03.07.2020

GRADUATION REPORT

HANGAR OF THE FUTURE

Concept development using VR as an alternative prototyping tool

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EXECUTIVE SUMMARY

The global aircraft fleet was predicted to grow by approximately 40% between 2017 and 2027 by Oliver Wyman (2017). This fast-growing fleet needs to be supported by equally developing Maintenance, Repair, and Overhaul (MRO) divisions of airlines. In light of the growing need for more efficient and technologically advanced aircraft maintenance, this project called the Hangar of the Future was initiated.

The Engineering and Maintenance (E&M) division of KLM Royal Dutch Airlines is one of the largest MRO service providers in the airline industry. KLM's Hangar 12 at Schiphol carries out A-checks for its entire Boeing 737 and 787 fleet. These are the airplanes that are the most promising for future use and KLM is acquiring more of them every year. For this reason, Hangar 12 has an increasing responsibility for sustaining the company. For the development of the hangar, KLM has several priorities that were initiators of the project:

• New technology is required to continue to be competitive and to maximize the efficiency of maintenance.

• KLM believes in retaining a sustainable workforce for which ergonomics i.e. providing a pleasant and healthy working environment play a huge role.

• Sustainability is a strategic pillar for the company and is hardwired into KLM's future mission (The attention to this topic was minimized going forward in the project due to several reasons).

While considering these factors, the project was tackled with a fairly methodological approach. It was guided by the overarching Double Diamond structure of industrial design. The scheduling of the project was done in line with the four phases: Discover, Define, Develop, and Deliver. Clear goals were set for all the phases before starting them and within each phase, one or more design/research methods were used to achieve these goals.

In the Discover phase, research was carried out about the working of the hangar, the employees, their problems, and requirements. A broad understanding was gained and documented in this starting phase.

In the Define phase, the research was analyzed and converted into usable data. The problem statements that would be the most beneficial to address were identified. This phase was crucial in guiding the focus of the project.

The Develop phase was the one that resulted in the highest quantity of innovative ideas due to the brainstorming activities incorporated in this phase. It was intended to go broad again, explore ideas, research on the possibilities, and come up with multiple directions that address the problem statements.

Lastly, the Define phase was the one where it all came together. The ideas were filtered, concepts were given shape, and validation was carried out. Virtual prototyping and concept animation was done for presenting the concepts.

The project resulted in a family of three concepts that fit the hangar: a collaborative inspection robot for full ground and drone inspection, an Automated Guided Vehicle (AGV) for moving materials and tools, and a dashboard that updates the teams with realtime information at the hangar workfloor. These three concepts address the top priorities of the stakeholders and are backed by well-grounded research.

ACKNOWLEDGEMENTS

I would like to acknowledge the following people without whom the project would have been a very different journey:

Jan Willem Hoftijzer, for providing outstanding support throughout the project and for his critical remarks which were key to the quality of my work.

Mark Sypesteyn, for being my mentor and always pointing out details that I might have missed at every step on the way.

Timo Pauel, for giving me everything (and more) that is expected from a colleague, supervisor, mentor, friend, and for being a constant source of inspiration.

Anouk Akkermans, for giving me the opportunity to carry out this project and for her enthusiasm at every milestone.

Jens van Houwelingen, for acquainting me with the company and his passion for airplanes, and for accompanying me on the commute with interesting discussions.

Tom Kooreman, John Telleman, Mark Kuilder, Hylke Visser, Joris Hampsink, for making me feel like a part of the team, answering all my questions, and making me feel at home.

Marius Sypesteyn and Team 3 & 4, for being ever so enthusiastic, letting me accompany their shift, and for participating in my research whole-heartedly.

Hangar 12 and Hangar 11 (planning team, plant support, and other employees), for giving me a warm welcome and letting me conduct interviews right away that were a large part of my initial research.

Arno Freeke (VRZone) and José Manuel Rodriguez Diaz, for helping me set-up VR and answering my questions whenever needed.

The KLM VR Team, for showing me around and giving me a solid direction related to their expertise.

My parents and family, for always being available to discuss anything related to the project, the difficult situation of the world during the time of the project, and for being there.

Thomas Abraham and Krishna Jani, for always being there to support me whenever it was required.

A memorable picture with the Plant X team at Hangar 12.

LIST OF ABBREVIATIONS

AFI	Air France Industries
AGV	Automatic Guided Vehicle
AI	Artificial Intelligence
AOG	Aircraft on Ground
AR	Augmented Reality
CIL	Continuous Improvement Lead
Cobot	Collaborative Robot
CS	Component Services
E&M	Engineering and Maintenance
FBX	Filmbox - 3D filetype
GWK	Grondwerktuigkundige - Ground Engineer
H10/11/12/14	KLM Schiphol Hangar 10/11/12/14
IC	Inspection Cobot
IS	Information Services
MRO	Maintenance, Repair, and Overhaul
MVI	Manual Visual Inspection
PTZ	Pan Tilt Zoom (Camera)
TRL	Technology Readiness Level
VR	Virtual Reality

LIST OF ABBREVIATIONS

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KLM
E6
27-09
A13
N2
E22

INTRODUCTION

company, project & more

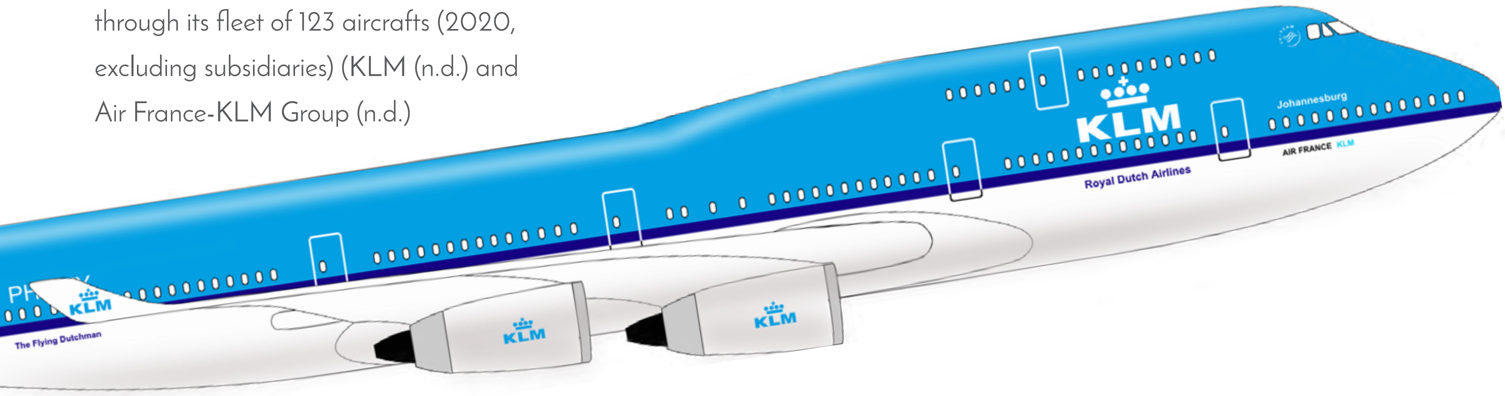
It was predicted by Oliver Wyman (2017) that the global aircraft fleet will grow by approximately 40% between 2017 and 2027. The current economic crisis in the aviation sector due to Covid-19 will have an impact on this percentage but it is conceivable to assume that the long term growth trend will resume once the crisis subdues. This fast-growing fleet needs to be supported by equally developing Maintenance, Repair, and Overhaul (MRO) divisions of airlines. To adequately serve the rising demand, a high value needs to be placed on increasing the efficiency of maintenance and repairs. The Engineering and Maintenance (E&M) division of KLM Royal Dutch Airlines is one of the largest MRO service providers in the airline industry. Together with Air France Industries (AFI), KLM E&M provides maintenance and repair solutions consisting of line maintenance, base maintenance, engine services, and component services to over 200 customer airlines to maintain airworthy fleets. The KLM hangars at Schiphol perform scheduled letter checks (A-check and C-check described in Section 1.2) and occasional unscheduled repair for aircrafts. Three hangars at Schiphol-East as well as the plant operations at Schiphol base serve to maintain KLM's entire fleet regarding airframe maintenance and repair operations. Besides the KLM fleet, KLM E&M also partakes in maintenance and repair contracts to service other airlines and they visit the hangars as well.

In light of the growing need for more efficient aircraft maintenance, the project to adapt one of the hangars to suit the future requirements of the company is initiated. KLM is in favor of sustainable growth, increasing the quality of its services, and staying atop the field of the aviation industry players. New technology is required to continue to be competitive and for maximizing the efficiency of maintenance while environmental sustainability is an important factor because it is a strategic pillar for the company. KLM also wants to ensure that there is a balance between the company's interests and those of its employees. For the hangar, this means considering ergonomics for its workers and providing a pleasant working environment. This requirement is derived from KLM's inclination for sustainable employment and issues with its aging workforce. Incorporating these factors, the project is carried out with an aim to arrive at an encompassing vision of the future hangar along with its virtual prototype.

1.1 Company Profile - KLM

Established in 1919, KLM Royal Dutch Airlines is the national flag carrier airline of the Netherlands. It is headquartered in Amstelveen which is very close to its hub at Amsterdam Airport Schiphol, from where the carrier operates freight services and all service operations.. KLM operates an extensive network which includes services within Europe and to Asia, Africa, North America, Central and South America and the Middle East. KLM recently celebrated its 100th anniversary and is known as the oldest airline operating under its original name. More than 35,000 employees help the company offer cargo and passenger services to more than 145 destinations worldwide. This is made possible through its fleet of 123 aircrafts (2020, excluding subsidiaries) (KLM (n.d.) and Air France-KLM Group (n.d.)

*"**KLM** was established on 7 October 1919, making it the world's oldest airline still operating under its original name. Operating out of its home base in Amsterdam, the **KLM** Group served its global network with a fleet of 123 aircrafts, employing more than 35,000 people. In 2017, the **KLM** Group generated 10 billion euros in revenue." (KLM, n.d.)*



MISSION

Together with Air France (partner since 2003), KLM is at the forefront of the European aviation industry. Offering reliability and a healthy dose of Dutch pragmatism, the 32,000 KLM employees (now more than 35,000) work to provide customers with innovative products, and to maintain a safe, efficient, and service-oriented operation with a proactive focus on sustainability. KLM strives for profitable growth that contributes both to its own corporate objectives and to greater economic and social development (KLM, 2015.)

VISION

KLM wants to lead the industry by outsmarting its competition. By merging with Air France, KLM has come to occupy a leading role in the global aviation industry. KLM desires to be the customers' first choice, to be an attractive employer for its staff, and to be a profitably growing business for its shareholders (KLM, 2015).

"Over the past hundred years, KLM's entrepreneurial spirit and quest for innovation have played a pioneering role in the aviation industry. Our centenary is an opportunity to reaffirm our commitment to our ambition: to become the most customer-centric, innovative, and efficient European network carrier with a deep-rooted determination to address the challenges that lie ahead..."

- KLM President & CEO, Pieter Elbers (2019)

1.2 Engineering & Maintenance

KLM's Engineering & Maintenance is the technical division (MRO) which ensures the smooth operation of aircrafts that customers entrust to them. KLM E&M has more than 5000 employees serving customer airlines around the world. Among these, KLM Royal Dutch Airlines is the prime customer. E&M offers comprehensive technical support ranging from engineering and line maintenance to engine overhaul as well as management, supply, and repair of components. This is carried out by E&M's three units:

AIRFRAME

Airframe provides MRO services to aircrafts in their entirety.

- **Base maintenance:** Heavy, scheduled maintenance executed in the hangars.
  - ***Hangar 11:*** A-check for Boeing 747, 777, Airbus A320
  - ***Hangar 12:*** A-check for Boeing 737, 787
  - ***Hangar 14:*** All C-checks
- **Line Maintenance:** Minor scheduled and unscheduled maintenance and cleaning at the gates between turnaround for another flight.
  - ***Line Maintenance Schiphol***
  - ***Line Maintenance International***

ENGINE SERVICES

Performs maintenance on both KLM and third-party engines. In addition to engines, repairs are also carried out on engine and aircraft parts and accessories. (MyKLM, Internal documentation, 2017)

COMPONENT SERVICES

Ensures the availability of serviceable components for KLM and third parties in accordance with agreements made regarding time, place, quality, quantity, and costs. (MyKLM, Internal documentation, 2019)

TYPES OF AIRCRAFT CHECKS

A-check

Inspection, repairs, maintenance and cleaning of aircrafts to keep the fleet airworthy.

• Every 400-600 flight hours or every 200-300 flights (depending on aircraft type). Approximately once every 8-10 weeks.

• 50-60 man-hours long. Usually 17 (summer)-24 (winter) total hours at KLM.

C-check

Much more extensive than A-check with majority of aircraft components inspected after complete overhaul.

• Every 20-24 months

• 6000 man-hours long. 2-3 weeks long

1.3 Hangar 12

Hangars are buildings where the majority of extensive aircraft maintenance takes place. Among the hangars at Schiphol Airport, KLM performs all its passenger and cargo fleet maintenance at Hangar 11, 12, and 14. Hangar 12 currently performs A-checks for KLM's 52 Boeing 737s and 18 787s and other customers.

Glimpse of history

Kok (2015) found that Hangar 12 was built in 1979 as an extension to Hangar 11 to facilitate C-checks of 747s. Other hangars were too small or busy to accommodate this new aircraft. In that year, KLM's fleet had 13 747s. The shape of the hangar floor was derived from the space required to accommodate 2 747s at the same time. Taking into account the growing fleet and developments in intercontinental flights, KLM decided to convert Hangar 12 to use for A-checks and moved all C-checks to Hangar 14. The A-checks of 747 are now done in Hangar 11.

WORK DIVISION

Teams

Hangar 12 consists of 8 teams of approximately 18 mechanics/engineers each. These teams work in shifts of 8 hours and usually have 5 shifts per week. These shifts could be day, evening, or night. The shifts can change every week for the teams and the planning team makes sure that the distribution is fair. The levels of these mechanics/engineers vary from Level-0 (can only assist) to Level-3 (GWK, can act as support staff and sign-off tasks).

Team leads (Lead GWK)

Each team is led by 2 team leads. They are present throughout their team's shift and are responsible for handover from previous shift team leads and to the next shift team leads. Team leads know their teams' capabilities well and assign tasks to team members. They serve as a point of contact for any questions or issues. They also communicate with Materials and Logistics Center, Support team, and Operations Control Center whenever necessary.

Planning and Support

The Planning team is responsible for the scheduling of airplanes for A-checks and further scheduling tasks within the A-checks. The Support team provides direct support to the team leads, engineers, and mechanics. This could be in maintaining the long-term integrity of the teams and also addressing individual questions or requests. The Support team includes positions like the Plant Leader, Plant Support Officer, and Culture Lead.

1.4 Plant X

Plant X is a team of engineers, designers, and innovators formed to bring forth innovation within Airframe to improve its functioning and to make it future-ready. The engineers who are a part of Plant X, referred to as X-builders, still work shifts at their original jobs in Hangars 11, 12, 14, and Line Maintenance half of their time. Every second week, they work at the Plant X office on various projects that may be experimental, hands-on, or strategic in nature. Their experience as aircraft engineers helps them contribute deep insights into these X projects. Other members of Plant X bring knowledge and expertise from other fields onto the table. They bring design methodologies, tools for promoting innovation, team-building, CAD & 3D printing, among many other skills that are valuable for the team.

VISION

Plant X is the explorative 'innovation lab' unit for Airframe. Together with suppliers, universities and startups, we aim to explore, test & validate the future value propositions of the Airframe department and the 'hangar of the future'. (Pauel, 2019)

MISSION

- ***Focus on 'the day of tomorrow', and 'the day after tomorrow'***
- ***Airframe: explore future value propositions***
- ***H12: Deliver tangible innovations that build towards a hangar of the future***

(Pauel, 2019)

1.5 Hangar of the Future

1.5.1 ASSIGNMENT

To develop a concept of the 'Hangar of the Future' in virtual reality. Research will be carried out on technological trends, user needs, sustainability requirements, and the future of aviation and the results will be combined into an encompassing vision.

1.5.2 THE DRIVERS

There are multiple drivers (or driving factors) that are considered while exploring solutions for the found problem statements: Technology, Ergonomics, and Sustainability. There is interconnectivity between these drivers and a solution that is primarily related to one of them can in-principal enhance the other two. The project was carried out in a way that these drivers are benefited in a balanced manner and comparable attention is paid to each of them. An increase in fleet availability can be deemed as the ultimate goal resulting from addressing the drivers.

Technology
The grade of technology used (tools, equipment, infrastructure) in carrying out the tasks of an A-check.

Ergonomics
The comfort and effectiveness of the working environment for mechanics and engineers.

Sustainability
The use of resources and materials in the hangar in a responsible manner in light of the future.

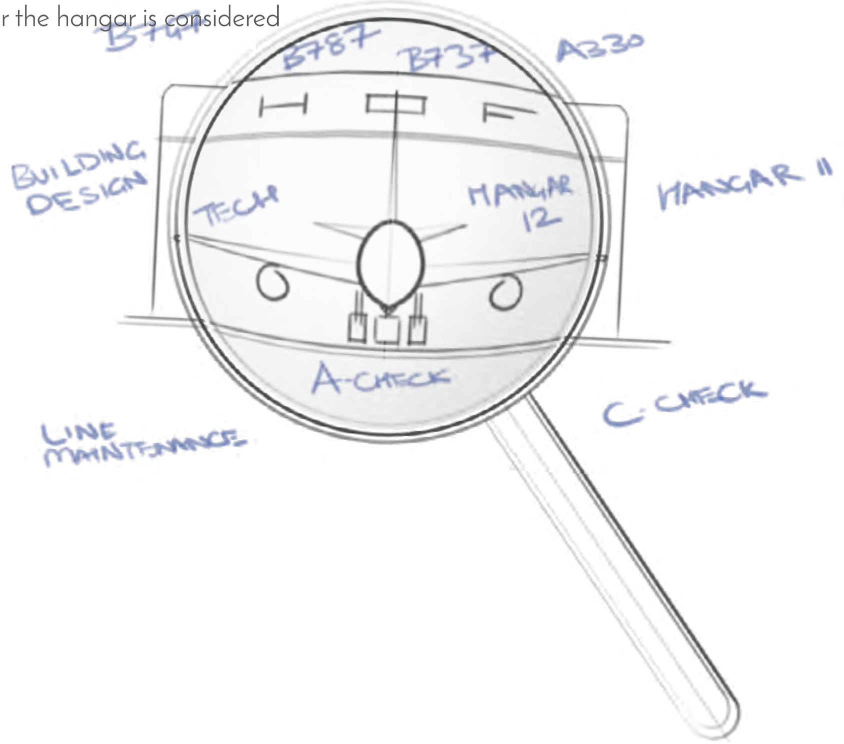
Resultant fleet availability
Improvements in the above drivers helps ultimately contribute to more efficient A-checks which can help KLM maintain a higher fleet availability.

1.5.3 SCOPE

Defining a concrete scope for this project is crucial to its execution in a limited span of time. The scope is limited to changes in the interior of the hangar and changes in the equipment or technology used for various tasks. The exterior of the hangar and the hangar building is a predefined starting point for the project. From all the KLM hangars in Schiphol, this project will exclusively be focused on Hangar 12. However, recommendations of how the proposed changes can be implemented in the adjoining Hangar 11 will be made.

Moreover, there exist different kinds of airplane checks which are carried out in KLM hangars. Hangar 12 focuses on A-checks which take place every 8-9 weeks for each airplane. An A-check takes 17-24 hours for completion. Reduction of this total time of an A-check as a result of the proposed redesign lies within the scope of this project. Other types of checks (C and P) are excluded from the direct scope. However, as some activities of the other checks overlap with those of A-check, suitable recommendations will be made in the project report addressing this topic.

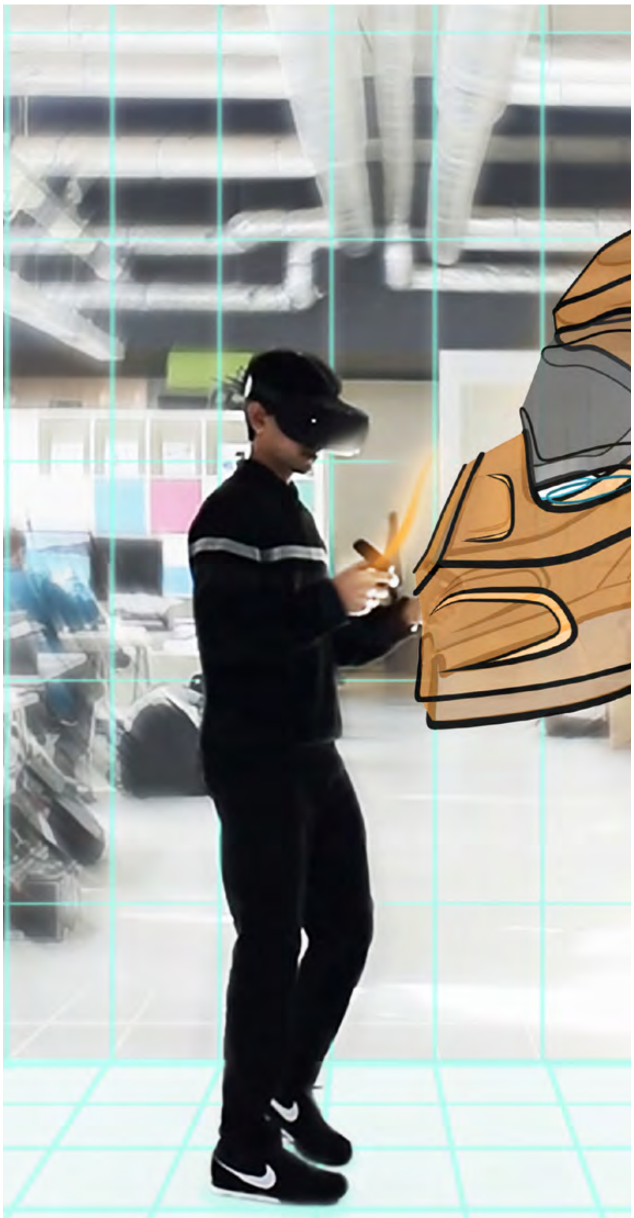
An important point to note is that this project will explore existing technology from other industries which can benefit the hangar and help increase the fleet availability. Developing technology from scratch specifically for the hangar is considered out of scope.



1.5.4 INVOLVING VIRTUAL REALITY

VR is currently developed to a stage where it is immersive enough to give you an excellent idea of the virtual space you are present in. It can serve as a cost-effective and efficient method of prototyping products, large spaces, or systems.

In the case of the hangar of the future, having such a virtual prototype will have numerous applications and benefits. The following is a list of reasons why VR is a fitting tool for the project:



Conceptual level
The aim of the project is to arrive at a conceptual design of the hangar. VR helps demonstrate a concept as close to reality as possible which is useful for presenting it to other stakeholders.

Increasing acceptance
An immediate concern that the Discover phase arrives at is that in general the use of modern tools is not readily accepted by (veteran) engineers. To cross this barrier for change, a visual and immersive experience of the future hangar could help increase acceptance.

Prototyping environment
This project will give form to a virtual environment that can be used in the future for prototyping changes before they are invested in or executed in the real hangar.

Demonstrating systems and interactions
In a system where umpteen activities are taking place at the same time, it can be intricate to communicate a future vision on paper or using animations. Giving the design a form where one can observe various systems functioning and interact with objects (if it works out within the timeframe) will clarify the ideas well.

1.6 Project Planning

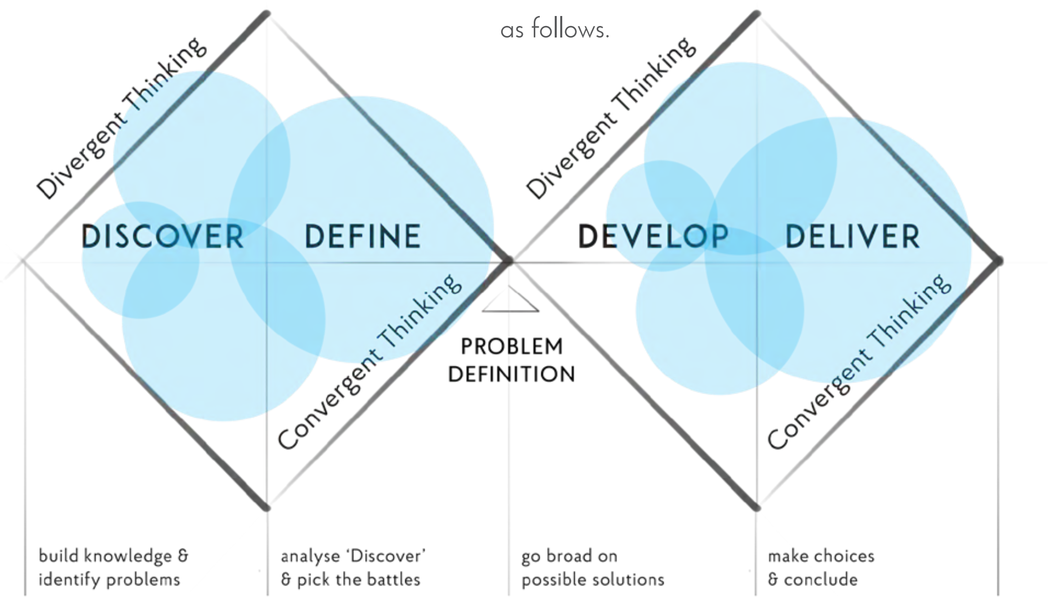
The planning for the 20-week long graduation project was well-addressed since the beginning as the 100 working days could be quite limited for such a broad project. The project was broken down into smaller phases (Double Diamond) which were further laid out using the design methodologies to be implemented and the variety of tasks that need to be carried out in each phase. Tentative week numbers for meetings were scheduled prior to the start of the project which helped define deadlines for deliverables.

1.6.1 THE DOUBLE DIAMOND

The project was divided into four main phases: Discover, Define, Develop, and Deliver, taken from the Double Diamond model by Design Council (2005).

Why the double diamond?

This well known method was chosen to help structure the project effectively in a short duration. It would keep the project sufficiently open-ended in the research and exploratory parts while making sure that timely decisions are made and solutions are reached at the end of the converging phases. The conceptual nature of the project required this openness and the possibility of using various design methods and tools. The framework of the double diamond would work as an umbrella under which smaller activities would fit in. Each phase of the method is briefly elaborated as follows.



PHASES OF THE DOUBLE DIAMOND IN OUR CONTEXT

1. DISCOVER

Build knowledge and identify problems

The design brief is elaborated. Research methods are selected/added. Information about the problems to be solved is gathered using these research methods and observations in the field. Boundaries are kept open and an exploratory mindset is maintained throughout this phase.

2. DEFINE

Analyze 'Discover' and pick the battles

The output and remaining raw from the previous phase is synthesized to reach the root. Out of many, the important problems are identified and the brief is distilled to its core. A clear solution space is defined. This phase is carried out with a converging mindset.

3. DEVELOP

Go broad on possible solutions

Given the solution space, it is time to go broad again to explore the possible creative and innovative solutions. Technology research is carried out to find relevant adaptable solutions. Ideation and brainstorming is done using fundamental (sketching) and advanced (VR) tools. Preparation for the next phase of VR prototyping is also done simultaneously.

4. DELIVER

Make choices and conclude

Final choices are made regarding the concept. The VR prototype is developed. A guiding document is written which informs about the usage of the VR prototype, its capabilities, and future application.

DISCOVER

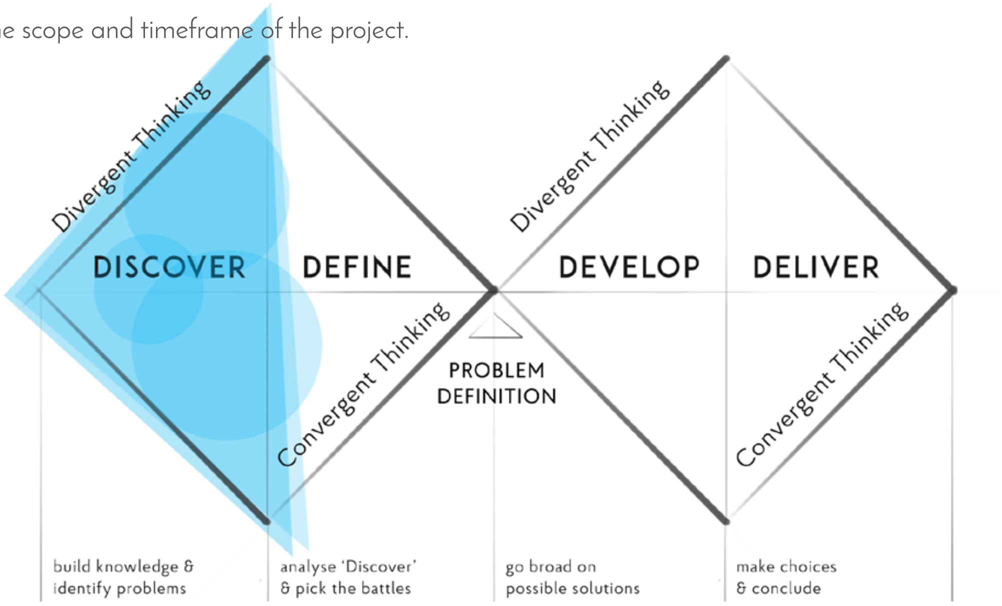
build knowledge & identify problems

2.1 Introduction

The very first phase of the double diamond is meant to collect data, experience the context, and discover problems. In this phase, the context is looked at using a broad lens and research is carried out to build knowledge that will be used throughout the project.

It was important for me to give this phase enough time (5 weeks) as the hangar and the airlines industry was a brand new situation for me. I met several people working at KLM to understand the structure of the organization and functioning of the hangar. At the same time, I asked them questions that pointed me in the direction of possible problems and areas that need improvement. This was supported by my own observations of activities going on in the hangar, an analysis of the process tree, and also analyses of trends and competitors in the market.

The learnings from all of these explorations are brought together in the conclusion which defines the problems identified in relevance to technology, ergonomics, efficiency, and sustainability. These identified problems are then taken forward to the next phase to frame them within the scope and timeframe of the project.



2.2 Goals of the phase

• Build general and specific knowledge about the working of the hangar.

*• Meet relevant stakeholders (within **KLM**) who might be useful to know in later parts of the project.*

• Identify problems with the working of the hangar and issues that employees face.

2.3 Collection and Analysis

"Fantastic solutions to non-problems are no solutions at all"

This section summarizes what (and how) knowledge was collected for setting the ground for the project. Collecting and analysing information is important to reach conclusions that lead to identification of the correct problems. In the Discover phase, this was done using a rather methodical approach. The incoming information was analyzed individually for each method. This was followed by the conclusions that reflect these analyses in a collective way.

2.3.1 CONVERSATIONAL INTERVIEWS

Conversational Interviews have been the most efficient technique to collect information related to KLM and E&M in general and Hangar 12 in particular. I adapted the formal interviewing technique with an informal conversational setting to make it easy for people to open up with me in the first contact. Therefore, I call this sectional conversational interviews. I started conducting interviews early on to break down the complexity of the organization and start the flow of information from all sources. Interviewing also gave me the opportunity to get to know people within and outside Hangar 12 in my first few weeks who could later help me in various aspects of the project. According to van Boeijen et al. (2014), 10-15 interviews will reveal about 80% of the needs. The 15+ interviews I conducted indeed revealed reasons that prevent the hangar from operating at its full capability. This points to the needs and problems of the engineers and other employees who work on the A-check. The summaries of these interviews is laid out in Appendix A.

"People have become more independent. They used to take instructions from a man in a suit. They don't need that anymore."

"The dashboard is not updated regularly enough...problems are found very late"

"The schedules are printed every morning, hundreds of sheets. If everyone has the iPad, why print anymore?"

"Quite often we have to take a plane out to put another one in and that costs plenty of time, especially when tug drivers have to come from Schiphol centrum."

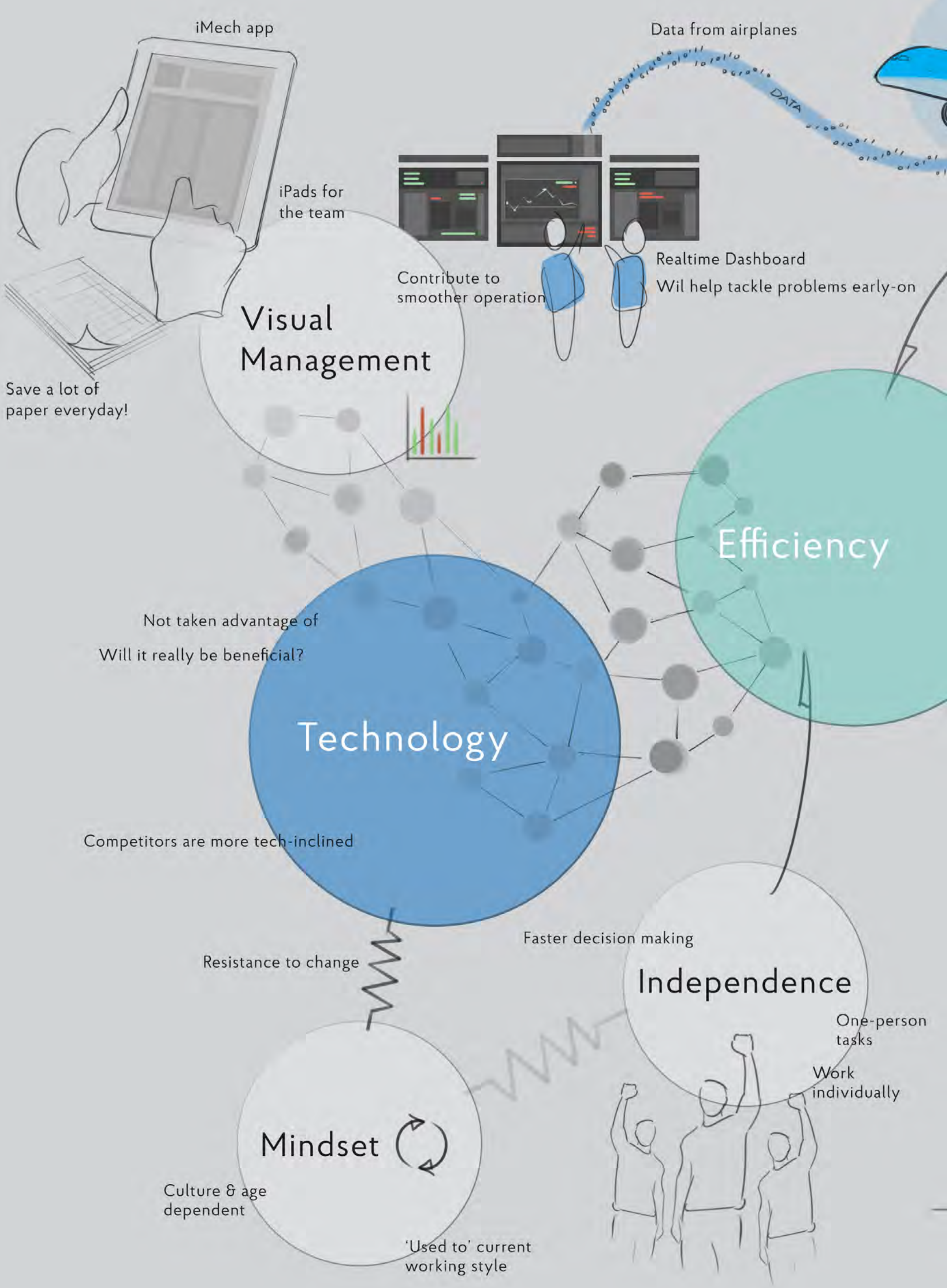
"More than waiting for tools, waiting for materials is an issue."

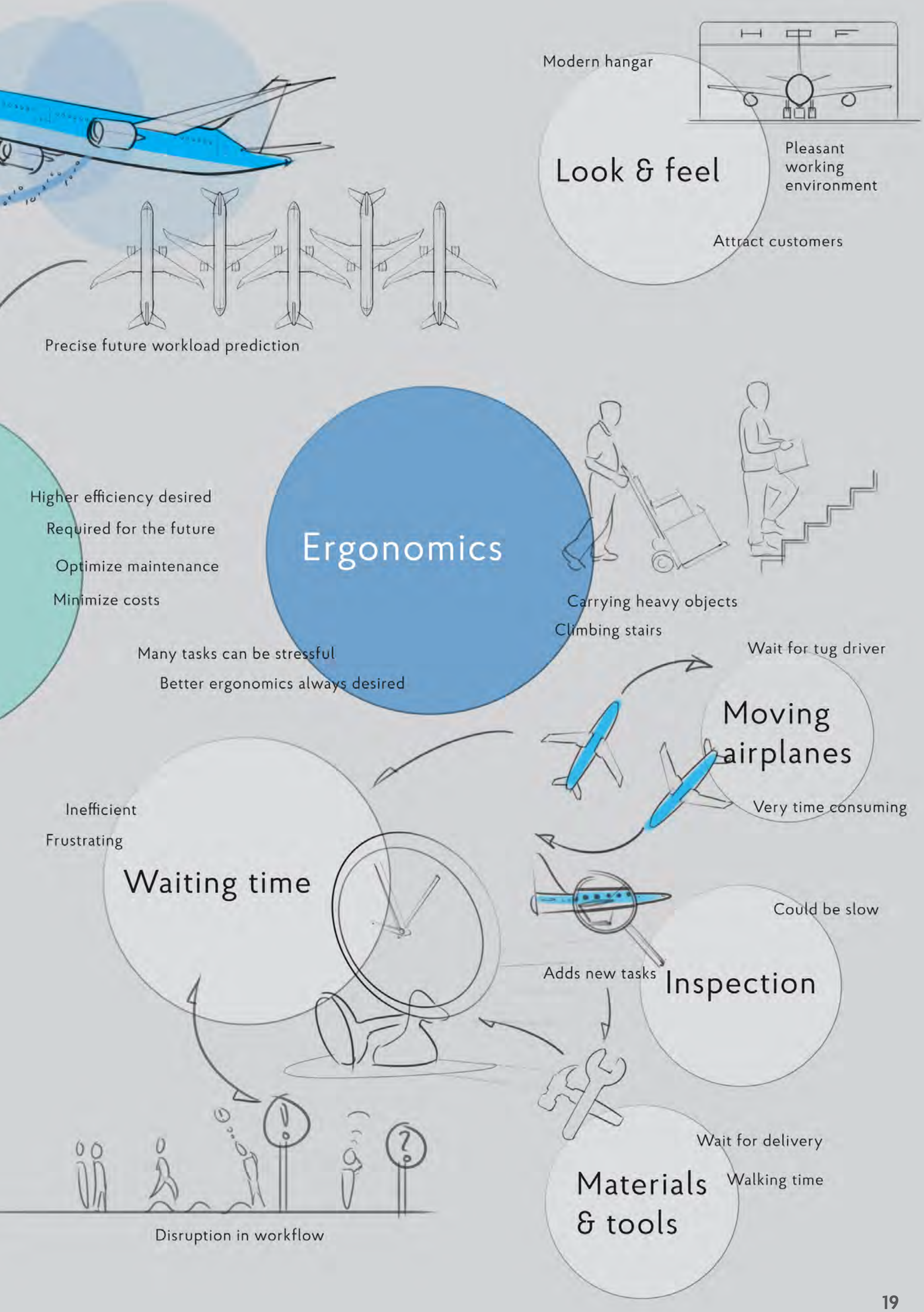
"Tasks are paused when the runners or mechanics are bringing materials from another place."

"Walking up and down the stairs many times every shift for years is not good for the knees."

"...(referring to modern solutions) if it doesn't work as they think it should, they blame IT."

"In the airline industry, convincing people of the new ways can be difficult. If they can see it (referring to VR), they have all the more reason to believe that it would work."


iMech app
Data from airplanes
DATA
iPads for the team
Contribute to smoother operation
Realtime Dashboard
Wil help tackle problems early-on
Visual Management
Save a lot of paper everyday!
Efficiency
Not taken advantage of
Will it really be beneficial?
Technology
Competitors are more tech-inclined
Resistance to change
Faster decision making
Independence
One-person tasks
Work individually
Mindset
Culture & age dependent
'Used to' current working style


Modern hangar
Look & feel
Pleasant working environment
Attract customers
Precise future workload prediction
Higher efficiency desired
Required for the future
Optimize maintenance
Minimize costs
Ergonomics
Carrying heavy objects
Climbing stairs
Many tasks can be stressful
Better ergonomics always desired
Wait for tug driver
Moving airplanes
Very time consuming
Inefficient
Frustrating
Waiting time
Could be slow
Adds new tasks
Inspection
Wait for delivery
Walking time
Materials & tools
Disruption in workflow

2.3.2 CONTEXTUAL OBSERVATIONS

A non-interruptive method of finding information about activities is contextual observations. This gives a perspective to designers about the ongoing activity without too much influence from the doers of the activity. Such observation helped me obtain pure understanding without any disruption due to the biases of those who've been doing the activities for a long time. This outsider's viewpoint was useful in forming insights that might either be too obvious to mention for the daily-doers or too easy to miss due to their tunnel vision.

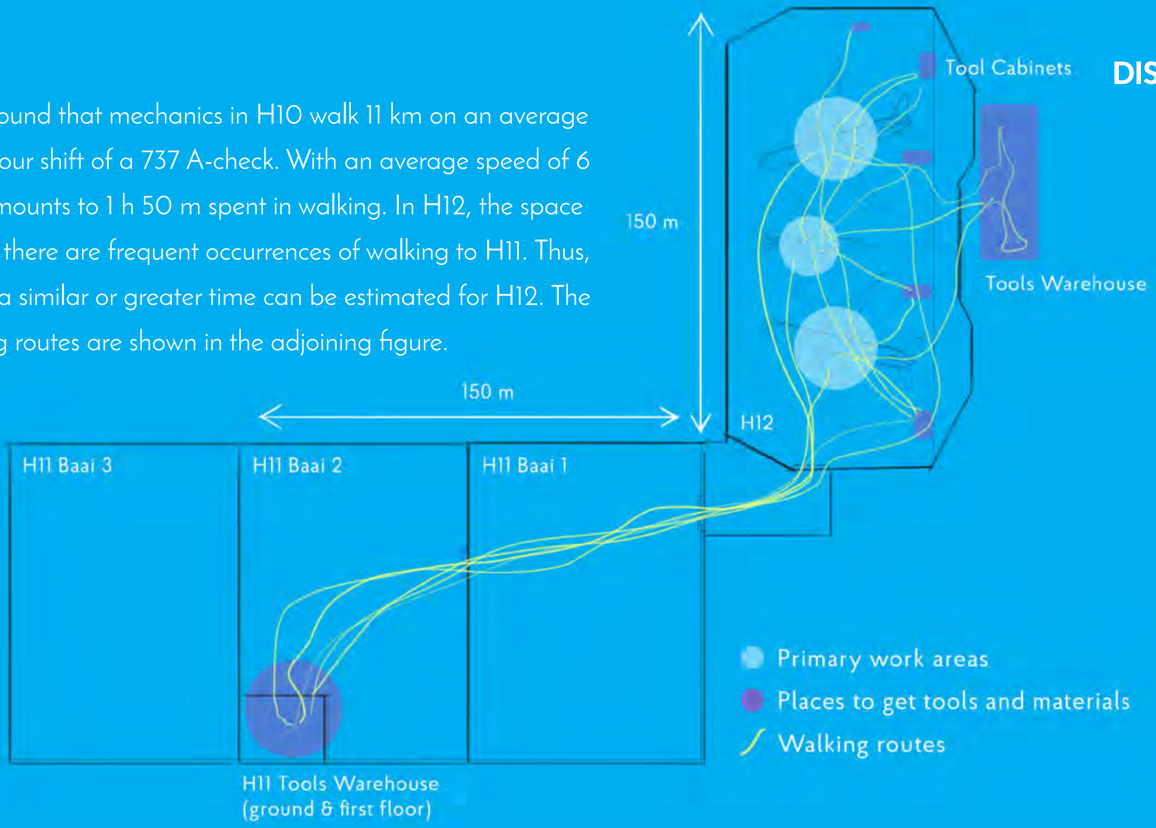
Most of the following observations are ones that might be related to underlying problems within the scope of the project and have a chance of improvement in some manner. The complete table of observations is present in Appendix B.

Idleness around aircrafts: Aircrafts appear to be not being worked on during the day and evening shifts. This was noticed 8 times in my 15 observational walks (approximately) spread over 3 weeks during the morning or afternoon shifts.

Unoccupancy: H12 is capable of accommodating from 5x 737s to 2x 787s with 1x 737 in the middle. Full occupancy was never observed. During the observational walks, usually 1 or 2 aircrafts were inside.

Lighting: Areas under the wings and fuselage are too dark, especially after sunset. Use of a torch is often required for working on those parts. This is because all lights are on the ceiling which is 35 meters high.

Kok (2015) found that mechanics in H10 walk 11 km on an average during a 9-hour shift of a 737 A-check. With an average speed of 6 km/h, this amounts to 1 h 50 m spent in walking. In H12, the space is larger and there are frequent occurrences of walking to H11. Thus, more or less a similar or greater time can be estimated for H12. The usual walking routes are shown in the adjoining figure.



Plenty of walking: It is very apparent that a big part of the jobs of mechanics/ engineers involve walking throughout their shifts (also confirmed by Kok, 2015).

Materials warehouse in H11: Mechanics are often on the bike to go to the materials warehouse bringing back both small and medium sized material in their bike baskets. Some prefer to do the same by walking.

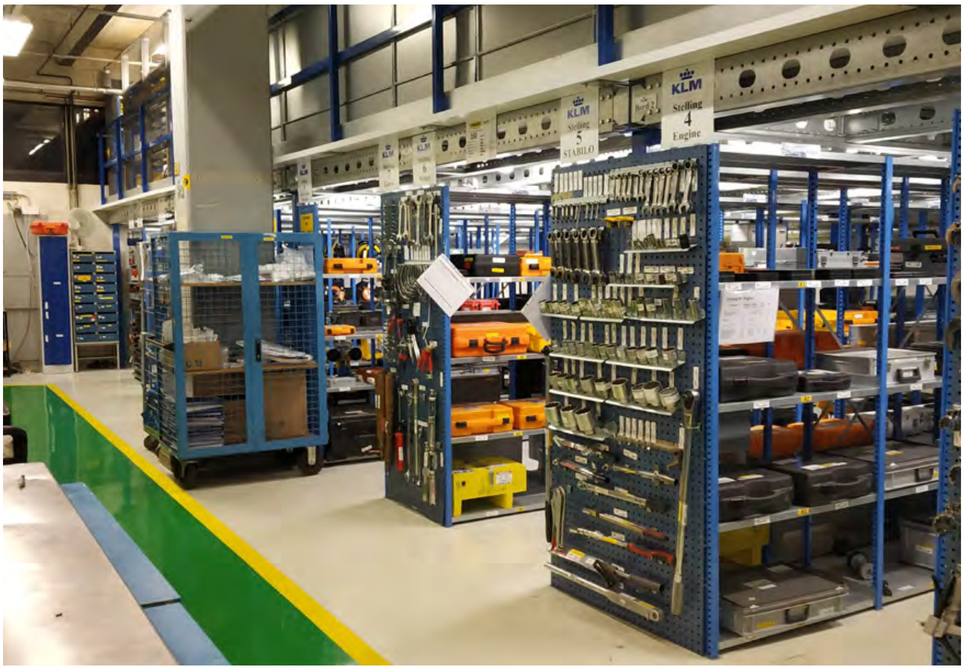
Distant tool cabinets: Tool cabinets are placed close to the end walls of the hangar. These cabinets can be opened using the KLM pass after being assigned tasks for the shift and the borrowed tools are registered in the system.

Lifting: Be it from H11 warehouse to H12 or within H12 during tasks, lifting objects (both light and heavy) is a regular part of the job.

Unused equipment: There is equipment lying around which seems to be gathering dust.

Custom designed equipment: There is much equipment (eg. carts, trolleys, contraptions) which is custom-made in the workshop for certain uses in the hangar.

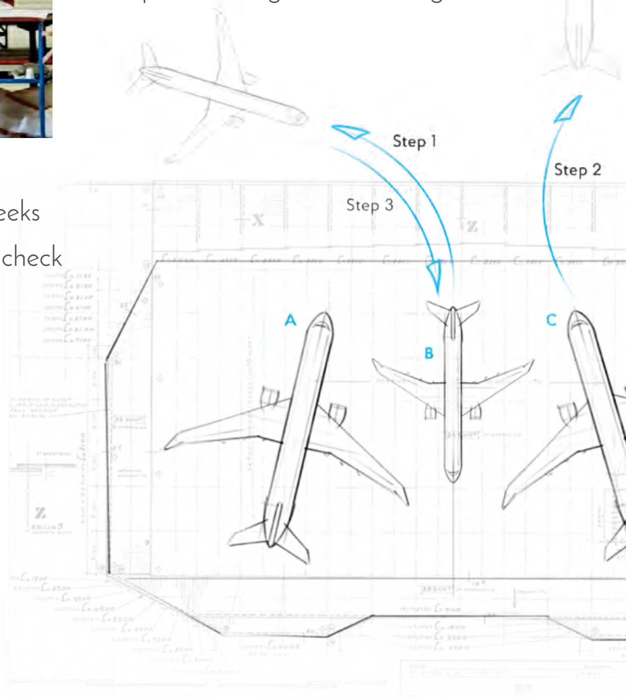
Tools storage room: In H12, there is a room full of tools with a 'librarian' who on request finds particular tools that engineers and mechanics need. The number of tools here is in the thousands and it could certainly be a few minutes before they can be issued.



Climbing the stairs: While working in the aircraft cabin, mechanics and engineers go up and down the stairs several times to move tools or materials.

Standing work: Due to the nature of work, much of the 8 hours of the shift are spent working while standing.

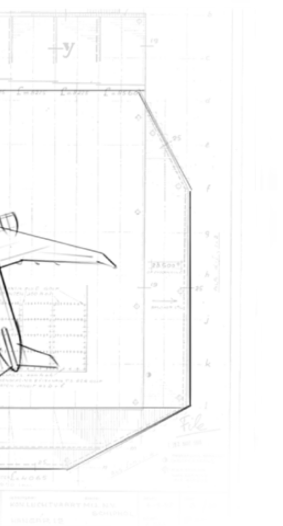
In and out: I noticed 4 times in 2 weeks that a 737 had to be taken out mid-check so a 787 can enter or go out.



Cleaning exteriors: Wiping the exterior of aircrafts with long mops is a common task which appears to be demanding on the shoulders

Looking up: Since the airplanes are tall, during many tasks mechanics and engineers are looking up for a significant amount of time straining their neck muscles.

Task distribution: Task distribution is done using task cards which can be picked up by mechanics from a manual dashboard kept beside an aircraft. The status of this dashboard is usually checked by team leads at the end of every shift.



2.3.3 EXPERIENTIAL RESEARCH

To experience a shift was a crucial activity to undergo for this project as it is equivalent to stepping into the shoes of the most active users of the hangar. The teams of engineers and mechanics work in 3 shifts: Morning, Evening, and Night. As I have been working out of the hangar during the day, I chose to join a night shift with team lead Marius Sypesteyn.

NIGHT SHIFT

This shift lasts for 8 hours starting at 11 pm. In these hours, I had enough time to observe the role of the team leads, tasks being handed over from the previous shift, and the teams of engineers and mechanics carrying them out. Since this particular night was less busy than usual, I was able to freely have discussions with the teams and join them in the break(s). Relevant conclusions derived from this experience, observations, and interviews are stated in this section. My detailed experience is elaborated in Appendix C along with all the conclusions. Selected conclusions are stated in this section.

Shift preference: Most engineers have a preference for the evening shift followed by the morning and night shifts. Morning shift requires them to wake up too early whereas the night shift requires them to stay awake all night. Moreover, almost every week there is a change in shifts which disrupts their sleep cycles.

The night shift of 5 March 2020 at H12

Waiting times between tasks is where efficiency is lost. Waiting for tools delivery or material collection is the most common source of waiting. It occurs quite regularly and especially for unscheduled maintenance (non-procedural). This is frustrating for engineers and mechanics as they have no control over it and also no possibility to accurately predict how much they will have to wait.

Frustrations with walking: The number of times engineers and mechanics have to walk long or short distances is found frustrating by them. When they are focused and working on a task and have to plug out of it to find tools or materials, combined with waiting, it is common that they feel annoyed. The location placement of tool cabinets in the corners, warehouse in H11 (shown above), and tool storage room (shown right) in H12 can be identified as a few reasons for this.

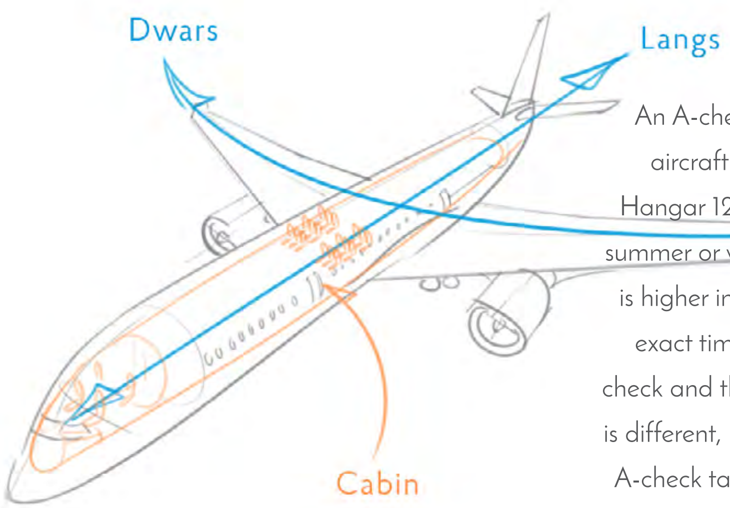
Stressful tasks: When talking about which tasks can be the most stressful, answers pointed out that every aircraft check and every shift is different. Depending on the condition of the particular task-related parts of the aircraft, the task can be easy or difficult. In general, any task can be stressful due to time pressure, logistic issues, difficult/old aircraft, and so on.

Duration of tasks: On an average, most tasks that require one person can be done within 1-2 hours in ideal conditions (tools and materials available). But almost every time the tasks take longer than their designated times.

Working inside: For tasks inside the plane, not all tools can/should be carried at once because of safety requirements (forgetting or losing tools inside is disastrous). Due to this, they have to go up and down the stairs several times during these tasks.

Former experience: A few engineers have had experience working at other hangars in their careers. For them, H12 is not close to the state of the art or even the current state of other hangars. They aren't satisfied particularly with the logistics, material waiting times, and the unsmooth course of tasks.

The shift experience enabled me to confirm some of my personal observations and find overlaps with thoughts of the engineers. Though not all conclusions are relevant or in the scope of this project, they helped form an overall understanding of the way checks are carried out. Moreover, they helped me as a designer to sympathise with the needs of engineers and mechanics.



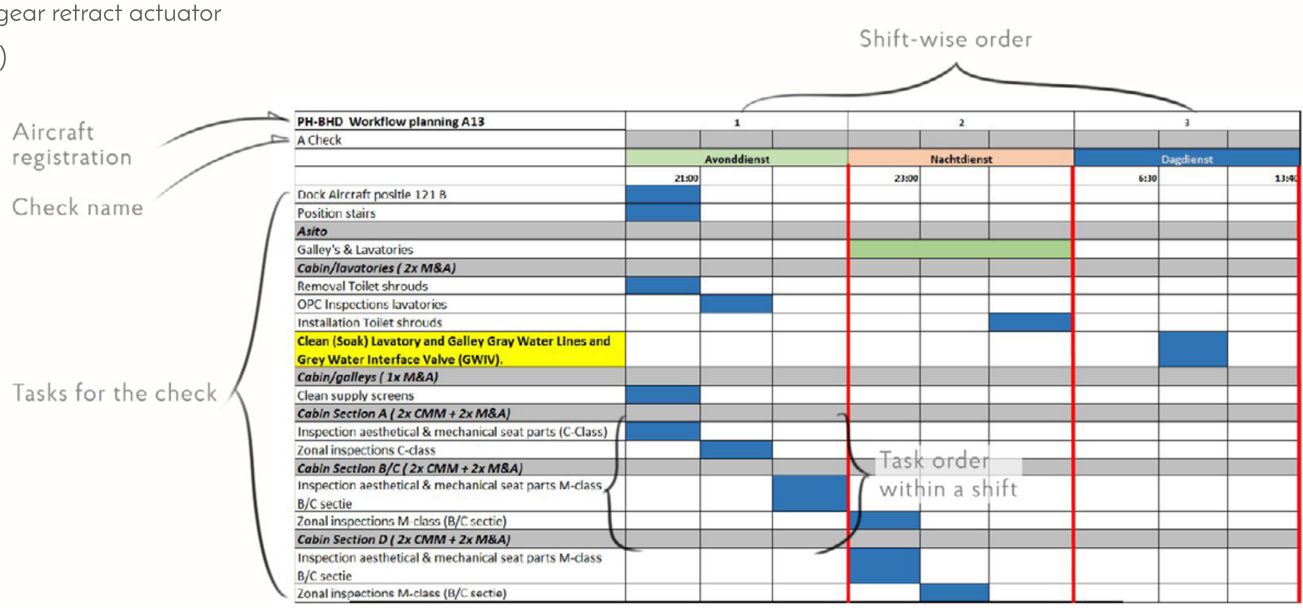
2.3.4 A-CHECK

An A-check consists of detailed inspection, maintenance, and cleaning of an aircraft. It is conducted once every 8-10 weeks for 737 and 787 aircrafts. At Hangar 12, this takes between 17 and 24 hours depending on whether it is the summer or winter. This is because the frequency of flights and fleet requirement is higher in the summer, thus, a faster A-check is necessary and vice versa. The exact time it takes for an A-check also depends on the tasks of the particular check and the amount of non-routine tasks encountered. Though every A-check is different, general tasks from a typical A-check are specified in this section. All A-check tasks are divided into 3 areas of the aircraft: Dwars (along the wings), Langs (along the fuselage), and Cabin (inside the cabin).

Examples of A-check tasks:

- Visual inspection of aircraft exterior for damage, deformation, corrosion, or missing parts
- Check crew oxygen system pressure
- Check operation of emergency lights
- Check parking brake pressure
- Change of air conditioning filters
- Built-in Test Equipment (BITE) test of flap/slat electronics unit
- Lubricate nose gear retract actuator (Hessburg, 2020)

There are several routine tasks in every A-check (such as inspection), some planned tasks for the particular aircraft (such as engine change), and some unplanned non-routine tasks that arise from inspection (such as broken component replacement). Since an aircraft is in for a check usually for more than half a day, the tasks need to be divided over multiple shifts. A sample planning of a 787 A-check is shown in the following work task order (Hampsink, 2019).



Example 737 A-check work task order from Hampsink (2019)

2.3.5 INDUSTRY ANALYSIS

Since MRO is a competitive market and the customers of KLM E&M are not limited to KLM Royal Dutch Airlines, it is important for KLM (and for this project) to stay updated about the activities and innovations of MRO industry and competitors around the world. How this was done is explained in Appendix D.

• **Ryanair's** Prestwick (Scotland) hangar features a shiny white floor (Kowalczyk, 2017). This brightens up the space making it easy to work under aircraft body and wings, to clean, and to find tools after finishing a job. Such a white well-lit interior is also seen in **AirAstana's** newest Kazakhstan hangar (Chui, 2018).

AirAstana, Kazakhstan Hangar (Chui, 2018)

• Zhang (2020) found that the energy efficient hangar of **RSAF** (Republic of Singapore Armed Forces) generates 30% more energy than it uses. This is achieved through the use of solar panels, air ventilation louvres, green insulated rooftop, high volume low speed fans, and fibreglass panelled doors for natural light (images in Appendix D).

• According to Brown (2013), **Teleplatforms** (images in Appendix D) are used by various airlines to facilitate swift travel of an engineer and his tools for maintenance access. They remove any floor area requirement as they are mounted overhead.

• **British Airways** uses electric remote controlled pushback devices called **Mototoks** since August 2017 to move upto 1100 aircrafts per week at Heathrow removing waiting times for tugs or tug drivers (Media Center British Airways, 2019).

A mototok from BritishAirways in action (Media Center British Airways, 2019)

Austrian Airlines testing drone inspection (Aamir, 2019)

• Aamir (2019) wrote about **Austrian Airlines**, a subsidiary of **Lufthansa**, having tested (along with **British Airways**) drones to be used for aircraft inspection. These drones are automated to identify paint and structural damage using patented laser technology and technicians can further inspect using the drone camera and a tablet. They reduce the inspection times to under 2 hours compared with 4-10 hours of a manual inspection.

• **Airbus** (2016) unveiled an innovative concept for the hangar of the future in 2016. This was initiated by the Singapore government and resulted in a vision which aims to use technology to increase operational efficiency of maintenance. Intelligent inspection robots (**Air-Cobots**), preliminary scanning at the hangar door, drone inspection, interactive control room, etc. are prime features of this concept.

A collaborative robot being tested by Airbus (Airbus, 2016)

Engineer at Austrian Airlines testing drone inspection (Aamir, 2019)

• **Airbus** (2014) also has a concept for its 'factory of the future' wherein cobots (collaborative robots) are used to assist workers eg. for drilling holes, digitally printing electric circuits, laser technology for precise assembling, reducing repetitive work, **RFID tags** for monitoring production, automated delivery, etc.

Emirates Engineering's underground technical pits (Haridas, 2012)

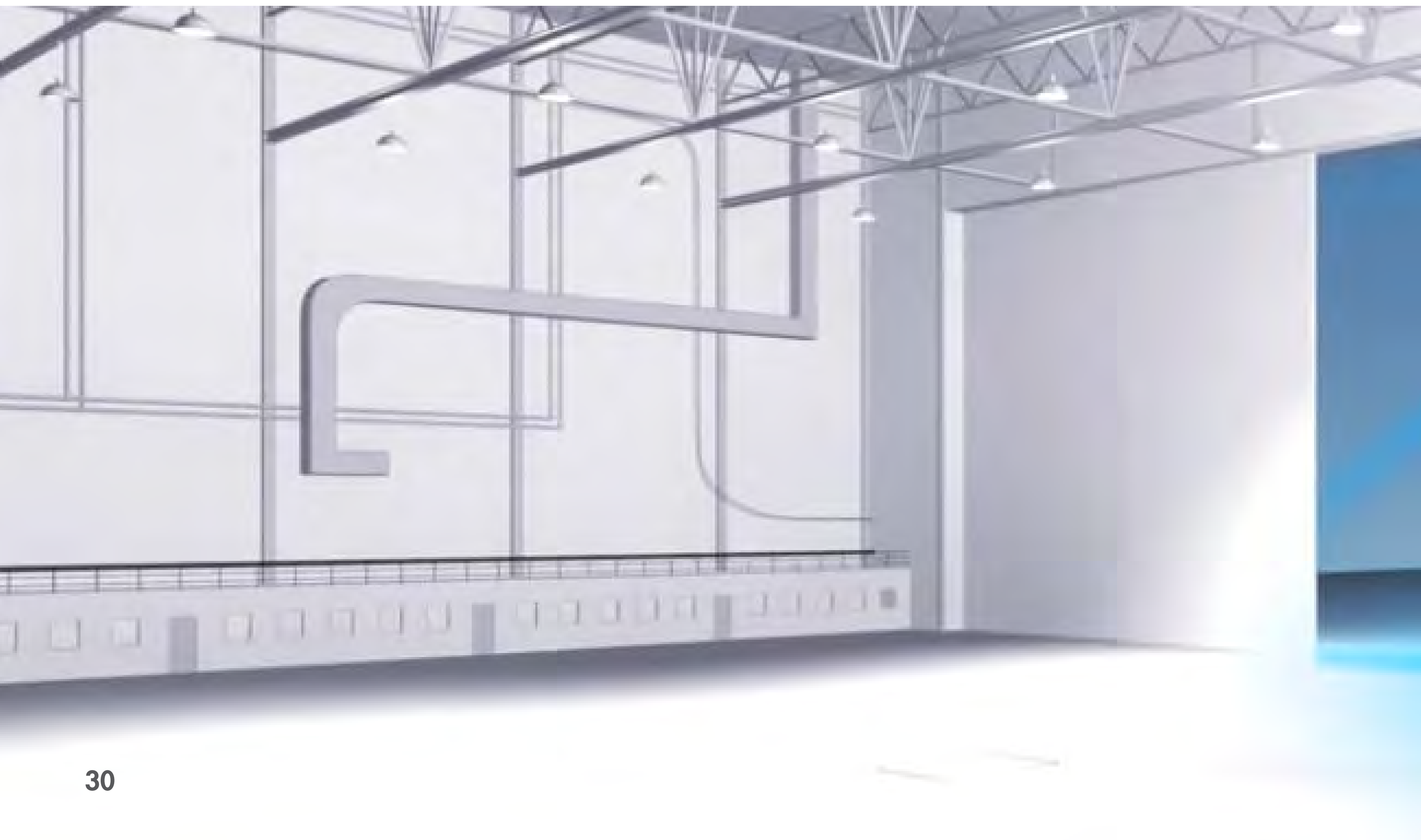
• **Emirates Engineering** hangars store supplies required for maintenance activities on the hangar floor using underground technical pits which can be lifted to operational level with small manual effort (Haridas, 2012).

• **GemDT** is a photogrammetry company that has taken Airbus's and other future hangar visions and provides services of **visual inspection** and **damage assessment** using both fixed and mobile rigs (GemDT, n.d.).

DEVELOPMENTS AND TRENDS

There is a huge push from airlines towards modern, high tech, and sustainable hangar environments. Photovoltaic panels for generating electricity, ground source heat pumps, natural lighting, are suited and available to MROs for development of new hangar facilities. As aircraft fleets are on the rise, companies are looking into increasing efficiency of checks. To achieve this, market leaders in innovation such as British Airways, Lufthansa, Austrian Airlines are investing to explore automated or supporting technology as the answer. On the other hand, fast followers either wait and watch and improve their capability by better training and tech-friendly younger workforce.

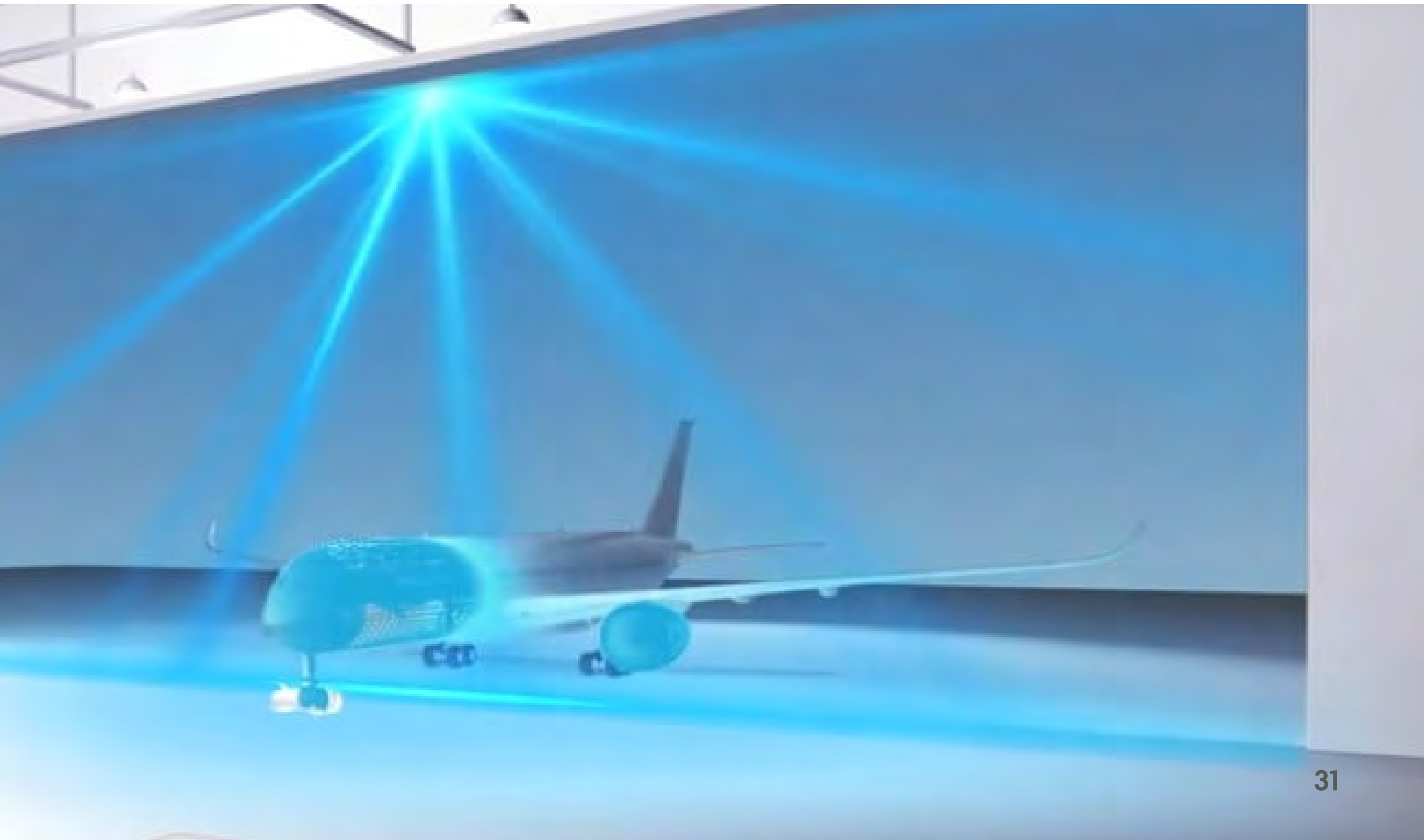
A common trend among MROs is the need for digitizing the maintenance process. This eliminates paper and brings everything online such that a check can be monitored and optimized in real-time. In order to reach the peak of efficiency, this is a must. Airlines, for instance RyanAir, have internal 'digital labs' whereas easyJet, Lufthansa, and British Airways have incubator programs or partnerships with innovative companies to assist them in digitizing operations. Air France-KLM does have a digital innovations team, however, the companies have been reportedly lagging behind the market and is only now adopting solutions that some competitors have had for a while. In the digital innovation landscape, low-cost airlines are seen to be more responsive and fast moving than legacy airlines.



The construction and materials used in the hangar have undergone no big leap in the past decades. The only consistent tendency is the growth in the size of hangar buildings. With the upcoming growth in the aircraft fleet in the next 10 years, new hangar constructors are expected to look into sustainable construction materials. For bigger hangars, the doors have become substantially wider. Emirates Engineering has been seen to replace 8 doors with 4 wider ones to accommodate more aircrafts simultaneously.

Looking at the regions of operation, North America and Western Europe respectively stand as the top 2 shareholders of the worldwide fleet. They are also the top spenders in the MRO sector. Their MRO spend is closely followed by Asia Pacific, Middle East, and China.

Taken from Airbus's vision for the Hangar of the Future (Airbus, 2016)



2.4 Conclusion

The Discover phase gave me a broad understanding of the working of the hangar, its challenges, and problems. It introduced me to the perspective of several involved parties - mechanics, engineers, team leads, planning team, innovation team, digitizing team, etc. From these sources, common topics that need to be dealt with in the hangar of the future were identified or confirmed, primarily, the level of technology and issues with ergonomics. Moreover, this initial phase allowed me to research, observe, experience, and form my own opinions.

The interviews exposed me to how the working style in the hangar has moved from hierarchical to independent and the clear task division and efficiency that comes with it. They also helped me understand that technology could benefit this independent working approach and prepare the hangar for the future. In my mind, this led to a strong foundation for the reasoning behind this project. Light was thrown onto some of the most commonly found problems like waiting times for materials and tools, time wasted in walking, ergonomic issues like climbing stairs too often, and the inertial mindset of older employees. My personal observations, research, and the night shift experience substantiated some of these problems while also leading me to new possible areas of improvement. My shift experience was invaluable due to several reasons. The first being, it got me closer to the ultimate users of the hangar and opened me to their perspective. Experiencing the tasks helped me understand the frustrations that come with waiting time, the pains caused due to repetitive use of the staircase while working inside the aircraft cabin, and the case of possible injuries due to repeated lifting of heavy objects.

One recurring observation in my research and conversations was that the aforementioned aspects are very much interlinked. Suitable improvement in technology can cause improvement in efficiency, ergonomics, and sustainability at the same time. This confirmed my reasoning from the project brief for looking toward innovative technology-based solutions.

The industry analysis led me to a variety of existing and future solutions by competitors of KLM and other aviation-related companies. It was necessary to look out for what is going on outside the company to get an idea of what is already possible and envisioned. In this analysis, I found that the ideas that were discussed in interviews eg. automation in moving components, robotic assistance to mechanics, smart gadgets like drones, etc. were quite in line with those that are being worked on by other companies. This competitive landscape was an inspirational starting point to have at this point in my research and for the next phase.

All in all, there appeared to be several aspects that could benefit from a new outlook and different manner of tackling them. Such a comprehensive overview served as a significant first step into the project and the next phases will be the time when its rewards are realized. While all collected information can be interesting and serves as a useful playground, my priority in the next step is to converge toward the problems that are the most relevant and piercing. The end of the Discover phase is thus marked with the gathered data and is welcome to be referred back when needed anytime in the upcoming phases.

DEFINE

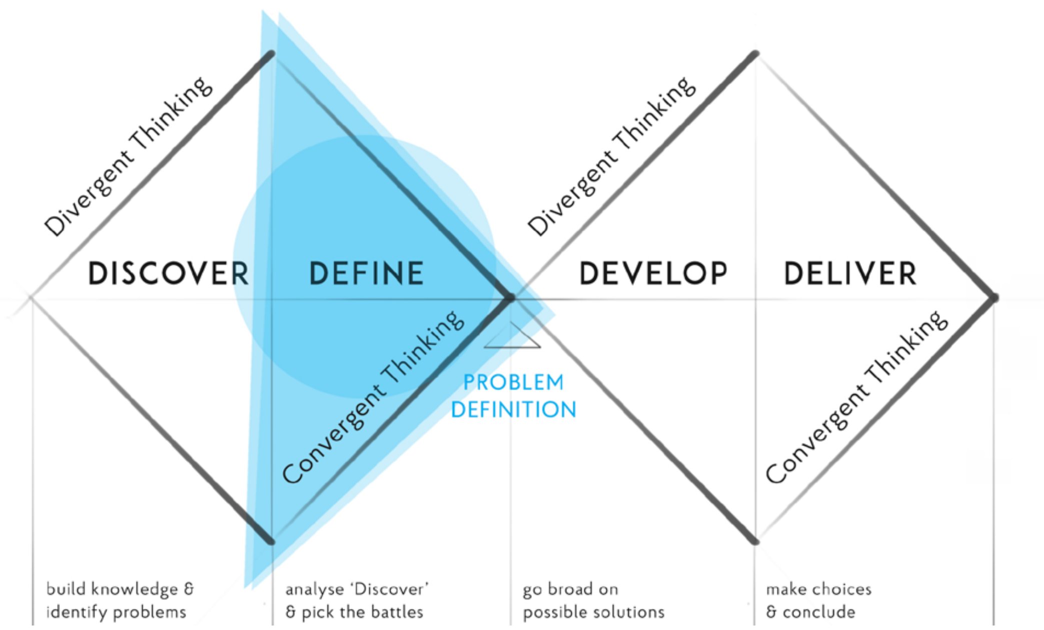
analyze ‘discover’ & pick the battles

3.1 Introduction

The second phase of the double diamond is responsible for defining the direction of the project by choosing which problems encountered are relevant to the scope and should be explored further. While until now it was preferred to go broad and acquire a variety of knowledge about the hangar, it is in this phase that this knowledge was channeled down into what would be most interesting for the hangar of the future.

The approach for this phase is a combination of methods, intuition, and insights gained from experiencing the Discover phase. The conclusion is essentially the conclusion of the previous phase passed through a funnel of analysis and reasoning.

Since the problems identified in the Discover phase were plenty and of different kinds, the ones which can be solved through design are recognized in this phase. Moreover, some of these problems could be solved using low-tech solutions while for some others high-tech solutions are expected. This is also noted in order to get an idea of what to expect going further.



3.2 Goals of the phase

• Identify problems ('pick the right battles') which are relevant and lie within the scope.

• Formulate problem statements ready for the Develop phase.

3.3 Collection and Analysis

"Choose your battles wisely because if you fight them all, you will be too occupied to win the truly important ones."

In design research, one oftens encounters far more problems than expected. My Discover phase has been a similar experience. Such an extensive research is great for forming an overall picture of the context. But there is a fine line beyond which it can turn overwhelming. To identify this line and switch to a converging phase helps in having strong control and giving direction to the project. In the 2-3 weeks of the Define phase, this was done as portrayed further in this section.

3.3.1 PERSONAS

There will be various kinds of employees in the hangar of the future and they will have roles similar to the current employees. Some will be direct users of the hangar (eg. mechanics) while others will be indirect guiding members (eg. support office). To better present where they stand and what they expect out of the project, a few personas were created that represent these employee stakeholders. For the define phase, having these personas at the back of my mind helped me think about the end users and their requirements while choosing the problems (as well as further on while exploring solutions). Please note that these personas (names, pictures, and details) are only imaginary representations.

The personas created here are given a voice in 5.3.5 (Storytelling Questionnaire) by the method of role playing. The method and the results are tabulated in Appendix H.

Youssoef Hassouni

TEAM LEAD

Age: 54

Languages: Dutch, Arabic, English

Work experience:

- Aircraft Mechanic at MartinAir (5 years)
- Aircraft Mechanic at KLM Hangar 11 (7 years)
- Ground Engineer (14 years)
- Team Lead (4 years)

Interests: Airplanes, Woodworking, Fishing

Goals: Successfully do his job until retirement. Satisfied with current position

Frustrations: Thinks that young mechanics don't have a strong foundation these days so training is challenging. Changes in working style and tools is mentally challenging and he prefers the old ways.

"Working at KLM for 30 years has been great and I will work here until I retire."

Ronald Weerwind
AIRCRAFT MECHANIC

Age: 24

Languages: Dutch, English

Work experience:

- Intern at KLM Hangar 12 (8 months)
- Trainee (1 year)
- Mechanic (2 years)

Interests: Cars, Aviation, Technology, Cycling, Fitness

Goals: Get hands-on experience and develop skills. Become a capable young man on his way towards a promising future in the aviation industry.

Frustrations: Colleagues have a very different mindset and a calm attitude. The team doesn't reflect his energy and ambition and works just enough to get the job done. He feels that they lack a drive for improving themselves or their work.

"I work with my full energy and am curious about everything. I am working towards becoming an expert at my job."

Experience

Job satisfaction

Change acceptance

Innovative mindset

Team management

Harry van der Werf
PLANT LEADER

Age: 49

Languages: Dutch, English

Work experience:

- Support Staff (5 years)
- Project Manager (12 years)
- Plant Leader (5 years)

Interests: Business, Technology, Golf

Goals: Bring some significant positive change in the working lives of his team. Make the hangar ready and competent for the upcoming 10 years.

Frustrations: Not entirely happy with how the ground engineers and team receives his innovative approach and ambitions. Efficiency of the hangar is low and he is convinced that this is not yet the 'hangar of the future'.

"My ambition is to truly prepare this hangar for the future. There are many roadblocks but we will get there."

Experience

Job satisfaction

Change acceptance

Innovative mindset

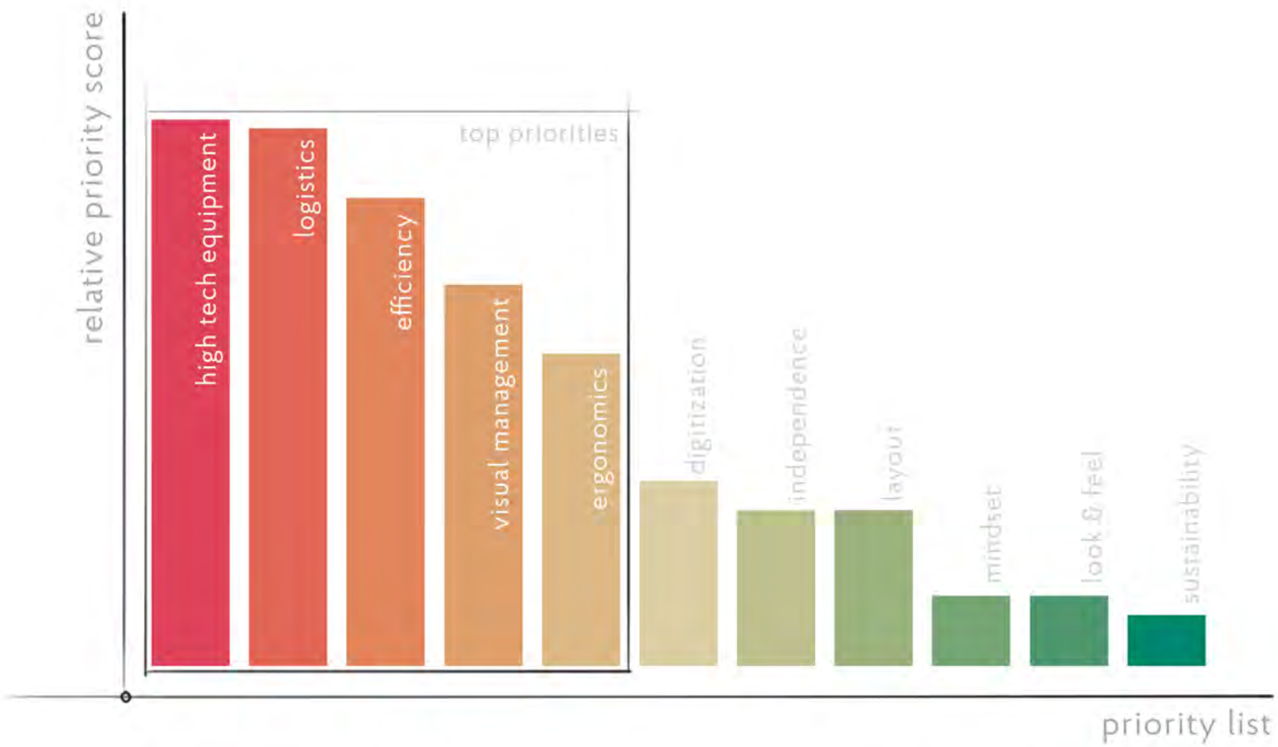
Team management

3.3.2 VALUE CURVE

The value curve extracts information from the workfloor to find out which problems are the most important to tackle. During the conversational interviews and the night shift, employees were asked questions in general about the hangar and specifically about their roles. This information was synthesized into top 3 priorities for 16 people and an aggregated graph was plotted to indicate what comes up the most often. This graph, called the value curve, indicates what areas of development would the hangar and its employees benefit the most from. Going further, problems related to these categories are considered in selecting the problem statements.

The concerns identified were divided into 11 categories. These categories were extracted from the conversations, in some cases directly stated and in others indirectly pointed at. Furthermore, they were assigned relative weights and a 'score' was calculated to find out the top 5 priorities across the hangar employees. The calculation of this score and other details are shown in Appendix E. Some of these priorities are interconnected as they are inseparable but needed to be explicitly stated. It is also important to note that the priorities which do not fall in the top 5 might still be touched by the solutions explored and chosen in the next phases.

The value curve (calculation elaborated in Appendix E)



The priorities that are identified using the value curve in respective order are: High tech equipment, Logistics, Efficiency, Visual management, Ergonomics. The problems and opportunities identified related to these priorities are further elaborated:

High tech equipment: The overall state of technology of equipment used for aircraft checks has not evolved much in the past years. This is the topic mentioned by the most number of employees (8) spread across different roles. They would like to see upgrades in the equipment used so that work can be faster, more comfortable, pleasant, and more effective. It is necessary to note that various competitors are diving deep into making the best use of available technology because it is an important aspect of the hangar of the future.

Logistics: Logistics here refers to the planning, organization, and execution of the A-check. This includes movement of people, equipment, materials, and tools to facilitate the same. It was recalled the most number of times (6) as the top priority and totalled for a score very close to 'high tech equipment'.

Efficiency: Efficiency is directly related to the total time of an A-check compared with its time in ideal conditions when everything goes perfectly well. Every A-check is composed of several tasks and in most cases, there is an ability to carry out these tasks faster than they are being carried out right now. At the same time, it is possible to ensure higher continuity between tasks and eliminate waiting and walking times. All these factors can account for an increase in efficiency in several aspects of an A-check leading to a higher overall efficiency.

Visual management: Visual management refers to a project that aims to infer data from aircrafts before and during a check and make it available in a visual format for team leads and the planning team to interpret. Using this information, they can better manage their teams, prioritize important tasks, and handle issues right when they occur. This tool can have a significant positive impact on efficiency and promises effective A-checks.

Ergonomics: In a place like the hangar, where physically intensive tasks are a part of daily work, ergonomics play a big role. Easily identified ergonomic concerns are frequent use of staircases, excessive walking, carrying heavy objects, etc. Where possible, excessive movements which cause harm in the long term, must be eliminated to maintain a healthy workforce.

Special mention - Sustainability: Environmental sustainability is not directly identified as a priority for most stakeholders of the hangar. However, as stated earlier and interpreted from KLM's ambition, sustainability should be a factor while designing anything for the future to address the challenges that lie ahead. For this reason, the possibilities of incorporating sustainability while addressing the priorities are always kept in mind.

3.3.3 SELECTED PROBLEM STATEMENTS

A problem statement identifies the gap between the current state (i.e. the problem) and the desired state (i.e. the goal) of a process or product in a way that is actionable for designers. Distilling the information stated upto this point (including the Discover phase), the following problem statements are framed which take into account the identified priorities from the value curve. The method of coming up with these statements was to list out all the problems identified previously and find those that overlap with the priorities and are relevant to the project brief.

***Inspection:* Provide a quicker way to inspect the exterior of airplanes to reduce the direct time spent by a team on inspection and anticipate early-on the materials and tools required, specially for unforeseen tasks.**

Inspection was selected as it is knowingly one of the most time consuming tasks of an A-check. It may or may not change the tasks to be performed in a check but it cannot be ignored as a certain level of safety needs to be ensured for each aircraft. Since inspection is carried out at the beginning of a check, a thorough and accurate inspection means a better handle on the entire check. Moreover, selecting this problem comes with a possibility of addressing the priorities of using high tech equipment, improving efficiency, and improving ergonomics. The industry analysis also shows inspections to be an area that some competitors are working on.

***Movement:* Facilitate movement of materials and tools in such a way that the movement of engineers and mechanics is minimized and there are less breaks (delays and waiting time) in the continuity of tasks.**

It isn't difficult to notice that there are plenty of people moving in the hangar at times of a check and that oftentimes the airplanes are unattended. This is usually because engineers and mechanics are going from one place to the other to obtain materials or tools. Every minute these people spend away from the aircraft is time that could be saved if the correct materials or tools for the appropriate task were available closer to the location of task. There are noted complaints of having to walk too much, going up and down the stairs frequently, going to the delivery point to check if their orders are delivered multiple times, or having too much waiting time during tasks. Such a high number of movements are not ergonomic and inefficient. This is where solutions could be explored and technology could step in to address several priorities at once. The overarching nature of this problem is such that its solution can positively affect a variety of attributes of an A-check and that is one more reason for it to be selected.

***Process:* Enable the teams, leads, and planning team to better understand the operation status of checks so they can optimize before it is too late.**

It was commonly discussed, especially by team leads and employees in managerial roles, that issues with a check are found out only when the check is over and it is already too late to address those particular issues. All they can do is to take them into account for the future checks but every check is unique and so are the issues, so that is not very helpful. If the real-time operation status is known better by these involved parties, they can actively do something about it then and there. There is already an ongoing (new) visual management project by Plant X and executing this on the workfloor is identified as a priority in the value curve. Since this problem is connected with most of the identified priorities, it is selected to be tackled as a part of this project.

3.4 Conclusion

The initial research (Discover phase) served to create a strong foundation to understand the workings of the hangar. It led me to some major problems and concerns while also allowing me to do my own research as a designer and dive deeper where needed. Going forward, It was important to keep the project from becoming overwhelming and in control making sure it is bound by the predefined scope. The massive amount of information needed to pass through a filter to appropriately `pick and choose'. This filter was provided by the Define phase. In this phase, the information gathered previously was sorted to make it usable. This was done by the means of a value curve and looking back at the research to construct problem statements.

The value curve helped identify dominant concerns and priorities of a variety of employees. It helped me make sense of the gathered information and classify it into a comprehensible format. The top ones came out to be: high tech equipment, logistics, efficiency, visual management, and ergonomics. At that point, it was clear that the problem statements that would be formed later would need to overlap with these priorities. It was distinctly noted that sustainability, though a priority for KLM, was not found to be a priority for its employees. However, since it was a part of the project brief, it cannot be totally eliminated. Thus, further on, sustainability would remain in the background while coming up with solutions.

After careful analysis of the overlaps between these identified priorities and all the research done previously (observations, interviews, industry analysis, and experiential research), three problem statements were discussed with the mentors and formed as a result of the Define phase. They were related to three different aspects of the hangar: Inspection, Movement, and Process. Inspection concerns visually inspecting an aircraft usually at the start of the check. It is a time-consuming task that almost always needs to be performed. Movement concerns the slow movement of materials and tools and the unnecessarily excessive movement of people in the hangar. Finally, Process concerns the representation of an ongoing check in realtime to the concerned people working in the hangar, which is currently lagging behind.

These problem statements are independent of each other and are capable of having individual solutions to address them. It was always mentally checked that none of the factors, priorities, or data sources are allowed to have too much influence and that decisions are made in a well-balanced manner. The end of the Define phase formed a strong basis for the upcoming creative phases.

DEVELOP

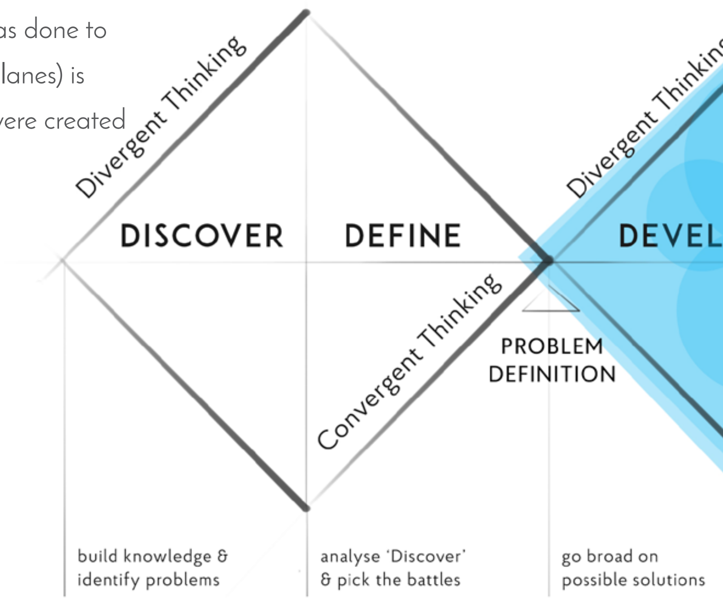
go broad on possible solutions

4.1 Introduction

The Develop phase marks the beginning of the second diamond of the overarching design method. At this point, the problem statements were well defined. Since this project is multi-faceted, there were multiple directions to look into to address these problem statements. These directions, however, were clear and are supported strongly by the priorities found in the previous phase.

In this phase, I intended to go broad again and explore ideas with an open mind. This was done with the aid of researching and brainstorming myself as well as discussing ideas with colleagues, and conducting a brainstorm session. I also chose to revisit to the previous diamond and collected all the bits and pieces of ideas that I had come across there. This resulted in a compilation of a basketful of ideas that were analyzed for their pros and cons, effectiveness, feasibility, and so on. They were further passed through a Datum method analysis to compare them among themselves and figure out which ones should be taken forward.

Work on building the VR prototype (including learning software for it) was simultaneously carried out along with the development of ideas. This was done to ensure that the virtual environment of the hangar (building, layout, airplanes) is ready to receive chosen solutions in the next phase. All the 3D models were created and the preliminary hangar environment was set-up during this phase.



4.2 Goals of the phase

• Come up with multiple solutions to address each problem statement.

• Create the virtual environment of the hangar and make it ready to demonstrate solutions.

4.3 Solution Exploration

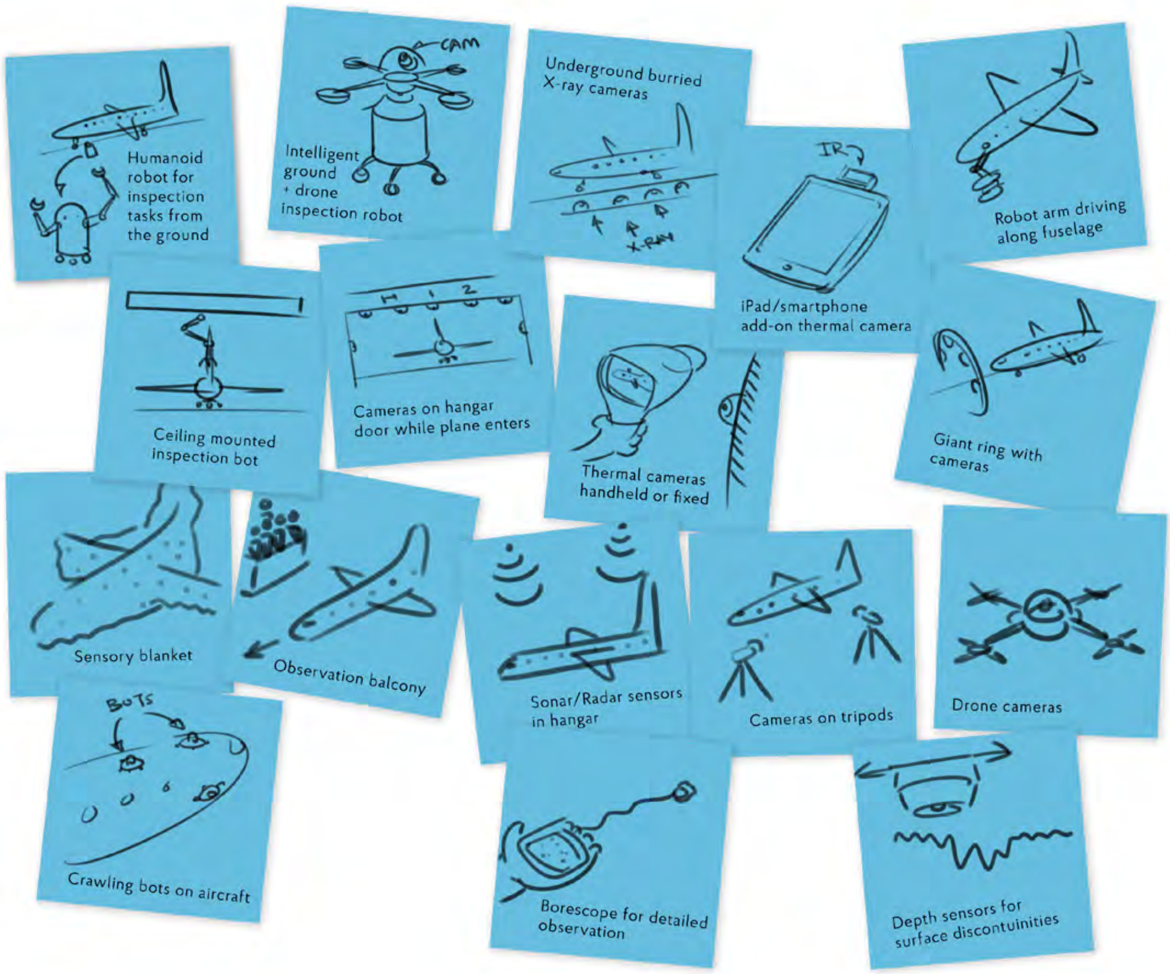
"One way to have great ideas is to have a lot of them."

This section carries the story forward from the selected problem statements to the exploration of ideas. The manner in which arriving at these ideas was facilitated is explicitly stated and the ideas are analyzed in brief. It is important to note that during an activity like a brainstorm, the mind thinks creative thoughts, recollects knowledge and experiences, connects dots, and puts these into the given context. The exact origin of each single idea would be obviously extremely difficult to identify especially given that there are so many minds, ideas, and other factors involved. Thus, the method of facilitating such an environment wherein creative ideas are developed was found to be worthier and more practical to document.

4.3.1 BRAINSTORMING

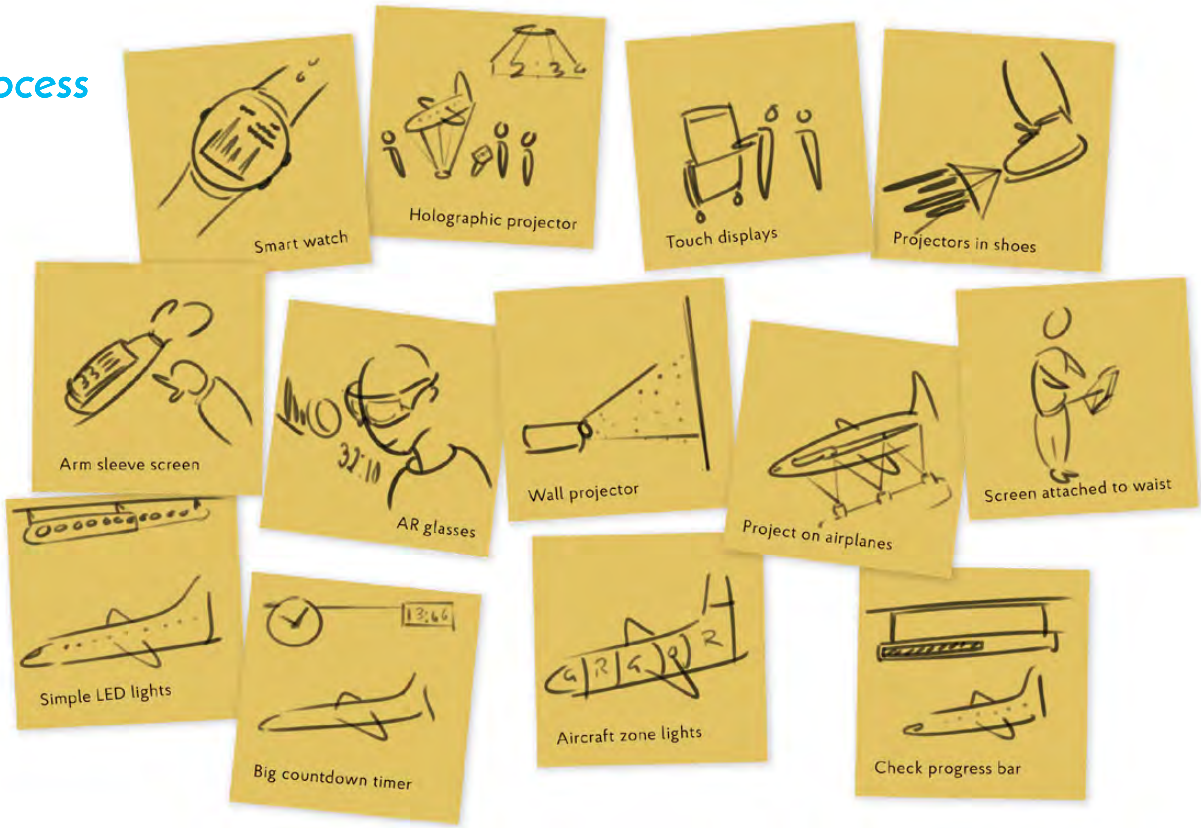
After defining the problem statements, it was natural for me to conduct a brainstorm to explore innovative ideas. In this exciting exploratory phase, I chose to go broad again and tried to have a lot of ideas as I believe that that often serves as a breeding ground for great ones. Since this brainstorm was a group activity, I made sure that this mindset was communicated at the beginning of my brainstorm presentation with a preparatory talk and subsequent reminders. 'How-to' statements (van Boeijen et al., 2020) were used as fuel for feeding the brainstorm session. Brainstorming was done while keeping these factors in mind: go for quantity rather than quality, no right solution and no judgement at this point, break free of logic, keep it simple and don't dive deep. Another reason for me to prefer to keep the nature of these ideas out-of-the-box was because an analysis of the more pragmatic and reasonable solutions would already be a part of 4.3.3. A detailed explanation and direct results of the brainstorm can be found in Appendix F. Within this section, the ideas of the brainstorm are (re)sketched on post-it notes and that was the limit of detail within the brainstorm. Some interesting ideas that came up were analyzed a bit further as can be seen in 4.3.2.

Inspection



Movement

Process

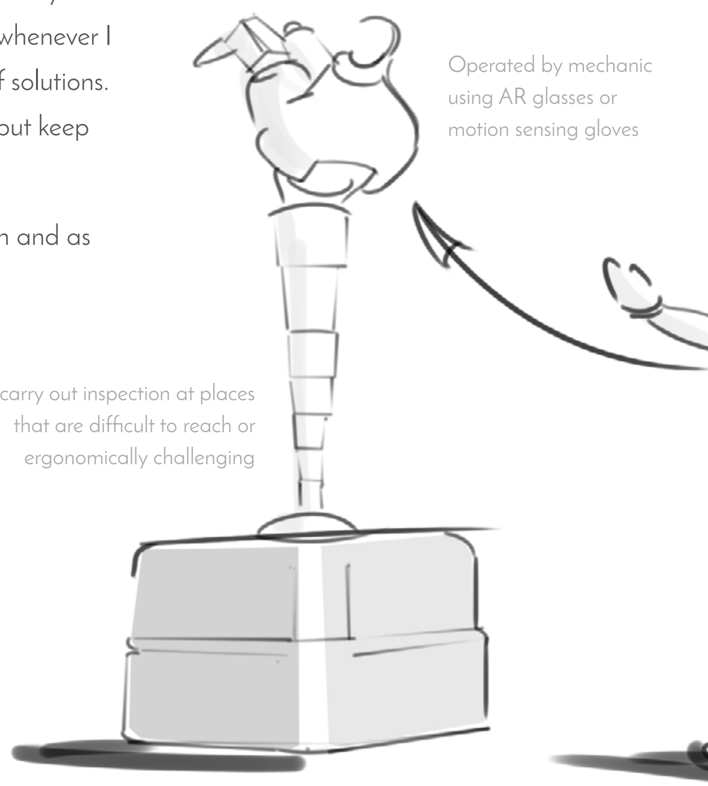


4.3.2 BRAINSTORM IDEAS ANALYSIS

The brainstorm resulted in a plethora of ideas which were interesting to think about but they needed some analysis in terms of effectiveness and feasibility. Some ideas didn't stand strong individually but made sense when mixed up with other ideas. After translating these into a legible format, preliminary research was carried out, and they were mentally clear enough for discussions and to pass through further filters of choice. In this section, they are sketched out into communicable format, described, and their pluses and minuses are summarized in brief. (Note: The pluses are strengths of the ideas and the minuses are the limitations beyond the assumption that the ideas are executable.)

Since some people in the hangar have an innovative mindset and job, ideas are already floating about the future hangar among them. Some of these ideas are well connected with the identified problem statements. They are actively thinking about improving the working of the hangar in the coming years. In the first diamond, while I did acknowledge their ideas, I looked at them with caution so that they would not influence and bound me too much. However, it would be unreasonable to ignore them any longer because they have a big say in what gets implemented and they have got to these ideas after their own research and brainstorming. Now is the time for me to refer back to these ideas, research about them, and evaluate them to see where they stand. Moreover, as a designer, I have a constant flow of ideas myself. In the first diamond, even when the problem statements were not defined, whenever I had conversations or observed problems, I would sub-consciously think of solutions. Since I didn't want to get biased by these, I decided to note them down but keep them aside for further scrutiny which is carried out in this section.

The ideas analyzed as follows are those that resulted from the brainstorm and as mentioned from the first diamond.

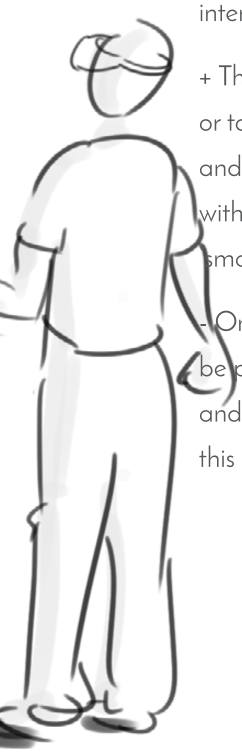


Inspection

The ideas related to visual inspection are elaborated hereon. Since the inspection is visual, these ideas involve the use of cameras (digital, infrared, x-ray, etc.) or LIDAR as input tools (on robots or simply mounted in the hangar environment). Other ways (surface depth sensing, other analog sensors, etc.) have been thought about but in inspection related use-cases, after research and discussion, cameras in different configurations made the most sense to be a part of further elaboration. It is also kept in mind that currently all the mechanics are equipped with an iPad and that could be used as an input/output device in relevance to these ideas.

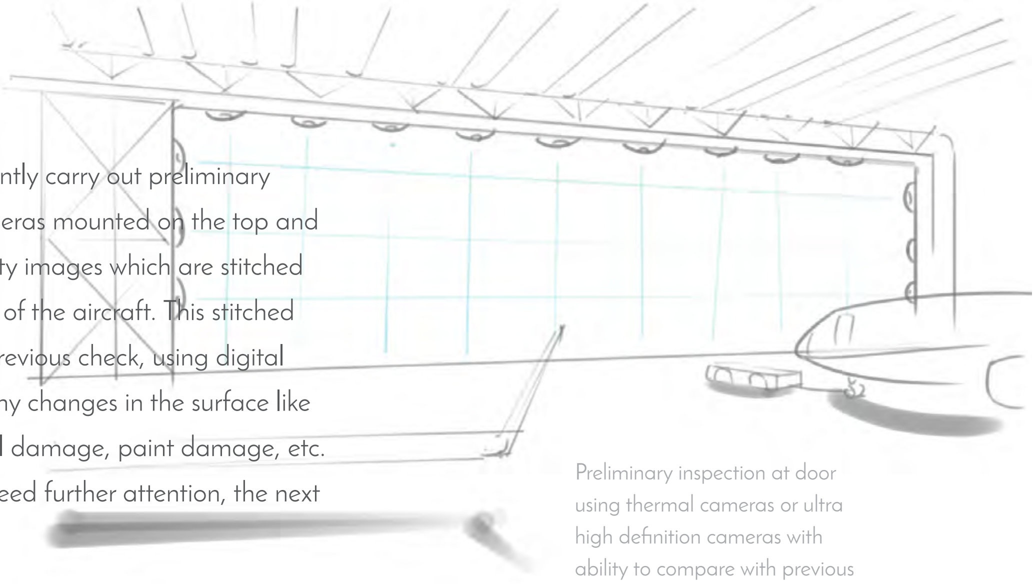
- **Collaborative Ground Robot**

A collaborative robot (hereon Cobot) is one that is capable of learning multiple tasks to assist human beings. It is not designed to replace human work but rather help to carry it out in a more efficient and easier way. A Cobot on the hangar workfloor can be imagined to be of great help for inspections. This particular idea of a Cobot involves two gripper arms to unlock, unbolt, unscrew, etc. (or vice versa) aircraft parts when needed for inspection, and also carry and maneuver those components. These arms would either have cameras in them or there would be a third camera arm which is meant specifically for direct observation i.e. the camera would be wirelessly connected with a device (such as an iPad) or an AR glasses that would manually let the mechanic observe what the camera sees. It is also possible to have a borescope incorporated in one of the arms for detailed observation in the interior of parts when required. The operation of the Cobot arms could be using the AR glasses (which identify hand movements of the human using their internal cameras) or motion sensing gloves.



+ This could be useful in places where there is not enough light to inspect confidently or for components that are too far or too high for reliable observation. Essentially, the Cobot is imagined to be able to replace direct human observation and basic maneuvering on the workfloor, thus providing better ergonomics and more consistent observation. Moreover, with the cameras, there is a possibility of incorporating computer vision/machine learning algorithms to observe 'smartly' and thus, more efficiently and reliably.

- One possible downside could be that a Cobot might miss the other human senses of smell, touch, and sound. It might be possible to incorporate these in the future but such technology is currently difficult to find from preliminary research and could be a part of a completely separate project if this idea is implemented. ***Workaround:*** The obvious solution to this is that the mechanic who is operating the Cobot steps in when these senses would be needed.



Preliminary inspection at door using thermal cameras or ultra high definition cameras with ability to compare with previous checks

• Hangar Entrance Inspection

An obvious place to put cameras to efficiently carry out preliminary inspection is on the hangar entrance. Cameras mounted on the top and sides of the entrance could click high quality images which are stitched together and show all visible exterior parts of the aircraft. This stitched image, in comparison with one from the previous check, using digital image processing algorithms can detect any changes in the surface like scratches, lightning strikes, visible structural damage, paint damage, etc. When specific parts are identified which need further attention, the next steps would be taken on by mechanics.

+ The basic inspection, which involves going around the aircraft to observe tiny details, is reduced to no additional work as these cameras and algorithms can do the job. This saves a lot of time and scope for error.

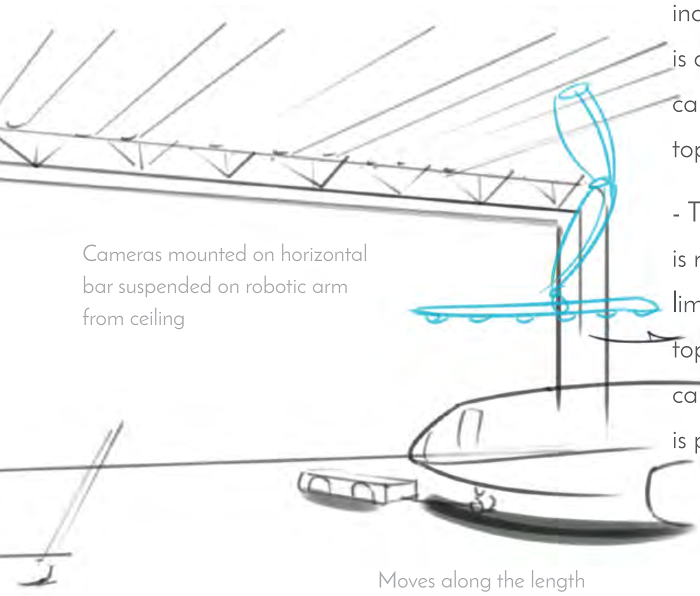
- Parts which are not in the line of sight of the cameras cannot be observed using this method. ***Workaround:*** It might be interesting to explore infrared thermography or x-ray cameras or lidar/sonar to find the possibility of observing something beyond the closest surface.

• Roof Inspection

This idea involves inspecting the top part of an aircraft using cameras on a horizontal or slightly curved beam. This beam would be mounted on trusses or a lifter machine on the ceiling of the hangar. The cameras could be high definition digital cameras with image comparison capability or thermal cameras, whichever type is found more suitable after further study.

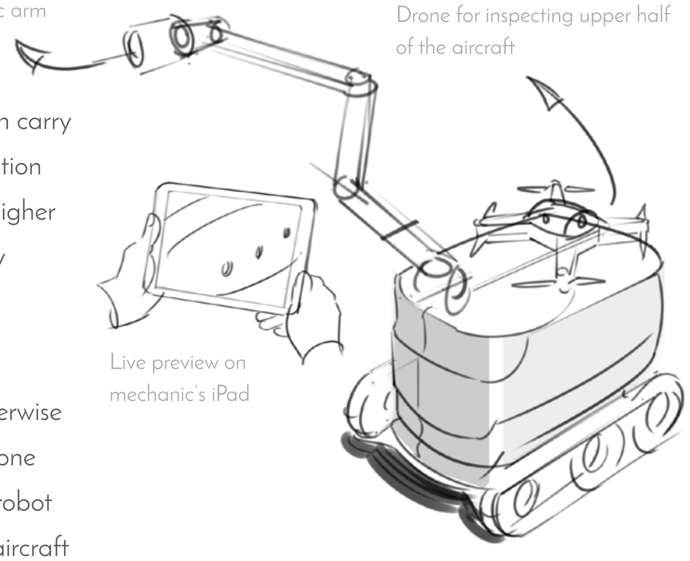
+ Such an inspection can be fairly automated since it can be carried out independently from other inspection tasks. The reason being the inspection is done from the roof and does not interfere with ground mechanic work. It can eliminate the difficult task for mechanics to observe aircrafts from the top eg. for lightning strikes damage and save time from the same.

- The idea might require to permanently use up space on the ceiling which is reserved for lifters for heavyweight equipment. Also, there would be limitations on the field of view of the cameras due to all of them being on top of the plane. ***Workaround:*** The beam could be designed such that it can change shape and embrace the aircraft (still keeping distance) when it is performing inspection.



Cameras mounted on horizontal bar suspended on robotic arm from ceiling

Moves along the length of the airplane

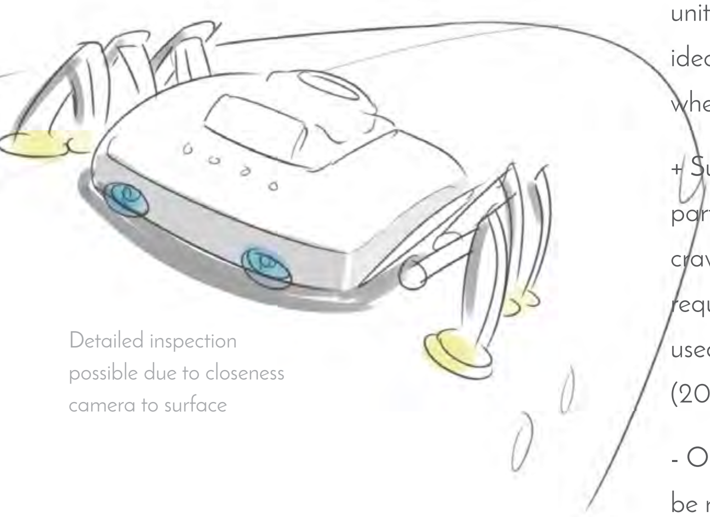


- **Full Visual Inspection Robot (Ground and Drone)**

This idea is a supplement to the ground Cobot in the sense that it can carry out visual inspection from every angle. This is facilitated by an inspection arm with a camera and a dismountable drone which can fly to the higher parts when needed. This set-up is wirelessly connected (and manually controlled if required) and the camera input can be automatically analyzed or manually observed on an iPad when necessary.

+ The arm can be designed to extend to higher places which are otherwise difficult to access for mechanics while simply walking around. The drone can fly to even higher places and also to the top of the aircraft. The robot can be programmed for a preset inspection procedure of the entire aircraft and when certain faults are identified, manual override can be done for detailed inspection.

- If this idea is implemented as described, it is difficult to identify its limitations since it offers a full visual inspection with high efficiency and manual intervention when required.



- **Crawler Bot for Detailed Inspection**

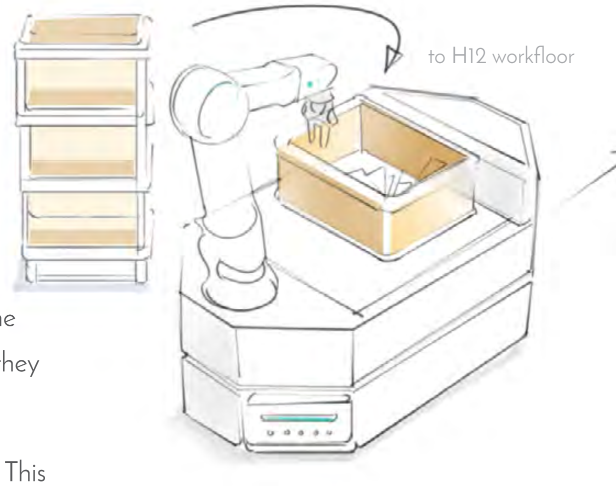
Going closer to the airplane, a crawler bot is imagined which crawls all around the outer surface of the aircraft (fuselage, wings, etc.) and has digital/thermal cameras or surface depth detection ability to identify discontinuities, cracks, or other faults. This bot sends data to a computing unit where it is analyzed and converted to legible format. Like the previous ideas, the bot could be controlled manually with a remote device (or iPad) when required to observe something specific.

+ Such a bot offers detailed observation capabilities virtually on any exterior part of the aircraft with a certain minimum surface size. An army of several crawler bots could make the inspection process detailed and faster to a required degree. For even crispier detail, LIDAR laser technology could be used inspired by bots that inspect pipelines as shown by Pure Technologies (2016).

- One minor disadvantage is that for the so-called army, several bots would be required for each aircraft inspection, thus, the entire system would be non-coherent. This also means that when the aircraft traffic is high in the hangar, too many of these crawler bots would be required to operate simultaneously. ***Workaround:*** The solution for this lies outside the scope of this project in planning and scheduling the checks in such a way that inspections of each aircraft occur at different times. In such a case, one team or army of crawler bots would be sufficient.

Movement

The ideas related to movement of materials (components), tools, and people are elaborated hereon. They either intend to facilitate movement of components and tools while reducing movement of people or directly quicken the movement of people. A variety of ideas were explored and the most promising ones were researched further here.

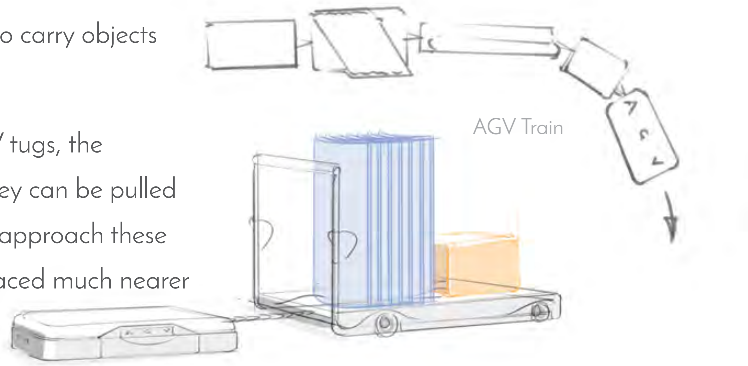


• Automatic Guided Vehicles (AGVs)

AGVs are portable robots that can follow marked line paths, use vision cameras, magnets, or lasers for navigation. They can be useful for bringing objects from one location to the other as once they are programmed to deliver at a certain place, they can complete the job independently.

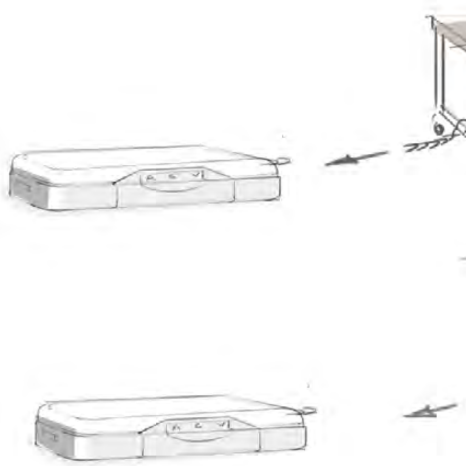
Standalone: One idea is to use AGVs that have allocated space to carry objects. This could be in the form of space to put crates which can hold tools and small components inside them.

Tugs: Another idea is to use AGVs as tugs. These do not have space to carry objects themselves but can pull onto trolleys or other wheeled objects.

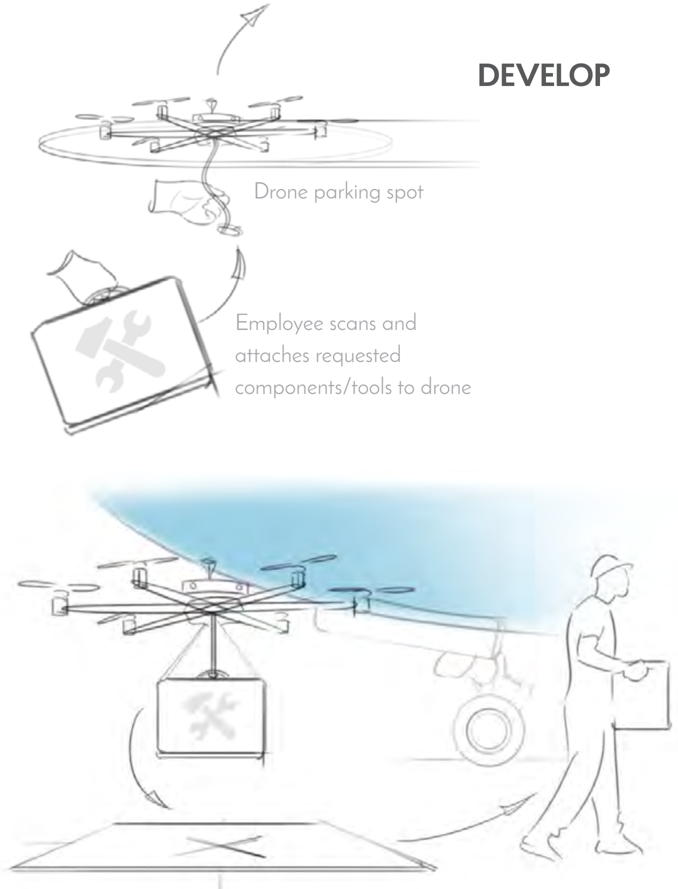


Portable workbench and tool cabinet: To add onto the idea of AGV tugs, the workbenches and tool cabinets can be fitted with wheels such that they can be pulled by the AGVs to the workfloor. This would reduce the time required to approach these workbenches or cabinets multiple times by a check as they can be placed much nearer to the aircraft without physical effort.

+ AGVs come in different forms and capacities. They can carry quite a heavy load while being compact themselves. The standalone type of AGV can carry heavy loads of small objects and the tug kind of AGV can be used for large components which are cumbersome to be moved around by mechanics. The tug kind of AGV can also be used to pull several trolleys in a row like a train eg. for components and tools that are required for a single task at once. The ability to bring workbenches and cabinets near to the workplace reduces the walking time for several team members multiple times during a shift and this will make the check much more efficient.



- The doors between H11 and H12 might need to be optimized such that there is not much waiting time and blockage for the AGV. A special track might need to be constructed for AGV use.



• **Drone Delivery**

This is a popular upcoming way of delivering objects from one place to the other as Amazon (n.d.) and several other companies are working on it. In the hangar scenario, drones could carry packages which contain lightweight components, lubricants, fasteners, fabrics, tools, etc. from the warehouse to the mechanic's position or the nearest drone dropzone.

+ Drones could have several dropzones since they do not require any specific position or equipment to land on. This means using this method, components and tools can be delivered closest to the live location of a mechanic, saving maximum walking time.

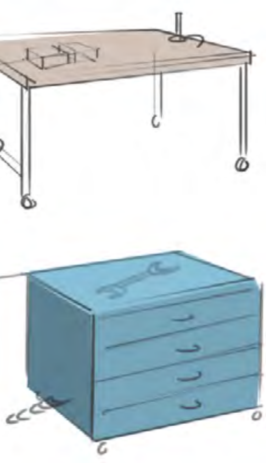
- There is a limit on how much drones can carry. This is both in terms of the weight and the size of the object. This means that bigger or heavier components would still have to be moved in different ways.

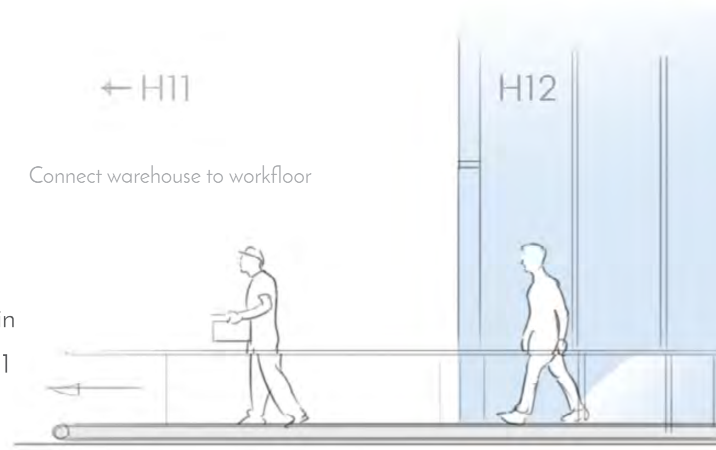
• **Conveyor Belt**

A straightforward way to move components and tools from one point to the other would be a conveyer belt. Like it is used in factory assembly lines or for baggage at airports, a conveyor belt could deliver from the warehouse to a specified location on the workfloor (H12). When parts or tools are ordered (or specific tasks which require those are scheduled), the warehouse employees (H11 or H12) can simply place these on the conveyor belt after scanning them and mechanics can pick them up. After their use is over, they can be sent back in the same way to the warehouse.

+ Since the receiving point is on the workfloor, mechanics don't have to walk long to pick up components or tools. As the belt operates continuously, they don't even have to wait for runners who often deliver from the warehouse. This could thus ensure a more continuous workflow, less walking, and higher efficiency.

- To make sure such a design works well, extra care must be taken in developing the infrastructure that objects sent from one point are scanned out and on receiving they are scanned in so losing things is not an issue. Moreover, as H12 receives components and materials from multiple locations, connecting all these to the workfloor with a system that works flawlessly would take up a significant amount of space and planning.





Connect warehouse to workfloor

1.5x walking speed

• Walkalator for Busy Routes

Walkalators are installed for people in buildings like airports, malls, and skybridges to get around faster. This idea involves installing walkalators in both directions on busy walking routes such as from H12 workfloor to H11 warehouse.

+ As the speed of walkalators is around 2.5 km/h, they could practically mark up the regular walking speed 1.5 times. Every shift, this would save several man-hours of walking time (for the team in total) in an ideal scenario. They would also reduce the amount of fatigue during a shift due to walking for a significant amount of time. Moreover, heavy objects could be laid onto the walkalator instead of lifting them by hand the entire way, which adds to better ergonomics.

- Since installing a walkalator requires changes in the building infrastructure and much space, it would be only possible to install them for certain routes. Since mechanics need to walk all around the workfloor and not only on these certain routes, the time saved compared with the maximum potential time that could be saved would be relatively small. Also, in the end, they are only reducing the walking time and not eliminating it. Mechanics would still need to go from one place to the other to pick objects up.

• Seated Mobility Scooter

A seated electric mobility scooter is one similar to Scoozy (n.d.) which can take one passenger at a time and move at around 15 km/hr. This could be a viable mode of going back and forth between H11 and H12.

A speed of about 15 km/hr without exerting physical effort and while being seated means faster movement of mechanics when required and an easier way to carry components and tools from the H11 warehouse and back. That speed is around 3 times the normal walking speed and also gives the mechanics a small rest from physical exertion.

Large components cannot be carried on a mobility scooter as there is limited space. There might also be some waiting or slow down time to be accounted for when the automatic doors between H11 and H12 open and close.

Seated mobility scooters for moving heavy equipment to workfloor

Ergonomics + Speed

• Raised Workbench Platform

A platform that levels with the aircraft door and equipped with a workbench with tools, cabin tools, space to lay components, dashboard screen etc. was already an idea being explored by Plant X. As it can be seen in the image, this platform would be able to raise and lower on demand and can achieve the required height for 737 and 787.

A clear plus is that using such a platform reduces the need for mechanics working inside the cabin to go up and down multiple times via the staircases. Working in the cabin is reckoned to be horrible for ergonomics because it is not allowed to carry a lot of tools or material inside the aircraft due to the possibility of losing it inside (which is a huge risk for flying). Since this platform offers a way to just step out, get the work done or collect objects, and step back in, it could be a great way to work long hours inside the aircraft.

Such a platform requires large space to be stored when not in use. If multiple of these need to be stored, their sizes need to be optimized such that storage is not an issue within the limited hangar space.

Kooreman, T., Plant X (2020)

Process

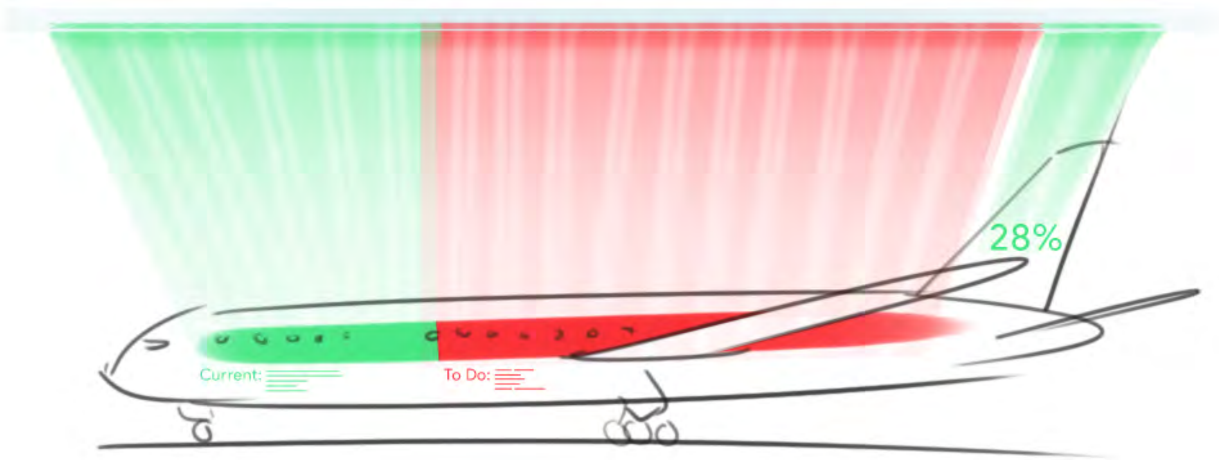
The ideas related to presenting the real-time process data are elaborated hereon. Various mediums through which this can be done are discussed. Different mediums are capable of presenting different kinds of data with varying levels of detail. These ideas are sketched out in the hangar environment for discussion and comparison.

• Projection Mapping on Aircraft

In this idea, information is projected directly on the body of the aircraft. Basic real-time data such as check progress bar, time left, task list, assigned team members, etc. can be seen by the mechanics right on the aircraft while they are working beside or inside it.

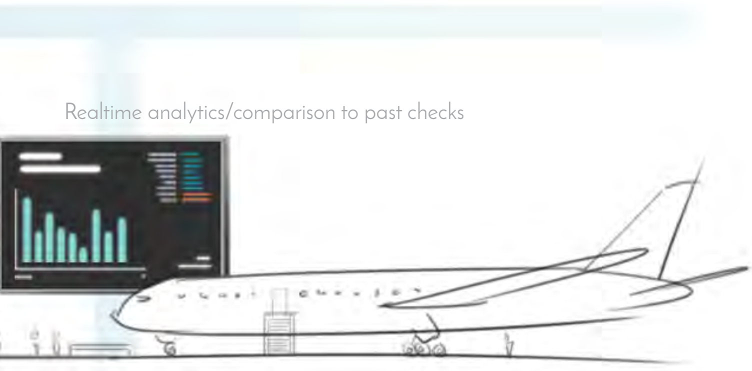
+ The same data is visible to the entire team that is working on the aircraft. This offers the possibility of discussion with other team members while they are looking at this data to clarify any questions. Information such as the progress bar, when made so clearly visible to everyone, can motivate the team to work hard to stick to the schedule and finish their tasks before the deadlines.

- It might be technically difficult to project bright light in the first place as there needs to be much light in the hangar. Different aircrafts (customers other than KLM) have different liveries which add to the complication. There could be a fine line between when such data is useful and when it becomes distracting. While designing this further, this needs to be researched well and taken care of.



Project basic information – progress bar, time left, task list, assigned team members, etc. right at the workplace

Large screens visible to everyone. Continuous mapping of a check and useful information/alerts for action by the team/leads



• **Screens on Workfloor**

The most straightforward way to present digital information currently is by using television screens. These could be large and placed on the hangar workfloor such that they are visible to the who they are meant for (the teams and team leads). The data presented on them could be of various kinds (numerical data, graphs, progress bar, task list, assigned team members, live location of team members, etc.) and can be changed by a master control (eg. the iPad of a team lead).

+ The simplicity of this idea allows it to be readily implementable and is can be clearly understood by the teams. Since the teams are used to using apps like iMech (developed for the teams), the learning curve on this idea is the flattest. The variety of data and the level of detail to which data can be presented in this format is broad.

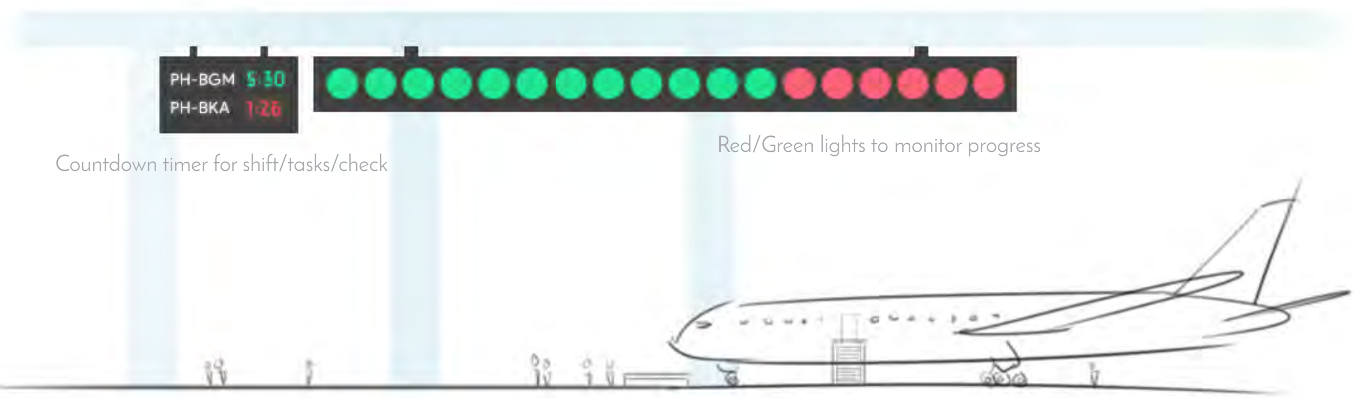
- Due to the same reason that it appears to be not very innovative, it could be ignored by the team members. The distance to which the screens and show information is limited by their size.

• **LED Lights for Basic Information/Countdown Timer**

Simplified information such as the progress of a check or the time left for various tasks can be presented by using green and red LED lights or a LED numeric display mounted on the ceiling trusses or another widely visible place.

+ The information being so simple and the display being large communicates the message to everyone in a clear manner.

- The effectiveness of this information might be different for different people. Some would be motivated by a countdown timer or progress bar while others would be pressured. ***Workaround:*** A further user study needs to be carried out to execute this and obtain positive results.

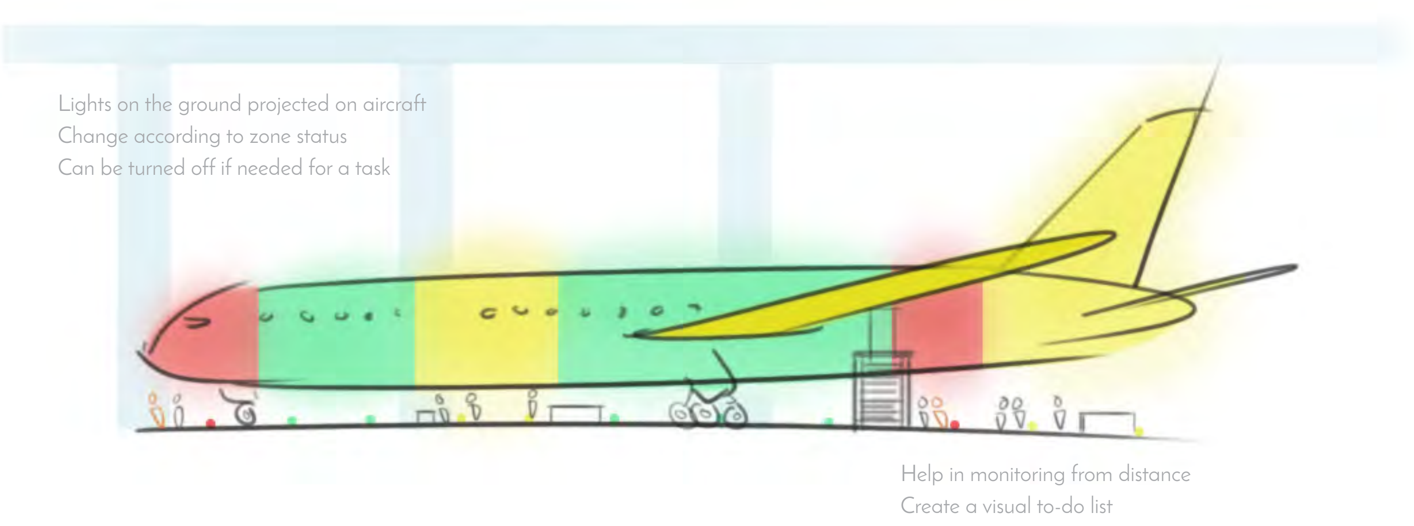


• Lit-up Aircraft Zones

This idea is quite innovative and involves visually lighting up zones of the aircraft according to their check status. The aircraft would be divided into a certain number of zones from nose to tail (and wings) and lights would be placed on the ground such that they can light up these zones from outside. If there are tasks pending, the zone would be lit yellow, if the tasks are complete in a zone, it would be lit green, and if there are problems and need for supervision, it would be lit red.

+ With such a color coded lighting system visible from afar, both the team members and the team leads would be able to check the status of a check from a long distance. This would give the leads a good general idea of whether the check is going as planned or assistance (or more personnel) is required in specific areas.

- The lights might be distracting for working on specific tasks where identifying the color of components or wires is important. Workaround: For such tasks, there should be an option to turn off the lights for each particular zone.



• Hologram Projector

This idea involves using a hologram to project information to be viewed by several people at once. One way to use holograms would be using equipment at specific positions on the workfloor where information is presented and can be interacted with using a touchscreen. This would be ideal for a group standing around this hologram for a discussion regarding this information. Another way to present information would be using a hologram projector on the ceiling. This information would be visible across the entire hangar and can be of general nature eg. the progress of a check presented on top of each aircraft.

+ Such a modern technology could bring excitement into the workplace. The widespread visibility could push the team to work efficiently and stick to the schedule.

- It is not clear for what kind of information would offer a competitive advantage and justify the costs that would go into developing and executing this idea.

4.3.3 DATUM METHOD

From the many ideas explored in this phase, it was an important task to select the ones to take forward. To execute this, the most promising ones (which are the ones analyzed in 4.3.2) were discussed and compared on the basis of these criteria: effectiveness, innovativeness, feasibility or technology readiness, and cost. The factors technology, ergonomics, and sustainability were not reiterated in the comparison since they were used to arrive at the problem statements (and solutions) in the first place. The Datum method was a part of this phase because I did not wish to flood the next Deliver phase with too many tasks and keep it primarily focused on conceptualization and design decisions. Practically speaking, it would be just as suitable to consider the Datum method in the beginning of the Deliver phase.

• **Effectiveness** was chosen as a factor to make sure that a solution is actually capable of addressing a problem statement and is not merely replacing current methods by a new approach.

• **Innovativeness** was chosen as it is in the interest of the stakeholders to address problems using technology and prepare the hangar for the future. The company can benefit from using an innovative approach both directly (efficiency) and indirectly (attracting customers).

• **Feasibility/technology readiness** was chosen because ultimately the solutions would be relevant and useful only if they are feasible to execute in the real scenario. While thinking of feasibility in implementing the idea, the readiness of its technology is also considered.

• **Cost and viability** was chosen because everything in the real world works on the basis of cost of implementation and profitability. If the cost is unreasonably high, the chances of implementation would reduce drastically, especially after the Covid-19 related financial crisis. It is however expected that in the long term, profitability would be given higher importance than cost.

The Datum Method (as described further) was used as a comparison tool because of its ability to compare various ideas with each other and render the most suitable one based on the given criteria as the output.

What is the Datum Method?

According to van Boeijen et al. (2020), the Datum Method enables designers to evaluate design alternatives using design criteria. One of the options is randomly chosen as the 'datum' which represents neutral performance and the other designs are compared with it on each criterion as worse (-1), the same (0), or better (+1). The datum has a score of zero and the other designs end up with a positive, zero, or negative score (total over all criterion). The scores are relative and thus, the highest scoring option is independent of the choice of the datum. The analyzed ideas were passed through the datum method separately for inspection, movement, and process to arrive at the resultant choices.

INSPECTION

Criterion	Idea 1 (Datum) Collaborative Ground Robot	Idea 2 Hangar Entrance Inspection	Idea 3 Roof Inspection	Idea 4 Full Visual Robot Inspection	Idea 5 Crawler Bot
Effectiveness	D	-1	-1	1	1
Innovativeness	A	0	0	1	0
Feasibility/Technology Readiness	T	0	0	0	0
Cost and Viability	U	1	-1	0	0
	M				
Total score	0	0	-2	2	1

MOVEMENT

Criterion	Idea 1 (Datum) Drone Delivery	Idea 2 Walkalator	Idea 3 AGV Standalone	Idea 4 AGV Tug	Idea 5 Seated Mobility Scooter	Idea 6 Raised Workbench Platform	Idea 7 Conveyor Belt
Effectiveness	D	-1	0	1	-1	0	0
Innovativeness	A	-1	-1	-1	-1	-1	-1
Feasibility/Technology Readiness	T	1	1	1	1	1	1
Cost and Viability	U	-1	1	1	1	0	-1
	M						
Total score	0	-2	1	2	0	0	-1

PROCESS

Criterion	Idea 1 (Datum) Projection Mapping on Aircraft	Idea 2 Screens on Workfloor	Idea 3 LED Lights for Basic Info	Idea 4 Lit-up Aircraft Zones	Idea 5 Hologram Projector
Effectiveness	D	0	0	0	0
Innovativeness	A	-1	-1	1	1
Feasibility/Technology Readiness	T	1	1	0	-1
Cost and Viability	U	1	1	-1	-1
	M				
Total score	0	1	1	0	-1

Output of Datum method

The output of the Datum method are the ideas which are the strongest in comparison with their alternatives. Using the Datum method for ideas in the three categories, we have the following results.

For the category of Inspection, the Full Visual Inspection Robot garners the highest score as it appears to be both effective and innovative while being equally feasible and viable as the other ideas. Its effectiveness can be explained due to the complete aircraft inspection capability it offers while some others offer only partial. It is innovative as such a combination of a ground and drone robot is not found in any other application. However, each of its ground and drone components are equally ready in their technology as the other ideas.

For the category of Movement, the AGV Tug is found to be the most effective due to its adaptability and multiple uses (moving material carts, workbenches, tool cabinets, etc.). It is less innovative than say Drone Delivery as such AGVs are used in automated warehouses while delivery by drones is still being developed. But its use in a hangar environment is still very new. It leads on the scale of feasibility as the technology already exists and only needs to be customized for our use-case. Moreover, such AGVs are available to buy and don't need much development or installation costs as some other ideas. Once it is implemented correctly, it will save many hours of walking for team members which in return means a more efficient workflow.

For the category of Process, having screens on the workfloor come out to be a winner as they are technologically ready and the most cost effective. Other ideas require much further development and would be expensive while they would just have similar effectiveness. A sum up of the above factors make them have the highest score. As can be seen from the table, LED lights showing basic information also fairs equally well due to the same reasons. In order to limit to one solution per problem statement, the screens were chosen over the LED lights because of that already being an existing visual management project by Plant X.

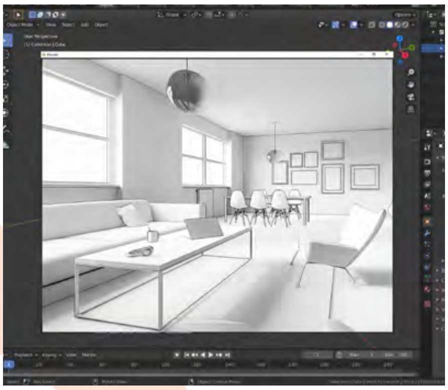
The Datum method thus provided me with a concrete output in terms of 'what' is to be designed. This output was taken forward to the Deliver phase in order to convert it to visual and understandable concepts of all three solutions.

4.4 Virtual Reality

As explained in 1.5.4, VR was a deliberate choice of prototyping tool due to its applicability in such a large-scale project.

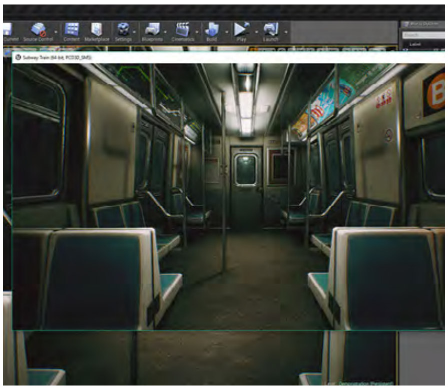
VR IN DEVELOP PHASE

Since the tool is new for myself, Plant X, and IDE TU Delft, I started to learn the software(s) required to effectively develop a VR prototype alongside the Define and Develop phases of the project. After consulting experts (Arno Freeke from VRZone, TU Delft Library) and the KLM VR Team (Chris Koomen, Chris Roos, Shane de Hundt, and Tom Simons), it was concluded to use the following software combination for making the prototype.



BLENDER

Blender is an open-source computer graphics platform for creating 3D models, renders, animations, films, visual effects, etc. Its toolset for 3D modeling, UV unwrapping, texturing, and rendering will be particularly interesting for the hangar of the future. Compared with SolidWorks (which was an option for 3D modeling), Blender provides more free-form modeling and provides an easier workflow to produce models for VR in case of large models (like the hangar building itself or an airplane).



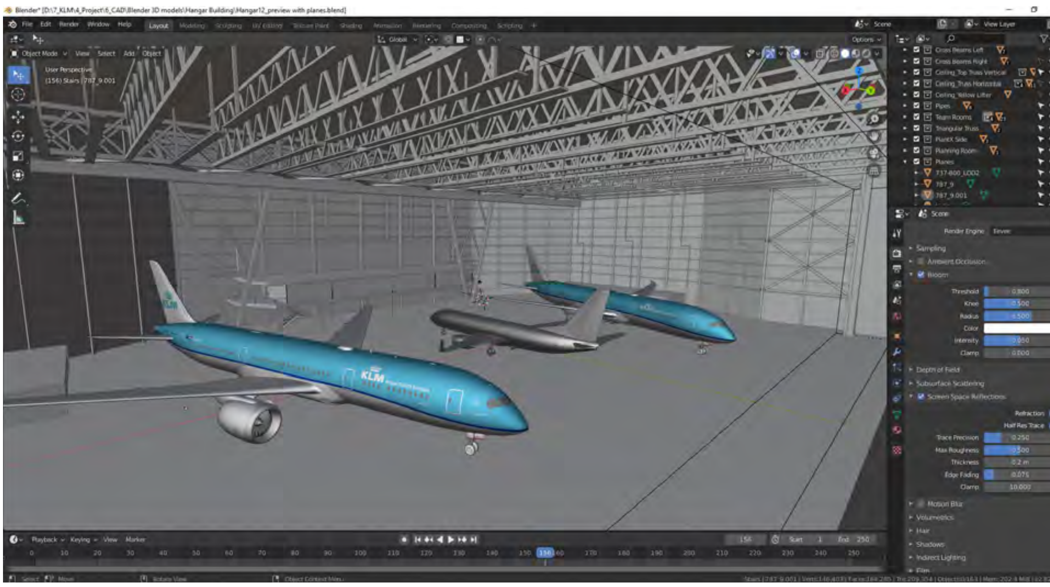
UNREAL ENGINE

Between Unity and Unreal Engine, which are the two major open-source platforms for VR related app development, UE was chosen for its gentler learning curve and less involvement of coding. Given the strict timeline of the project, I was advised to choose UE by all the experts I consulted.

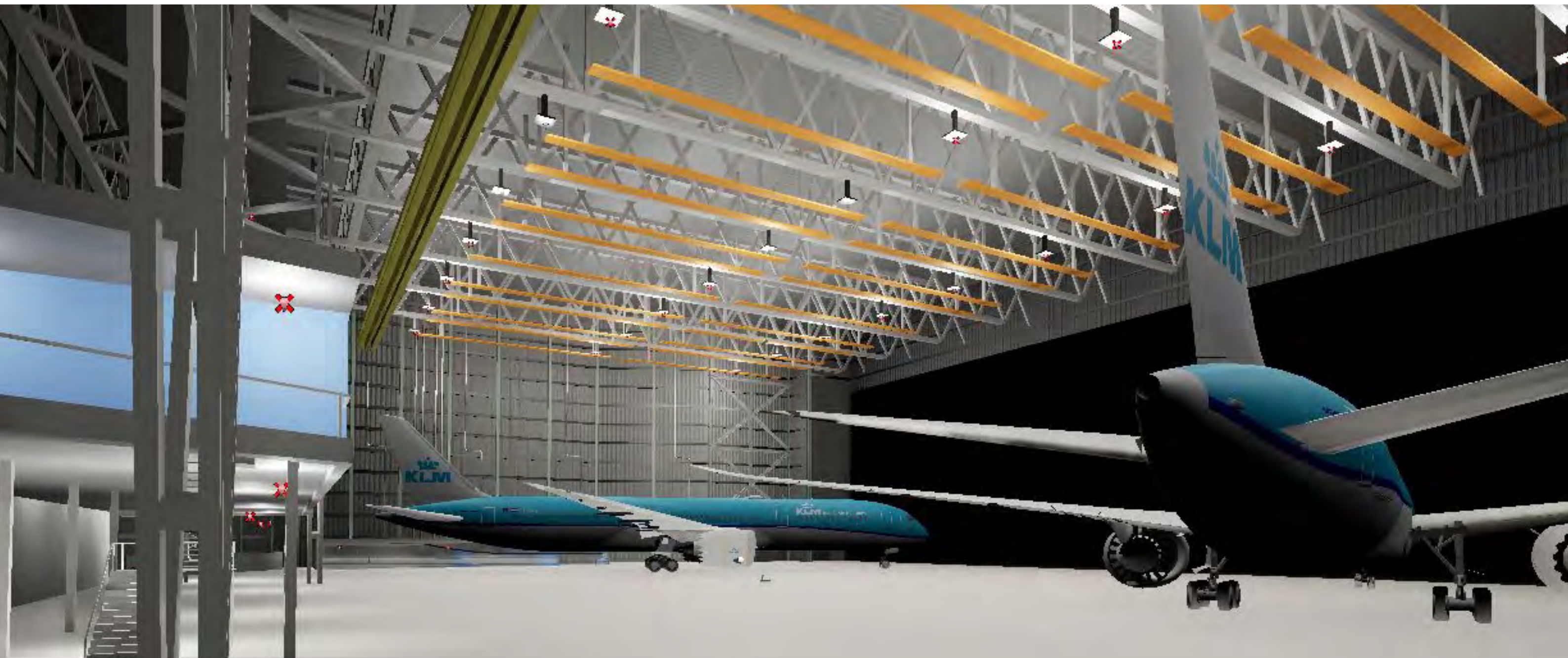
STATUS OF VR PROTOTYPE

Halfway into the project, the 3D model of the hangar was built in Blender (Build 2.81). This was done using pictures taken for reference and from the hangar layout provided by Sodexo (2018). Several methods were tested to transfer this model (FBX files) to Unreal Engine (Build 4.24). Using New Game > Blueprint > VR and setting up as instructed by GoggleHead XR (2019), it was possible to view the model on Oculus Quest, a standalone head mounted display by Oculus. Suitable materials were applied to various structures within the hangar, lighting was replicated, and the virtual hangar was ready for further, more intensive steps. The models of airplanes, 737-00 and 787-9, with KLM livery were found from the KLM VR Team and Kaichinshih (2016) respectively. While the VR-related steps are summed up relatively shortly, please keep in mind that learning the required software, developing the 3D model, and making everything work together involved many weeks of effort and should not be underestimated.

3D model of the hangar under construction in Blender - snapshot from Week 12 of the project.



A view of the 3D model after importing to Unreal Engine and applying materials and lighting.



4.5 Conclusion

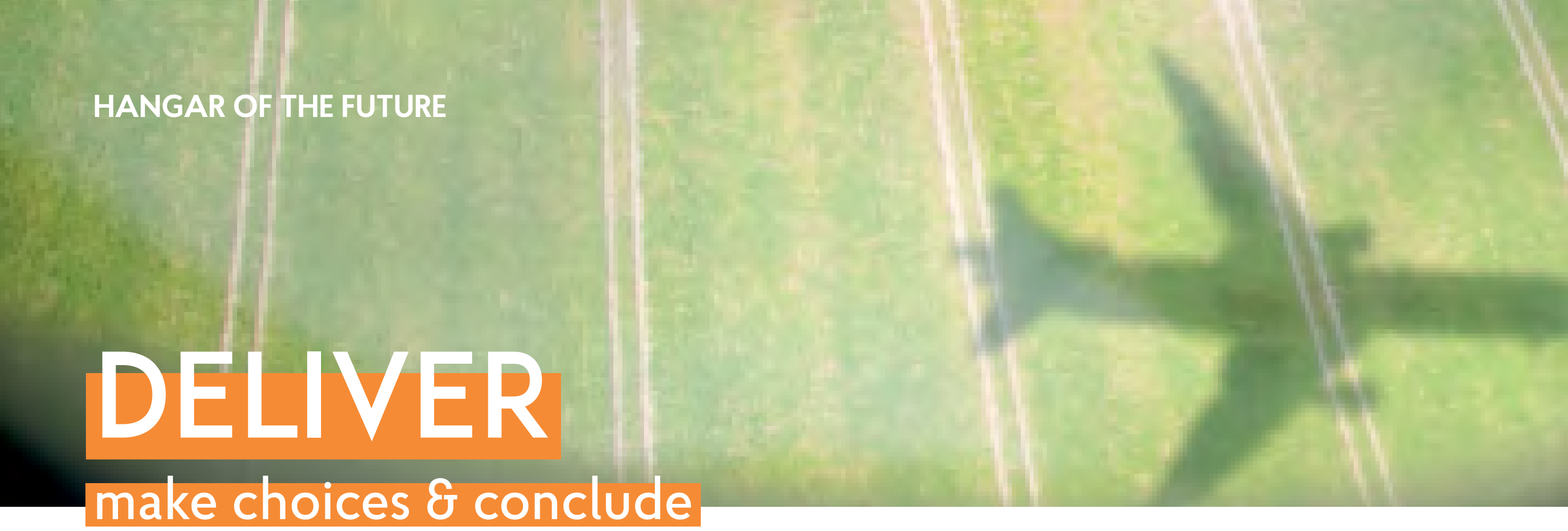
The Deliver phase was, according to me, the crucial one as important design decisions were made during this time. Taking input from all the research and converting it into suitable solutions was done using a carefully considered methodical approach with enough room for creativity.

Brainstorming gave rise to ideas that wouldn't have been so obvious otherwise. Though only a few of these many ideas were carried forward, it was necessary to have options to choose from in order to be thorough. Dividing the brainstorming and ideation into the three chosen problem statements was a logical choice. It was kept in mind that while going further, the three solutions should be at a similar level in terms of how far into the future they would be. The reason for this was that the Hangar of the Future is imagined at the same time into the future (tentatively five years) for all the ideas.

Roughly 5-7 ideas each for Inspection, Movement, and Process were explored in more detail by research on the internet and discussions. This was done in order to get a clearer idea of their feasibility, development costs, availability of technology, etc.

Among these promising ideas, further choices were still to be made. The Datum method was chosen for this purpose due to its ability to compare several ideas at once in a purely relative manner. The output of the Datum method was clear and useful. Moreover, it was in tune with my intuition, which was satisfying for me as a designer. Firstly, the Full Visual Inspection Robot or further referred to as the Inspection Cobot was found to be the most comprehensive solution with the right balance of feasibility and innovativeness. Secondly, the AGV Tug for accelerating the movement of materials and tools would be a solution that already exists in other industries (eg. logistics) but needs some adaptation to use in the hangar, especially for pulling workbenches or cabinets. Finally, the Screens on Workfloor was the most practical choice among the alternatives which required much development without promising higher effectiveness.

At this level of choice and descriptive detail of ideas, a more than satisfying output of the Develop phase was reached. This was the ideal starting point for the Deliver phase to detail the ideas out further, make design decisions for each one, and convert them into concepts.



DELIVER

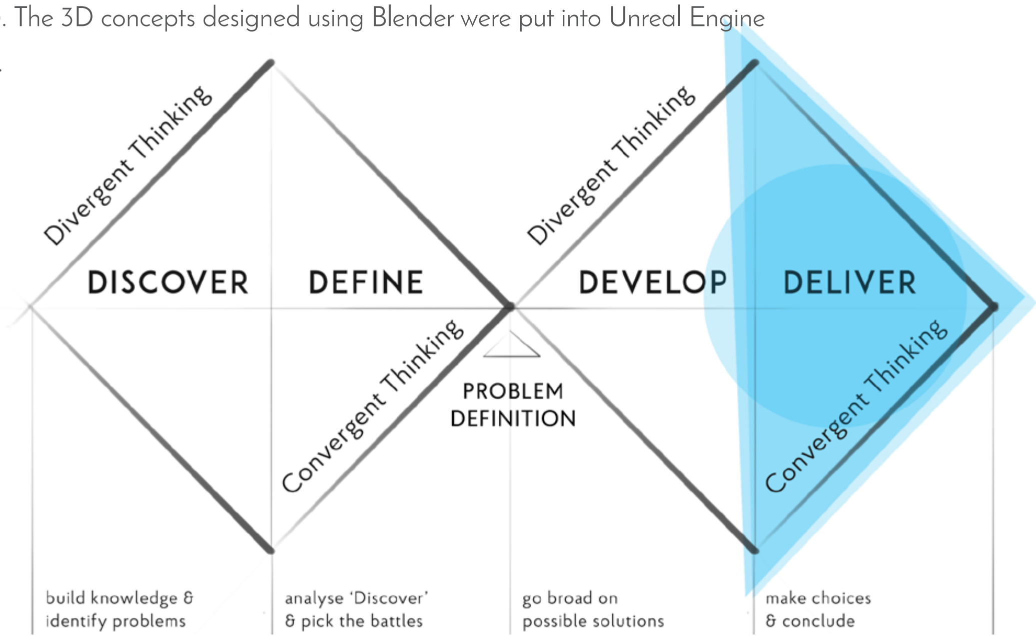
make choices & conclude

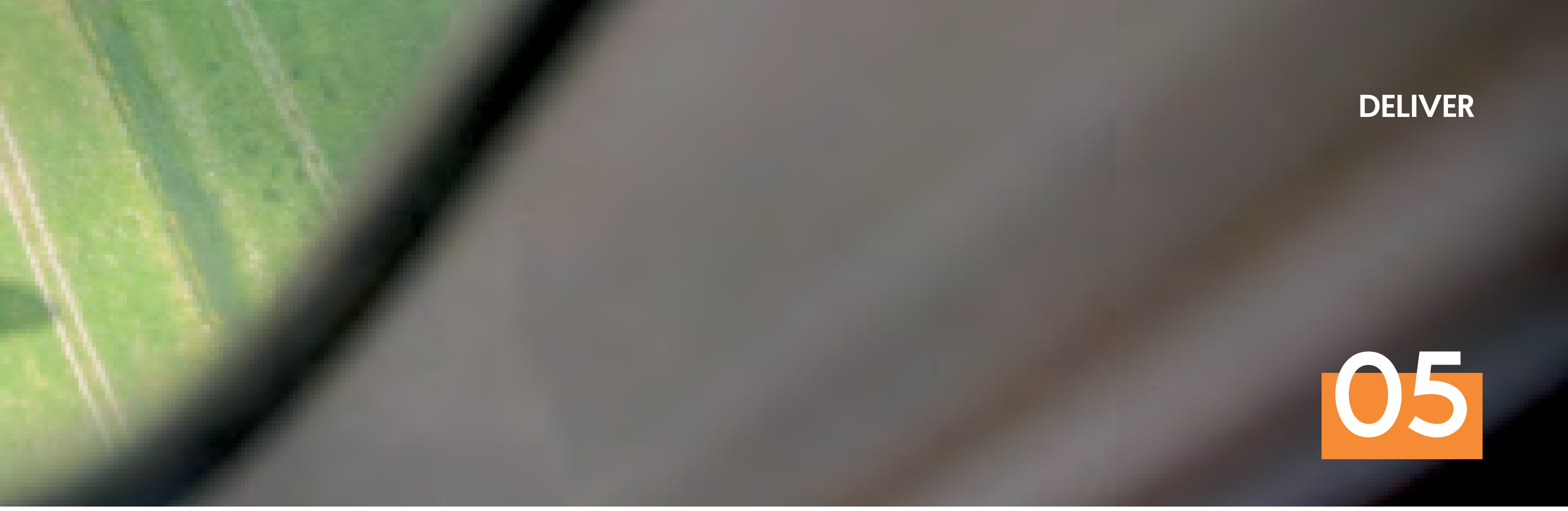
5.1 Introduction

The Deliver phase is the final part of the Double Diamond method. The solutions for the problem statements were already decided at the end of the previous phase. After that point, various aspects of these individual solutions were researched further and related design decisions were made. Since this was a converging phase, it was preferred to come to conclusions and concretize the concepts.

The solution ideas were initially converted into visual 3D models to test them in the virtual hangar environment and present them for discussion. After receiving feedback about their functionality and aesthetics, a further iteration was carried out to improve upon them. To demonstrate how they would be interacted with by the team members, storyboards were made for each of them. These storyboards also served as a starting point for the story to be presented using the virtual hangar. A round of validation was carried out using a questionnaire with qualitative input from the Plant X team. Feedback from this was used to finetune the concepts wherever possible. Due to limitations of time, priority was given to adding value to the concept first while aesthetics and VR demonstration played a secondary role.

For the virtual prototype, the 3D geometry, materials, and lighting were optimized to be compatible with a standalone VR headset (Oculus Quest). The 3D concepts designed using Blender were put into Unreal Engine for demonstration in the virtual hangar.





5.2 Goals of the phase

- ***Convert selected ideas into clearly defined concepts.***
- ***Create storyboards for the working of the concepts.***
- ***3D model the concepts and envision them in the VR hangar environment.***

5.3 Conceptualization and Results

"Befitting design is a balance between having ideas, enough research, knowing which ideas to keep, and being able to deliver."

The final deliverables of this project are the concepts that serve as solutions for the problem statements and a vision of their implementation in the hangar of the future. This is done in this phase through the means of research and design decisions, visualization using sketching, storyboarding, and 3D modeling, and ultimately demonstrating everything in a virtual hangar environment. Reasoning and methods were used to build up to this phase and there is a clear story of how we got to the selected concepts. Since it majorly involved research within concepts and their visual presentation, this was the least methodical phase of the double diamond.

The resultant concepts are intelligible, well backed up by reasoning, and ready to be taken forward for further scrutiny, testing, budgeting, more detailing, and execution.

5.3.1 CONCEPT DETAILING

The Deliver phase is the final part of the Double Diamond method. The solutions for the problem statements were already decided at the end of the previous phase. After that point, various aspects of these individual solutions were researched further and related design decisions were made. Since this was a converging phase, it was preferred to come to conclusions and concretize the concepts. The solution ideas were initially converted into visual 3D models to test them in the virtual hangar environment and present them for discussion. After receiving feedback about their functionality and aesthetics, a further iteration was carried out to improve upon them. Due to limitations of time, priority was given to adding value to the concepts first while aesthetics and VR demonstration played a secondary role. To show how the concepts would be interacted with by the team members, storyboards were made for each of them. These storyboards also served as a starting point for the story to be presented using the virtual hangar. For the virtual prototype, the 3D geometry, materials, and lighting were optimized to be compatible with a standalone VR headset (Oculus Quest). The 3D concepts designed using Blender were put into Unreal Engine for demonstration in the virtual hangar.

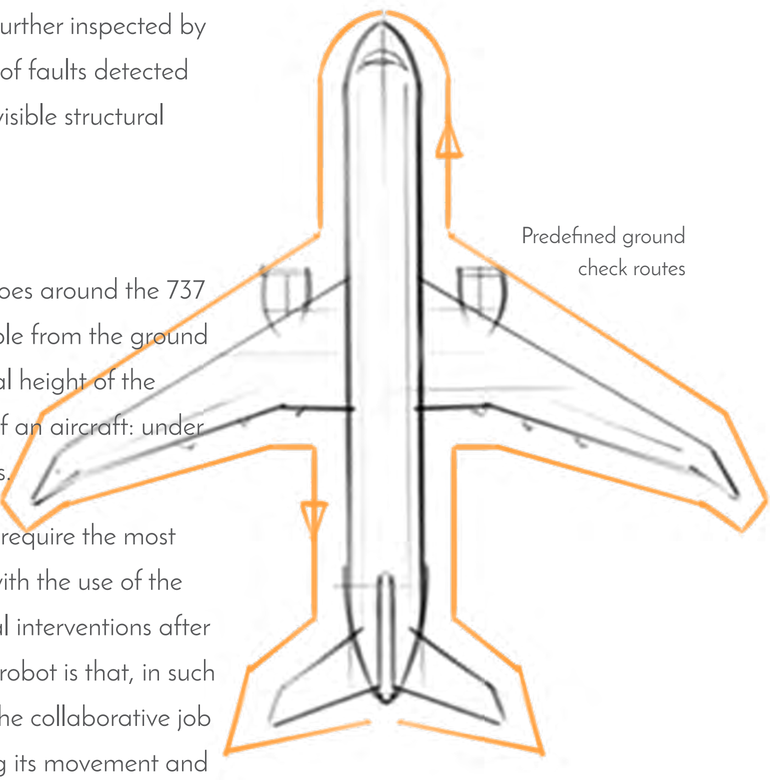
INSPECTION COBOT

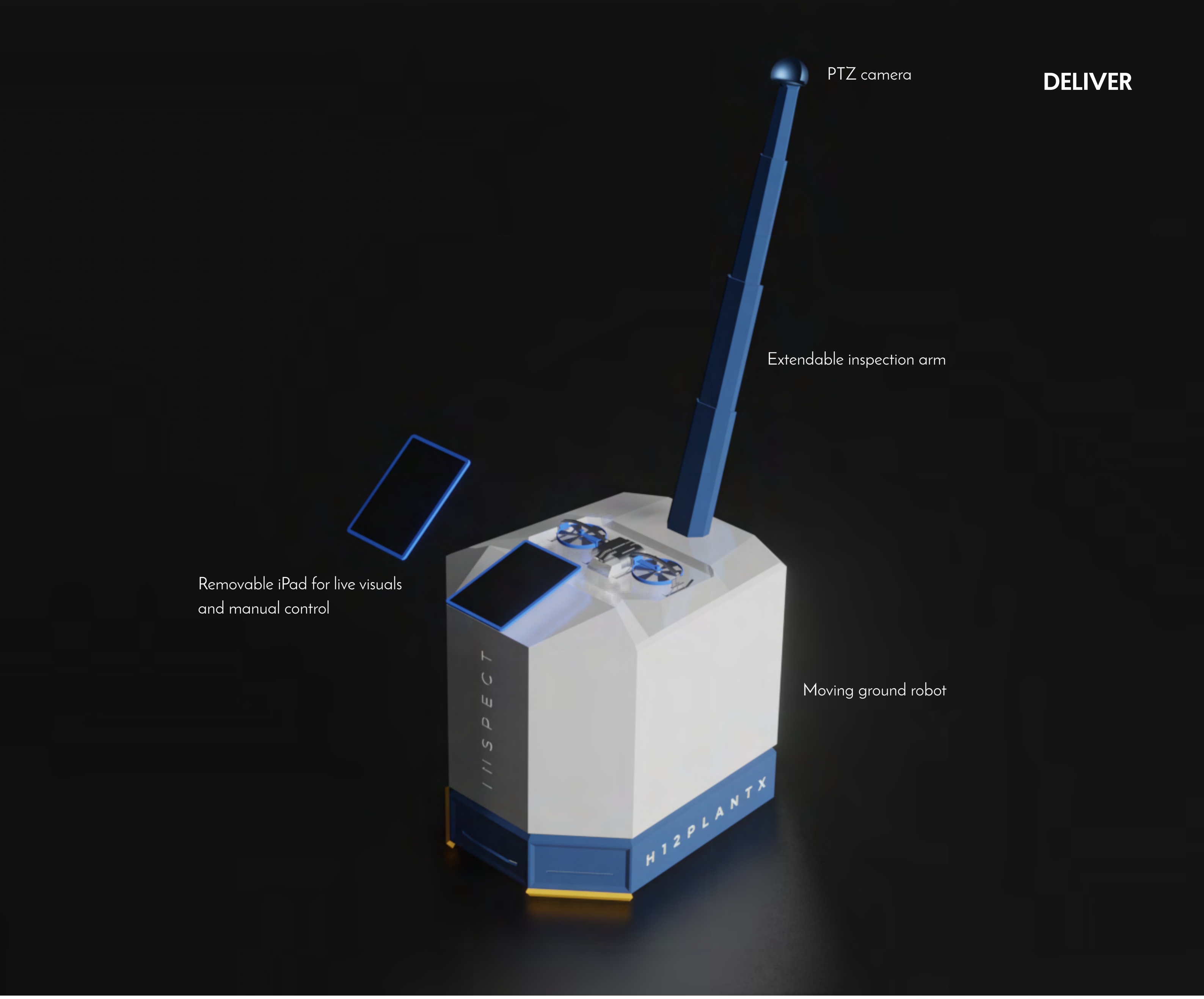
The Inspection Cobot (IC) is a robot meant to partially automate manual visual inspections (MVIs) to make them more efficient and dependable at the same time. It can visually inspect any part that is visible in the exterior of the aircraft. The operation of this robot is initially automatic where it will move on predefined checking routes to cover the entire aircraft from all sides using a ground robot and a drone. The live video can be seen on an iPad that can be taken out of its docking station on the robot. The video is analyzed in realtime and the detected faults are noted. After the automatic run, a summary of the faults is available to the mechanic and they can be further inspected by manual control of the ground robot or drone. Examples of faults detected by the IC are: surface scratches, dents, lightning strikes, visible structural damage, removed paint, etc.

Functions

Predefined check routes - Ground: The ground robot goes around the 737 and 787 in predefined paths to inspect all areas accessible from the ground upto a height of 8 meters. This is the approximate neutral height of the wingtips of the 787. This includes the following sections of an aircraft: under the fuselage, under the wings, landing gear, and engines.

The undersides of aircrafts are the areas which currently require the most amount of manual inspections. It is thus predicted that with the use of the IC, the underside will require the most amount of manual interventions after the automatic round. The reason for choosing a ground robot is that, in such cases, a stable ground robot would be able to perform the collaborative job better than a drone as less effort is required in controlling its movement and more attention can be paid to manual inspection.



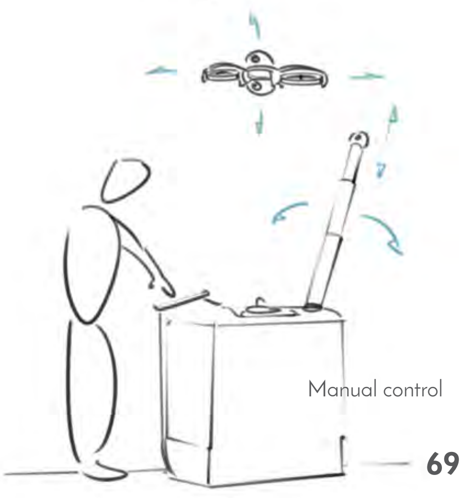


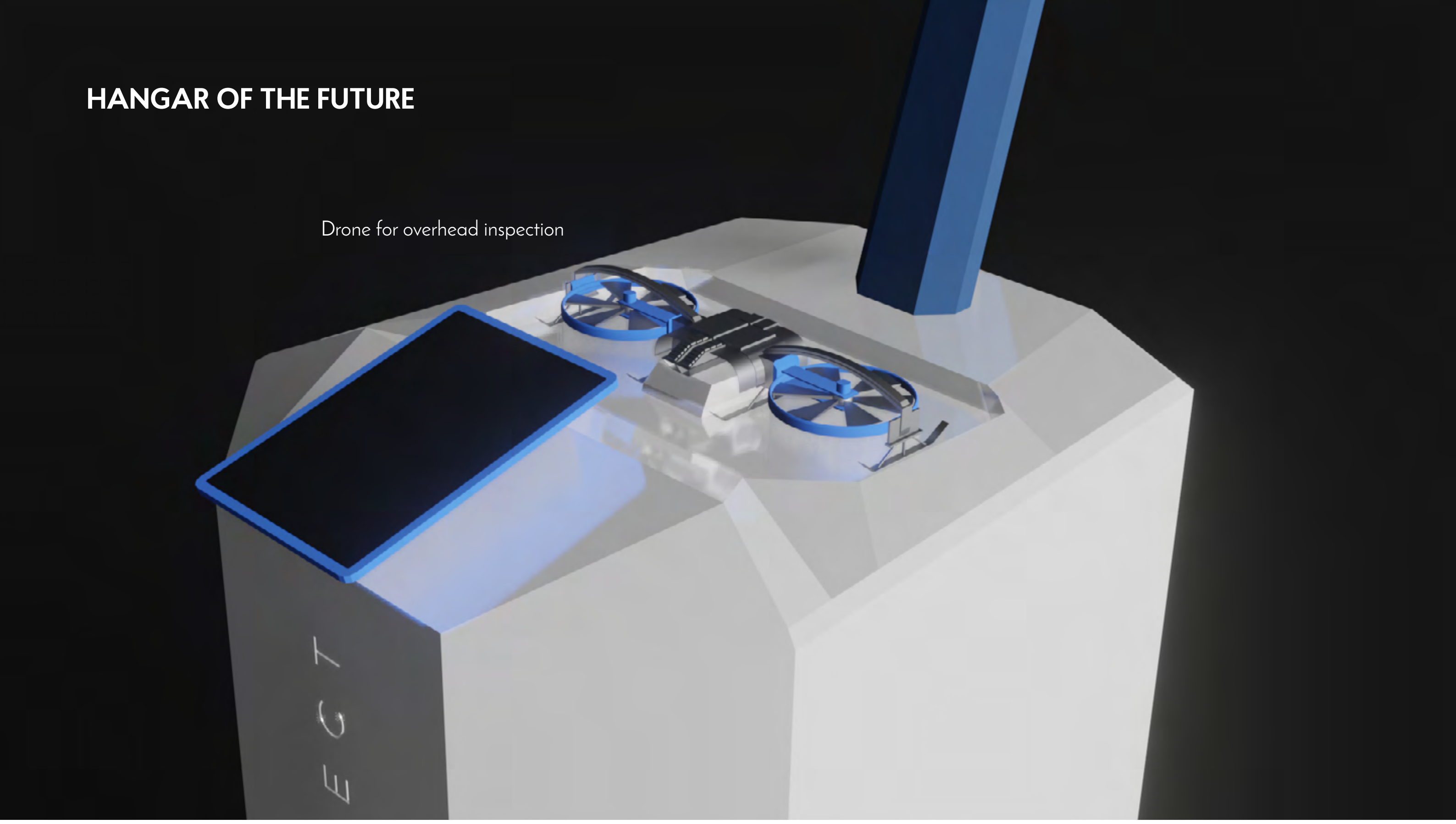
Predefined check routes - Air: The drone is able to fly around the 737 and 787 in predefined paths to inspect all areas that are not accessible by the ground robot. This includes: above the fuselage, top of the wings, nose, tail, fin, and tailplanes.

Live video transmission: While inspecting on the predefined routes, live video feed is visible to the mechanic who is in charge of the task. The video is meant to provide the mechanic a rough idea about the ongoing inspection but a more concrete summary is provided after the automatic round.

Fault notification and logging: The video feed is analyzed in realtime and the detected faults are encircled on the video (along with a sound alert) so the mechanic knows roughly where and how many locations need to be manually inspected. These detected faults are logged into a summary checklist which the mechanic uses after the automatic round to recheck with/without the IC depending on their accessibility.

Manual operation: Manual operation of the IC kicks in two cases:
• Fault detection notification: When faults are detected and the mechanic visits the logged locations one-by-one to manually inspect them.





• Pre-decided: When the aircraft is presumed to have faults in certain locations and they need to be inspected well.

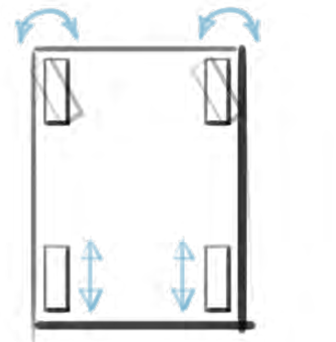
The following manual control is possible for the IC:
• 2-axis movement of ground robot
• Telescopic and rotational movement of inspection arm
• TPZ movement of inspection arm camera
• 3-axis movement of drone
• TPZ movement of drone camera

Charging: The IC is able to provide power to recharge the drone and the iPad while the IC itself needs to be recharged from an external source.

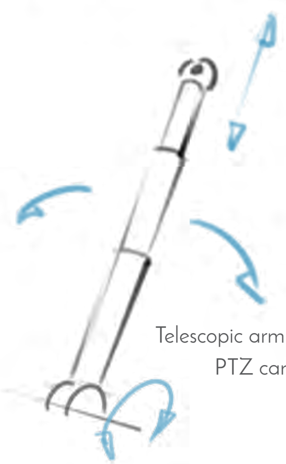
Components

Drivetrain for movement: For the cobot to be able to move on the ground, it needs a drivetrain. Using a 4-wheel drivetrain similar to that of a car, the IC is able to position itself anywhere on the workfloor. The ubiquitous familiarity of the operation of a car lets the mechanic control the IC well in the manual mode.

Drivetrain for movement



Telescopic arm with PTZ camera: Once the cobot is set in place, the inspection arm should be able to rise to the suitable height for receiving clear high resolution images of the parts it is looking at. This is achieved using a telescopic arm that extends upto a suitable height in locations where the parts to be inspected are far off. The arm is able to rotate around an axis which is parallel to the axis of the wheels so that it can access parts like the wheels closely. The tip of the arm is equipped with a



Telescopic arm with PTZ camera

Drone with
PTZ camera

PTZ camera which can pan, tilt, and zoom which in combination with the physical movement of the IC allows it the flexibility to cover all the parts of an aircraft.

Vision based navigation: The IC consists of cameras which allow it to navigate in the hangar and carry out its inspection rounds around the aircrafts. These cameras allow it to recognize obstacles and its recognition ability gets better using machine learning algorithms, just like in the AGV described later.

Drone with PTZ camera: The drone can move in all the 3 X, Y, and Z axes in the air. Just like the inspection arm camera, the drone camera can pan, tilt, and zoom to cover the entire upper side of the aircraft effectively.

Landing and storage area for drone: The drone has a parking position on the IC wherefrom it can launch during an automatic or manual inspection and land after its completion.

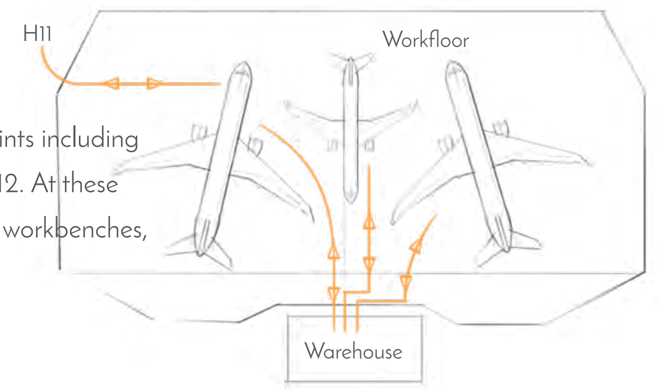
Internal components: Inside the ground part of the IC, a few more components are necessary for its operation:

• Power unit: The power unit consisting of a battery pack and charging unit is able to provide power for the operation of the ground robot. It is also able to recharge the drone and the iPad when they are docked.

• Computation and wireless link: The computation components receive input from the inspection arm (wired) and drone camera (wireless) and analyze it to further send it wirelessly to the iPad. The wireless link uses a WiFi connection between the ground robot and the iPad for live transmission of the video and its analysis. Moreover, it further sends the data wirelessly to desktop computers in the hangar where it is stored for future reference.

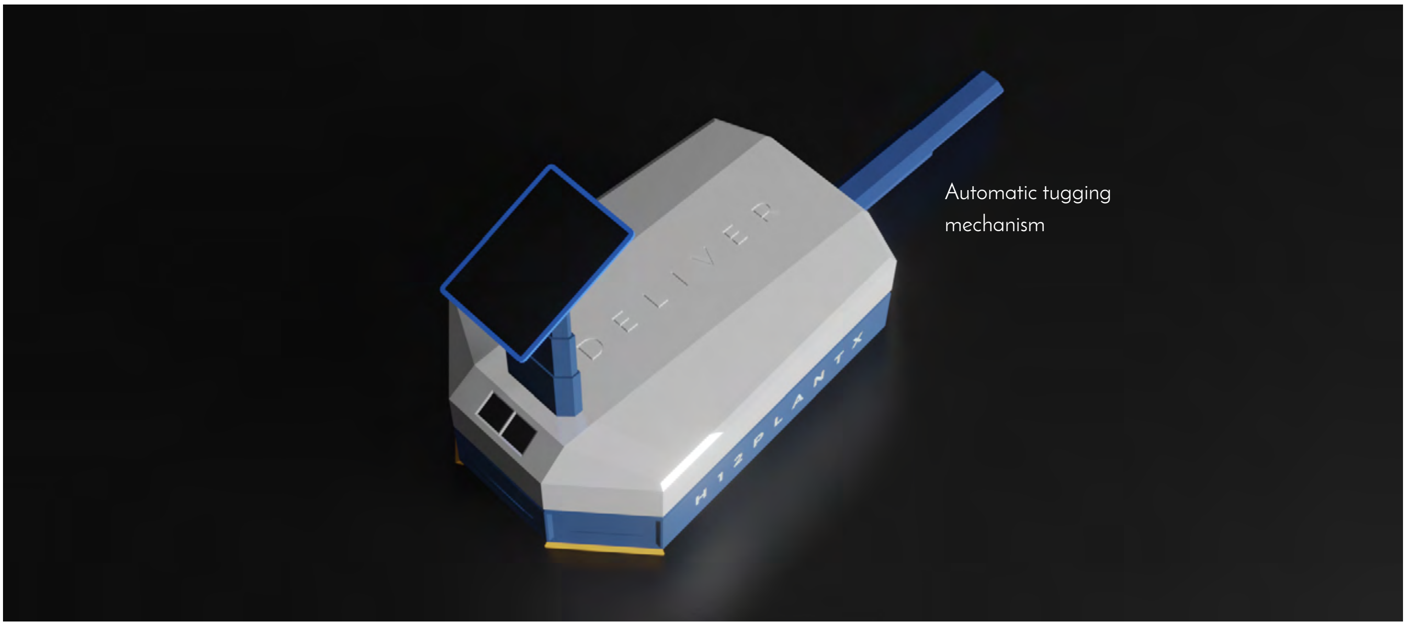
AGV TUG

The AGV Tug is a multi-purpose vehicle meant for moving carts (loaded with materials and tools), workbenches, or tool cabinets from the warehouse to the workfloor (near the aircrafts) and back. Its job is to bring the required objects to the right place at the right time.



Functions

Predefined routes: The tug has predefined starting and end points including H11 warehouse, H12 warehouse, and all 5 aircraft positions in H12. At these pick-up or dropzones, it can attach and detach itself from carts, workbenches, and tool cabinets.



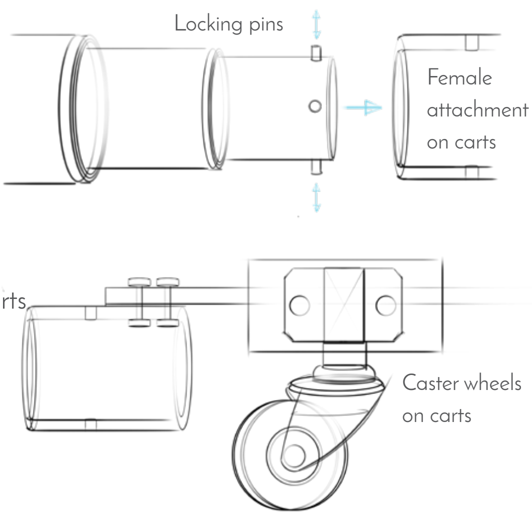
Manual control: The manual walk-along mode lets a mechanic control the AGV using an iPad. This is useful if one needs to carry a large bunch of components from one location to the other and wants to attach more than one cart (a train of carts) for this purpose.

Attach/detach carts, workbenches, tool cabinets: The AGV is able to attach and detach carts on its own. This is a necessary function for the fully automatic operation of the AGV without manual intervention.

Components

Drivetrain for movement: A 4-wheeled drivetrain, similar to the Inspection Cobot, allows the AGV to move in all directions on the ground similar to that of a car. The ubiquitous familiarity of the operation of a car lets the mechanic control the AGV well in the manual mode.

Automatic tugging mechanism: This enables the AGV to mount and dismount carts onto itself. A proposed mechanism for tugging is shown in the adjoining figure.



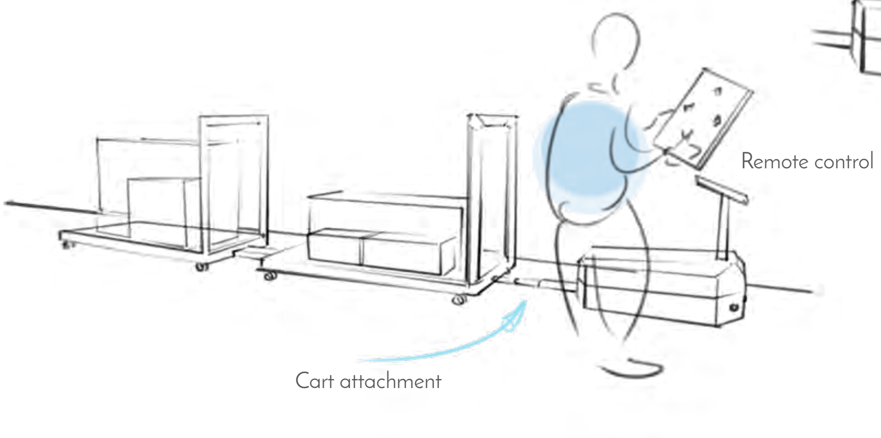
Modification of existing carts, workbenches, tool cabinets: For the working of the tugging mechanism, existing carts, workbenches, and tool cabinets need to be modified with the receiving end of the tug and caster wheels.

Vision-based navigation:

• Cameras: Cameras on the AGV are able to recognize obstacles on the path using artificial intelligence and improve its (and that of other fellow AGVs) driving ability over time using machine learning algorithms as it encounters new situations in the hangar.

• QR (object) recognition: Specific carts that need to be picked up are identified and positioned using their QR code.

iPad for manual mode: The iPad docked onto the AGV is capable of programming it to pick up carts by entering their pick-up and drop locations. The iPad can be dismounted from the dock and used for controlling the AGV in manual mode.

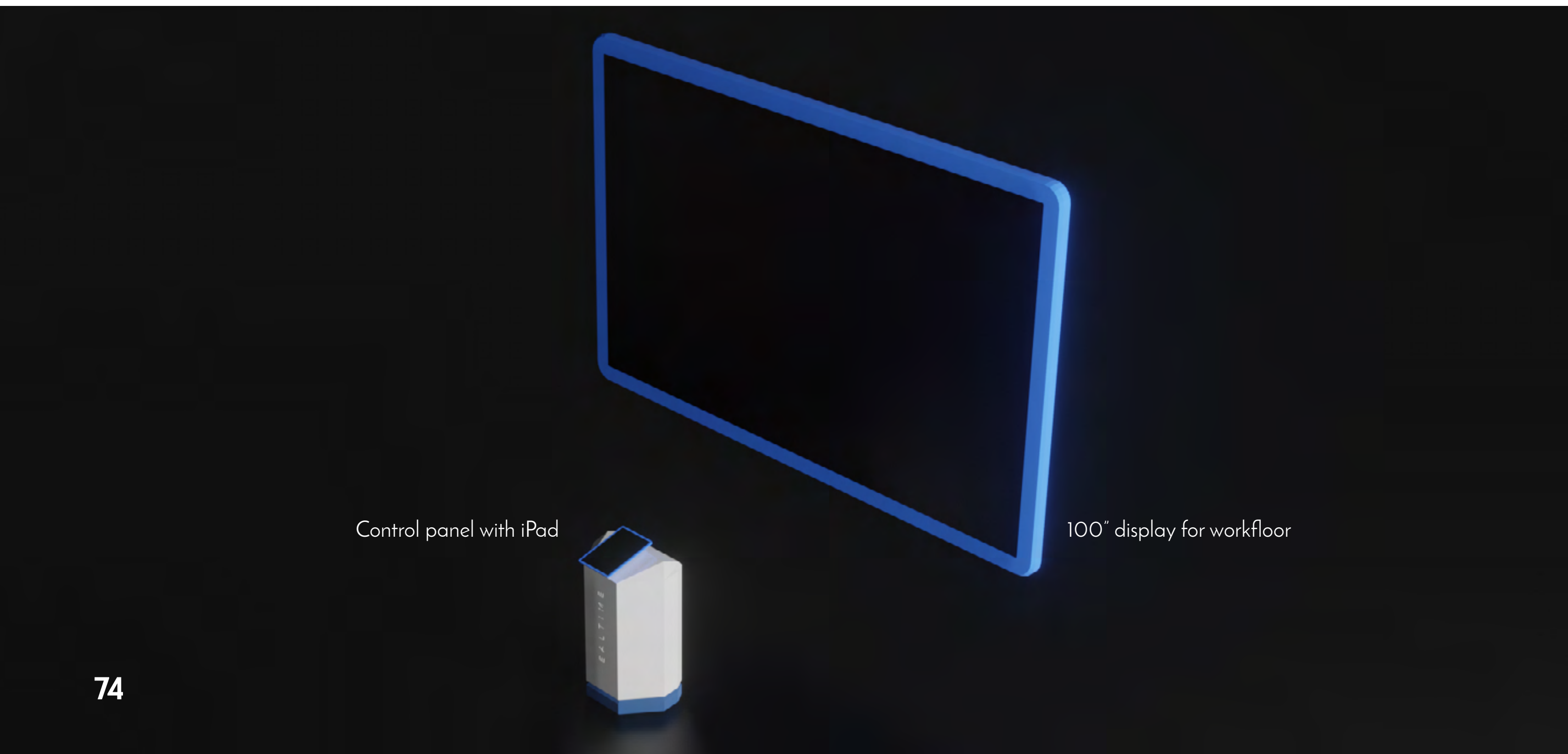


WORKFLOOR DASHBOARD

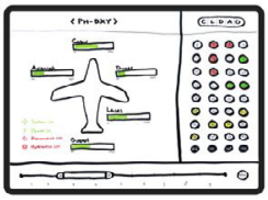
The Workfloor Dashboard is a screen visible from the hangar workfloor which displays data about the ongoings of the live checks. The data is updated in realtime to clearly communicate to the teams and leads how the check is going and what needs to be paid attention to. This is done using various kinds of information like Overview A-Check status of all aircrafts, Detailed status of particular aircraft, Presence of (task) skills, Progress graph of check, etc. shown on the next page and in Appendix G.

Functions

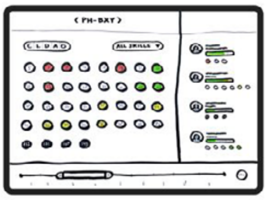
Realtime data presentation: The dashboard presents data and information which is coming in realtime from individual iPads that are used by each team member. This information is presented in such a way that it communicates the status of a check



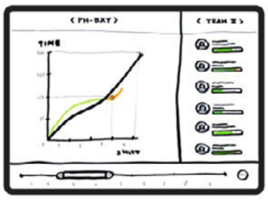
Overview status of aircrafts



Status of particular aircraft tasks

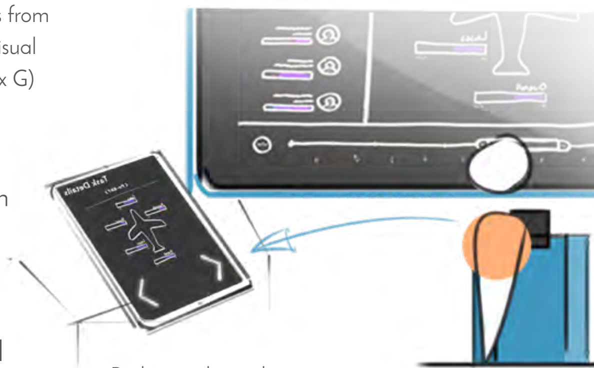


Presence of skills



Progress graph of a check

Examples of dashboard screens from research done for the Plant X Visual Management project (Appendix G)



iPad control panels

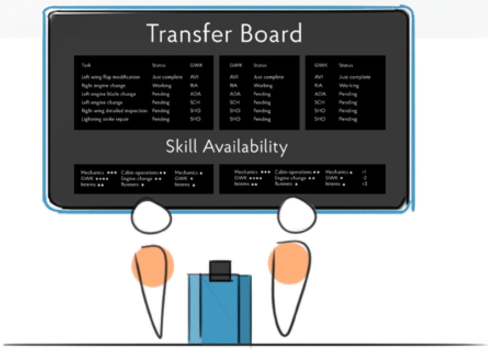
accurately with the team and team leads and helps them finish the planned tasks in a timely manner.

Interact with information: The large dashboard can show a variety of information but is limited in screen space. Thus, the screens can be interacted with at the control panel using the docked iPad to view details, change information.

Components

LED display: The main part of the dashboard is the LED display which visually presents all information. According to Easescreen (n.d.), a tentative screen size (diagonal) of 60 inches should be used to view digital signage from a distance of 5.5 m. For about the same distance, a minimum font size of 50 pt should be used. For a distance of 10.5 m, they suggest to use a font size of 100 pt. Overlapping their font and screen size distance guide, a screen size of tentatively 100 inches is selected for the LED dashboard so it is visible to the mechanics around 10 m away from it. This would save walking time when only an overview is needed and they do not need to interact with the information.

LED screen on workfloor

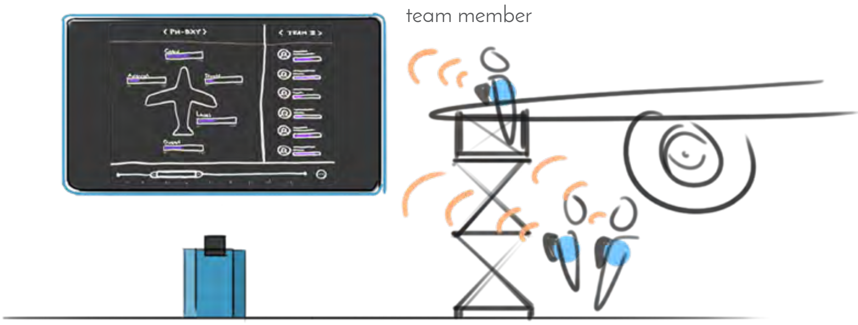


Control panel: The control panel is a podium in front of the display where an iPad is placed to interact with the information on the LED display. This is primarily for use by team leads who need more detailed information than an overview.

Wireless link to central computer:

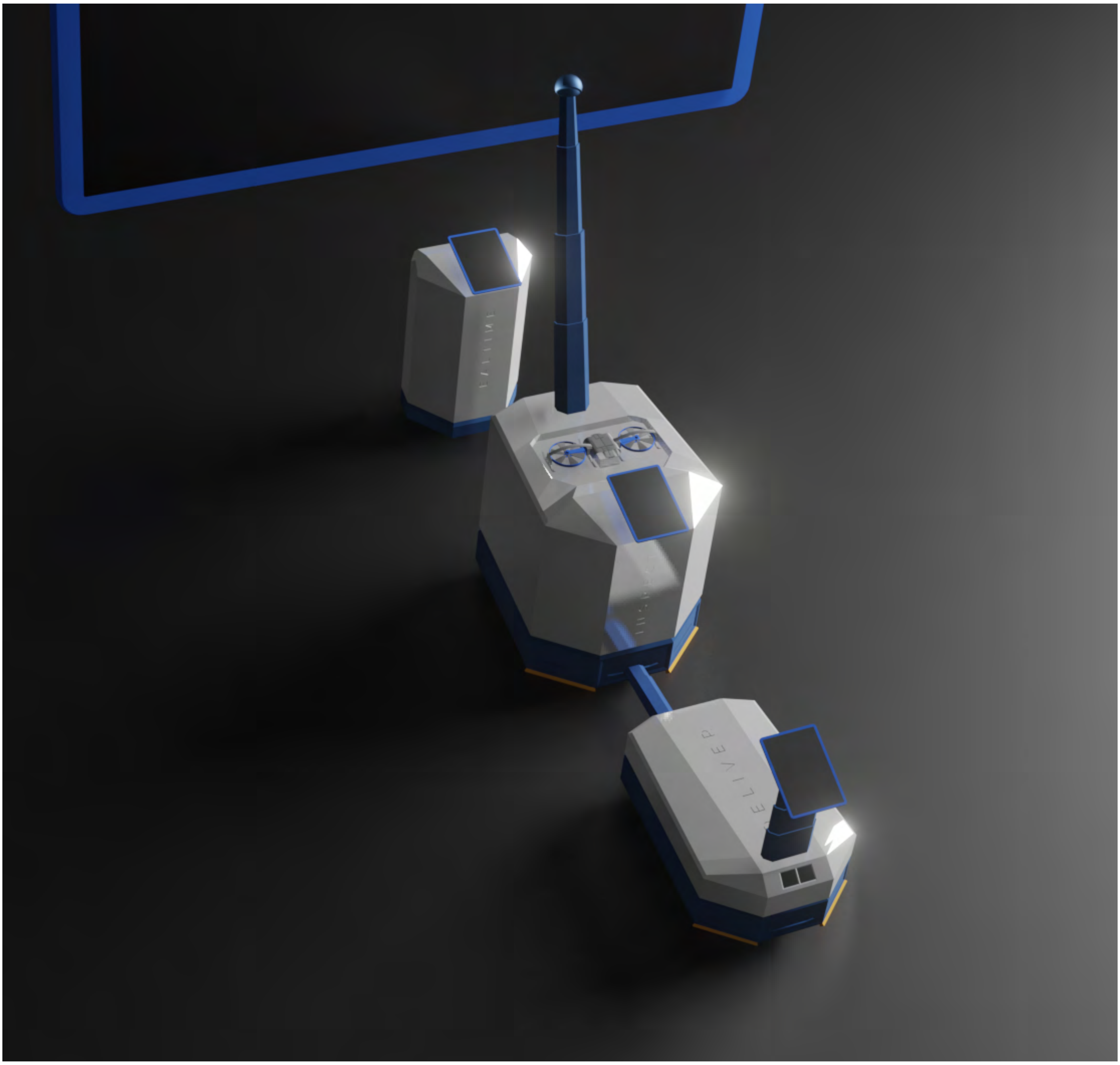
• iMech app: The iMech app is currently used to assign and pick-up tasks to mechanics. The skills required for a task are stated along with the duration they would take. It is also able to track which tasks are complete and carry forward this information to a central computer. This central computer is where the data will be processed and transmitted in a presentable format to the dashboard.

Connected to each team member



INITIAL VISION

Compiling the concepts described in this section, the initial combined vision is shown in the following renders. These 3D models were a way to present the concepts to the team and gave rise to valuable feedback. It was aimed to show that the three concepts, though address different problems statements, can have common elements like the iPad and the design language. Thus, they can fit a unified vision of the future hangar. The lack of human interaction shown in the renders is addressed by the use of storyboards made before going to the next iteration. The looks of the concepts are quite simplified and old fashioned at this point and this has also been taken into consideration for the next iteration. Hence, this initial conceptualization proved to be important in order to gain insights and deliver improved designs further on.



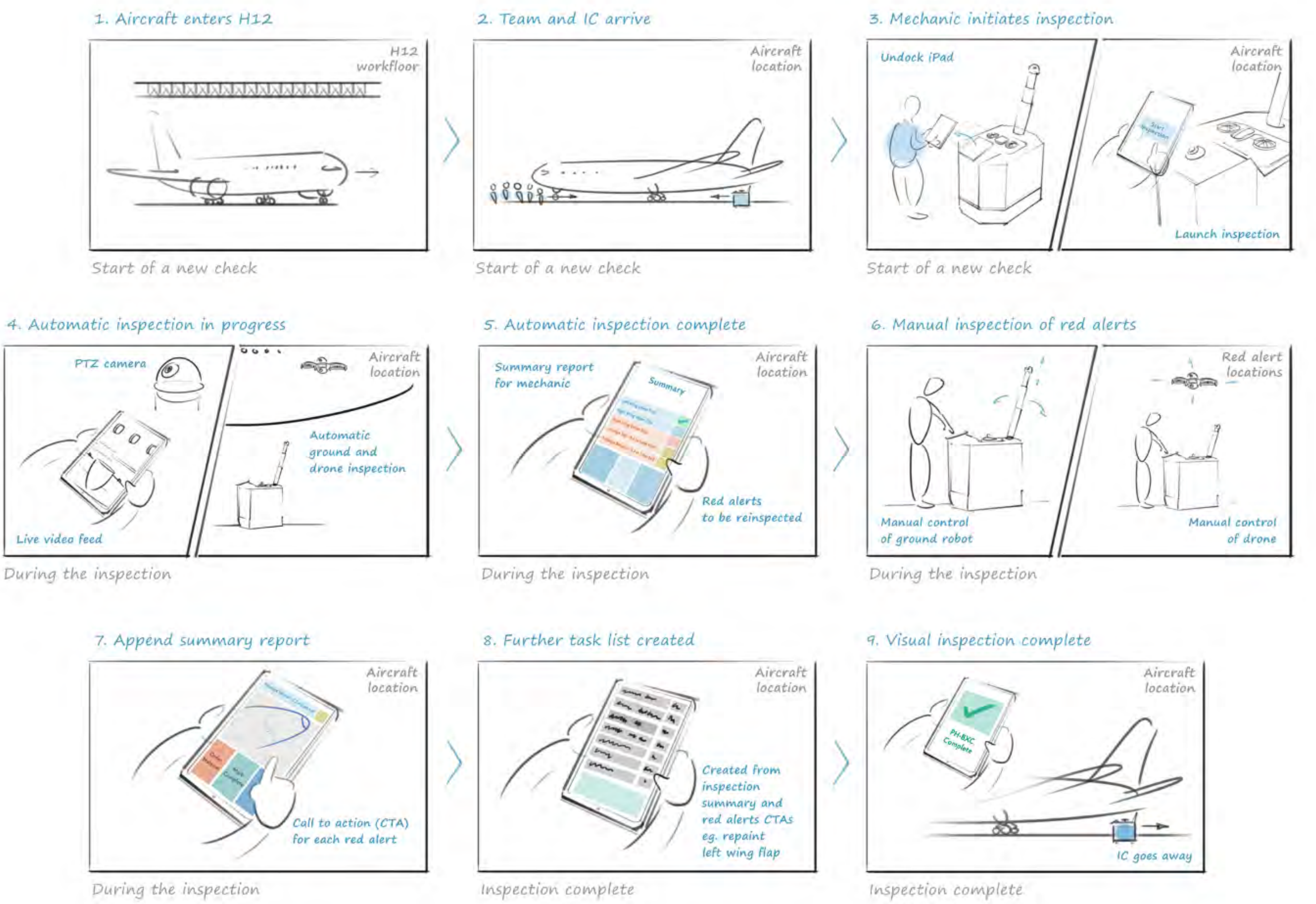
Renders of the concept family from an initial concept presentation session

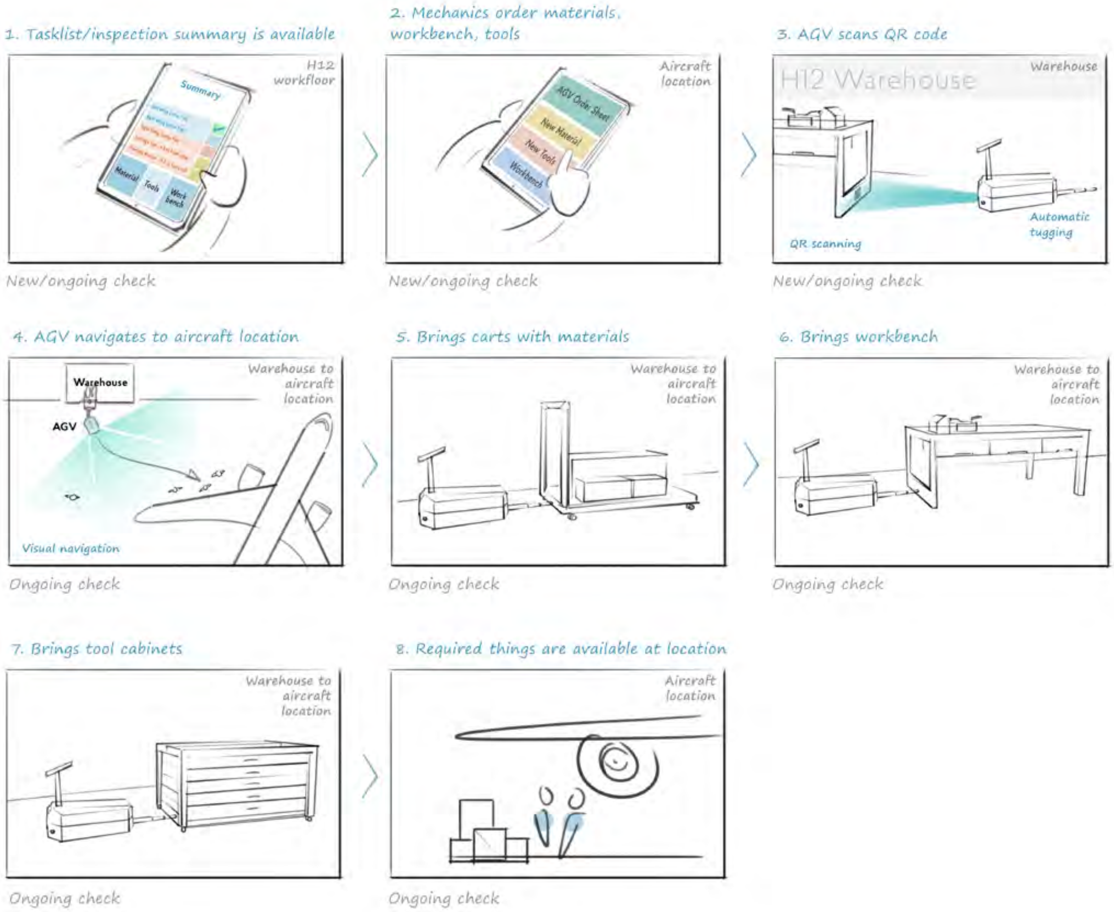
5.3.2 STORYBOARDING

To communicate the working and use of the concepts effectively, storyboards were created for each one. These show the moments of both automatic functions and human interaction with the concepts. The use of the concepts by the team is an important aspect to understand the actual use cases in the hangar scenario or a 'day in the hangar'. The user journey and interaction touchpoints were laid out for each concept. The same storyboards were also found to be useful in creating the virtual demonstrations of the concepts in VR. Several insights were gained by making these storyboards for each concept as stated in the following.

Inspection Cobot

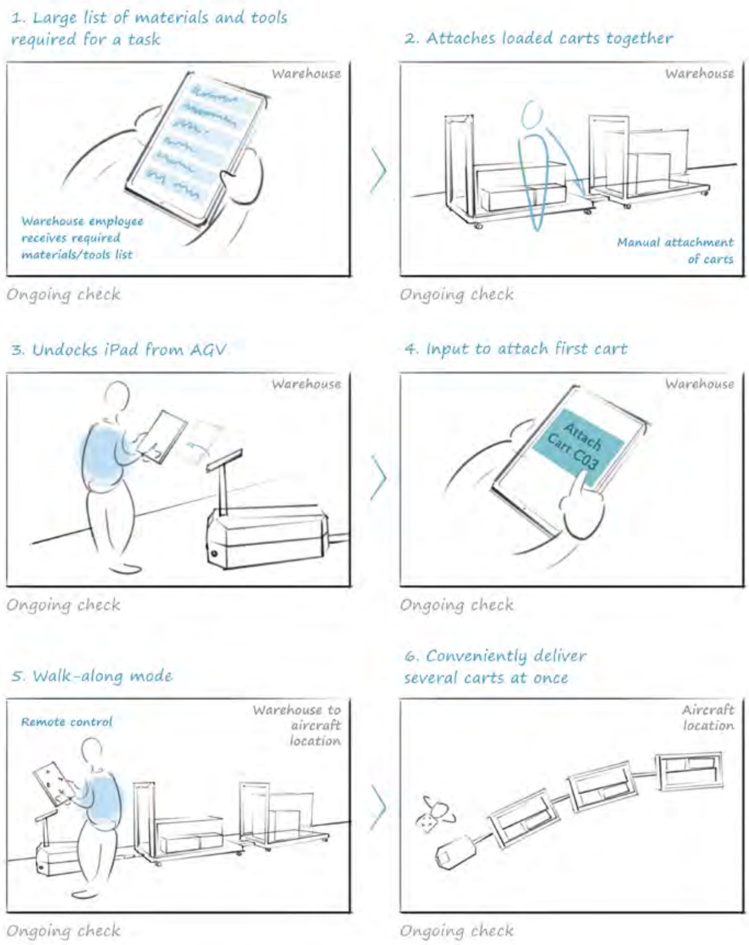
Since this concept requires both automatic and manual functions, it was clarified with the storyboard which parts of using the concept are automatic and where manual intervention would be required. From the beginning to the end of an inspection, all steps the Inspection Cobot would carry out were clearly understood as the story was mapped out. Several steps within the inspection require using the iPad. Rough examples of what options the app on the iPad would have were thought about for some frames.





AGV Tug

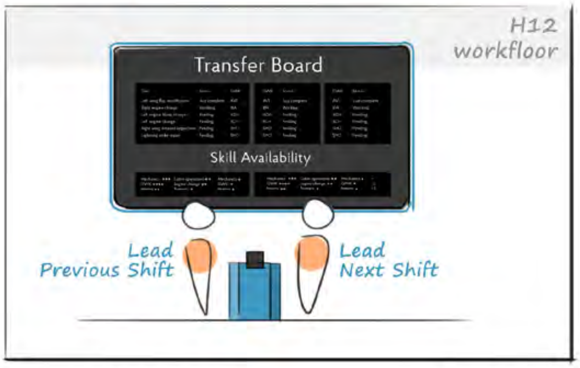
Like the Inspection Cobot, the AGV Tug also requires some manual steps before its automatic functioning. How this manual interaction with the iPad would be, followed by the tugging of carts, and the AGV's journey to the workfloor was understood. Moreover, the interaction during the manual walk-along mode of the AGV while bringing a larger batch of carts was mapped out. Steps like attaching multiple carts, which would have to be manually done, were thought about, which could've been missed if a storyboard wasn't made.



Workfloor Dashboard

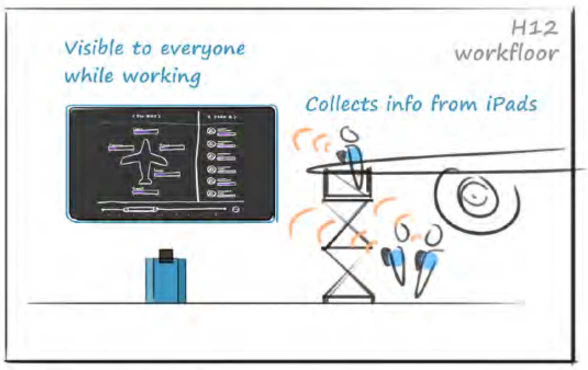
The Workfloor Dashboard is a rather static concept compared with the other two. Since it is a screen, most frames of the storyboard show examples of what information would be on the screen at what point of the interaction. Who (lead/engineers/mechanics) would be interacting with the screen in what form (viewing/control panel/filling in information on iPads) was defined. At the times when either the control panel or the team members' individual iPads are interacted with, examples of interaction on the iPad screens were also thought about to make the storyboard complete.

1. Work package transfer/discussion



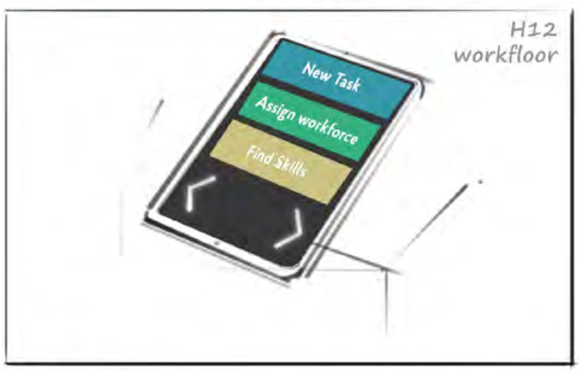
Start of new shift 10:45 pm

4. Realtime updates on dashboard



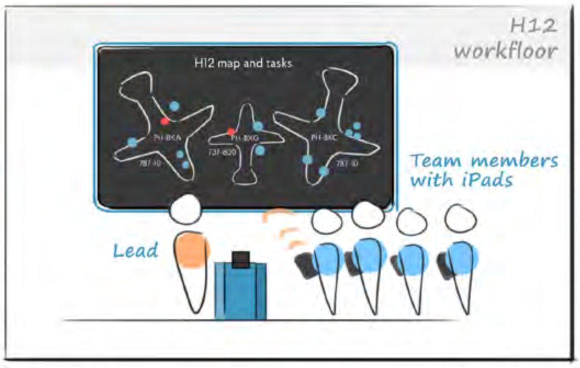
During the shift

9. Leads take action in realtime



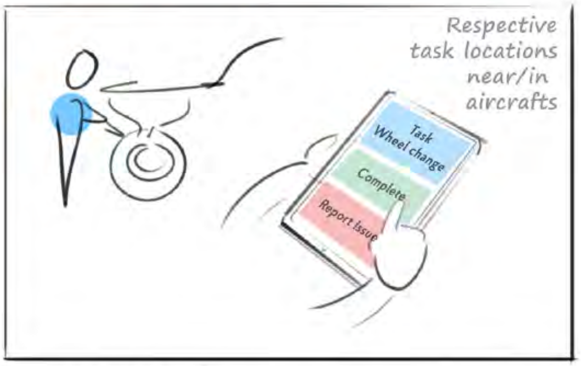
During the shift

2. Work distribution



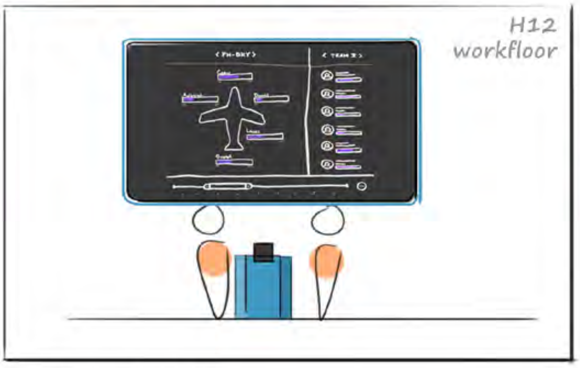
Start of new shift 11:00 pm

3. Team updates personal task status



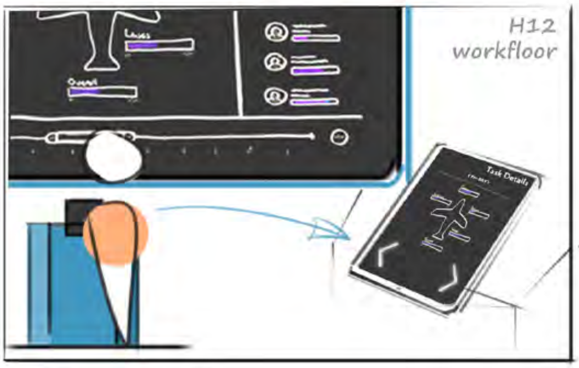
During the shift

5. Leads/team check live status



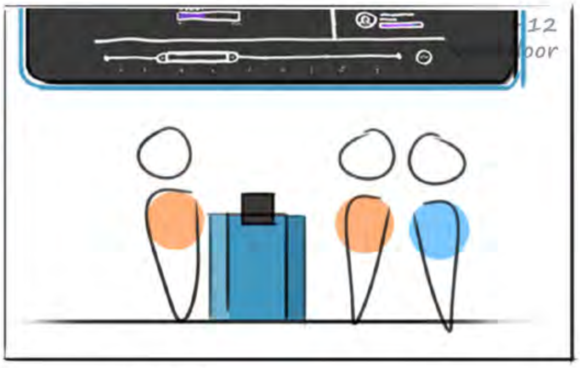
During the shift

6. Interact with various info



During the shift

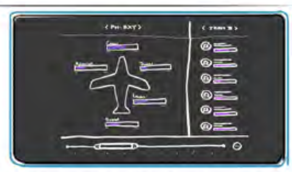
8. Convenient communication/discussion with visuals



During the shift

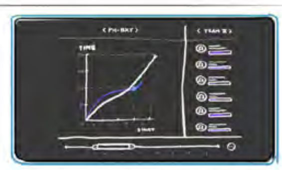
7. Different types of info available

Overview of checks



Status of individual aircraft

Team availability



Check progress graph

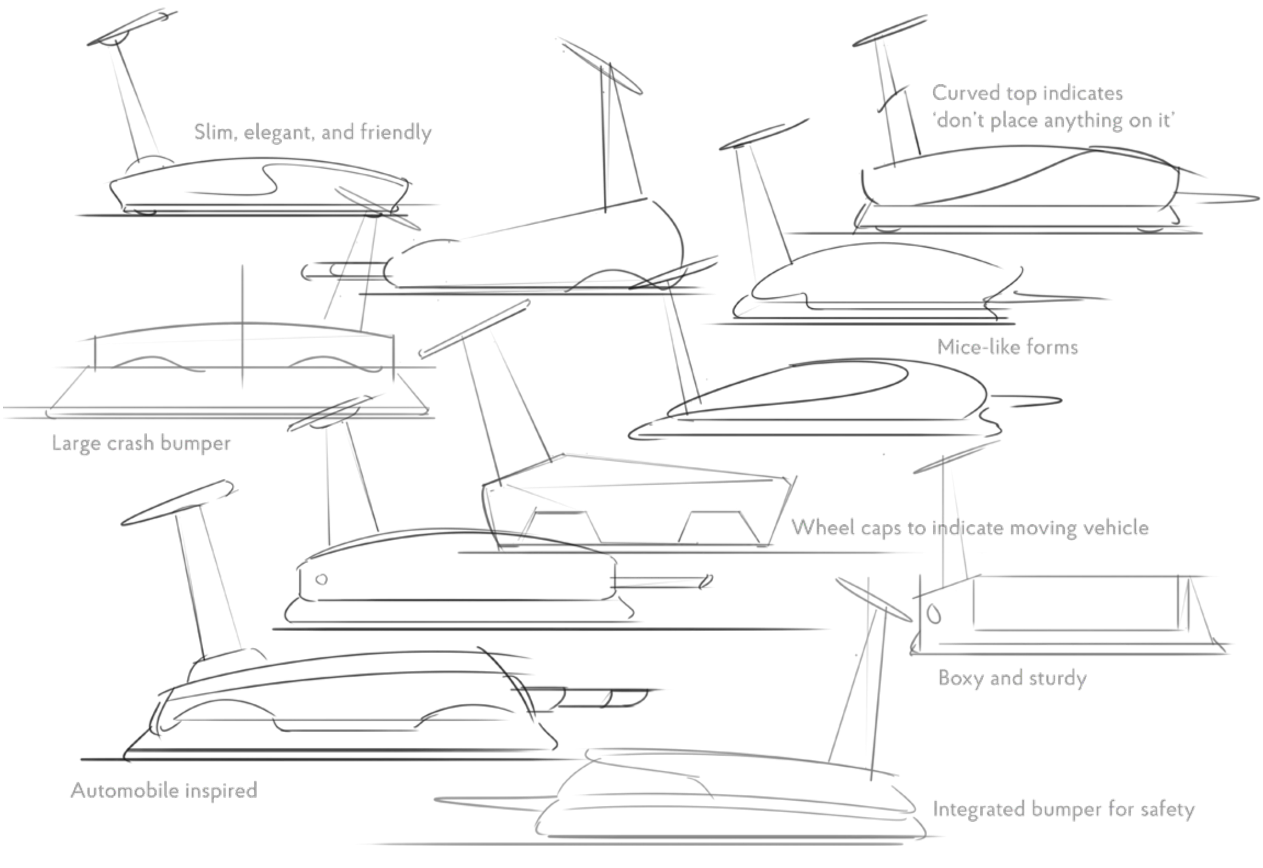
5.3.3 FEEDBACK EXECUTION AND CONCEPT IMPROVEMENTS

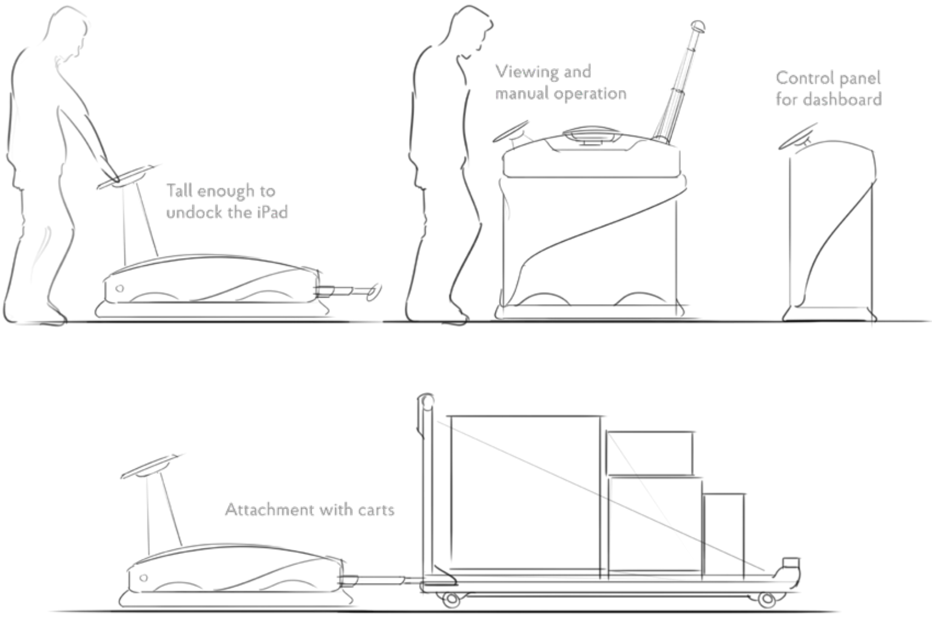
After a round of feedback on the initial concepts and storyboarding, the concepts were updated in their functionality and look and feel on various discussed points. The method of doing so was by sketching various ideas, choosing a design language, and synthesizing all the concepts into this language. The details which remain the same have not been reiterated in this section but the updates and their reasons are described sufficiently.

Exploring look and feel: For the initial concepts, their look and feel was not given much importance. Exploration was not carried out and only basic, low-poly, functional forms were chosen to illustrate how things would work. The design language of these initial concepts was found to be old-fashioned and boxy.

Going forward, along with some critical feedback, it was decided to update the language into something that is more friendly, smooth, and modern yet simple. Noting that the Inspection Cobot and AGV Tug are robots on wheels, their ability to move was to be communicated through their looks. Moreover, sharp edges were to be avoided to avoid injuries in case they happen to collide with people. The iPad on the Dashboard control panel should feel comfortable to interact with while a person stands in front of it. These details related to human interaction were kept in mind in the coming iteration of design.

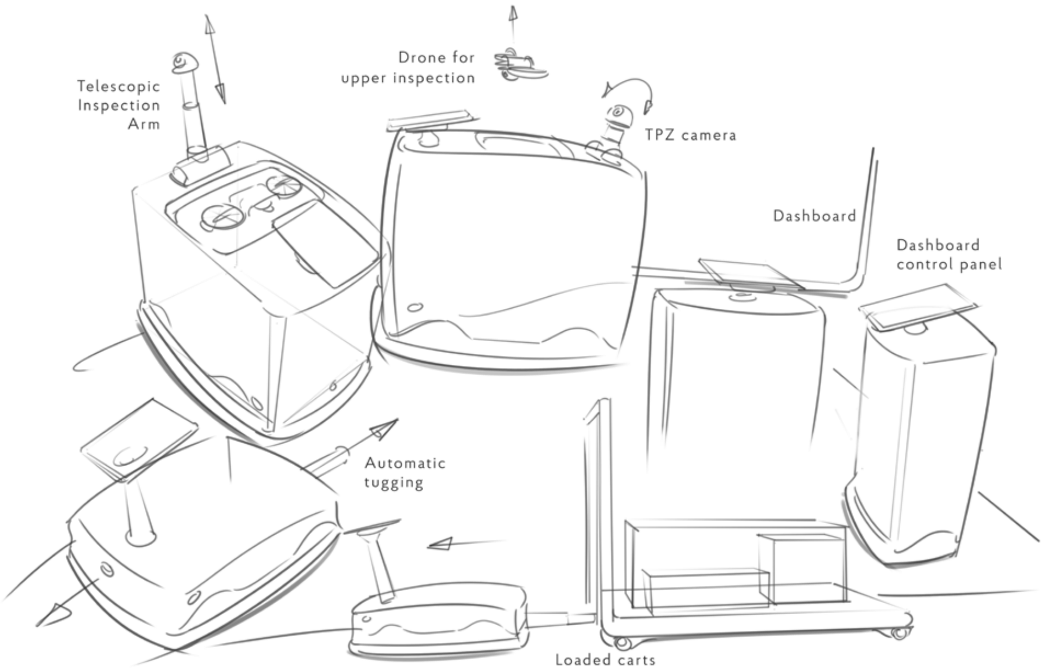
Inspiration was taken from fast moving automobiles, moving robots of various kinds, and sleek modern industry machines to sketch and ideate various forms. This was done using side profile views and further details were added in perspective sketches of the chosen form. The selection of the design language was on the basis of its gentleness and simplicity, friendly form, elements signifying movement, and modern look.



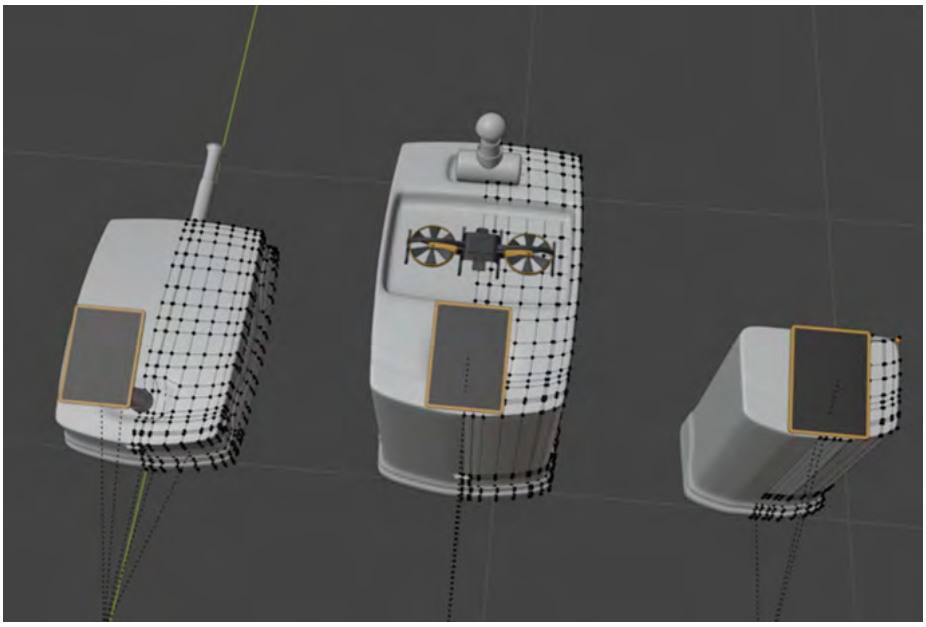


Side profile concept sketches were made along with human scale to understand the proportions and tune them for interaction.

Perspective sketches in the chosen design language were made to illustrate the concepts in 3D space. This helped in understanding some functions and configurations of the concepts better like the placement of the drone or the movement of the telescopic inspection arm.



Screenshot of subdivision modeling in Blender



After perspective sketches of all concepts, their 3D volume was clear to myself and I was able to convert them into 3D models using subdivision modeling in Blender. They were given basic materials in order to render and present them. The feedback on the new design language was positive and sufficient improvement was seen compared with the initial concepts. Given that aesthetics were not the primary concern of the project, it was agreed upon that the design was at an adequate level for the final concepts.

Collective Vision

The concepts were developed while keeping a balance such that they are not too far from each other in the sense of how futuristic they are. They are a part of one encompassing vision of the hangar, thus, it was also a conscious decision to use a coherent language for their designs. They also have common goals of providing innovative solutions by using technology to increase efficiency and provide better ergonomics to workers. Thus, making them look like they are part of the same family made complete sense. The 3D models created in Blender were rendered out for presentation and documentation after assigning some basic materials and colors.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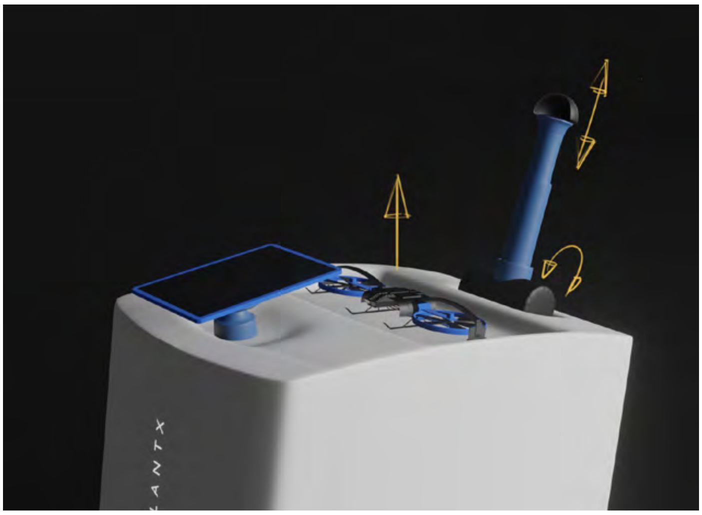

Updates in Inspection Cobot

The Inspection Cobot was questioned on several aspects during the discussions. One of them was that it did not look like a moving object. To address this, various ideas were sketched out but the one that stuck was to add embossed wheel caps to the outer casing to signify movement. A more aerodynamic overall design language was chosen to accentuate the same and increase the safety during collisions. A bumper that surrounds the IC in all directions was added at the bottom for safety of the IC and people around it. The IC uses optical navigation and this was indicated by bumps added for cameras in the front bottom half of the outer body. The telescopic inspection arm was made cylindrical since that went the best with the new smooth design language. This helped communicate its extension movement more clearly. Moreover, the hinge around which this telescopic arm can rotate is now shown clearly using a cylindrical base. The height of the IC was derived from human interaction sketches where one is either using the iPad touchscreen or undocking it from the stand.

Updates in AGV Tug

The updates in the design language in the IC were taken originally from the new design language of the AGV.
The AGV was more convenient to sketch out as a moving object due to the resemblance of its volume to that of an automobile. For this reason, the wheel caps, bumper, smoother edges, and more curvy features are similar to the ones in the IC. The telescopic tugging arm at the back of the AGV is made cylindrical similar to the telescopic inspection arm in the IC. The height of the iPad was derived from human interaction sketches. It is lower than the iPad in the IC or Dashboard control panel due to this one being used only when it is undocked. It was made sure by the use of sketches and simple experimentation that the height would be sufficient for docking/undocking.

Updates in Workfloor Dashboard

The Workfloor Dashboard was the concept which was updated the least out of the three. The design language of the control panel simply followed that of the Inspection Cobot and the AGV Tug. The design of the screen remained unchanged as it would be a technical choice that comes later rather than an aesthetic design. However, in the concept sketching and 3D modeling, more attention was paid to ergonomics and use of the iPad on the control panel. Majorly, this concerned the height of the podium and this was estimated by using human figure sketches in a position that would be used to interact with the iPad. For the sake of ergonomics, this aspect should be practically tested during further development.

5.3.4 EXPERIENCE PROTOTYPING

One of the chosen ways to present the concept falls in the category of Experience Prototyping. It involves situating a product/service prototype in the context of use (van Boeijen et al., 2020). In such a way, designers can explore and communicate how everyday situations with the concepts could look and feel like.

In a project like the hangar of the future, a massive budget, team, topical understanding, and time would be required to make real-life working prototypes. In the timespan of the graduation project, it was simply not possible or within the scope to get to such a Technology Readiness Level (TRL). Among the conceptual prototyping methods, due to the need for the concepts to be presented in a much larger and specific environment like H12, the method that is now named Experience Prototyping was found to be the most appropriate since the start of the project. For these concepts, this `experience´ is the virtual version of prototypes of the concepts in the form of 3D models and animations presented in a virtual version of H12.

Initially, it was aimed to get to a level where these virtual prototypes of concepts would be animated and interactable in the virtual hangar using a VR headset. However, in the middle of the project, it was found that acquiring the expertise required to do so while implementing it would not fit the timeframe as well as planned. This was aggravated by the Covid-19 situation (work from home) and unavailability of powerful workstations that would be required for optimum execution.

I still had the ambition to try out virtual prototyping and completed the virtual environment of H12 in Unreal Engine in which the virtual prototypes were placed and viewed. As an alternative to animation in Unreal Engine (which was taking an excessive amount of time to learn), I animated the 3D models in Blender and ended up with a self-explanatory showcase video (Dalal, 2020) wherein the functions of the concepts are shown first, followed by showing the concepts in action in the 3D hangar environment. The choice for animation was changed from Unreal Engine to Blender not only due to the time constraint but also because of a recent update (Blender 2.83 LTS) in the software with supports scene inspection using VR (Blender Foundation, 2020) and looks promising for future use. In the end, the showcase video turned out to be perfect for an explanation of the concepts and to serve as a visual aid during the final presentation.


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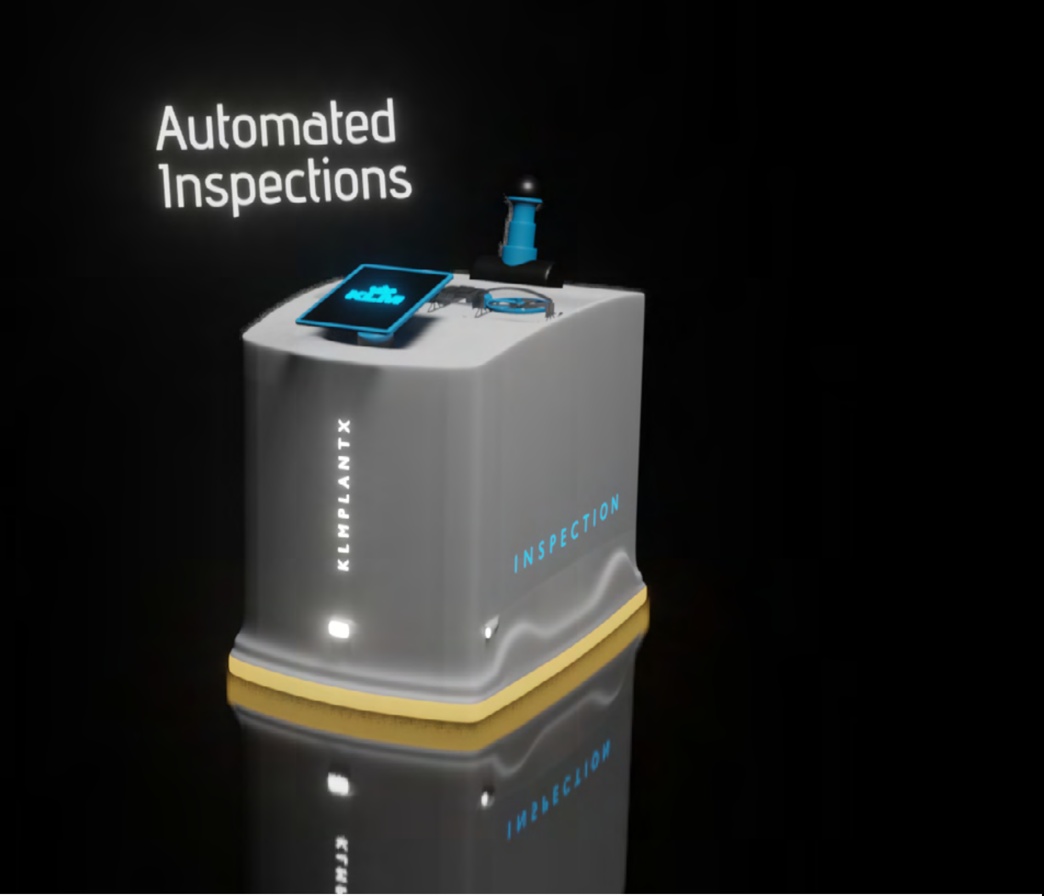
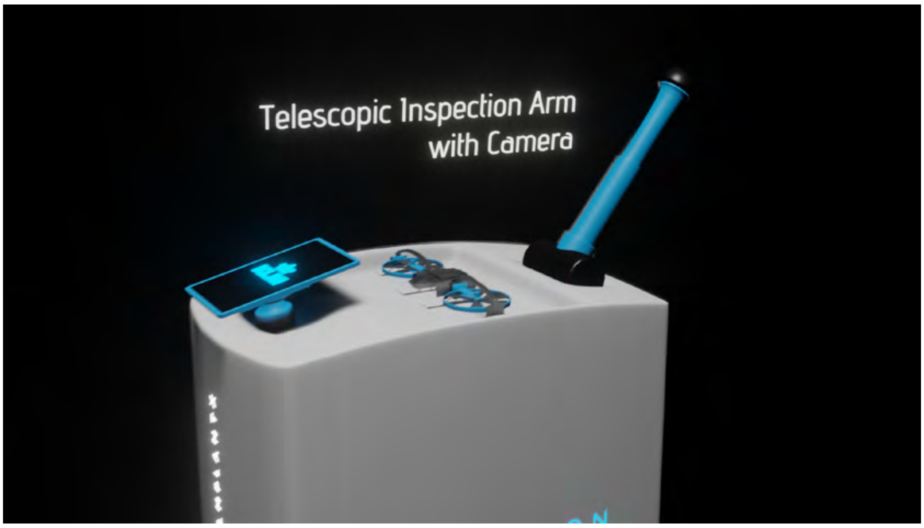
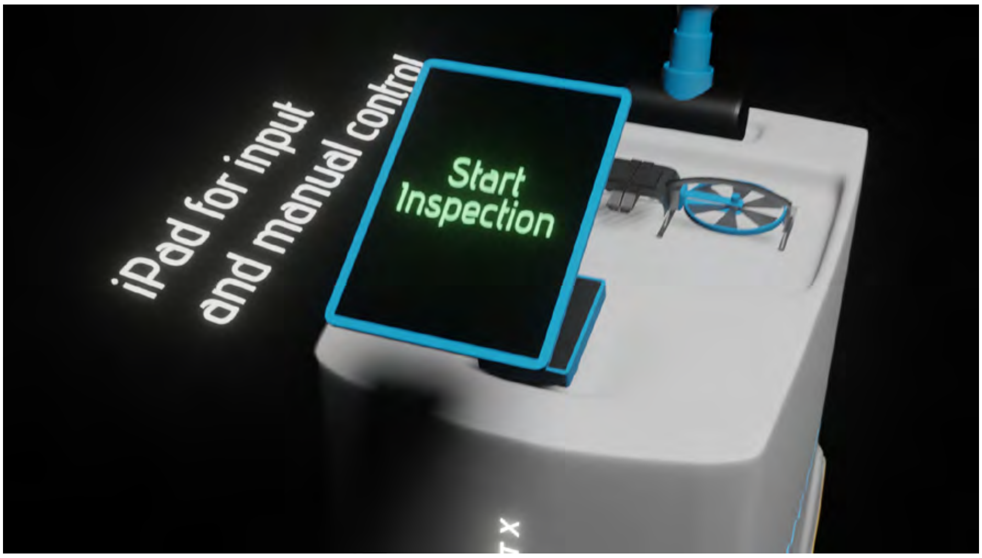


Apart from the renders already shown until now, the following were created as a part of the showcase video and are a combination of 3D animation of the concepts themselves and the explanatory text that goes along with them. These video frames serve as descriptive static images and thus, some of them were chosen to be added here to the concept results.

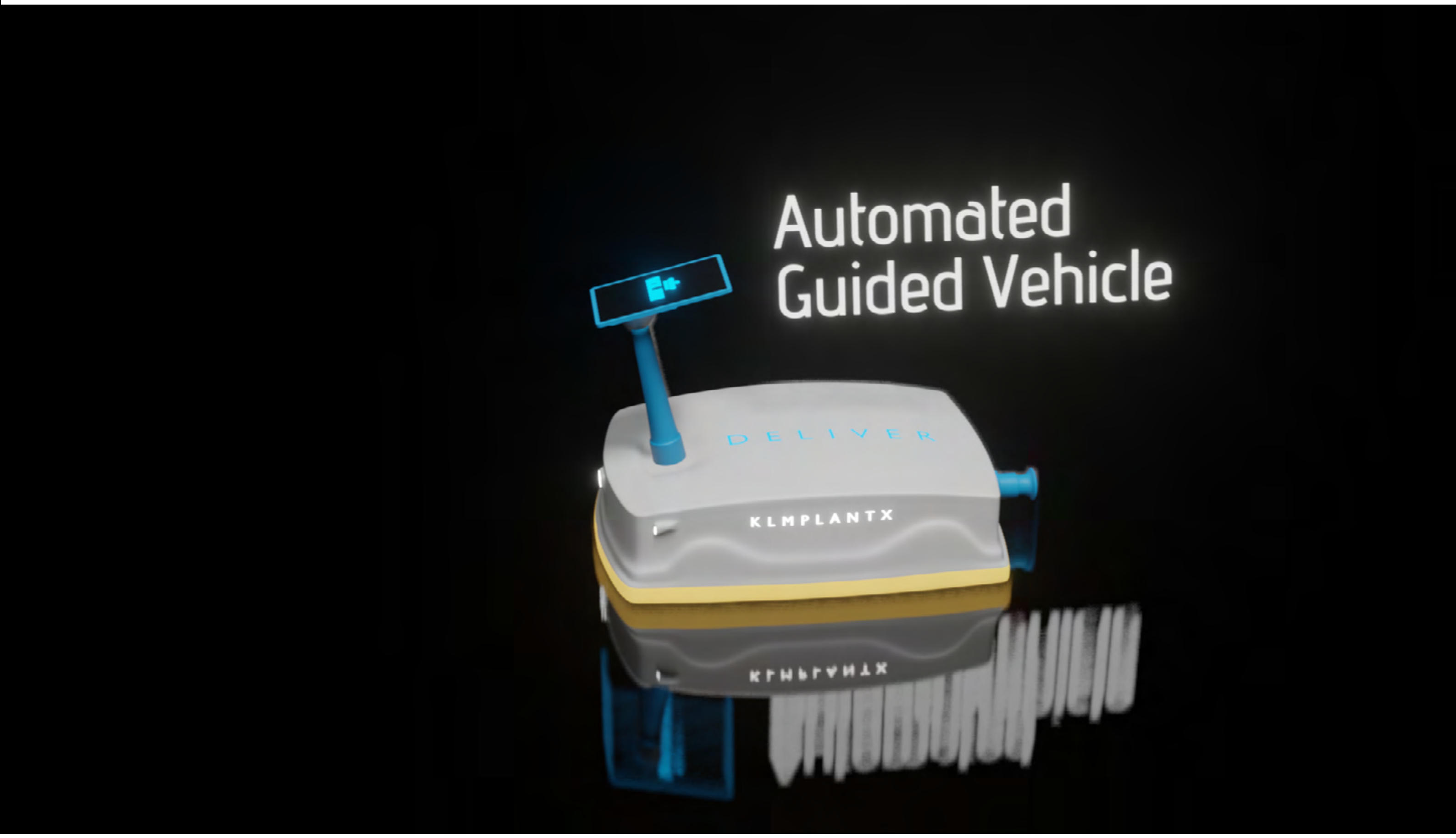


Video frame showing the telescopic inspection arm going up and down and rotating around the hinge.

Video frame showing the drone launching and landing on the Inspection Cobot.

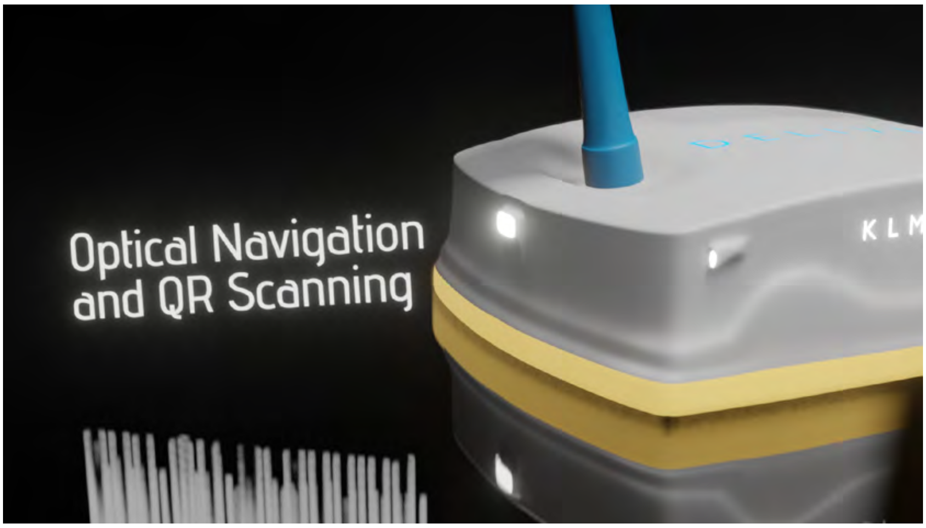


The iPad of the Inspection Cobot in an undocked position just before starting inspection.



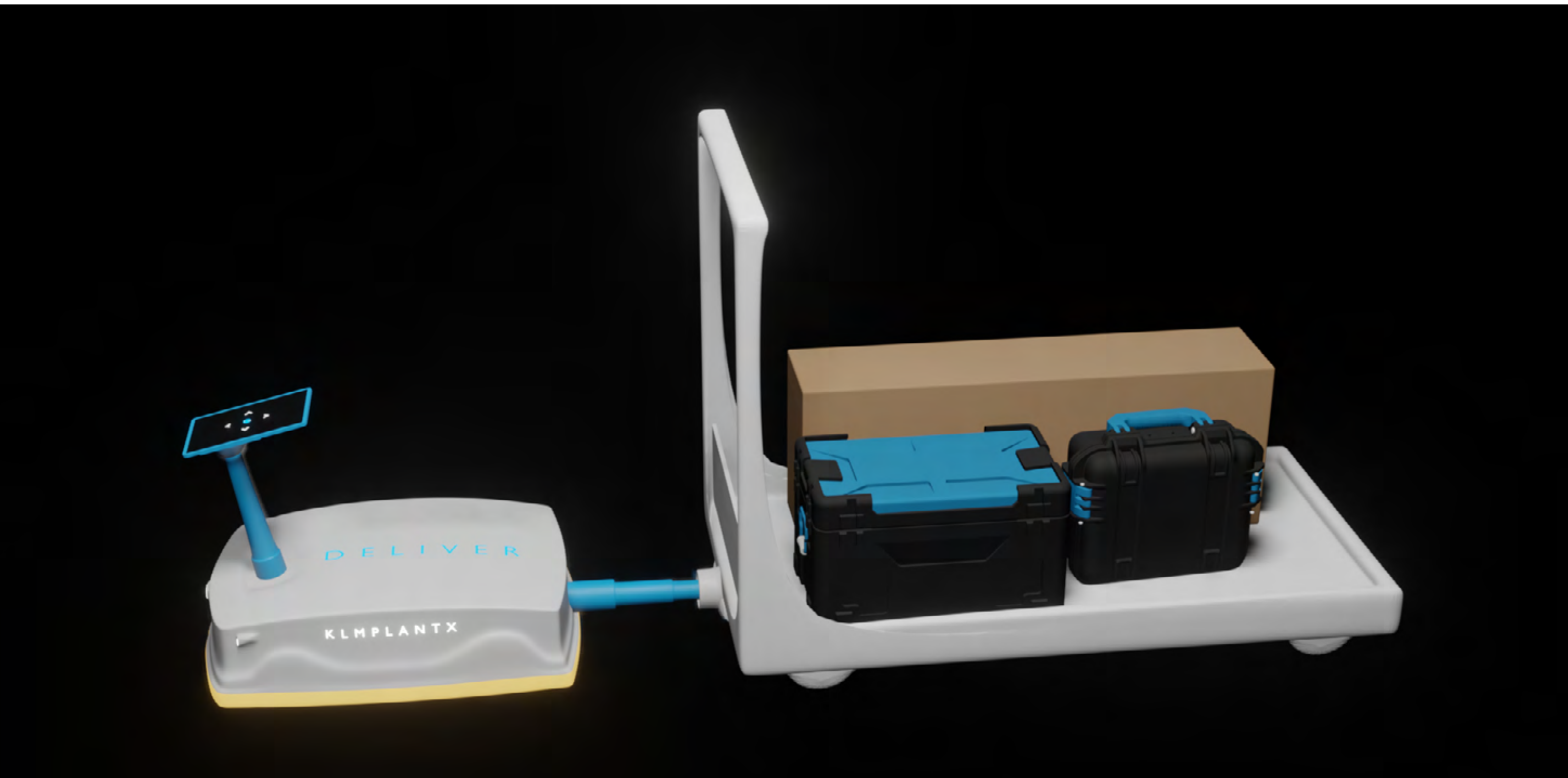
A frame showing that the rear end of the AGV features a tug that can be extended to pull carts, workbenches, and tool cabinets.

The front part of the AGV featuring cameras for optical navigation and scanning QR codes located on carts, workbenches, and tool cabinets.



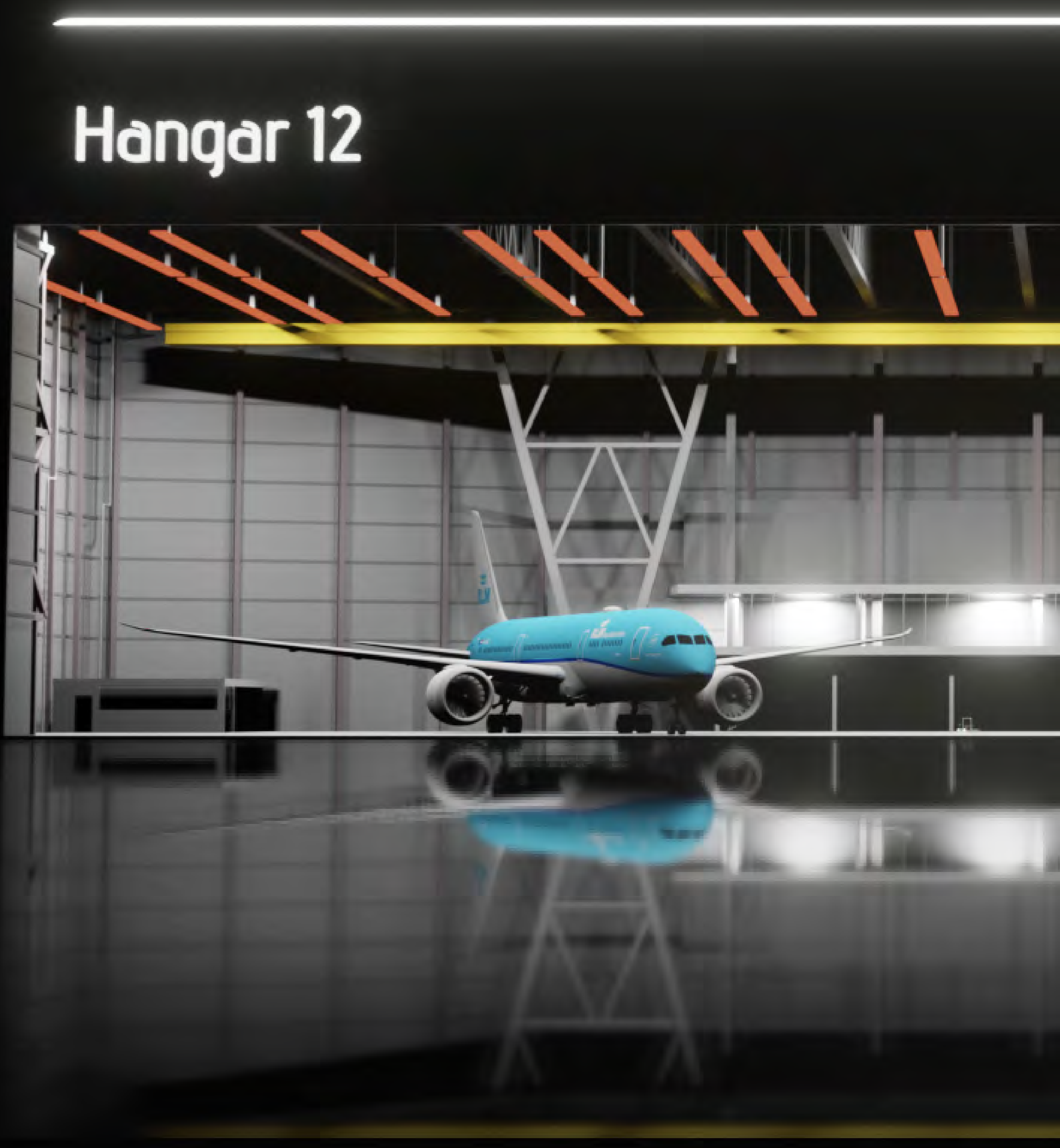
The AGV iPad which can be used for manual control when needed eg. for pulling several loaded carts at once.

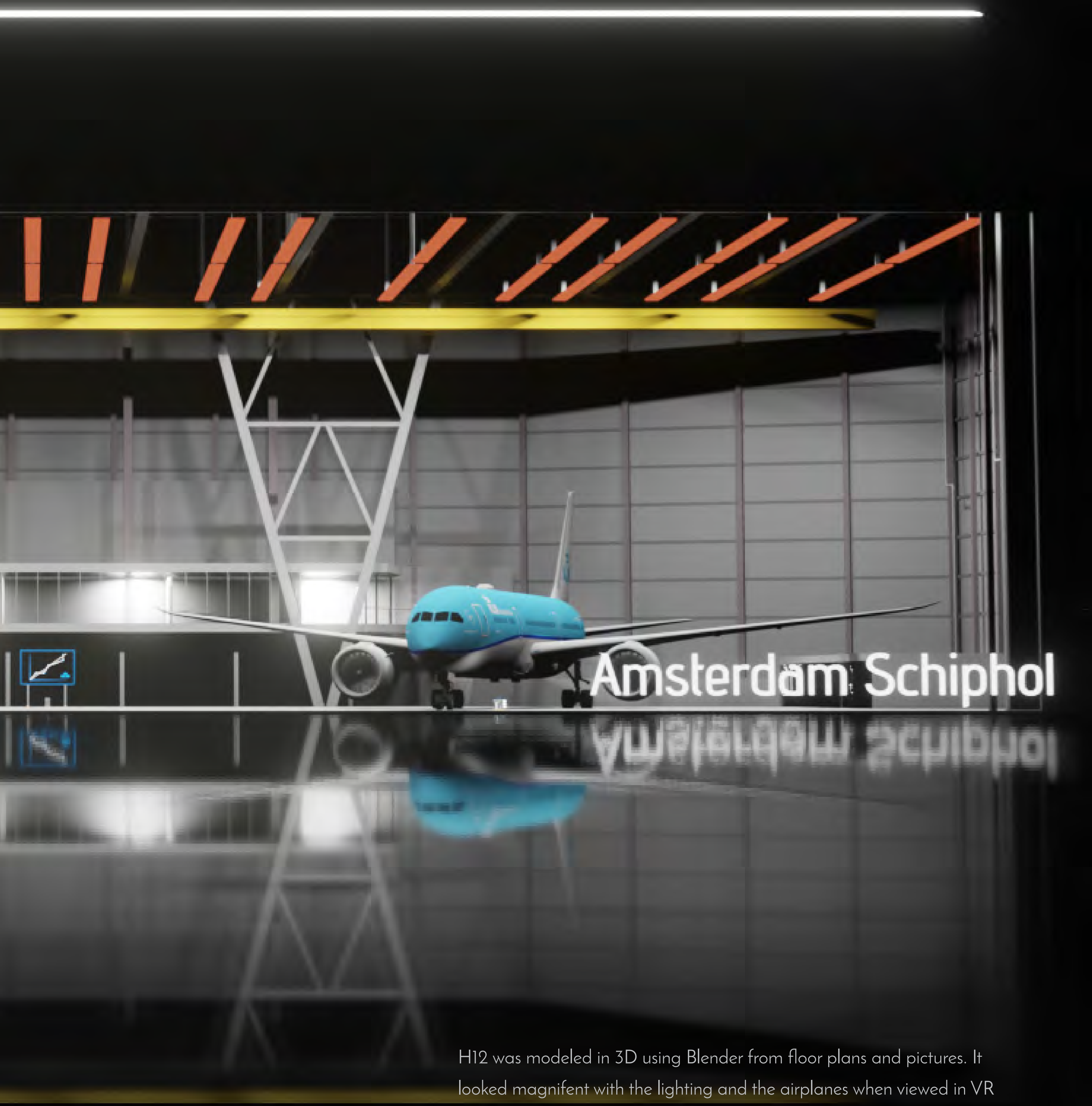
A video frame showing the AGV pulling a cart loaded with tool boxes and a large elongated carton containing material.



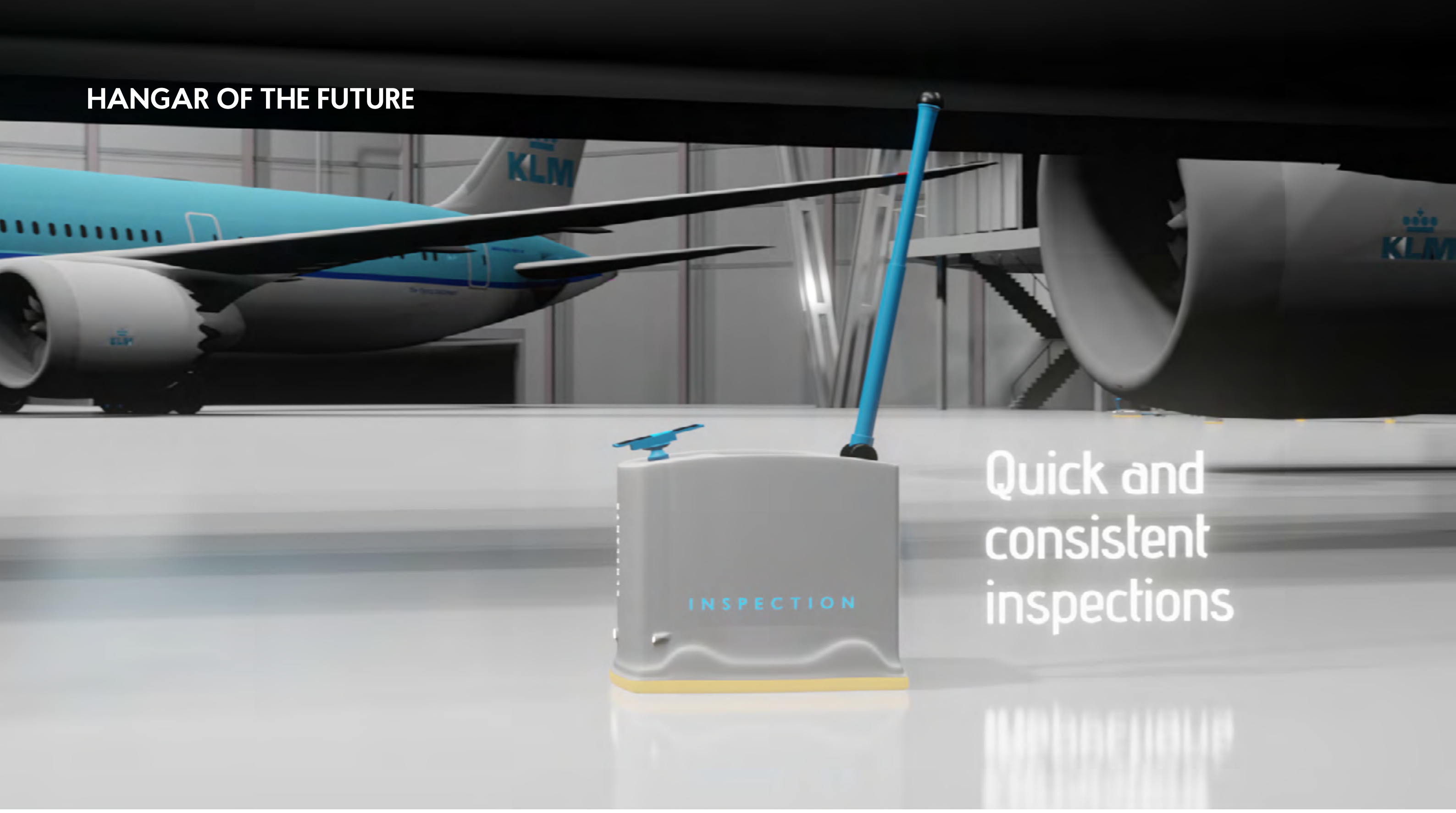
An example of the dashboard screen showing the status of a check.

The iPad at the Dashboard control panel with the ability to perform several tasks like the examples shown on its screen.


Hangar 12



H12 was modeled in 3D using Blender from floor plans and pictures. It looked magnifent with the lighting and the airplanes when viewed in VR or in renders such as the one here. It was later used to demonstrate the animated concepts as shown in the showcase video (Dalal, 2020)



The Inspection Cobot in action in the virtual hangar. The animation shows the movement of the inspection arm and the IC itself. The second render is that of the inspection drone performing its job over the fuselage of a Boeing 787.

The AGV in action delivering a loaded cart from the warehouse to somewhere close to the aircraft.

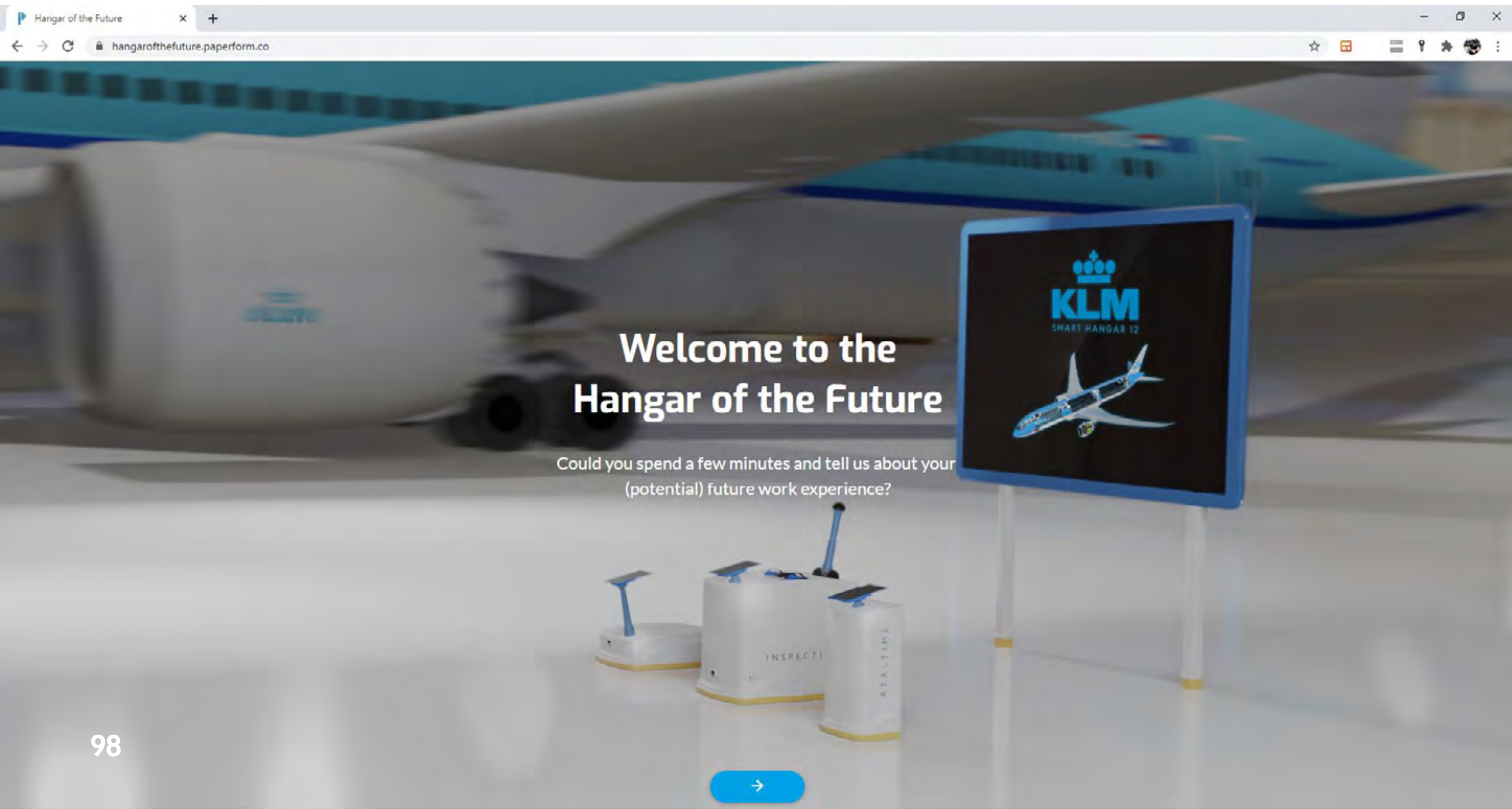
The dashboard placed in the middle of H12 showing realtime information that is visible to the teams from a distance.

5.3.5 STORYTELLING QUESTIONNAIRE FOR VALIDATION

There are several ways to validate ideas, concepts, or prototypes. In case of intangible concepts, an effective way to validate is using stories. Stories help users understand concepts better than sketches or renders alone and take them through interaction touchpoints that they will experience if the concept is realised. For this reason, Storytelling (van Boeijen et al., 2020) fit my purpose well and was chosen as a method to seek input from end users i.e. mechanics and engineers.

A story of how all three concepts would fit into a day in the future hangar was written. Storyboards, sketches, and renders of concepts created until section 5.3.4 were used to support this story. The text part supported consistent communication among all participants and the visual part helped their imagination. I found it necessary to cover the functions of the concepts well as a part of the story because it was the first time the participants were introduced to them while making sure that the narrative is understandable. Some assumptions in the story were taken such as it is set in the year 2025 and some details like the time of day, name of the aircraft, examples of tasks, etc. were given to make it realistic. The stories were written in the active form of writing along with the use of the second person pronoun 'you' to make the participant feel a part of them. These stories were sent out to 7 mechanics and engineers with a few questions following each story. The complete story along with questionnaires and their responses can be found in Appendix H.

Screenshot of the startpage of the storytelling questionnaire (hangarofthefuture.paperform.co)



Type of questions

Each of the three scenes of the story were followed by 5 questions. The first 3 of the 5 questions were close-ended (multiple choices on a scale) and the following 2 were open. The first close-ended question asked about how well they understood the concepts so the validity of the following answers can be perceived. The second and third questions aimed at understanding how comfortable would users be with the concepts and whether they would prefer them to the existing methods. The multiple choices given were descriptive for better communication, such as "confident to explain to others" and "would absolutely love it". The questions that followed were open-ended and asked for a tip and a top for each concept.

Analysis

Engineers, mechanics, and team leads were asked to participate in the storytelling questionnaire as they would be the ultimate direct users of the concepts. The responses of 7 participants were recorded and analyzed.

Personas and role playing

The personas created in 3.3.1 were also given a voice in the questionnaire. Using role playing, described in Appendix H, the personas were made to answer the same questions just like the participants. The results from this pursuit can also be found in Appendix H.

Inspection Cobot

Most of the participants completely understood the concept and the others understood it reasonably well. All of them were either reasonably comfortable with using the Cobot or would absolutely love it. 4 out of 7 would prefer switching to the Cobot compared with manual inspection and the others were neutral between the two. There were absolutely no negative opinions about this concept.

Tops: The participants liked that the Cobot would 'make their life easier' and provide a consistent inspection quality throughout all checks and different planes. 3 of them stated that they cared about the risk elimination due to this concept for inspection at heights. The time-saving aspect, especially for inspection at heights, was also considered positive.

Tips: A common tip was to take this concept to a functional prototype level in order to test if it works. It was pointed out that the assumption of a faster inspection time must be verified. A comparison between the inspection times of the ground robot and the manual general visual inspection should be sufficient for validation. Another tip was to check out X-ray or IR cameras for application in detailed inspection.

AGV Tug

Most of the participants completely understood the concept and others understood it reasonably well. They would either absolutely love using the AGV Tug or would be reasonably comfortable with it. There was a unanimous clear preference of using the delivery tug i.e. preference to get materials and tools delivered instead of the current manual pick-up from the warehouse.

Tops: The participants liked that the AGV Tug would make work easier and that it could save a lot of searching time. It would reduce manual workload and give the engineers and mechanics time do carry out their tasks that require their skills more. One of the participants was excited about the possibility that the materials and tools related to particular tasks can be obtained using the AGV Tug as pre-allotted kits and this would save plenty of time on the workfloor. It could completely transform the way the supply chain works in the hangar for the better.

Tips: A major tip was that if the AGV Tug comes into the picture, things related to ordering materials and tools can also be automated. Orders could consist of kits of tools and materials instead of manually ordering via the individual iPads as shown in the concept storyboard.

Workfloor Dashboard

All the participants at least understood the concept reasonably well out of which half were confident to explain it to others. Around half of them would be reasonably comfortable with using the dashboard and the other half would absolutely love it. 5

out of 7 would prefer using the dashboard for discussions with the team or updates and the other 2 were neutral between the dashboard and the current way of working.

Tops: The obvious positive aspect of the concept was mentioned that the dashboard makes information visual and more clearly and quickly understandable. An overview of the check can be seen and this would be useful for the teams throughout the check. It was pointed out that the screen presents facts invariably to everyone and factual data is important and missing at the moment. This would eliminate poor and emotional decision making which could be inefficient and counterproductive.

Tips: A tip on what information could be shown on the dashboard, like the duration of a check and the highlights, was noted down. It was remarked that like other IT-related technology, this might bring more IT problems to the hangar. In the future development of the concept, maybe an employee would need to be present to keep the dashboard updated and that would be a point to keep in mind. There was a last tip that add-on devices like smart eyeglasses could be connected with the dashboard to serve the function even better.

Summary

As can be grasped from the analysis, the participants understood the concepts well and their overall opinion about them was positive. The storytelling was clear enough for them to understand all the concepts well to answer the questions that followed. They understood the functions and pointed several of them out as tops for the concepts. They pointed out important tips that must be taken into account in the improvement and further development of these concepts. The opinion of the personas from role playing was also found to be positive.

NEXT STEPS

The end goal of the project was to design concepts and that was achieved. However, the project would not serve its purpose until it is used later in reality. This section lists various tips and recommendations on some topics that would be useful in the next steps to take the project forward.

Prototyping in VR: The virtual prototype needs to be further developed until it can be called complete and is interactable. If this is of interest for proper user testing, the KLM VR team should be consulted as they possess the expertise in this area. I was able to get to a static model of the hangar in Unreal Engine with the concepts but animating the concepts and creating interactions requires using bluescripts (visual scripting) which would consume plenty of learning time. Thus, this must be a part of a longer project or should be carried out by experts.

Prototyping and testing: Prototyping is of utmost importance after conceptualization in this project. In all three concepts, prototyping requires not only a physical model but also the digital counterpart that is of the essence to the concepts. Due to these two parts, it can be quite challenging to make everything work at once. A logical recommendation would be to prototype each function separately wherever possible so that it would be more doable. In this way, we can build up to the concept in smaller steps with lesser risk and with better insights.

User testing and validation: At the end of this project, validation was carried out via a storytelling questionnaire. Given more time, this should be done in a more elaborate way with more number of users and interviews where the concepts are discussed at a higher detail. Once the virtual prototype is completed, this can be used to initiate users before interviews or discussions to replace the storytelling questionnaire which I used.

Computer vision and machine learning: The fact that the working of the concepts relies heavily on computer vision algorithms, machine learning, and possibly artificial intelligence cannot be ignored while taking it to the next TRL. In further development, experts on these topics must be consulted on how to go about conceptualizing and prototyping this aspect. Doing this as soon as possible would be helpful to gain insights into this area which was not in the scope to explore in detail.

Sustainability: Sustainability was an aspect that KLM was interested in at the start of the project but was not paid much attention to later as it was found to be not of interest to most internal stakeholders and it was broadening the scope too much for a short timeframe. It was however kept in mind that the decisions taken and the resultant concepts should later be able to align to sustainability requirements. The workfloor

dashboard is the concept that can be connected to sustainability the best as it eliminates the use of all paper in the hangar. It is clearly a step toward a paperless hangar. In the next steps, sustainability should be factored in by conducting more research on how these concepts can contribute to reducing the carbon footprint of the hangar and if they do not, how can they be adapted to do so.

Use of the 3D models: Several 3D models (Dalal, 2020) were created in this project which would be useful for further steps. The 3D model of the hangar is accurate for a visual representation and can be used if it is decided that the virtual prototype should be developed further. Alternative uses of the 3D data are VR training for the A-check or VR training for emergency situations in the virtual hangar environment.

Implementation in H11: H11 carries out A-check for 747 (just retired) and 777. The concepts, once tested in H12, can be tuned to be used in H11 also. The IC and dashboard can be imagined to work in the same fashion as in H12. The use of the AGV Tug might be different as H11 teams do not have to go far for materials and tools since the larger warehouse is in H11. Moreover, the configuration of the hangar and the arrangement of aircrafts also affects the profitability of the AGV Tug. These factors should be thought about if at all implementation in H11 comes into the picture.

Implementation for the C-check: H14 conducts C-checks for the entire KLM fleet and it would be interesting to see whether the same concepts, with some changes if required, can benefit the C-check as well. It can be speculated that since the C-check is much more elaborate, a surface level inspection would not be sufficient for it. However, for instance, using infra-red or sonar instead of digital cameras could help in more detailed inspection but such speculations must be verified for further development in this direction. The usefulness of the AGV Tug versus the current manual way of transporting materials and tools would also need justification as the walking distances in H14 seem to be shorter than those in H12. Lastly, the dashboard can be imagined to be useful because of the higher complexity in task distribution and the longer duration of the C-check. This also means that more people would be working on one aircraft and more confusion could be caused. This is where the dashboard could step in and help clarify realtime check status to improve the efficiency and meet tight deadlines. However, the information that should be displayed on the dashboard must be re-thought and made relevant to the C-check.

Lastly, it is understandable that the viability of carrying this project forward is affected vastly by the Covid-19 crisis but it is hoped that recovery takes place soon and the hangar of the future can take a closer stand to reality and some of these next steps would be implemented.

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APPENDICES

Appendix A: Conversational Interview Summaries

Please note that these pieces are only summaries and majorly include topics that are relevant to the project. Some of the following interviews have been written in a question and answer format whereas others have a monologue-style summary. They are paraphrased to resemble as closely as possible what the interviewees had to say. Summarizing notes were made during each interview and compiled immediately after. Audio recording was not chosen due to the large number of interviewees and the lack of time or requirement to analyze each of them rigorously.

Sr. no.	Date	Name	Position	Office location	Summary	Concerns/ My observations
1	12-Feb	Harry	Innovation Lab Coordinator	H12	I have been working with KLM for 33 years. This workshop, which we call the Innovation Lab, is where I design and build various parts and products that offer support to the equipment to maintain and repair airplanes. Custom-designed parts, equipment, solutions for equipment that breaks, carts to carry things like engine fan blades, KLM signboard, etc. everything that is possible to physically make in the workshop. I work most of the time by myself. If someone wants to use the workshop for a small task, I might permit it. No, I don't need too much help usually unless for really big things. I work for Hangar 12 but I also have other 'clients' i.e. some other departments of KLM.	- One person has a disproportionate amount of responsibility
2	12-Feb	Marco Steinmetz	Continuous Improvement Lead	H11	What is your role at Hangar 11? I am the Continuous Improvement Lead (CIL) of the Hangar. My job is to make sure that the operation and efficiency of the hangar is getting better and to execute changes in the hangar that help in doing so. We have meetings/brainstorms with CILs from all the hangars to discuss how this could be achieved and to discuss the projects we have been working on for the same. I have been working at KLM for 30 years now. What is your interest in Plant X? Plant X is looking at small and big aspects of improvement which can Increase efficiency. This is naturally interesting for me even though I am responsible for continuous improvement in Hangar 11. View on Hangar 12 Hangar 12 is called the Hangar of the Future but we have decided to have only 737s in H12 in the future and that is not actually the airplane of the future, it is the 787. H12 currently does (sometimes) line maintenance for 737. H11-B3 does (sometimes) line maintenance for 787. After the 747 will retire (except for cargo) the 787 workload from H12 could be shifted to H11. In the future, H11 will regularly maintain 787 fleet thus needs to be updated to be the actual hangar of the future.	- Makes sure that the hangar is always working towards improvement - Supports adoption of new technology that helps - Increase efficiency in whichever way possible - Make engineers more independent - Visual management and more control on realtime tasks - Convincing people to adopt new tech

Sr. no.	Date	Name	Position	Office location	Summary	Concerns/ My observations
2	cont.	cont.	cont.	cont.	What processes, aspects of the hangar do you really like and think these are good as they are? The hangar has been undergoing improvement in the last many years. It is more efficient. People have become more independent. They used to take instructions from a guy in a suit, the project manager, they don't need that anymore. They can take their decisions and act themselves. What troubles that the employees face are you aware of? Dealing with changes. Older employees who've been working at the hangar for many years do not agree with new methods and technology eg. the introduction of iPads in their workflow. When we along with the IT dept. brings new tech to them, they say that it always has IT issues. Doesn't work smoothly. Plenty of complaints regarding this especially after introducing new things. If it doesn't work as they think it should, they can always blame IT. What do you think needs a change? The Dashboard, which is the big planning board you see in front of the team leads offices, is how the tasks are assigned. It is not updated regularly enough. Most often, the status of the dashboard is only updated at the end of a shift. This means that the leads cannot find out the lags/problems until much later and solving them would further take more time. This dashboard could become digital and we are working on it. We have an idea to put in three big screens. Left (completed tasks), Center (current tasks), Right (future tasks) or something like that. This will show problems and delays in real time. Thus we hope to cut down time which would usually be spent at the end of the process after realising something went wrong. This might also be able to show a longer chain of events eg. if a flight is coming from the Carribean and a drug test is expected, time for this is added and we can see this on the dashboard. Using this information, this time could be used by the employees maybe for a team meeting instead of uncertainly waiting for the airplane. We already have bought screens (75 inch) x 4 for the same project - Visualization of dashboard in Hangar 11. Anything else that helps increase the efficiency of the hangar should be changed. VR model of Plant X - what do you think this could be used for? Convincing people of the new ways. If they can see it, they have all the more reason to believe that it would work. In the airline industry, most things are worked on in 'text' format. It needs to get more visual. This is where your help could come in. Training new employees is also an interesting prospect for such a model.	cont.

Sr. no.	Date	Name	Position	Office location	Summary	Concerns/ My observations
3	13-Feb	Chris Koomen	VR Specialist	Next to IS	I started the VR team at KLM. I was interested in VR since 1996! When the Google Cardboard was launched in 2014, I rediscovered my interest. I helped set up the VR team but am working from a different office now. Your project to design the hangar sounds quite interesting for KLM. It can be further used for say, fire evacuation training for the hangar staff. The KLM VR team uses Unity. Unreal is easier to learn but we haven't used it much yet due to it being paid (verified later that it is free for commercial use without selling applications). If you do it in Unity, your work can probably be carried forward for other projects. But if due to time constraint, that is not possible to learn, go ahead with Unreal. Creating the 3D model of the hangar in itself is a big task. For that, you should get in touch with Jessica Lamars or Arlette van der Veer who might already know where you can get it from (if it exists). You should meet Chris Roos from the current VR team. They are the right people to guide you and might be able to offer you equipment for working or borrowing. If they for some reason cannot do so, you can always write back to me. Also checkout Brix KLM and BitBucket KLM resources for past documentation, might be interesting for you to look into.	- Research on use of apps and visual management - Improve efficiency by realtime check analysis
4	14-Feb	Anouk Akkermans	Director Digital & Innovation	H12	Organizational Overview of E&M and H12	n/a
5	17-Feb	Remco van den Top	Interaction Designer	H12	Lead of the iMech project. Maintenance is carried out in 3 areas of the airplane: Langs (along the fuselage), Dwars (along the wings), and Cabin (inside the cabin). This is how the team is also divided during a shift. This information is needed for us to design how work is assigned on the app, iMech. There is a triangular relationship between Planning, Visual Management, and iMech. Each component supports the other two. Each team is composed of a Lead and 18 Engineers. Each Engineer has a specific set of skills. Each task requires certain skills. First, tasks are assigned by the support staff to themselves. Following this, the skills of engineers are compared with the skills of the task to appoint them. This can be done in two ways depending on the hangar. In Hangar 11, tasks are assigned by the support staff to engineers, the old-school way. If engineers want to switch tasks, they can go to the support staff. In Hangar 12, the engineers are more independent and can choose their own tasks. We are now going to work on the visual management project which will be a part of the future hangar. The idea is to synchronise in real time the status of a check so the team leads can take actions to make sure it is carried out within the given time.	- Research on use of apps and visual management - Improve efficiency by realtime check analysis
6	17-Feb	Marc Kesting	Lead Materials Equipment Facilities	H11	Information about Materials, Equipments, & Facilities. MEF is divided into: - Materials Planning - Plan, order all material and components needed to repair, maintain, and clean planes. - Equipment - In charge of the equipment needed to carry out repairs, maintenance, and cleaning. - Warehouse - engineers can borrow tools from here - Front office - direct in contact with engineers	- Data received from the plane in advance can be used to plan checks in a better way - Faster and more automated inspections

Sr. no.	Date	Name	Position	Office location	Summary	Concerns/ My observations
6	cont.	cont.	cont.	cont.	Vision for the future We have a vision for the airframe of the future. Anouk was working on it. In the future, what if the plane could be self-aware, can self-inspect. That could save plenty of time. The plane would be ready with data and information when we start its A-check. Or think about scanners on the doors when the plane comes in. Or drones using cameras to check for lightening strikes or inspect cracks the top of the plane. These things are currently quite time consuming and these areas are not easily reachable. What if we could adopt the window cleaning technology to make our lives simpler while cleaning plane windows, which are difficult to reach from outside. From MEF point of view, engineers carry heavy equipment all the time. Maybe it is possible to support the load somehow. Using robotic arms of some sort? (Note to self: Think about Skelex). The engineers' time is wasted while running back and forth to the warehouse for tools. This is also a big problem if you think about efficiency. Can they order tools and we could logistically make this function better? How about a platform equipped with tools so they don't have to go up and down while working in the cabin. It should suit all the different planes 737/747/777/787. All such problems need to be tackled in MEF of the future. Engineers should be able to work flawlessly and smoothly.	- Time consuming tasks which can be replaced by tech - Carrying heavy equipment - Too much walking back and forth from the warehouse - Lack of flawless workflow
7	20-Feb	Bas de Glopper	MRO Lab Head	Bldg 411	NLR (Nederlands Lucht en Ruimtevaartcentrum) is a company we are in collaboration with. They have been around since longer than KLM itself. We develop new ways in which employees could be trained for maintenance and repairs. In 2018, we had 3 main training programmes for Boeing 777: Fuel Tank Safety Training Air-conditioning Equipment Cooling For the collaboration, you can have a look at http://nuveon.com/. The videos I just showed you can be found in the Training section of the website. In 2019, we started to move trainings to AR using the Hololens. The reason for this is that it is difficult and expensive to find airplanes to train new employees. Moreover, on the airplane, what you can do is look at the fuel tank and the trainer would explain things about it. With AR, it is possible to have beautiful animations and have trainees look at the air, oxygen, and fuel flow lines for instance, which gives them an instantly clear understanding. We chose to go for AR rather than VR because in AR it is possible to see the training while also seeing other people in the room. This permits interaction and lets the trainer explain while several people in the room are using the Hololens. Currently we train upto 8 people in one session, each with a Hololens put on. Warp VR is a company that does VR training related projects for KLM. You should check them out and may be talk to them if you are interested in training.	- Hangar virtual space could be used for training

Sr. no.	Date	Name	Position	Office location	Summary	Concerns/ My observations
8	20-Feb	René Kruithof	Plant Leader	H12	More than it is about ideas, it is about if they get implemented and how to implement them. For implementation, we sometimes face resistance from individuals in the teams. When I came into this hangar and I was told that this is the hangar of the future because it has; 1) people using iPads, 2) working with teams, and 3) a nice modern look and feel, I was not satisfied. But iPads are already more than 10 years old! I was not completely satisfied with that answer. For the future, we have plenty of things in the pipeline but implementing them and getting Engineers accept them, is the challenging part. I was working in Cargo (also KLM) for 20 years. Unmanned delivery vehicles have been there for a long time. If we put them in the hangar, they can save so much time in walking around that is not productive. Engineers walk all the way to the shop from the airplane to ask for a tool. The tool is brought to them by an employee in the shop and then they go back to work. What challenges do you face in managing the team? With respect to innovation, I have a strong opinion. Going back to the iPad example, we provide them to Engineers to use them during the job and not to watch Netflix during the breaks. Some people might be reluctant because they feel that they would be losing jobs because of technology but it is not the case. Will the number of employees reduce in the hangar? No, in fact, the opposite. When I came in, we had 85 Engineers. In the past 1.5 years, the number has risen to 150. This is due to increase in the workload and higher number of aircrafts in the fleet. We have hired young Engineers and the average age has fallen from 50/51 to around 40. The older colleagues help train the younger Engineers. On the other hand, the younger Engineers, who are more acquainted with technology, even simple things like the iPad, help older Engineers get the hang of it so they can use the apps we develop for their job. What are your goals for the next 5 years? We are looking into drones for inspection and it has been a while since we are talking about it. To implement this is a goal for the next few years. We always want to place orders for unmanned delivery vehicles this year and test them in the hangar. We are open to suggestions but I would say it is nice to go step by step. If you say let's have drones for delivery in 2025, I would say let's aim for unmanned ground delivery first.	- Resistance faced from team members - Not worthy of being called the hangar of the future - Cutting time with technology - Unmanned delivery - Enforce technology because it is the way forward - Higher workload in the future
9	20-Feb	Shariff Jacob	Planning Team	H12	My team deals with planning the A-checks of 737 and 787 and the order of tasks for the checks. The organizational structure in Hangar 12 is really flat. The engineers are more autonomous and independent than any other hangars. Previously, the entire plan used to be laid out for the engineers and they just had to follow it step by step. Now they can even choose the tasks they want to take on. They get to make plenty of decisions themselves during the progress of a check. We, at planning, make the recommended plan for every check and hand it over to the team leads. Most of the times, they follow our recommended plan but they do have the authority to change somethings during the check if need be. We do get feedback in the end of a shift of what plan was used, how much time it took, and we can compare it with the plan we recommended. This helps align and improve our planning for the future checks.	- Independence of engineers - Empathise with engineers to understand their tasks - Look & feel of hangar is important to provide a nice working environment and attract clients - Realtime feedback of checks is not yet obtained

Sr. no.	Date	Name	Position	Office location	Summary	Concerns/ My observations
9	cont.	cont.	cont.	cont.	For 5 years at the start of my career, I was an engineer myself. This lets me have more insight on how the checks work. Not many working in this department have been engineers themselves so they might miss that insight. Regarding the hangar of the future, I have a few pointers: Get to know the tasks the engineers do and talk to them. They are the most active users of the hangar so their needs and problems should be given priority. Pay attention to the look & feel of the hangar. It is quite important and making it look nice, giving people a nice working environment could be very beneficial in keeping the spirits high. Good look & feel can also help KLM benefit from other clients. We usually get the feedback about a check at the end of a check. Now that we have all these digital tools, it is possible to get real-time feedback. The hangar of the future will have no paper. It will be more efficient and though its quite fascinating already with the planes, it will be an even nicer place for everyone to work. Let me know when you want to experience a shift and talk to the engineers, I will help you schedule it.	cont.
10	21-Feb	Paula Kools	Plant Support Officer	H12	As a Plant Support Officer, I offer direct support to the teams. If they have concerns or problems, they can directly come to me and I would try to solve it or guide them to the right people. I also handle documentation related tasks. When level-0 (new) employees have authority issues, because they are not authorized for anything apart from observation, they come to me for getting some documents signed. My first project here was to set up Plant X (office) along with Anouk Akkermans. It has taken a long time to get the office ready for use because of various issues (with Sodexo). In the coming 2-3 months, we want to get it ready for use. Among other tasks, I also help with communication and marketing of the hangar. Every week, we have a report that comes out that has stories about the week or that of new employees with a picture so everyone gets to know them.	- Authority to perform tasks depends on the engineer's level
11	26-Feb	Peggy-Ann Braafheid	Project Lead Teaming/ Culture Lead	H12	What is your role? My role is equivalent to what they call the Culture Lead. I am the point of contact for members of the team. Hangar 12 consists of 8 teams with 18 members each. Each team is led by 2 team leads. A couple of teams are currently missing 1 team lead though. The 4 councils - Materials, Safety, IT, and Team Spirit, each have one team member from each team and this member is called the starpoint. Each starpoint communicates back and forth between the team and the council. The councils help bring concerns from the teams to the platform for discussion and proposing changes. Every quarter, I have 2 meetings with each team. That accounts for a lot of meetings in my schedule. In these meetings, team members can raise concerns and bring forward issues that they are personally facing. This way I know each team member (18 x 8) personally. The plan leader (René) also has 1 meeting every quarter with each team.	- Engineers do like their work and like to talk about it

Sr. no.	Date	Name	Position	Office location	Summary	Concerns/ My observations
11	cont.	cont.	cont.	cont.	In order to cultivate the culture, I help conduct events such as the Day-Out for New Members where new members of the team go out to, for instance, a handicap facility and help painting the room or build something. Such activities help in team building and bonding between new people. How would this project be relevant to you? Since I am not on the technical side of things here, I cannot help you there. But if you need help from the teams, I can set you up. I can guide you to the right teams and the right people within the teams. I can say go to Team X for this matter and not to Team Y because of this reason. I know the teams and the members very well so I can definitely help you set up How do you advise me to approach the teams? As you've heard, some teams might be easier to approach than others. I'd say for asking questions or filling questionnaires, just approach the members personally and they will be ready to help. They like to talk about their work and experience thus, it shouldn't really be an issue. Maybe ask the team leaders if the time you are interrupting them is fine. But in general, you can just walk around (in safety shoes!) and find people to do your research.	cont.
12	17-Feb	Mark Kuilder	Engineer/X-Builder	LM	Working at KLM since 30 years. Started with Hangar 10 and have been most of the time at Line Maintenance Schiphol (LMS). Alternate weeks, I work as a part of Plant X (X-Builder) but this is my last week here. I'm going back to LMS full time as I am not getting to work with my hands enough here. It is more designing, planning, meeting instead of building which is what I really enjoy doing. I am 51 years and have been working here for 30 years but I am completely in favor of digitizing. iVop app - brings everything on paper to the iPad. The schedules are printed every morning for the entire day. Everyone has the iPad anyway so why print anymore? It can save so much paper and can make the maintenance more efficient. I prefer the iPad one of the older employees but half the people do not want this. 70% of engineers are over 50 years old but 50% of the total engineers don't want the new tech even though it is better and more efficient.	- In favor of digitizing - Could save much paper on a daily basis - Not everyone my age is as accepting yet - Tech can improve efficiency
13	20-Feb	John Telleman	Engineer/X-Builder	H11	The platform you see in the left side of the hangar was earlier used for the 747. It moves on the two rails you see on the ground to approach the airplane when it is parked. This worked really perfectly for the 747 but now those planes are not maintained by Hangar 12. We are working on a project (within Plant X) to adapt this platform for the new 787s. The benefit is that this platform connects directly to the middle door of the airplane. Engineers, once they climb over this platform, don't have to go up and down the stairs multiple times during their shift. The stairs have many downsides: Climbing down the stairs is terrible for the knees, this creates long term injury. It is mentally exhausting when you have to go up and down when you forget a tool or need to bring something up several times during the shift. It is also, of course, time consuming. A lot of time could be saved if make this function.	- Not all equipment in the hangar is operating - Stairs are terrible for knees and workplace ergonomics - Workbench platform, not new tech, but should definitely be a part of he hangar of the future

Sr. no.	Date	Name	Position	Office location	Summary	Concerns/ My observations
14	27-Feb	Hylke Visser	Engineer/X-Builder	H12	I'm a relatively new engineer in my team. Worked for 1.5 years now. Also an X-Builder with Plant X in alternate weeks. At the start of the shift, I take a look at the general overview on the iMech app to get a feel for what the work for the day is like. I don't have the authorization yet but I can sign my own tasks after a while when I get it. For now, I go to the support who signs them for me. If you ask about the problems, quite some time is spent waiting for material. I would say, more than waiting for tools, waiting for materials is an issue. It sometimes takes hours after ordering them. We can order materials using the iPad (MaintainX) or on the computer or just by going to the office. But then it takes a long time to get delivered and until it is there, time might not be used efficiently. We usually get material from Hangar 11. I get it on the bike or if its big take the small electric cart. The tools are usually available unless they are gone for calibration. Moving aircrafts in an out of the hangar can be time consuming. A lot of waiting is done here as well. They were looking into getting MotoToks which are electric tugs that occupy very small space and can tug the whole plane. They can be controlled using a remote. Not so difficult to operate as far as I know.	- Used to iMech app - Time spent in waiting for materials - Tools can usually be picked up faster than materials - Moving aircrafts in an out is time consuming
15	27-Feb	Marius Sypesteyn	Team Lead	H12	I have been in the hangar for 33 years now and my role is the team lead (team 3). I make sure the shift is planned well, functions smoothly, and solve issues during the shift. I take calls from the team all day or night to answer questions, redirect them to the right people if something is missing, etc. The job is quite active and doesn't allow me a minute's rest (laughing). Availability of space for planes in the hangar is sometimes an issue. We have to quite often take one plane out and put another in to do some work and then bring the first one in again. Meanwhile some planes stand outside without being worked on. This costs plenty of time. For such a switch, one plane needs to be closed down, the stairs be taken away, etc. and the opposite for the incoming plane. If we simply had more space, we could just keep all planes inside. Getting materials on time is also a major issue. Once the engineers order parts or material, the order goes to the MLC (Material and Logistics Center). The runners pick up materials from this center. But they take some time to do so and in that time the task stays paused. If the material is not available in the MLC, they need to order it from elsewhere (could be Hangar 14) and it takes even longer. It is difficult to point one person to be responsible for this so there is no one to blame. If the runners are more efficient and we can do this process better in some way, it would be very useful. Aircraft on Ground (AOG) is a situation occurs when pilots complain that something is wrong with a plane or when a replacement component is not available and so on. The aircraft cannot fly when it is less than perfect in its maintenance. This costs a lot of money for the company. It occurs quite frequently and can be seen every week. There are some ergonomics issues as well which you should look into. Walking up and down the stairs every shift for years is not good for the knees. It makes you old faster! Getting tools up and down the airplane, running around all day, etc. is not the best for the body. A platform that Plant X is working on can be helpful in this aspect.	- Active job without rest as team lead - Plenty of issues, calls in every shift - Switching or moving aircrafts is a very time intensive tasks - Too tight space to keep all aircrafts inside - Materials are not present on time and time spent in picking them up - AOGs cause huge losses - Ergonomic issues in daily work

Sr. no.	Date	Name	Position	Office location	Summary	Concerns/ My observations
16	27-Feb	René Heynemans	Team Lead	H12	We got this expensive staircase but never used them and the teams want to return them. They cost maybe 20 times and are technically advanced. They can go up and down and can be used both on the 737 and 787. But they are very heavy, difficult to operate, need a tugging car to pull them, etc. Instead, the simple stairs are much more usable. We've been using them for a long time without issues and would like to return these. The simple ones might need to be different for different planes but are easier to use and more convenient. Technology is not always the best solution. The other manually operated staircase is long and takes up more space but works effectively.	- Unused equipment in the hangar
17	27-Feb	-	Mechanic	H12	Joined KLM just 4 months ago. Was working at Martin Air previously. They were prototyping AR apps on iPads which you point at the airplane and it gives you all sorts of information. You see how the fuel tank functions for instance and how to replace parts. This is great for learning and training.	- Tech to assist engineers, already being done by MartinAir

Appendix B: Contextual Observations

A summary of my observations in Hangar 11 and 12.

Activity:

Idleness around aircrafts: Aircrafts appear to be not being worked on during the day and evening shifts. This was noticed 8 times in my 15 observational walks (approximately) spread over 3 weeks.

An engineer walking with a toolbox in H12

Plenty of walking: It is very apparent that a big part of the jobs of mechanics/ engineers involve walking throughout their shifts (also confirmed by Kok, 2015).

Materials warehouse in H11: Mechanics are often on the bike to go to the materials warehouse bringing back both small and medium sized material in their bike baskets. Some prefer to do the same by walking.

Waiting time: Mechanics and engineers are often involved in chats, coffee, or a smoke. This is during breaks or while waiting for a prerequisite of their task to be completed or for decisions from others.

Unoccupancy: H12 is capable of accommodating from 5x 737s to 2x 787s with 1x 737 in the middle. Full occupancy was never observed. During the observational walks, usually 1 or 2 aircrafts were inside.

In and out: I noticed 4 times in 2 weeks that a 737 had to be taken out mid-check so a 787 can enter or go out.

Inside the tools storage room of H12

Hangar Design and Equipment:

Distant tool cabinets: Tool cabinets are placed close to the end walls of the hangar. These cabinets can be opened using the KLM pass after being assigned tasks for the shift and the borrowed tools are registered in the system.

Lack of space: Apart from the open floor for aircrafts, there is not much space for accommodating new equipment.

Unused equipment: There is equipment lying around which seems to be gathering dust.

Absence of modern technology: Standard tools and equipment lack any notable modern technology except iPads (which are already quite aged).

Custom designed equipment: There is much equipment (eg. carts, trolleys, contraptions) which is custom-made in the workshop for certain uses in the hangar.

Lighting: Areas under the wings and fuselage are too dark, especially after sunset. Use of a torch is often required for working on those parts. This is because all lights are on the ceiling which is 35 meters high.

Tools storage room: In H12, there is a room full of tools with a 'librarian' who on request finds particular tools that engineers and mechanics need. The number of tools here is in the thousands and it could certainly be a few minutes before they can be issued.

Picking up some materials for a task from the H12 tools/materials warehouse

Ergonomics:

Climbing the stairs: While working in the aircraft cabin, mechanics and engineers go up and down the stairs several times to move tools or materials.

Cleaning exteriors: Wiping the exterior of aircrafts with long mops is a common task which appears to be demanding on the shoulders

Looking up: Since the airplanes are tall, during many tasks mechanics and engineers are looking up for a significant amount of time straining their neck muscles.

Standing work: Due to the nature of work, much of the 8 hours of the shift are spent working while standing.

Lifting: Be it from H11 warehouse to H12 or within H12 during tasks, lifting objects (both light and heavy) is a regular part of the job.

Cold temperatures: The hangar doors are huge and radiators are present only on the ceilings.

Open door for an incoming aircraft during an evening shift

Sustainability:

Packaging of material: Parts from the warehouse come packaged in 2-3 layers of plastic.

Waste liquids: Liquid by-products of the cleaning process are filled in barrels and are sent for throwing away.

Carpets: Carpets stripped off from planes are dropped into a separate container.

Importance: I observed that sustainability doesn't come up often in conversations. It does not seem to be a topic of importance for individual stakeholders but only for the company as a whole.

Miscellaneous:

Checking the manual: During any task, checking of the manuals is possible on the iPad and computers in the team rooms. Physical copies of these manuals are still available.

Task distribution: Task distribution is done using task cards which can be picked up by mechanics from a manual dashboard kept beside an aircraft. The status of this dashboard is usually checked by team leads at the end of every shift.

Appendix C: Night Shift Experience

A description of my experience of the night shift of 5 March 2020 at H12.

To experience a shift was a crucial activity to undergo for this project as it is equivalent to stepping into the shoes of the most active users of the hangar. The teams of engineers and mechanics work in 3 shifts: Morning, Evening, and Night. The number of teams present during these shifts are as follows:

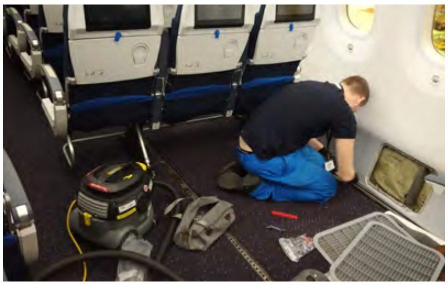
	M	T	W	Th	F	S	S
Day	2	2	3	2	2	1	1
Eve	2	2	3	2	2	1	1
Night	1	1	2	2	1	1	1

As I have been working out of the hangar during the day, I chose to join a night shift with team lead Marius Sypesteyn. For the Wednesday night shift of 05 March, two teams were present. The teams gathered at 22:45 while the team leads had a handover meeting from the team lead of the previous shift. During these meetings, the previous team lead shares information about the aircrafts currently in the hangar, the scheduled tasks, and a quick recap of the previous shift. Any issues faced or predicted are discussed during this meeting. When more than one team leads are taking over, they discuss and assign themselves tasks for the night. One of the leads takes charge of being in contact with the Operations Control Center (OCC) during the shift to communicate the timeline of the checks. Following this, the team leads go to the teams and appoint the tasks for the shift to the team members. Any questions, concerns are clarified before they all go out to work. When there are two or more teams, the team leads prefer to allot tasks involving multiple members to members of the same team as they know each other's working styles and capabilities well. Immediately after this, the teams go to their aircrafts and again have a quick talk with the previous shift teams to understand any complications related to their appointed tasks.

The two major tasks I got to witness during the shift were completion of an engine change on a 737 and carpet change on a 787.

Engine change: Usually only one of the engines of a 737 is changed during an A-check so it can be tested safely on a flight. It was a right engine change and the engine was already put into place by the previous shift. 4 men (including 1 intern) were assigned the task. The pending work for the shift were the final steps; to mount the nuts and pins and put on the panels. For this a sealant was required which needed to be picked up from H11 warehouse. For the specific engine, it wasn't clear which exact sealant the client (Jet2.com) uses. The manual was checked in the team lead room and calls were made to the customer. Finally an engineer of the customer visited the hangar to make sure all questions are answered. All of this cost between 30-45 minutes. After ordering and waiting for (approximately) 25 minutes, one of the engineers (whom I accompanied) collected the sealant from H11 which was a 15-minute walk. During this time the other engineers and intern were either doing small tasks or waiting. The aircraft was to be ready to leave for engine testing by 4 am. However, the tug drivers were not available till after the night shift so the 4 am deadline was not followed. The team took their time and completed their tasks by the end of their shift.

Carpet change: The floor carpets of 737s and 787s are usually replaced every 1.5 years. The 787 of the 5 March shift was supposed to be there 1 week later for a carpet change but came in early due to change/miscommunication in planning. All the carpets were removed in the previous shift and then it was found new carpets are not available to be put in. All they could do is wait for the carpets. No one checked if carpets were available before removing them because they expected them to be there. The carpets were delivered during the night shift and 6-7 mechanics worked on putting them in and mounting back the seats. The attachment process used tapes and sticky underside of carpets. The skirting of the sidewalls of the plane were broken and were replaced.



Replacing the carpets and the side skirting

Conversations with mechanics, engineers, and leads helped me arrive at the following conclusions about working in the hangar:

Shift preference: Most engineers have a preference for the evening shift followed by the morning and night shifts. Morning shift requires them to wake up too early whereas the night shift requires them to stay awake all night. Moreover, almost every week there is a change in shifts which disrupts their sleep cycles.

Waiting times: Waiting times between tasks is where efficiency is lost. Waiting for tools delivery or material collection is the most common source of waiting. It occurs quite regularly and especially for unscheduled maintenance (non-procedural). This is frustrating for engineers and mechanics as they have no control over it and also no possibility to accurately predict how much they will have to wait.

Frustrations with walking: The number of times engineers and mechanics have to walk long or short distances is found frustrating by them. When they are focused and working on a task and have to plug out of it to find tools or materials, combined with waiting, it is common that they feel annoyed. The location placement of tool cabinets in the corners, warehouse in H11, and tool store in H12 can be identified as a few reasons for this.

Working inside: For tasks inside the plane, not all tools can/should be carried at once because of safety requirements (forgetting or losing tools inside is disastrous). Due to this, they have to go up and down the stairs several times during these tasks.

Duration of tasks: On an average, most tasks that require one person can be done within 1-2 hours in ideal conditions (tools and materials available). But almost every time the tasks take longer than their designated times.

Stressful tasks: When talking about which tasks can be the most stressful, answers pointed out that every aircraft check and every shift is different. Depending on the condition of the particular task-related parts of the aircraft, the task can be easy or difficult. In general, any task can be stressful due to time pressure, logistic issues, difficult/old aircraft, and so on.

Aircraft tugs: Tugs are vehicles that are used to move airplanes by tugging the front wheel. These vehicles are available but licensed drivers are only at Schiphol Centrum and are not available all the time to move the aircrafts. This is especially the case during nights.

AOG: Aircraft on Ground is a situation when it is not possible to carry out a repair within the promised time and the aircraft is confined to the ground until action is taken by other related parties. This occurs several times in a week according to team leads and in such cases, they have no other option but to wait for parts or other departments to respond.

Mixed culture: The mechanics and engineers working in Hangar 12 come from various corners of the world with roots in Aruba, Surinaam, Turkey, Iran, UK, etc. Some teams are therefore culturally diverse and open.

Former experience: A few engineers have had experience working at other hangars in their careers. For them, H12 is not close to the state of the art or even the current state of other hangars. They aren't satisfied particularly with the logistics, material waiting times, and the unsmooth course of tasks.

Other departments: All the other departments are closed while the hangar runs 24x7. When aircraft checks take longer than expected, the hangar and teams are held responsible. Employees from other departments who are not present during these times, eg. materials supply might be the reason for delays but they are presumed to be not responsible for them.

A tools cabinet that was shown to me during the night shift that can be operated only using the KLM pass of an employee of that particular shift. The drawers have cameras inside which check for missing or wrongly placed tools.

The shift experience enabled me to confirm some of my personal observations and find overlaps with thoughts of the engineers. Though not all conclusions are relevant or in the scope of this project, they helped form an overall understanding of the way checks are carried out. Moreover, they helped me as a designer to sympathise with the needs of engineers and mechanics.

I would like to thank Marius Sypesteyn (lead), René (lead), Fenny, Murad, G, Mohammad, Chagi, Hans, Avinash, Adrian, Richard, and the rest of the teams for letting me join them and having honest and valuable conversations with me during the shift.

Appendix D: Industry Analysis

This section presents images that are missing from 2.3.5 Industry Analysis.

Structuring the industry analysis

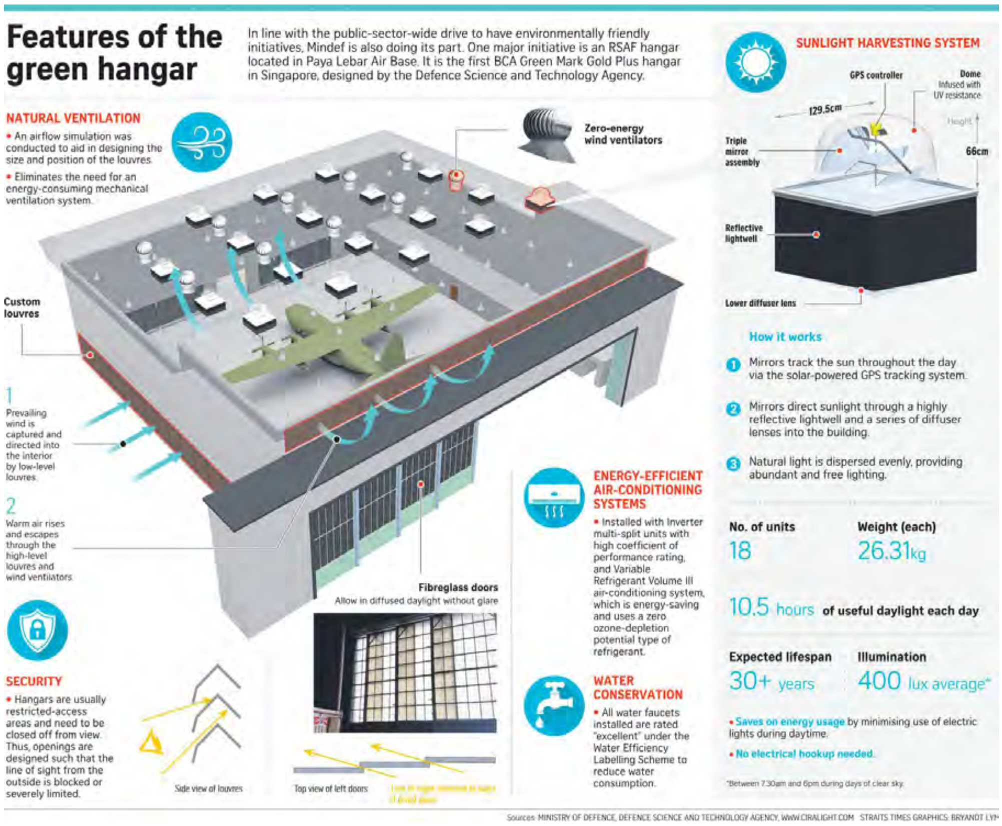
At the point when I did the industry analysis, I was actively trying to go broad and find out the variety of developments in the recent past, current time, and planned for the future in the aviation world, and specifically in the maintenance divisions of airlines. The industry analysis was primarily research using the internet. Since there is an overwhelming amount of information available on the internet, it was necessary to structure my searches. Most of the searches were initiated using Google or Google Images which linked me to the original articles. My search terms included (among others), in various permutations: hangar innovation, smart hangar, future aircraft maintenance, automation in aircraft maintenance, innovative airlines, technology in aviation industry, and then specific names of the big players KLM, Air France, Lufthansa, British Airways, Emirates, and so on. Following this, I tried to look inside these airlines by finding videos made in their hangars on Google (their own websites) and YouTube. For these, apart from the above mentioned terms, I added terms like: hangar tour, how are airplanes maintained, inside aircraft maintenance, behind the scenes, aircraft engineering, etc.

Using this method, I got a good overview of the level of innovation in the aviation MRO sector. I came across a few private jet hangars with specific elements (such as a white reflective floor), which I was inspired by. I chose not to go deep into each subject, theme, or concept I found as I did not want it to influence my thinking too much but rather serve as a background overview study. The ones I chose to document were the ones I found most interesting in relation to the topics of technology, ergonomics, and sustainability tackled in the project.

Following are some additional pictures that were left out from the main section due to space constraint.

The energy efficient hangar of Republic of Singapore Armed Forces (RSAF) at Changi Air Base (Zhang, 2020).

Features of RSAF's green hangar (Tan, 2018)



Teleplatforms in use in a hangar in South Korea for maintenance of Airbus A380 (CTI Systems, n.d.)

Appendix E: Value Curve Calculations

The calculation of the value curve from 3.3.2 is elaborated in this appendix.

The value curve extracts information from the workfloor to find out which problems are the most important to tackle. During the conversational interviews and the night shift, employees were asked questions in general about the hangar and specifically about their roles. This information was synthesized into top 3 priorities for 16 people and an aggregated graph was plotted to indicate what comes up the most often. This graph, called the value curve, indicates what areas of development would the hangar and its employees benefit the most from. Going further, problems related to these categories are considered in selecting the problem statements.

The concerns identified were divided into 11 categories. These categories were extracted from the conversations, in some cases directly stated and in others indirectly pointed at. Furthermore, they were assigned relative weights and a 'score' was calculated to find out the top 5 priorities across the hangar employees. The calculation of this score and other details are shown in Appendix E. Some of these priorities are interconnected as they are inseparable but needed to be explicitly stated. It is also important to note that the priorities which do not fall in the top 5 might still be touched by the solutions explored and chosen in the next phases. The aforementioned 11 categories are stated below.

Digitization: related to the extent to which tasks have been digitized to (iPad) apps and possibilties in the future

Efficiency: related to the speed of executing tasks

Ergonomics: related to the comfort of working for engineers and mechanics, especially for labor intensive tasks

High tech equipment: related to the state of technology of the equipment used for aircraft checks

Independence: related to the decisions the mechanics and engineers can make themselves and their reliance on the planning and support team

Layout: related to the positioning and management of equipment, tools, warehouse, etc. inside or outside the hangar

Logistics: related to the overall implementation of a check, its continuity, waiting times, movement of tools and materials, etc.

Look & feel: related to the visual look of the hangar and the feeling of working there

Mindset: related to the ethos and attitude of the engineers and mechanics

Sustainability: related to anything concerning environmental sustainability

Visual management: related to the visual representation of a check and its (realtime) data to the concerned persons

The following table shows the priorities of each individual.

Sr. no.	Priority 1	Priority 2	Priority 3
weight	10	8	6
1	Efficiency	Independence	Visual management
2	Efficiency	Digitization	High tech equipment
3	Logistics	High tech equipment	Visual management
4	Efficiency	Visual management	no 3rd priority
5	High tech equipment	Efficiency	Ergonomics
6	High tech equipment	Mindset	Efficiency
7	Visual management	Look & feel	Independence
8	Efficiency	Visual management	Independence
9	Visual management	High tech equipment	Layout
10	High tech equipment	Ergonomics	Layout
11	Logistics	Ergonomics	no 3rd priority
12	Logistics	Efficiency	Ergonomics
13	Logistics	Layout	no 3rd priority
14	High tech equipment	Logistics	Digitization
15	Logistics	High tech equipment	no 3rd priority
16	Logistics	Ergonomics	Sustainability

The weights of 10, 8, and 6 for the priorities in decreasing order were chosen to calculate the weighted aggregate score that helps find aspects which are most commonly mentioned and prioritized by various kinds of employees (engineers, team leads, planning & support office, higher positions, etc.). These specific numbers were chosen to reduce the bias which would be caused by, for instance, weights 3, 2, 1 which essentially mean that priority 1 is 3 times as valuable as priority 3.

The next step of calculating the aggregate score for each priority is shown below and the priorities are ordered according to their respective ranks.

Rank	Priorities	Occurences as Priority 1 (A)	Occurences as Priority 2 (B)	Occurences as Priority 3 (C)	Total mentions (A + B + C)	Aggregate Score (Ax10 + Bx8 + Cx6)
1	High tech equipment	4	3	1	8	70
2	Logistics	6	1	0	7	68
3	Efficiency	4	2	1	7	62
4	Visual management	2	2	2	6	48
5	Ergonomics	0	3	2	5	36
6	Digitization (apps)	1	1	1	3	24
7	Independence	0	1	2	3	20
8	Layout	0	1	2	3	20
9	Mindset	0	1	0	1	8
10	Look & feel	0	1	0	1	8
11	Sustainability	0	0	1	1	6

Appendix F: Brainstorm Session

A summary of the brainstorm session on 5 May 2020.

After defining the problem statements, it was natural for me to conduct a brainstorm to explore innovative ideas. In this exciting and exploratory phase, I chose to go broad again by having a lot of ideas as I believe that that often serves as a breeding ground for great ideas. The brainstorm was a group activity with Timo Pauel (Plant X Lead), Jens van Houwelingen (Plant X Intern, Industrial Designer), Tom Kooreman (Ground Engineer, H14). This set of participants was chosen as they all had an innovative mindset and could think of out-of-the-box ideas. At the same time, Tom also brought in a touch of ground experience.

Mindset and format:

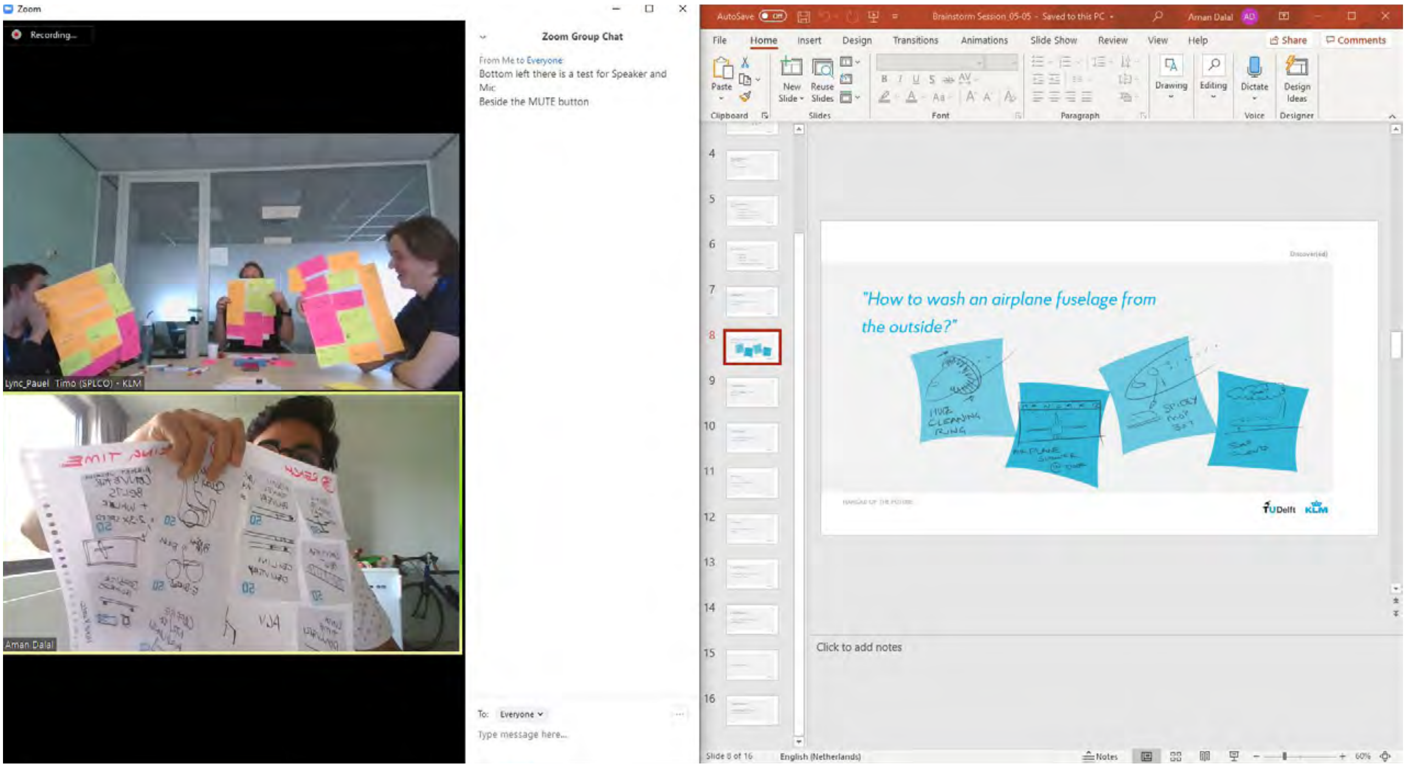
As a preparatory step for the brainstorm, I made an orientation presentation to communicate my goals for the session and align our thoughts. I stated that technology is of great value to the project and for a virtual prototype, physical solutions are encouraged. However, I also mentioned that they do not have to worry about feasibility at that point and can think of ideas which seem 'crazy'. In this presentation, I strongly persisted on the importance of having a lot of ideas rather than thinking how good they are. Some tips I communicated in my presentation for a fruitful brainstorm were:

- No right solution
- Postpone judgement / Bad ideas don't exist
- Break free of logic / Chance to think crazy
- Keep it simple / Don't dive deep
- Pay attention to keyword / root problem
- Read question again after every 2-3 ideas

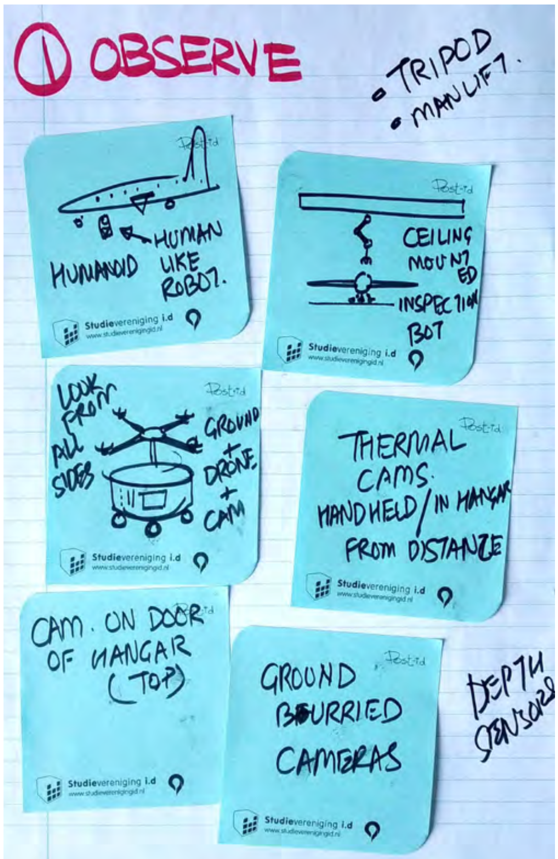
I also clearly communicated the format for the session which included a set number of questions related to the problem statements.

- 6 questions
- 'How To' format for most questions
- 4-5 minutes individual ideation + 4-5 minutes sharing/short discussion
- Write or make simple drawings. Each idea on separate Post-it
- Collect Post-its and put on A3 sheets for each question

To calibrate my participants, I had prepared a sample question with sample ideas. To my surprise, all three participants came up with ideas for this sample topic that matched the ideology behind the brainstorm. Given everything I described above, the brainstorm exceeded my expectations and went on very smoothly even though it was online. The questions and their outputs are shown in the following pages of this Appendix. These idea collections have been refined and discussed in the main report.

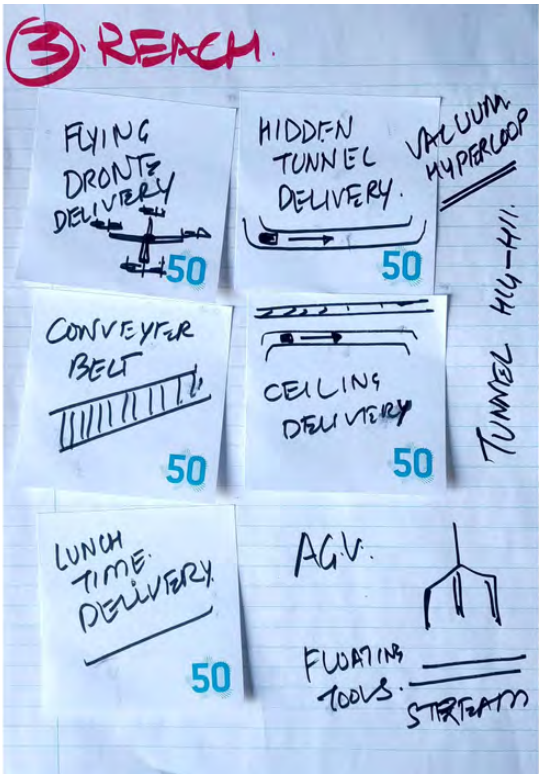


The brainstorm session held using a Zoom call

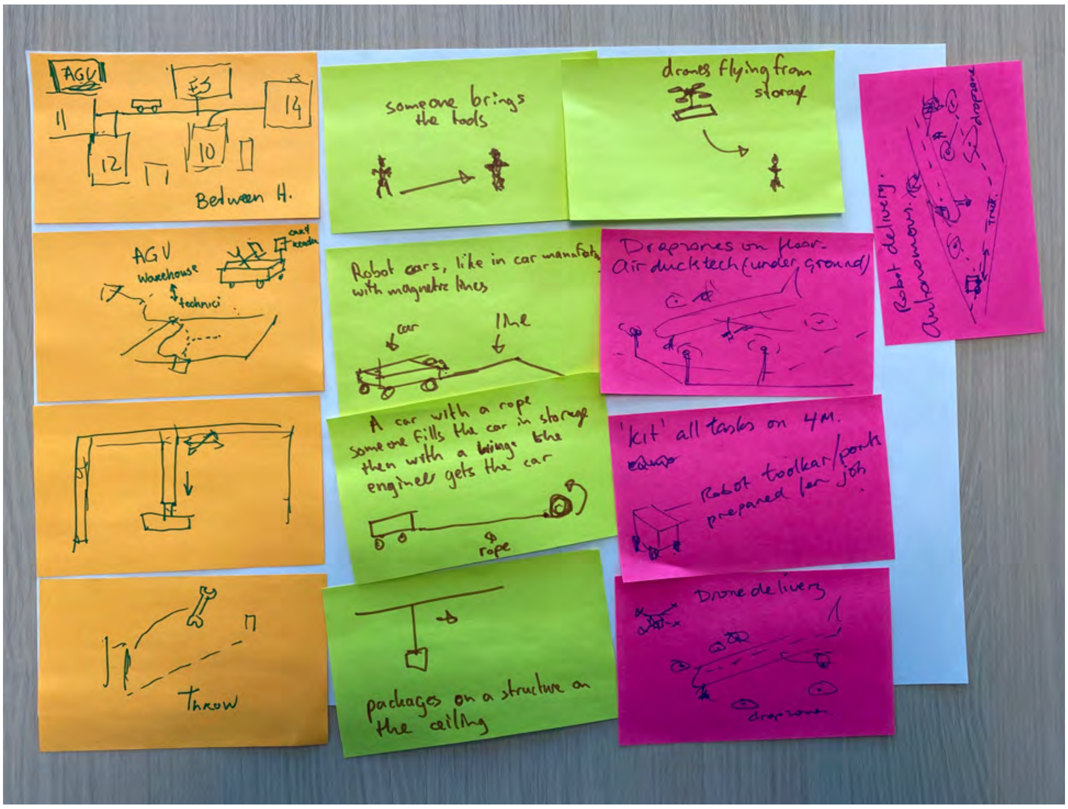


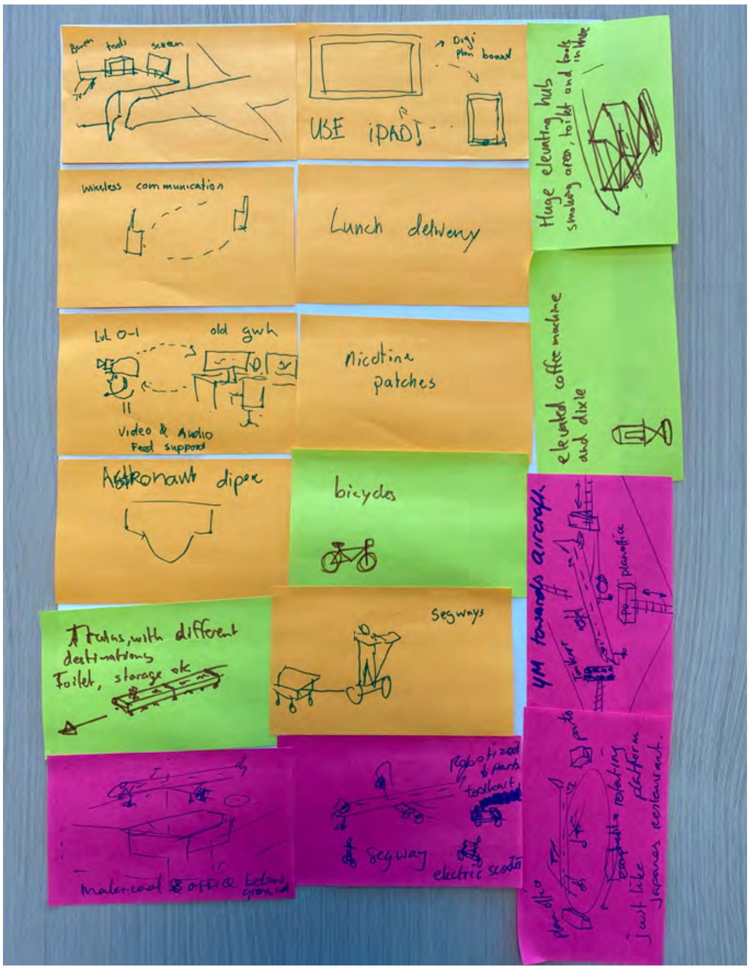
Q1: How can you **observe** an airplane externally?

Q2: How to find **defects** on the fuselage or wings of an airplane

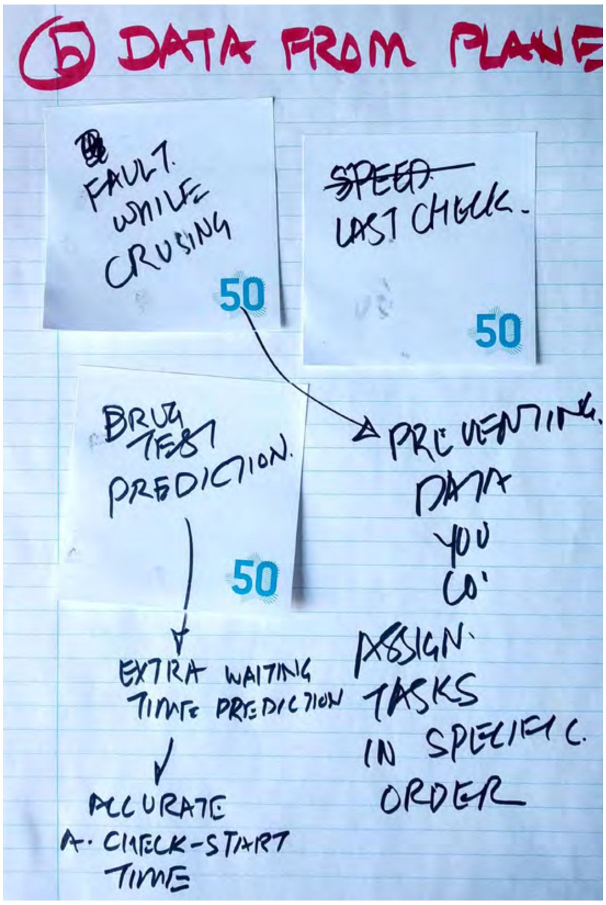


Q3: How can materials/ tools **reach** the engineers?

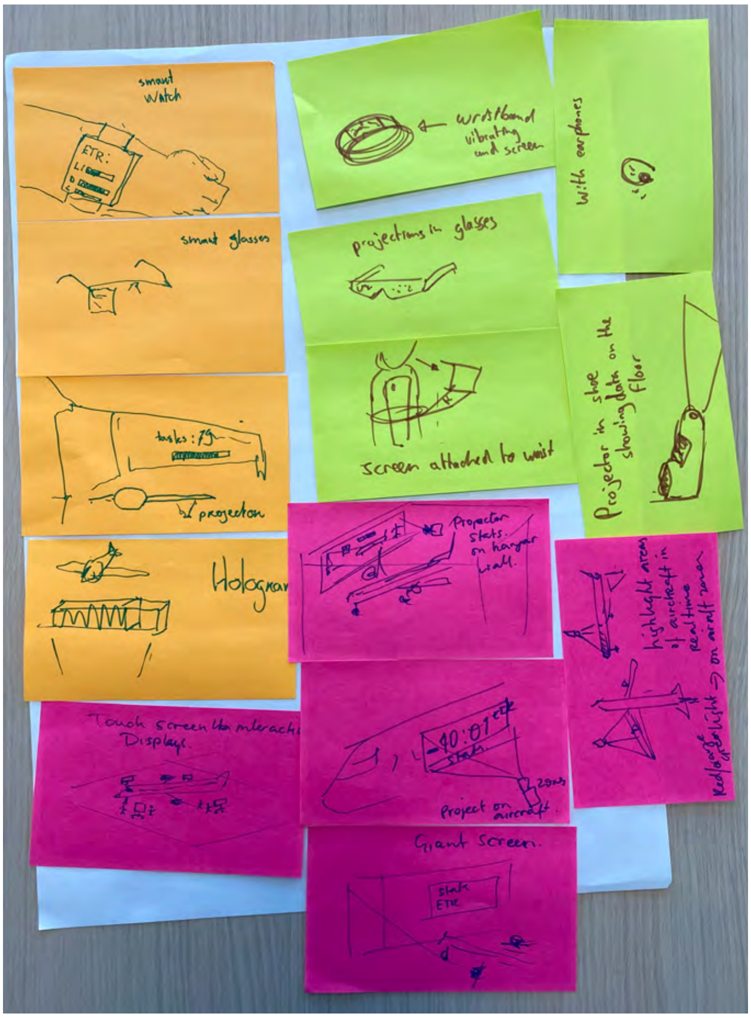


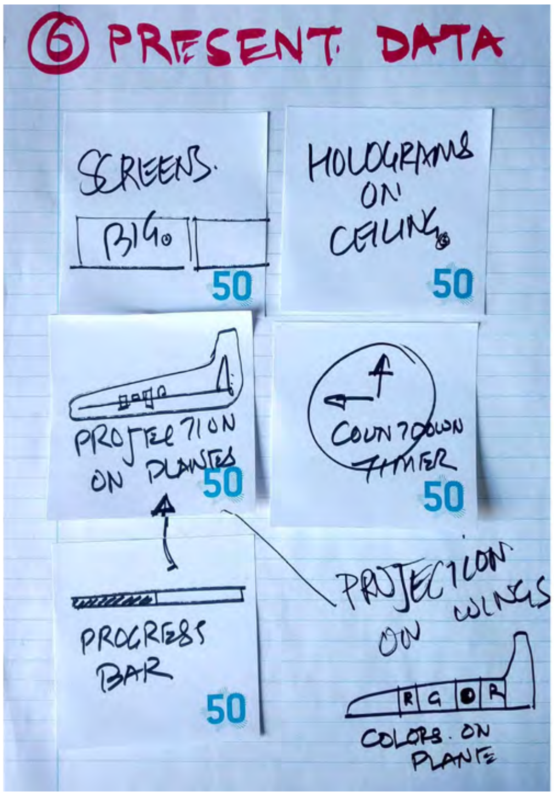


Q4: How to reduce **walking time** during a shift



Q5: What **data** from the airplane can help in better planning of a check?





Q6: How can real-time visualized data be **presented** to the team leads?

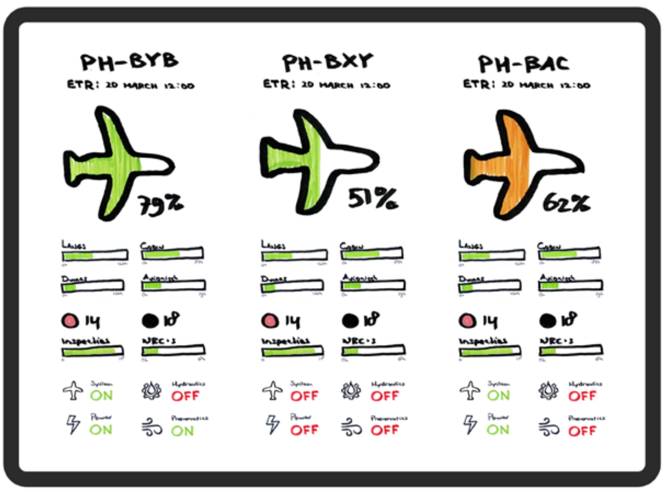
Appendix G: Visual Management Project

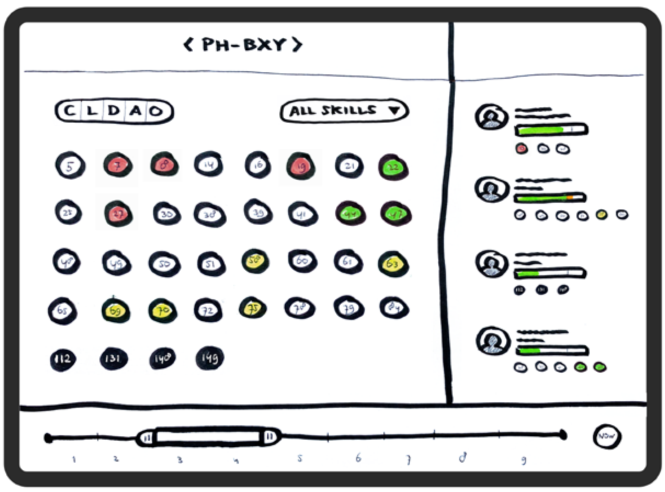
Research from the Plant X Visual Management project that are used in the Workfloor Dashboard concept development

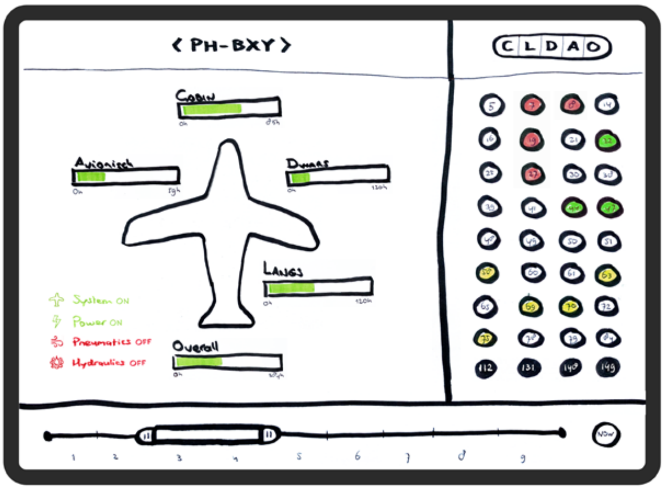
At the time of the Discover phase, Plant X was already into a project on the topic of visual management and carried out research on it. As a part of this research, interviews were carried out among engineers and mechanics about the kind of data that they would like to be informed about. This data was aggregated for all participants and converted into scores. The direct results from this survey (in Dutch) are shown below and were used in giving examples of the information that the Workfloor Dashboard could show.

Voortgang	Alex	Evert	Aswin	Ronald	Michel	Ronald	Rob	Willem	Gerrit		Avg.	Majority positive (majority has score of 4 or 5)
Lopen we op schema van de ETR?	4	5	5	4	2	4	2	5	5		4.0	7
Wat is de status van milestones (fases in werkvolgorde)	1	5	3	4	3	3	3	3	5		3.3	3
Wat zijn de highlights van het takenpakket (bijv corrosie)	5	3	4	4	5	4	4	5	5		4.3	8
Wat zijn de belangrijkste punten voor de overdracht	3	5	5	4	4	5	5	3	5		4.3	7
Personeel												0
Hoeveel man komt er op?	5	2	5	4	2	4	5	3	5		3.9	6
Hoeveel werk is er toegewezen per teamlid	3	3	3	2	2	1	4	3	1		2.4	1
Takenpakket												0
Wat is de voortgang van de inspecties	5	4	4	4	5	4	5	3	4		4.2	8
Hoeveel NRC's zijn er aangemaakt + voortgang?	3	2	2	2	5	1	3	4	1		2.6	2
Hoeveel taakkaarten per werkgebied?	2.5	2	1	3	5	1	2	2	2		2.3	1
Wat is de status van het materiaal	5	5	5	4	5	5	4	5	5		4.8	9
Hangar												0
Wat is de vliegtuigplanning	4	3	3	4	4	3	3	4	4		3.6	5
Welke andere teams zijn er op?	2	2	3	4	5	1	4	2	3		2.9	3

The results from the aforementioned interviews were represented in visual format using drawings of this information on screens. These drawings, shown below, give a clearer idea of how the Workfloor Dashboard could show such information.



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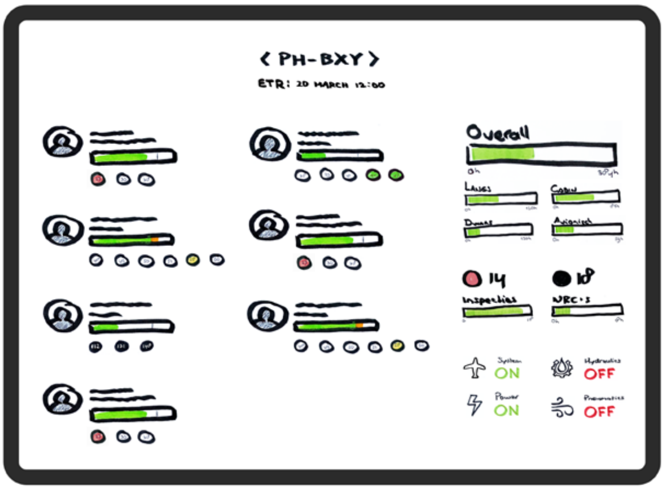
C L D A O
Cabin
Avionics
Doors
Lav
Overall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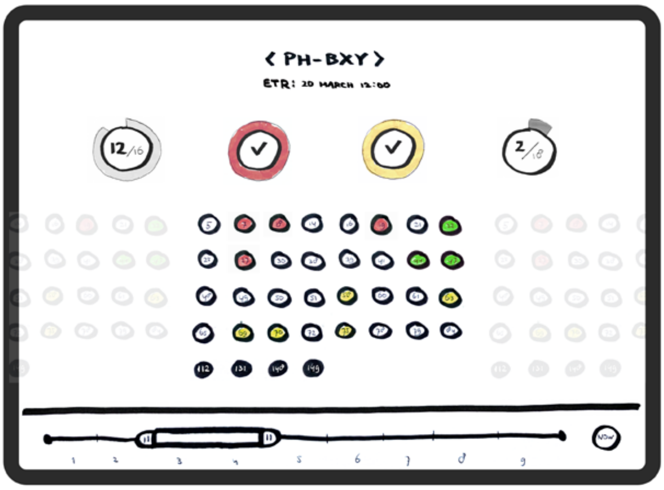
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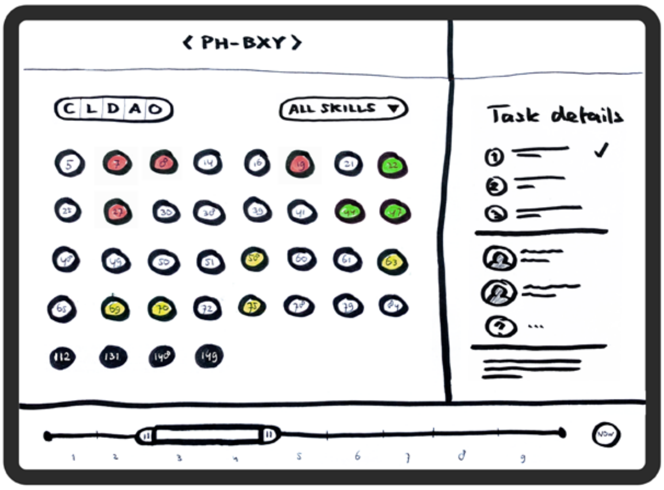
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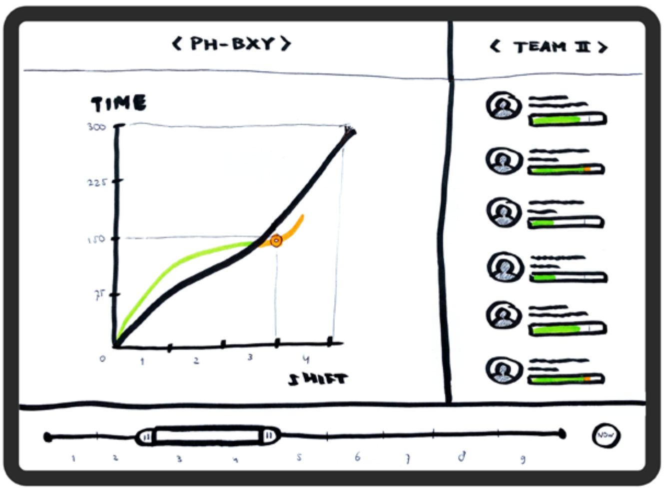
C L D A O
ALL SKILLS
Task details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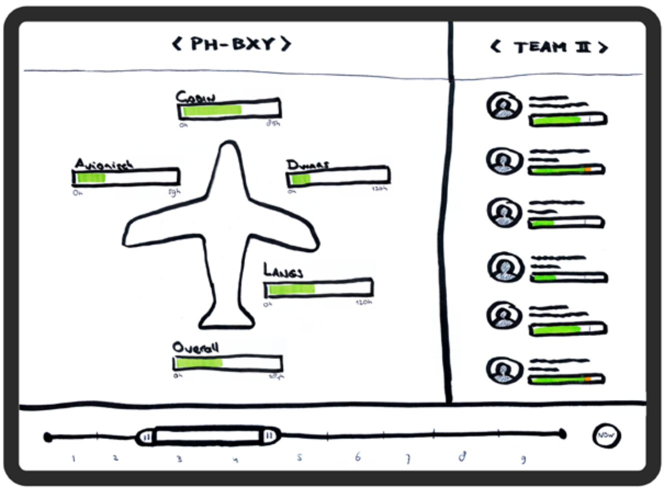
TIME
SHIFT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Cabin
Avionics
Doors
Lav
Overall

Appendix H: Storytelling Questionnaire

The story, questions, and responses from engineers and mechanics

In the Storytelling Questionnaire, a 'day in the hangar of the future' was portrayed by the use of a narrative story. The story served as a tool to set the context and introduce the concepts to the participants. Engineers, mechanics, and team leads were naturally chosen to be the target group for validation as they would be the direct users of the proposed concepts. The following textual part was sent out to the participants supported by visuals from the storyboards, concept sketches, and renders from 5.3.2 to 5.3.4. Paperform.co was used to compile the story with the visuals as shown in the following screenshots. The questionnaire was responded to by 7 participants. The results are stated in the upcoming table and were discussed in 5.3.5 (Storytelling Questionnaire for Validation).

Text of the story:

Welcome to the Hangar of the Future. Could you spend a few minutes and tell us about your (potential) future work experience?

Thanks for helping us. We will go through an A-check shift, set in 2025, with the aid of a story consisting of 3 tasks.

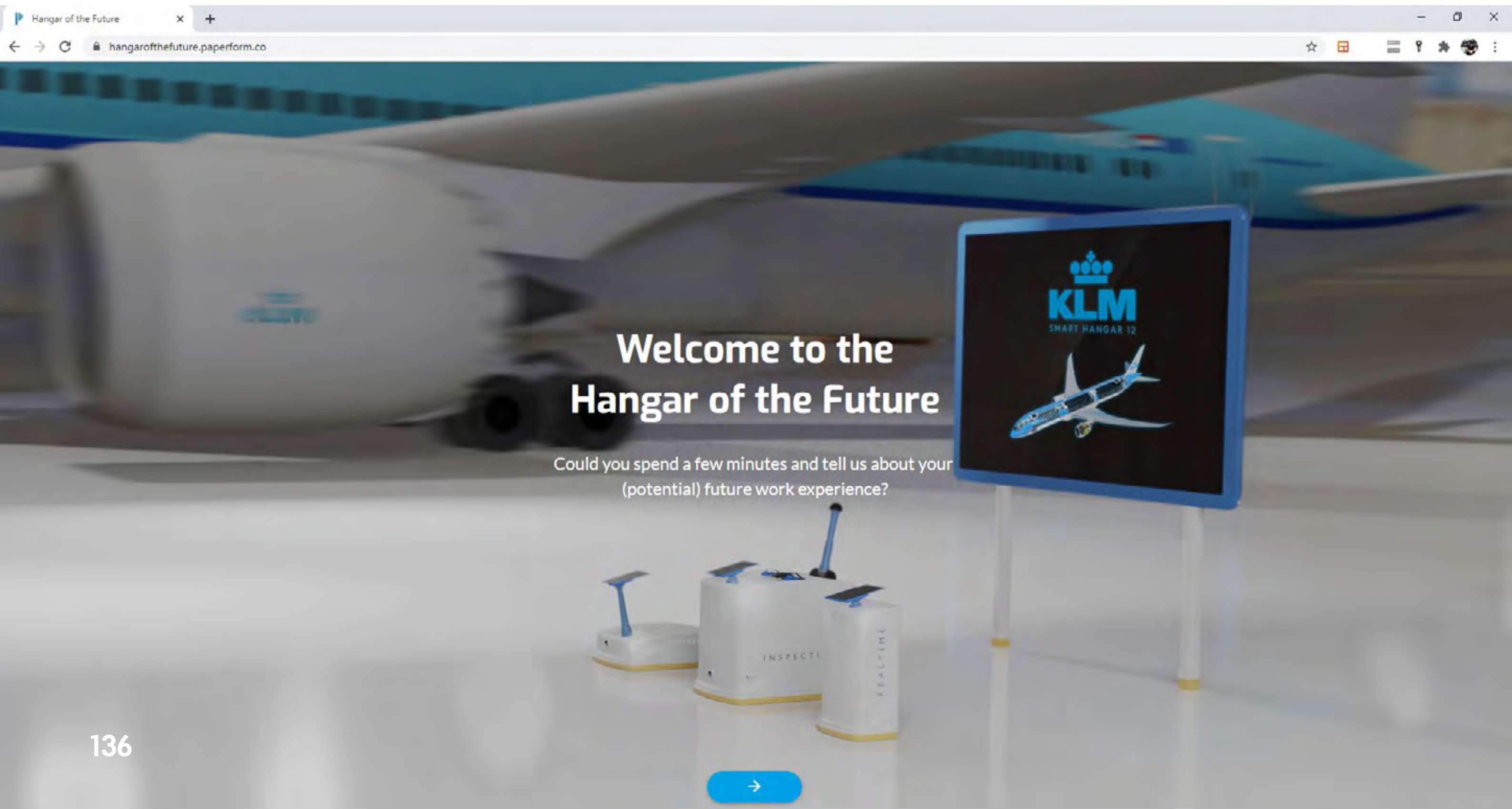
Task 1 takes you through the visual inspection of a 787.

In Task 2, you change the left engine with 2 of your colleagues.

Lastly, in Task 3, you discuss the ongoing check with the team lead.

Imagine yourself in 2025, standing in the hangar of the future. You are ready for your afternoon shift with your team. The shift has just started and the 787 PH-BKA arrived in the hangar. Your first task is to visually inspect the aircraft exterior.

Screenshot of the startpage of the storytelling questionnaire (hangarofthefuture.paperform.co)



Scene 1

You approach the aircraft and the Inspection Cobot (collaborative robot) is waiting for you there. You pick up the iPad located on the Cobot and the screen has a button called 'Start Full Visual Inspection'. You click on it and the Cobot starts moving on the ground around the aircraft.

The telescopic arm with a camera changes its length and angle now and then, looking at every surface of the bottom half of the aircraft. At the same time, the drone located on it takes off and flies around the aircraft analysing the upper half.

While the Cobot does its job, you take your personal iPad and pick-up your next tasks on the iMech app, order materials, and get an overview of the shift. After around 15 minutes, the drone has landed and the Cobot iPad shows you a summary of the inspection.

Two identified faults need further human inspection:

1) Paint damage at the bottom of the left wing

2) Lightning strike at the top of the fuselage

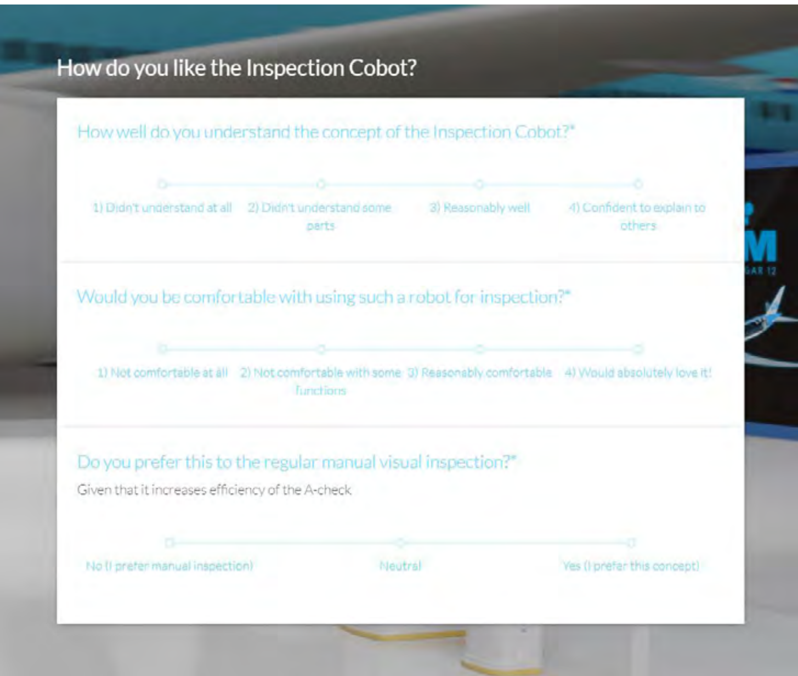
You drive the Cobot to the left wing using the remote control feature. You control the inspection arm and take a closer look at the paint damage using the Cobot camera telecasted on the iPad and make a note of it in the summary.

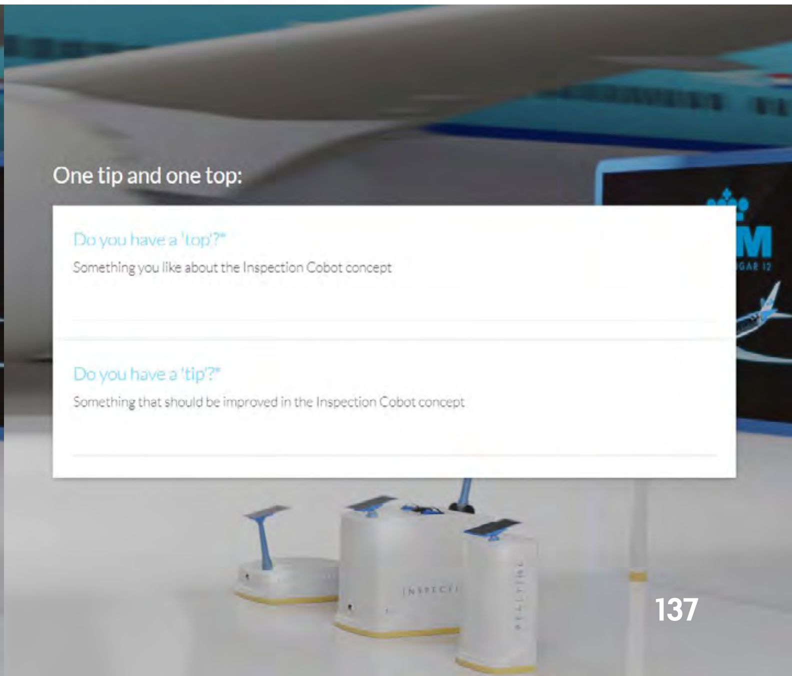
Next, you launch the drone and it automatically flies it to the lightning strike when you click on the fault. Again, you take a close look using the high definition drone camera and make a note in the summary.

After the drone lands, you fill in the two identified faults in the iPad with the material needed for each detected fault and create new tasks to repair them. These tasks will be picked up later by someone else.

Your task is complete. You put the iPad back on the Cobot and mark the inspection as complete.

Screenshot showing the questions following Scene 1.
Similarly phrased questions follow Scene 2 and 3 also.





Scene 1 Questions

• How well do you understand the concept of the Inspection Cobot?
1) Didn't understand at all
2) Didn't understand some parts
3) Reasonably well
4) Confident to explain to others

• Would you be comfortable with using such a robot for inspection?
1) Not comfortable at all
2) Not comfortable with some functions
3) Reasonably comfortable
4) Would absolutely love it!

• Do you prefer this to the regular manual visual inspection?
1) No (I prefer manual inspection)
2) Neutral
3) Yes (I prefer this concept)

• Do you have a 'top'? (something that you like about the Inspection Cobot concept)

• Do you have a 'tip'? (something that should be improved in the Inspection Cobot concept)

Scene 2

You move on to your next task which is the right engine change on the same aircraft. The new engine is already near the aircraft and while the inspection was going on, you had picked up this task and ordered the engine change material and tools package using the iMech app.

An Automated Guided Vehicle (AGV) from the warehouse tugging a loaded cart drives by and leaves it near the right engine. As soon as you walk to the engine, you are all set-up to work on your task with 2 more colleagues.

When your task is complete, you call an AGV to help you drop off the remnant engine and tools. You load these on 3 carts and pick up the iPad from the AGV. The AGV latches onto the first cart and you use the iPad remote control to drive everything to the drop-off point near the warehouse.

Scene 2 Questions

• How well do you understand the concept of the Automated Guided Vehicle (AGV)?
1) Didn't understand at all
2) Didn't understand some parts
3) Reasonably well
4) Confident to explain to others

• Would you be comfortable with ordering materials, tools, workbenches, etc. on your iPad and receiving them via this vehicle?
1) Not comfortable at all
2) Not comfortable with some functions
3) Reasonably comfortable
4) Would absolutely love it!

• Do you prefer this concept instead of walking to the warehouse to get materials/tools?

1) No (I prefer manual inspection)
2) Neutral
3) Yes (I prefer this concept)

• Do you have a 'top'? (something that you like about the AGV concept)

• Do you have a 'tip'? (something that should be improved in the AGV concept)

Scene 3

It is past 6 pm and after your coffee break and you are wondering how the check is going. You meet your team lead in the middle of the hangar by the dashboard and discuss various ongoings of the check.

The screen shows the live status of tasks, what tasks are lagging behind, what skills of the team are available in the coming hours, etc. You use the iPad on the control panel to navigate the screen and check that the estimated time of delivery is behind schedule and this is majorly because carpet change is lagging behind. Along with the team lead, you decide to assign more people. You can do this by using the same control panel iPad and the selected mechanics are notified about their next task.

Scene 3 Questions

• How well do you understand the concept of the Workfloor Dashboard?

1) Didn't understand at all
2) Didn't understand some parts
3) Reasonably well
4) Confident to explain to others

• Would you be comfortable with getting realtime information about your shift and A-check on this dashboard?

1) Not comfortable at all
2) Not comfortable with some functions
3) Reasonably comfortable
4) Would absolutely love it!

• Do you prefer this concept over primarily vocal discussions?

1) No (I prefer manual inspection)
2) Neutral
3) Yes (I prefer this concept)

• Do you have a 'top'? (something that you like about the Dashboard concept)

• Do you have a 'tip'? (something that should be improved in the Dashboard concept)

Questionnaire Responses

Responses to questions following each scene of the story by the 7 participants in a tabular format.

Questions after Scene 1 (Inspection Cobot)

Sr. no.	How well do you understand the concept of the Inspection Cobot?	Would you be comfortable with using such a robot for inspection?	Do you prefer this to the regular manual visual inspection?	Do you have a 'top'?	Do you have a 'tip'?
1	3) Reasonably well	3) Reasonably comfortable	Neutral	Makes life more easy.	Look for existing technology.
2	4) Confident to explain to others	3) Reasonably comfortable	Yes (I prefer this concept)	How many Cobots will be used during an inspection?	No
3	4) Confident to explain to others	3) Reasonably comfortable	Neutral	Yes, not working at heights. Constant quality of inspection.	Well, too early to tell. Build a prototype first.
4	3) Reasonably well	4) Would absolutely love it!	Yes (I prefer this concept)	For the inspection with the Cobot, you stay safe on the ground. Safe and easy!	No tip at this moment.
5	4) Confident to explain to others	4) Would absolutely love it!	Yes (I prefer this concept)	Computers always have the same outcome and routine humans not.	Maby other camera's like x-ray or scan. For detailed inspection
6	4) Confident to explain to others	4) Would absolutely love it!	Yes (I prefer this concept)	I especially like the drone performing the upper fuselage inspection! Normally this is a hassle getting access with telescopic cranes, risk on the ground while moving, things in the way, etc. It takes a lot of time!	I think that on the ground i'm quicker in doing the inspection than the robot, especially since nine times out of 10 this is a 'GVI' General Visual Inspection, which can be performed from ground level. In case of suspecting a finding you move closer to the area. As long as it doesn't operate autonomously there isn't a direct win. But having said that, that maybe something to develop towards and in any case i would definitely try cobot out with an open mind!:)
7	4) Confident to explain to others	3) Reasonably comfortable	Neutral	n/a	n/a

Questions after Scene 2 (AGV Tug)

Sr. no.	How well do you understand the concept of the Automated Guided Vehicle (AGV)?	Would you be comfortable with ordering materials, tools, workbenches, etc. on your iPad and receiving them via this vehicle?	Do you prefer this concept instead of walking to the warehouse to get materials/tools?	Do you have a 'top'?	Do you have a 'tip'?
1	4) Confident to explain to others	3) Reasonably comfortable	Yes (I prefer getting it delivered)	Makes life more easy, let me wait or work on other work.	Get information at Gregor Klemencic, director of Deep innovations BV.
2	4) Confident to explain to others	4) Would absolutely love it!	Yes (I prefer getting it delivered)	Not at this moment	Not at this moment
3	3) Reasonably well	3) Reasonably comfortable	Yes (I prefer getting it delivered)	Yes, could save a lot of searching time.	Stands or falls with the quality of delivered goods. Automatic or not.
4	3) Reasonably well	4) Would absolutely love it!	Yes (I prefer getting it delivered)	It reduces workload in the hangar.	No tip.
5	4) Confident to explain to others	4) Would absolutely love it!	Yes (I prefer getting it delivered)	Safer because you search for part numbers and tool numbers.	N/a
6	4) Confident to explain to others	4) Would absolutely love it!	Yes (I prefer getting it delivered)	Knowing that all the equipment & tooling is 'Kit-ted' meaning that every tool and/or equipment needed to perform a specific task, in this case an engine change, is known and represented in a dedicated 'Kit' and thereby deliverable by AGV on location. No more unnecessary 'waste' in the process by searching for tools and equipment! This will revolutionize not only the way you perform, prepare or get ready for a task but will change the whole supply chain. Saving a tremendous amount of time. note: this is applicable for at least 60-70% of Maintenance tasks in the C-check!	Manually ordering of material should not be necessary if the task is planned...? :) it should be part of the kit. Unless what is ment that you "order" the whole kit which consists of the Tools, equipment, material etc.
7	4) Confident to explain to others	3) Reasonably comfortable	Yes (I prefer getting it delivered)	n/a	n/a

Questions after Scene 3 (Workfloor Dashboard)

Sr. no.	How well do you understand the concept of the Workfloor Dashboard?	Would you be comfortable with getting realtime information about your shift and A-check on this dashboard?	Do you prefer this concept over primarily vocal discussions?	Do you have a top?	Do you have a tip?
1	3) Reasonably well	3) Reasonably comfortable	Yes (I prefer this visual dashboard for discussions)	Makes work visual.	How long is the check? What are the highlights?
2	4) Confident to explain to others	4) Would absolutely love it!	Yes (I prefer this visual dashboard for discussions)	Not at this moment	Not at this moment
3	3) Reasonably well	3) Reasonably comfortable	Neutral	Yes, clear information.	Same as with all IT. Shit in is shit out.
4	4) Confident to explain to others	4) Would absolutely love it!	Yes (I prefer this visual dashboard for discussions)	Everyone have a clear overview of the FA inspection.	In the shift you need someone to keep the information on the Dashboard update.
5	3) Reasonably well	4) Would absolutely love it!	Neutral	N/a	N/a
6	4) Confident to explain to others	4) Would absolutely love it!	Yes (I prefer this visual dashboard for discussions)	I like that, in this case a screen, presents facts! This factual data is really important and what is missing at the moment. This leads to poor and sometimes emotional decision-making due to lack of project overview which is inefficient and counter productive on a whole.	As an add-on you could feature a device like 'Apple Glass' for instant realtime status and other useful information. (i have some more ideas)
7	4) Confident to explain to others	3) Reasonably comfortable	Yes (I prefer this visual dashboard for discussions)	n/a	n/a

Role playing with Personas

	Youssoef Hassouni	Ronald Weerwind	Harry van der Werf
How well do you understand the concept of the Inspection Cobot?	3) Reasonably well	4) Confident to explain to others	4) Confident to explain to others
Would you be comfortable with using such a robot for inspection?	3) Reasonably comfortable	4) Would absolutely love it!	4) Would absolutely love it!
Do you prefer this to the regular manual visual inspection?	Neutral	Yes	Yes
How well do you understand the concept of the Automated Guided Vehicle (AGV)?	3) Reasonably well	4) Confident to explain to others	4) Confident to explain to others
Would you be comfortable with ordering materials, tools, workbenches, etc. on your iPad and receiving them via this vehicle?	3) Reasonably comfortable	4) Would absolutely love it!	4) Would absolutely love it!
Do you prefer this concept instead of walking to the warehouse to get materials/tools?	Neutral	Yes	Yes
How well do you understand the concept of the Workfloor Dashboard?	3) Reasonably well	3) Reasonably well	4) Confident to explain to others
Would you be comfortable with getting realtime information about your shift and A-check on this dashboard?	3) Reasonably comfortable	4) Would absolutely love it!	4) Would absolutely love it!
Do you prefer this concept over primarily vocal discussions?	Neutral	Yes	Yes

The personas created in 3.3.1 were given a voice to answer the questionnaire. This was done by playing their role: reading through the persona a few times and thinking from their side followed by answering the questions after storytelling. This was done by two designers (including myself) and most of the answers matched and were agreed upon. The ultimate answer to whether these personas would prefer the concepts to their current alternative was answered with either a neutral or a yes for every concept.

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