacturers. EME Electro Metall created a motor driven by a biometric scanner (see fig *Fig.1.33)*. The ideal application for this tech is a touchless waste flap, which earned a Crystal Cabin Award. This innovation has since been purchased by many of the larger companies for use in new lavatory designs.

Conclusion

Innovations in aircraft lavatories revolve around space saving, cleanliness and controlling the flow of passengers in and out of the cabin. While each company seems to believe there is greater merit in some ideas over others, there is also quite some overlap. Only the strongest ideas survive in this business, making it of greater value to provide products which fit present day needs.

A wide range of options for a new clean lavatory concept is of benefit to Zodiac as it shows some of the potential for future products. Furthermore, focusing on technologies and design principles which have not yet been considered for aircraft should be explored as products and technologies already available may be protected by patent law.

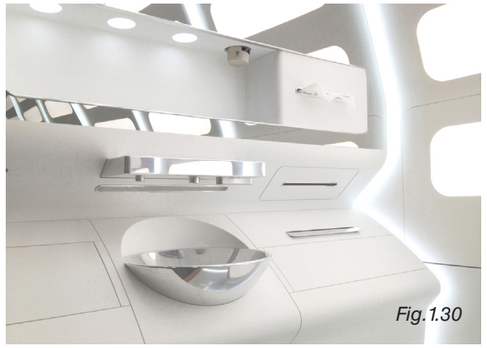


Fig.1.30


Fig.1.31


Fig.1.32

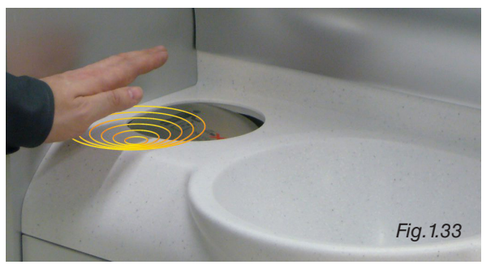


Fig.1.33

Chapter 2:
Product Analysis

Chapter Summary

In this chapter, the product and its context at present will be examined. The information in this chapter was gathered throughout the research phase of the project and expanded upon throughout concept development.

The product context is first discussed. This includes an investigation of public restroom hygiene, the context of the aircraft cabin and

A product review focuses on the hygienic aspects of the lavatory design which will influence the design of the product. The history and development of the lavatory monument is discussed. An overview of the components, manufacture and usage of the product is given.

Contents:

Public Restrooms

Context Analysis 2.1

In this section, the context of public restrooms both on and off airplanes is explored. Contemporary lifestyles require people to use different types of restroom in their daily lives. Restrooms vary greatly depending on building/vehicle type, location and the cultural and personal preferences of the main occupants. The following are some generalised examples of restrooms which were are examined for their ability to stay clean.

In hospitality

A hotel's reputation relies on its service and relies upon ensuring a personal experience for each customer (*Fig.2.01)*. Hotel rooms are cleaned between each guest by a member of the cleaning staff. This job also includes changing the bedsheets, vacuuming the floor and restocking amenities. In theory guests can make as much mess as they want and not have to clean it. The toilet in the lobby differs from the hotel room as it is fully public and therefore used by multiple people at a time. Transitional zones such as this have low levels of ownership for users but are very important for the hotels brand and image. (*Fig.2.02)*

In restaurants, guests often stay for 1-2 hours or perhaps longer for a meal. The frequency of cleaning matters greatly for the experience of each guest, so restaurants employ around the clock cleaning staff (*Fig.2.03)*. Cafe's, bars and nightclubs are similar in that they have a rolling clientele of individuals with low anonymity. The restroom designs in bars and nightclubs are designed to be cool and different in order to reflect their image (*Fig.2.04, 2.05)*. The chance of sexual activity and drug abuse are also higher. With so many anonymous people, some of whom may be drunk or on drugs, the toilets at the end of a busy night can be left in catastrophic state for the cleaners. (*Fig.2.06)*

In the workplace

Office restrooms are often gender specific multi-user rooms with stalls, urinals for men, mirrors and multiple sinks (*Fig.2.07)*. The number of amenities varies depending on the size of office and number of people. Restroom hygiene is important for office satisfaction. Factories are also workplaces, but will have different hygiene standards due to the nature of work being performed.

Universities are usually sources of social innovation and change. There is an ongoing debate is taking place over the lack of provision for transgender individuals on university campuses and in society in general in the US (*Fig.2.08)*. There has been outcry for years over the favoritism displayed by better provision for men than for women (Greed, 1995). A woman was recently arrested in Amsterdam for attempting to use one of the male only street urinals (*Fig.2.13*).

On transportation

The lavatory on a train is similar to an aircraft lavatory in that it is in a state of motion and provides a unisex single-user cubicle. Train toilets are also notoriously poor in terms of hygiene and cleanliness (*Fig.2.10)*. On a bus there is even less space than on a train or an aircraft (*Fig.2.11)*. However, a bus has the advantage of being able to stop suddenly in the event of an emergency. Boats experience the highest factor of motion and are comparable to aircraft with respect to space limitation (*Fig.2.12)*. In order to save fuel, vehicles must keep weight low to improve fuel economy.

Other public spaces

Cities like Amsterdam and London have open public toilets on some street corners. These restrooms accommodate all people are sometimes general neutral. Depending on the location, public restrooms can either be free or operate on a pay-per-use basis. These restrooms have a very bad reputation due to having the widest variance of users and being subject to foul play such as alcohol and drug abuse, cottaging and vandalism. (*Fig.2.13-15)*

Restrooms in movie theatres and sports arenas are used by people in waves. The average film-goer knows to empty their bladder before the film starts so as not to miss anything important. Similarly, large arenas and sporting events have restrooms designed to accommodate large numbers of people at key moments such as before the game, at half time and then at the end (*Fig.2.09).*

Washrooms in private homes vary hugely depending on the individuals, family's or groups living situation and their hygiene preferences. While some people hire cleaners and maids to clean their restroom, most people must do it themselves. This is done either for self-benefit, the benefit of a partner or family member or the benefit of guests in the home. Visiting another persons home is similar to using a public restroom, but with lower anonymity.

Analysis

Public restrooms and toilet areas come in many different shapes and sizes. There is a very high degree of variance in styles and methods of use, making in challenging to categorise all forms of public provision. For example, many public toilets in non-Western societies do not feature seated toilets, but holes in the floor for squatting.

There are some consistent themes however, such as the role of gender, the class of building or vehicle and the culture within which the establishment is situated. The remainder of this section will examine restroom variance with respect to class as this most closely relates to the aircraft context.


Fig.2.01


Fig.2.02


Fig.2.03


Fig.2.04


Fig.2.05


Fig.2.06

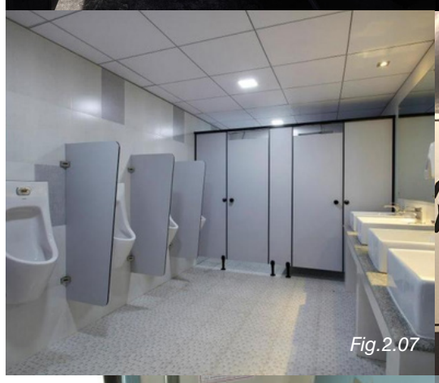


Fig.2.07

Fig.2.08


Fig.2.09


Fig.2.10


Fig.2.11


Fig.2.12


Fig.2.13

Fig.2.14

Fig.2.15

The Aircraft Context

Context Analysis 2.1

The aircraft cabin serves both as a vehicular mode of transport and a quasi-living space. Cabins are used for work, entertainment, dining and sleep; all of the most crucial human experiences (except for sex, which we'll get to in a moment) rolled into one space. These activities are catered to with the inclusions of reclining seats, tray tables and indeed lavatories.

Given the long tubular shape of the fuselage, the cabin layout is restricted to the a primary configuration; rows of seats in blocks, separated by galleys, lavatories and other service zones. Fig.2.20 illustrates the common layout of a short and long haul aircraft. Notice how the lavatory configurations are different in each section. This will be described in greater detail in the section *Lavatory Form and Layout*.

The environment is subject to motion. Movement of the aircraft ranges, from a busy take-off and landing to moments of intense turbulence in the air. It is also an environment subject to a very high density of people. A quick calculation demonstrates that 150 seat narrow body has an average of 1 person per 1.5 square metres.

On the ground

The lavatory is locked by flight crew when the plane begins to land and also remains out of service until the aircraft has finished refueling. However, during this time the FA may enter to tidy the lavatory. The lavatories receive a deeper clean along with the rest of the cabin when the aircraft stops overnight for maintenance. A further deep clean procedure is undertaken when the aircraft receives scheduled maintenance checks or is upgraded.

In the air

The lavatory is primarily used by passenger while the aircraft is in flight. The lavatory is not available for use while the seatbelt sign is on. While taking off and landing the aircraft is angled, making it more difficult to stand up and to walk, increasing the likelihood of an accident. Passengers are generally allowed to use the lavatory when the aircraft is in a steady flight path, after take-off and before landing begins. In the event of heavy turbulence or an emergency lavatory service is also suspended and passengers are asked to take their seats.

When the seatbelt sign is off passengers may use the lavatory one at a time and form an orderly queue in the aisle while waiting. However, this is often to the detriment of flight crew and other passengers trying to pass. The cabin walkways are narrow and become crowded quickly. In the air, the lavatories receive a superficial cleaning by cabin crew. This includes disposing of visible rubbish, wiping surfaces and corners clean and refilling the paper and soap containers.

Semi-public space

The lavatory presents a duality onboard the aircraft between public and private space. The cabin is a shared space in which there is a very low chance of privacy (unless the occupied seating row is empty). The lavatory offers a zone where privacy is possible. However it is still a shared space which can be used by all passengers. This presents the dilemma that a passenger cannot truly obtain privacy on the aircraft. The inability to have any privacy for an extended period of time (the time of a flight) can be a stressful experience for passengers.

Captive audience

Unlike a bus, car or train, passengers cannot easily disembark to take a break to go to the toilet. Once everyone has boarded and the aircraft doors close, one must persevere onboard. On shorter flights it is possible to plan toilet visits before and after the flight. Increased length of time and the consumption of food and beverages make this nearly impossible on longer flights. A passenger choosing not to use the lavatory during the flight will run the risk of experiencing extreme discomfort or even soiling themselves.

The lavatory not only provides relief and sanitation, but is the sole location on the aircraft where passengers can have privacy. This can be useful for other activities which are unrelated to relief or sanitation, such as changing clothes or simply taking a moment to be alone. Passengers are also known to engage in sexual activity in the lavatory with a partner to join the "*mile high club*". This behaviour is prohibited and should be mitigated in the design of a new lavatory.

Emotional factors

Having to stand in the aisle being watched as they enter and exit can make people feel awkward. While inside the lavatory with the door locked, one has complete privacy. However, it is often the case that someone is waiting outside to use the lavatory next. This can lead to a negative emotional responses like embarrassment or stress.

A fear of flying can lead to intense anxiety (Vanden Bogaerde and De Raedt, 2008). Discomfort can arise from the close proximity of other people, most of whom are strangers. For people that are claustrophobic, the idea of an aircraft lavatory can be incredible daunting since it is effectively a cocoon within a cocoon.

Social factors have an important influence on an individuals behaviour, which will be discussed in *Chapter 3, User Analysis*.

Fig.2.19 KLM Aircraft ready for service

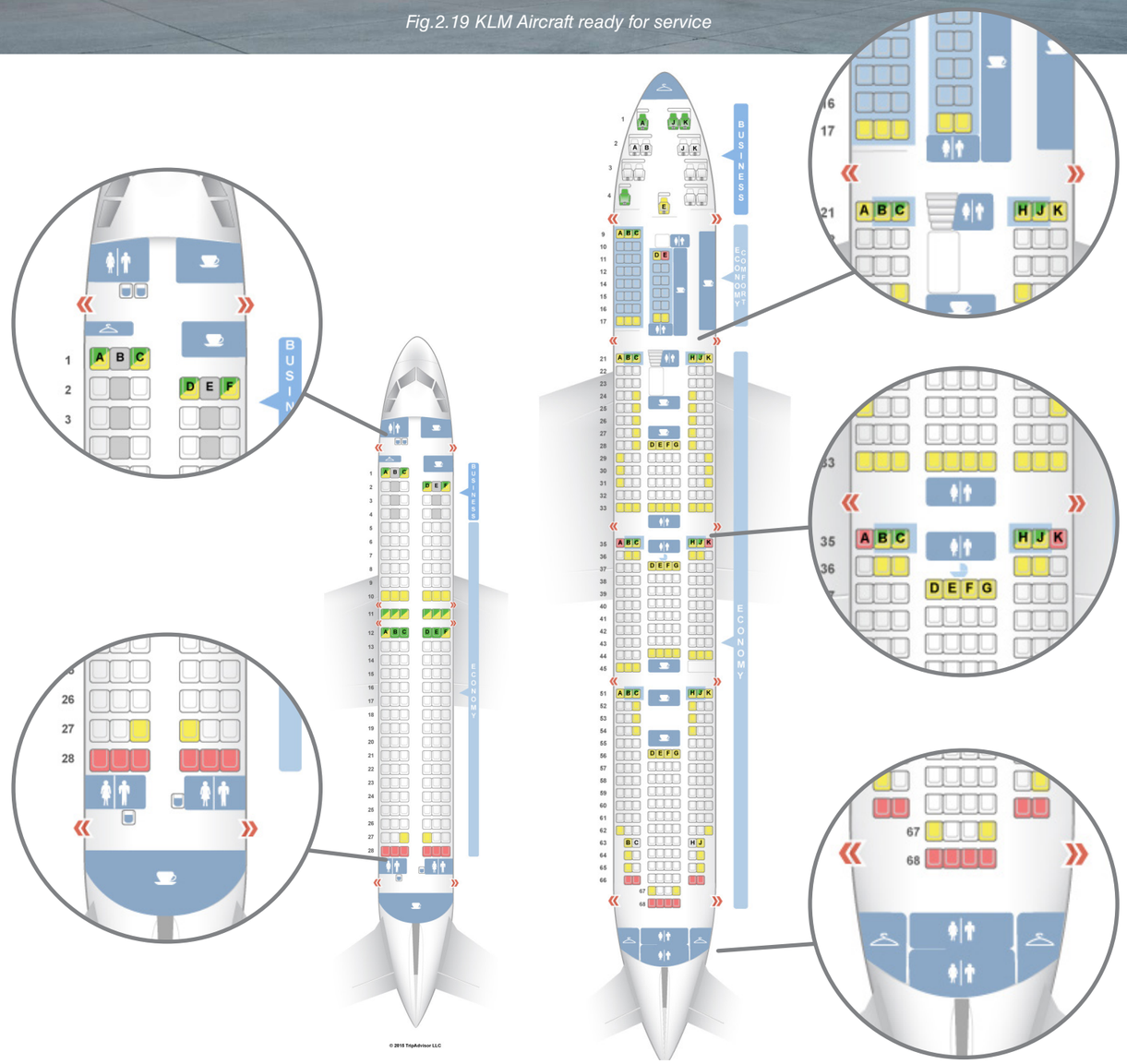


Fig.2.20 Seat maps; KLM 747 (Top), Finnair Airbus A320 (Bottom)

Hygienic Factors

With such widely variable parameters for use, a restroom can be one of the most challenging rooms in a building to design. Architects and developers must carefully consider who will use their restroom the what activities they are likely to preform.

A good example are the toilets in primary school buildings. They must have separate toilets for children and adults. Toilets for children must be smaller and use educational stimuli to teach children the appropriate toilet behaviour.

When an individual experiences and unclean restroom in a facility, they are likely to perceive the entire facility as unclean (Barber and Scarcelli, 2009). Restrooms which are poorly designed and maintained are likely to become unclean and therefore are unpleasant for people to use. This section will focus on what separates good and public restroom design.

Class

Hygiene conditions can be objectively good and bad, and good hygienic conditions appear to be a luxury. The establishments mentioned on the previous page vary in class, an important contributing factor to consider in the quality of the restroom.

The level of effort and investment in the design and maintenance of an establishments restrooms reflects the class. Higher investment gives the facility access to scheduled cleaning, better access to training and equipment as well as higher quality fixtures.

In context

In airplanes seating class is a determinant of passenger experience and product quality. Passengers in economy pay less than business and first class and therefore receive an experience which has received lower funding and is likely to be of a comparatively lower standard.

The examples to the right compare aircraft lavatory class (*Fig.2.16)*. The first is an economy lavatory which looks worn down with drab colour and lighting schemes due to age and damage. The same sized unit can have a much cleaner appearance, as seen in the next example of a premium economy lavatory. The third is a first class lavatory with much more space more features included. The design is clean and inviting.

In the examples used for bars, the first looks unclean and unhygienic. This is likely a bar where clientele with free inhibitions care little for hygiene. In the next example, the restroom is clean, yet paper is overflowing. This is common is the average restroom. In the third example, the restroom is clean and tidy. The surfaces are shimmering and everything is where it needs to be. Like the first class lavatory, it is difficult to imagine this restroom in a mess.

Privacy

Consider a private residence, washrooms almost never feature more than one toilet and remain clean to the standard of the home owner. Compare this to a busy sports arena during a game, when there can be dozens of people queuing to use a toilet, with no time or space for cleaning to take place.

Excretion is considered shameful behaviour, which some scholars believe is due to the soiling of the self (Thepsychologist, 2018). Contemporary social norms dictate that a more desirable restroom is private and clean because it allows people to hide their shame and remain unsoiled without others noticing.

Restroom desirability

A basic scale has been developed to categorise the different types of public restroom comparative to one another (*Fig.2.18)*. Restrooms in the upper right corner of the scale are the most desirable as they offer consistent cleanliness as well as privacy, whereas restrooms in the bottom left are the opposite, offering limited privacy and a high likelihood of poor hygiene.

The restroom in ones own home is considered at the top of the chart as it is used infrequently, cleaned to ones own standards and offers maximum privacy. A public urinal is the opposite, being used often by many different people, cleaned infrequently and is used in the open air. The top left and bottom right are mostly empty. This is because completely private restrooms are usually very clean and public restrooms are never completely clean.

First class lavatories are desirable whereas economy are not. This low perception of hygiene in economy is due to the fact that more people are using the lavatory, therefore providing an enhanced level of privacy. The exclusivity of first class and higher investment in services also add to their desirability. Economy class lavatories are evidently comparable to fast food restaurants and train toilets, and not too far off a factory floor.

The goal of the design is to align with the more favourable and desirable public restrooms. These restrooms have traits which may be transferable at user level such as the provision of hygienic products and use of space.

Bathroom goers "*may lay claim to any unoccupied stall in the bathroom,*" but *"once such a claim is laid, once the door to the stall is closed, it is transformed into the occupying individual's private, albeit temporary, retreat."*

Quote from the book:
Meanwhile Backstage: Behavior in Public Bathrooms

Lower class ***Middle class*** ***Upper class***

Fig.2.16 Aircraft lavatories in economy, premium economy and first class

Lower class ***Middle class*** ***Upper class***

Fig.2.17 A range of class in the restrooms of various bars

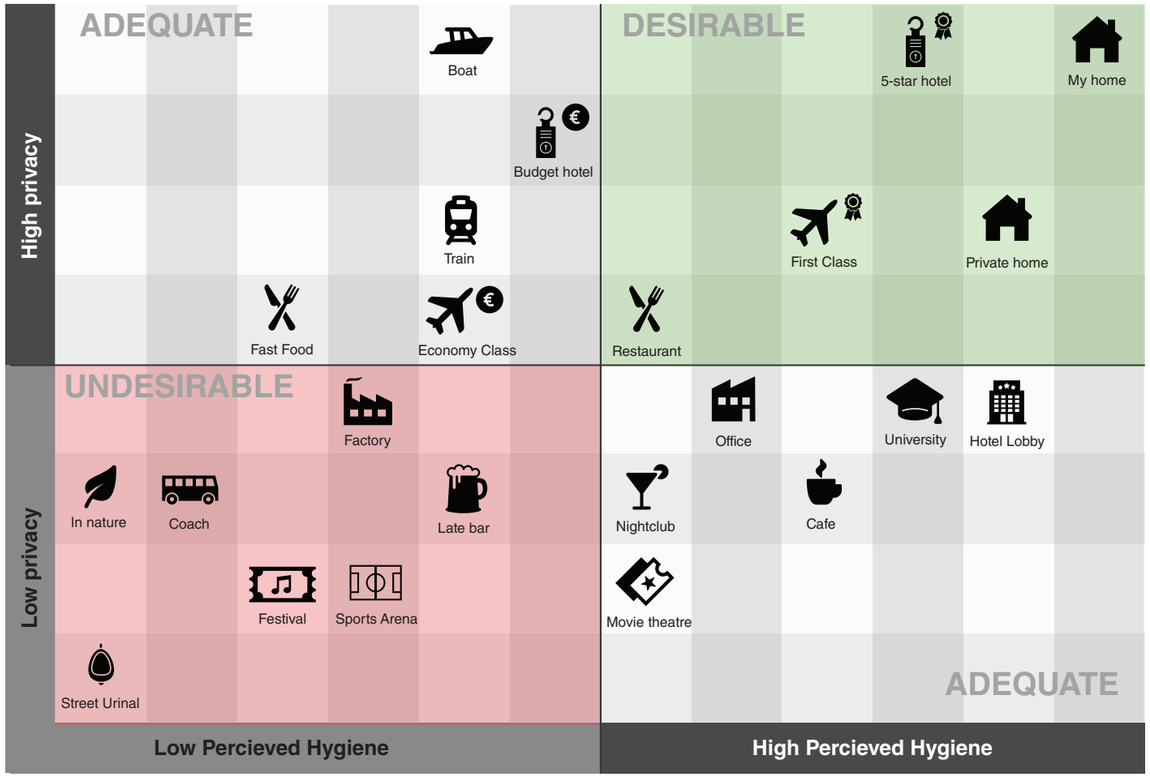


Fig.2.18 Public Restroom Desirability

Lavatory Overview

Product Definition **2.2**

This section gives a descriptive summary of the lavatory monument; what is it and how does it work. Included to the right are several images of lavatories in different classes from different airlines and manufacturers.

Product definition

An aircraft lavatory is a special type of public restroom which is purpose built to fit and operate within an airplane. The lavatory can be used throughout the flight by passengers who wish to use the toilet or freshen up. Lavatories range in style and functionality depending on the airline, geographic location, position in the aircraft and seating class.

History

Before civilians took the skies, the problem of in-flight relief belonged to military pilots. Evac tubes were included to help pilots relieve themselves and concentrate on their mission, however, most aircraft would not be able to sustain flight long enough to require relief (Toilets of the World, 2018). The same would then apply on commercial aircraft. These planes flew at lower altitude and may have only lasted up to an hour. Over time the flight experience became longer and necessitated toilet provision. In the 50's and 60's commercial air travel became popular among the wealthier classes and business travelers and lavatories became ubiquitous on planes. Features seen in normal toilets began to appear such as flush toilets and water faucets. An attendant was hired to guide passengers and keep the space clean.

Modern lavatories

Through constant research and development, more hygienic and space efficient lavatory designs have been developed, all without sacrificing passenger comfort. Lavatory design is often simple and functional, but there is now an increased drive towards high end design and styling. First class lavatories on the worlds best airlines are now as lavish as those found in hotels on the ground. The Emirates A380 now features two showers with full time shower attendants to give high paying passengers the most luxurious experience imaginable. Lavatory design involves the complex combination of space design, component selection, human ergonomics, styling and lighting design as well as ultra-lightweight material engineering.

Product usage

The passenger enters from the galley through a single door. Once inside the user locks the door which also turns the lights on. Passengers can then use the toilet as they need and wash their hands and face. Paper dispensers provide facial tissues and hand towels to dry off. There are often additional paper products such as toilet seat covers and sanitary pads for female hygiene available in drawers in the cabinet. Lavatories are unisex and take one user at a time. Passengers who wish to use the lavatory while it is occupied must wait in their seat until it becomes free. This rule is often broken however and a queue forms in the aisle, blocking the passage of flight attendants and blocking the flow to the galley.

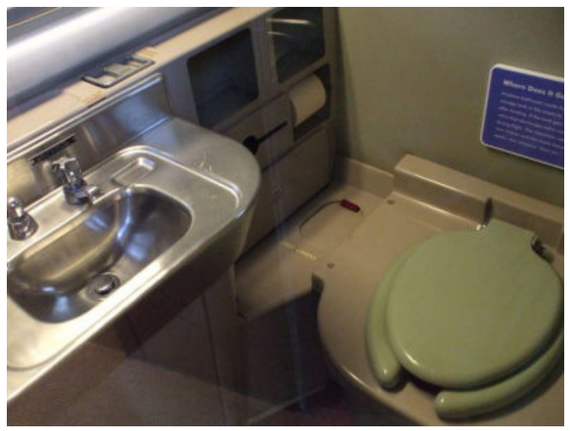


Fig.2.21

Older designs, like the one pictured to the left, were bulky and heavy. Over time, more attention to design, better manufacture techniques and higher demand led to the more hygienic look and feel seen today

The lavatories to the right are examples of current day lavatories. These products offer a balance of style and functionality, with the goal of ensuring the best passenger experience.

Fig.2.22 Images of Various Aircraft Lavatories

Lavatory Components

Product Definition **2.2**

The lavatory can be considered as a single product with multiple components inside. To make a distinction, the monument will henceforth be referred to as *"product"* and objects within will be referred to as *"components"*. Each component inside has a role to play in the design of a new concept.

The design of the components themselves and the relationship between them aim to provide a familiar and user-friendly passenger experience while carefully disposing of waste and decreasing the risk of onboard contamination. The following is a rundown of all of the major components featured inside the average lavatory and a brief description of their purpose.

Toilet shroud
Every lavatory features a toilet as a means of disposing human waste effectively. The toilet shroud houses the seat, lid, waterless bowl and flush mechanism. The passenger can sit on the toilet to relieve themselves and men can stand facing the toilet bowl to urinate. Beneath the shroud is the toilet vacuum system. The system is connected to an outlet which carries the contents of the bowl to large tanks in the rear of the aircraft. A water inlet is also connected to release a small amount of water each time the toilet is flushed.

Sink basin
The sink is comprised of a round basin for the collection of water and one or more water faucets. Hot and cold water are provided through a mains pipe which is connected to the lavatory when it is installed. The shape of the sink is often either an oval or square shape and the size is just about big enough to accommodate a person's hands.

Wash area
Next to this sink is a small surface upon which the passenger can place any objects he/she brings into the lavatory. Airlines also supply soaps and lotions in this area which are used to clean the hands.

Waste bin
The bin is located inside the wash cabinet and is accessed with a stainless steel flap on a hinge. All hand paper is to be discarded after use with toilet paper to be discarded in the toilet. The bin can be removed and emptied by a crew member by opening a door on the front of the cabinet.

Toiletry cabinet
The purpose of the cabinet varies between lavatories. Primarily it is used to contain all of the stock-able items and contain the sink, mirror and plumbing system. It also has extra drawer space containing female hygiene products, extra toilet paper and toilet seat covers in some lavatories.

Hand paper dispenser
Hand paper is the preferred method of hand drying in aircraft and can be seen in virtually every lavatory design. The paper is stored, usually in multiple bins and refilled by the flight attendants during inspection.

Toilet paper dispenser
A small bar holds the toilet paper in place. It is often not concealed so passengers can find it easily and so the rolls can be changed quickly. The holder can be equipped with an aluminium flap which allows the user to tear a sheet using just one hand. Used toilet paper is disposed of in the toilet, not the waste bin.

Mirror
The mirror is positioned above the hand wash area and allows passengers to check their appearance. Certain larger high-end lavatories have a full length mirror on the facing wall rather than a small head and shoulders mirror. The mirror is made from a shatter resistant non-glass material.

Floor pan
The pan shape prevents liquid spillage onto the base layer of the lavatory envelope and further into the aircraft. A rubber mat with an anti-slip surface finish coats the floor of the lavatory. The rubber prevents the buildup of liquid and enables the floor to be cleaned quickly.

Door
There are two types of doors used; blade door and bi-fold. A blade door is a single panel which slides on a central bolt. This gives the passenger enough space to enter the lavatory. The door opens outwards to give the individual inside enough space to exit. There are a number of secondary features on the door such as the locking mechanism, kickstrip, ashtray and coat hook.

Passenger service units (PSU)
The ceiling houses lights and the air filtration system. Positioning these components overhead puts them out of the way of the passenger and provides a fully illuminated space.

Baby nurturing table
A tray is attached to the rear wall above the toilet via hinges. It can be opened flat using a clip which lowers the tray. Rubber stoppers on either side are included to give the tray resting points. The tray is made of molded plastic and can be raised and lowered by hand. It allows a parent to change and care for their baby in privacy.

Sub-components
There are a number of additional objects inside the product which act as sub-features. Some are essential features and some are non-essential. These include the accessibility handles on the aft wall, smoking ashtray, signage and a small coat hanger. The lavatory also features a series of small panels which display information in the form of text and symbols.

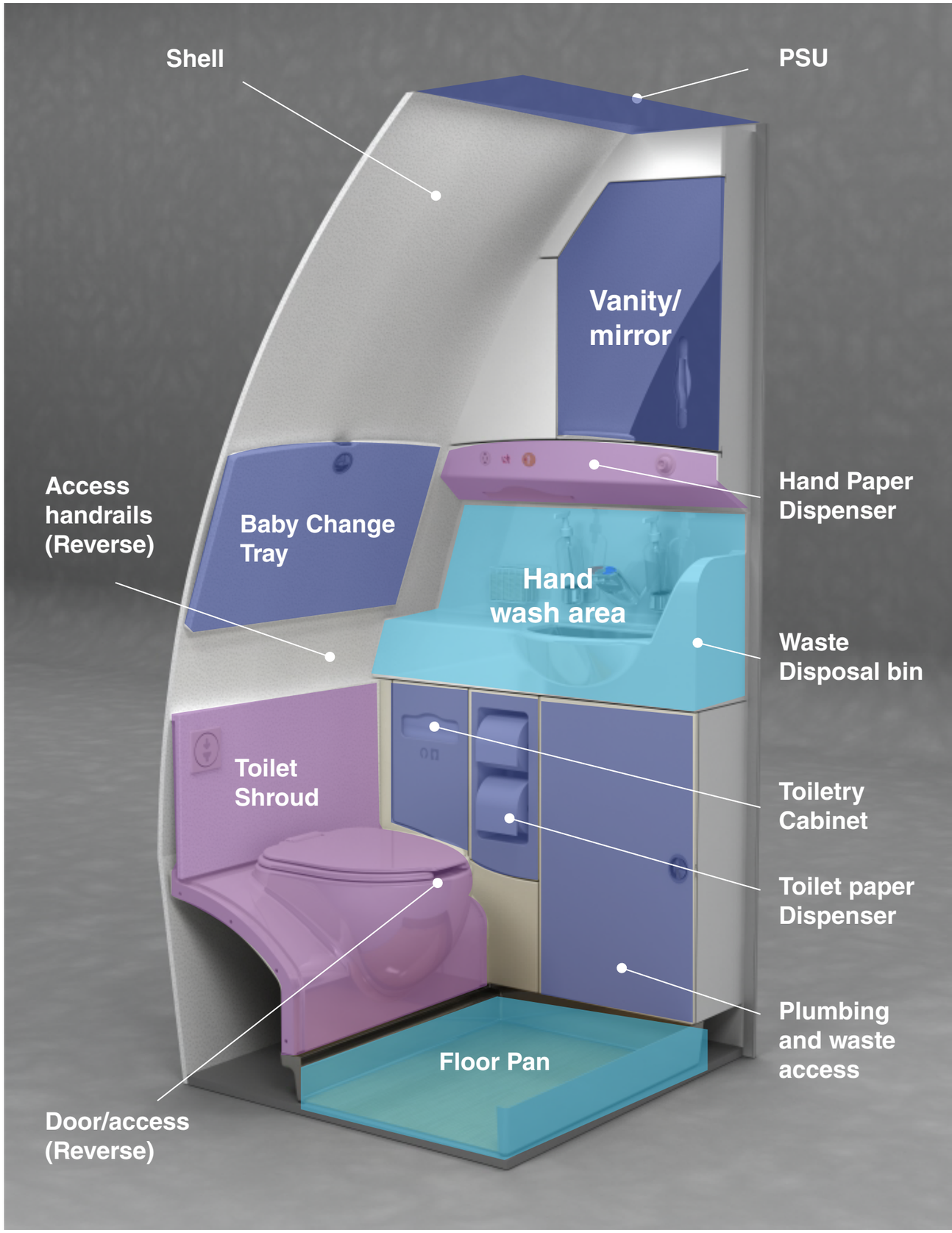


Fig.2.23 Lavatory Component Sub-Systems

Layout & Form Design

Product Details 2.3

The layout of passenger accommodations (LOPA) is perhaps the most important aspect of lavatory design. The size, shape and location of each component is carefully planned and implemented based on the amount of space alloted to the particular lavatory. Also factored in are the seating class and budget of the airline. This section will look at the determinant factors in lavatory design with respect to the layout of the cabin.

Lavatory type

There are essentially three types of lavatory; *Space saving, standard and comfort*.

- Standard lavatories are the most common, these lavatories measure between 32-34 inches in the X direction (width section of the cabin).
- Space saving lavatories are the smallest and therefore have the fewest features and components. Given recent trends it is likely that this class will become more popular. Good design is imperative for space saving lavatories to improve experience and revenue.
- Lavatories in the comfort class can be much bigger; 34+ inches. The extra space allows the inclusion of more features and higher investment enables more ambitious designs. Comfort options are either part of a premium class or intelligently designed to fit within a special configuration (see *fig.2.26*).

Aircraft type

Boeing and Airbus offer a range of aircraft sizes to accommodate various flight lengths and passenger capacities, these are called missions (see *fig.2.24)*. The number and size of lavatories on each mission varies depending on the needs and wishes of the airline. The more seats an aircraft has, the more lavatories it will require. On average there should be one lavatory per 50 passengers (an observed range of 35-68 passengers per lavatory has been observed on *SeatGuru.com*).

Short haul aircraft

Narrow-bodied aircraft such as the Boeing 737 and Airbus A320 most often features three lavatories, one forward and two aft. In case where there is a separate premium economy, the forward lavatory can be larger and include more features. There are two seating arrays on these single aisle aircraft; 3-3 and 2-2. Narrow-bodied aircraft have a shorter range and are used for short-haul missions, though some analysts maintain that this could change soon to include long haul.

Long haul aircraft

Widebody passenger aircraft, also known as twin-aisle aircraft, can have up to 544 passengers in a 3-3-3 or 3-4-3 configuration. The much larger Boeing 747 and Airbus A380 can have ten or more lavatories including additional first class and business class options. Economy class lavatories are given zones in the middle and aft of the cabin, with a variety of options at the forward area of the aircraft for business and first class. The aft lavatory is most often where the PRM specific lavatory is placed, as require by law.

Layout

The lavatory is a square cubicle with a door that opens inwards. The door must be able to swing 90 degrees inwards to open with an individual inside. Bi-fold doors were an excellent innovation as it allowed the passenger more space to open the door from within. The occupants knees should be a comfortable distance away from the door and walls while seated on the toilet.

Taking the door, walls, toilet and wash basin as the most critical components, ergonomic feasible is already limited to a just a small number of logical configurations (see fig.2.25). As layout is driven by the largest and most critical components, it quickly becomes challenging to move components around in a redesign.

Form design

All monuments must fit within the cabin in relation to one another, the seats, galleys, exits and cabin itself. Lavatories in the centre of the cabin will have straight box-like form whereas lavatories at the side will have a curved back wall. The curved variant is a good option for saving space. Boeing aircraft most often feature four mid cabin straight profiled lavatories, whereas Airbus are more inclined to include two curved lavatories either-side two adjacent mid-cabin lavatories.

Lavatories are designed to be functional first and foremost. The internal form is determined by which components are included and the space envelope. In a highly competitive market, branding and differentiation are becoming increasingly important. The form design encases all of the components within walls and cabinets and gives the lavatory its unified appearance, but also separates different companies in terms of style and usability.

Analysis

The main focus of the new concept design is the middle aircraft passenger lavatories on wide-bodied aircraft. Situated in the middle of economy, these lavatories are used the most throughout the flight and are therefore the most problematic. Boeing and Airbus each has a different approach to lavatory provision in this location, and different airlines further differentiate themselves by created their own desired layout based on seat density. This will be discussed in much greater detail in Chapter 6; Detailed Design.

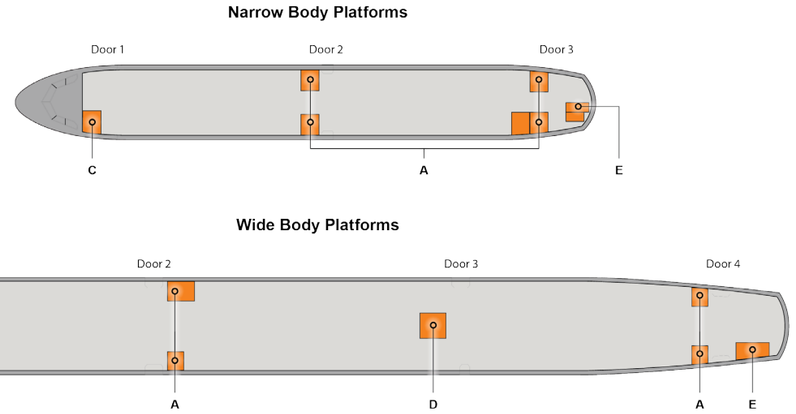


Fig.2.24 Narrow and widebody aircraft lavatory locations

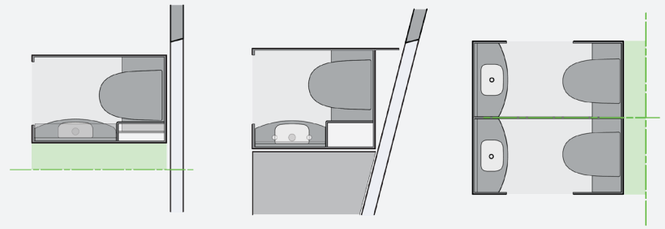


Fig.2.25 Standard Lavatory Configurations

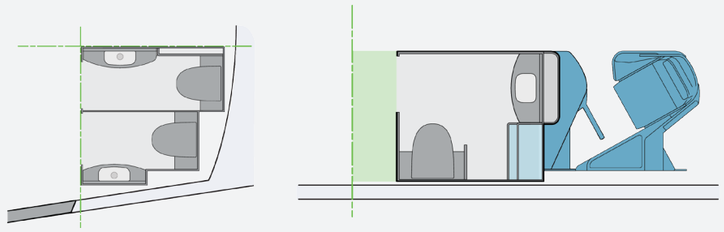


Fig.2.26 Special Lavatory Configurations

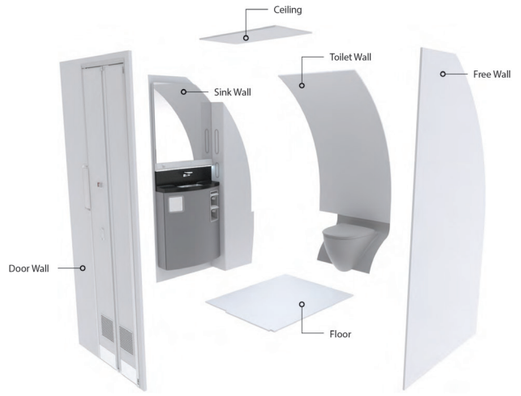


Fig.2.27

Pictured left is an exploded view of Zodiacs DMS Lavatory. As we can see each wall serves a unique purpose. This gives the lavatory a degree of modularity, enabling multiple configuration types with different floor and ceiling widths, for example.

Lavatory Technology

Product Details 2.3

Flush systems, hand dryers, ultraviolet lamps and motorised self cleaning toilets are all relatively recent innovations in human history. In many parts of the world, people are without this hygienic technology, increasing the chance of disease and death.

Advanced technology has the opportunity to improve product experiences by offering greater control and personalisation as well as eliminating errors during usage. The following is a look at some interesting technology used in lavatories to help the user stay clean and fresh.

Vacuum flush system

The most sophisticated piece of modern lavatory technology is the waterless vacuum toilet. These toilets 80% less water by transferring human waste to large tanks inside the aircraft at high speeds. Between each flight, the tanks are emptied by what is called a honey-truck. The honey-truck dumps the waste into the city mains of whichever airport the plane lands. Vacuum toilets have proven to be excellent in the aircraft lavatory application and are now also in use onboard trains and at outdoor public events.

Touchless control

Sensor technology makes it possible to operate a device without touching it. This is important for hand hygiene as it restricts the potential for pathogens to spread from one person to another. The most common sensor type is infrared. Infrared light detects motion and can be programmed to electronically trigger a valve or motor. This is already used in faucets, hand dryers, paper dispensers and even flush the toilet. These sensors are inexpensive and their application has many user benefits. A biometric proximity sensor is used in the touchless waste flap concept which senses the human body, preventing accidental triggers.

Lighting

Gas and filament bulbs are volatile and outdated. They have been entirely replaced onboard aircraft by LEDs. LEDs are small, lightweight and highly versatile Multiple bulbs can be arranged in patterns and strips and last up to a year. Lavatories use light to guide the user through the space. Intelligent lighting programs can enable an environment which can change the mood and behaviour of passengers. Low lighting conditions might make it harder to see, but will also reduce the appearance of dirt.

Hygienic materials

It is required that materials in use must comply with safety regulations, be lightweight, durable and shock absorbing. They must also be cleanable and consider the effect of cleaning chemicals over time. To manage each of these requirements, surface materials are often built up in layers. With respect to cleanability there are two principles which improve the surface; self cleaning surface and anti-microbial.

Self-cleaning surfaces

The efficiency of the cleaning process not only depend s upon the optimization of the process itself and on the equipment design, but also on the characteristics of the soiled surface i.e. mainly its roughness, surface chemical composition, and surface energy (Detry, Sindic and Deroanne, 2010). There are materials which can immediately repel microscopic matter and others which heal overtime. Titanium dioxide is used to treat surfaces to become self-cleaning. The benefit is that no additional cleaning products are required, just water. The effort required to clean these materials is minimal.

Anti-microbial surfaces

Some materials have the ability to self-disinfect by neutralising bacteria which lands on the surface. Copper and silver are naturally anti-microbial materials so most coatings contain them in nanoparticles. Any surface can be treated with an anti-microbial coating. In principle a surface can be made self cleaning or anti-microbial, but not both.

Hand drying

Paper is the established standard in aircraft lavatories. However new technology could replace paper with hand dryers. The *Hydrowashr* features a space where users vertically insert their hands (see *Fig.2.30*). This differs from a normal paperless hand dryer in that it also wets the hands. This contains bacteria that is usually blown into the surroundings (Huesca-Espitia et al., 2018). This product is currently in development for public restrooms but is deemed too large and heavy for aircraft installation at the moment.

Analysis

The following are some example of hygienic design which can currently be seen in most lavatories.

- Touchless provision of clean water and soap.
- Teflon surface coating for non-stick toilet bowl
- Surface pattern shows or hides appearance of dirt
- Odor enhancing ventilation
- Touchless controls; faucets, flush and waste flap
- Automatic controls; toilet seat lift and flush
- Paper products instead of air for hand washing
- Anti-microbial and self-cleaning surfaces
- Self disinfection of surfaces

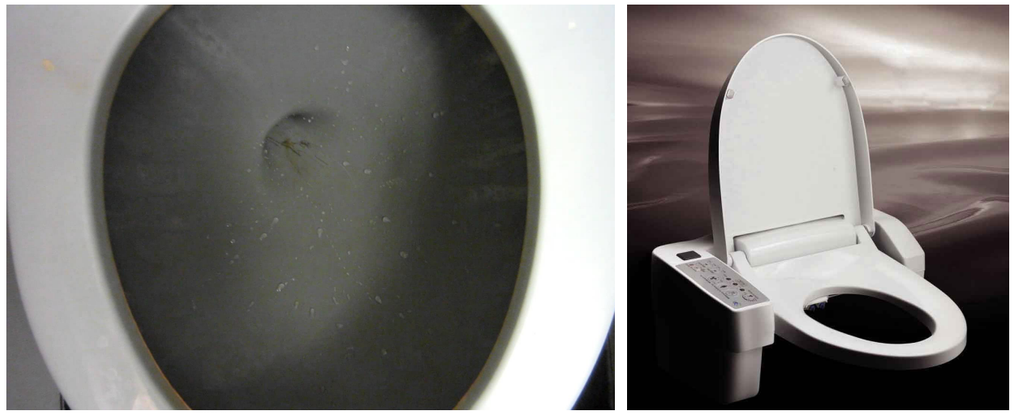


Fig.2.28 High tech toilet designs; Vacuum toilet and Advanced control

Fig.2.29 Aircraft cabin materials

Fig.2.30 Hands free bidet and Hydrowashr

Lavatory Production

Product Details 2.3

Information about the design and manufacture of Zodiacs lavatory monuments was gathered during a visit to the facility in Carson, USA. The following is an account of the products, materials, design requirements and targets presently employed by Zodiac.

Manufacture and assembly

The lavatories currently in production are built from scratch by laborers at Zodiacs production facilities in the US. To make the envelope, workers use large metal frames to align parts the external walls and junctions. Honeycomb panels are cut to size and fixed together using special glue and joining methods. The separate lavatory units pass through the warehouse to be fitted with each component and hooked up to air and water inlets and outlets for testing. Finally each lavatory receives a decorative finish and is removed from the assembly line for inspection. It takes 3 days on average to build a lavatory.

- The supporting structure of the aircraft is built using aluminum sheets and extruded bars.
- Composite materials are used for structural components and components which require a high weight to durability ratio.
- Aircraft grade fiberglass honeycomb panels make the walls
- Lightweight thermoplastics are used for small fixtures
- Thermoplastic rubber is used for the flooring.
- Larger parts such as the toilet shroud and wash basin assembly are made of molded polycarbonate.
- Zodiac uses stainless steel for the trim and fittings such as faucets, door handle and dispenser openings.
- Using the same materials and shape design adds to the harmonisation of the lavatory, which Zodiac believes is important for a clean and uniform appearance.

Zodiac are currently focusing their research and design efforts on a lavatory which has more standardised components, increasing their lavatories adaptability to a range of configurations and reducing the manpower required in assembly. This has the added benefit of utilising high volume manufacture for parts and components.

High volume methods such as injection molding have a much lower part tolerance than vacuum forming or simply cutting and stitching parts together by hand. The higher accuracy will allow designers to create tighter fitting parts of higher quality. This is massively beneficial to the hygiene effort as it will reduce the size and impact of gaps and provides greater control for the size and weight of all components.

Zodiac also focus heavily on improving the tooling for each product. Fig.2.32 shows a tool for fitting together the various parts of a bi-fold door. It is noteworthy that the door itself is designed for this tooling method as much as it is designed for use by the passenger. Design for ease of manufacture is of great importance to this product and influences how quickly new products can go to market and meet order deadlines.

Sustainability

Cabin interior manufacturers strive to have a green image in order to win favour with airlines and with passengers. It is not essential but potentially adds towards user satisfaction. Energy and material efficient design is beneficial as it contributes to the “reduce weight, reduce fuel consumption” approach to sustainable aircraft design. Material design and manufacture largely follows this principle.

Given the crucial need for safety in airplanes, sustainable design principles can be difficult to apply in aircraft. Recycling is not possible where adhesives and coatings are applied to surfaces. Furthermore, lavatory use requires electrical energy, clean water and disposable paper products.

A sustainable approach to the design seeks to minimise the use of all three of these resources. The amount of water used across an entire fleet was reduced significantly when waterless vacuum toilets were introduced in the 1970’s. Sustainable design is crucial to cut costs in this respect and is therefore a design requirement.

Limitations

There are a number of universal and immutable limitations with design in aircraft.

- Fire safety onboard aircraft is taken very seriously. All parts and products must undergo testing and evaluation to pass the FAA’s standards on fire safety.
- Aircraft are also tested rigorously for crash-worthiness. The same applies to components and product inside the cabin.
- The weight of components is restricted based on fuel consumption; a heavier aircraft requires more fuel to fly. However this is mostly market driven. A competitively priced product option may be preferable if there is an addition in weight accompanied with a guarantee that revenue will be increased in some other way.
- Patent law dictates that any product or system filed by a company must be licensed by the new design to prevent infringement. In this case it has been expressed by Zodiac that no patent be infringed upon with the proposed concept or that the license for said patent is obtainable. This is often not possible if the patent is held by a company in direct competition with Zodiac.
- Proposed new technologies or application of technologies must be justified based on novelty and patent-ability. Ideas which have failed in the past to reach the market are not disallowed. Such ideas are examined and evaluated equally.

Fig.2.31 Concept Development at ZEO in California; Durinal model, early A350 model, advanced A350 model

Fig.2.32 Tooling of a bi-fold door

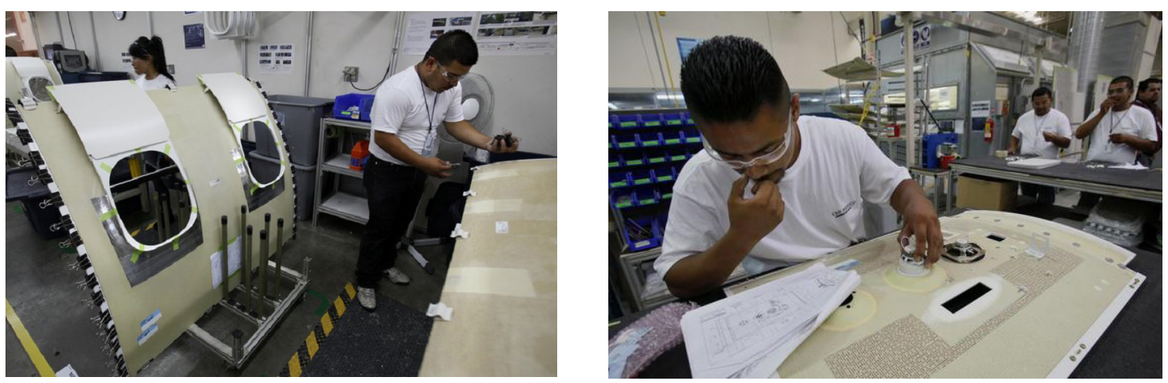


Fig.2.33 A technician assembling part of the cabin

Chapter 3:
User Analysis

In this Chapter...

... the users of the product are identified and analysed. In the first section an overview of all stakeholders is given. This is followed by descriptive sections of each stakeholder, how they interact with the product and their individual needs.

As the focus of the project is human hygiene, the next section will focus on the health implications of hygienic design, including a definition of what makes an object clean and an analysis of why humans need to be clean and want to be tidy.

The final section will examine the tools and models used to predict human behaviour, especially in the context of health. Given that there are multiple stakeholders, this method is used as a way to manage the range of factors influencing the problem, which is necessary for designers on complex projects (Gabrielsen, 2001).

Contents:

Stakeholder Overview

Stakeholder Analysis 3.1

For all intents and purposes there are three of sets stakeholders involved in the product; primary, secondary and tertiary. As this is a user-centred design project, the primary stakeholders are people for whom the lavatory is built, passengers. Secondary stakeholders are individuals who come in direct contact with the lavatory. These are flight crew, maintenance crew and installation crew. Tertiary stakeholders are airlines and manufacturers, who stand to make a profit from the product and influence its creation.

The needs of all stakeholders are ascertained through analysis of the product in context. This is achieved by examining current practices on board aircraft, visiting work sites and interviewing different stakeholders. The next three pages give a breakdown of each stakeholder including information regarding their involvement in the product and their needs.

Primary stakeholders

Passengers are the primary stakeholder in this case as their involvement in the product justifies its existence. If passengers no longer needed to use an onboard toilet then airlines would stop buying them and manufacturers would stop producing them. This may have been a possibility if commercial supersonic flights getting passengers to their destination in a fraction of the time had not failed to gain popularity. For the foreseeable future, lavatories are required for a comfortable flight.

Passengers drive the need for this product and also perpetuate the problem, poor hygiene and untidy behaviour.

Secondary stakeholders

There are several groups of people who must also interact with the lavatory on a regular basis. These are the crews who operate and maintain the lavatory. One crew assembles the lavatory and installs it in the aircraft, another cleans it in between flights and another keeps it clean throughout the flight. Cabin crew spend their working hours onboard aircraft and in close proximity with the lavatory. Cabin crew are also expected to clean and maintain the units mid-flight.

Cabin and ground crews mainly need for the product to be intuitive to clean, install and replace.

Tertiary stakeholders

Airlines and manufacturers have perhaps the largest stake in the production of lavatory facilities. Production and purchase of a lavatory requires co-operation from multiple companies at a time.

Balancing needs

With so many stakeholders involved it can be difficult to apply new solutions. For example designing an aircraft lavatory which caters to every passenger need will likely be too expensive to produce, have many complex parts to clean and take up too much space in the cabin.

A more detailed overview of stakeholder needs is given in Chapter 4:Problem Definition.

Fig.3.01 Users of the product; Cabin crew, passengers and maintenance workers.

Fig.3.02 Overview of the worlds biggest airlines

Tertiary Stakeholders

Airlines

Airlines purchase entire fleets of aircraft from either Airbus or Beoing. The fleets are then assigned to a mission and outfitted accordingly. When the airline changes their flight mission, the aircraft can be stripped and re-fitted to suit the changing needs of crew and passengers. All of the parts and services within an aircraft are under constant use and are therefore finite. It is in the airlines best interest to save money buying and using equipment.

Airlines must hire staff to repair and maintain aircraft services and in some cases retrofit older aircraft with new cabins and cabin services. There are hundreds of airlines worldwide, each with its own unique branding and business models. This market differentiation is what drives competition and growth in the industry. The emergence of budget air travel has changed how the industry attracts customers and sells their services.

The image of an airline can easily be sullied by an unclean or nonoperational lavatory. While companies like Zodiac and Rockwell Collins design and manufacture the monuments for sale, airlines purchase them based on price and suitability with their brand.

Airlines have a stake in cleaner lavatories to improve passenger satisfaction and to reduce ground time in order to continue making a profit and growing.

Manufacturers

The companies which produce the lavatory monuments hold the knowledge of how they are built and operate and ultimately determine how they are designed. They rely on the success of the product in order to stay profitable. Therefore the OEM's stake is to both provide and improve the product. Competitors have a stake in new designs as they can breed new challenges and change the industry standards. An example is Boeing's concept using UV light to disinfect the surfaces, which inspired Zodiac to pursue new ideas.

Government

The FAA is a governmental organisation which regulates aircraft production and operation. There are strict guidelines in place which all aircraft components must pass to be eligible for flight. Flammability and crash-worthiness are both tested on all cabin components and must be passed. The lavatory must withstand abrasion and high velocities. They must also have water tight components and be anti corrosive. This greatly limits the materials which can be used in their construction, as weight reduction is also a core requirement with respect to lowering fuel consumption.

Secondary Stakeholders

Stakeholder Analysis 3.1

Flight crew

Flight crew are the members of airline staff who work on the aircraft throughout the flight, namely flight attendants and pilots. Pilots have the same stake in the product as passengers since they need to use the same lavatory, often the one closest to the cockpit.

Cabin crew use the lavatory but are also required to clean and service it. The main goal of the flight attendant is to look after all of the passengers and maintain order during the flight. This includes catering to special needs and emergencies but also performing a superficial clean when necessary. It helps when passengers follow the rules and maintain it themselves, but there is always some degree of error.

Cabin crew are trained and required to have hard skills efficiency and technique as well as soft skills such attention, care and kindness.

The cleaning task takes the FA 3-5 minutes per lavatory unit. The FA first removes any visible mess and discards it in the waste bin. Next they quickly wipe down the surfaces and primary components with disinfectant wipes. Finally, the FA inspects the paper and soap available and refills them where necessary. The FA does this wearing rubber gloves which are then discarded.

Flight crew have limited time to focus on lavatories as they have many other tasks to achieve such as serving food. Toilet cleaning and food service are two tasks which are better performed by separate people.

A well designed lavatory considers the needs of flight crew by reducing the time needed to tidy the lavatory or eliminates the cleaning task entirely. It provides safe tools to do so and minimises risk of contamination within the galley and cabin.

Ground crews

The World Health Organisation (WHO) have standards in place for routine cleaning and disinfection of aircraft. This is primarily related to preventing the spread of harmful pathogens which can carry diseases to other regions of the world (Klaus et al., 2016).

There are three different levels of disinfection with descending frequency; a superficial clean which deals with the removal of visible dirt and dust, a deep clean which fully disinfects all surfaces and objects and finally a chemical clean which uses harsh chemicals to strip the coatings from the surfaces.

Separate crews are given tasks to prepare the aircraft for its next flight. When the plane lands, one crew empties the waste from the plane and another crew is responsible for cleaning the cabin while there are no passengers onboard. This task needs to be completed quickly and autonomously to prepare for the next flight on time.

The onboard cleaning task is completed using simple materials and cleaning products. The toilet is cleaned by flushing ice and vinegar down the tube a few times. The temperature and abrasion lifts away any matter still in the tubes and the vinegar neutralizes bacteria. Surfaces are scrubbed using safe chemicals and rags and the floor is sometimes steamed clean. Crews also work through the cabin and galley to vacuum the carpets. The carpet outside the lavatories must be cleaned thoroughly with soap on a regular basis and it is highly likely to become odourous due to foot traffic.

Maintenance crew

A KLM crew working on the maintenance of the toilet system was visited at Schipol airport. During this visit the procedure of cleaning the toilet bowl was demonstrated. The entire process can take up to one week and requires expertises

While aircraft are grounded a number of crews inspect, remove and fix parts which become broken or no longer meet the standards set by airlines and the government. They require tools which are designed to complete the task and a space which has been designed to suit their tools. If parts become damaged it must be possible to fix them quickly and easily (see fig.3.08-.13)

A well designed lavatory considers the needs of maintenance crew by reducing the time needed to fix and replace parts in the cabin. Each crew can have different working conditions, preferences and goals. Communication between crews also varies from bad to good. Errors in, or the lack of communication can lead to reduced accountability. This slows down the maintenance procedure and can be costly as a result.

The same parts in the system are likely to break down and need to be replaced. Well designed standardised parts and a small part count are of greatest benefit to maintenance crews.

A number of crews in different operational units of the airline services department handle maintenance of the lavatory, and indeed all other serviceable components within the aircraft. It is a complex and strictly monitored procedure with little room for error. Mistakes and delays can lead to an aircraft being grounded, which costs airlines money and frustrates passengers.

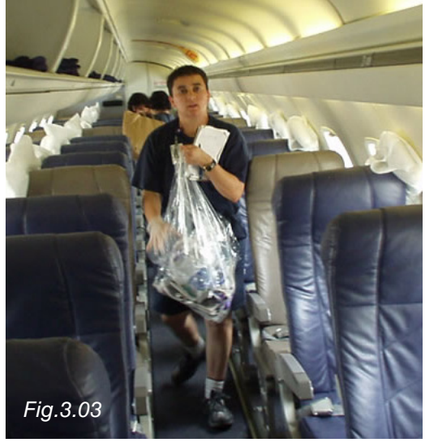


Fig.3.03

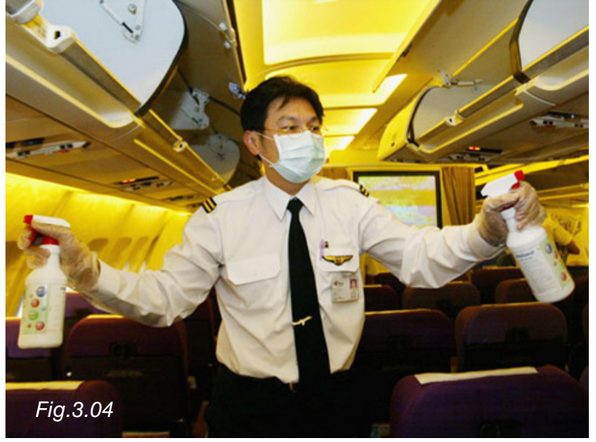


Fig.3.04


Fig.3.05


Fig.3.06


Fig.3.07


Fig.3.08


Fig.3.09


Fig.3.10


Fig.3.11


Fig.3.12


Fig.3.13

Primary Stakeholders

Stakeholder Analysis **3.1**

Passengers

Aircraft passengers are the main user of the product. Gender, age and occupation are all factors which alter how a passenger's perceives and interacts with the aircraft services. A universal approach is taken when designing aircraft lavatories in order to cover a broad range of users that choose to travel by air. Following user analysis, passengers are divided based on gender and flight frequency; *Male/female, frequent/infrequent.* Age and ability are also important factors which will be examined.

Further factors include nationality, ethnicity and even if an individual is travelling alone or with a group. Hygiene and toilet provision is approached differently in different cultures and the airlines country of origin is likely to buy product that suits it peoples needs where possible. The focus of this project is western societies such as Europe and North America.

Functional needs

The main function of the lavatory is human waste disposal and cleaning the hands and face. Passengers also use the space for tasks which require the need for privacy such as changing clothes, brushing teeth, shaving, changing babies and checking their appearance. These basic human needs are facilitated with a private space, toilet and wash area and mirror.

Passengers must also be aware that the space is shared by all onboard. It is a cooperative effort to keep the space clean and tidy. Universal symbols and signage are used so the majority of people understand the instructions.

Gender

Most males stand up to urinate and only sit down to defecate, whereas women sit down for both. The average male restroom has urinals and fewer toilets while the average female restroom has more mirrors (Greed, 2008). However, on average women spend more time in the lavatory than men and are often subjected to longer queues. Most public restrooms separate by gender to accommodate these differences, whereas aircraft lavatories are gender neutral despite gender differences.

First time and infrequent flyers

First time and infrequent flyers fly in economy en masse. Having a good first time experience can be a determining factor in whether or not they choose to fly again (citation). Infrequent flyers are those who fly one round trip per year or less. An individual who has never flown before has little experience with airplanes and is more prone to make mistakes when using products and services onboard.

Frequent flyers

Experienced passengers know what to expect from the lavatory and are equally prone to frustration when the space is not clean and expectations are not met. Frequent flyers make up the bulk of premium economy, business class and first class. According to a 2016 survey, they are also mostly men (citation). This is a possible reason why provision leans towards males and not females.

While there is plenty of overlap between infrequent and frequent flyers in all classes. Passengers who frequently fly independently for pleasure are likely to choose economy as a means to reduce cost. Similarly, business travellers for smaller companies on a budget will likely choose economy. This further increases the variance of people in economy class. Differentiating between the different types of passenger makes it possible to manage multiple sets of expectations.

Passengers with reduced mobility (PRM)

Passengers who require assistance getting on and off the toilet require enough space in the lavatory for an extra person and the wheelchair. Many efforts are made to increase provision for PRM's and this should also be considered with respects to hygiene and sanitation. In theory all restrooms should be designed this way, to accommodate everyone. However in practice this is not always possible given the small population segment of PRM's as well as space and resource limitation.

Age

Young children may not be capable of attending the lavatory by themselves and a parent or guardian may need to accompany them. This can be difficult due to the space constraint. Furthermore children are not as developed in their hygiene behaviour and skills as adults.

The elderly may have more difficulty using the lavatory due to a range of latent health issues such as incontinence or arthritis. The elderly can also have limited mobility, which can cause problems in such a small space. This is made more challenging by cabin motion.

Analysis

Designing for a wide range of ages and abilities is very challenging and requires taking preventative design measures.

To manage these intricate user overlaps, the new design relies heavily on design principles already in place. These principles are carefully studied and applied where alternatives are not possible. For example the heights of surfaces and size of the toilet seat.


Fig.3.14


Fig.3.15


Fig.3.16


Fig.3.17


Fig.3.18

Clean & Tidy

This section will outline the fundamentals of cleanliness and tidiness, what it is and why it is important.

Whats the difference?

It is pertinent to draw a distinction between these two terms as they will be used frequently throughout this report. Definitions:

Clean; free from dirt, marks, or stains.

A surface, object or space can range from clean to dirty depending on the level of visible and invisible dirt, grime and bacteria present. The prevention of dirt buildup and removal of dirt are both necessary steps in maintaining cleanliness. This can be achieved by frequently cleaning it.

Tidy; arranged neatly and in order.

A surface, object or space can range from tidy to untidy depending on the relative disarray. Disarray is experienced by an individual when one or more elements in an arrangement are out of place. The solution is to organise the system by arranging the components in the intended array. In the case of an aircraft lavatory this is controlled by the waste bin, paper dispensers and toilet.

Need to be Clean

Wanting to be clean represents a fundamental human need. This need developed to form and maintain social groups for the purpose of social grooming and mostly disappeared with the introduction of language (Schnall, 2011). This need is a moral intuition that evolved from the general need to physically safeguard one's own body from contaminants and pathogens that are spread by physical contact (Schaller & Duncan, 2007).

Cleanliness and hygiene are also a part of Maslow's hierarchy of human needs (see fig.3.19). The second level of needs relate to safety and security which includes bodily health and well-being. Good health and hygiene practices can prevent disease and infection and lead to feelings of personal safety and security.

In relation to the third level of the pyramid, love and belonging, it is necessary for individuals to practice good hygiene in order to relate to other people and be accepted by friends, peers and family. People with bad hygiene habits are often objects of disgust for those around them. Higher up on the pyramid cleanliness relates to personal confidence and self-esteem. Poor hygiene can make an individual feel like they have less self-worth.

Hygiene is a secondary or in some cases tertiary human need or desire as it is not as important for survival as food, water or shelter. However, in contemporary societies where basic needs are largely taken care of.

Desire to be tidy

Where cleanliness can be a matter of health and safety, tidiness can be viewed more as a subjective measure of an individual's level of tolerance for disorder and chaos. A personal preference to be tidy, messy or somewhere in between arises out of habit. Habits form based on repeated affirmation of previous behaviours which have lead to autonomy in completing a certain task. Some people develop to have the ability to tolerate a some mess and choose not to devote their energy to cleaning it. Others cannot bear to see parts of a system in a state of disarray.

Tidiness appears to be more of a personal preference than a distinct character trait Some people maybe be neat at home because they prefer to live clutter-free,

Fig.3.19 Maslows hierarchy of human needs.

Fig.3.20 The sink to the left is dirty, the one to the right is clean as it is free from dirt, marks and stains.

but messy at work as they wish to work quickly and be not let the careful process of cleaning impede creative. Similarly, individuals may prefer to practice better hygiene in public for the sake of preserving a clean image in the face of others and then live in squalor, where their social indecencies will go unnoticed.

Germ sensitivity

Germaphobes are highly conscious of bacteria and obsess about cleanliness. In close parameters with other people this can become stressful and lead to trauma. Disgust is the emotional response linked to which has been known to cause distress (Olatunji and Armstrong, 2009). Furthermore germ sensitivity pertains to all people whether they are aware of it or not.

The spread of viruses and bacteria can cause cold and flu pandemics and lead to the outbreak of more severe diseases and illnesses. Individuals who suffer from immunodeficiencies are also at a high risk of infection.

A Clean Society

With such variety in the wants, needs and desires in relation to cleanliness, it is no surprise that individuals standards are not met. Left to our own devices, hygiene no longer becomes an issue. Indeed, other people are the source of our hygienic discomfort.

The challenge in designing for hygienic behaviour becomes about meeting the standards of a wide range of people. This is particularly the case on aircraft, where strangers from many different locations and backgrounds comes together to share a very small space and are expected to be comfortable about it.

Aircraft lavatories are meticulously engineered for safety, durability and repeated use. These are the primary product requirements. Hygiene is a secondary need, but must be catered to nonetheless for the reasons stated in this section. The next section will take a look at

Fig.3.21 The closet to the left is untidy as it has no discernible order. The one to the right has order and is tidy

Human Hygiene

Hygiene relates to conditions or practices conducive to maintaining health and preventing disease, especially through cleanliness. Clean objects and environments are essential for maintaining good hygiene. While there are many different types of hygiene, this section will examine human hygiene in toilets and restrooms.

Human factors

Microbes can survive and travel on surfaces, in the air and through water. This means that humans can carry infectious bacteria and viruses on their skin and inside their mouths and bodies. Bacterial transmission is caused by people through their urine, saliva, faecal matter, blood and semen.

Contacting surfaces with unwashed skin, water particles from the toilet flushing and breathing are all part of regular use despite being potentially harmful. Poor handwashing behaviour and the improper disposal of waste are key actions of misuse which lead to contamination risk. Human factors are influenced both by the environment and by predisposition of the individual.

Environmental factors

The design of the lavatory can reduce the impact of dirt, stains and odor using surfaces free of open splits, sharp corners and dirt traps. Dust buildup is largely prevented in a space with such constant and repetitive use and cleaning. Proper air filtration and regular cleaning is necessary to remove dust, spills, marks and stains that do gather.

Larger organisms such as vermin and insects also pose a threat to hygiene. Both are known to find their way inside aircraft and thrive. Maintenance and cleaning crews practice caution in dealing with these threats to hygiene.

The physical degradation of materials and surfaces leaves the space looking unkempt. Surfaces which have lost their coating or have been damaged are more likely to harbor dirt and stains.

Contamination

In healthcare environments microorganisms are primarily transmitted in three ways:

Contact transmission; Direct - involving body-surface-to-body-surface contact, or indirect - involving contact between a susceptible person with a contaminated inanimate object.

Indirect contact is initiated when contaminated hands touch an object or surface, which in turn becomes a source of contamination. Contaminated hands can rapidly spread bacteria if not washed properly (see fig.xx). Hand washing with soap (HWWS) is an effective solution.

Fig.3.22 A simple guide to proper handwashing from the World Health Organisation (WHO)

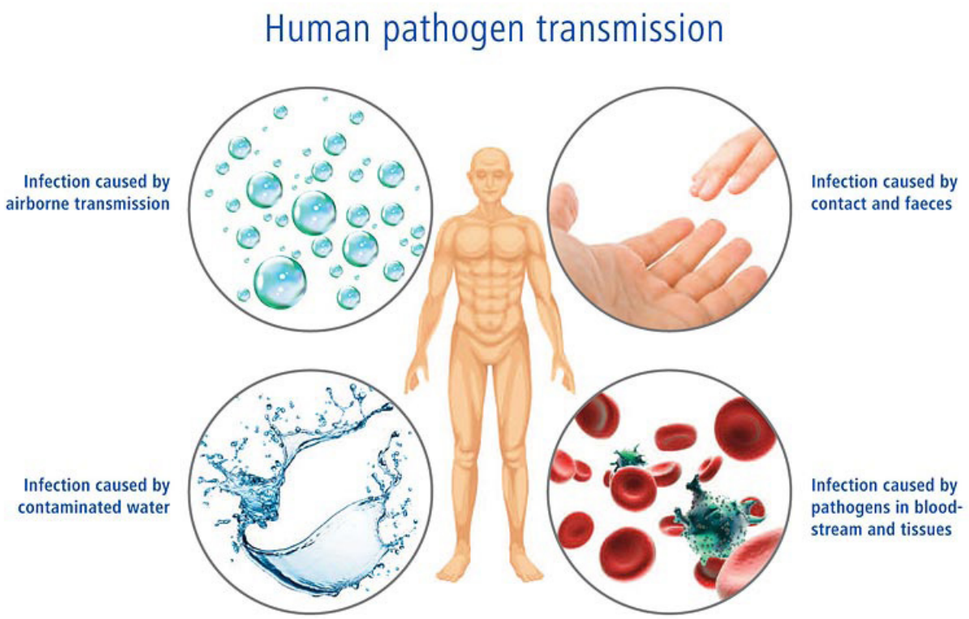


Fig.3.23 Illustration of how pathogens can be transmitted to and between humans, from BODE science centre.

Droplet transmission: When someone coughs, sneezes or talks and then transmits an infection to someone else via the conjunctiva and mucous membranes of the nose or mouth. While droplet contamination is generally considered to be a form of contact transmission, it can also contaminate the surrounding environment and lead to indirect contact transmission. The is especially prevalent in the lavatory as multiple liquid transmissions occur.

Airborne transmission: This occurs when respiratory airborne droplet nuclei are disseminated, usually by coughing, and then inhaled by a susceptible host. Airborne transmission can be prevented with good air ventilation and filtration.

In an lavatory, bacterial pathogens are transmitted from surfaces via the hands. Bacteria is also more likely to spread on wet skin via droplet transmission. Proper hand washing and drying is vital in the removal of bacteria before it has a chance to spread. (Huang, Ma and Stack, 2012). It is thereby not only the washing of hands but also effective hand drying which constitutes the best hygiene practices.

Proper disposal of waste

All bodily materials have the potential to contaminate a surface, object, human or animal. The minimisation of solid and fluid transmission can be achieved using appropriate waste disposal facilities. Toilets, urinals and sinks have proven to be effective in their hygienic and dignified handling of human waste.

In countries like India there are many societal health problems linked to the improper disposal of waste, where outdoor defecation is the leading cause in the spread of illness. In the case of Indian outdoor defecation, solutions were aimed at behavioural change through improved provision and community integration (Hathi, Spears and Coffey, 2016). A combination of both can lead to environments which have a reduced risk of contamination by altering the behaviour of inhabitants over time by bringing them together.

Implications

The example of handwashing is often used when talking about good and bad hygiene because it is simple and highly effective. Poor handwashing can be a major societal issue. HWWS is the number one means to prevent bacterial spread among humans, yet for many people there is a barrier towards this ideal behaviour.

The next section will focus on the reasons why people might practice adverse hygiene. These sections are included in the report to give some background on key decisions made in the final design with relation to how people are inclined to behave within the context.

Behaviour Models

Behaviour Research 3.3

Human beings are not born with knowledge or instinct for hygiene (citation). It is learned during a child's developmental years and is adapted based on the environment they grow up in. It is difficult for an individual to change these habits past maturity, but it is not impossible. Like any other habit it can be changed with proper drive and motivation. This section will take a look at the psychological aspects of toilet behaviour.

"Its not my toilet"

A multi-country study found that the frequency of handwashing with soap related to how automatically it is performed (Aunger et. al, 2016). This relates to behaviour, which will be discussed in the next section. The study also found a correlation between domestic surface cleaning and having a cleaning routine, the perception that one is living in a dirty environment and that others are also doing the behaviour. Social factors have an influence on hygiene behaviour, concern for good manners is also linked to the performance of hygienic behaviour.

In the case of a public restroom, many people will reject any ownership of the space and deny their responsibility to keep it clean. According to Loth, this occurs on trains for multiple reasons, but is largely due to low anonymity (Loth and Molenbroek, 2011). It is possible, however, to drive desired behavioural patterns using appropriate design cues. With a whole field of theories and models to chose from, the following are examples of models which can directly influence toilet behaviour in the context of public toilet design.

TPB and NAM

The two main theories in explaining and predicting behaviour are the theory of planned behaviour (TPB) and the norm activation model (NAM). Both state that decisions to act in an altruistic manner rely upon the knowledge, ability and willingness for individuals to conform to what they believe is socially normative behaviour. Passengers therefore decide whether or not they will clean up after themselves based on their own attitude towards hygiene, what they believe other people would do and whether or not they can perform the behaviour.

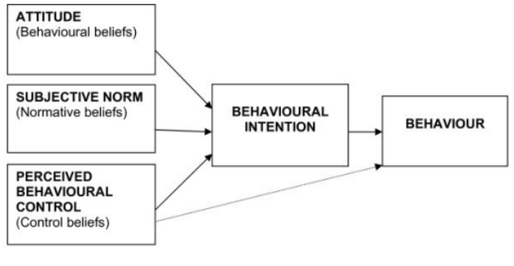


Fig.3.24 Planned behaviour model

Health belief model

This theory is primarily applied in healthcare to analyse and predict behaviour patterns. It can also be used to change long term behavioural habits such as gaining weight and smoking. The model includes six factors which influence an individuals decisions to conduct healthy behaviour; perceived susceptibility, severity, benefit and barriers, cues to action and self efficacy. Individuals will address one or more of these perceptions and factors when making health based decisions.

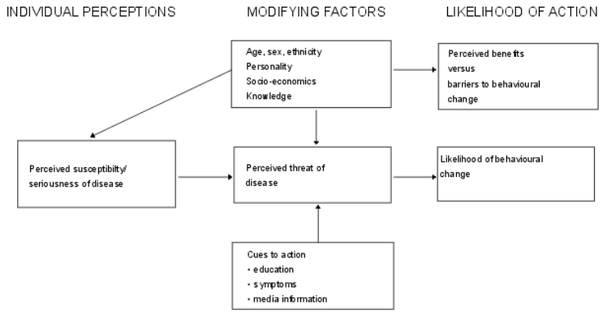


Fig.3.25 Health Belief Model

Using hand washing as an example, the desired behaviour is that everyone washes their hands to avoid cross contamination. Individuals have their own perceptions about the benefits of having clean hands, their susceptibility to infection and the severity of the health risks they may incur. External cues to action, such as signage and a clean wash basin may influence their behaviour, but ultimately the individual must rely on their own self efficacy to perform the behaviour (Rothman et al, 2004).

The Fogg model

This model asserts that the correct behaviour only takes place when high motivation and ease of use align with the necessary trigger (see fig.xx). In the case of aircraft

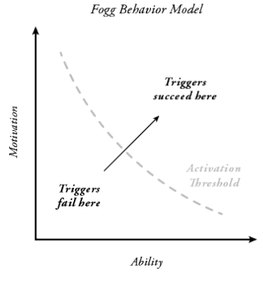


Fig.3.26 Fogg Behaviour model

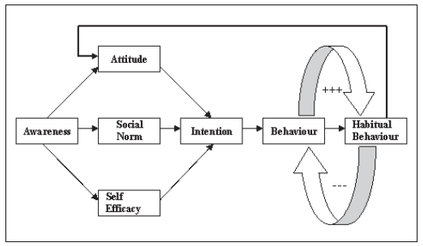


Fig.3.27 Model form habit forming

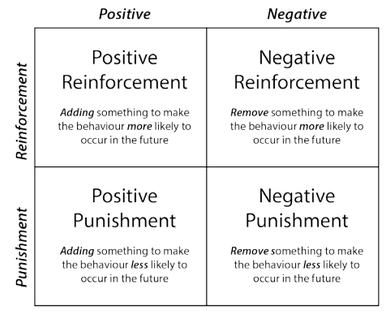


Fig.3.28 Operant Conditioning

passengers in the lavatory, the desired behaviour can achieved by providing adequate motivation, ability and a trigger (Fogg, 2009). It is a simplified version of the previous models which focuses on designing triggers to nudge behaviour, such as desgning buttons on an interface which are enticing and rewarding to push.

Behavioural modification

Not all behaviour is the product of reasoned action. Habits are cognitive associations that we form with repeated experience. It is believed that up to 45% of human behaviour is based on habit (Neal, Wood and Quinn, 2006). Habit forming adds a degree of autonomy to the mundane and repeatable tasks in life such as driving to work, brushing your teeth or using a toilet.

Humans have the ability to modify their own behaviour to form healthy habits (Jager et al., 1992). Habitual behavioural modification is frequently used in marketing to influence consumer behaviour, but it can also be used effectively to drive user behaviour.

Conditioning

This is a basic method to change a behaviour. Classical conditioning is used to teach behaviour based on the process of association. For example most people associate a fresh scent with clean objects. Operant conditioning uses different responses to behaviour to change it over time. The learner experiences direct consequences to their actions and modifies their behaviour as a result. Operant conditioning is primarily concerned with shaping the behaviour of children and adults but has also been used to treat addiction.

Each of these methods can have both positive and negative effects on an individual's behaviour over time. For example positive reinforcement may create a dependency on receiving a reward for good behaviour. In all cases the subject learns from their actions and learns a new behaviour by adapting an existing one. The behaviour becomes habit through repetition. When the reward system is removed it is possible for the bad behaviour to resume. Similarly, repeated punishment can lead to resentment and a rejection to change.

Embracing behaviour

Allowing people to behave in any way they want is a valid tactic when behavioural change is not possible or where the behaviours exhibited are relatively benign. Toilet behaviour is very challenging to change in adults because it is reaffirmed every single day, usually in private. This sort of repetition creates a highly personal and autonomous set of behaviours.

To use handwashing as an example once again, it is recommended to scrub with soap for 20 seconds, then rinse the soap with water for 10 seconds and dry the hands completely. To save time the average person will take less than ten seconds for the entire procedure (citation). Since the negative effects of poor handwashing are not immediately felt or seen, preference is in time saving, not hygiene. There is no perceived reward for washing the hands properly and it is therefore doing it properly not the desired behaviour. One method of improving hand hygiene is to observe the user. (Pfattheicher et al., 2018) It is believed that this feeling of being watched strongly influences better behaviour.

Design for desired behaviour

In summary, the behaviour one exhibits can be linked to either reasoned action through social influence and/or self influence and habitual tendencies.

People are either aware of their behaviour or they are not. In the case that they are aware of their behaviour, for example if the lavatory is dirty, one may think about the health risk and decide not to act by cleaning up. The other side of the coin is when the lavatory is dirty and the occupant believes that this is acceptable.

It is important to make these distinctions when designing a restroom as there is a wide variance of user and an even wider variance in their personal habits and behaviour. Following details about the user needs in the lavatory, in *Chapter 4: Problem Definition*, a desired set of behaviours will be established and discussed further.

Behaviour in Context

Behavioural Research **3.3**

All passengers contribute to the uncleanliness and disorder in the lavatory. It is established that each passenger has their own unique range of characteristics which define their hygiene behaviour; from unconscious to conscious behaviour. In comfortable surroundings, like at home, there is a high level of autonomy in how we behave in the washroom, leading to unconscious behaviour (citation).

Individuals become more conscious of their behaviour in public and must consider external factors more, such as social norms how other people will perceive our behaviour. A simple spectrum has been established upon which five core personalities have been identified based on hygiene consciousness;

1. ***Hyper conscious -*** These people treat the whole space as though it is potentially harmful to them. These people may have mental illnesses such as mysophobia or OCD.
2. ***Highly conscious -*** These group are irritated by a mess and will clean it or ensure that it is cleaned before and after use. Self confessed clean people, may call themselves “borderline OCD”.
3. ***Conscious -*** These people are hygiene conscious but somewhat indifferent about hygiene and try not to think about it, they will.
4. ***Unconscious -*** These people do not think about hygiene when they use a toilet or washroom. These people include people who practice hygiene primarily out of habit and are not very attentive. They are unlikely to clean up after themselves.
5. ***Adverse hygiene*** - This group of people do not know the hygiene rules of a particular culture or society and behave in a manner conflicting with the social norm.

It is possible that a single individual may not exclusive exhibit one of these behaviour types. As mentioned previously, the individual’s behaviour can be modified based on their environment. This can best be explained using the planned behaviour model.

Passenger type

Infrequent flyers can benefit from behavioural conditioning to foster new behaviour. As a first time user one will draw on their previous toileting experience to determine how they should behave.

A frequent flyers repeated use of the product would lead them to form habits and develop a more clearly defined personal standard than a first time user.

- In the case of operant conditioning, passengers do not experience any consequence for their own behaviour,
- Behaviours are reinforced by their own self-efficacy.
- An added factor is that toileting is not openly discussed in many cultures. It is more acceptable to keep be discreet about it.

Normative behaviour

Social norms are somewhat lacking in this context as the space is shared but only ever used privately. The social norm becomes to mistreat the space for the sake of self preservation. This is strengthened by the shared dissatisfaction passengers have.

Passengers are left to their own devices to behave as they please and subsequently remain anonymous. Good behaviour is not rewarded and bad behaviour is not reprimanded.

A potential determinant in change is to make the individual feel like a member of a group. There is then an increased likelihood that the individual will conform to the standards of the group.

However, no one should not feel like they will be ashamed or embarrassed for behaving improperly in accordance with the standards of someone else. The lavatory must remain a safe space where individuals can express themselves.

A standard must therefore be established and enforced in an appropriate manner. For example, provide privacy where necessary (i,e, urination, defecation, baby-changing) and add a degree of social influence to other tasks such as queuing, hand washing and tidying up.

Conclusions

- The design should focus on nudging better behaviour.
- Drawing attention to hygiene and the impact of bad behaviour may serve as an effective motivator for change.
- Motivators such as better access to information and the necessary tools for cleaning can be used to alter behaviour.
- Multiple behaviour types are considered when designing a lavatory.
- Toilet hygiene is the shared task of all individuals involved which should be emphasised.
- Motivation in this case must be strong in order to break long standing habits. Appeal to strong human emotions such as fear, pride, achievement and guilt.
- Establish sociallly normative behaviour; sharing.

Fig.3.29-.35 The 6 simple steps of using the lavatory;
Raise the seat, sit to use the toilet, stand, wash hands, dry hands, dispose of paper

Chapter 4:
Problem Definition

In this chapter...

... the problem is addressed and defined. This is a short chapter intended to highlight the main insights gained during the research phase of the project.

The goal is to understand what needs to be achieved in the design phase of the project.

First the core problems are listed and discussed. Each problem is given further context and analysed. From this analysis a list of product design requirements is created.

Contents:

Problem Overview

Problem Analysis **4.1**

In this section, a general overview of the problem is given. This stage of the project was completed using the second half of the first diamond as mentioned earlier in the report; *define*. As such, this methodolgy is based on defining the problems which arose during research.

Methodology

Problem definition begins by examining the research and determining problems to which need to be solved. The next step categorises problems based on the stakeholders involved. A list of design requirements is made which broadly covers the problems. The aim is to give a balanced and fair representation of whether or not certain concepts will fail or succeed in the real aircraft context.

In this section we will explore the main issues using design from first principles. Each problem that has been identified in the analysis phase is explored further from its root cause.

What is the main problem?

Passengers fail to practice proper hygiene and the lavatory becomes dirty and untidy for the next passenger. When passenger A leaves the lavatory in one of these conditions, their presence can be felt by passenger B which affects their comfort. The following is a list of discrepancies one is likely to encounter upon entry of the lavatory:

Unclean

- The presence of physical dirt or human excrement (faeces, urine, saliva, vomit, semen)
- Appearance of residual dirt or human excrement (stains, damage, wear)
- Appearance of liquid droplets and wet stains; water, soap, urine, other
- Odour caused by dirt or human excrement

Untidy

- Paper misuse; Discarded outside of bin, resting or stuck to the floor or other surface
- Paper rolls unravelled or protruding, indicates previous user's carelessness
- Products out of place: toilet seat left up, change table down, cabinets open
- Bins full or overflowing with used paper.
- Foreign objects left inside lavatory by passengers or crew.

*Ab*sense of care

- Empty paper bins or toilet roll
- Empty soap or hygiene products
- Products damaged or not functioning properly
- Visible vandalism and graffiti

Problems in context

The images to the right (*fig.4.0-4.12*) show some examples of dirty objects and surfaces in the lavatory. These are mostly related to liquid and paper, but attention is also drawn to the quality of construction and materials.

Liquid from the toilet and wash basin add moisture to the environment. This increases the chance of bacterial growth. When mixed with paper this looks very unclean. The combination of human and environmental poor hygiene factors in such a small space are a perfect storm for the build up of scum and residue over time. This is highly problematic as soiled surfaces immediately denegrade the hygienic appearance of the lavatory.

The interior of the aircraft did not look quite as worn down and susceptible to mess as the lavatories did. KLM's 747 fleet is over 20 years old so it is likely that this lavatory has beem in service for a few years. The state of the lavatory is a good indication of when a fleet needs refitting as wear and tear is more apparent than on seats for example, where the upholstery is easily uprgraded.

"Promote better hygiene and tidy behaviour among passengers by providing a space that stays clean"

A flight attendant was observed pressing a gloved finger in the door handle to remove dirt. This image was taken afterward, as you can see there is still some residual dirt inside. Cracks and gaps are where dirt and grime appear the most, particularly on horizontal surfaces. *Fig.4.06-08* show where dirt has built up inside crevices and on top of surfaces. This can be seen more clearly under UV light, which is also known to kill bacteria.

The floor and toilet are almost always wet and very often have paper stuck to them. This lavatory was older and indeed dirtier than those examined on the short haul test flights. The

Ideal scenario

What is the best situation for passengers and crew?

- *The fulfillment of each set of user needs represents a scenario in which the user no longer has to worry about poor hygiene.*
- *The space passively stays cleans and disinfectants all surfaces between each use. Passengers enter to find the lavatory completely spotless and can use it in any way they desire.*
- *If they leave in a hurry and do fail to clean up, the space can be tidied up quickly and efficiently by the next passenger or flight attendant.*

These images show the reality of aircraft cabin hyigene. They were taken during the primary research investigation onboard a Boeing 747 from Amsterdam to Los Angeles.

See Appendix B for detailed descriptions of the problems found

Fig.4.01-06 Damage, discoloration and water scum

Fig.4.06-4.012 Stained surfaces, liquid mess and mishandled paper

Product Misuse

Problem Analysis 4.1

The Urination Problem

"Spilled urine soaks the lavatory floor."

What is the problem?

The most unsettling hygiene concern for passengers is seeing, smelling or touching the excrement of a stranger. This problem is ubiquitous in public restrooms around the world.

Large amounts of liquid on the floor is troubling as the floor is already very small and there is not much room to maneuver and avoid the wet spots. Urine from passengers missing the toilet bowl and water falling from the sink are both contributing factors.

The problems of dirt and wetness on the floor are mutual as one contributes heavily towards the other. Dried urine leads to very unpleasant stains and a bad odor. A wet floor is virtually impossible to clean with the door of the lavatory closed as one must contort themselves to reach down. If a passenger wishes to clean the floor (which is highly unlikely) they will find it to be no easy task.

Why is this a problem?

Males are mainly responsible for urine on the floor. It occurs because many men approach the toilet and urinate as they would in any public restroom.

However, women who squat or hover on the seat have also admitted to missing their target. The primary concern of the passenger is not the welfare of the space, but to prevent splashes ending up on their clothing.

Some men admitted that they will stand back as far as possible to achieve this, despite making it far more difficult to aim on target. In the struggle between hygienic behaviour and self preservation, an individualistic behaviour pattern is prevalent.

Key Causes

- Small space factor, not enough room to take care.
- Perception of a dirty seat, passengers choose instead to use the handrail to hover or in some situations stand on the seat (which can cause damage).
- Provision of a single standard toilet design.

Fig.4.12 Boeing 747 floor coated in urine

Fig.4.13-16 Boeing 747 paper products, dispensers, full waste bin and floor covered in paper

The Paper Problem

Passengers are provided with various paper products to keep themselves and the space clean and dry. This includes toilet paper, hand paper, disinfectant paper and toilet seat covers. Some airlines also provide sanitary pads for female hygiene and small paper cups to fill with water.

"Used paper ends up outside the bin!"

Aside from used toilet paper, all paper waste is disposed of in a waste bin built into the amenity wall. The waste bin in a standard lavatory is made from aluminum sheet metal and is located behind a closed door. It is quite robust and has a reasonably large volume, considering the limitations on space and fire safety restrictions.

Disposable paper is a hygienic solution when used correctly. Towels are not used because they are too costly to dispose of and the job of washing them will require staff, adding more cost.

What is the problem?

Standard bins are large and easy to refill for the benefit of the FA. However there are some problems which arise from this setup.

1. The FA must restock multiple paper products
2. Overstocked paper shreds when it is pulled out
3. The waste bin fills up quickly and overflows
4. Germ-ridden paper ends up on the floor and other surfaces, contaminating them.

The volume of a piece of paper becomes over 50% air when it is crumpled up. Studies have shown that paper has very different mechanicals once it has been crumpled (Hanaor et al., 2017).

- Crumpled paper piles up in an unpredictable and extremely volume inefficient manner.
- Paper gets trapped in the waste flap (see fig.xx)
- Wet paper sticks to other surfaces easily and once dried it becomes harder to clean.
- Wet paper also has a higher contamination risk than dry paper, with paper soiled in dirt posing an even greater risk.
- Passengers do not want to handle paper waste and therefore it remains on the floor.
- Waste paper also generally spoils the appearance of the space and makes it seem untidy.

Key Causes

- Multiple paper products in the lavatory
- Flight attendant overstocking the bins
- Seemingly limitless supply for passengers to use, leading to abuse of paper use.
- Infrequent emptying of bins; between flights
- Voluminous nature of used paper

Product Dissatisfaction

Problem Analysis 4.1

The Space Problem

What is the problem?

Passengers stated that it is too difficult to behave in a hygienic manner when one cannot maneuver to clean up after themselves. This excuse is valid, lavatories are very small when compared to everyday public restrooms.

Not only must passengers be able to fit inside and move around, but interaction relies on the ability to turn to look at objects. A condensed feature layout further restricts space. Passengers over a certain height and weight will experience difficulty fitting inside the lavatory, let alone try to be careful when dropping paper or missing the toilet.

It is determined that most of the problems outlined in this section can be improved by adding space. This is based on

Why is this a problem?

Aircraft interiors are small and every product is competing for space. Airlines will do whatever they can to include a maximum number of seats, including purchasing the smallest lavatories.

When creating a LOPA, standard sized lavatory units allow designers to easily integrate more vital services. The problem is that lavatories are simply too small. PRM's and passengers of size have particular problems getting in and out. There is also an aspect of comfort, or lack thereof, when wedging oneself into the cramped space.

This begs the question; is it of greater benefit to passengers if there is one small lavatory per 50 passengers or one large lavatory per 100 passengers? This is the simple reality of lavatory provision on board aircraft and there is little airlines can do about it without losing profit.

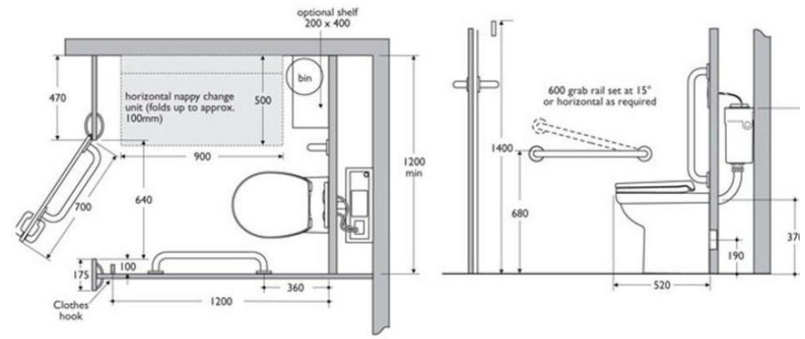


Fig.4.15

Public restroom standards differ around the world.

A typical western standard is a floor size of 1500x800mm

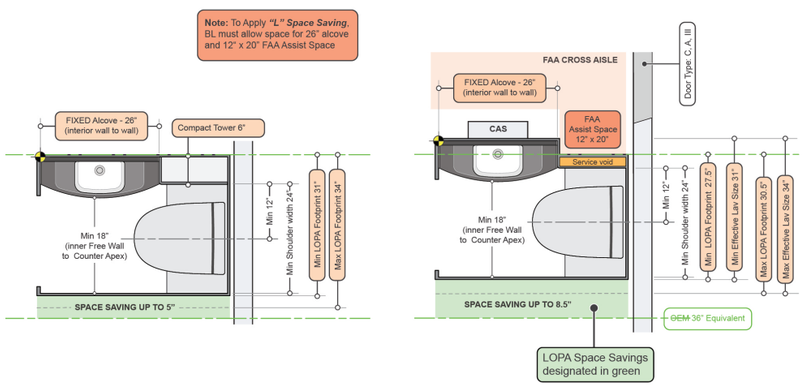


Fig.4.16

Aircraft lavatories are typicallly 3x3.5 ft, which is 1066x915mm

When the wash basin is factored in, the usable space is greatly diminished

The Queuing Problem

Passenger to lavatory ratios can vary and with them the likelihood of unwanted queue's also varies. Short queue's in first class with a ratio of 1 lavatory per 20 passengers are likely, whereas queue's on a busy economy class widebody are almost inevitable given that there can be only one lavatory per 50 passengers.

"Queuing in the aisle is a problem since flight attendants can be blocked by passengers standing in the aisle."

The gender neutral aircraft lavatories mean that everyone queue's for the same amount of time. However, some people are going to spend longer inside the lavatory, lengthening the waiting time for people outside. Queues should be minimised to create a better cabin flow.

The Odour Problem

Given the dark colour of the floor it can be difficult to distinguish whether the liquid is water or urine. However, the smell is unmistakable. The lavatory will have a foul odour if it has not been cleaned in a while. This is caused by the presence of excrements on surfaces and dirt remaining inside cracks and gaps.

For the most part the air in the lavatory is cycled through a vent. In some lavatories there is also a fresh scent module in the vent on the door to keep the lavatory smelling fresh. It was observed during flights that the lavatory smelled most fresh following a refresh and clean from the FA.

A foul smelling lavatory is greatly problematic to the passenger experience because it reminds one of the previous passenger and what they were doing. It is primarily attributed to frequent use is extenuated by misuse, for example urine on the floor or passengers failing to flush the toilet.

Fig.17

This gentleman got more than he bargained for when he tried to maneuver himself inside the lavatory

Requirements

Having identified the problems in the lavatory, an important next step is to link them back to the stakeholders. A set of general stakeholder and product requirements were established to ascertain who is influenced the most by each problem. Using the space problem as an example, there is a conflict between what airlines want and what passengers need.

Requirements are split three categories of requirement, each with four core requirements;

User needs and desires

- Ability for the space to remain clean.
- Ability for the passenger to clean themselves.
- User-friendliness of the features included.
- Additional space provided to let the passenger move.

Production requirements

- Is Zodiac capable of producing the concept?
- Novelty of ideas with respect to current products.
- Repairability; maintenance crew task.
- Modularity; adaptability of the solution.

Resource management

- Waste created by the passengers.
- Approximate weight added to the aircraft
- Water usage during normal operation.
- Energy usage during normal operation

While there are more detailed requirements, this list is intended to give the reader a digestible overview of the complexity of aircraft lavatory design.

These requirements are also considered during idea generation and also serve as a tool for concept evaluation. On the next page, each requirement is discussed in greater detail.

Design Requirements

Following the general analysis of problems in the lavatory, a set of more detailed stakeholder requirements is created Passengers, flight attendants and cleaning crews all have very different needs when using the lavatory. The following is a breakdown of each user groups primary product needs.

Passengers

- Provision of a functioning toilet, clean water and method of drying water from the hands and face.
- Adequate provision of sanitary products to clean self.
- Provision of tools to clean any mess made.
- Privacy inside the lavatory.
- Access to assistance when needed.
- Clear guidelines of use for interactive features.
- Provision of balance aids; hand rails

Within different passengers are further needs.

- Men require a place to urinate standing up so they do not miss their target.
- Women should feel comfortable using the lavatory without needing to squat or hover.
- Children should be able to reach the sink and paper towels.
- Passengers with reduced mobility must be able to access the lavatory and have enough space to turn around to sit down.

Cabin crew

The primary need for flight crew is a clean and safe working environment. This means that reducing the lavatory cleaning and inspection task or indeed eliminating it entirely, the latter is the best course of action to take.

- Provision of adequate cleaning gear and supplies for the cleaning task.
- Cabin crew require access to information and awareness of problems as they arise.
- When a passenger is in need of assisstance the flight attendant must be alerted.
- Cabin crew must have sufficient space to move in the cabin (In relation to passengers qeueing in the aisle)
- Minimal cleaning time to focus on other tasks.

Cleaning crew

Speed and efficiency is the most important need for ground crew to prepare the aircraft for flight. A safe and hygienic work environment is less of a concern for ground crew as they are provisioned with hygienic clothing and work zones.

- Adequate provision of tools and equipment
- Minimum number of parts
- Standardised component design for quick maintenance
- Access to information in the event of a problem

User needs and desires

Users appreciate a product which is clean and safe to use while providing the tools and services they need. The focus of the redesign is a lavatory that is pleasant and easy to use while still being effective at keeping people clean and disposing of waste. User input and opinion is used to qualify these requirements in the concept phase.

Cleanliness

How well the space can be maintained and kept in a clean, orderly fashion by passengers and crew.

- The level of difficulty required to clean a surface must not be excessively high.
- A space with many surfaces and perishable items will take more time to clean and restock. This should be minimised.
- The cleaning task should be achievable for passengers to help with. Even if its only in a small way, passengers must be involved in the process.

Personal hygiene

- The user must be able to safely clean themselves and dispose of their waste safely.
- Provide passengers with a range of experiences that they can chose from to suit their individual needs.
- The risk of contaminating oneself should be minimised by providing safe means to carry out tasks autonomously and with minimal effort.

User friendliness

- With the user at the centre of the product, it is imperative that the selected components and form design enable the user to have a smooth and complication free experience.
- The inclusion of a range of users abilities as well as the intuition, speed and joy of product use.
- The level of information and feedback provided to the user is also considered.

Space provided

Users must have sufficient space to move and maneuver the environment.

- For passengers a wide range of body types must be consider to ensure everyone can fit inside.
- For crews there must be space to clean and perform maintenance on the unit.
- Removing entire components give an illusion of added space while also giving air more room to circulate.
- Smaller lavatory sizes give the impression the rest of the cabin is larger, though space is likely to be used.

Production requirements

As tertiary stakeholders, OEM's, manufacturers and airlines needs are mainly concerned with how the product is made and the impact it has on the aircraft with respect to fuel consumption and turnaround time. The lighter, cheaper and faster, the better. The following criteria attempt to capture the product benefit for tertiary stakeholders.

Producibility

Zodiac is capable of producing hygienic lavatories using components and materials that they are familiar with.

- Introduction of new materials or parts which require alternative manufacturing techniques may hinder the likelihood of the concept getting made.
- Design should also consider repeatability and adaptability; not a single solution but the blueprint for a possible product range/ideology.

To satisfy this requirement, Zodiacs products are studied and used as inspiration for the design.

Novelty of ideas

- How innovative are the ideas?
- Is the new product different enough from Zodiacs current offerings and the rest of the market to cause a disruption?
- *Examples are given in Chapter 1*.
- Selected idea is viewed as the latest and greatest by Zodiac and by others in the industry.
- Innovation is judged by newness and deviation from the norm.

Modularity

Zodiacs DMS lavatory focuses on modularity to provide the following benefits:

- High volume manufacture to produce standard part s
- Lower dimension tolerance than traditional parts.
- Benefit to repairability as damaged or soiled parts can be swapped out and replaced.
- Adaptable to a wider range of cabin configurations

Repairability

- All finite elements are bound to fail eventually and must be designed for removal from the lavatory for maintenance.
- Sealed surfaces is sealed into place to prevent moisture leaks or if the maintenance crew are inexperienced in fixing newly included parts.
- Additional components and more complex monuments will be more challenging and time consuming to maintain.

Resource management

The lavatory uses water and electrical energy during regular use and produces physical waste, mainly paper. Management of these resources is essential to the redesign as it is linked to the core problem of passengers making a mess.

Airlines can reduce cost and weight if their services require a minimal amount of water, energy and perishable waste. An added benefit is devoting these resources to other areas of the aircraft which need it more, such as the galley for food service.

Waste created

- Waste is primarily created by paper used by passengers to dry themselves off.
- Toilet paper is flushed away and all other paper is discarded in the lavatory waste bin.
- Ideas should seek to minimise to amount of paper and plastic ending up in the waste.
- The FA task of emptying the waste bins mid-flight should be minimised where possible.

Approximate weight added

Weight savings lead to better fuel economy and a better overall profit for airlines.

- Reducing the number parts is favourable, in particular where robust parts are required for motion.
- Weight addition is estimated based on two factors; The addition or subtraction of features and the size and weight of components. For example an automatically raising toilet seat adds weight to a standard seat by including a battery and motor.

Water usage

Water is limited onboard and so usage must be controlled and distributed fairly. Look for solutions which reduce the amount of water passengers use.

- Giving the user too much control to use the water in the lavatory puts a greater burden on the clean water supply.
- Services such as a bidet are sure to use more water, whereas an atomised water tap will likely use far less.

Energy usage

- Energy is delivered for a component which requires electricity, such as an overhead light or touchless faucet.
- A heavy reliance on components which require electric energy to function will put a higher demand on the aircrafts onboard energy system.

Chapter 5:
Ideation

In this chapter...

... the design phase of the project is initiated. Following research and analysis of the problems, the design of new solutions can begin. This process begins with a detailed plan of the objective, including a definition of key goals.

This is followed by a set of creative brainstorming sessions where ideas are generation. Next the ideas are clustered and categorised based on component subsystem and represented on morphological charts. These charts are used to create a number of new concepts ideas. An iterative approach is taken to create multiple concepts which are evaluated using the design requirements.

Finally, the evaluated concepts are refined further towards a final concept, which is discussed in the next chapter. Admittedly, this process was very loosely structured. Conceptual imagery is used frequently in an attempt to give context to the process.

Contents:

Design Overview

Design Objectives 5.1

The design process is the second major phase of the project. It was completed using the second half of the double diamond technique mentioned earlier in the report; define and deliver. As such, this chapter will focus on the *Develop* quadrant of the double diamond technique, with the final chapter focusing on *Delivery*, focusing on product solutions and turning them into product designs.

The following methodology covers the final two chapters of the report and will include ideation, concept development and detailed design.

Ideation

Following the ideation phase an unstructured process of exploration was completed to categorise and examine the ideas produced. The categorisation was defined as the five core concept drivers which influence the design of a lavatory which puts hygiene first;

"Awareness, Provision, Prevention, Translation and Transformation."

Given the space limitation mentioned previously, concept generation was carried out using thumbnail line-drawings of a standard looking lavatory size and shape. This eliminated the possibility for alternative shapes and focused on component solutions only.

Ideas from the previous stage were mapped out on sketch pages in relation to each driver. This process lead to an overview of all known solutions and an integration the main problems witnessed.

Concept generation

Ideas were then manifested as objects and principles in the aircraft context and assigned an image which is represented on a morphological chart. The charts are used to identify logical component configurations and develop a first round of new product concepts. User feedback provided the more information for a second round of development which integrated layout and form design.

A final concept is created based on a multitude of factors including user feedback, company feedback, industry innovation and adherence to the product requirements listed in the previous chapter.

Detailed Design

When the systematic approach failed, the design process was approached in an exploratory fashion. A final concept was achieved primarily through the process of elimination of all known solutions. Components on the morphological chart which have the greatest benefit to hygiene are selected and modeled in CAD. From there a final design vision is created based on user and company input.

Designing a new lavatory

"A lavatory is one of the most challenging monuments to design due to space constraints, demanding ergonomics, high service requirements, and affordability"

- Zodiac Aerospace

Additional space naturally improves comfort and promotes tidy behaviour. Creating space where there is none is impossible. Modern technology and production techniques are essential to understand and utilise when creating a new state-of-the-art. This will be the focus of this chapter.

F.I.S.H. factors for user satisfaction

This principle is employed for the new design. The new design must be friendly, informative, safe and hygienic (Silva and Simoes, 2011). Each of these four elements have been closely considered.

Friendly; A design which is inviting and non-threatening. Products which are easier to use or are fun and playful are more enjoyable to use. Intuitive, quick and easy use is preferred. Colour schemes should be bright and uplifting

Informative; Provide clear and a balanced guidelines of use using intuitive products and relevant signage. Too much information can inundate the user and lead to further error. Practicing simplicity in design is an effective method of providing information without confusing the user.

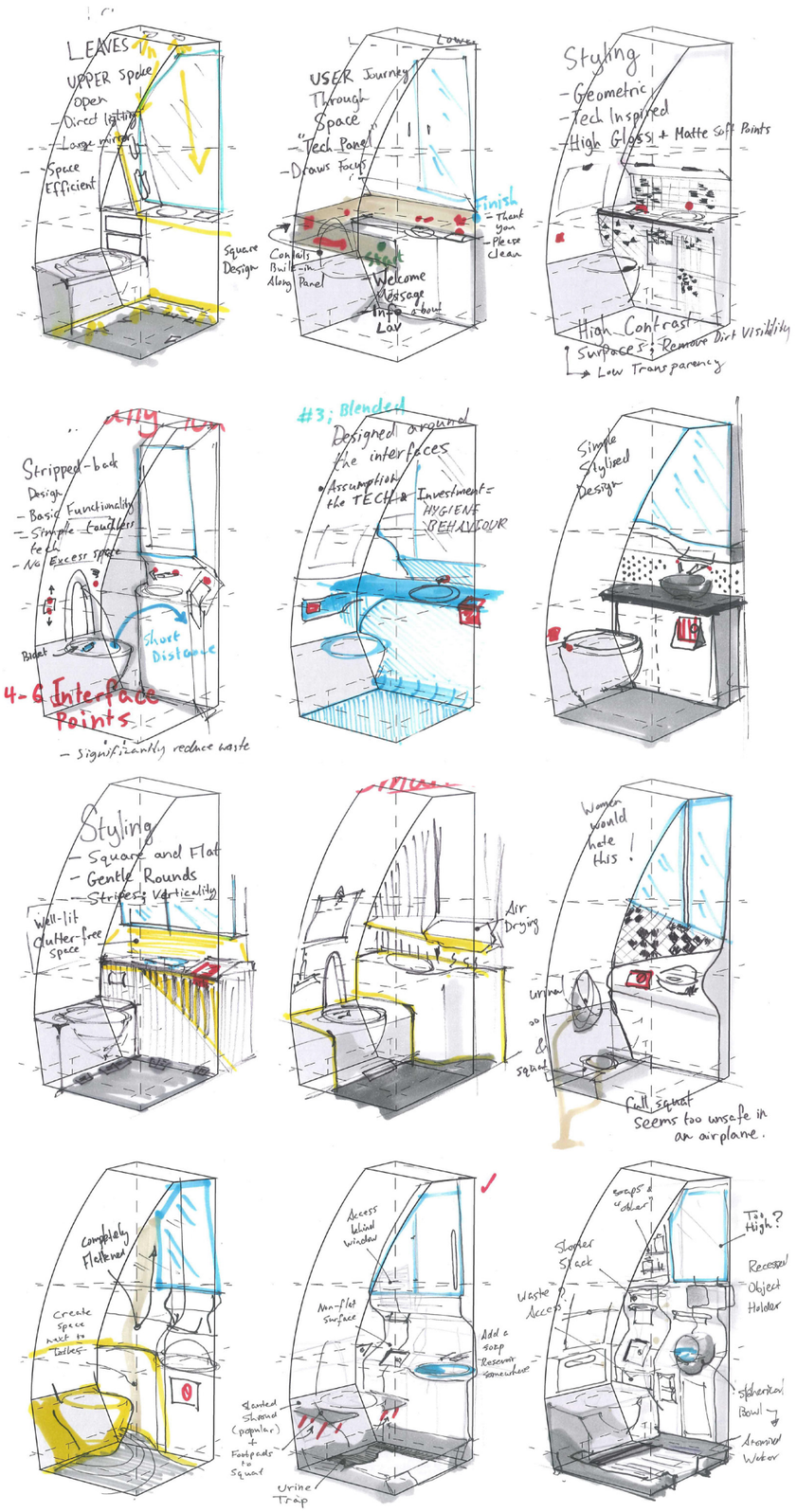
Safe; Minimising the potential risk of accidents and mishaps. Passengers can hurt themselves on sharp protruding surfaces or trying to squeeze into spaces that are too small. Passenger safety is embedded in current designs with fire retardant materials and parts.

Hygienic; As the focus of the project, hygiene is of the utmost importance when selecting ideas and creating a new design. Design for more hygienic conditions is essential.

Fig.5.01

Since the goal of this project phase (and chapter is to create inspiration, sketch pages will be littered throughout this chapter to give some context to the process.

These are idea generation sketches showing the range of considerations and possibilities for lavatory redesign.



Design Focus

Design Objectives 5.1

Managing complexity

Throughout the process of ideation, it become clear that the lavatory is a complex product with many parts and features working in unison. The design of any one component is a project in and of itself. The design task is broken down into three parts. These are:

- Concept feature selection - the investigation, selection and design of features within the lavatory.
- Concept ideology - the overarching principle behind the concept driving innovation.
- Concept form design - form follows function inside the lavatory. Styling is layered over components through harmonised shapes and material selection.

Work surface heights and signage have been developed to meet universal standards. The product design specification for one of Zodiacs lavatories was used for general dimensions and sizing.

Regular rules apply as with seats and the rest of the cabin. Lightweight, durable, fire retardant materials are a must .

Feature selection

In order to further manage the complexity of choosing which components and features are used, morphological charts are used. These charts map all known solutions and make them communicable for the designer and users. Ideas are frequently communicated to users and the company in this way for feedback.

Multiple rounds of iterative feature selection produced several versions of what the inside of the lavatory can be. Initially, six concepts were generated and discussed

Having explored many possibilities for a new internal composition of features, a small user evaluation was performed using the 12 key design requirements. The result was that none of the component configurations would solve the core problems.

Concept ideology

Though the initial concept generation process failed, it gave way to a second stage of development. With further research, a new set of solutions were realised.

Form design

In order to fit within Zodiacs product catalogue, the design of the lavatory form, its styling and appearance, largely follows existing products such as the ISIS lavatory and Durinal. These designs are minimal and utilitarian.

Aircraft type and mission

Three airlines (which Zodiac have partnered with before) were focused on; Finnair, Singapore airlines and Emirates. KLM was also included as the primary research investigation took place on one of their 747-800's. Finnair is the primary target of investigation for narrow-body aircraft. Singapore and Emirates are examined for wide-body aircraft.

The plans for these aircraft were studied to ascertain the seating layout and position of lavatories. The figures on these pages show the range of aircraft sizes. Pay particular attention to the locations and layouts of the lavatories relative to the rest of the cabin. Most interesting is that Singapore have one more middle aircraft than emirates, who instead have a staircase to the upper deck.

Fig.5.02

Finnair
Airbus A319

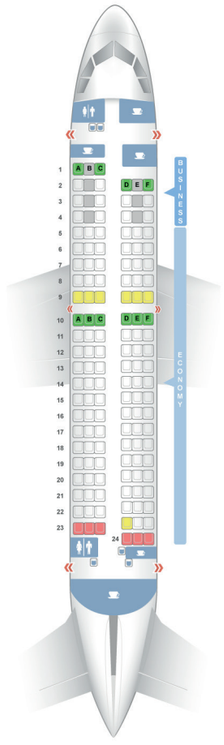


Fig.5.03

Ryanair
Boeing 737

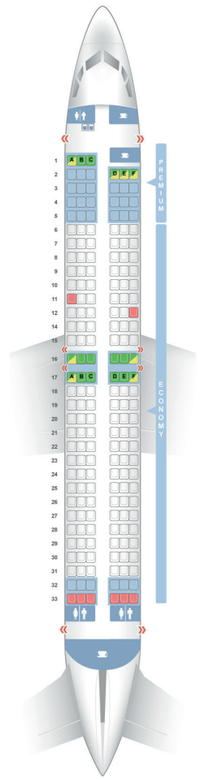


Fig.x5.04

KLM
Boeing 777

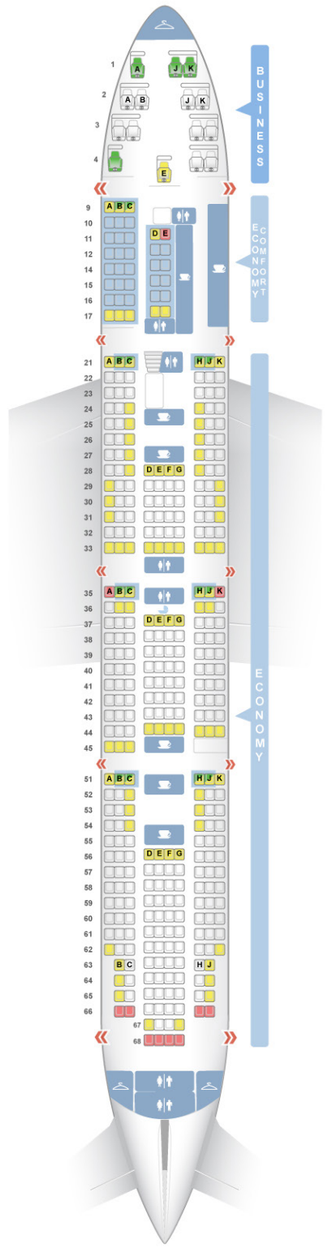


Fig.5.05

Singapore Airlines
Airbus A350

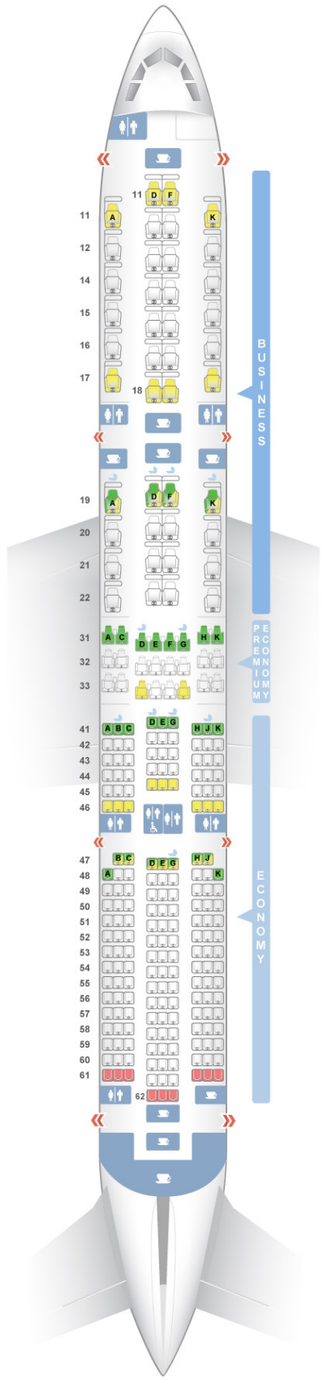
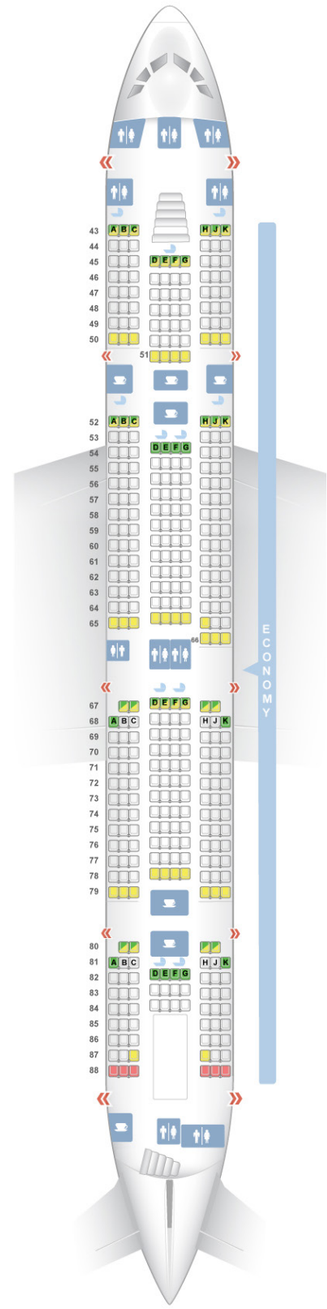


Fig.5.06

Emirates
Airbus A380



Creative Sessions

With a range of clearly defined problems to address, the ideation stage of the project is initiated. Each new idea opened up the possibility for more ideas which were also explored. The image below illustrates this framework.

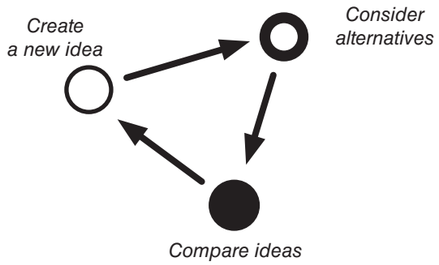


Fig.5.07 Idea generation process

Creative Sessions

A number of creative sessions were planned and carried out in order to produce ideas outside of the established solutions mentioned in the previous chapter. There were 3 sessions in total, each lasting 1-2 hours with five participants involved (including facilitator). The participants were primarily design students at the IDE faculty with experience on long haul flights with both male and female participants.

Participants were shown imagery of various lavatory designs, as well as images from the inflight reference. The sessions were semi-formal discussions about the meaning of hygiene, the role of the users in the design, the steps involved in cleaning a toilet and finally ideas for promoting better hygiene and creating a clean lavatory design.

Session #1

In the first sessions the user needs were discussed and mapped. The group established that the flight crew are currently completing the majority of the cleaning task. Passengers are not equipped to clean the space and therefore do not see it as their responsibility. The needs of the passengers are met for the most part, but space is the biggest limitation.
When asked the question “what is hygiene”, the group agreed that hygiene is as much about staying clean as it is about cleaning oneself. This would include avoiding any mess created by other passengers. It was concluded that passengers may feel like minimising their own interaction with unhygienic surfaces is enough to keep themselves clean. This leaves out the responsibility to clean up afterwards. Therefore it is best to meet the passengers halfway and provide a certain amount of autonomy in the design, i.e. self cleaning objects and features or minimise the chance of waste creation and misuse.

Session #2

In the second session a range of human behaviour types and sensibilities towards hygiene were discussed. Within the group there were three different sets of behaviours revealed; Very hygiene conscious, hygiene aware and undeterred by hygiene. Passengers must have a high enough motivation to clean and the ability to do so, then be effectively triggered to do so. In the second part of the session the problems experienced by passengers were mapped (see fig.6.03). This mapping session lead to the conclusion that there are a select number of core problems to address, which was the focus of the previous chapter.

Session #3

In the third and final session, component solutions were discussed. At the end of the sessions, the ideas were clustered together based on their relation to the user then sketched out on paper. Five clusters emerged from the idea generation stage of the design process, these are: Passenger awareness of hygiene, provision of hygienic products, prevention of misuse, translation of objects within the space and transformation (alternative component options). The next section is a detailed description of the clusters, as well as the main ideas discussed for each. The next four pages will present the ideas from each cluster.

Results of ideation

This method of brainstorming provides an effective starting point for idea generation as it frames the problems from the users perspective. The result of the creative session is a series of abstract concepts which are used to drive the creation of more ideas. The aforementioned idea clusters will be referred to as concept drivers from now on. It can be revisited again later on once the ideas have been developed further.

Note: *this stage of the process is intended to be abstract and does not always necessarily relate to aircraft. The abstraction helps to think through possible solutions without thinking too much about concrete final solutions.*

The goal of this exercise is to allow the designers to map the known, as well as the yet unknown solutions. Furthermore, the spirit of the creative session is to let ideas flow without a filter. Some ideas may never work, but they are still valuable to discuss as they may provide a source of inspiration.

The next step is to create more concrete product solutions. This is the focus of the remainder of this chapter.

Fig.5.08

Creative Session

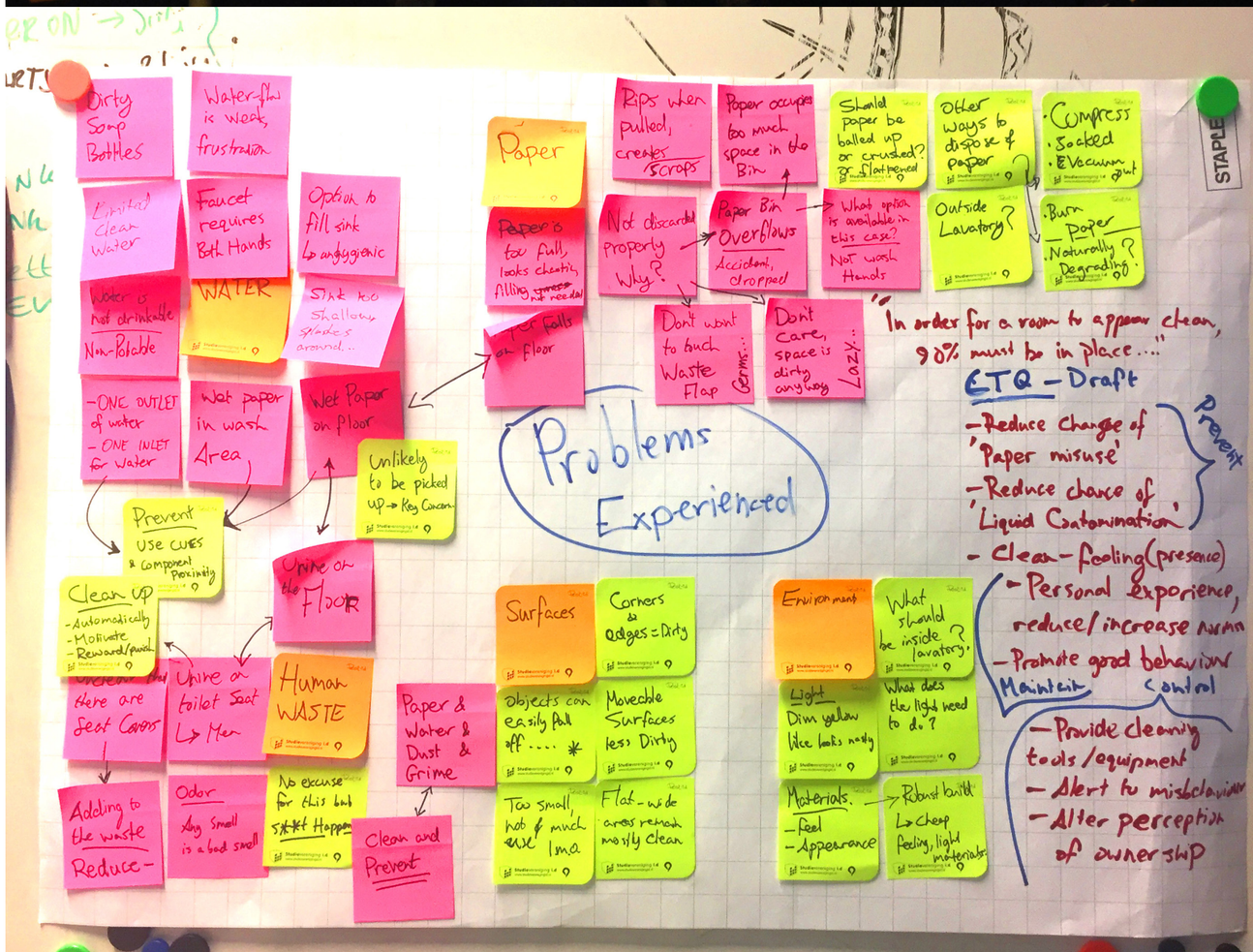


Fig.5.09

Idea Gen. Wall

Core Solutions

Idea Generation 5.2

This section directly correlates with the core problems section in the *Chapter 4*. The largest challenge in this project is identifying why some solutions work and others don't. The design requirements are closely observed when analysing and evaluating these solutions. The following is a rundown of key solutions for each of the core problems.

The space solution

Though it was stated as a source of dissatisfaction among users, a recent trend has seen reductions in lavatory size to accommodate more seating. Dimensional constraints are set by airlines and cannot be relied upon to change for the better in the future. It is therefore unlikely that a concept will be successful if it relies upon the creation of additional space inside the cabin.

The options for design are as follows; the design must either be :

A small number of larger lavatories:

- Provide more comfort for each passenger
- Creates the space for additional features and components such as cleaning products and urinals.
- Creates more space for flight attendants and maintenance crews to clean and repair the space.
- Reduces provision and increases waiting times.
- Fewer fail safes in case of an emergency breakdown.

A greater number of small lavatories:

- Increases provision for all passengers and shortens waiting times.
- Possibility to make public restroom style cubicles.
- Requires a reduction in the number of features.
- Makes it more difficult for larger passengers to enter.

The layout and contents of each lavatory:

- A single-size lavatory solution which closely adheres to a strict set of dimensions with the same features.
- An adaptable solution which is applicable to a range of lavatory sizes featuring unique components; Urinal only, PRM, female, unisex, etc...
- Fully stocked - toilet, wash basin, paper towels, sanitary products, mirror and waste bin.
- Partially stocked - toilet, paper towels and waste bin.

A singular size of lavatory improves repeatability. Producing the same lavatory is perhaps more profitable and better for crews in terms of repeatability and familiarity. A single design is preferable where a homogenous layout can be found which solves the tidiness problem

Adaptability of features and components will allow for a wider range of product offerings, such as urinals and PRM lavatories. An adaptable design is preferable when there is no single lavatory design that satisfies all needs.

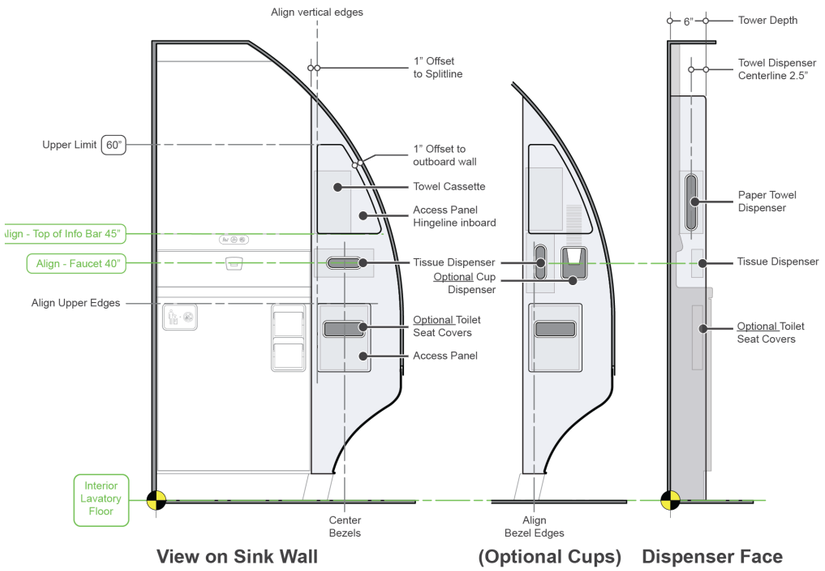


Fig. 5.10

Dimensions of the amenity wall

Fig.5.11 Signage used to deter standing urination.

Fig.5.12 A funnel to enable female standing urination

The urination solution

Solutions in this case are two-fold and relate to the user behaviour principles. Behaviour can either be changed or embraced.

Change behaviour

There are a number of techniques which have proven to make a difference such as placing an image of a fly in the bowl. The design of the bowl is crucial in providing an adequate target for urination.

Men who would usually stand every time they urinate are suggested to sit down instead in aircraft lavatories, but they stand anyway and risk making a mess due to personal convenience. Women that usually sit comfortably on the seat are worried about germs and instead hover over it or use a toilet seat cover. Providing a new method for women to urinate is also an option.

Passengers are changing their normal behaviour to match the tools they are provided with. It is possible to drive behaviour change by providing information and signage which informs how to use the lavatory. This practice is common in public restrooms.

Continuing with this trend, it may be possible to enforce new behaviours. For example getting men closer to the toilet bowl rather than further away from it. Instead of providing a urinal, it can be suggested that men kneel before the toilet. This allows them to urinate as they usually would without spraying (fortunately, this suggested was not taken seriosuly by anyone who was asked). Changing behaviour is evidently more difficult than embracing it.

Embracing behaviour

Allowing everyone to urinate in a way that makes them comfortable is the ideal solution in preventing urine spills. For women this means sitting or squatting. Some women would also like to stand like men do, though female urinals have never gained popularity.

Inversely, men would rather stand to urinate, with a smaller number preferring to sit. The current solution is a toilet whose seat can be raised. This is technically accommodating to all methods of urinating, but is evidentially not ideal with respect to cleanliness.

Another means to embrace bad behaviour is to design features which handle the spill of urine. The floor pan is designed to collect liquids and prevent leakage into the aircraft. Similarly, the shape of the toilet shroud and bowl have an influence on the behaviour of liquid spills.

Provision of a toilet for men or women to sit or squat on, urinals for men and a variation for women would embrace all behaviours and allow a maximum number of passengers to urinate comfortably. This solution would require the inclusion of multiple toilet types inside the aircraft, which coincides with the space solution.

Fig.5.13 The classic Fly in the urinal trick for better aim

Fig.14 Polymer toilet mat to absorb spillages

Core Solutions

Paper solutions

"What is of greater benefit to the passenger, a wide array of paper products to use, or a tidy lavatory?"

Reducing the amount of paper waste generated is imperative. In addition, designing a waste receptacle to contain the paper mess more effectively will extend the time between emptying. A further solution is to address the disposal behaviour mentioned above.

New type of paper

The overflowing paper problems occurs in large part due to the fractal nature of crumpled paper. This can perhaps be prevented using different paper.

- Using paper which folds flat after it dries or does not crumple at all
- Dissolving or disintegrating paper to create more volume in the waste bin.

The problem with bidets and hand dryers is that they put more demand on the aircrafts energy and water supply. Bidets are not used by many people worldwide and may make some people feel uncomfortable. Hand dryers have been known to spread more bacteria, whereas paper does a better job in containing it.

Get rid of paper

When the toilet flushes a powerful vacuum sucks the water down a tube. This solution suggests that the same can be done for the paper. Boeings new dry floor concept seems to manage the liquid on the floor, but not the paper. Wet paper on a grate will seep through the cracks and potentially cause blockages.

A simple test shows how easily crumpled paper can be compressed inside a bin. The paper can be pushed down with a hand or plate, but quickly springs back. A heavy plate could be placed on top of the compressed paper to increase the capacity mid-flight.

Make the lavatory 100% paperless

Waste prevention seems to be the best option. Removing paper from the lavatory entirely would eliminate the need for dispensers, refilling, a waste bin and cut out paper waste entirely. It can be replaced using the following:

- bidet instead of toilet paper
- washable towels instead of facial cloths
- heated air blow dryer instead of hand paper.

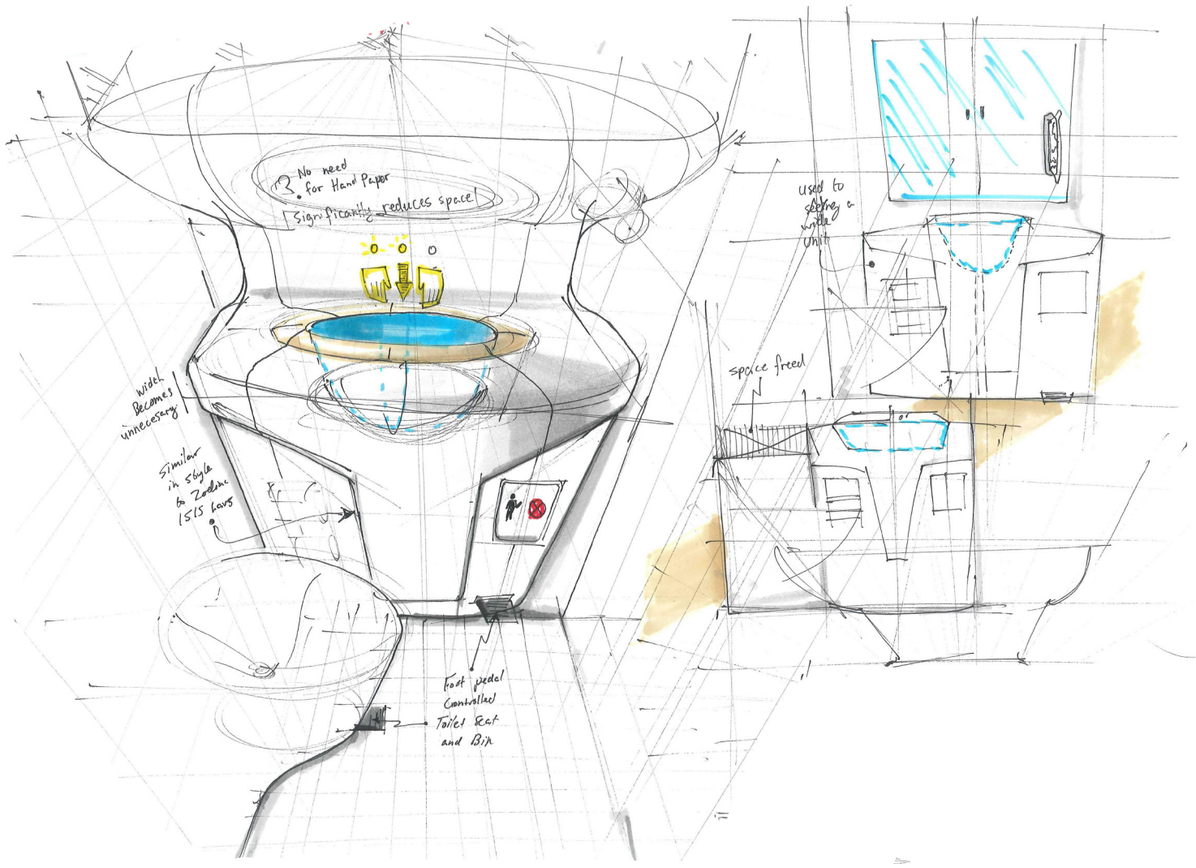
Disposable paper has long been the standard in public toilet design because it is cheap and puts no demand on facility resources, which each of the products above do (water and electricity).

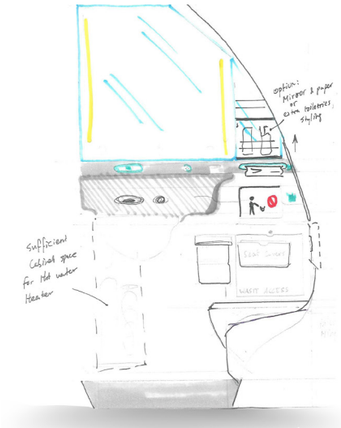
Fig.5.15

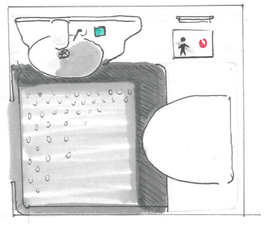
Bin full of waste paper

Fig.5.16

Waste paper out of place in the lavatory







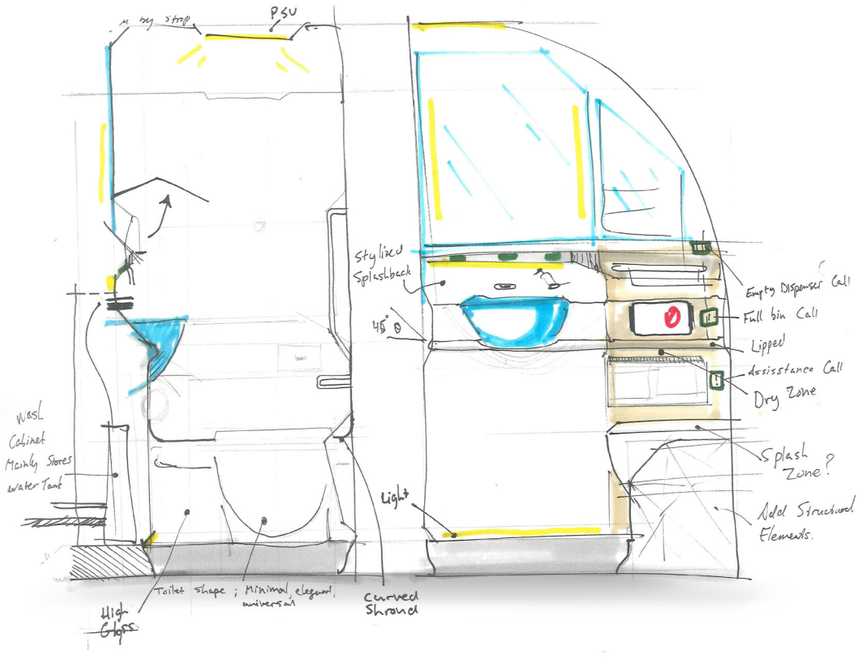


Fig.5.17

The right above sketch is a paperless lavatory concept. Rather than providing a wash basin and paper dispensers, there is a deep bowl into which users place their hands.

Atomised water coats the hands in soapy water then jet blows them dry, maintaining any water mess. The focus of the sketches below is the separation of wet and dry spaces.

It is possible to create a logical flow from one component to the next by clustering similar objects together. This is an example of nudging behaviour as discussed in chapter 3

Component Solutions

Product Solutions 5.3

Enabling creativity has now lead to the creation of fundamental solutions to these problems. The first step in to create product solutions which align with the universal concept drivers. The goal here is to manifest the previous suggestions as tangible objects.

This section gives an overview of the product ideas that came out of the idea generation stage of the project. The ideas are categorised by the different subsystems in the lavatory. The following is a complete list of the subsystems and their components:

Toilet area

The toilet is one of two central components in every lavatory. The subsystem is most often aligned opposite the door or perpendicular to the door. The components within this subsystem are as follows:

- Toilet bowl - collection are for human waste
- Toilet seat - place to sit on the toilet
- Toilet shroud - housing for the toilet towl
- Urination solution - alternative urinate methods
- Baby change table - table to change a baby

Wash area

This is the second central sub-system. . It is used by virtually every passenger to check their appearance and wash up. The components within this subsystem are as follows:

- Wash basin - fills with water to wash the hands
- Basin drainage - removed water from basin
- Faucets - provide water to passenger
- Surface configuration - number and location
- Surface geometry - shape of countertop

Floor

The floor is a lipped pan which prevents leaks and provides grip for the passenger not to slip. The components within this subsystem are as follows:

- Floor texture - material and shape of surface
- Floor features - additional built in objects
- Floor lip - contact area with other surfaces
- Drying method - how to dry the floor
- Cleaning tools - provided to passengers
- Cleaning products - provided to passengers

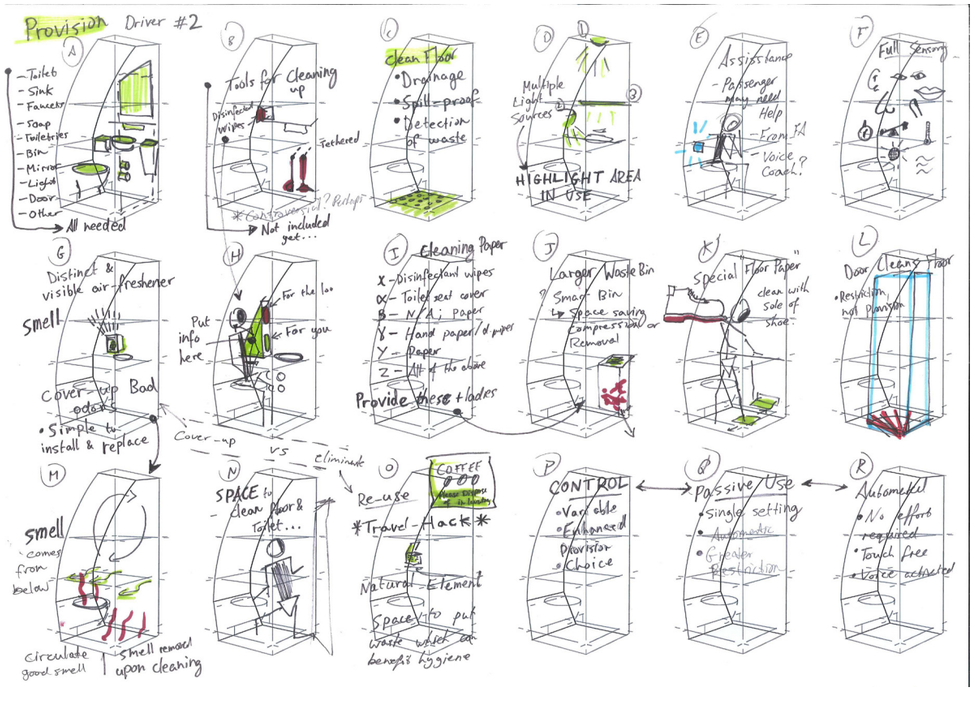


Fig.5.18 Idea sheet of basic values for the concept driver Provision

Storage

There are multiple cabinets and bins which contain paper and other disposable products within the lavatory. The components within this subsystem are as follows:

- Paper dispenser - method of paper provision
- Paper types - different types of paper provided
- Cabinet types - how products can be stored
- Cabinet opening - type of door mechanism
- Waste bin volume - internal bin dimensions
- Waste bin access - how the bin is removed

Styling

Lavatory differentiation is based on two things; component selection and form design. This will be discussed in much greater detail in the next chapter. While the previous zones primarily focus on the selection of functional components, styling is more focused on components which give the lavatory its aesthetic value. The components within this subsystem are as follows:

- Light source - where the light is coming from
- Light type - bulb type and arrangement
- Light colour - can change mood and appearance
- Lavatory walls - colour schemes, patterns and decals
- Surface finish - materials and textures
- Signage - iconography and information

Method of exploring solutions

1. Identify each zone in the lavatory and break down its key components and issues.
2. Create 5 new solutions for each component based on the ideas which came out of the creative sessions.
3. Express ideas on a morphological chart.
4. For components which have many more possible solutions, keep the solutions which relate more to hyigiene and cleanliness.
5. Combine into robust new concepts. Through multiple rounds of iteration a range of possibilities was imagined and through trial and error ideas were selected and explored further.

A complete overview of the solutions can be found in Appendix B. In the interest of report length these pages are not included in the main report as the most relevant solutions will largely be mentioned throughout the coming pages. Examples of the process and solutions generated are given to the below. (see fig.5.13 and 5.14).

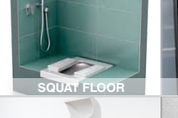
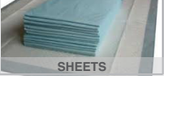
	#1	#2	#3	#4	#5
TOILET BOWL	 REVOLUTION TOILET	 BIDET INTEGRATED	 SELF CLEANING	 SCENT CONTROLLED	 DISINFECTANT
TOILET SEAT	 LIFT SEAT	 AUTO-LIFT SEAT	 FOOT LIFT	 SELF CLEANING	 WIPES FOR SEAT
TOILET SHROUD	 STANDARD	 ANGLED PROFILE	 FLAT SHELF	 SQUAT FLOOR	 RAISED STAGE
URINATION SOLUTION	 NO STANDING ON TOILET SEAT SIGNANGE	 URINAL AND TOILET	 COMBO DESIGN	 EXPANDABLE URINAL	 URINAL IN WALL
FLUSH BUTTON	 FLUSH HANDLE	 FOOT PANEL FLUSH	 GESTURE SENSOR	 DETECT OBJECT	 DOOR LOCK
BABY CHANGE	 SMALL FOLDING TABLE	 BI-FOLD TABLE	 WIDE SHELF	 SOFT MATERIAL	 SHEETS

Fig.5.19 Graphic Morphological chart of solutions aligned to the toilet wall

Component Configurations

Product Solutions **5.3**

A trial and error approach of linking components together eventually led to the emergence of similar ideas being clustered together. This was achieved using morphological charts of the solutions mapped in the previous step.

Component selection directly reflects user control. The goal of this exercise was to apply the component solutions to create full lavatory designs and ask users their opinion. The concepts are as follows:

#1 - Touchfree Control

"The users skin should never have to contact the surfaces of the lavatory"

This concept aims to completely eliminate all touchpoints in the lavatory. This is made possible with heavy technology integration and a fundamentalist approach to the design. It is perhaps more expensive to produce a lavatory this way, but would ensure minimum contamination and promote good hygiene practices through intuitive use, curiosity and experimentation. Sensor technology, antibacterial materials and are used heavily in this concept.

#2 - Balanced control

Ref.

"Users will focus their attention on curious alternative elements to "

This is a spread of ideas connected by logic. It integrates only the most essential technology integration; those used for hand washing, thus reducing the weight and complexity of the lavatory. Users may also feel more familiar in this space and save time using intuitive and familiar controls. A safe and pragmatic approach to the design.

#3 - Blended Environment

"The surfaces and components in the space are seamless for maximum cleanability"

Rather than focus on the individual components, this minimal and fluid design aims to guide the user through the space and to make cleaning as effortless as possible. This is achieved by reducing the distance between parts and water sealing them with thermoplastic strips. Liquid spills on all surfaces will wash to the floor where they can be managed by the sloped floor design.

Ref.

#4 - Foot controlled

"Optionally touchless for the hands while maintaining the same features"

This concept is entirely possible to achieve using either electronic and mechanical foot controlled switches, pads and levers. The user will focus much of their attention on the floor to operate the toilet seat, bin flap, door lock and faucets. This allows them to keep their hands clean and potentially provide more incentive to keep the floor clean. Though this concept is abstract and impractical, it provides an interesting alternative which may influence future decisions.

#5 - Smart system

"A step in to the future of onboard toileting."

A fully touchless environment with smart space saving solutions and electronic data driven control. This concept was created by including all of the more technologically advanced solutions. Sensor technology can read the hygiene conditions within the lavatory and provide cleaning and maintenance on its own. It features safe ultraviolet disinfection as well as interactive surfaces and alert systems for when perishables run low or the space is misused.

#6 - Paperless

"A sustainable approach to lavatory cleanliness"

Paper waste is among the leading causes of observed lavatory untidiness. Paper ends up in all of the places that it should not. Coupled with liquid, waste paper quickly becomes very messy. This concept draws from ideas which do not require paper. The removal of paper also means no waste bin or dispensers, freeing up a wealth of space for the passengers. The key components in this concept are water based cleaning systems and air drying. Air drying is often shunned as the high velocity hot air is known to spread bacteria, not kill it.

Imagery and reflections on each of these concepts can be found in Appendix B.

Fig. 5.20

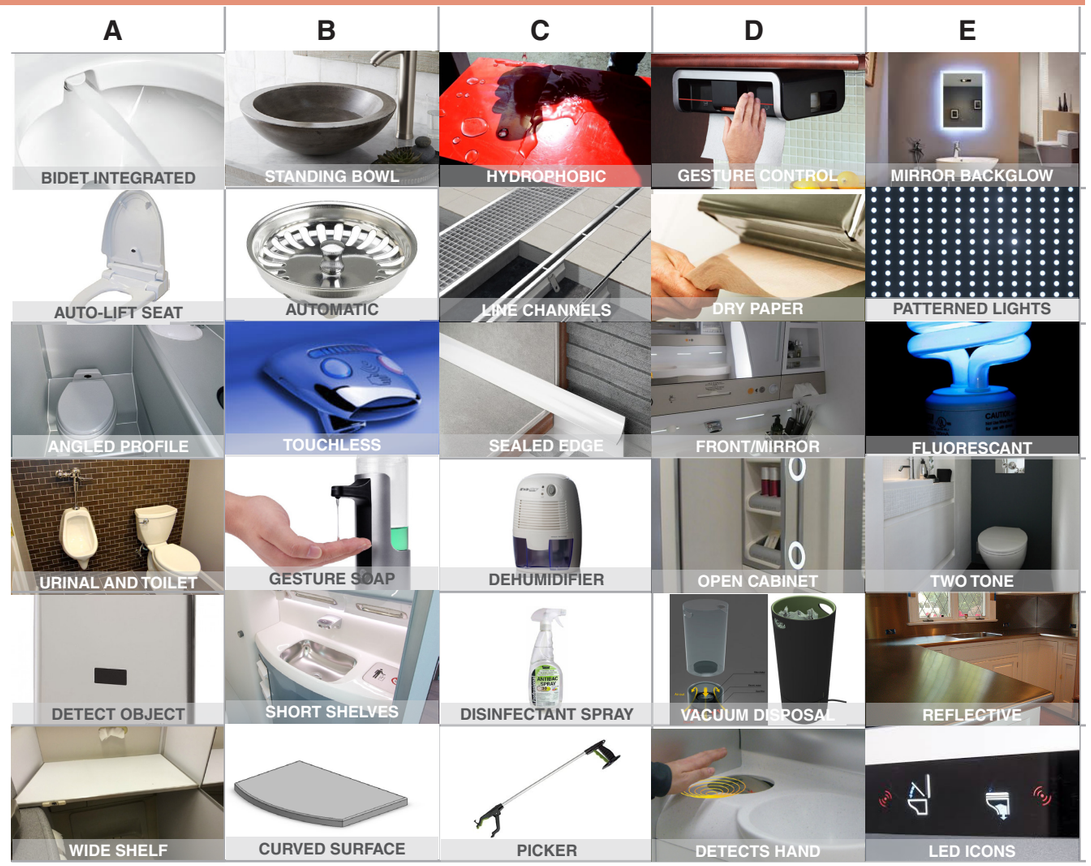
New morphological charts are populated with product solutions and catergorised based on the users level of control. In the example shown, the end lavatory can be imagined with all of the components listened

Fig.5.21

Sketches of the concept enable the designer to discuss the ideas with stakeholders and get their opinions

CONCEPT 1 - FULLY TOUCHLESS

Fig 5.15



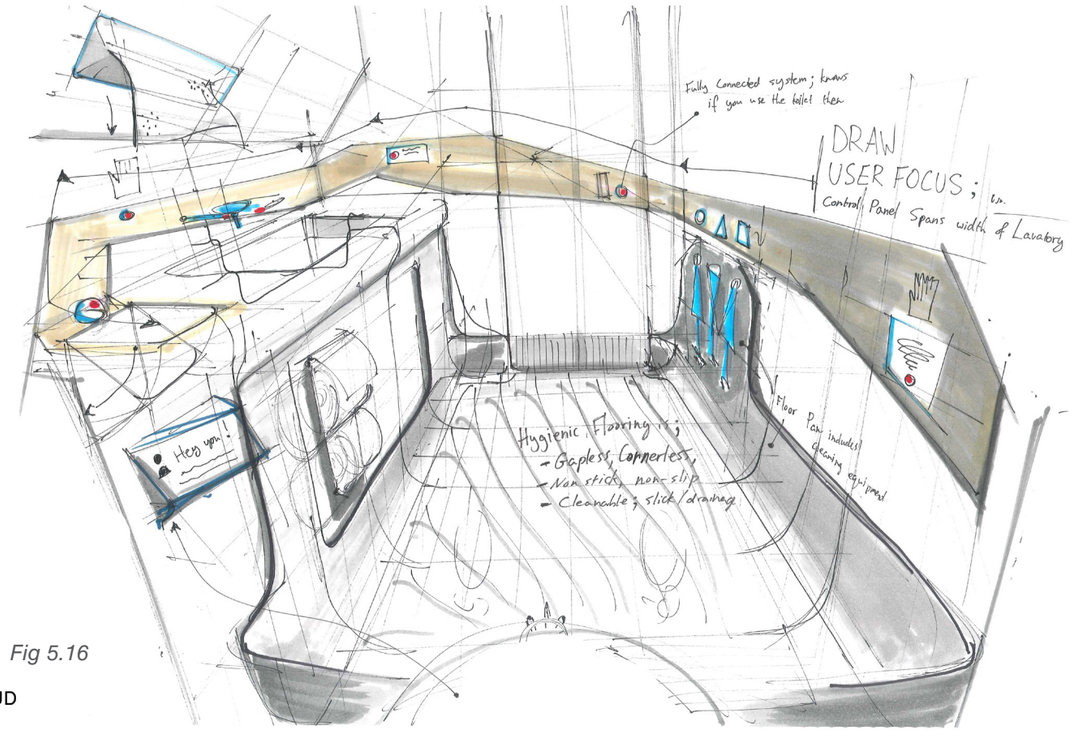


Fig 5.16

Idea Evaluation

Failed first round

Each concept has its strengths and weaknesses. The expected result of conceptualisation was to find an ideal marriage of solutions based on the predetermined criteria to create a final concept.

This failed however as the final solutions underperformed on many criteria and were not complete enough solutions on their own. Through this process it was learned that there is no single solution to the problem which can be found by combining technological ideas alone in a single sized lavatory.

The concepts were tweaked in order to match the selection criteria, but still did not fundamentally solve some of the problems. It was then decided that component selection alone would not solve the problem and more solutions were created.

Re-conceptualisation

Based on the result of the first conceptualisation round, three new concepts were developed which would fundamentally determine how the lavatory is created and operated. These ideas focus on the core problems which arose during problem definition;

- Lack of space
- Male and female urination
- Paper waste
- Lack of communication
- Toilet odour

The following are concepts were created following the creation of the morphological charts and a review of the recent industry innovations. The new concepts are as follows:

Homogeneous design

Creating a single and repeatable lavatory design which addresses the problems encountered was the original vision for the product. This is still possible with the correct set of components and features.

- Most lavatory designs have the same look and feel, with similar components and an overall design language. This design would embrace and enable a design which users will be familiar with.
- The goal is a robust, high quality lavatory design with all new features and components.
- This approach is utilised by virtually every other companies in the market . It is perhaps less versatile within the aircraft, but the dedication to good quality design and repetition means an overall better quality.

Pros:
- High-quality design.
- Can integrate more ambitious component layouts.
- Blended surfaces promote cleanability.
- Strong potential for brand differentiation

Cons:
- May lack adaptability to range of configurations.
- Challenging to accommodate all user needs.
- Familiar design, lacks innovative edge.

Transformative design

This ideology features components which can be used in more than one way. Intelligent component design enables a system architecture which can be modified between each use.

A key example is including a male urinal. When in use by a female, the urinal is invisible. It can, for example, expand from within the toilet bowl or fold out from a wall. When a male enters he can change the space as he desires.

Pros:
- Accommodating for all passengers
- Greater sense of control for passengers.
- One lavatory design to rule them all.
- Interaction may lead to greater care of the space.

Cons:
- Adds to the complexity of lavatory and the potential to complicate the maintenance task.
- Moving parts and more likely to fail.
- Design may become cluttered.
- Adding features likely to increase the cost.

Modular design

The latest trend in component design, and indeed a large focus of Zodiacs new design, is modularity. Modularity has been discussed a number of times in this report and its benefits cannot be understated.

- It makes work much easier for maintenance workers and vastly improves the flexibility and adaptability of the companies product options within the aircraft.
- Rather than design a single system, which is dependent on the sum of its parts, a modular system can have parts removed and still function.

Creating multiple lavatory types for different users needs is also possible. For example a modular toilet shroud mounting system can be designed which can attach different types of shroud can enable different behaviours such as sitting urination, standing urination, squatting and finally going shroudless in a washbasin-only lavatory. This principle would enable airlines to buy multiple types of lavatory with only a few additional, rotable parts.

Pros:
- Accommodating for all passengers needs.
- Faster maintenance on rotable modules.
- Closely relates to Zodiacs latest design vision.
- Airlines may tailor the experience to specific missions.

Cons:
- Segregation based on gender has been known to cause some public backlash.
- Manufacture of additional modules is only economically viable if the tooling and materials are very similar.

Selection

The second draft concepts visualised using sketches and morphological charts (see *Appendix B*) and discussed within a user group to obtain a score in each case. The scoring of each criteria is unique and ranges in subjectivity, therefore the task requires multiple user perspectives and opinions.

This scoring system was devised based on the designers belief that each category is deserving of an equal weight to make a final decision inclusive of all stakeholders involved. Component groups are selected using this method and a final concept sheet is created. Unfortunately, once again the systematic approach failed to yield a scientifically backed decision (see fig.5.17).

Modular component design was chosen as the leading ideology. There are many possibilities for successful homogeneous and transformative designs, but the focus will remain within Zodiacs current interest. The decision to design a modular system similar to Zodiacs was made because it has the most potential for adaptability, innovation and producability.

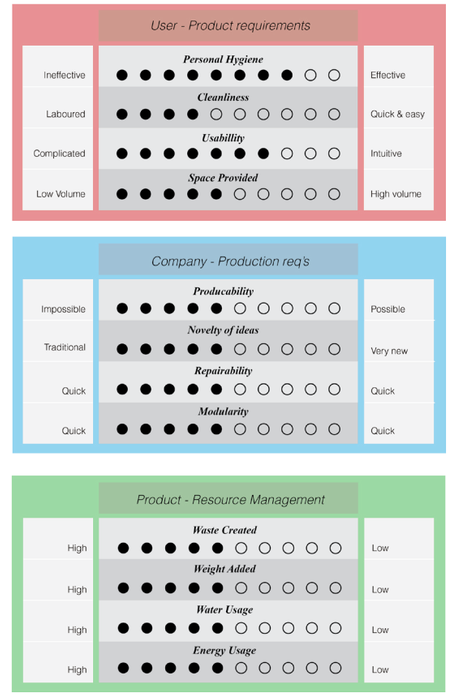
Form Design

Usability, manufacture and maintenance are driven by the selection and positioning of components within the lavatory. The form design binds that all together and gives the lavatory its unified appearance. The form design presents the company with an opportunity to add character to the design.

The principle of form follows function is true in this case. Once the components are selected and integrated within the lavatory shell, the space quickly fills up. Form is most often suggestive of the components in relation to one another.

As adequate time was not devoted to analyzing the aesthetic value of lavatories, a simple solution was implemented to align the design language with Zodiac products. To achieve this, the object sizes and contours of Zodiacs SmartLav design were studied and emulated.

Fig.5.22 Requirements expressed as scores



Result

The concept generation process was quite chaotic in the end and did not yield a clear cut result. It was not a complete failure, however, as a final concept was eventually reached.

- The process of developing these configuration concepts and discussing them with users gave new perspective to the ideas.
- While a broad range of ideas was been established and considered, a major part of the user feedback is that none of these concepts satisfy all of the core problems on their own.
- Concepts were assigned complex scoring and evaluation measures but ultimately user feedback showed that there was greater benefit to alternative solutions. Due to time constraints this would need to be fast tracked.
- The design would not rely on the introduction of new gadgets, but rather take an ideological approach which influences better human behaviour.
- A fundamentally new approach to lavatory provision is the focus of the final concept.

Chapter 6:
Concept Design

In this chapter...

... the final concept design is communicated and evaluated. Following directly on from the previous chapter, this chapter will examine the steps taken creating the final design as well as the key decisions made. This includes a descriptive list of features and imagery of the design.

Concept evaluation is performed based on a self assessment of the design requirements and a comparative analysis between this concept and the current state of the art in lavatory design. After that is a set of recommendations for the future development of the concept. The report concludes with a personal reflection from the author about the project result and process.

Contents:

Design Vision

Design Details 6.1

Following the exploration of various component solutions, a redefined design vision was created. The concept was built on the strongest elements of each concept based on the user evaluation and criteria based scoring as well as new ideas which were drawn from a detailed analysis of the *core problems*.

"A lavatory which embraces user behaviour and provides each user with a space that they can use comfortably."

Singular lavatory designs which attempt to accommodate all passengers are lacking in that the adverse intention is achieved and passengers become dissatisfied. The new design attempts to accommodate the different types of passenger while remaining adaptable and affordable to produce.

Truly, modular design is the future of cabin design. This is evidenced by Airbus new cabin concept (*see chapter 1: Latest Innovations*). The adaptability of lavatory features is imperative to create a design which accommodates all passengers, benefits crew working conditions and is future-proof. Each lavatory unit can then have its components updated and changed overtime or when the aircrafts mission is re-purposed.

Public restroom in the sky

Aircraft lavatories are an anomaly. Its rare to find a public restroom with a personal toilet, wash basin, toiletry cabinet and bin provided in each cubicle. The reasoning behind this likely stems from the fact that this is always how it has been done and has become the accepted standard.

Disruption is necessary to create a configuration that suits present day needs and solves mess generation. Alignment with effective public restroom design is the key solution in this case. The goal of the design is to emulate public toilets, specifically those found in offices, restaurants and hotel lobbies, where there are rows of cubicles/urinals and a common wash area.

- This new concept takes a modular approach by removing and relocating component groups. This was inspired by Zodiacs Durinal which provides just a urinal and wet wipes for men and a fully stocked lavatory for women.
- This concept aims to create a contained lavatory zone which is more similar to a public restroom. A maximum number of toilets are provided in the zone as cubicles without sinks and wash basins, just toilets.
- The concept instead features large wash basins in the cabin. A single, full sized and fully equipped lavatory may also be included on the side of the cabin.
- The middle aircraft section is the most densely seated and therefore most in need of provision. Being next to the emergency exits also provides space to stand.

Sex segregation

It is not possible to accommodate all the needs of both sexes without adding space to the facility, like in the NS train toilet. The consensus in aircraft however, is that the economy lavatories will never be large enough to do so. Segregation is therefore an appropriate solution to improve the hygiene perception.

With ongoing debates involving the definition of gender, important to note is that sex does not include gender. Since the lavatories are single-user at a time only, gender is not an issue on aircraft. A male only lavatory is preferable to anyone who wishes to stand up to urinate. Provision of a quick urination solution for women as well is more fair, however this is not standard practice anywhere yet and 40,00ft in the air is not the best place to start the trend.

At any rate, toileting should be kept discreet. The design aims to create a sheltered zone in the aircraft where it is possible to enter and exit privately.

Phasing out paper

Western populations are already accustomed to using paper or hot air to dry off. A paperless design onboard is preferable as it eliminates the waste and potential for disarray in the lavatory. JAMCO currently holds the patent for hot air dryers in aircraft lavatories, though they do not appear to have integrated them in their lavatories yet.

The success of a modular system would allow Zodiac to upgrade their product into the future, offering more and more configurations options of the same fundamental design. When technologies such as the Hydrowashr become suitable for aircraft, it will be possible to integrate them due to the principle of rotable modular component design.

In the meantime, a standard wash basin is included in the cabin outside of the cubicles. Using a familiar setup will make it easier for frequent flyers to adopt the new layout and communal wash practice.

Usage implications

- Individuals can wash their hands in the cabin.
- Men can have their own lavatory to urinate quickly.
- Women and PRM's can have a lavatory which has more space to urinate sitting down comfortably.
- Individuals who wish to shave, change their clothes or change a baby can still do so in the larger aft lavatory, which is not affected by this concept and has a basin.
- Cabin crew can control the flow of passengers in the aisle by creating a space for them to wait that does not block the aisle.
- Airlines can experiment to find a configuration that fits their customers changing needs.

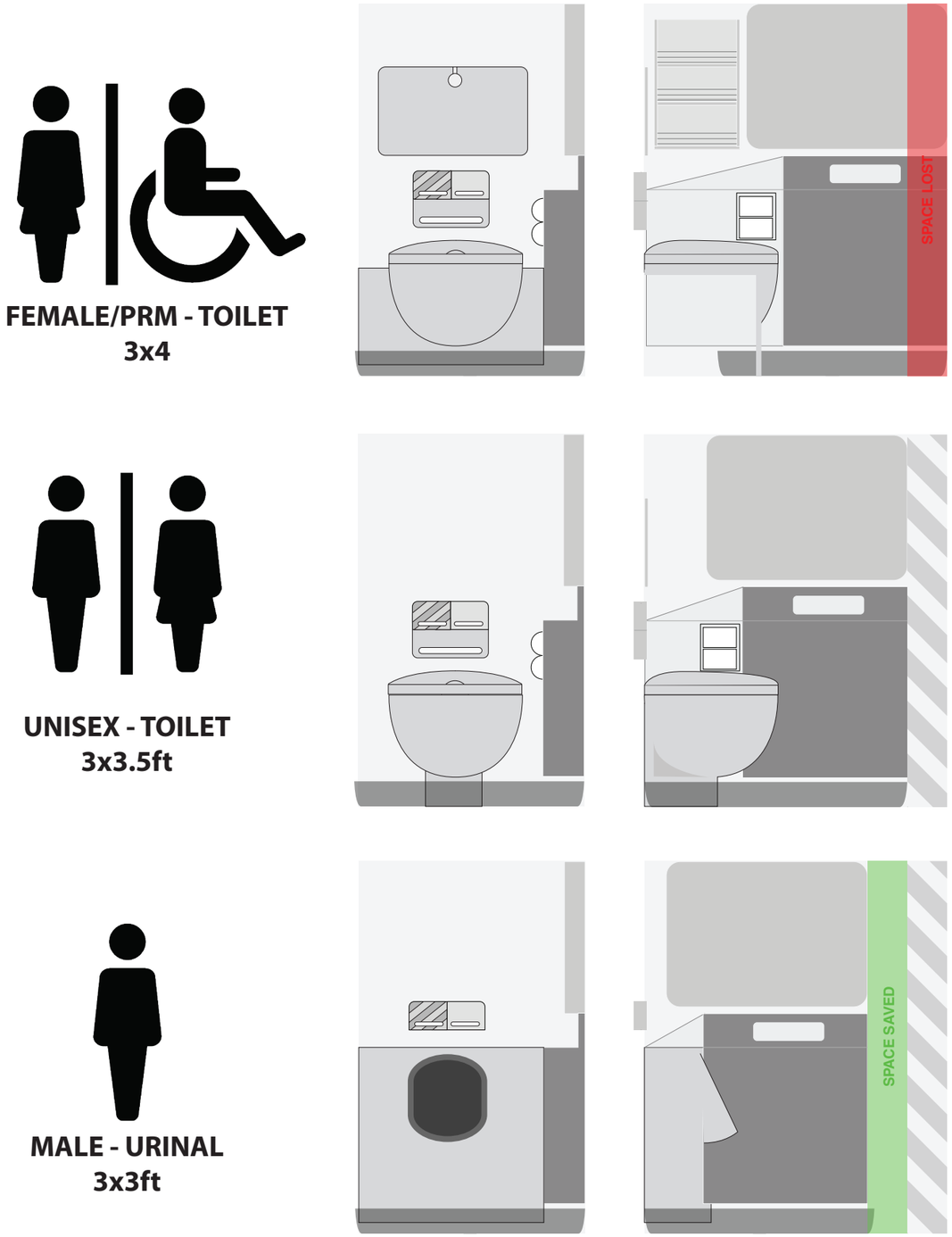


Fig.6.01 An indication of how gendered aircraft lavatories would appear in an aircraft.

The largest lavatories are restricted to males to prevent urination on the floor.
Fewer paper products are offered in smaller lavatories.

Concept Development

Design Details 6.1

Ideas and product solutions are built using the 3D software *Solidworks* and iterated upon multiple times. This method was chosen as it is very quick and allows the creation of various mutable versions of objects in multiple configuration and to communicate dimensions and part relationships.

This is the ideal approach for aircraft cabin design as a change in dimension of a single part or subsystem can have a knock-on effect to the dimensions of all other parts. Furthermore it helped to manage the complexity of all the components in the design.

Process

Using Zodiacs product design specifications, the size and shape of multiple lavatory envelopes was established and created (see fig.6.02). Numerous lavatory shells are crated to emphasise the modularity of each component. The minimum and maximum sizes of key subsystems (toilet, floor, wash basin, dispensers) was established and built.

A virtual aircraft cabin environment mock-up was created to give an impression of space and to iterate within multiple real world layouts. Three cabins were created; two wide bodied with the seat configuration 3-4-3 and 3-3-3 one and narrow bodied aircraft with the configuration 3-3.

The purpose of these models is to capture component layout and adaptability to different purposes within the cabin. This does not include the detailed design of parts or the form design. These will be discussed later in this chapter.

Note: Boeing and Airbus have alternative layouts. However, since Boeing have exclusive contracts with JAMCO for the 747 and Rockwell Collins for the 737, only Airbus' cabins are used. The A380, A350 and A320, respective to the seating configurations mentioned.

Lavatory types

The concept is called Z-Lavs. It comes in *space saving*, *standard* and *comfort* sizes. Since the wash basins have all been removed, the lavatories have increased empty volume. Each size serves a different purpose with respect to the sex and task of the occupant. The following are common features in all of the lavatories:

- 32x32 inch floor pan. An achievement of this concept is that identical floor pans are used.
- A plastic trim which runs around the perimeter of the shell. This creates separation of space and keeps the lavatory walls from being vandalised and damaged.
- A small dispenser for disinfectant wipes and a small waste bin to dispose of them.
- Bifold doors to make entry and exit easier.
- A large mirror which is flat against the wall.
- Physical flush button and passenger feedback panel.

Urinal lavatory

The space saving lavatory has a 32x32 inch footprint and features a urinal only. The design of this urinal shroud is based on the concept imagery of the *Durinal*.

Unisex lavatory

The medium lavatory is unisex. It features a curved shroud toilet and has a 42x32 inch footprint. This lavatory is designed to accommodate all passengers and therefore closely resembles the current setup, without a basin.

Female/PRM

The female lavatory is 46x32 inches. It may seem counterintuitive to give women a larger space since men are bigger on average, but most of the space is occupied by the toilet and need for women to sit while they urinate.

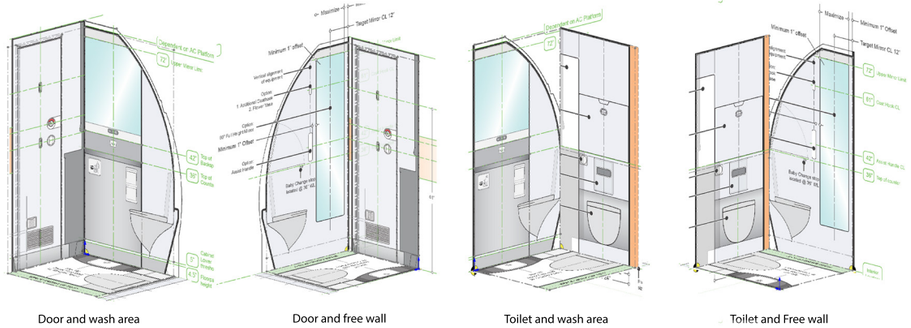


Fig.6.02 Standard lavatory dimension interfaces used for CAD modeling

Fig.6.03

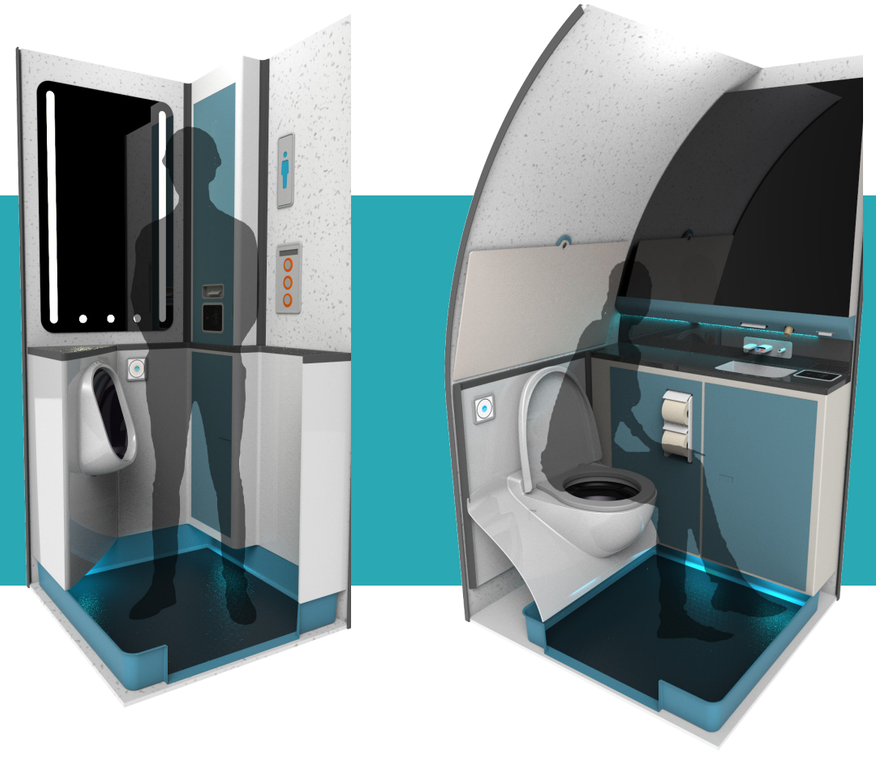
The unisex variant (right) sits on the side of the aircraft and features a curved ceiling

The female variant (left) has a maximum space volume for a standard lavatory size.

Fig.6.04

The male variant (left) is the smallest and is expected to be used quickly.

The lavatory (right) emulates a standard lavatory. This is used in areas where a shared basin is not possible



Concept Details

Design Details 6.1

Wide body - A350/A380

The standard middle aisle four lavatory configuration on a wide body aircraft features two medium sized lavatories side by side opposite two more lavatories. In this setup, all passengers are free to use whichever lavatory is available. In this scenario, men and women enter and exit, only having to wait when all four are occupied.

When placed side by side, a male and female lavatory are the same size as two unisex lavatories. Placards show passengers from their seats where to go. For a female sitting by the left aisle, the preference is to cross to the other side. She can also use the unisex lavatory to her left.

There is also an option to position two more lavatories at the edges of the cabin. In some situations the middle aisle sections are replaced by a crew area where meals are prepared. For the purpose of demonstrating this concept, all of the unisex lavatories are at the side of the aircraft.

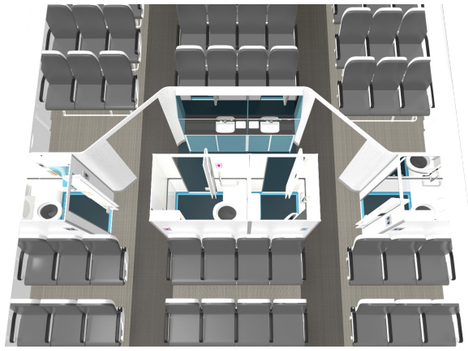


Fig.6.05 A3580 Cabin with 4 Z-Lavs

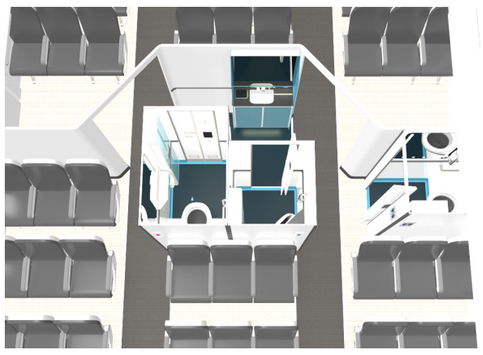


Fig.6.07 A350 Cabin with one Z-Lav removed for a seat row

Narrow body - A320

Long haul flights are the focus of this project and soon it may be the case that smaller aircraft are able to fly much longer distances. If single aisle aircraft do become re-purposed for long haul, airlines will need to rethink lavatory provision. The concept is transferable to narrow bodied aircraft, such as the airbus A320 as follows.

The lavatories on a narrow bodied aircraft are all curved and are therefore smaller. The urinal is too small to feature a curved roof, but can be positioned away from the wall. This creates a gap which can be used either for the communal wash basin or for additional galley services

There can be one or two forward lavatories. As there is no space for a communal wash area, this lavatory comes fully equipped. This can be used as a purchasing incentive for passengers in premium economy. The smallest lavatories are preferable on small aircraft, making the urinal suitable.

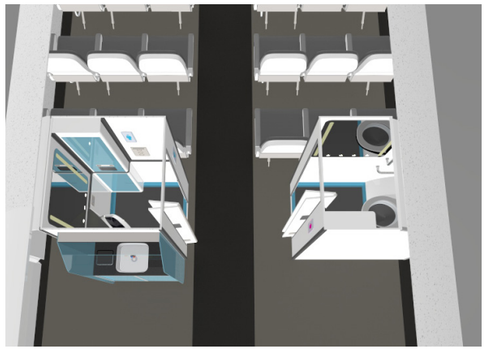


Fig.6.06 A320 aft cabin

Fig.6.08 View from the rear of rhe A320 cabin

Fig.6.09

Widebody Middle aircraft Z-Lav area

LOPA

In this layout the lavatories line up across the cabin parallel to one another, similar to most Airbus aircraft. 6-9 inches of space is saved inside each lavatory when the wash basins are removed. This can either be repurposed as additional cabin space or be given back to the passenger.

The small footprint of the urinal lavatory creates up to 4 inches of space, which is given to the female lavatory which now has a total size of 46x32, most of which is empty space.

As this space is located next to the emergency row, there is plenty of space for waiting passengers to stand ans no seats are lost either side of the cabin. A row of seats front of the wall will be lost due to the space created between the lavatories and sink, however these seats can be won back on the far side when a lavatory is removed. This is the case in the A350 design where the reduced width makes the wall space tighter (see fig.6.05).

These configurations can allow airlines to produce creative layouts and differentiate themselve from their competition. The modular cubicle design can be viewed as a toolkit for airlines to make entirely new cabin layouts.

Shared sinks

The wash basin outside the lavatory features two standard sized wash basins. The communal wash space is open for passengers in the aisle to see at all times. it has the same flooring as the floor pan inserts. This acts as a buffer between the lavatory interiors and cabin carpet.

A closed system dispenser is used for soap refilling. During inflight ressearch it was noticed the the bottles and holders were filthy. Closed sytem dispensers reduce germ exposure since the operator never contact an exposed vessel while filling (Hongsoongnern, Britton and S, 2016).

Also included is an atomised water tap. Atomised water nozzles claims to use up to 90% water. A mist of water vapour quickly soaks with an adequate amount of water for HWWS. An atomised water tap won the Crystal Cabin award this year in the university category.

The shared sink space is planned to create socially normative behaviour and get passengers to wash up more frequently. Disinfectant paper inside each Z-Lav can be used as a buffer when touching surfaces. The last thing the passenger does before returning to their is wash their hands, rather than touch the door lock.

Concept Features

Design Details 6.1

Awareness

A feature is added which give users the ability to relay specific issues to flight attendants. There are now a total of four buttons to call an FA (see *fig.6.03*)

- One general assistance button intended for passengers in distress (included in all lavatories as standard).
- There are three buttons on a nearby panel
- The first is a general poor hygiene distress indicator used when the lavatory has become a mess
- A second button is pressed when the primary paper dispenser needs to be refilled.
- Finally a third call button for an overly full bin which needs to be emptied.

This will allow passengers to silently relay their displeasure to cabin crew, who are alerted via the flight attendant panel or on their personal devices. This allows a more functioning relationship between everyone onboard, leading to better control of lavatory use and hygiene.

Fig.6.10 Passenger interface

Provision

Providing adequate tools and products to passengers to keep the space clean.

- Automatic cleaning devices have been determined to put excessive demand on the aircrafts resources.
- The amenities and methods for personal hygiene will largely remain the same, but vary in quantity.
- Toilet paper and simple disinfectant wipes for the seat and surfaces are provided for females lavatories.
- Disinfectant wipes are provided for males.
- The central wash basin in the cabin will have a larger bin and more paper products, including cups.

Prevention

Reducing the potential for misuse and preventing (or limiting) the core problems from occuring is achieved in the following ways:

- It is expected that the provision of a urinal will give all lavatories cleaner floors by reducing the instance of men urinating on the floor.
- Female lavatories are larger and have larger mirrors.
- Signage is used to deter standing urination when men have to use this lavatory (if none are available).
- In all of the lavatories, the usable components are clustered together as closely as possible. The goal here is to focus all of the users attention on one area in a clear and simple way.

Unisex lavatories may be used in much the same manner as before, with men and women both contributing to a messy space. However this now only accounts for half of the provision in the zone. It is important that these lavatories are provided in the event that a male or female lavatory breaks, which is common.

Translation

The movement of components and people within the space is controlled by a simple and uncluttered design.

- The design of the wash area remains largely unchanged.
- Closer positioning of the waste bin ensures a shorter travel distance for paper and minimised tracking of water in the wash cabinet.
- The elimination of sinks in the cubicles means that there will be no water on upper surfaces
- A small foldable side table is attached to the amenity wall. This is useful to place a bag or object.
- There are two posable hooks on the door, one up high for a coat and one down low for a hand bag.
- More space is provided to the user in the lavatory, so they will have more room to move.

Transformation

- A touchless flap is included as standard. This innovation has already started to catch on within Zodiac and the rest of the industry.
- The other touchless control is the faucet for cold water. A faucet with an atomised tap is also included for people who wish to use it.
- The flush and toilet seat are still manual. This is to prevent accidental set-offs. If the toilet is set off during use it would scare the daylights out of you.
- Handrails are still provided on the “free wall” to allow people to squat, hover and brace themselves.

Additional features

The trim design in each lavatory is made of a lightweight polycarbonate with a highly glossy finish. It is treated with self cleaning titanium nano-particles to remain clean and white throughout its life in case of urine splash. The top of the trim is an soft rubber material which provides a degree of grip to the user in the absence of a place to brace oneself. There is also a set of handrails in the lavatory which can be seen in fig.6.07.

One benefit standard lavatories have is that they provide a surface to rest objects. During inflight research, foreign objects left in the lavatory were a source of frustration. The Z-Lavs feature a side panel which folds down. Passengers who need to rest an object can do so, whereas passengers who do not need it will feel like they have more space.

Below is the view of the Z-Lavs from the cabin. Placards are placed on the sides of the lavatories to indicate which passengers can use them. Passengers can determine from their seat which is their ideal lavatory to go to. A male seated on the right side will likely glance over to see if the urinal is free, otherwise he can use the unisex lavatory on the right, then wash his hands in the communal basin and return to his seat.

Signage should be used to discourages male urination in unisex and female lavatories. This relates to the goal of making passengers more aware of heir behaviour. The unisex lavatory is a place where similar problems could possibly arise. However, since men know that there is a urinal onboard for their benefit they are more likely to use it. Men should take more care in the other lavatories knowing that a special one has been provided for them.

Fig.6.11 View from the cabin

Design Evaluation

Project Conclusion 6.2

This penultimate section will focus on what the new concept design achieves when compared to the current industry standard. In the absense of a quality validation procedure, a self evaluation is performed.

The goal throughout the project has been; *Keeping the space tidy by promoting better hygiene behaviour in users*. This has been achieved in the following ways.

1. Increase passengers awareness of their lavatory behaviour. This was achieved through space design, signage, placement of products and most importantly, relationship between the passengers and flight crew.

2. A design which more closely resembles more desirable public restrooms such as hotel rooms, movie theatres and private homes; communal (social norm) and inviting with the opportunity for privacy when its needed.

3. Establish a design which is suitable for aircraft, one which fits inside existing aircraft and adheres to the bulk of air safety requirements. The design demonstrates that it is possible to imagine fundamentally different usage patterns for passengers and crew.

4. The waterless lavatories are expected to last longer in the aircraft and require less time to clean and maintain. Later integration of paperless technology will boost the hyigene of the space and create a zero chance array for unclean conditions.

This design was heavily insipred by Zodiacs DMS and Durinal lavatory systems and the new NS train toilet designed at TU Delft. The merit of the new design is assessed based on a comparitive analysis between these designs, as well as the current single cubicle arrangemenents in aircraft.

The durinal effectively doubles provision for men without addressing the needs of women. Designing a lavatory intended for women creates a more equal experience onboard while continuing to aid men.

The much larger NS train toilet, while better for families, has been criticised for not solving the hygiene problem. One female user said that the urinal was clogged and filled with urine when she entered. As the train moved the urine spilled. It smelled terrible and forced her to leave. She said she will never try to use it again. If the urinal breaks down in the aircraft it will be locked and men can still use the unisex lavatories .

With no wash basins inside the lavatories, there is a reduced likelihood of scum buildup, as we saw during the problem definition. The only water now comes from the toilet rim, and it is unlikely this will escape and cause a mess. Without the presence of water the lavatory will stay cleaner for longer and reduce the spread of pathogens.

Benefits and drawbacks

The experience will improve for primary and secondary stakeholders in the following ways:

- Passengers now have options with respect to which toilet they use. When asked if they would be satisfied with this arrangement, a number of users stated they would prefer the extra space and gender specificity (with respect to hygiene).
- Preventing men from using the largest lavatory and most comfortable lavatory is to provide a clean haven for women. Women want equal provision to men, which likely means a solution similar to a urinal for greater ease and conveinience.
- With more males queuing for the urinal the female and unisex queue is also expected to shorten.
- Men can enjoy shorter waiting times due to the speed of the urinal and women have more space.
- The introduction of a common activity (handwashing) is expected to demand better participation.
- Significantly reduced liquid mess in all lavatories. It is debatable however that hygiene conditions will improve for men. In all likelihood the urinal will get the most use and become an even dirtier space.
- PRM's and passengers of size will have a better time using the spacious female lavatory.

- Flight attendants need not check the lavatories as often. Most of the untidiness is relegated to the new wash zone, which can be tidied while passing by.
- FA's are also alerted on their personal device when an individual has a specific issue, allowing them to focus and prioritise their tasks.
- Cabin crew can use the external cabinets to store items and retrieve them quickly.

- The cabinets, bins, floors, mirrors, hand rails and passenger panel are all standardised and are featured in each lavatory. The only fundamental difference in how each Z-Lav is made is the space envelope and shroud attachment. This is of great benefit to the speed of production and maintenance.
- The only plumbing fixtures to attach in these lavatories is for the vacuum flush on the toilet and urinal. This greatly simplifies the procedure of attachment and maintenance.
- The number of objects inside the lavatory is minimised, making it far easier to maintain an organised system array (fewer objects that can be to disorganised).
- The minimisation of components within has the added benefit of reducing the number of places a foreign object can be placed, which is a security benefit.
- Reliability is driven by low maintenance cost. Fewer parts reduce the maintenance of an individual unit. It is therefore held that these basic units will last longer in the aircraft.
- When these lavatories become older and need to be replaced, the level of effort is reduced. It is a win-win scenario for airlines and crews to invest in simple, stripped back designs.

Airlines and OEM's

It is not easy to estimate what it would take for airlines to purchase a lavatory based on hygiene benefit but it appears that airlines will continue to purchase products which reduce weight and increase space. This puts pressure on equipment manufacturers to focus their efforts here, instead of on hygiene and passenger experience.

- Sharing wash basins reduces the weight of the overall system by eliminating more than half of them.
- The cabin wall gives queuing passengers a place to stand in the cabin out of view of other passengers.
- This concept requires the elimination of 3 seats on the A330/A350 and 4 seats on the A380. Airlines may see this as a dealbreaker. In that case airlines can produce a more favourable layout.

Research recommendations

- Passenger satisfaction research with this new setup is recommended. Asking different individuals their opinions is not enough, a larger scale questionairre is required to collect data on passenger preference
- Following this analysis a full scale test environment can be use to test prototypes of this design.
- Relevant investigations include passenger flow in and out of the wash area.
- Comfort factor of the extra space provided to females (and reduced for males) and the FA's cleaning task, whether it is helped or hindered.
- Qeueing theory can be applied to this model to better understand how it will flow given different gender ratios
- Fly-on-the-wall investigation of behaviour inside aircraft lavatories within a moc-up style environment.
- Cultural differences of Airline in different countries.
- Aesthetic integration; how the styling of the product influences passenger behaviour.
- Methods of reducing odours and stains passively
- The impact of lighting on the appearance of hygiene.
- The potential for cyber systems integration and data driven information to improve operational cleanliness.

Design

- A single lavatory design for everyone is simply too limiting. Production should focus on balancing multiple types of provision with a LOPA that ensures passengers always have access to a clean lavatory.
- Shrinking lavatories is a short term solution which may lead to long term problems, such as the loss of customers. Given the The first company that starts providing bigger lavatories will likely receive admiration from the public and boost ticket sales.
- The urinal is expected to have issues with the smell of urine, given how small the space is. Furthermore it is likelt that urine will still end up on the floor. Boeings dry floor concept is an ideal partner to this design.
- Technology plays a role in improving the passive hygiene of the space behavioural controls influence people. A combination of the two is recommended.
- The use of a touchless control interface is preferable; reduced water usage, reduced spread of infection through surface contact and improved psychological hygiene for the individual.
- A touchless flush, faucet and waste flap are predicted to be included in all lavatories on next generation aircraft in the coming years.
- Interactions should be kept to key functionalities used by all passengers for the sake of simplicity and avoiding error.

Process evaluation

- The design is intentionally realised up to a level that is communicable. It is not a full imagining of the product, nor is it by any means ready for production. Significant further analysis and testing is required. This is best achieved by building prototypes.
- The final concept is lacking a comprehensive validation stage. Full scale aircraft mock-ups can be used to test the validity of the concept prototypes with respect to space and user experience. There are two levels to this; movement within the cabin and movement inside the lavatory.
- The passenger movements in the cabin relate to how they choose a lavatory and how long they are willing to wait to use their preferred Z-Lav.
- Movement inside the lavatory relates to how users use the space they are given. This can identify if features must be added.
- The concept development stage took much longer than expected to complete. This is attributed to the validity of ideas with respect to the real aircraft context.
- Finding novel solutions which are also of benefit to the majority of stakeholders and are suitable for aircraft takes time to refine and get to a point where they make sense.
- A simple, stripped back design became the result in part because it was achievable to design a lavatory with the fewer components. The result is valid however, as it considers the needs of each stakeholder and provides benefits for each.

Personal Reflection

Project Conclusion 6.2

This final section serves as a personal reflection from the author about this project

Having reached the end of the project, there are a few points to make about the process and final result. While many aspects went very well, the following are arguments that I believe require attention when assessing the merit of my work.

Process

As it is with all project based work, I could not cover everything within the timeframe of the project. Areas which I would've like to give more attention include:

Research always begets more research. Learning a new piece of information often opens up multiple new avenues to investigate and this process can be endless if you let it be. In hindsight it would have been better to focus as much as possible at the beginning of the project and find a primary goal early on, rather than exploring endlessly.

A substantial effort was required to define the problem, given that there were multiple problems worth solving. In the end I tried to focus on multiple "core" problems. As a result I feel as though I spread myself thin over the topic. At the end of ideation I flirted with a decision to design a floor pan which evacuated liquid waste; lo and behold one month later Boeing revealed this concept at AIX.

The concept development process started off well, but quickly lead to solutions which are not possible or are not necessarily any better. Coming up with creative solutions becomes more difficult the closer one stays to the rules. Being required to stick to what is possible in aircraft limited the creativity of ideas.

However, casting a wide net during research did lead to creative ideas. Public toilets and washrooms are very interesting topic to study and design for and lead to the final solution. I was especially interested in learning about human nature and exploring how different a washroom can be, even though the activities are largely the same.

Refining ideas towards the final design was incredibly challenging. I forced myself to be strict on the dimensions and weight of components and constantly pored over the list of requirements so as not to forget anything, saying them aloud while I worked, like a mantra.

Overcoming complexity

At the beginning of the project it was agreed by all parties involved that this was not an easy task to complete. Aircraft equipment is notoriously difficult to design effectively given the depth of product requirements and fierceness of industry competition.

Furthermore the problem of poor hygiene is one which is universal and some would say is inevitable among humans. What I found is that it is not possible to influence people in a meaningful way without some individual or group having an issue. What works for some does not work for everyone

This is a product which requires a high degree of planned consideration in order to operate safely and effectively. Having spent ample time gaining familiarity with the product and the people who make it, I can comfortably make suggestions on how the product can be improved based on my experience and research.

However, the complexity of subject requires multiple specialists, each with their own focus. As an individual it is easy to drive ideas forward and disallow others based on intuition and personal sensibilities. For example, as a male it was challenging for me to design for females without asking many different women their opinions.

To combat this challenge I spoke to many people throughout the project to get their opinions on issues relating to hygiene, flying and the toilets (I have not been a good dinner guest these past months). I spoke to friends, family, coworkers and strangers to build a picture in my mind of how people think and what they might want. The conclusion of this general analysis is that people are very different and designing one product for such intimate use is never going to satisfy everyones desires

Result

The product that I designed satisfies the aims and requirements of my own research and analysis. This means that it is valid with respect to the information covered in this report. In relation to the real world context there are many more aspects to consider, for example fire safety and cost benefit for airlines.

Several elements were left out of the final design. For example Zodiac were interested in reducing the impact of foul odours and creating a paperless toilet. These elements are alluded but not quite solved. Solutions were found but not integrated due to lack of detailed information. Again this relates to the wide scope of the project.

This design certainly has its drawbacks when compared to current systems. I believe that the core of the concept is valid and with further development this solution can become more favourable.

I believe that this new concept can work with the right amount of cooperation from airlines and passengers. There are plenty of benefits for both sides and the future of air travel depends on positive change, not reusing the same products that have always been on board.

Fig.XX

To finish with, heres a photo of me mucking about in a lavatory.

Slán go fóil
agus lean ag féachaint
ar an spéir

My opinion

I have learned that an aircraft lavatory is an incredibly well designed product that satisfies virtually all of its requirements. People are in fact the problem here. Trying to design more detail into the monument is the challenge the industry faces, but the solution should relate more to changing society and how people behave.

Behaviour in public restrooms is bad, but in airplanes it is simply unusual. From my experience it is anti-social and selfish - low interpersonal interactions and focus on personal comfort. In order for this to change there needs to be less anxiety towards flying. This can be achieved by introduced new activities to do on the plane or by making vast improvements to comfort in all classes.

Given the ecological damage flying does, the rise of budget air travel needs to be regulated better. Flying is so cheap that many now take it for granted. This includes being outraged by an untidy lavatory when it is simply inevitable in a cramped space. While there is an aspect of health concern involved, many of the problems people have seem to relate to a deviation from their preference.

Lavatories will continue to improve as they've recently gained a spotlight focus in the industry. Unfortunately I cannot say whether my solution is better than what is currently in the air, but I believe there is great value in re-imagining the scenario and creating new products to solve present day problems as they arise.

Final word

This is the end of this thesis report. Throughout the process there were highs and lows, but always curiousity and learning. I managed to learn a significant amount about the design of aircraft cabins as well as about human behaviour during this project and

Thank you for reading the report, I hope it has provided you with the information or inspiration that you were looking for.

David Randles.

Delft,
July 2018

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Project Conclusion 6.2

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