AMBULANCE DRONES IN THE NETHERLANDS: A VISION + CONCEPT DESIGN FOR 2035.

Graduate student

Jasper Dielemans
5137187

Supervisory team

Chair: J. W. Hoftijzer
Mentor: D. I. Brand

Delft, September 2021

Delft University of Technology
Msc. Integrated Product Design
Faculty Industrial Design Engineering

TUDelft

MODYN

AMBULANCE DRONES IN THE NETHERLANDS: A VISION + CONCEPT DESIGN FOR 2035.

PREFACE

Knowing that this was the final project I would perform in a study related context is quite surreal, having spent most of my life working up to this point. It all led to here quite naturally. Starting from hobbies like drawing and crafting with wood and other materials, Industrial Design was the obvious choice for me more than 6 years ago. It has gone by so fast, and now I am proud to show what skills I have acquired.

I am thankful to Modyn, the client, for providing me this project that allowed me to fully make it my own and entrusting me with painting a vision for them. It was a very complex and conceptual subject to tackle, which taught me a lot about dealing with complexity and keeping a conceptual project grounded to reality.

Executing the graduation project during the pandemic was a strange experience as working from home was the norm for the majority of the project. Nonetheless, I always felt supported by the supervisory team and the experts that were willing to share their insights with me.

ACKNOWLEDGEMENTS

Jan Willem
Thank you for your guidance during the project. Although we never met face to face up to this writing, the feedback sessions were always relaxed and positive. You also suggested Modyn as a possible external party, which I am grateful for.

Dicky
You always managed to take away any of my concerns and uncertainties regarding the project. Your positive constructive coaching helped me to stay motivated and extract the most out of my graduation project.

Rik
Although we had not seen each other until halfway into the project, you regularly kept in touch about what I was doing and how I was doing. Thank you for the effort of bringing me in contact with experts.

Gert-Jan
Thank you for guiding me during my time at Modyn and making me feel part of the team. I enjoyed your enthusiasm when sharing my results with you. Your effort to connect me to Sabino was also of great benefit.

Sabino
Thank you for collecting insights from so many valuable experts and bringing me in contact with them. Without your assistance this project would not have been possible.

Manon
You experienced most of my project along with me and it is thanks to you that I kept my head up during the last half year, during which we experience some big changes. You always provided a listening ear and often untangled the mess in my head at difficult stages in the project.

COLOFON

Graduate student

Jasper Dielemans
5137187

Study program

Msc. Integrated Product Design
Faculty of Industrial Design Engineering
2019-2021

Supervisory team

Chair	Jan Willem Hoftijzer
Mentor	Dicky Brand
Mentor Modyn	Rik de Reuver
Mentor Modyn	Gert-Jan van Breugel

Educational Institution

TU Delft
Landbergstraat 15
2628 CE Delft

Client

Modyn
Industrieweg 8
4191 NV Geldermalsen

EXECUTIVE SUMMARY

In the previous decade, a new type of air travel has seen a surge of interest from established and start-up companies alike: Air Mobility, a type of short range air travel as an alternative to taking the train or the car. Part of air mobility are a new type of aircraft, called Electric Vertical Take-off and Landing vehicles (eVTOLs), which hold potential for many new use cases.

Design agency Modyn wants to profile themselves within the field of air mobility through a vision concept for an ambulance drone. This use case, they reckoned, would be a good starting point for Air Mobility and eVTOLs, as it attracts more public acceptance than commercial use cases, such as an air-taxi service.

Modyn's vision project was turned into this graduation thesis: an ambulance drone concept for the scope of 2035. Far enough in the future to capture the imagination, but near enough for it to relate to our present day reality in 2021.

Keeping the project grounded was one of the main challenges. It required a good understanding of the current ambulance system in The Netherlands. Which was the first research subject. A visit to ambulance station Delft and interviews with people from the field were all valuable input.

After establishing the current status quo, a look into the future was taken. Here, plans towards Air Mobility were investigated, in order to see how much The Netherlands is interested in this idea. The influence of technological and societal developments that relate to Air Mobility were plotted on a timeline, creating a roadmap towards 2035. This roadmap would create an input for the technical architecture of the ambulance drone.

Having a good picture of the present and a potential future, the research was distilled into a vision and a mission. The focus now clearly went towards using ambulance drones to replace the current ambulance helicopters. Also, the design challenges were identified and a program of requirements was compiled.

The design phase started off with the ideation, in which Virtual Reality was used to generate interior layouts. The interior is the most fundamental part of the design, as it is responsible for 90% of the interactions that the users have with the ambulance drone. An inside-out design approach was therefore the most sensible.

From the VR based ideation, the most promising interior layouts were translated into concepts. The direction was still rather open at this point, so in order to converge towards the final concept, a lot of experts were consulted for feedback on the concepts and the direction of the project.

This led to the creation of the final design, which was loosely based on two of the concepts. Thanks to the feedback from experts, the final design underwent quite a metamorphosis compared to the concepts.

The result is an ambulance drone concept with novel features and interesting ideas regarding the interior layout. The final concept has a recognisable, yet unique identity from a visual standpoint, being professional and approachable at the same time.

TABLE OF CONTENTS

A

INTRODUCTION

PROJECT BRIEF

1. The potential of Air Mobility

Hand in hand with the electric revolution in the automotive industry, other industries started looking into electric mobility solutions as well. One of these is the aviation sector. In the past decade the interest for electric flying vehicles has developed into a major spearpoint for most well-established aircraft manufacturers, such as Airbus, Boeing and Embraer. However, in the pursuit of the best performance, electric solutions are not the only ones being put forward, but also hybrid systems, hydrogen systems and many other variations. In general this emerging field of aviation is called “air mobility”. At this stage the developments in air mobility consist of a large amount of vastly different concepts and prototypes. Manufacturers are all trying to discover the best solutions for achieving the performances that are desired, trying to overcome significant technical challenges and limitations. Because air mobility is at the forefront of aviation development, there is no evidence or experience from practice showing what will be the best solutions for this type of air travel. In other words, the field of air mobility is very much in a phase of divergence and in the coming decade real world tests will start to form a better picture of what air mobility will become.

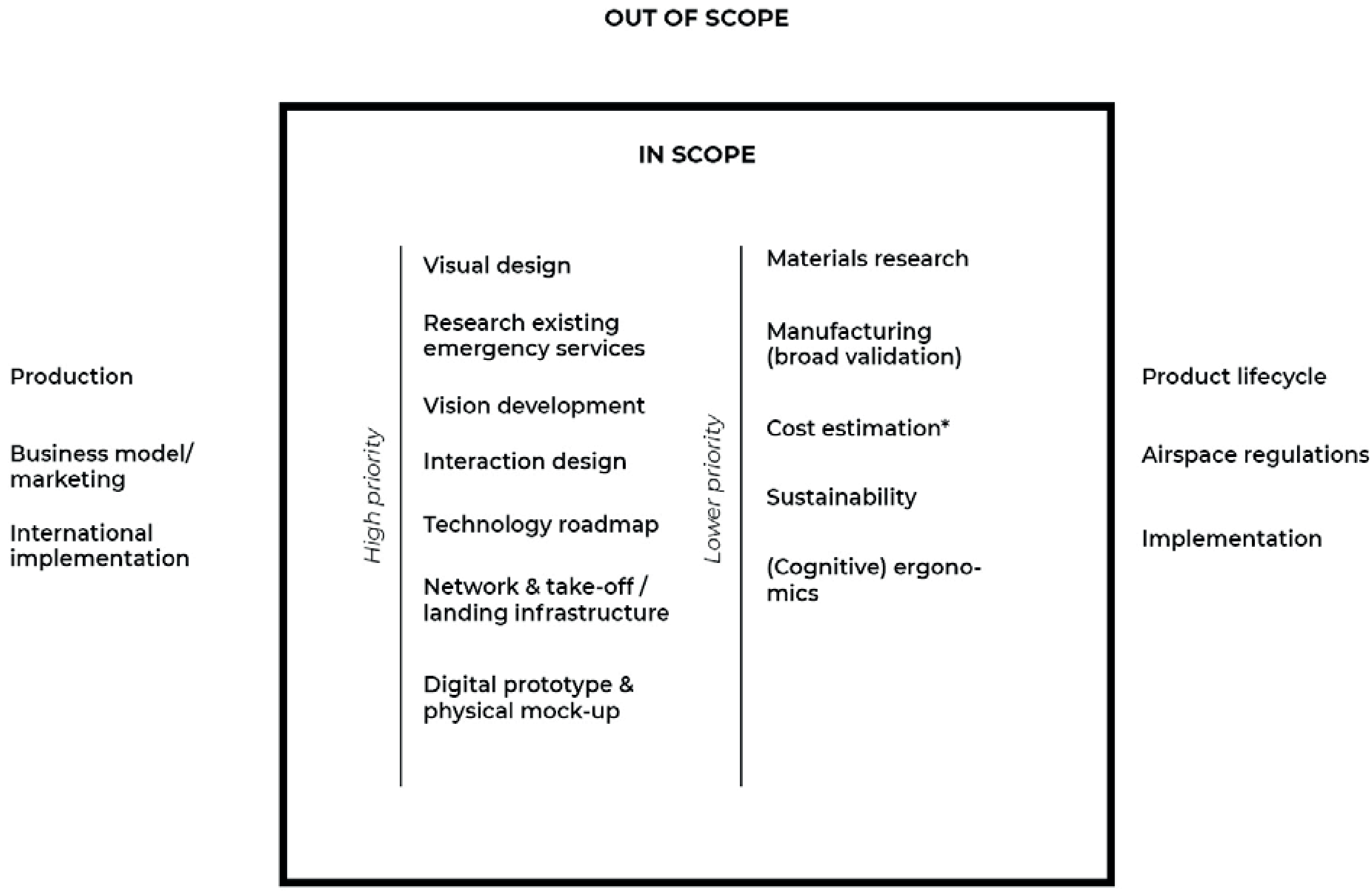
In the past decade a lot of new players have entered the air mobility market, trying to disrupt the field of aviation and established companies with their concepts and (working) prototypes. Most commonly, these are of the so called VTOL aircraft type, which stands for an Vertical Take-off and Landing aircraft. These are small, manned aircrafts that have the ability to take-off and land in a vertical direction, making them very capable in spaces that would normally not be suited for helicopters and airplanes. In a sense they are a large scale version of a drone, equipped with multiple rotors and operating (semi) autonomously, but are able to carry passengers as well. This gives VTOL’s a large range of new potential use cases that could be interesting from both a commercial and a societal standpoint.

Since the emergence of air mobility, a lot of the “hype” is based on the idea of flying taxi’s that can drastically reduce inter- and intracity travel times by avoiding congested traffic on the roads. Most of the concepts and prototypes that are in advanced stages by now are based on this use case. Currently, however, other implementations of VTOL aircrafts are being proposed that are not just taxi services for a select group of people.

2. Project backstory

When I contacted mobility design agency Modyn, who were suggested to me by chair and supervisor Jan Willem Hoftijzer, they were open to the idea of a thesis project that would really suit my interests and sufficiently challenge me. They proposed a vision project for an ambulance drone concept which would allow them to take a stance within the field of air mobility. This project would give me a lot of freedom and independence, allowing me apply my own vision and have a lot of influence on how the design would manifest itself.

For Modyn, the increased interest for VTOL aircrafts became apparent when visiting a mobility congress. Many of companies were presenting visions of VTOL aircrafts and therefore Modyn felt they also should get involved in this rapidly developing market. Since Modyn is not a party that could completely develop an aircraft in-house, they did feel an urge to profile themselves as potential party for other companies that are or will be developing a VTOL aircraft. Given the already saturated air taxi direction, they felt they needed to envision a more unique use case for a VTOL. That is how the idea for developing an ambulance drone concept came to be. Their reasoning was that ambulance drones could expect to receive more public acceptance, as their purpose is directly related to societal benefit. It is also a relatively small scale implementation, which also helps to lessen people’s apprehension towards air mobility.



3. Shaping the graduation project

Having the broad foundation in place for the vision-project, it was time to develop the project brief so that the outlines of this thesis could be formed. The most challenging aspect was to create a project scope that would be manageable within the given time of 100 days, but also include enough aspects to be meaningful.

Above, the scope that was established is shown. It is clear that the emphasis lies on the conceptual nature of the project and therefore aspects related to the eventual manufacturing and implementation were placed outside the scope. Within the scope, the distinction between high priority subjects and lower priority subjects was also made. A lot of emphasis is put on researching the existing ambulance system and involving as many stakeholders and experts as possible, to make sure the final concept is a well-founded collection of solutions that hold real value.

Next to that, it is important to establish a unique identity for the ambulance drone which creates interest towards Modyn and the development of ambulance drones in general. As such, the visual design is also a high priority.

Having explained the goal of the project, it is also important to relate the project to my personal ambitions. With the project having such an open and underdefined topic, project management is extremely important to prevent the complexity to become too overwhelming. This inevitably means that choices need to be made based on incomplete or unclear information and that, for time's sake, design choices need to be 'frozen' in order to move on. Finding the balance between subjective assumptions or going down deep rabbit holes of information is clearly one of the main challenges. As such, managing this project will allow me to develop the skills to deal with complexity and with stakeholders and experts.

This thesis project also allows me to use methods and tools that I am excited about. One tool I want to apply is virtual reality. This project could benefit from VR based design, because the ambulance drone is a rather large and complex product in which human interactions play an important role.

DEFINITION OF TERMS

Ambulance drone	Manned (semi) autonomous aircraft for medical aid
Ambulance Helicopter	Trauma helicopter, Lifeliner
Coaxial rotors	Two propellers placed on top of each other
Drone	(semi) autonomous aircraft
Ducts	Casing around the propellers
(e)VTOL	(electric) Vertical Take-off and Landing vehicle
Fully autonomous system	The system operates without any human assistance
MMT	Mobile Medical Team
RAV	Regionale Ambulance Voorziening (local ambulance service)
Rotors	Consists of propellers, motors and ducts
Rotor tree	The arms connecting the rotors to the body
Remote operator/pilot	A pilot who controls the aircraft from the ground
Semi autonomous system	The system performs certain tasks autonomously, but a human makes the decisions
Vertiport	Take-off and landing facilities

READER'S GUIDE

The report has been set up in 5 overarching sections, starting with the introduction (section A), followed by the analysis of the 'current situation' (section B). This section is about analysing the current ambulance system and establishing a basis for forming a future context for the ambulance drone. In section C, which is called 'shaping the future', this future context is explained. Both of the aforementioned sections are considered to be the research phase of the project. So, after section B and C, section D follows. In this, a synthesis of the most important research findings is provided. This synthesis, together with part of the Vision in Product Design method, will form the vision of the project. The vision section (D) concludes with a program of requirements.

The vision section is the basis for the design phase, which is part of the final section (E). It explains the process from ideation, to conceptualisation and the final concept in detail. The report ends with the references and attached are the appendices that are referenced throughout the report.

B

CURRENT SITUATION

CHAPTER 1
THE AMBULANCE SYSTEM

1.1 INTRODUCTION

This chapter aims to map out the current ambulance system in The Netherlands. This is an important knowledge base for identifying the problem space for the project. First, a general overview is provided, focussing on the organisational layers of the system, like the government and healthcare institutions that are responsible for managing the ambulance system.

In the second part, a range of subjects regarding ambulance vehicles are addressed, such as different types of ambulances, equipment, maintenance, etcetera. Next to this, the connection between primary stakeholders and the ambulance is established, by investigating interactions between staff, ambulance and patient.

1.2 ORGANISATION

1.2.1 Brief history

Transporting injured or sick people has been done for centuries. It is believed that the first form of mobile care was implemented by the Spanish military, which put up field hospitals for injured soldiers in the 15th century. In the 16th and 17th century transportation of patients happened mostly by carrying them on stretchers and occasionally on ships. In the 19th century the first ambulance vehicles start to emerge in the form of carriages with stretchers. It is not until after World War One that motorised ambulances started to gain traction. The term "ambulance" also became more widespread during this time. After World War Two, ambulance services started to develop rapidly as a result of the increase in motorised traffic and more frequent accidents. Every municipality had its own emergency control room, which caused a lot of issues in the communication with the ambulance staff.

Currently, the ambulance system is more centralised in order to save costs and increase efficiency (ambulancezorg.nl, 2021).

1.2.2 Ambulance regions

Since 2017 The Netherlands has been divided into 25 ambulance regions, which are called "Regionale Ambulance Voorziening" (RAV) (overheid.nl, 2021). Each RAV has their own emergency control room, which is shared with the police and fire department. The control room sends out calls to each of the separate ambulance stations within the RAV. The RAV's are legally appointed by law (tijdelijke wet ambulancezorg) as the only party who is permitted to provide ambulance care in the RAV regions.

Within RAV regions there are several ambulance stations from which the ambulance teams are deployed. These are all informed by a control room. In figure 1, a simplified overview is shown of this network of ambulance stations within the RAV.

Each station is responsible for the area within 15 minutes of reach, which is the norm for the maximum response time in The Netherlands. From within these areas, they deliver their patients to the hospitals that are located in the RAV region (with some exceptions). There can of course be several hospitals in the region and which one is preferred depends on the patient's registration and the treatment they need. Also, the ambulance stations themselves are interconnected as they exchange their capacities to always keep every station operational.

The number of ambulances seems to be strongly correlated to the population density in that area, whereas the number of stations is more correlated to the geographical size of the area (figure 2).

1.2.3 Management

Ambulancezorg Nederland (AZN) is the overarching sector organisation that represents the 25 RAV's. It mediates with different parties that are involved in the ambulance system, such as the government and other healthcare institutions. AZN is also responsible for the collective labour agreement of the ambulance sector, in consultation with employee organizations.

1.2.4 Responses

Types of responses are categorised according to A1, A2 and B urgencies. A1 is for life-threatening situations, with a maximum response

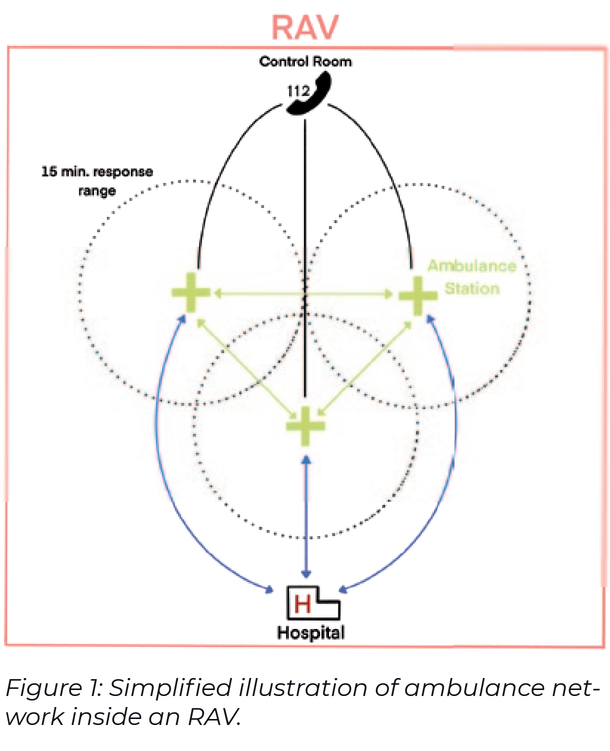


Figure 1: Simplified illustration of ambulance network inside an RAV.

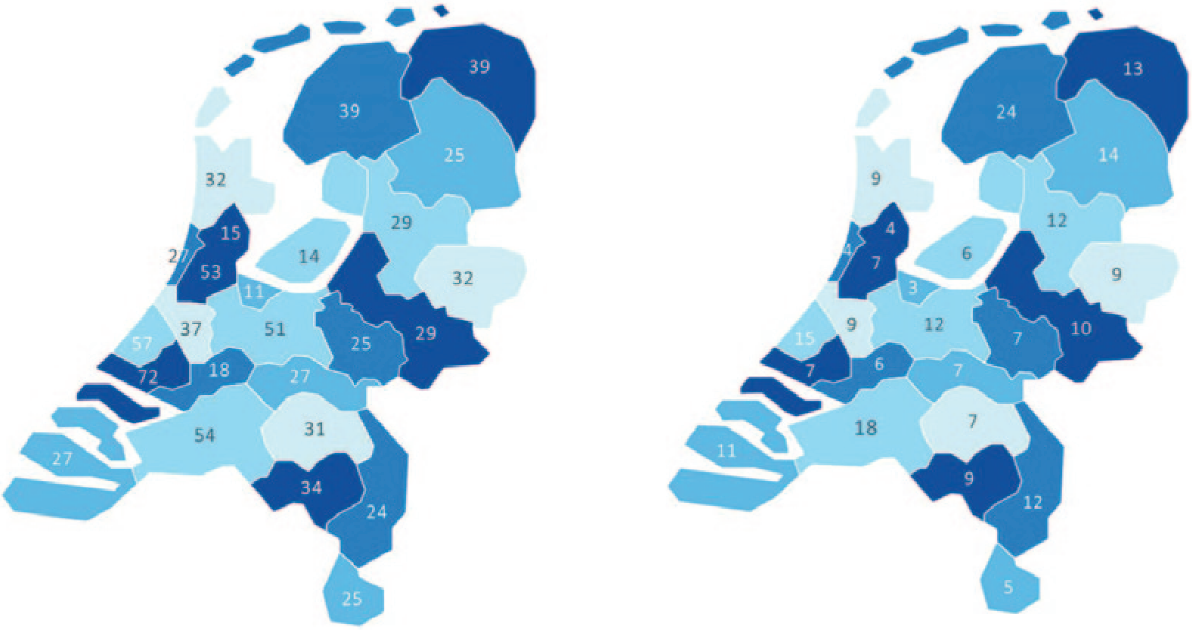


Figure 2: number of ambulances per region (left) & amount of ambulance stations (right). (ambulancezorg.nl, 2019)

time of 15 minutes for 95% of the population. A2 is for non-acute life-threatening situations, with a maximum response time of 30 minutes. B is for regular transport of patients between hospitals. Only during A1 type responses is an ambulance permitted to use signals and sirens (ikebho.nl, 2018).

A1 responses are the most frequent responses and cover almost half of the total responses, as can be seen in figure 3.

Looking at figure 4, we can see that many regions in The Netherlands seem to fail to reach the 15-minute maximum for 95% of the cases. Notice the 95% margin; there is no mention of the 5% that experiences even longer response times.

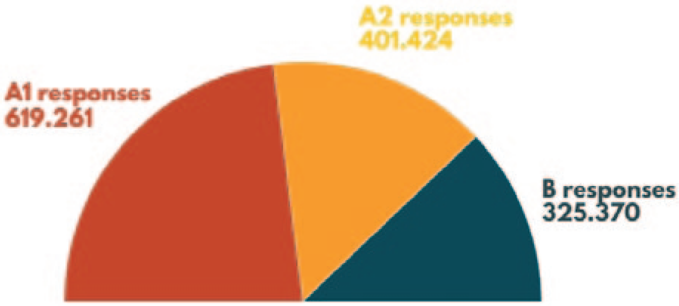


Figure 3: Amount of A1, A2 and B responses in 2019. (ambulancezorg.nl, 2019)

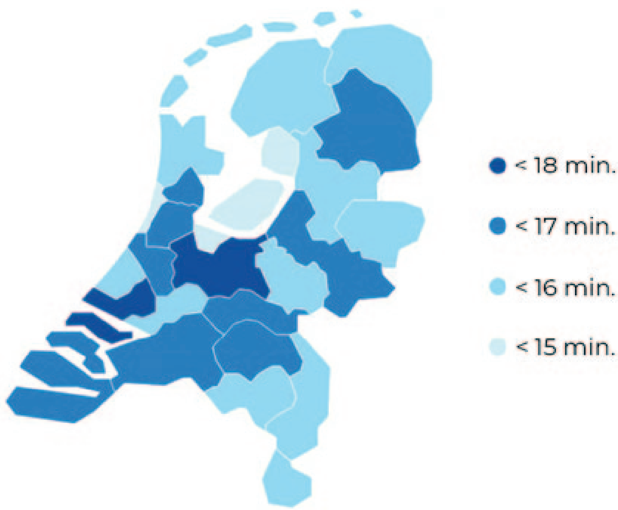


Figure 4: response time per region for 95% of A1 responses (right). (ambulancezorg.nl, 2019)

1.2.5 Funding & costs

Funding is arranged through the health insurance system. The ambulance system is provided with a national budget, established by the ministry of Health, Wellbeing and Sport. The Nederlandse Zorgautoriteit (NZa) is responsible for distributing these funds amongst the 25 ambulance regions.
In 2019 the national budget for ambulance care was 627 million euros. This covered a total of 1.322.844 responses. There also seems to be an increase in this budget each year, as in 2019 the budget was around 100 million euros more than in 2017. An interesting fact is that the 24-hour availability has much more influence on the costs of the ambulance system than the number of annual responses. (ambulancezorg.nl, 2021)

Figure 6: ambulance van (Van Loon, 2016)

1.2.6 Types of vehicles

There are a multitude of ambulance vehicles. The most common is of course the regular ambulance van, as shown in figure 6. These vans are used for all response types; B, A2 and the most urgent responses (A1). As such they exist in many slight variations.

Figure 7: rapid responder motorcycle (de Koning, 2020)

Next to ambulance vans there is also a category of ambulance vehicles called rapid responders (figure 7). These range from cars and motorcycles down to bicycles. They are operated by specially trained nurses and are able to reach the patient very quickly, often before the regular ambulance has arrived. They are not able to transport a patient, but they are critical in starting treatment as early as possible before the ambulance team takes over.
Lastly, there is the Lifeliner, or commonly known as the trauma helicopter (figure 8). This is an ambulance helicopter that is deployed to aid the regular ambulance team in extreme life threatening cases.

Figure 8: Ambulance helicopter (ANWB, 2021)

In the next section the ambulance van and the ambulance helicopter are analysed in more depth.

1.3 AMBULANCE VAN

In this section the ambulance van that is used for A1 emergencies is analysed. As mentioned before, there are many variations, but the choice was made to focus on the A1 type, as they are most complete and complex ambulance type.
In order to gain insight into the inner workings of the ambulance van and its staff, both literature and field research was done. An interview was held with Eduard van Belle, manager of ambulance station Delft and former ambulance nurse. His experience both as a nurse and as a manager gave him a lot of knowledge about the organisational structure as well as the work in practice. In this section the most valuable insights are mentioned in references. The full transcript of the interview questions can be found in appendix A.

1.3.1 The team

The team of a regular ambulance consists of a driver and a nurse. The nurse is aducated at the Academy for Ambulance Care in Harderwijk. They need have prior working experience at the intensive care or first-aid department in a hospital. Thanks to their education and high level of specialisation, ambulance nurses are permitted to make their own decisions about treatment and medication without having to consult a doctor at the hospital. The role of the driver is not only to navigate, but also to assist the nurse at the place of the incident. Like the nurse, the driver is also schooled at the Academy for Ambulance Care.

The interview with Eduard van Belle also provided insight into the work routines of the ambulance staff. What stood out was that they are responsible for the entire process. The staff usually end the day by preparing their ambulance for the next day. They clean it and make sure all equipment is present and working, for which they have an inventory list. The driver checks if the ambulance is mechanically sound by checking the oil pressure, lights, sirens, etc. Having done all this at the end of their shift means they are ready to go at the beginning of their next shift, after some quick double checks.
In between calls the ambulance can be cleaned and prepared at the hospital, so that they return to the station ready for the next call. Right now, cleaning is a lot more work due to COVID, so they have additional staff to disinfect every ambulance after each call.

When waiting between calls, ambulance staff usually do some relaxing activities and occasionally practice treatments and procedures to keep their abilities on point.
Shifts are 8 hours long and every 24 hours is divided into several overlapping shifts. This is done to prevent transitional periods in which no one is ready. In case a call comes in just before the end of a shift, the staff have to work overtime. It is simply the reality of their job sometimes.

1.3.2 Equipment

Each regular ambulance generally has the same equipment on board, even if they are of a different type, as dictated by NEN norms. Their equipment is still rather basic and focussed on treating the most common injuries, like heart failure, spinal/neck injuries and common illnesses for which they carry medicine. Next to these items, ambulances also have storage space for other items, such as helmets, breathing equipment and even a stuffed animal to comfort children. On the next page is an overview of the equipment in an ambulance.

Left: Stretcher for transporting a patient (Tulatech, 2021).

Right: Spine plank, a device used for stabilising spinal injuries (ambulanceblog.nl, 2013).

Left: Patient monitor, for resuscitation and monitoring a patient's heartrate, oxygen levels and vital signals (Ambulancepost Delft).

Right: Incubator to transport premature babies. Is not part of the standard equipment of the ambulance, rather used in specific situations (Ambulancedienst Zuid-Holland Zuid, 2015).

Left: Neck brace for stablising neck injuries (HPFY, 2021).

Right: Medication cases Ambulances have separate storage for adult medication and child medication based on difference in dosages (Ambulancepost Delft).

Left: Case with breathing equipment containing manual breathing equipment which can be carried to the patient (Ambulancepost Delft).

Right: Resuscitation device This device is used to perform resuscitations, so that the nurse does not have to perform it manually (Ambulancepost Delft).

Left: Stabilisation mattress for stabilising patients with spinal injuries (Ambulancepost Delft).

1.3.3 Interior layout

The layout of the ambulance van is generally similar in all RAV regions, although there are some differences depending on the vehicle type and the preferences of the RAV region.
Below, a schematic overview of a common interior layout is provided, showing all the main elements that comprise the interior of the ambulance.

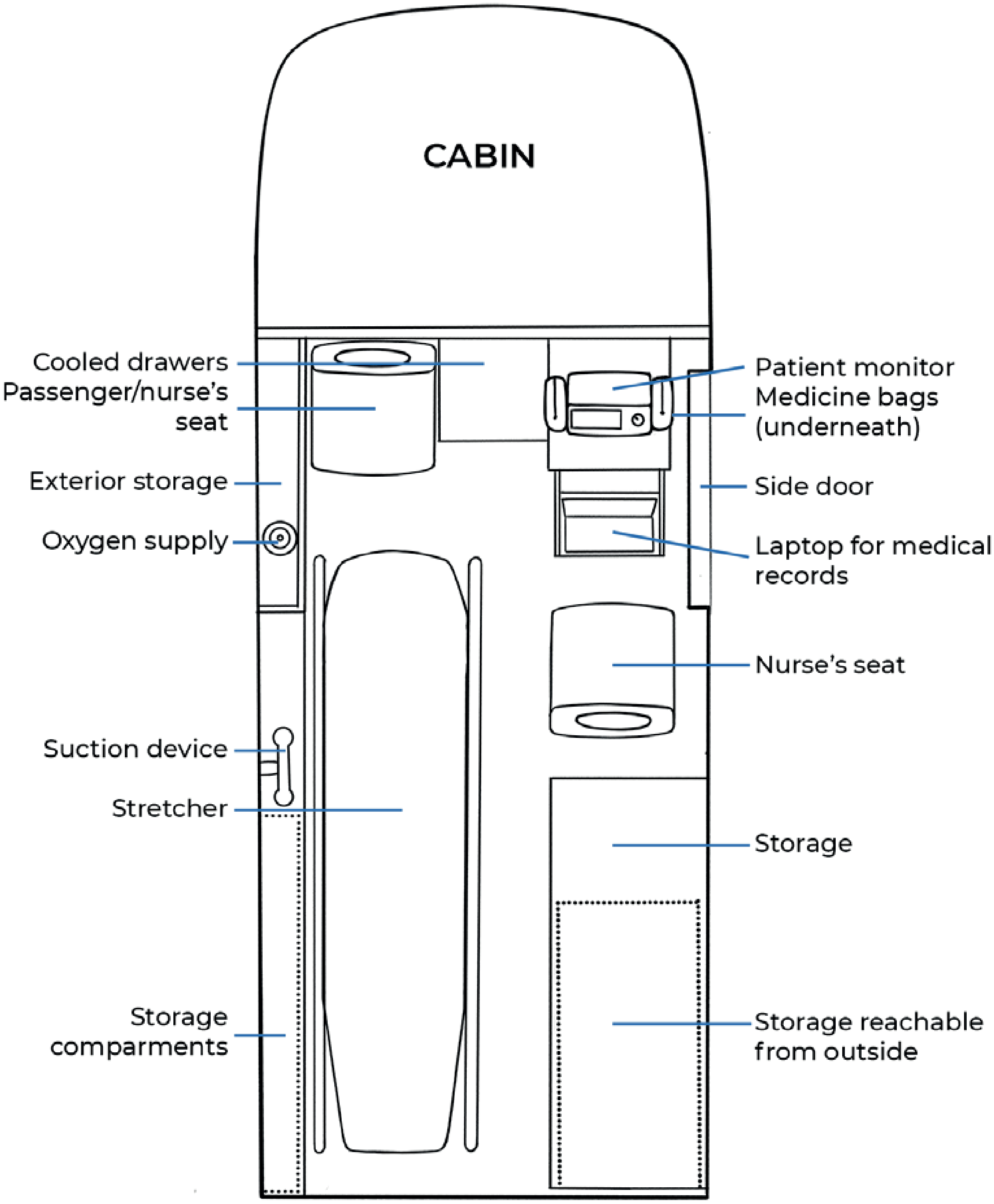


Figure 9: ambulance van of RAV Ambulance Oost (Kunst, 2019)

RAV Ambulance Oost
RAV Ambulance Oost went a step further in influencing the layout of their ambulances. They consulted their employees and experts and together with the manufacturer of the ambulance made the most ergonomic layout they could design.

The interior is arranged in such a way that the nurse can stay seated during transport, since most equipment is located within hand's reach. Previously the nurse had to stand up for certain procedures, which is unsafe and inconvenient during a fast and jerky ride to the hospital. Not only is the equipment within arm's reach, but it is also reachable from outside the van. This means the ambulance staff do not have to jump in and out of the van to retrieve items which is a crucial time saving. Figure 9 shows some images of the interior of Ambulance Oost's ambulance. Ambulance Oost initiated this design in 2019 and by now a lot of other RAV's in The Netherlands have adopted it (Kunst, 2019) .

Ambulance station Delft

The ambulances at the station in Delft (figure 11) show a lot of similarities with Ambulance Oost's layout mentioned in the previous paragraph. It must be noted that the ambulance in the photographs is a slightly older model which they use as their backup vehicle. Their newest models bear even more resemblance to Ambulance Oost's layout. There are some differences in equipment and placement of the storage compartments but looking at the interaction level they are quite similar, such as allowing access to the most important equipment from a seated position and large equipment being accessible from outside. The layout differs from Ambulance Oost in small ways, such as the exact placement of storage compartments, the use of medicine bags instead of suitcases and different brands of equipment.

What stood out most was that the ambulance carries a lot of items, even though it seems rather empty at first glance (figure 10). This is because it has a lot of neatly arranged storage compartments with all kinds of materials for different types of treatment. It practically is a small hospital room on wheels and is completely maximised to carry as many useful items as possible. The frequency at which these items are used varies, however. The basic equipment is certainly the most used equipment, like the monitor and stretcher. Things such as the drip and the onboard breathing machine are used a lot less. Eduard explained that they have a bag with manual breathing equipment, which they use a lot more because it can be taken out of the ambulance to the patient. Clearly there is still some room for optimisation but diving into exactly which items might be redundant was outside the scope of this visit as that would have taken too much time.

Figure 10 (left): Ambulance van contents (GGD Haaglanden)

Figure 11 (below): Interior showcase ambulance van at ambulance station Delft.

1.3.4. Organisation on a local level

It turns out the organisation on a local level is rather more complex than expected. RAV Haaglanden, to which Delft belongs, is responsible for the control room which puts out calls to each ambulance station within the region. The stations themselves, however, are all exploited by different institutions. The stations in Delft and in Den Haag are owned by GGD Haaglanden, the one in Zoetermeer is independent and another station in Den Haag is owned by Witte Kruis. It is a rather complex arrangement, but it works smoothly according to Eduard.

RAV Haaglanden provides all kinds of ambulance transport. The most obvious is emergency type transport (A1 responses). Next to that, there is also a lot of scheduled transport; patients that need to be transported between hospitals or to their home and even daytrips for terminally ill patients. Ambulances that are used for these kinds of transport are not as heavily equipped as the A1 ambulances, nor does the staff need to have the same level of expertise. Next to regular ambulance vans, RAV Haaglanden also has a range of rapid responder vehicles.

1.4 AMBULANCE HELICOPTER

In this section, the ambulance helicopter is analysed through both literature research and an interview. The interview was held with Frank Latour, who has been an ambulance helicopter nurse for more than 20 years. The questions that were asked focussed a lot on his experience working as a nurse, his knowledge regarding the context of his work and what it is like to work inside the helicopter. The full transcript of this interview can be found in appendix G. The main insights from this interview are referenced throughout this paragraph.

Figure 12: Service areas of helicopters; 4 bases, 4 helicopters with variable range and response times.

1.4.1 Lifeliner service

In The Netherlands, the air ambulance service is provided by the ANWB, who are mostly known as the help service for stranded vehicles on Dutch roads. There are four trauma centres in The Netherlands from which four helicopters are deployed (figure 12). Each helicopter is named a Lifeliner. The locations are Amsterdam (VUmc), Rotterdam (Rotterdam Airport), Nijmegen (airport Volkel) and Groningen (airport Eelde). The helicopters change location occasionally, according to their maintenance schedule and are thus not bound to a single centre. In total, ANWB employs 38 pilots who operate 8 helicopters. Currently, a fifth helicopter is on stand-by for COVID-19 related transport. An ambulance helicopter costs roughly 5 million euros and is funded through the national health insurance system (van der Laan, 2019).

1.4.2 Mobile Medical Team

The staff on board the air ambulance are called the Mobile Medical Team (MMT). The team consists of a doctor, who is responsible for first-aid care and stabilising the patient for transportation to the hospital. The doctor is also responsible for communication with the emergency control room during the flight. On board is also a nurse, who assists the doctor and functions as a navigator and assistant to the pilot during the flight. The pilot is solely responsible for operating the helicopter. He has no specialised medical training and stays with the helicopter to guard it. In some cases, the pilot can do some assisting, such as carrying equipment. These pilots all have prior experience in the military, since this is one of the few ways pilots learn to fly during night-time and to make complicated maneuvers. Pilots also perform some small maintenance on the helicopter, but thorough maintenance is done by experts.

According to Frank, the MMT distinguishes itself from the regular ambulance because the doctor is certified to perform certain invasive procedures and admit certain medicines, which ambulance nurses are not certified for. These procedures are often necessary in cases of severe injury, making fast response times crucial.

1.4.3 Responses

The MMT is only there to assist the regular ambulance. A regular ambulance is always sent out before the MMT is deployed and after assessing the severity of the incident the regular ambulance team can decide to call in the MMT. As can be seen in figure 13, in around half the cases the ambulance decides to call off the MMT while they are on the way, because they can handle the situation themselves. Actually transporting the patient to the hospital happens even less frequently, at only around 10 percent of cases. (van der Laan, 2019)

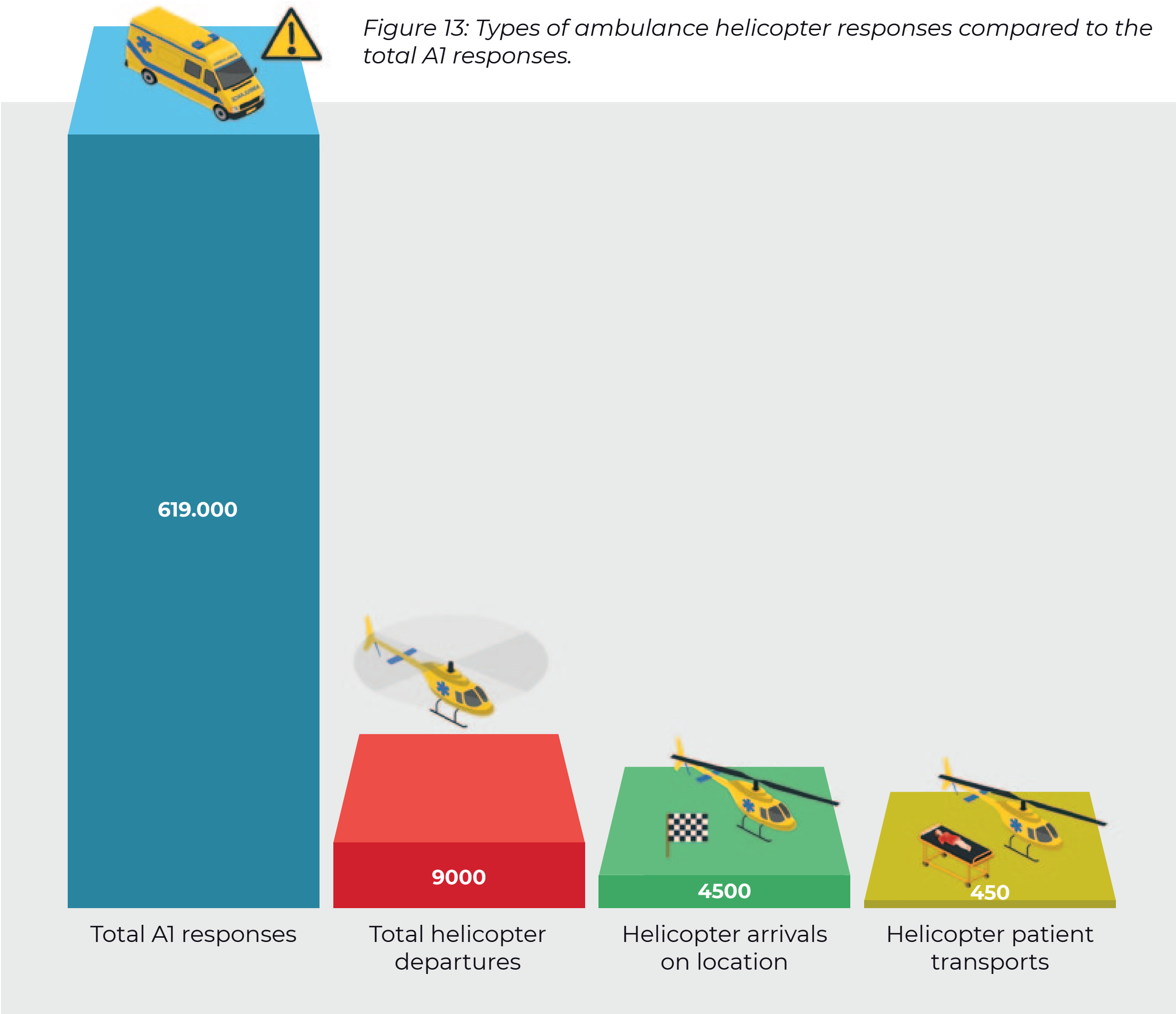
There is a clear difficulty in assessing the severity of an incident, since the system relies on witnesses to explain the situation before any help arrives that can assess the situation properly. On average air ambulances are deployed around 9000 times a year (anwb.nl, 2021).

According to the ANWB, time until take-off is within 2 minutes during daytime and 5 minutes at night. These helicopters can operate in the dark as well, using night vision equipment. Often the landing spot is an open area nearest to the place of the incident. The pilot is responsible for estimating which area is suitable for landing. Sometimes the police also helps scouting for a landing spot. Before landing, a short scouting round is made. During daytime, a clear landing area of 25 x 25 meters is the minimum and during night time it is 25 x 50 meters. Landing areas can be anything from football fields, meadows, roads, city squares and even gardens.

In regards to the total response time of the MMT, Frank explained that this varies a lot. In the cities, response times are on average 7 minutes, because they can reach the location quickly by car. The helicopter often takes too long to find a suitable landing spot in urban areas, so the car is preferred. A similar situations occurs at night time, when the darkness makes it difficult for the helicopter to scout landing spots, thus the car is used more. In that sense the mode of transport is always secondary to the main goal of getting the MMT to the destination as quickly as possible. In case the helicopter cannot land close to the destination, the MMT is often picked up by the police.

A patient in unstable condition is rarely transported by helicopter, as treatment during the trip to the hospital is a lot more difficult than

Figure 13: Types of ambulance helicopter responses compared to the total A1 responses.



in a regular ambulance. This is due to the lack of mobility, the lack of access to the lower body and the noise, which inhibits monitoring of the lungs. Frank also explained that the helicopter is filled with the exact amount of fuel needed for a trip based on the specific take-off weight. This take-off weight is calculated down to the exact weight of each crewmember. There are always margins in this calculation for unforeseen circumstances.

1.4.4 Interior layout

An ambulance helicopter carries a more basic selection of equipment than the ambulance van due to having less space, but the equipment it carries is similar to that of an ambulance van. This includes the patient monitor, stretcher, oxygen bottles, breathing device, medicine, protective clothes and backpacks. Below a schematic overview of the ambulance helicopter is provided.

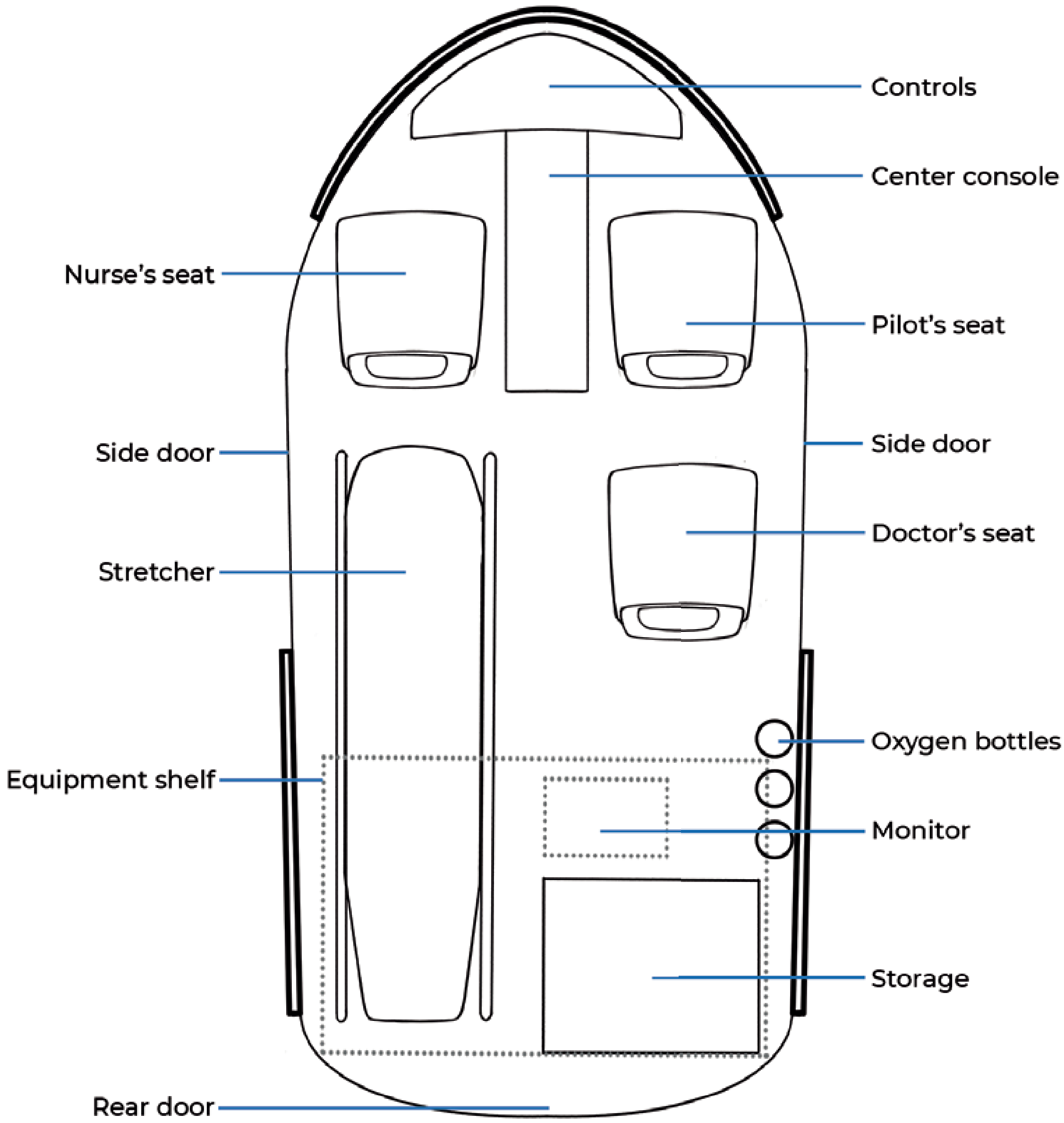


Figure 14: ambulance helicopter interior. (Srfotografie, 2014)

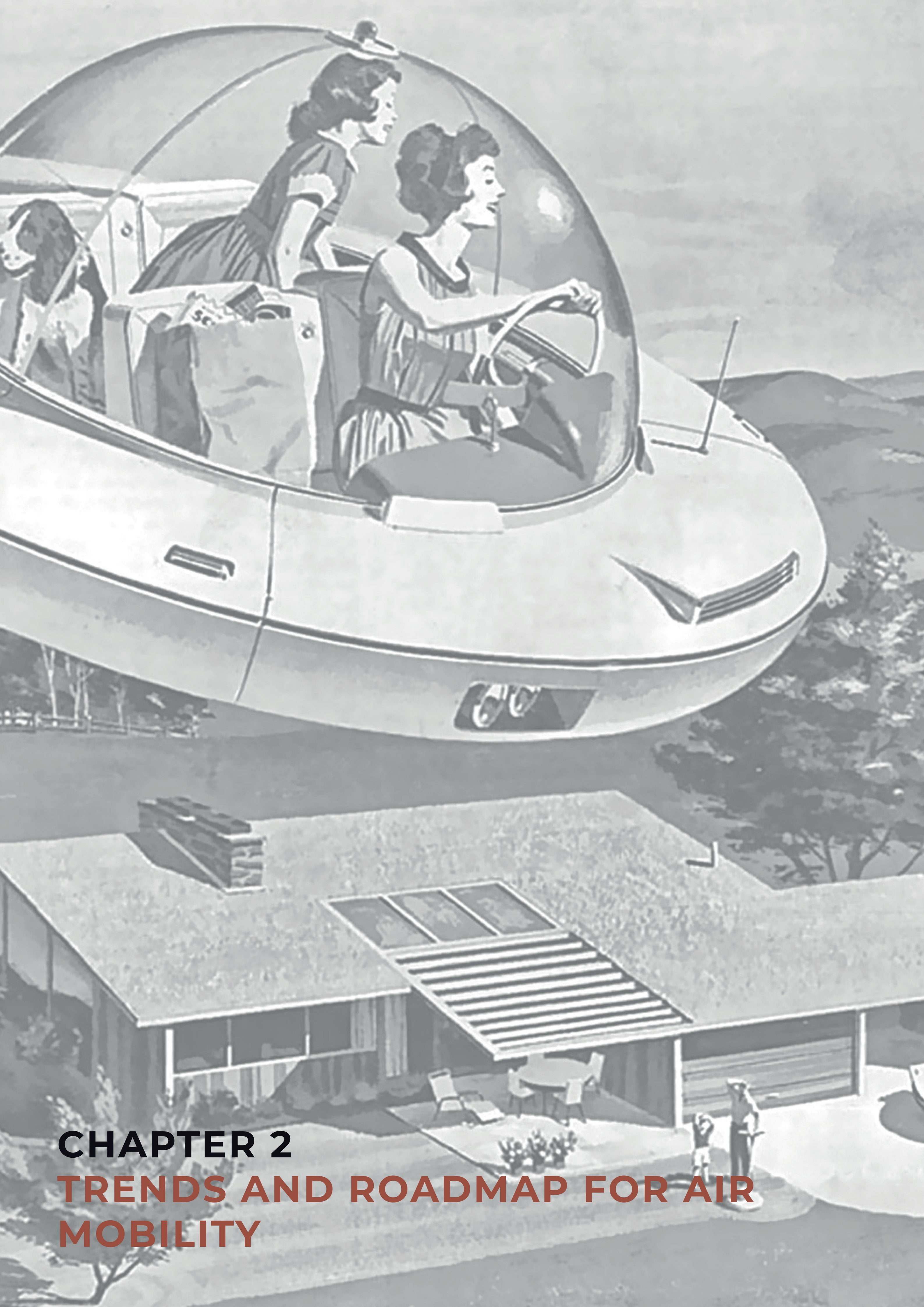
The pictures of figure 14 clearly show how crammed it is inside and that the equipment is less organised than in an ambulance van, because there is minimal room for storage compartments. Perhaps somewhat surprisingly, the helicopter can load a stretcher from the rear, in similar fashion to an ambulance van, which is a very useful feature for quicker loading.

Figure 15: MMT members carrying backpacks. (112-Zuidland, 2019).

According to Frank Latour, the most important equipment and medicine is kept inside large backpacks, which the crew carry to the scene of the accident (figure 15). These backpacks are rather large and heavy and can be cumbersome to take in and out of the helicopter. Furthermore, they do not really have a designated spot inside the helicopter, which sometimes means they get in the way. Frank explained that these backpacks are stashed full with as much equipment and supplies as possible, in case any of it is needed at the site of the incident.

C

SHAPING THE FUTURE



CHAPTER 2
TRENDS AND ROADMAP FOR AIR MOBILITY

2.1 INTRODUCTION

In this chapter the air mobility market is investigated in order to collect insights about the state of air mobility as of this moment and how air mobility is expected to develop. This creates the context for a future ambulance drone and helps to establish an informed vision later on. This chapter starts off with current projects and initiatives about air mobility in The Netherlands. The following questions are answered:

- What does The Netherlands envision for air mobility in the near to long future?

- What plans are made in pursuit of air mobility in The Netherlands?

- Which other developments are of influence on air mobility?

The chapter concludes with a roadmap that maps out the developments in the fields of technology, healthcare and society towards 2035.

2.2 STEPS TOWARDS THE FUTURE

There is a lot of activity in the field of air mobility today. A lot of Electric Vertical Take-off and Landing aircrafts (eVTOLs for short) are being put forward by large companies as well as start-ups. There are many variations of eVTOL concepts being developed, as becomes clear from the research in appendix E.

But no matter how much these concepts and prototypes become ready for implementation, they depend on a larger system that needs to adapt to these innovations. The path towards air mobility is complex, as there are a lot of stakeholders involved with conflicting interests and a very high influence on the development of air mobility. For this reason, institutions and the government are participating in initiatives which aim to get a grip on the complexity of air mobility, its opportunities, challenges and potential implications for society. The next sections explain which initiatives are emerging and what they might mean for the future of air mobility in The Netherlands in the coming five to ten years. This information helps to inform the roadmap that concludes this chapter.

2.2.1 What does The Netherlands envision for air mobility in the near to long future?

NLR, The Netherlands Aerospace Centre, is a leading party in aviation innovations in The Netherlands. They conduct their own research and tests for different implementations of drones. They also investigate the broader context, such as regulations and public acceptance of air mobility. With their knowledge NLR also provides consultancy to the Dutch government.
Within this role they have influence on the development of legislation, safety protocols and technological innovations.

NLR has identified a set of trends for the coming years, which they expect will influence the development of air mobility:

- The rise of unmanned systems - a trend that will coincide with an increased pressure on security, privacy and safety.
- The use of artificial intelligence and Big Data in the development of autonomous systems.
- The use of augmented and virtual reality for data visualisation and operation of aircrafts.
- The market value of drones in 2035 will be equal of today's market value of commercial and military aviation combined.

Also, NLR states that they expect developments in drone technology to have an impact on technology, society and economy. Drones will become part of everyday life, impacting society with new solutions to common problems in the field of mobility, security, inspection and emergency response. Drones can also offer economic advantages by optimising existing processes and systems. Next to that, drones create entirely new opportunities and business models (NLR, 2018).

2.2.2 What plans are made in pursuit of air mobility in The Netherlands?

AMU-LED

This program is a significant step in the direction towards Urban Air Mobility (UAM) in The Netherlands. With their target of performing around 100 hours of test flights over urban areas in cities like Rotterdam, Amsterdam and Enschede, this program is trying to prove that safe integration of air mobility in urban airspaces is possible. The tests will include all sorts of scenarios and applications for UAM, such as package delivery, medical care, police surveillance, inspection of infrastructure and taxi services. Clearly AMU-LED is trying to paint the larger picture instead of focussing on niche applications. It is not a program focussed on catering the happy few who will benefit from air taxis, but really looking at the benefits UAM could bring to society as a whole.

The project has attracted a multitude of institutions and companies, such as Boeing, Airbus, EHang, the municipality of Amsterdam, INECO and many more.

The results of this project will be provided to European airspace regulation services and aims to contribute to the development of regulations for UAM in European cities (NLR, 2021).

Dutch Drone Delta
Another initiative in The Netherlands is Dutch Drone Delta, a collaboration between KPN, Rijkswaterstaat, Port of Rotterdam, Achmea, Antea Group and others. This innovation platform will be a joint undertaking in researching all kinds of aspects in the broader UAM system. For example, Antea Group will be investigating possible take-off and landing places for delivery drones and air taxis, such as the roofs of carparks and train stations. NLR will focus on social acceptance by researching ways to combat noise and air pollution. Small tests have already started, such as test flights with delivery drones in the port of Rotterdam (Jager, 2020).

ANWB medical delivery drones
ANWB is also experimenting with small drones which can bring supplies and medication to hospitals very quickly and efficiently. These drones fly autonomously but controls can also be taken over by an operator. Currently, they do not fly over densely populated areas due to safety concerns. At some point, after extensive testing, they should be able to fly over such areas as well. (anwb.nl, 2021)

So, to conclude, the first two projects seem to complement each other as Dutch Drone Delta seems to be more research focussed and AMU-LED more practical. Dutch Drone Delta might help create the right context for air mobility and AMU-LED could bring the practical knowledge to the table. Of course, these programs are very much in their early stages and time will tell how effective they will be. It does show that there is a lot of activity in this field even within a small country like The Netherlands.

2.2.3 Which other developments are of influence on air mobility?

Relevant developments not only happen within the domain of air mobility. It is important to zoom out and to look at the larger overarching systems, such as society, technology and healthcare. Through investigating the developments within these systems, it might be possible to see how they relate to the domain of air mobility. Of course, predicting the future for these overarching systems is an immense rabbit hole of speculation, so in order to keep it manageable, this section will try to lay out the general trends and analyse what implications they might have for air mobility in the near future.

Acute healthcare related applications rank at the very top of accepted UAM applications.

A. Public acceptance
Recently, an extensive research into the public acceptance of European citizens regarding air mobility was performed by European union Aviation Safety Agency (EASA, 2021). According to their investigation, the result is surprisingly homogenous, with participants from different countries, ages and background all showing similar opinions. In general, the attitude towards UAM is rather positive. Specifically, emergency and acute healthcare related applications rank at the very top of the accepted UAM applications. This confirms Modyn's hypothesis that UAM for the benefit of society might be the most accepted. EASA also identified some of the general public's concerns.

The first concern that many people have is noise, visual -and environmental pollution caused by drones. In terms of noise pollution, for example, a drone delivery system would put high numbers of drones in the airspace at low altitudes. These could cause continuous nuisance to the public, without offering that much perceived benefit.

EASA's study also shows that the noise profile is of importance in the level of annoyance. For example, familiar loud noises are perceived as less annoying than unfamiliar loud noises.

The second concern is security. Drones are equipped with cameras, either as part of their flight system, for surveillance purposes or for recreational use. This causes privacy concerns regarding the many cameras filming from the sky. The concerns range from Orwellian "big brother" government abuse to perhaps a more realistic concern: cybercrimes. A very good security system needs to be constructed to prevent the wrong eyes gaining access to drone cameras for the purpose of spying, or other malicious intentions.

The third concern is safety. Things that fly can crash and, statistically speaking, will crash. Because of this, flights over urban areas are the highest barrier to overcome, as these are heavily restricted for drones at the moment. The question is how high the proven reliability will have to become before flights over urban areas are allowed. Some manufacturers claim that they aim for reliability as high as regular airliners. EASA's research shows that in terms of public acceptance, aviation level safety standards would be perceived as acceptable by the public.

B. Regulations & airspace management

Many steps still need to be taken in order to create a set of regulations that consider all the risks involved with air mobility. Institutions such as NLR and projects such as AMU-LED and Dutch Drone Delta are all investigating how to design these rules. The important first step is for the government to realise the demand and potential for air mobility solutions and to actively participate in shaping a regulatory framework for air mobility. All whilst involving commercial, public and independent parties. Traditionally, however, legislation is reactive rather than proactive, so the regulatory framework is likely the last step in the process towards large scale air mobility.

C. Healthcare

Many developing illnesses go under the radar until symptoms suddenly show up. These symptoms can sometimes be so severe that they become acutely life threatening. Things like heart failure, pneumonia, strokes, etc. There is currently no way of consistently and reliably tracking all facets of a person's health to identify problems in an early stage and prevent a disease from reaching fatal proportions. The first step in diagnostics through "household technology" is in the ability of phones and smart watches to track health. In the near future the integration of diagnostics in everyday technology might go much further.

Think of sensors in contact lenses that can track your heart and respiratory system, as well as identify symptoms of cancer. Regular smartphones and smartwatches will also become more equipped to perform diagnostics.

In short, everyday diagnostics will allow for faster and more accurate treatment of diseases and injuries and is expected to decrease the amount of acute health problems caused by undetected diseases. (Kraft, 2019)

The aforementioned innovation mostly focusses on prevention, but there are plenty of cases where a health problem suddenly occurs, like an accident. In such cases point-of-care diagnostics (POC) will provide a major benefit. POC diagnostics is a categorial name for any solution that enables to quickly establish a medical grade diagnosis, whether through a special testing device or people's own technology (i.e. smartphone, watch). This can speed up the selection of the correct treatment, increasing efficiency and the chances of saving the patient. It could be a relevant development for ambulance healthcare, as speed is of the highest importance.

Artificial Intelligence (A.I.) for healthcare

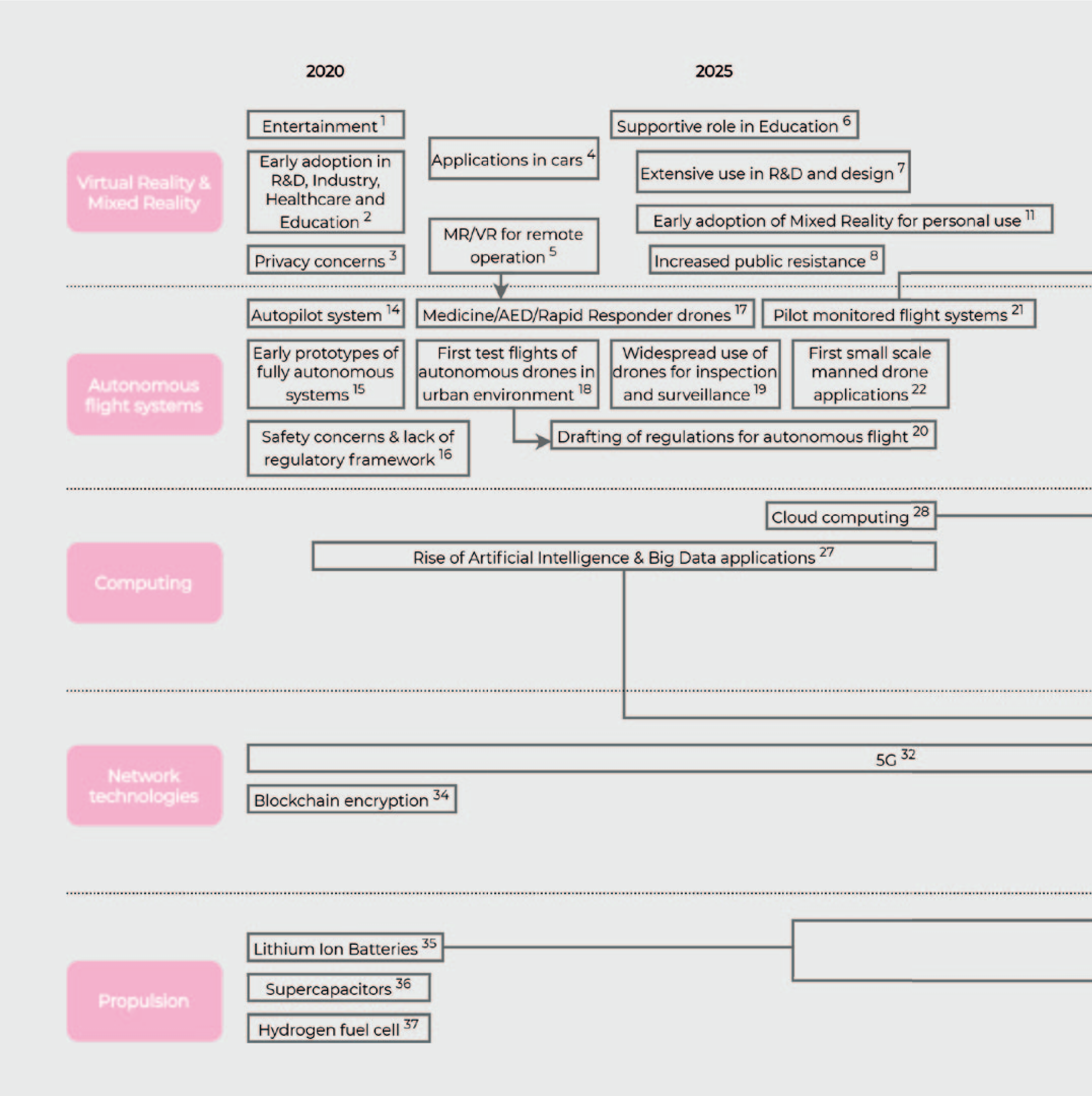
Artificial Intelligence (A.I.) is one of those developments that promises a technological revolution in many fields, including healthcare. Basic forms of A.I. applications in healthcare include the prediction of which medication and dosage a patient needs, based on their medical records and personal attributes. A more advanced A.I. application is the ability to discover patterns of certain diseases earlier and more accurately than a medical professional could. An example is the use of A.I. to analyse radiology images to identify tumours. Artificial intelligence could even play a role in treatments and procedures in combination with robotics. However, before this can happen a lot of valid ethical concerns need to be overcome. Some concerns are the lack of human touch and empathy and the problem with accountability in case A.I. makes a mistake (Davenport & Kalakota, 2019).

2.2.4 Conclusion

From appendix E, it becomes clear that there is no consensus yet about the best approach to designing an eVTOL, because there are many ways to solve different problems. Eventually natural selection is bound to bring out the eVTOL designs with the most potential Until then, determining the best philosophy for the design of an eVTOL remains speculative. The most sensible approach to have at least some assurance of what might work best is to look at the most successful prototypes that are currently on the market and how they are designed. Joby, Volocopter and EHang are amongst the most tried and tested prototypes, so their technical solutions hold the most potential and provide a valuable reference for the roadmap.

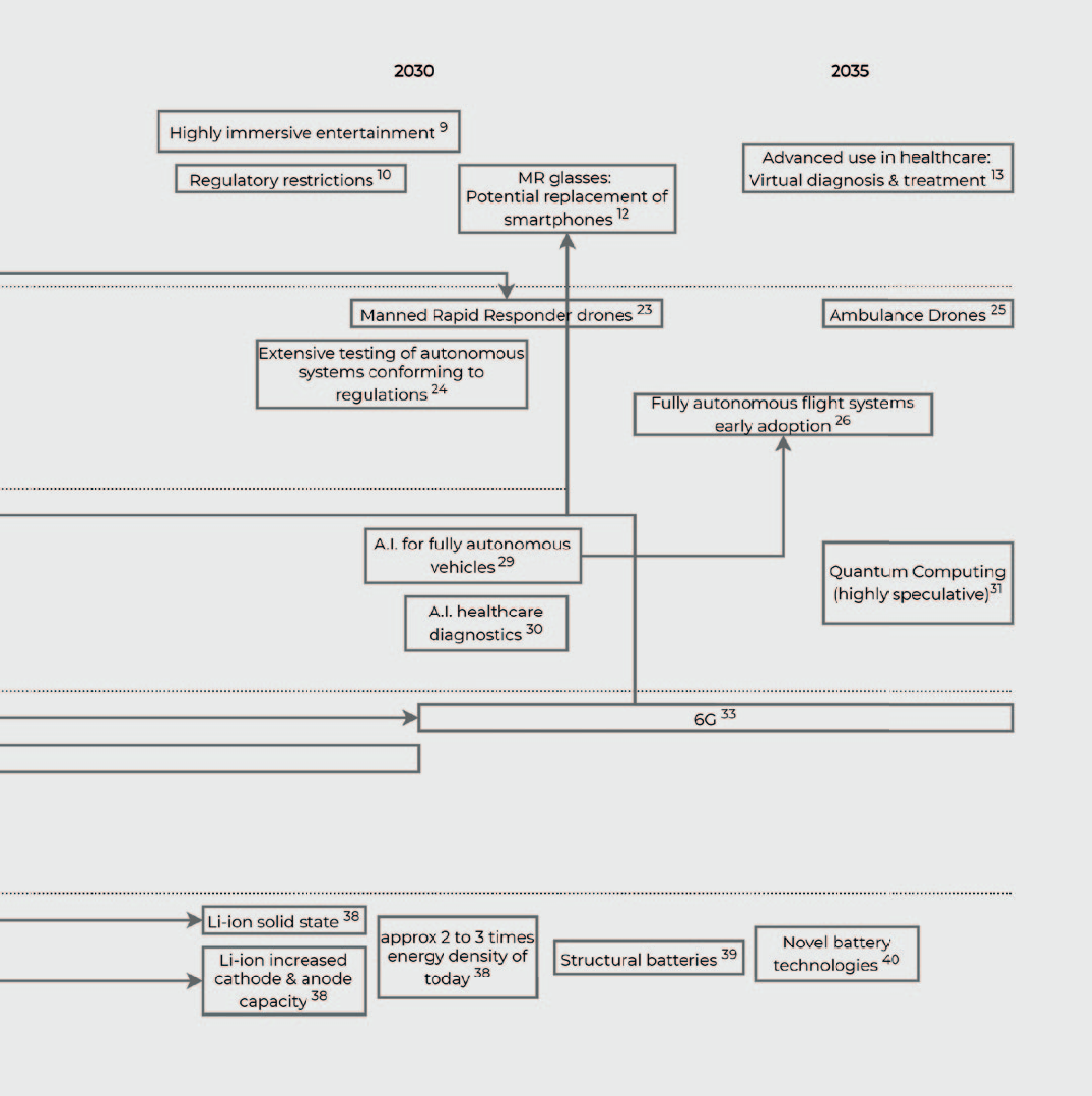
In terms of the air mobility context, the picture is a little more clear, as most innovations that will make up the world of the near future are already around in varying degrees of development. It is likely that promising emerging trends and technologies will at some point become widespread, but when and to what degree remains less clear.

Looking at 2035, based on initiatives such as AMU-LED, Dutch Drone Delta and experts like NLR, it is reasonable to expect that unmanned drone applications will have proven their usefulness for a long time. Small scale use cases of eVTOLs may be implemented around the world as well. For this to happen, it depends on public acceptance, regulatory frameworks and technological advancements to have created the right social, political and technological climate. Only then can the first large scale eVTOL applications be implemented, such as ambulance drones.



2.3 Technology roadmap

In order to further create a context for the ambulance drone within the scope of 2035, a technology roadmap has been created. It maps out developments for different categories of technologies on a simple timeline in increments of 5 years. While of course no expert or literature source can tell the exact chronology of these developments, nor which potential developments will occur and which will fail, an attempt has been made to roughly estimate this, whilst maintaining a conservative stance. A lot of emerging technologies are overhyped, even by experts and scientists, so making cautious estimates is important.



The roadmap has been created based on insights from literature and has been presented to experts within the field of aviation. On the next page the most important elements of the roadmap are explained. For the full explanation of each individual topic see appendix J.

2.3.1 Incremental development

The very nature of technology is to evolve and therefore technologies we consider established and common today also undergo constant incremental improvements. This is an easy to overlook influence on a potential ambulance drone, but it has a lot of impact. It means that every part of it, down to the nuts and bolts, will be a better version of what it is today. Things such as plastics, carbon fibre and other composites will all have underwent further development.

Standard equipment that today's ambulances carry will also go through incremental development, improving in aspects such as user-friendliness, weight, performance, durability, etcetera. Some equipment may even be replaced by new solutions that do not yet exist today. So in designing a concept for the future a standard factor of overall incremental development needs to be taken into account for almost any aspect of the product as well as the world around it. Even the field of design itself will have evolved and new tools and technologies will create new possibilities that designers do not have access to today.

2.3.2 Virtual Reality (VR) & Mixed Reality (MR)

Today, VR and MR use cases can be found in the fields of medical care, education and industry. Given the benefit they provide to these sectors already, it is reasonable to expect these trends will continue and expand into the coming decade and beyond. Next to that, new use cases are likely to emerge. Especially commercial and domestic types of use cases.

Basically, the initial hype of VR and MR being the replacement of smartphones could potentially come true, although later and more gradually than initially thought. This is not likely to happen before the early 2030's, not only because of technical hurdles that need to be overcome but also because of public acceptance and the need for regulations. By 2035 it can be expected that industrial and professional applications of VR will be in a state of maturity. This means VR and MR might provide potential within the ambulance drone system as well. An example of a use case might be VR or MR assisted remote-operation of the drone and aiding in maintenance tasks. It also holds a lot of potential for advanced communication between the crew of the ambulance drone, the hospital, emergency control room and the operator.

2.3.3 Autonomous Flight Systems

In order for the pilot not to be required on board, it is necessary for the drone to be able to automate certain tasks and eventually perform all tasks autonomously. Notice the clear distinction between automation and autonomy. The latter is expected to take a lot more time, as trusting a machine to make all decisions evokes a lot of privacy and liability concerns.

Before technology is ready to live up to the likely very strict regulations and expectations that autonomous systems would be subjected to, automation is a more likely solution. This means that board computers can process various flight data to inform and aid the remote pilot in their decision making. That way, a human is still involved in the process and responsible for what happens with the aircraft.

Around 2035 it is expected that fully autonomous flight systems will be possible from a technical perspective, but it takes the right regulatory framework and public acceptance to succeed. There is no indication as to when such legislation might be ready, therefore remote operation is a good alternative to full autonomy, for this timeframe.

2.3.4 Computing

Within this category a variety of technologies are shown. Firstly; artificial intelligence. There is no doubt A.I. will play a role in the increasing amount of data involved with applications such as autonomous systems, data networks, VR and MR. The potential of A.I. seems overwhelming and therefore pinpointing which implementations will become widespread at what moment in time is very difficult. However, the likelihood that A.I. and machine learning will play a significant role in the technological context for 2035 is high.

Cloud computing is another innovation that is on the rise. It will enable processing of data to happen via the cloud (i.e. on a remote server), instead of on a local device. This could potentially revolutionise technologies such as VR/MR, as they will require less local hardware whilst providing higher performance at the same time.

On the far horizon we might see a technology called quantum computing. This entirely new form of computer processing would see computing power increase by incredible amounts. The exact workings of the quantum computer are too complex to explain here, but it might prove revolutionary for purposes such as data encryption, providing a much higher level of digital security; an important aspect of autonomous systems. Before quantum computing can become a reality a lot still needs to improve as the computers are rather unstable right now.

2.3.5 Big data

As the world becomes more connected, the amount of data that is generated keeps expanding. Big data is data of vast quantities and variation. Examples of big data are things such as medical records of the entire population, traffic streams, geographical data, insurance data, weather data, internet traffic data and much more. Big data can reveal a lot of underlying properties about the data generator and knowing these properties is key in optimising many processes (Rai, 2020).

A common example we see today is targeted advertising, in which big data is used to tailor to personal shopping preferences of internet users. The use of big data will certainly increase in the future in applications such as traffic management and banking security. Big data and A.I. go hand in hand, as A.I. uses big data as the source for learning and recognising patterns. Big data will inherently be part of air mobility given the complex air management it requires and its role within autonomous systems.

2.3.6 Conclusion

A few insights from the roadmap stand out as especially relevant for the development of the ambulance drone.

Firstly, remote piloting is the likely option as long as regulations are not sufficient for full autonomy.

Secondly, ambulance drones will likely be preceded by other medical drone implementations, such as defibrillator (AED) drones and rapid responder drones.

An example of an already existing AED drone is the one developed by Alec Momont at the TU Delft, back in 2015. This drone is currently facing delay because of regulations, but it is expected that it will be implemented at some point in the near future (Frame, 2015).
Even rapid responder eVTOLs are in their early stages, as is shown by the collaboration between ADAC Luftrettung and Volocopter, who have done a number of test flights with a modified Volocopter for medical emergencies (ADAC, 2021).

By 2035, air mobility might be ready for the first full fledged ambulance drones. It is unlikely, however, that they will replace all ambulance vans at this point in time. A more realistic early implementation is as a replacement of current ambulance helicopters.

Thirdly, a number of technologies will work hand in hand for creating a strong remote operating system. Cloud computing, A.I., 6G, VR and MR will provide excellent communication tools and plenty of speed and bandwidth.

Lastly, the battery development forecast shows that even today’s Li-Ion batteries are far from reaching their peak perfomance levels. This is a promising insight for an electrically propelled ambulance drone.

D

VISION

CHAPTER 3
SYNTHESIS

3.1 INTRODUCTION

In this chapter the main findings of the research in chapter 1 and 2 are summarised. This forms the groundwork for the design phase.

The project's assumption is that manned drones (eVTOLs) could provide benefit for ambulance healthcare. However, it is the responsibility of the designer to validate this, based on research. As such, this chapter explains whether the project's premise still holds true and in what way. It could be seen as an updated project brief for the design phase.

3.2 WHY REPLACE HELICOPTERS?

The roadmap of chapter 2 and the infrastructure scenarios and concepts in appendix B and C point towards replacing the ambulance helicopter system as a first step for drones to enter the acute healthcare sector. In this section it is explained why this is the case.

While it has become clear that the ground-based ambulance system and the ambulance vans have certain shortcomings as well, both on a system level and a product level. Replacing this system is much more ambitious than replacing the ambulance helicopter system.

The scale of the ambulance helicopter system is much smaller than that of the ambulance vans. Ambulance helicopters are only called in for a fraction of the total A1 emergency responses (see figure 13, paragraph 1.4.3). This means that they are a much smaller part of the entire ambulance system than the regular ambulance van. Innovating the ambulance helicopter is therefore a lot less disruptive than innovating the regular ambulance vans.

Looking at the roadmap of chapter 2, replacing all ambulance vans with drones translates to a much longer timeframe. Here is why:

- It will require a time-proven regulatory framework for which the first tests are only just being initiated, as explained in paragraph 2.2.2.
- It would require fully autonomous flight systems that are capable of flying in much busier airspaces than there are today. Legislation might not be ready for this by 2035.
- A high level of political and societal acceptance is needed in order to drive this innovation forward.

Given these significant challenges regarding the replacement of ground based ambulances, replacing the ambulance helicopters is the *most advanced, yet acceptable* option for the timeframe of 2035. A timeframe chosen for not being too far into the future to lose any sense of relevance, but also far enough so that it allows for a meaningful and inspiring vision and concept design.

The relatively small scale of the ambulance helicopter system makes it easier for the ambulance drone to be introduced in small steps and gradually move towards larger scale implementation further into the future. Taking it step by step is the best strategy to shift public perception and gain political and societal acceptance.

3.3 THE POTENTIAL OF AMBULANCE DRONES

During the research phase, shortcomings of current ambulance vehicles (van and helicopter) have been investigated, as well as the status quo of eVTOL and Air Mobility developments. So now it is important to relate this to the ways in which ambulance drones could improve these shortcomings and see if and why they are desirable.

3.3.1 Staff & patient centered

The helicopter was never developed with the intention of using it for medical transport, having initially been a military vehicle. This is why their shape and layout is far from ideal for the staff and the patient, which also became clear in the interview with helicopter nurse Frank Latour (appendix G). An ambulance drone has the opportunity to be designed around the patient and the staff from the ground up. This is something completely new within the ambulance sector, as even ambulance vans are modified vans that were never designed to be an ambulance.

From the research into the ambulance van and the ambulance helicopter in chapter 1, it became clear that the helicopter suffers from more restrictions due to it being an aircraft and having to abide to technical limitations and regulations. The ambulance van, on the other hand, has seen iterations across many decades.

While there are still shortcomings to the van, it is still a much more user friendly environment than the helicopter. For this reason, the insights about the ambulance van are a very important basis for the design of an ambulance drone, as it is simply not necessary to reinvent the wheel for each and every function of the ambulance drone. Many of the interaction and workflow solutions in the ambulance van already make sense, so it is a case of translating these into the ambulance drone and improving them where possible. Some of these improvements have already become apparent and these are highlighted in the vision and the requirements.

3.3.2 Mechanical simplicity

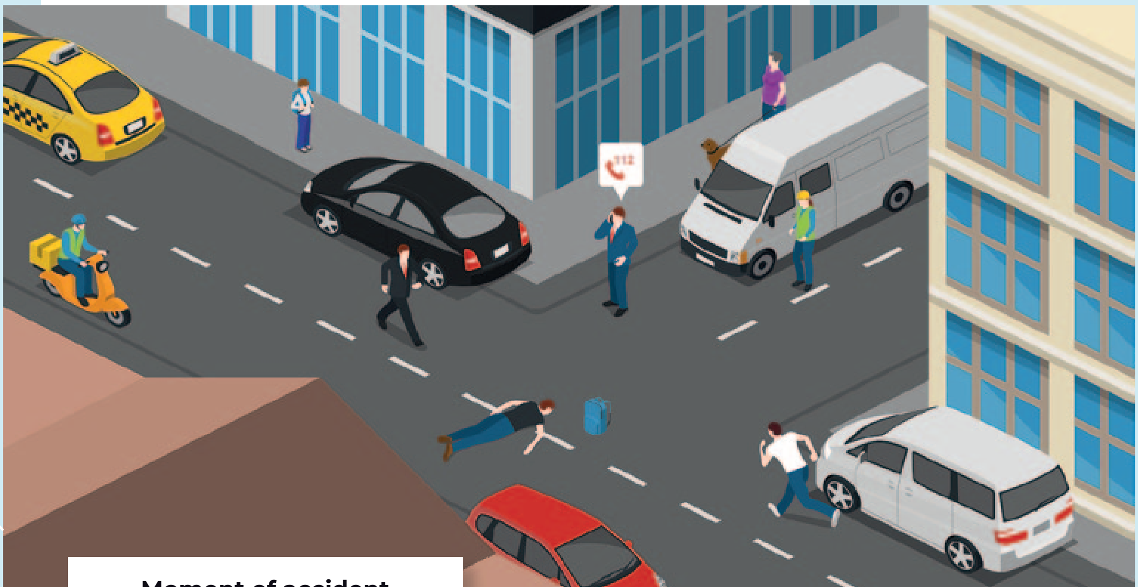
Helicopters use a time-tried, yet complex mechanical system for the rotors and run on fossil fuels that drive the rotors and two small yet engines. Electric propulsion has the potential to drastically simplify the mechanical components of the aircraft, because the drive train consists of fewer components. This frees up space for other purposes. Simplicity also translates to higher reliability and less need for maintenance. Next to that, electric propulsion reduces noise levels and pollution and lends itself better to be connected to an autonomous flight system.

Drones are always equipped with multiple smaller rotors, compared to a single large rotor on helicopters. This creates a more compact rotor configuration and creates redundancy for safety reasons. Also, because drones have several rotors, they do not need a tail rotor to act as a counterforce, like on a helicopter. This makes the drone much shorter, allowing it to land in smaller spaces.

SCENARIO: *The effectiveness of ambulance drones versus helicopters.*

In order to visualise how ambulance drones could improve ambulance helicopters in practice, the following scenario has been made.

MMT BY HELICOPTER



0-1 min

0-1 min

Moment of accident

The scenario follows two tracks: the current scenario (ambulance helicopter) and a future scenario for the ambulance drone. Both scenarios are related to a timeline which shows difference in response times for each of the scenarios.

MMT BY DRONE

3.3.3 Cost savings

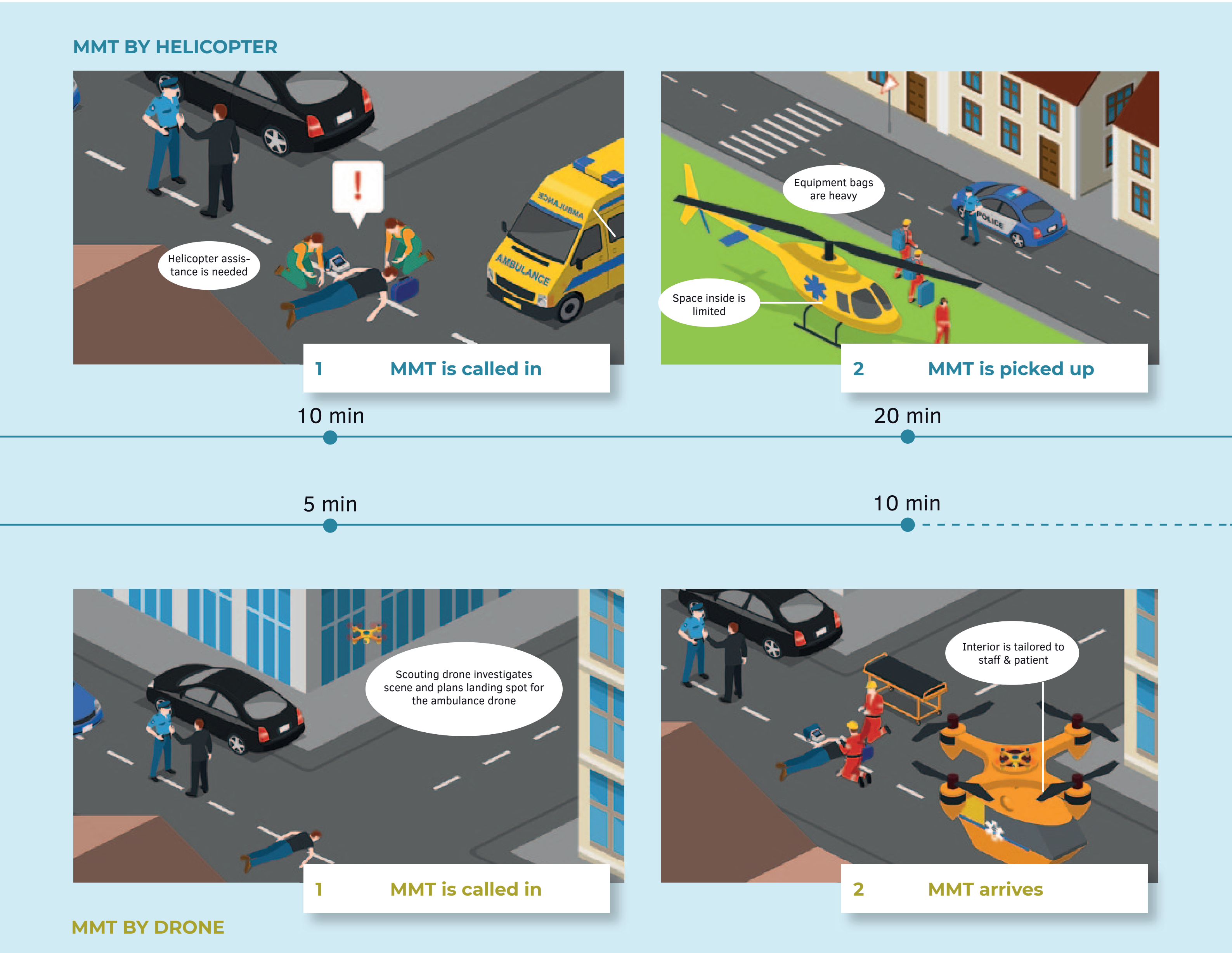
Autonomous ambulance drones are also attractive in terms of costs, saving the need for a highly skilled pilot and lowering maintenance costs and cost price compared to helicopters.

This means that more ambulance drones can be deployed, creating a denser network with shorter and more reliable response times. In short, more value for similar investments. This is explained in more depth in appendix K.

3.3.4 Reducing response time

As can be seen in the scenario, ambulance drones also have the potential to make responses a lot more efficient than current helicopters, removing the need for the regular ambulance van to assist. This is because the drone is a lot more capable at transporting a patient than a helicopter. Next to that, the drone is able to land in more places than a helicopter. This enables the MMT to arrive faster. Drones will also have shorter downtime, thanks to less need for maintenance.

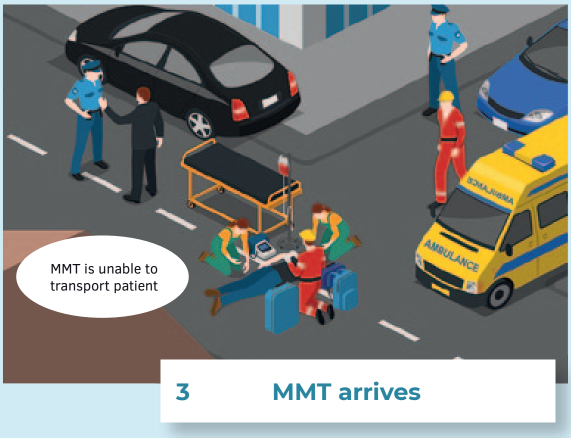
This innovation (Ambulance drones) would not yet be a necessity in the short term, but a potential for achieving the highest quality of acute healthcare possible.

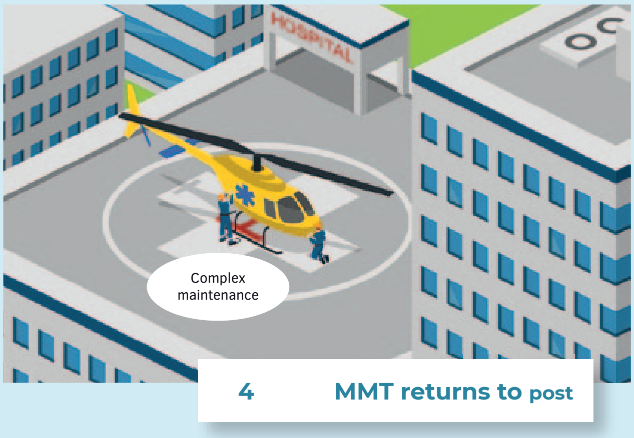


3.4 CONCLUSION

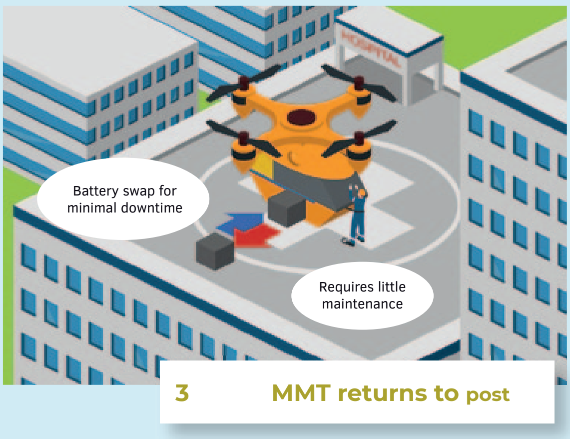
Having rounded up all the insights and opportunities identified in the research phase, it is safe to say that ambulance drones have potential to become the next generation of flying ambulances. There are still challenges that need to be overcome for an ambulance drone to become a reality, as are addressed in the Design Challenges section in the next chapter.

Also, it is important to realise that today's acute healthcare in The Netherlands is already outstanding. Ambulance helicopters are a great solution, but an ambulance drone holds the potential to be even better. This innovation would not yet be a necessity in the short term, but a potential for achieving the highest quality of acute healthcare possible.





25 min



Response Times

Response times are significantly shorter and more consistent for ambulance drones.

The ambulance drone can operate independently from the regular ambulance, which removes the delay between the moment of the accident and when the ambulance staff call in the MMT. Also, the ambulance drone can land nearer to the patient, saving time transporting the MMT to the destination.

CHAPTER 4
VISION

4.1 INTRODUCTION

Combining the important insights from the research, as explained in the previous chapter, with my own values and preferences, creates a vision for the design phase. In this chapter, this vision is constructed by combining a method called Vision in Product Design (ViP) and a method that was developed and implemented in a previous project, called Design Fundamentals & Challenges.

With the ViP method, the often abstract and intangible human-product relationships are identified. Through observation and consideration, the current ambulance vans and helicopters are deconstructed. Their underlying product qualities, interactions and relationship with the context are described in a way that I, the designer see them.

After the deconstruction, the development of the vision converges by creating short vision statements. These statements are based on personal preferences, insights and ideas regarding the design of an ambulance drone.

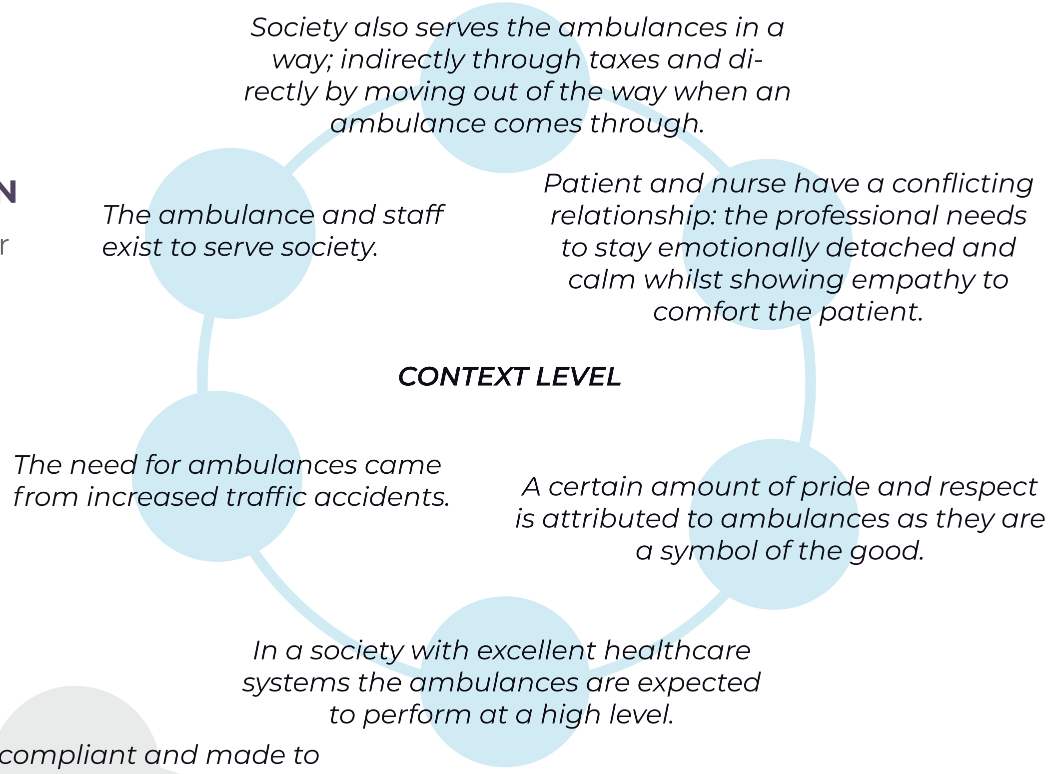
Having established the components of a personal vision, it is then combined with the insights gathered from research. This is where the method of Design Fundamentals & Challenges is used. It helps create a clear reference point, which ensures the solutions that come up during the design phase are well connected to the vision and the research.

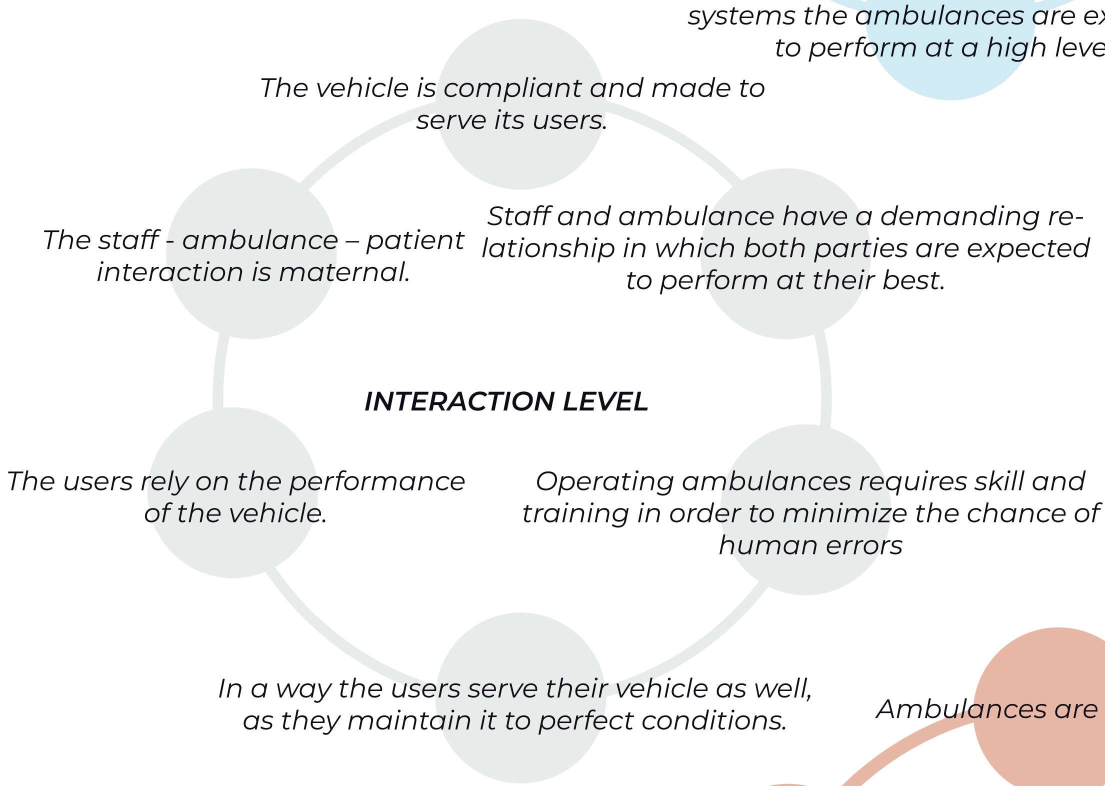
Vision in Product Design

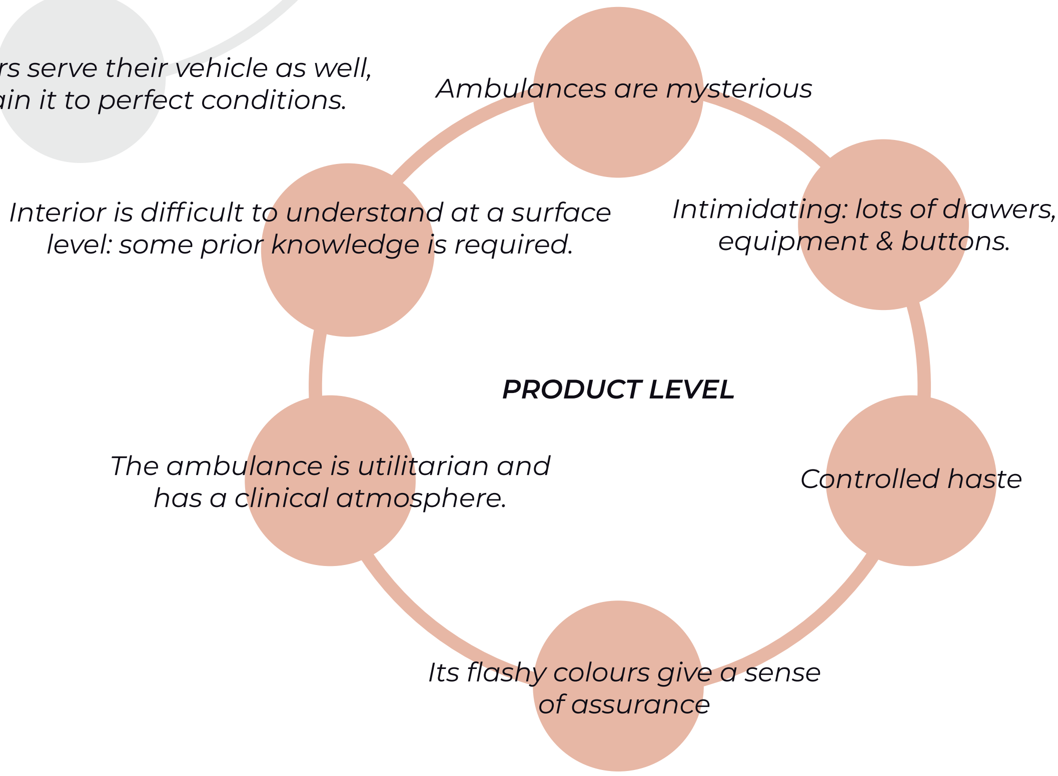
4.2 DECONSTRUCTION

Ambulance Van/Helicopter

Underlying product qualities, interactions and relationship with the context are described in a way that I, the designer observe them.







Vision in Product Design

4.3 DESIGN VISION STATEMENTS

Based on the previous deconstruction exercise and insights from the research phase of the project a list of vision statements that relate to the design of the ambulance drone is created. They can be seen as abstract thoughts that form the basis for the more concrete Design Fundamentals in the next section.

PRODUCT LEVEL

"The ambulance drone needs to mitigate fear of flying as much as possible, by providing stable transport and doing everything to comfort the patient."

"Visual complexity needs to be reduced as much as possible in order to remove the intimidating and technical impression that current ambulance helicopters give."

"Simplicity rather than complexity"

"The ambulance drone looks like a reliable friend"

"Rotor noise is minimal and does not add to the distress of the patient."

CONTEXT LEVEL

"The ambulance drone needs to be novel enough to evoke pride and interest, but recognisable enough to evoke trust."

"The ambulance drone's appearance reflects the role of its staff: professional yet empathic and personal."

INTERACTION LEVEL

"Inside the ambulance drone there is a balance between functionalism and an atmosphere that is psychologically comforting to the patient."

"The ambulance serves its staff , which is reflected in the way its functions are designed."

"The ambulance provides privacy for the patient from passersby."

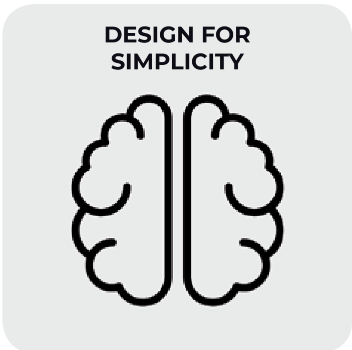
"The interior can adapt to the patient's needs."

Design Fundamentals & Challenges

4.4 DESIGN FUNDAMENTALS

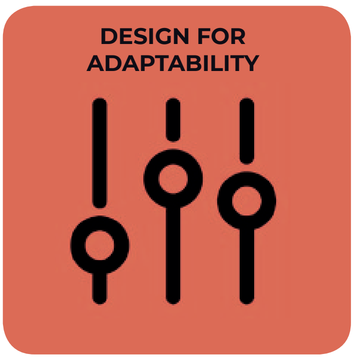
In the previous sections the components of the vision have been established. Now the link between the vision and the insights from the research is made using a method called Design Fundamentals & Challenges. Given the large variety of insights and input that has been generated in the research part of the project, concise and visual conclusions are a helpful way to stay in touch with the "bigger picture" throughout the design phase. They are a set of extra context based requirements that are like mantras for the design phase.

The design should express that it exists to aid. Therefore, its appearance needs to be professional to reflect the expertise of the ambulance staff and the importance of their role. Professionalism also reinforces the sense of discretion regarding the patient's privacy. However, cold professionalism needs to be avoided, as it is just as important for people to perceive the drone as friendly and trustworthy, in order to offset the intimidation associated with flying.



Simplicity translates into two benefits. The first is reliability; simpler components are less prone to breaking and as a result increase durability and safety. This also makes the aircraft certifiable. Secondly, simplicity aids intuitivity by taking unnecessary complexity and distractions away from the users.

Given that maintaining the ambulance is a large part of the staff's responsibility, the design needs to provide solutions that allow the most efficient way to clean, maintain, repair and upgrade the ambulance.

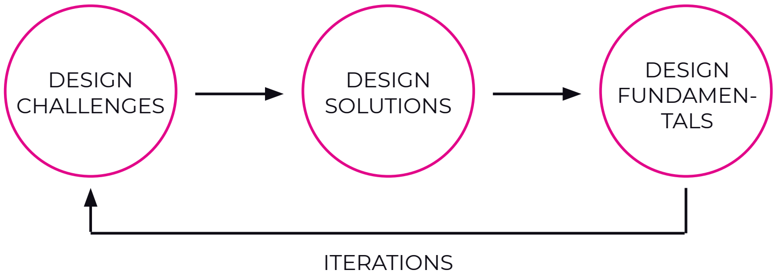


Like present ambulances, the ambulance drone can be adapted to fit the type of patient they are carrying.

Design Fundamentals & Challenges

4.5 DESIGN CHALLENGES

The design fundamentals provide a way to judge the quality of a design solution. This ensures that the design challenges are answered in accordance to the original vision and the most important insights from the research phase. As can be seen in the figure on the right, the Design Fundamentals are the test that solutions need to pass in order to successfully solve a design challenge.



The core design challenges that have been identified from the research are:

DESIGN CHALLENGE 1 **Efficient "last mile" mobility**

Since an ambulance drone is not expected to get as close to the location of the incident as regular ambulances can, a solution needs to be found for efficiently and comfortably transporting necessary equipment from the drone towards the patient.

DESIGN CHALLENGE 2 **Ambulance layout for efficient workflow**

Ensuring the layout of equipment is logical and convenient for the nurses, based on various tasks they need to perform.

DESIGN CHALLENGE 3 **Visual identity**

Being a visionary project, the appearance of the ambulance drone is also an important point of attention. As such the aesthetics of the exterior and interior need to be designed according to the vision of the designer and the needs of the users.

DESIGN CHALLENGE 4 **Transporting patients safely and comfortably**

Ambulance vehicles are shaky and helicopters are loud, causing discomfort to the patient and the staff. Therefore solutions to these issues need to be addressed in the design of the ambulance drone.

DESIGN CHALLENGE 5 **Integration of technical package**

The technical components need to be integrated with the optimal layout of the ambulance drone to complete the final design.

4.6 STYLE COLLAGE

Below is a collage that was made to investigate the visual style that would suit the ambulance drone. From ViP and the Design Fundamentals it became clear that the appearance requires a balance between friendliness and professionalism. Also, to stipulate the ambulance drone as a future vision, some level of sophistication helps set it apart as innovative.

4.7 VISION & MISSION

Now the chapter concludes with a vision and a mission statement. These are similar but also distinct in a key way.

The vision is **the long term goal that the project aims to help achieve**.
The mission is the goal within the scope of the project, or in other words: **the goal of the project itself**.

VISION

An ambulance drone that fits like a glove to its staff, patients and society and provides the best care anywhere in The Netherlands in the quickest, most reliable and effective way possible.

MISSION

A design proposal with a unique identity that inspires and informs the development of ambulance drones for the scope of 2035 and beyond, through context-driven and user-centered design solutions.

CHAPTER 5
PROGRAM OF REQUIREMENTS

5.1 INTRODUCTION

In this short chapter the Program of Requirements is presented and explained. The program consists of two types: requirements and wishes. Next to that, each requirement and wish has been indexed with the source type. These sources are: literature, expert and me, the designer.

Usually when following the rules of compiling the program of requirements, only qualitative data can be considered a requirement, whereas quantative data is always a wish. However, given the conceptual nature of this project, there is a lot of uncertainty regarding the exact specifications of many features and functions of the ambulance drone. Therefore it was decided to include quantative data as requirements as well. The distinction between requirement and wish has instead been based on how critical the function is for the success of the ambulance drone.

5.2 PROGRAM OF REQUIREMENTS

R = Requirement
W = Wish

Source type
L = Literature
E = Expert
D = Designer

1. Dimensions and weight

1.01	R | E, L	max. payload of 1000 kg
1.02	R | D	min. landing area of 25 x 25 m
1.03	W | D	min. landing area of 15 x 15 m
1.04	R | E, L	weight distribution that offers stability
1.05	R | D	max. width of 250 cm

2. Performance

2.01	R | D, L	max. response time of 15 minutes
2.02	R | E	energy reserve for emergency landing/take-off during transport to hospital
2.03	R | D	automated flight system in combination with remote operator
2.04	W | D	fully autonomous flight system

3. Safety

3.01	R | L	redundancy in critical components
3.02	R | L	battery reserve for unforeseen delays
3.03	R | L	safe workspace
3.04	R | E	rotor units placed on top of aircraft
3.05	R | L	cybersecurity system
3.06	R | D	ambulance drone is able to operate at night

4. Operation & connectivity

4.01	R | L	remote operator can communicate effectively with the on board staff
4.02	R | L	remote operator can communicate effectively with the control room
4.03	R | D	remote operator can communicate with the hospital
4.04	W | D	nurse can be virtually assisted by doctor in the hospital
4.05	R | D, L	access to patient records

5. Interior

5.01	R | D	space for two nurses + patient
5.02	W | E	space for extra passenger
5.03	W | D, L, E	modular storage units
5.04	R | D, E	sufficient lighting at night
5.05	W | E	adjustable lighting
5.06	R | E	easy to clean surfaces
5.07	R | E, L	seated access to monitor, patient records and a selection of gear
5.08	W | D	minimal visual complexity
5.09	W | D	psychologically comforting environment
5.10	R | D	min. 1,50 m^3 of storage space

6. Exterior

6.01	W | D	friendly/approachable appearance
6.02	W | E, L	access to equipment from outside
6.03	R | D	loading stretcher conveniently and safely
6.04	W | E, L	privacy; no visual access to the interior
6.05	R | D	yellow paint with ambulance striping

7. Stretcher

7.01	R | D, E	sufficient access to head
7.02	W | D, E	sufficient access to lower body
7.03	W | D, E	access to both sides of the patient
7.04	R | D	can be raised or lowered in order to position the patient
7.05	R | D, E	needs to be compatible with other healthcare facilities
7.06	W | D	integrated storage units

5.3 EXPLANATION

1. Dimensions and weight
The maximum payload has been estimated based on the payload of an ambulance helicopter, which carries around 1500 kg in terms of equipment and passengers. Given the simpler architecture compared to a helicopter and (usually) carrying only three people at most, a maximum payload of 1000 kg has been set for the ambulance drone.

The minimum landing area of a helicopter is 25 x 25 m. Since the ambulance drone has a smaller footprint, an area of 15 x 15 m would be preferred.

The maximum width of the drone has been set at 250 cm, which is the maximum width for roadgoing vehicle. This ensures that the drone is able to land on almost all roads and paths. Note that this dimension excludes the rotor tree.

2. Performance
The response time is based on the current maximum of 15 minutes. Energy reserves need to be built in for unforeseen circumstances. An automated flight system in the goal, but an alternative option is a remote pilot.

3. Safety
Redundancy prevents terminal damage and allows the aircraft to make an emergency landing. Placing the rotors on the top means more stability and is a safer location for bystanders. The cybersecurity system is needed for the (semi-)autonomous flight system. Lastly, the aircraft needs to be able to fly at night with the appropriate sensors.

4. Operation & connectivity
These points are mostly self explanatory.
They are included in the requirements, because they are a critically important functionality for the staff of the ambulance drone.

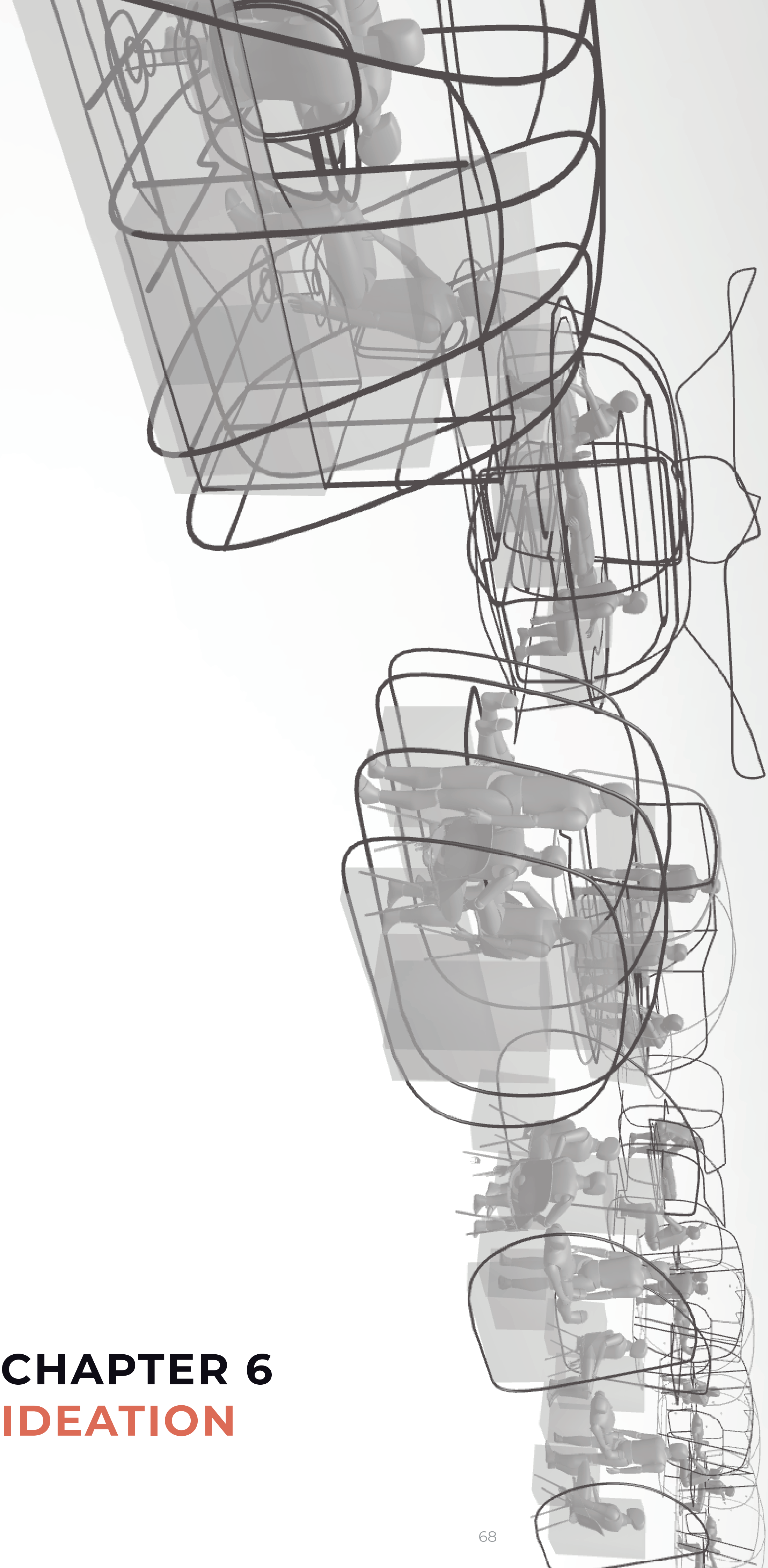
5. Interior
The drone needs to carry three people in total: nurse(s) and/or a doctor and the patient. A bonus would be for an extra passenger to be transported as well, which is a functionality normal ambulance vans offer. Next, the modularity of the interior is important, offering adjustability in terms of storage and seating. The interior also needs to be laid out such that the staff can stay seated while performing tasks. Total storage space should be around 1,5 m^3, this is around 70% of the ambulance van's capacity. Lastly, a wish would be for the interior to be visually inviting, as such all distractions and clutter should be removed where possible.

6. Exterior
As already explained in the previous chapter, the appearance of the drone needs to be trustworthy. Equipment needs to be able to be accessed from outside; an important time-saving functionality on ambulance vans. Privacy of the patient also needs to be taken into account, therefore visual access into the drone needs to be minimized. Lastly, the ambulance drone needs to be recognisable as being part of the Dutch ambulance fleet, this means it needs to be painted in the yellow livery with red and blue striping.

7. Stretcher
The stretcher is the center piece of the interior, allowing the patient to be transported safely and the staff to work effectively. Therefore access to the head is necessary and access to the lower body and both sides of the patient is desired as well. It should also offer plenty of adjustability and needs to be compatible with existing healthcare facilities (e.g. hospitals, ambulance vans, etc.) Lastly, the stretcher is an opportunity for improving the trip from the aircraft to the patient, by offering integrated storage units.

E

DESIGN



CHAPTER 6
IDEATION

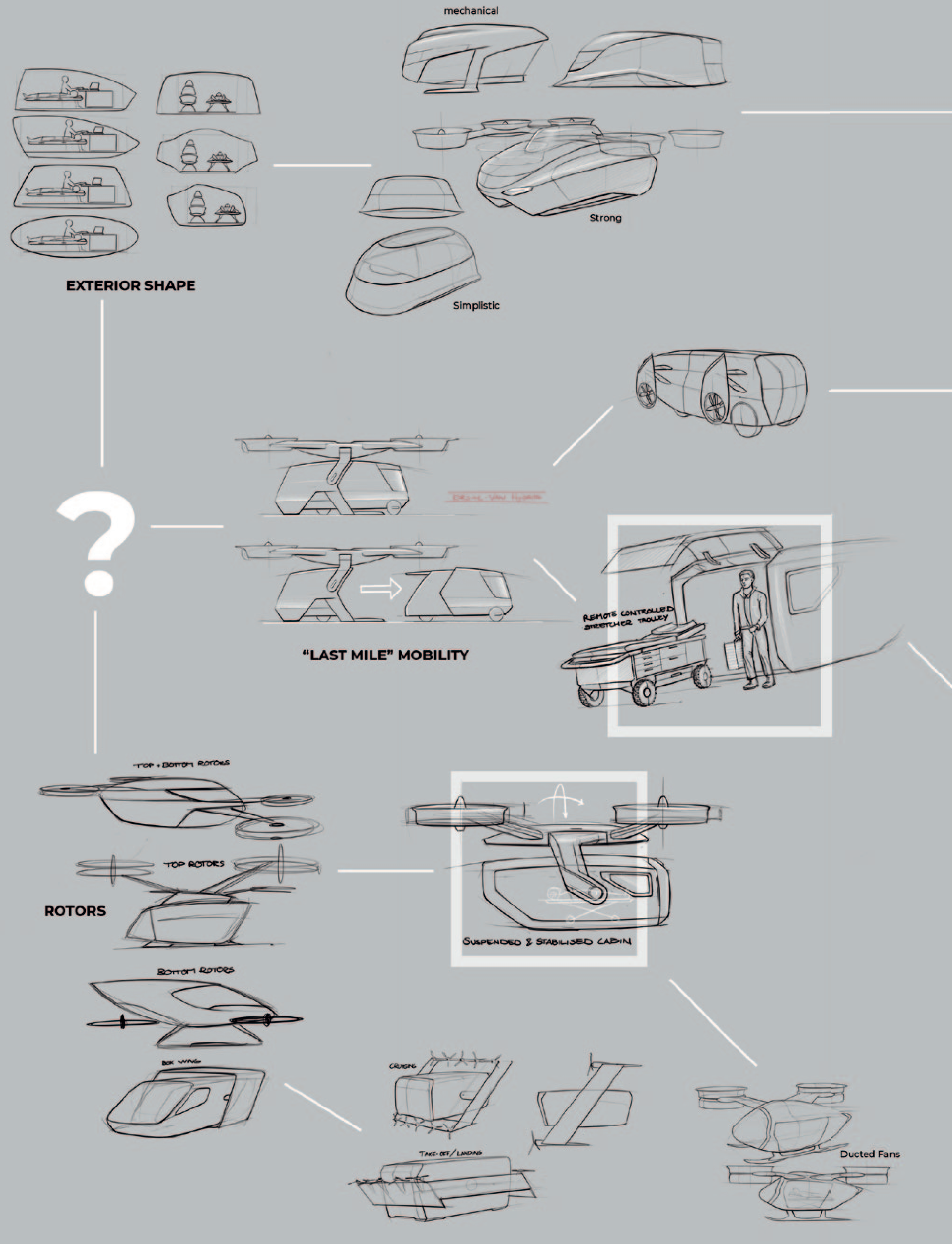
6.1 INTRODUCTION

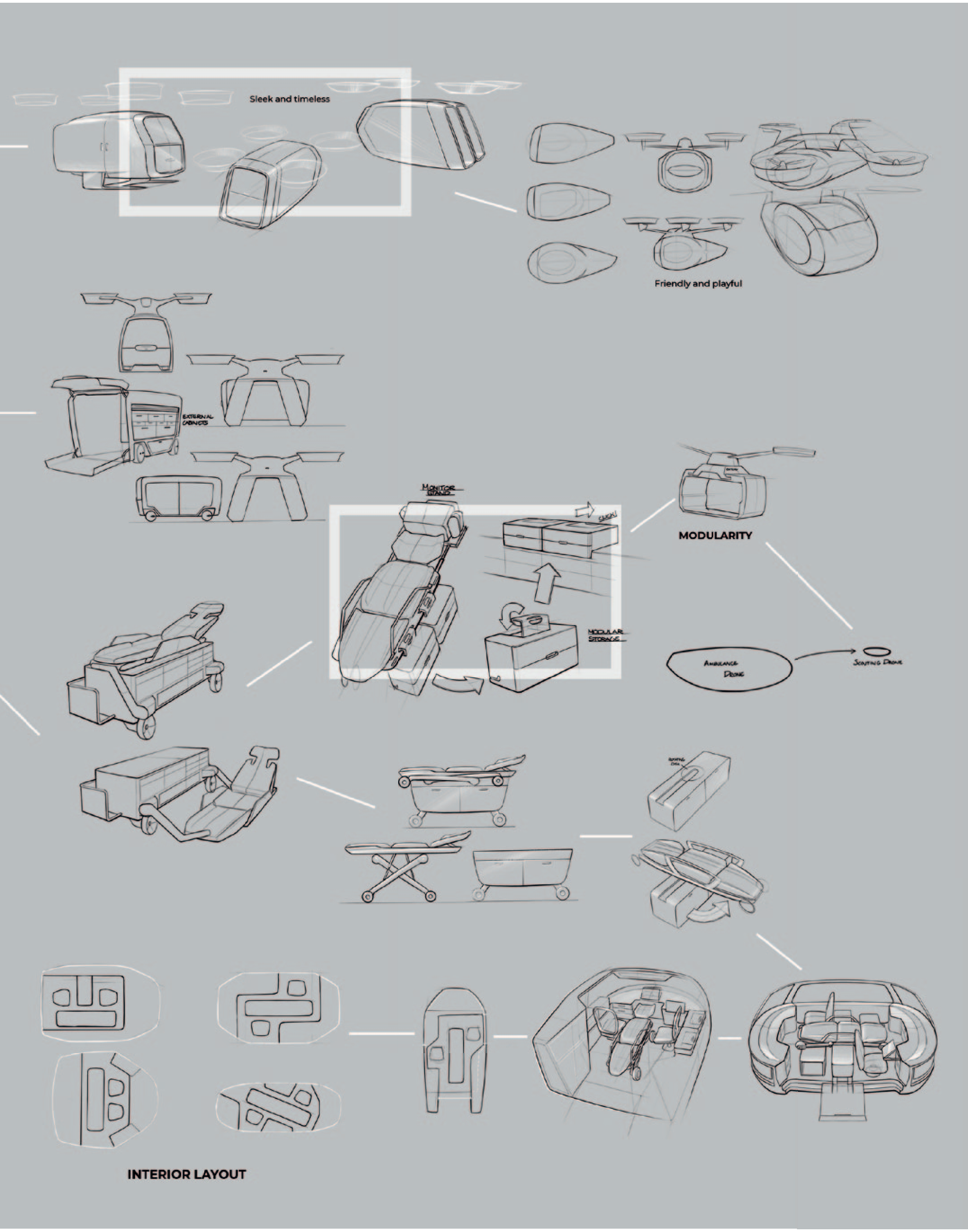
In this chapter the steps in the ideation phase are explained. In reality the ideation process already started during the research phase of the project and extended into the early parts of the design phase.

In order to log these ideas and sketches, the ideation “family tree” was made, as shown on the next pages. The reason behind ordering the sketches in such a way is that it creates a clear relationship between different directions of ideas, which can otherwise become quite chaotic in such a complex project.

Some of the ideas in this overview have a lot of potential and are highlighted. Later on it will become clear how these ideas were used in the rest of the ideation and design phase.

IDEATION FAMILY TREE




Sleek and timeless
Friendly and playful
EXTERNAL CABINETS
MONITOR STAND
MODULARITY
MODULAR STORAGE
Ambulance Drone
Scouting Drone
INTERIOR LAYOUT

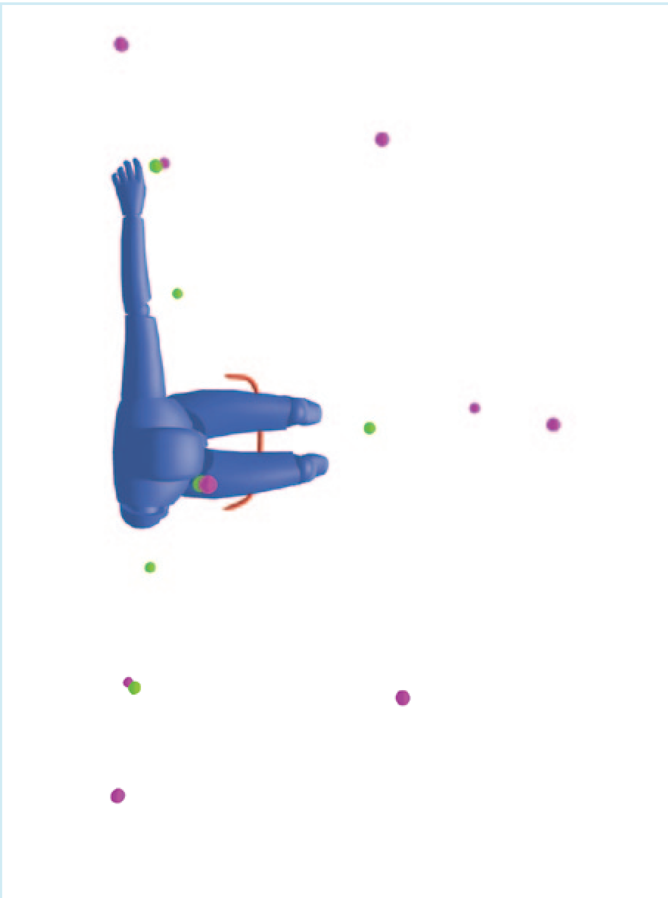
6.2 VIRTUAL REALITY AS AN IDEATION TOOL

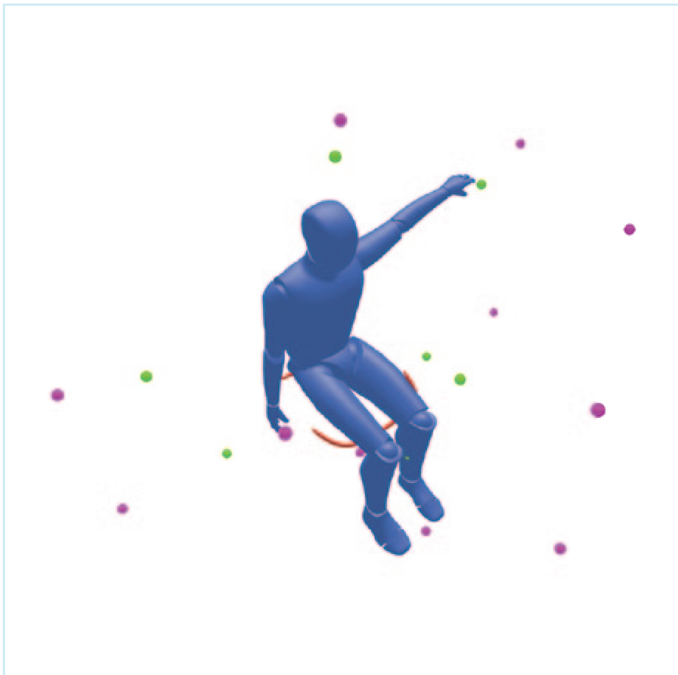
Having gone through the normal process of sketching ideas, I felt it limited my ability to get a grasp on the scale of the design and the relationship between the user and all the elements that make up the interior of the ambulance drone.

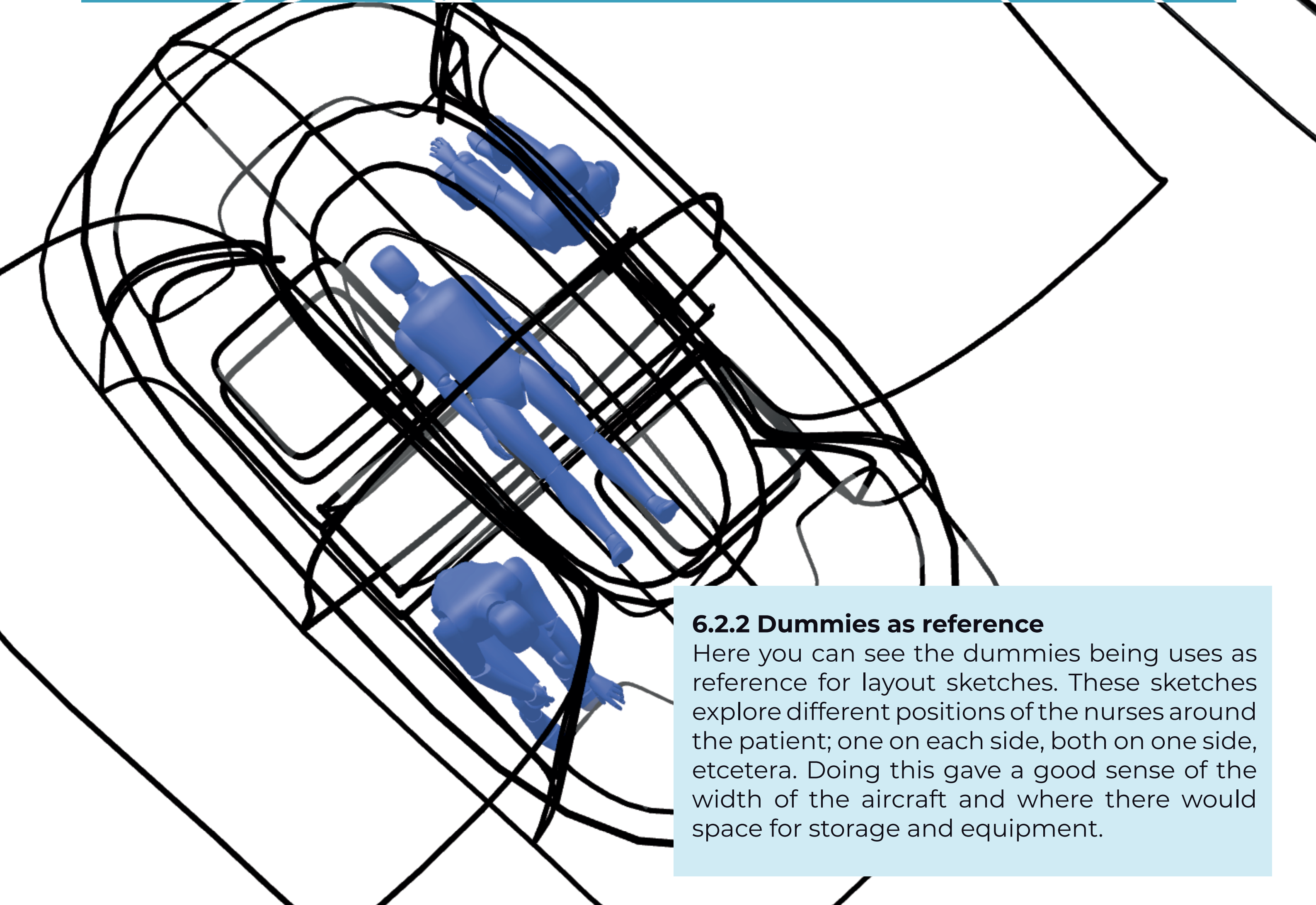
Having had prior experience with using VR for sketching and developing ideas, I knew that this would be a very helpful tool in this project. Using the program Gravity Sketch, I went through an iterative process of trying to discover the optimal layout for the interior of the ambulance drone. In the next section these steps are explained, with their according images.

6.2.1 Seated points of reach
The first step in determining the relationship between user and interior was to plot the area that is within reach from a seated position. This was done by using myself as a reference. I placed green dots around me by stretching only my arms and keeping my back against the chair. Then I placed purple dots by leaning all the way forward, down, sideways and upwards. These points are the farthest I can reach from a seated position.

Having plotted these points, I then placed a standard dummy and scaled it so that it corresponded with the plotted points. This could then be used as a basis for ideation sketches of the interior layout.

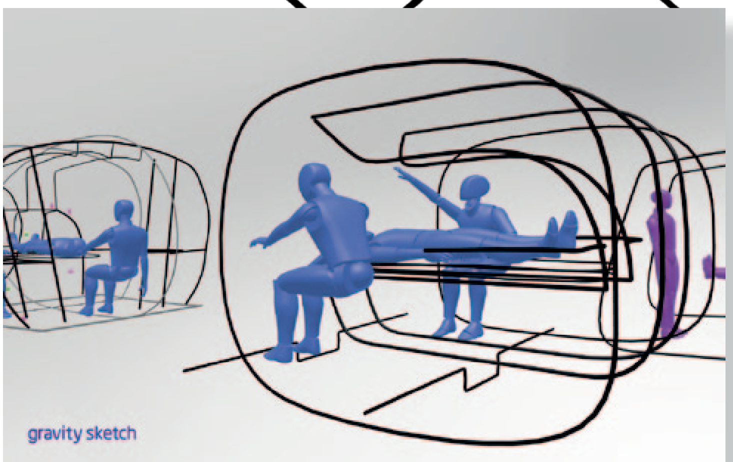


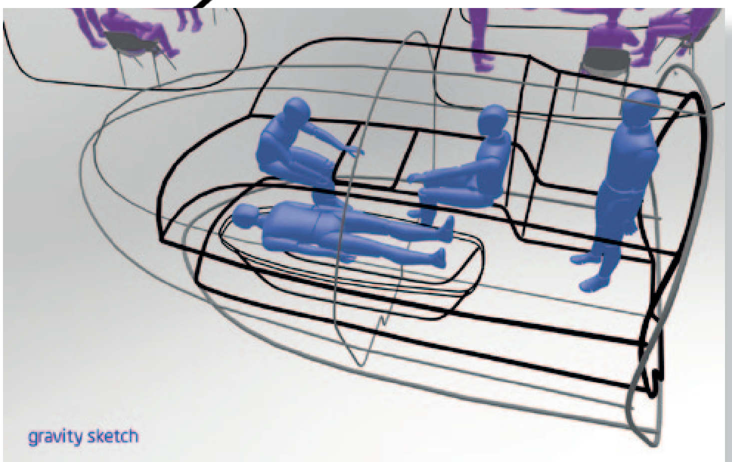


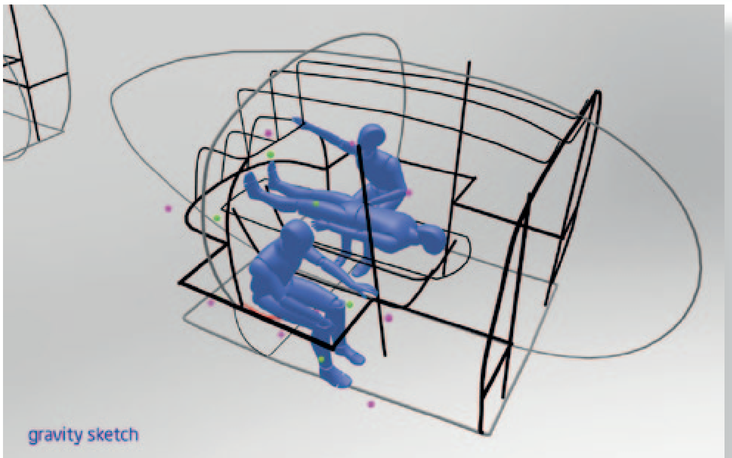


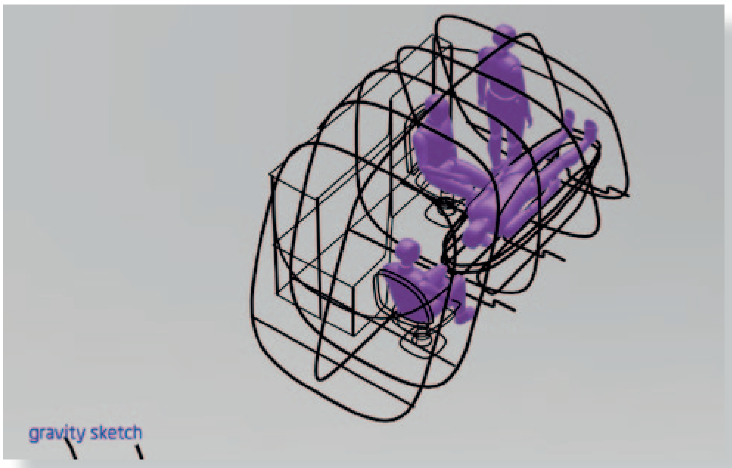
6.2.2 Dummies as reference

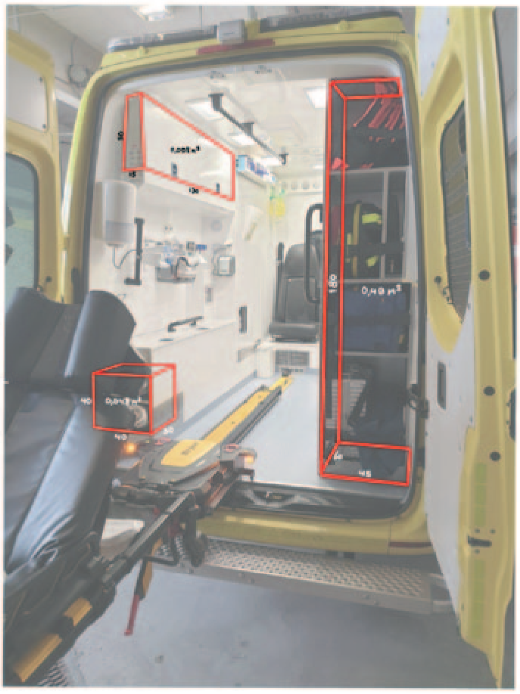
Here you can see the dummies being uses as reference for layout sketches. These sketches explore different positions of the nurses around the patient; one on each side, both on one side, etcetera. Doing this gave a good sense of the width of the aircraft and where there would space for storage and equipment.

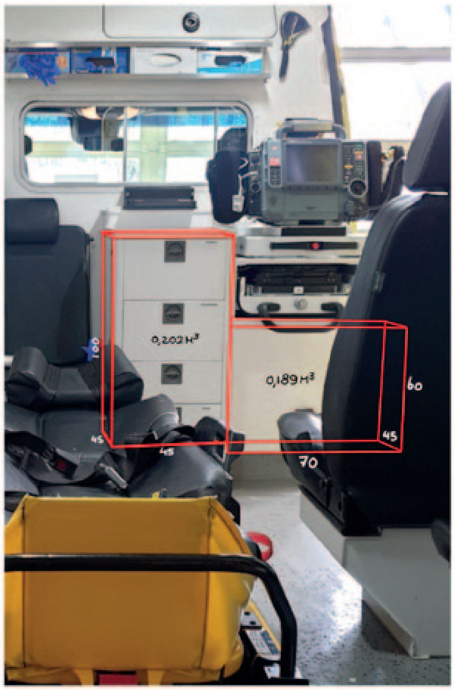


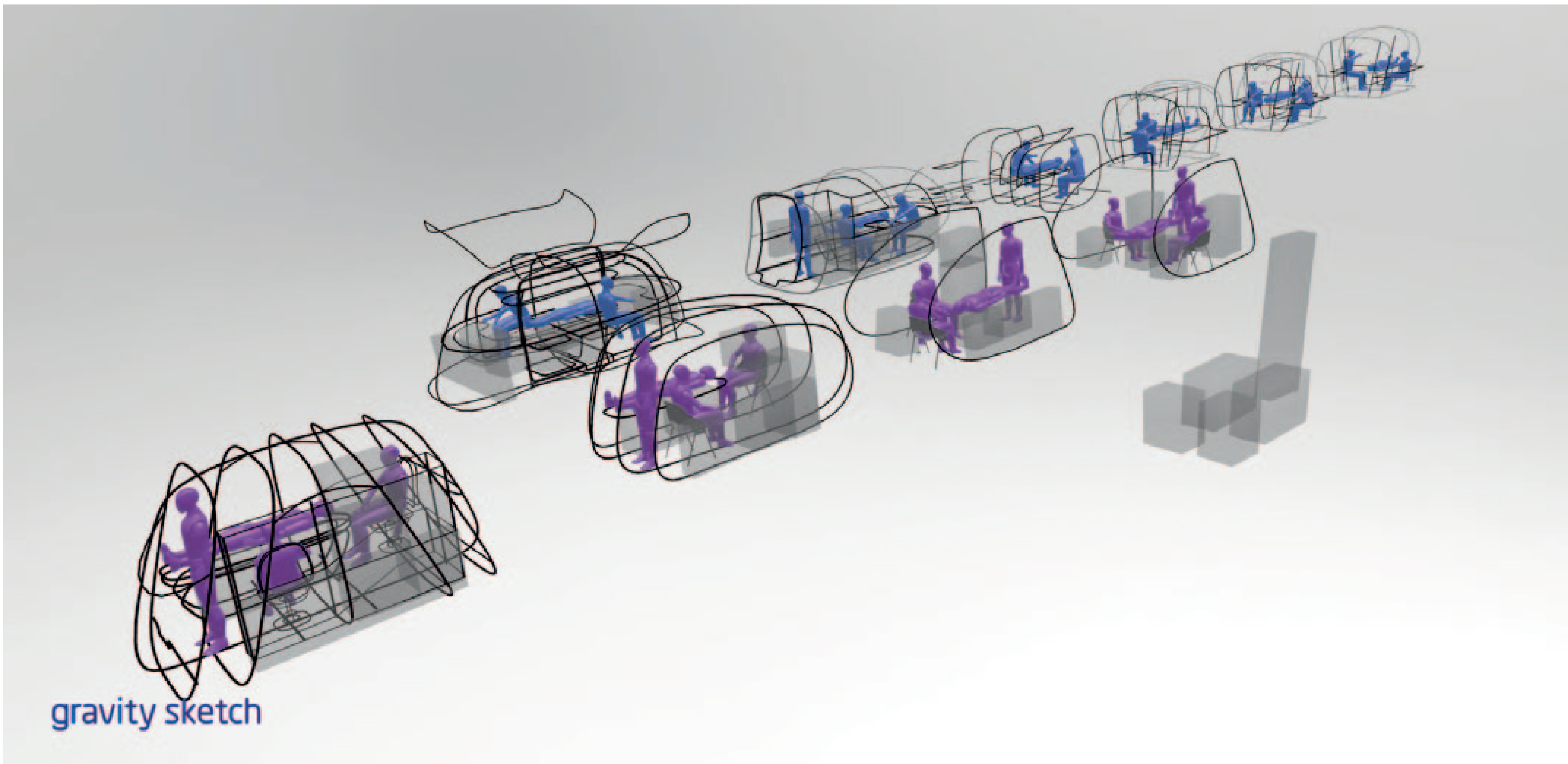












6.2.3 Volumes as reference
The total volume of storage space that the ambulance drone should need was based on that of the ambulance van, as can be seen in the first three images. I used this input to make several different volumes in SolidWorks which together would create the necessary amount of storage space. These volumes were imported to Gravity Sketch and used as reference for the interior layout sketches.

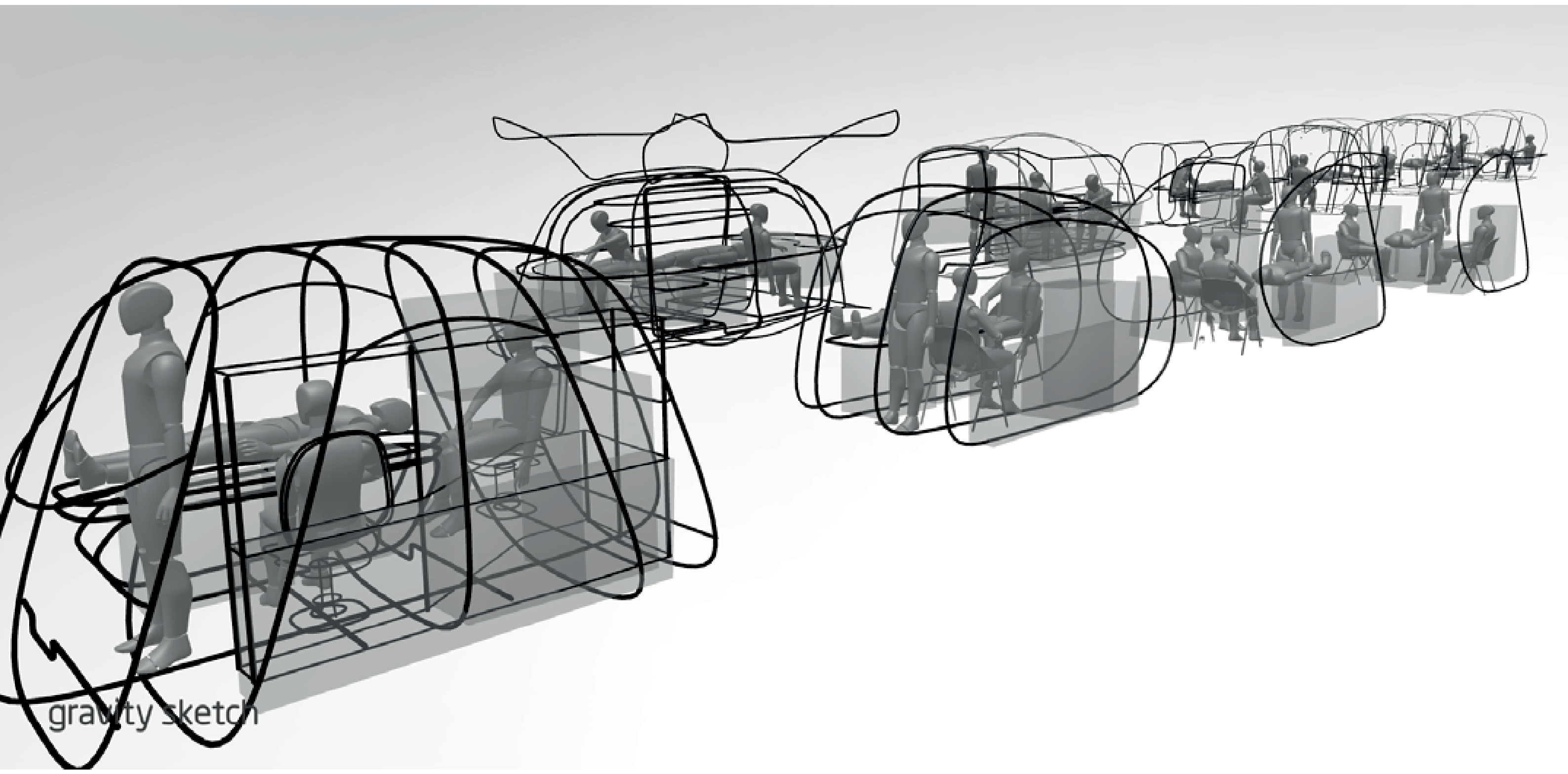
6.3 RESULT

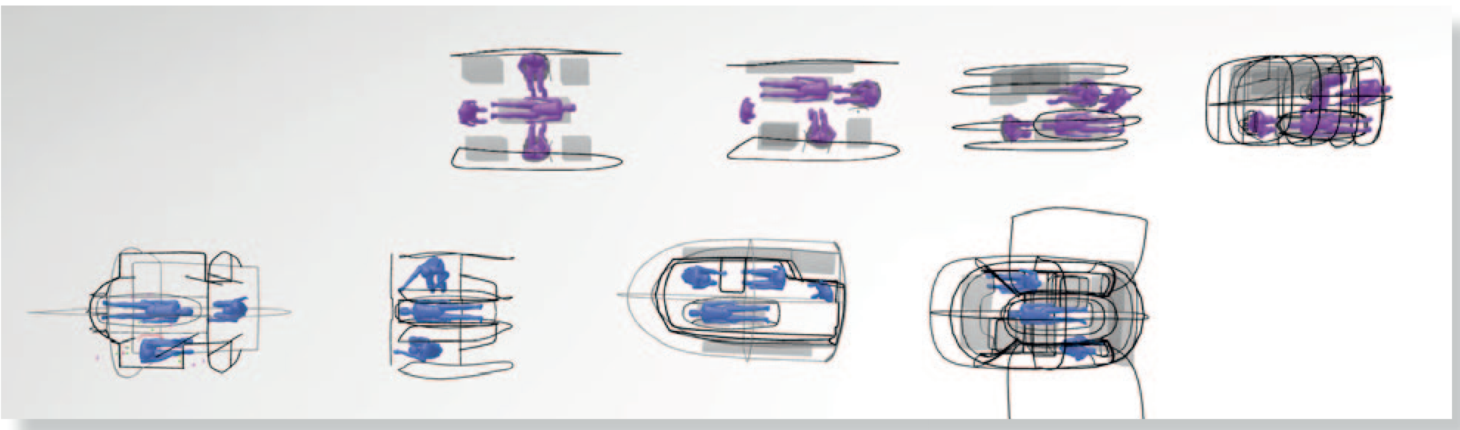
Creating two methods for basing the interior layout on real life dimensions (dummy and storage volumes) gave a lot of insights into the possibilities and challenges for creating the optimal interior layout.

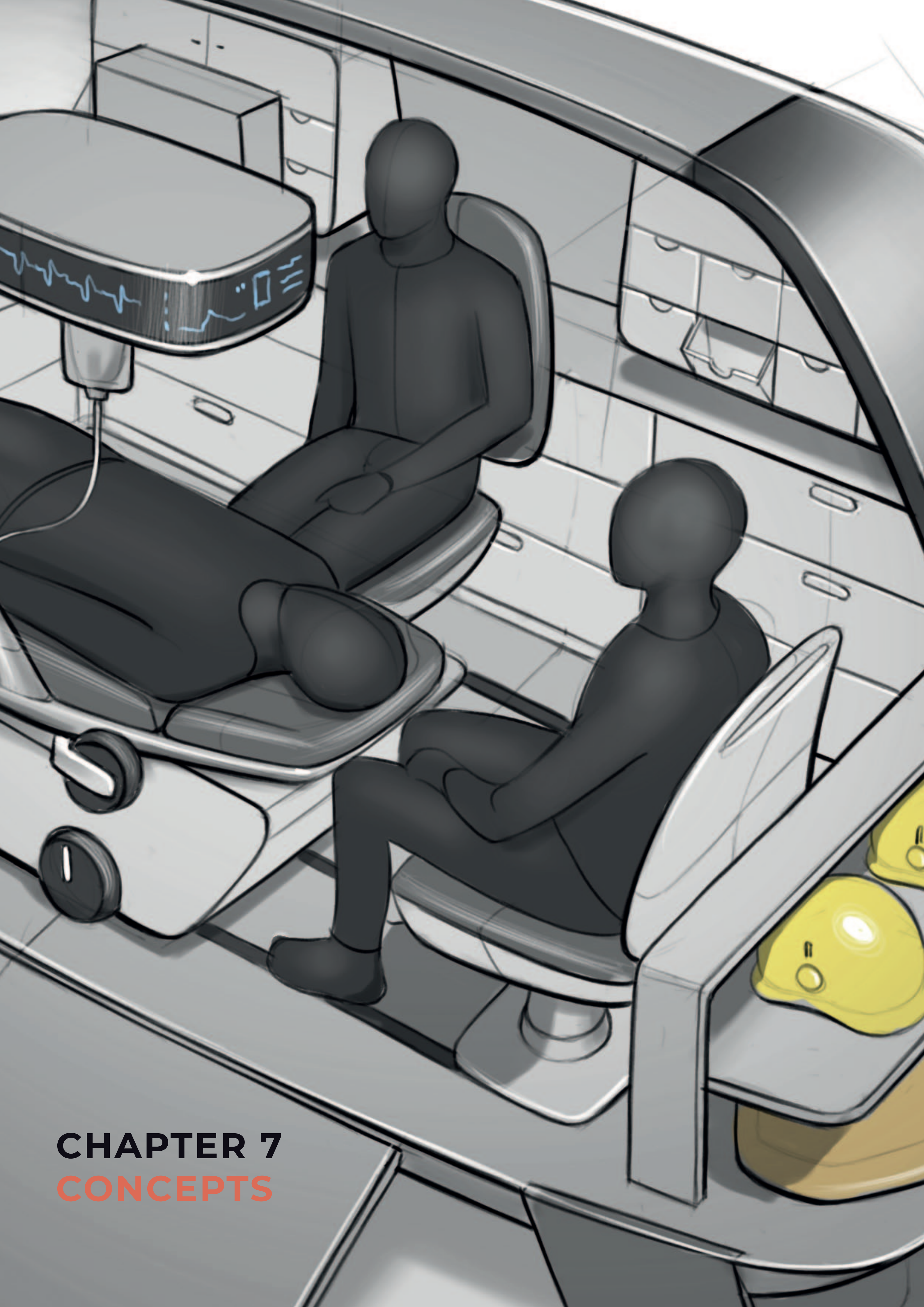
For example, the biggest challenge is to create a layout that allows optimal access to all parts of the patient's body. Ideally, there would be space on all sides of the stretcher, but this would make the cabin too large.

Another challenge is the location of the door. This needs to be placed so that the patient and stretcher can be loaded safely and conveniently. For some layouts the optimal placements of the entrance creates problems for the storage space. This is because the remaining useable spaces were a strange shape or simply too small.

In short, some ideas were clearly less feasible than others.







CHAPTER 7
CONCEPTS

7.1 INTRODUCTION

In this chapter three concepts are presented and explained. These are a result of the ideation in VR. At this point the design phase naturally evolved into an inside-out process.
This means that the foundation of the design of the ambulance drone is the interaction between patient, staff and interior.
The shape of the interior will therefore have a lot of influence on what the exterior will eventually look like.

7.2 CONCEPT 1

This concept was based on the VR sketch shown at the bottom of the page. It follows a traditional approach when it comes to the interior layout, as it is similar to the current layout of ambulance vans. The advantage of this is that it creates a narrower and taller design, allowing the staff to stand upright inside the cabin.

Interior

The storage compartments are mostly placed on one side of the interior, along the wall. It features shelves, drawers and refridgerated compartments for drip bags and blood. A screen can be extended from this unit as well, which creates a little workspace for reviewing patient data and staying in contact with the remote pilot.

The stretcher is placed along the opposite wall. The stretcher also features modular storage, which can be used to transport equipment towards the patient. The stretcher can be removed seperately, without the storage units, which effectively makes it a regular stretcher.

The medical staff is seated on the head and along the side of the stretcher. This is the same setup as used in ambulance vans. It has the benefit of providing good access to the head and most other parts of the body. The only drawback is that the side of the patient that is nearest to the wall is more difficult to reach.

Rotors

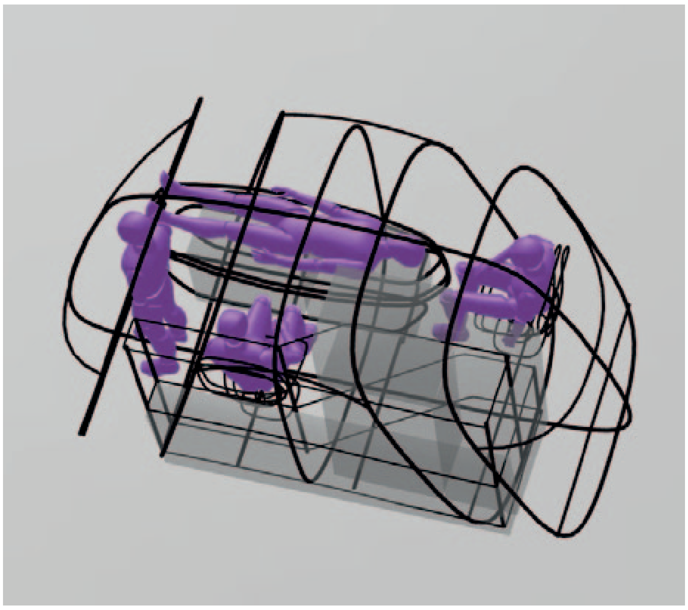
The rotors have been placed on top for stability and safety purposes and are connected to a base, which from now on is called the rotor tree. This tree allows space for the allocation of hardware components like wires, power control, flight controller, etc. The rotors also feature ducts. These add more thrust and also provide safety and noise reduction.

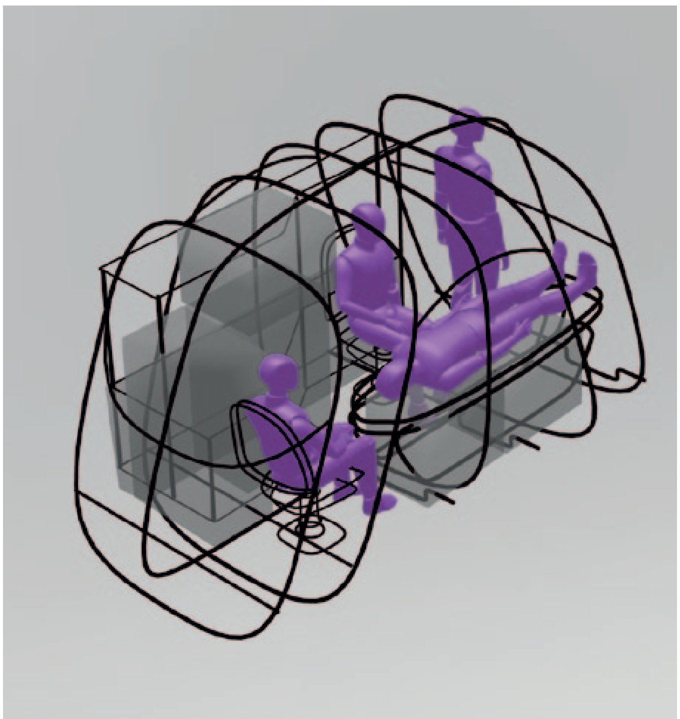
Exterior

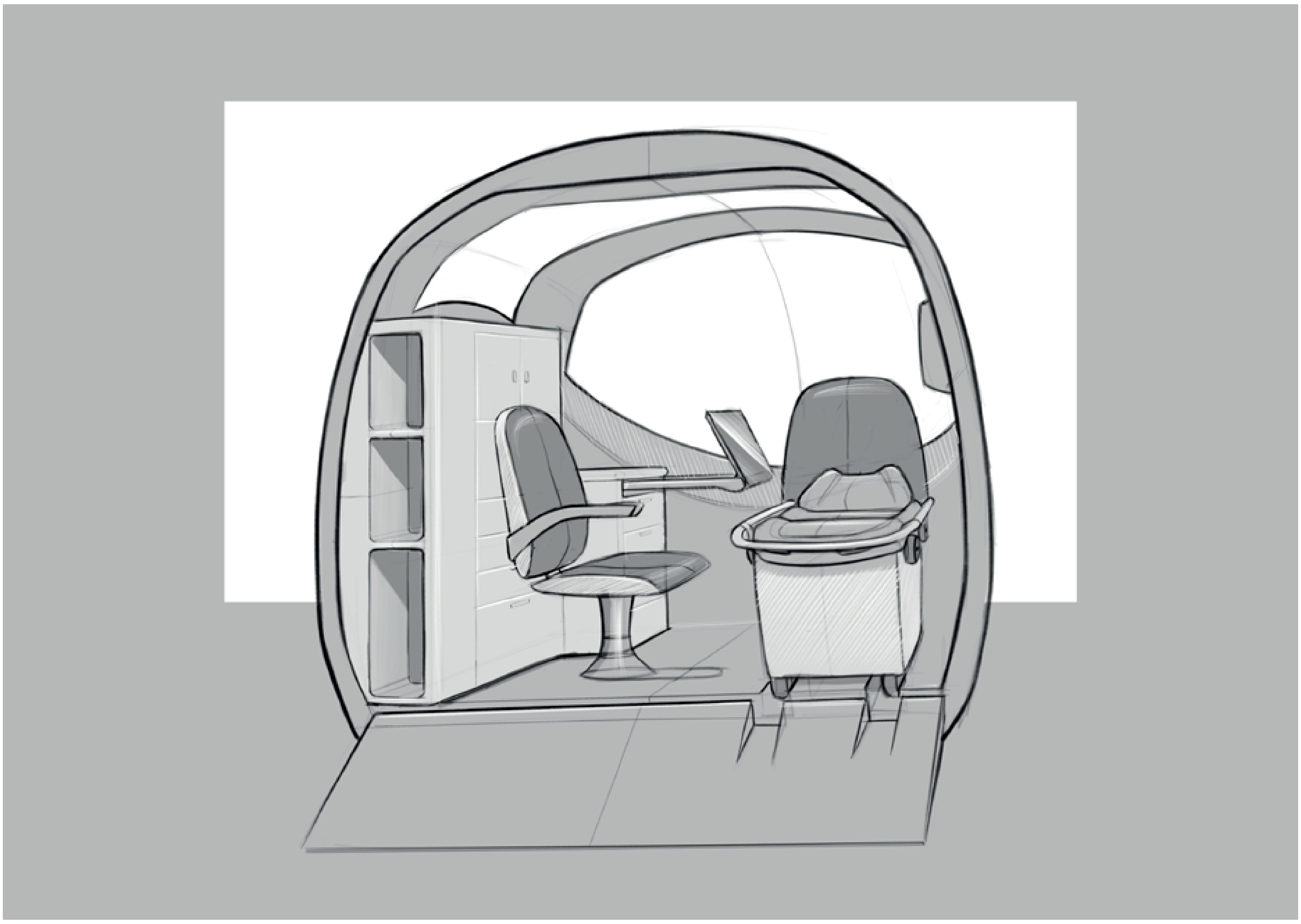
The exterior design has an emphasis on softness and friendliness. It features soft and simple curves with a wrap-around landing gear, which gives it a planted impression.

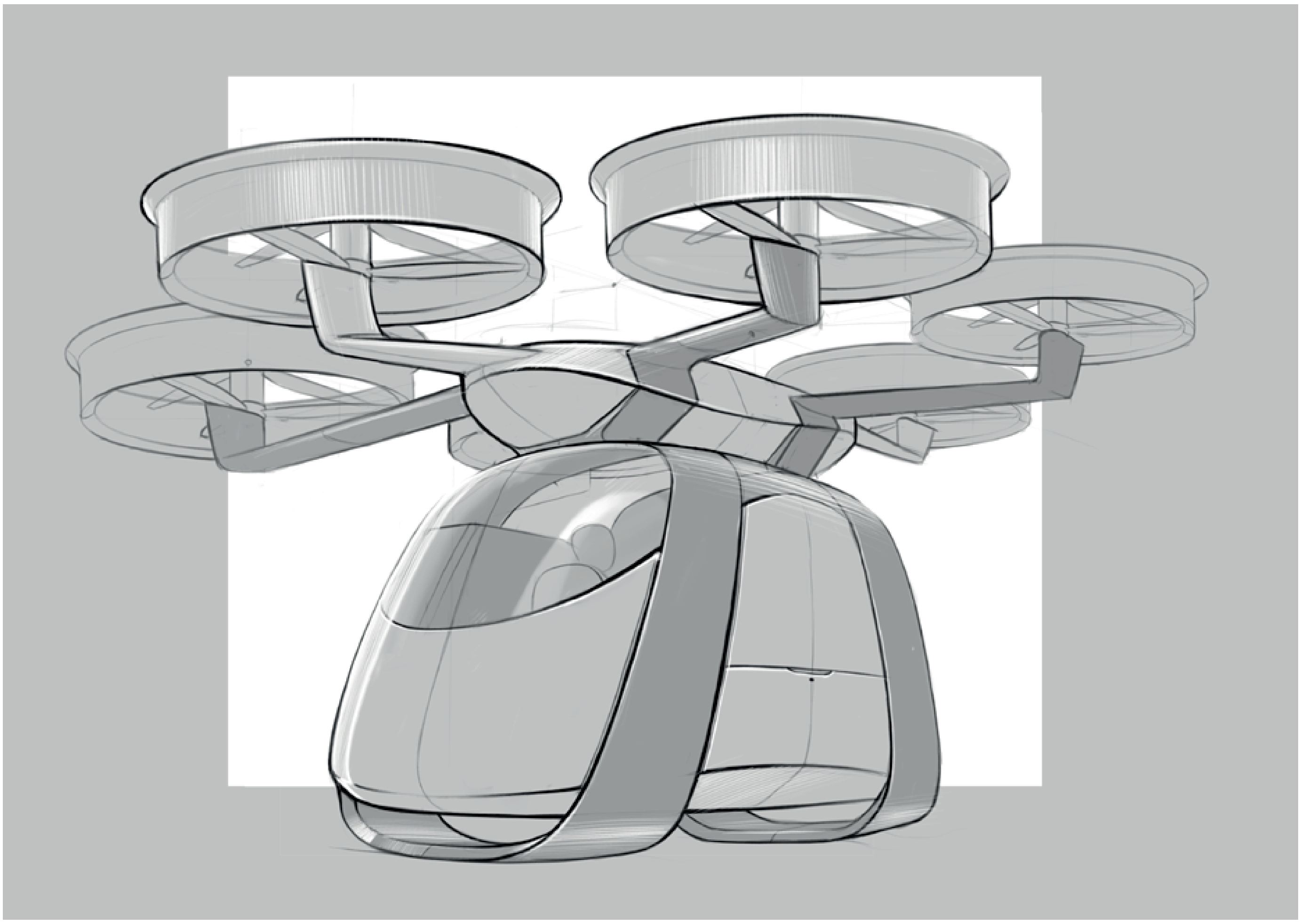
The windows are deliberately placed higher around where the patient lies, adding privacy. The exterior is completely symmetrical, because the drone can fly in any direction and orientation.

The dimensions of the cabin are approximately 4 meters long by 2 meters wide.









7.3 CONCEPT 2

This concept evolved from the VR sketch that is shown below. What makes this layout stand out is that the patient is at very centre of the interior, with the stretcher placed across the width of the aircraft. This creates space on both sides or the patient where the medical professionals can sit and move freely from side to side along the entire body of the patient.

Interior

Storage is symmetrically placed on either side of the patient in what could be considered the nose and the tail-end of the aircraft. The storage spaces are placed low in order to keep the field of view of the patient as clutterfree as possible.

Loading the stretcher via a side door has the advantage of creating a really large entrance, which creates a lot of space to move.

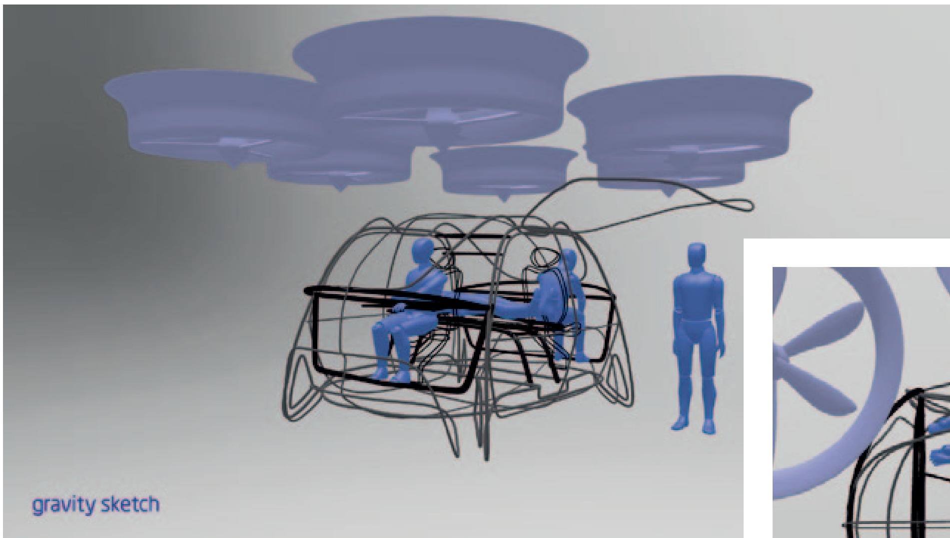
The stretcher also features the modular storage compartments underneath, like in concept 1.

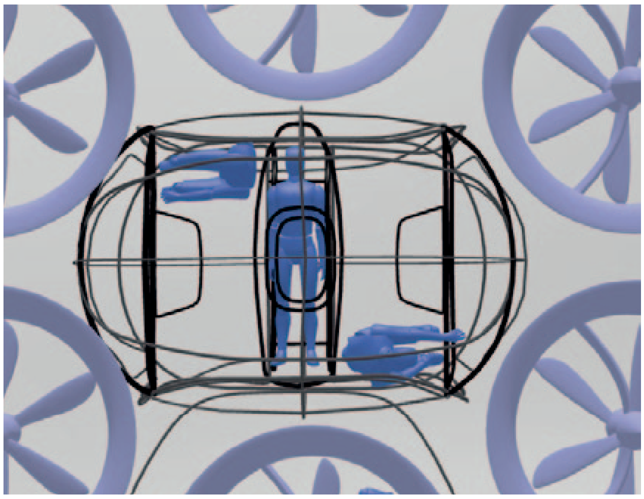
Rotors

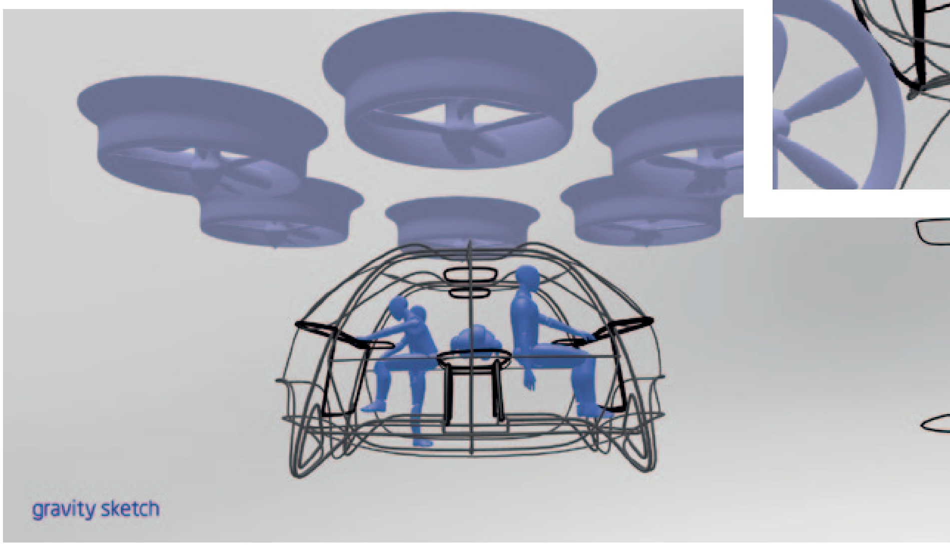
Like in concept 1, the rotors have been placed on top for stability and safety purposes and are connected to the rotor “tree”, which provides space for the hardware components. The rotors also feature ducts for the same reasons as mentioned in concept 1.

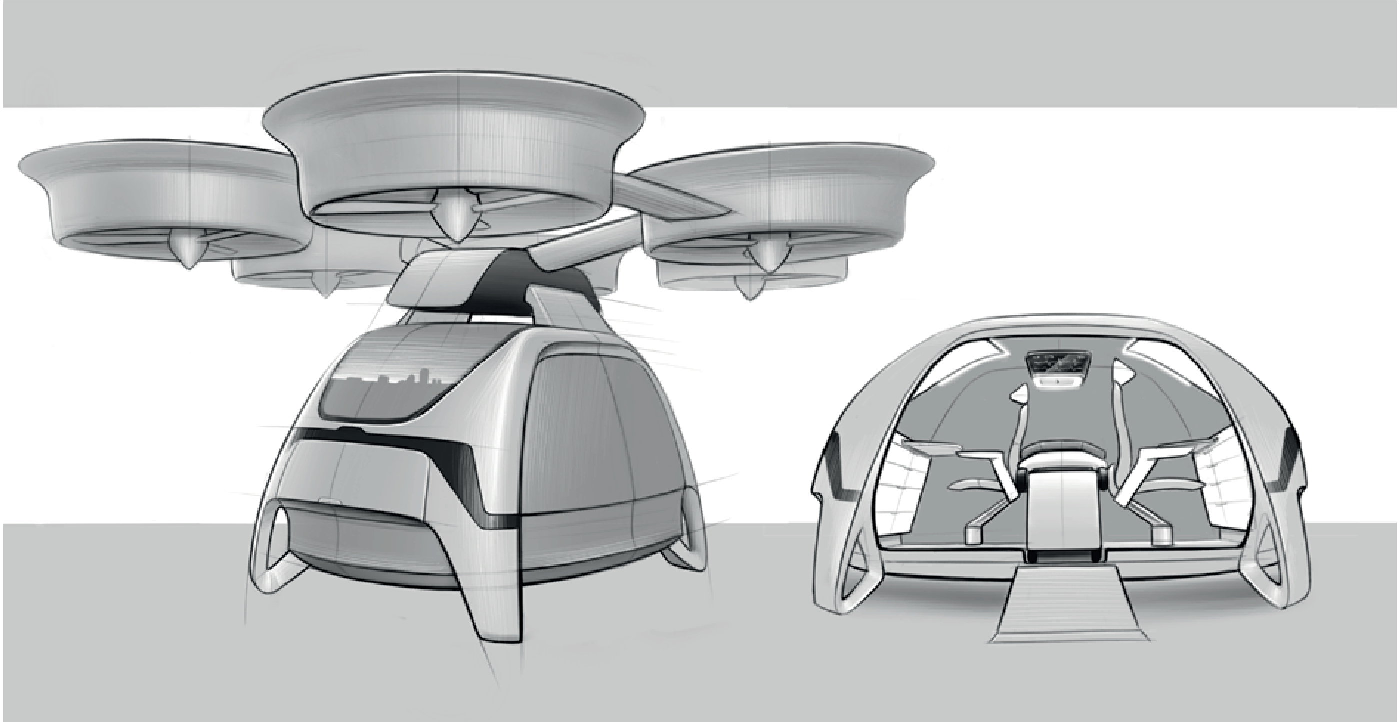
Exterior

The aircraft stands on four legs, which gives it a sense of stability. The design is completely symmetrical, because the aircraft can fly in any direction. The cabin is around 4 meters long and 260 centimeters wide.



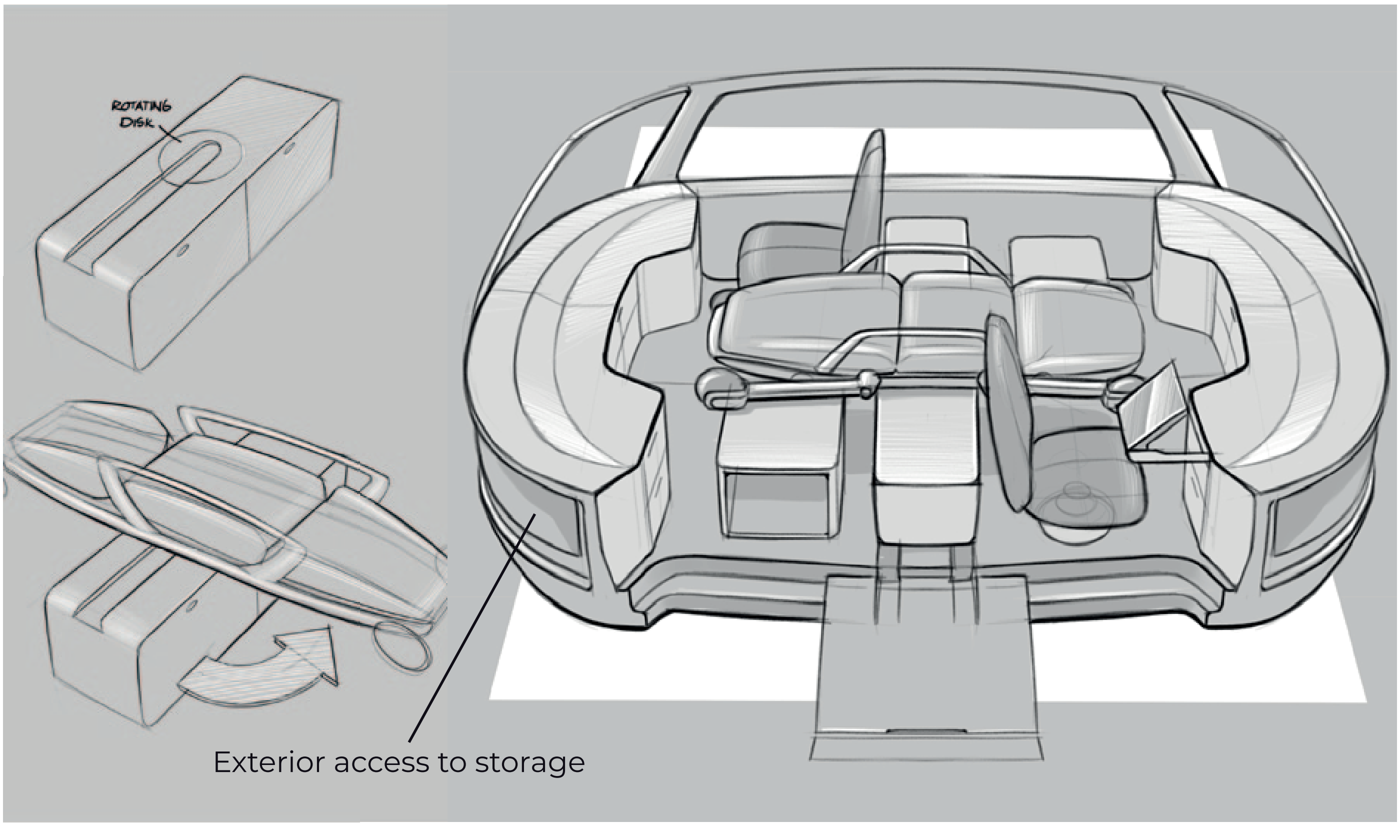






The sketch below is a variation of the initial interior (above), where the stretcher has been fitted with a pivot point, allowing the patient to be rotated 90 degrees. This makes the head and feet more accessible, a shortcoming that was a concern in the original interior.

The sketch below also shows that part of the storage units at either side are accessible from outside, which is for easily retrieving equipment that is mostly used outside of the aircraft.



7.4 CONCEPT 3

Like the previous concepts, this concept was based on one of the VR sketches, as can be seen below.

Interior

The interior of this concept is based around maximising the use of space. Similarly to concept 2, there is exterior storage space on both ends of the aircrafts. Like concept 1, the interior storage units are placed on the wall opposite the stretcher. It features drawers and shelves.

The stretcher is a similar design as in the other two concepts.

The chairs of the medical staff are placed on rails in the floor, which allows them to move along the side and head of the patient. This allows them to reach all storage and equipment from a seated position.

Above the patient is a unit that displays the monitor data. This unit also has built in lighting and hooks for attaching drip bags.

Putting the entrance to the aircraft on the side where the stretcher sits is optimal for maximizing usable space inside the cabin. This is because the wall next to the stretcher can not be used for storage anyway.

Rotors

Like in concept 1 and 2, the ducted rotors have been placed on top for stability and safety purposes and are connected to to the rotor tree, which provides space for the allocation of hardware components.

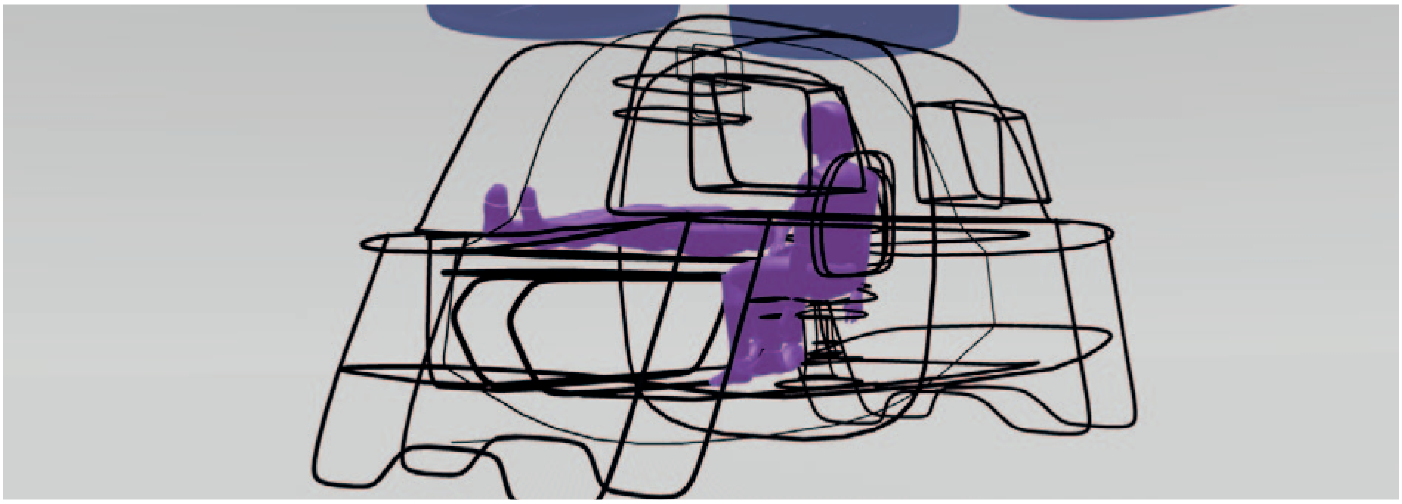
Exterior

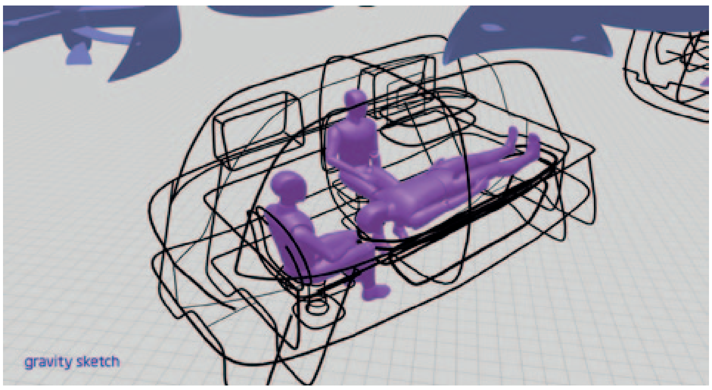
The exterior storage units on both sides protrude, creating the distinctive body shape. This is also a convenient placement, putting the equipment at a comfortable height to grab it.

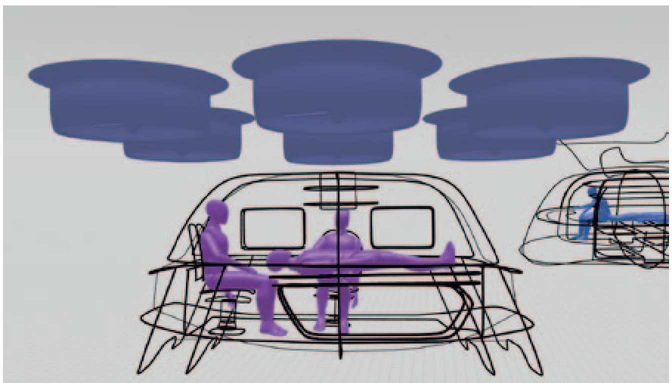
The exterior shape of this concept is more angular than the previous concepts, which gives it a more serious appearance.

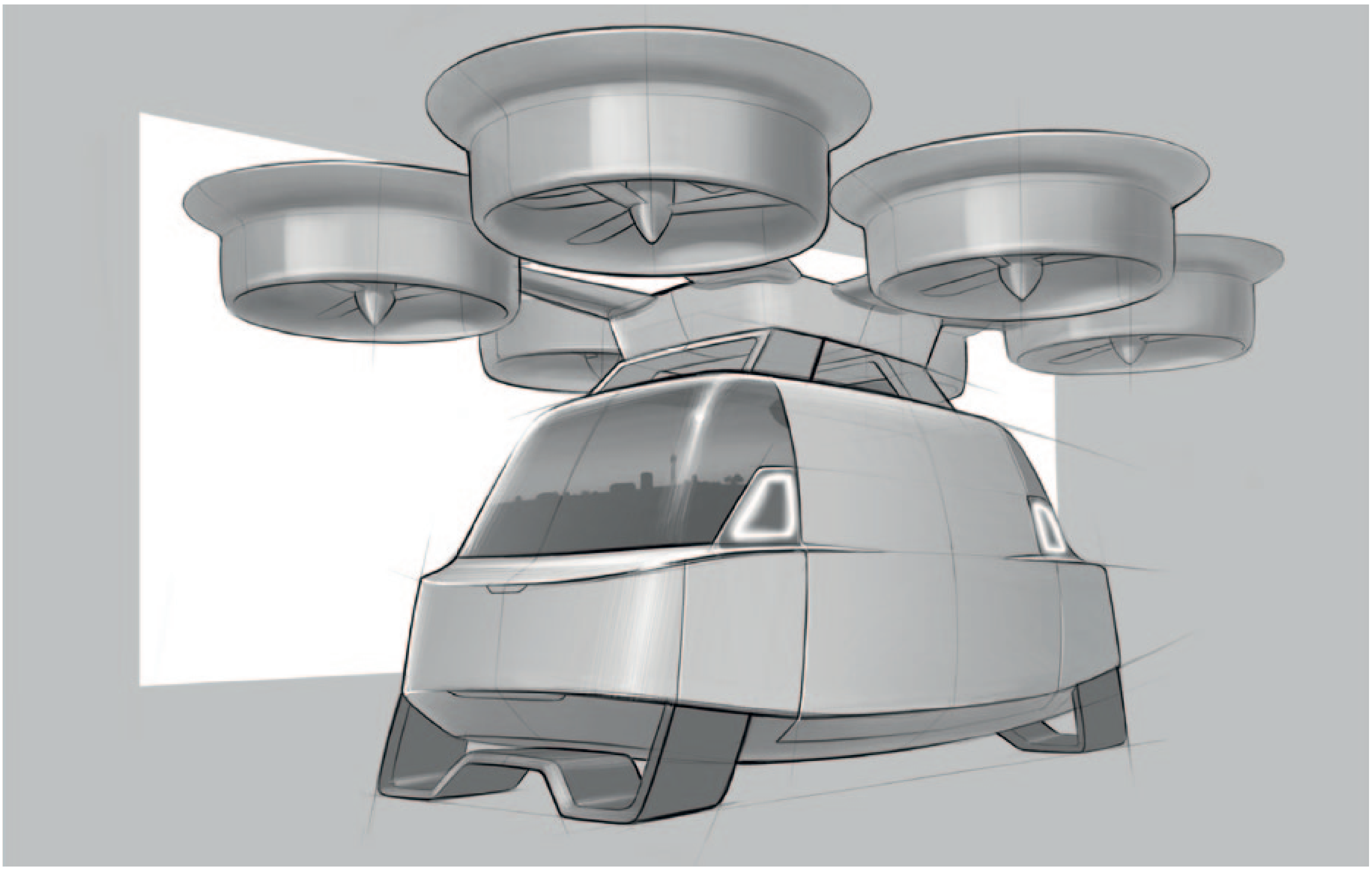
The landing gear is fixed, which is a simpler and less failure sensitive option compared to a retractable landing gear.

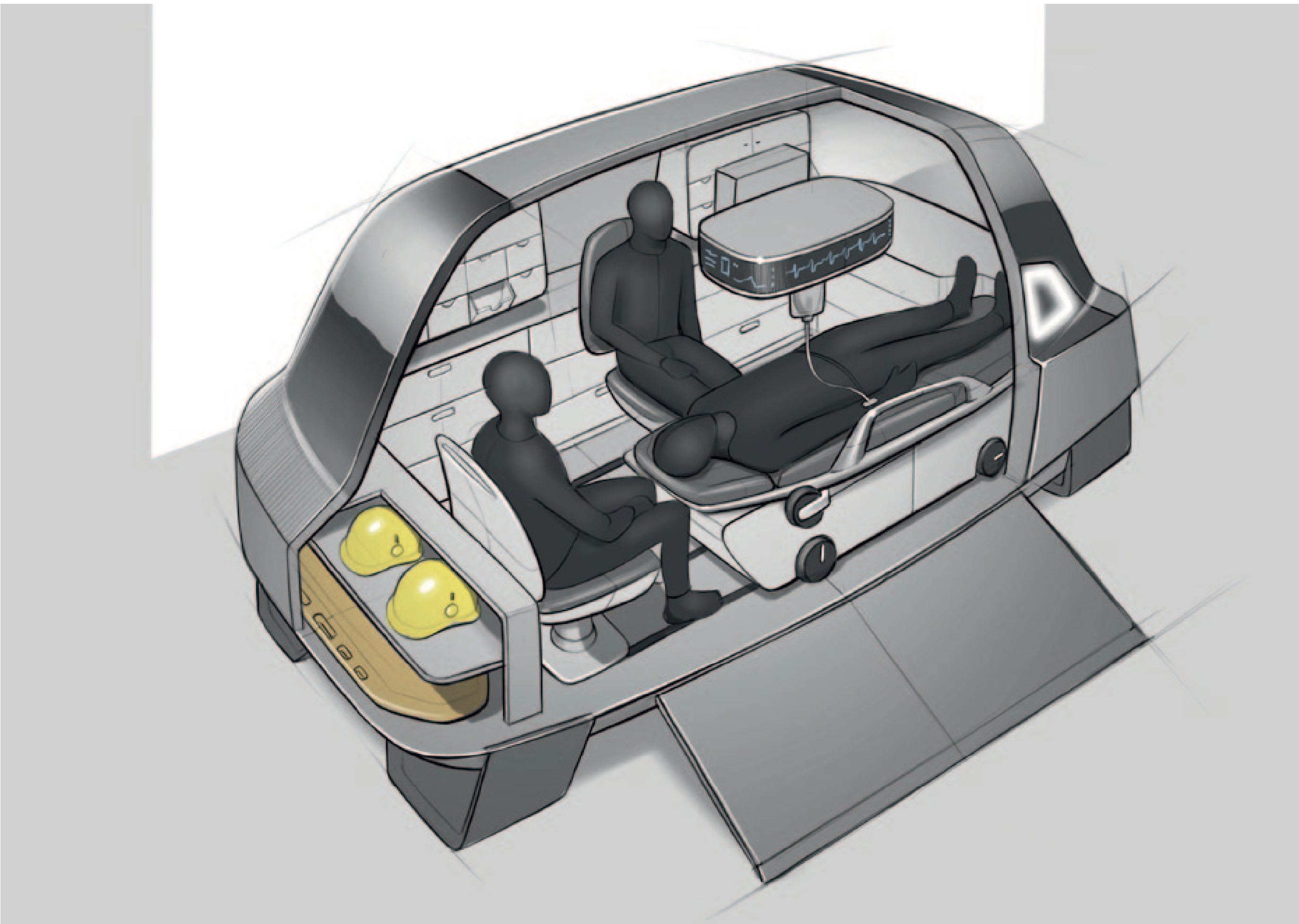
The dimensions of the cabin are approximately 4,4 meters long by 2,4 meters wide.











7.5 DESIGN CONSIDERATIONS

Having explained the three concepts, it is time to select elements of each concept and combine them into the final concept. The obvious guideline for this selection is the program of requirements, so in the next section the three concepts are evaluated based on the POR.

In this paragraph an overview is provided of all the insights and considerations that influence the selection and creation of the final concept.

7.5.1 Evaluation of Program of Requirements

In Appendix F, the program of requirements has been evaluated based on each concept's performance. This provides a first impression of the qualities, limitations and opportunities of each concept. The selection makes a distinction between a requirement and a wish. When a requirement has not been met, the concept cannot pass the selection in its current state. The concept that has met the most wishes is the preferred option, granted they have passed all requirements.

Concept 1's simplicity allows it to meet all requirements, but it lacks in areas such as flexibility and space. Access to the far side of the patient's body is limited, similar to current ambulance vans. The interior is fixed and cannot be rearranged or adapted.

Concept 2's interior layout provides a superior seating position for the staff, but is therefore also a lot less compact, causing the aircraft to become too wide. It fails to meet the maximum width requirement of 250 cm. Making the layout fit within the width requirement would alter it too much, causing the concept to lose its value.

Concept 3 has some of concept 1's simplicity and thus also lacks in the flexibility of the interior. On the other side, it has a lot of opportunities to combat these issues by altering the interior layout slightly. In terms of the exterior it provides the most benefit, because there are several exterior storage units, placed conveniently around the aircraft.
Concept 3 fails to meet one requirement, namely that of convenient unloading of the stretcher. This is because the concept features a side door, which causes the stretcher to tilt at an awkward angle when loading it into the aircraft. A rear door, like in concept 1, would solve this issue.

7.5.2 Input from experts

In order to get a better idea what the final design should look like beyond just the program of requirements, a number of experts were consulted from the fields of aviation and acute healthcare. They provided feedback based on the three concepts and the project in general. Below is a selection of important insights that were of direct influence on the final design. For all the insights see appendix G.

The following experts were consulted:
- Jaap Hatenboer: Innovation manager UMCG Groningen
- Sabino Valentino: ZERO-G Design – Aviation and transportation design consultancy
- Christoper Courtin: MIT - Department of Aeronautics and Astronautics
- Alexandra Slabutu: United Rotorcraft
- Frank Latour: Ambulance Helicopter Nurse

Jaap Hatenboer: **It is important to consider the use case of the drone in relationship to how it is equipped. Smaller, wingless multicopters would be suitable for shorter response times, as they do not need to provide much treatment during flight and so less equipment is needed onboard. This is a lot like Medical Evacuation, where the main goal is to get the patient to a safe location with better facilities for treatment. Generally these patients do not have acute life-threatening injuries. For longer range flights, where healthcare facilities are not closeby, larger, winged eVTOL's would be the best suited, as it basically becomes a flying emergency room where treatment can be performed during transit.**

Looking at The Netherlands, short ranged flights would be the most common, given the size of the country. Long range drones would be useful for extreme and less frequent situations in which a person needs to be saved from a remote area with no healthcare facilities nearby. Long range drones would certainly not be suitable for urban environments, which is a considerable downside and rules out a lot of other use cases. The best solution lies somewhere in between; a wingless drone that can be equipped to perform common procedures (like the current ambulance van), but can also be stripped down into a simpler version with minimal equipment for very short range flights. This way the drone can be adapted for most urban missions (short range with plenty of healthcare facilities nearby) and for most rural missions (medium range with fewer healthcare facilities). This also points to the need for modularity in the design of the ambulance drone.

Jaap Hatenboer, Alexandra Slabutu: **There is an increased focus on modularity in the design of the interior of ambulance helicopters today. Placing and removing equipment and storage is necessary to adapt to varying situations. A general rule is that simple solutions make an interior much easier to certify. Try to find the balance between adaptability and complexity.**

It is clear that there is a large need for flexibility in the interior of an ambulance, which makes sense given all the different use cases. Some examples are: patients of different ages, sizes, etcetera, a large variety of injuries, different locations of operation, several different primary users (nurses, maintenance, cleaning). So, incorporating modular solution is certainly the best way to cater to all these stakeholders. When designing modular solutions, it is important to maintain ease of use and limit the increase of complexity.

Sabino Valentino: **The rotor tree should preferably be integrated into the roof and the landing gear is best oriented along the length of the aircraft for aerodynamic benefit. Also, the contour of the aircraft is most efficient if it follows the airfoil shape.**

This applies mostly to the exterior design of the drone, which will have to be changed quite drastically compared to the three concepts, because all concepts feature a separate rotor tree and a completely symmetrical body shape.

Frank Latour: **The equipment that the ambulance helicopter team uses is mostly stored in large backpacks that are carried to the patient. These backpacks are heavy and can be a nuisance to take in and out of the helicopter. Also, there are many instances in which not all of the equipment is needed that is inside the backpack.**

This feedback again ties into adaptability and modular solutions, also stipulating the importance of “last mile” transportation solutions. This points in the direction of a stretcher with some sort of storage facility.

Sabin Valentino, Christopher Courtin: **The best bet in determining the size and weight of batteries, payload and total weight is to use an existing eVTOL as a basis (like the CityAirbus) and use weight fractions (e.g. W_payload/W_total). Scale these factors to the desired amount for the ambulance drone and use these weight fractions to see what the weight of each of the elements will become. Of course this only holds true for the same range and speed.**

To estimate the total weight of the new configuration, keep the same weight fractions and scale based on the payload. That will give you a reasonable first estimate, assuming the cruise speeds, ranges and battery specific energies are the same.
The power density of hydrogen fuel cells is at present quite low. There is also a delay in power output, making it a less responsive system than batteries.

With the premise the batteries for EV are different from those for VTOL, we can foresee the following variation from today towards the future:
- **Today: 250-350 Wh/kg**
- **In 5 years: 500-600 Wh/kg**
- **In 10 years: 700-750 Wh/kg.**

Determining the technical performance and battery size for an ambulance drone in 2035 is one of the major challenges of this project. It is therefore essential to use educated guesses based on information from experts. Thankfully these experts were willing to provide their estimates, which were used to compute a performance overview for the final design of the ambulance drone in the next chapter.

7.6 CONCEPT SELECTION

Having evaluated the three concepts based on the program of requirements and having collected feedback from experts, a few clear focus areas have arisen:

Modularity and adaptability
One of the major insights is the need for modular solutions, as such this needs to form one of the most important bases for the final design. Modularity allows the drone to be adapted for use cases in different environments, such as urban and rural areas. It also allows the onboard staff to create their preferred setup. Lastly, it caters to the needs of secondary users, such as maintenance workers and cleaners. This is because a modular interior is easier to take apart, clean and replace/repair.

Simplicity
There are several factors that call for simplicity, such as minimizing weight, reducing visual complexity, optimal user-product interactions and passing certification. This poses a challenge in combination with modularity, as modularity often sacrifices some simplicity.

Technical architecture
The final design will feature an electric propulsion system. Aerodynamics need to be a larger design constraint in the final design, as it plays a big role in achieving the performance requirements.

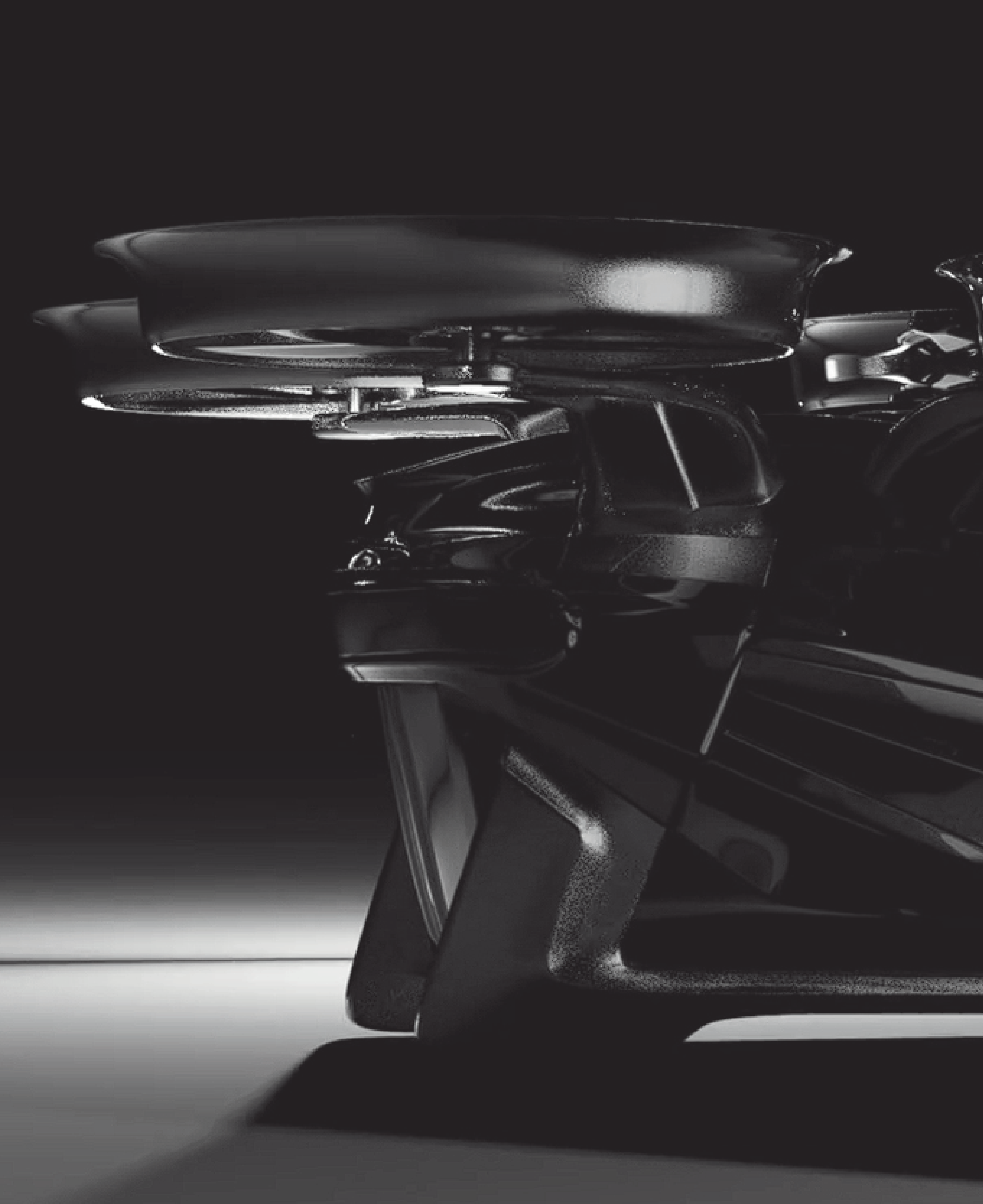
The vision (chapter 4) is also an important part of the final design and there is some clear overlap in the Design Fundamentals that were established in the vision and some of the aforementioned focus areas that have arisen. This is a valuable discovery, as it partly confirms insights gained in the research phase. According to the vision, the final design also needs to perform well in terms of the design fundamental "trust". This means the styling should take into account the perception of the public, users and fit well within its context.

7.6.1 Conclusion

So, with the focus for the final concept clearly established, concept 3 provides the most opportunities as the basis for the final design. It has a great balance between size, amount of storage space and access to the patient. It also has the best integration of exterior storage. It still lacks in terms of modular solutions, as the interior is mostly made up of fixed storage spaces. Loading the stretcher from the side of the drone is also not ideal. Lastly, it does not perform well from an aerodynamic point of view.

The final concept also needs to be adapted to incorporate modularity. The good thing is that this concept is more suitable for this than concept 2, as that is very restricted by the sideway position of the stretcher, which affects the size of the drone too much and limits useable space for equipment. Concept 1 is also a good inspiration for the final design, as it is on the simpler side of the spectrum. It has a very simple layout with minimal components, which makes the interior look neat and friendly. It can also be adapted for modular elements quite well and has a convenient rear door ramp.

In general, the process towards the final design is very much iterative instead of selective. This means that the concepts mostly function as a basis which, together with the input from experts, is built upon to create the final design. In the next chapter, the final design is developed using all the new insights.



CHAPTER 8
FINAL CONCEPT - AirMedic

8.1 INTRODUCTION

In this chapter the process of establishing the final design is explained. It is structured around the five Design Challenges as defined in paragraph 4.5, explaining the solutions that have been designed to tackle each of these challenges. For convenience sake, a list of all the design solution present in the final concept can be found under appendix H.

The final concept has been named AirMedic, which it how it is called in the rest of this chapter.

8.2 DESIGN CHALLENGE 1: EFFICIENT “LAST MILE” MOBILITY

The first design challenge is about solving the issues with the trip from the aircraft towards the patient. From the interview with Frank Latour (paragraph 1.4.2), it became clear that having to carry equipment in backpacks is not always ideal.

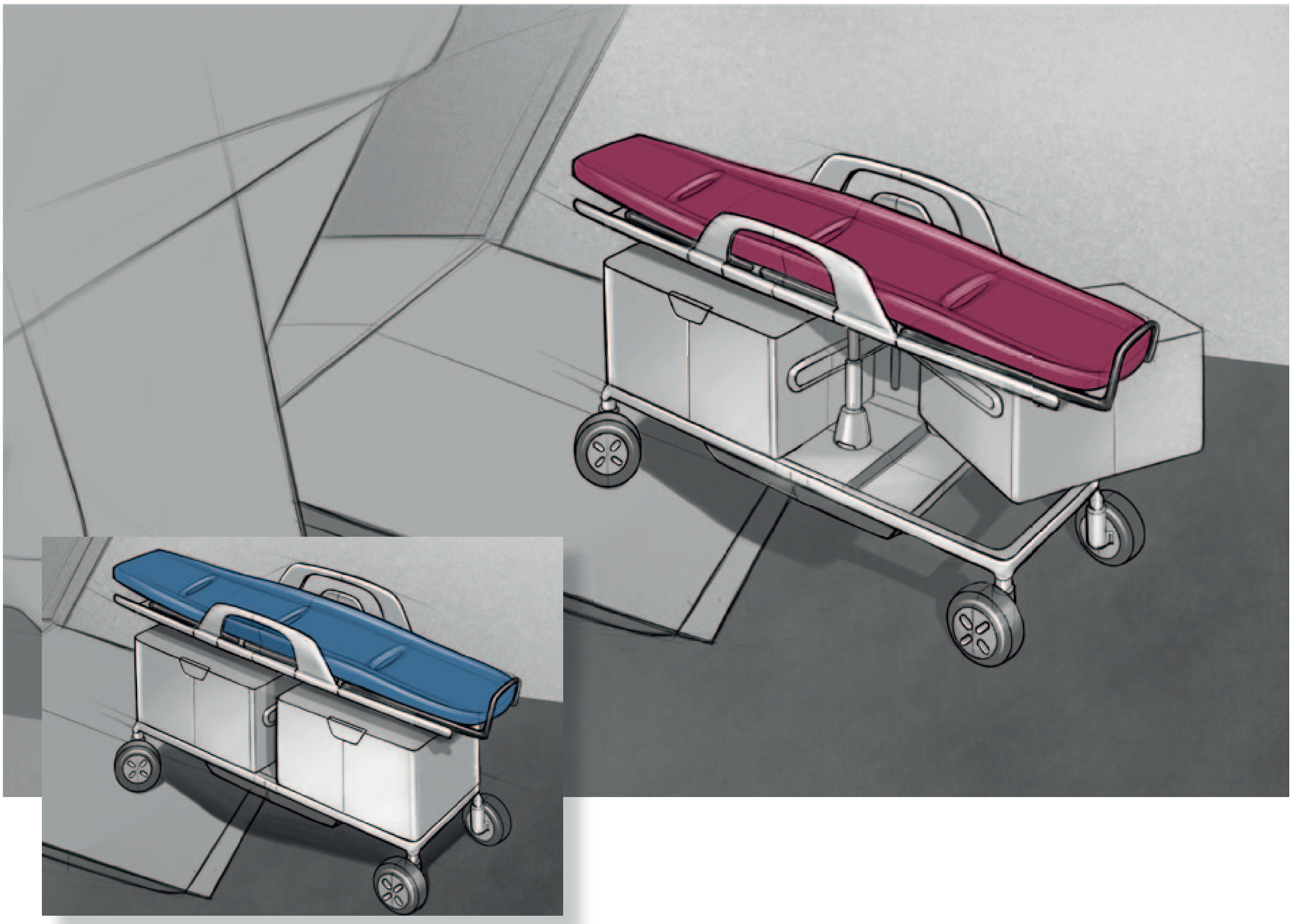
In the ideation phase, the idea for a stretcher with storage units started to take shape.
Having first explored more ambitious solutions in which the drone itself would be able to drive to the patient, it was decided a simpler solution was needed. The stretcher was a clear opportunity, as it is one of the most important pieces of equipment in the AirMedic. It has wheels and it has a lot of vacant space that could be used for storage.

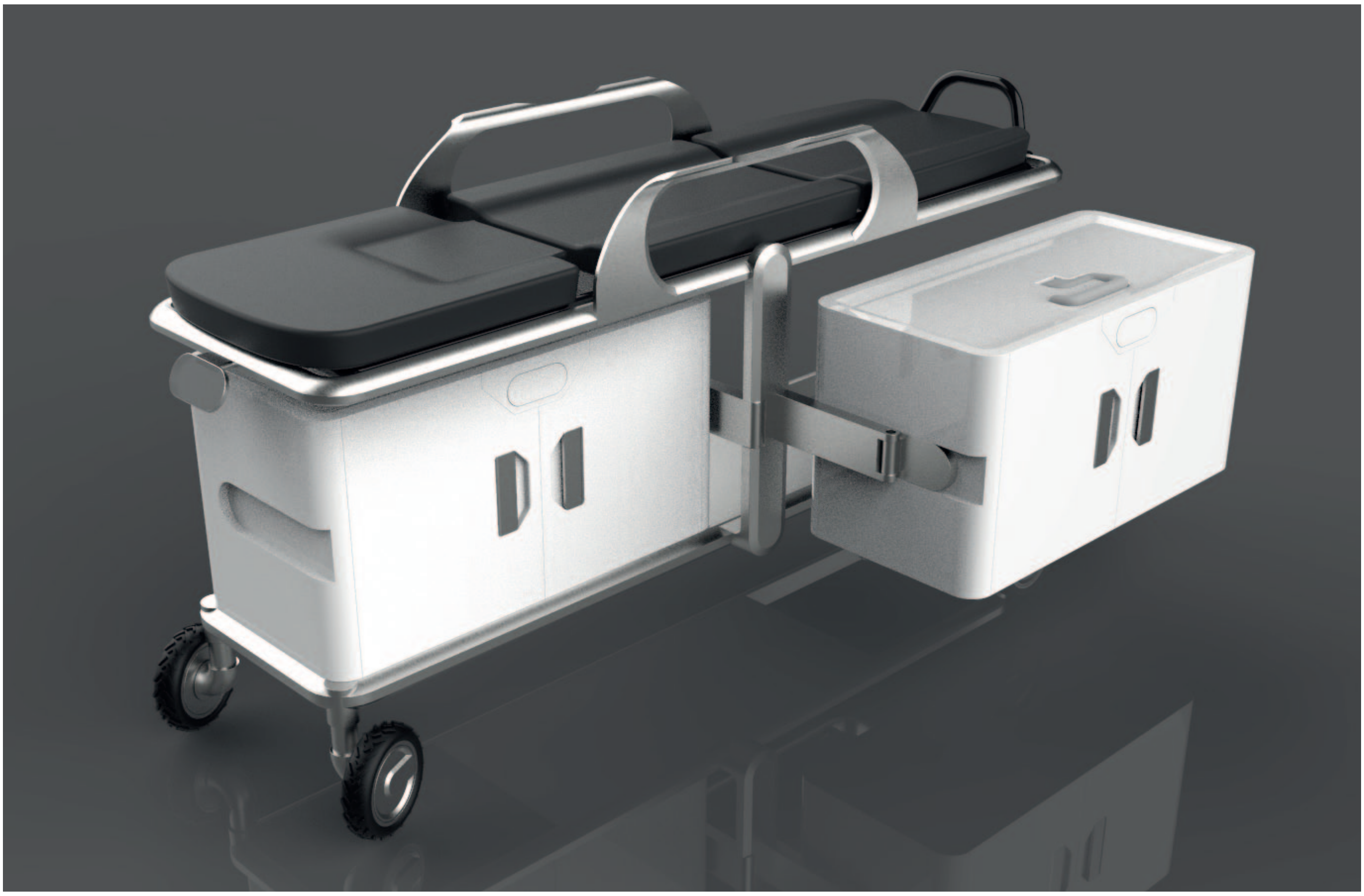
Trying to figure out which way the storage units should be attached to the stretcher was the biggest challenge, because the stretcher also needs to adjust in several ways. This means that the storage units need to be moved aside or be taken off in order to enable the other functions of the stretcher.

How this was achieved in the final design of the stretcher is explained in this paragraph.

1. STRETCHER DESIGN - The design below was made after several iterations for the stretcher design during the ideation phase. These can be found in the ideation “family tree” of chapter 8.

Based on this, a CAD model was made in SolidWorks, which can be seen in the rest of the visuals of this section.





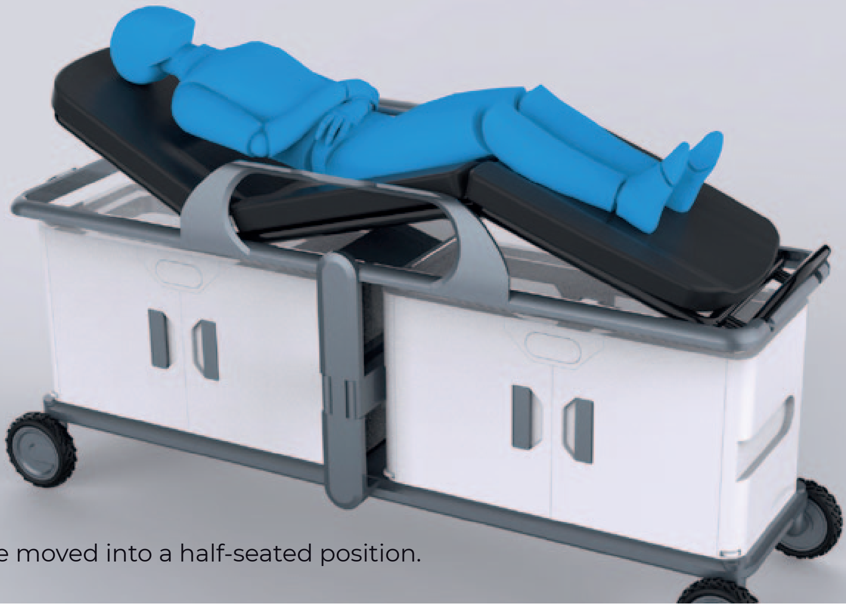
**2. STORAGE UNITS - ** The storage units move sideways with a double hinged arm, placing them along the side of the stretcher. This frees the space underneath the bed, so it can be lowered or raised.

The storage units can also be taken off completely, turning it into a lightweight stretcher that can be maneuvered more easily. The wheels are large and have all-terrain tyres for different kinds of surfaces.

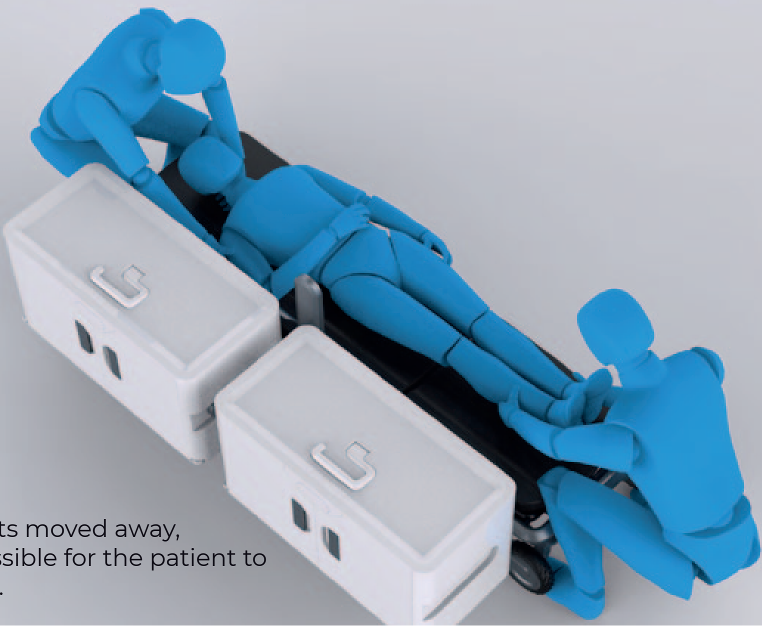
These images are from an emergency services practice, not a real accident.

3. ADJUSTABILITY

The stretcher is remote controlled; no pushing required.



The bed can be moved into a half-seated position.

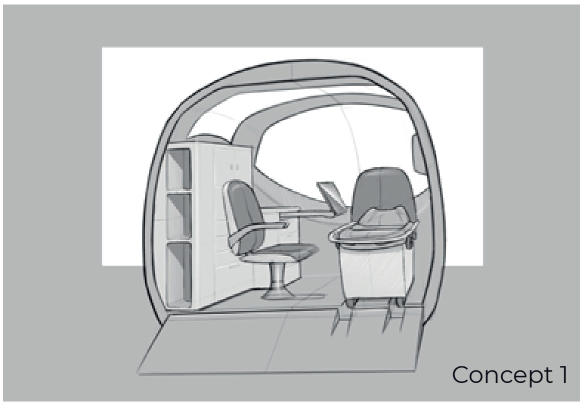


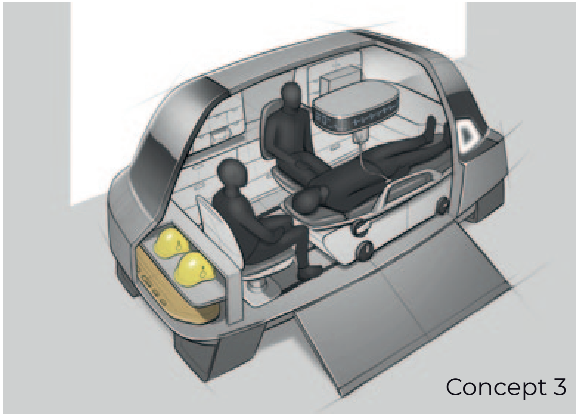
With the storage units moved away, the stretcher is accessible for the patient to be positioned onto it.

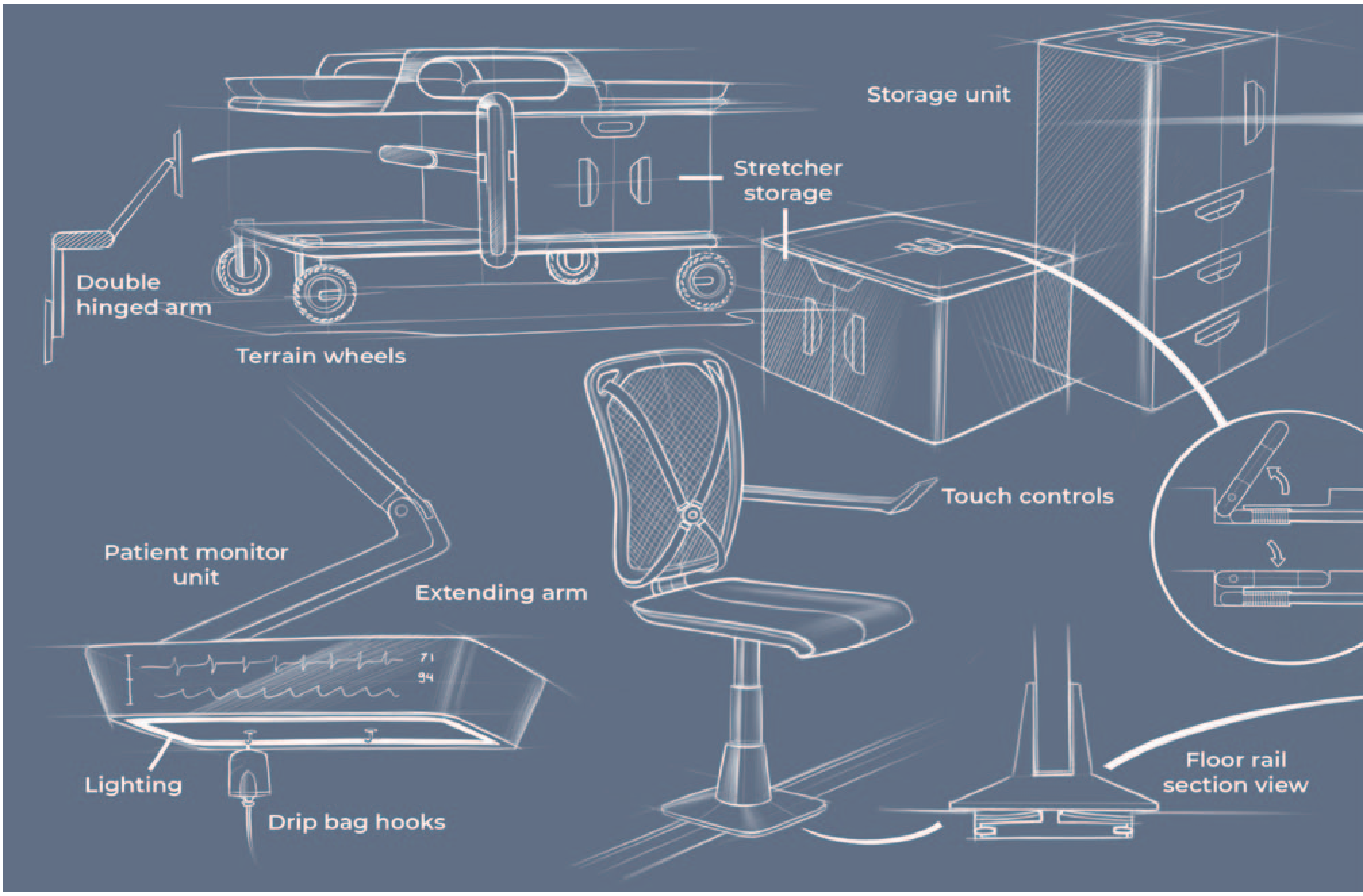
8.3 DESIGN CHALLENGE 2: INTERIOR LAYOUT FOR EFFICIENT WORKFLOW

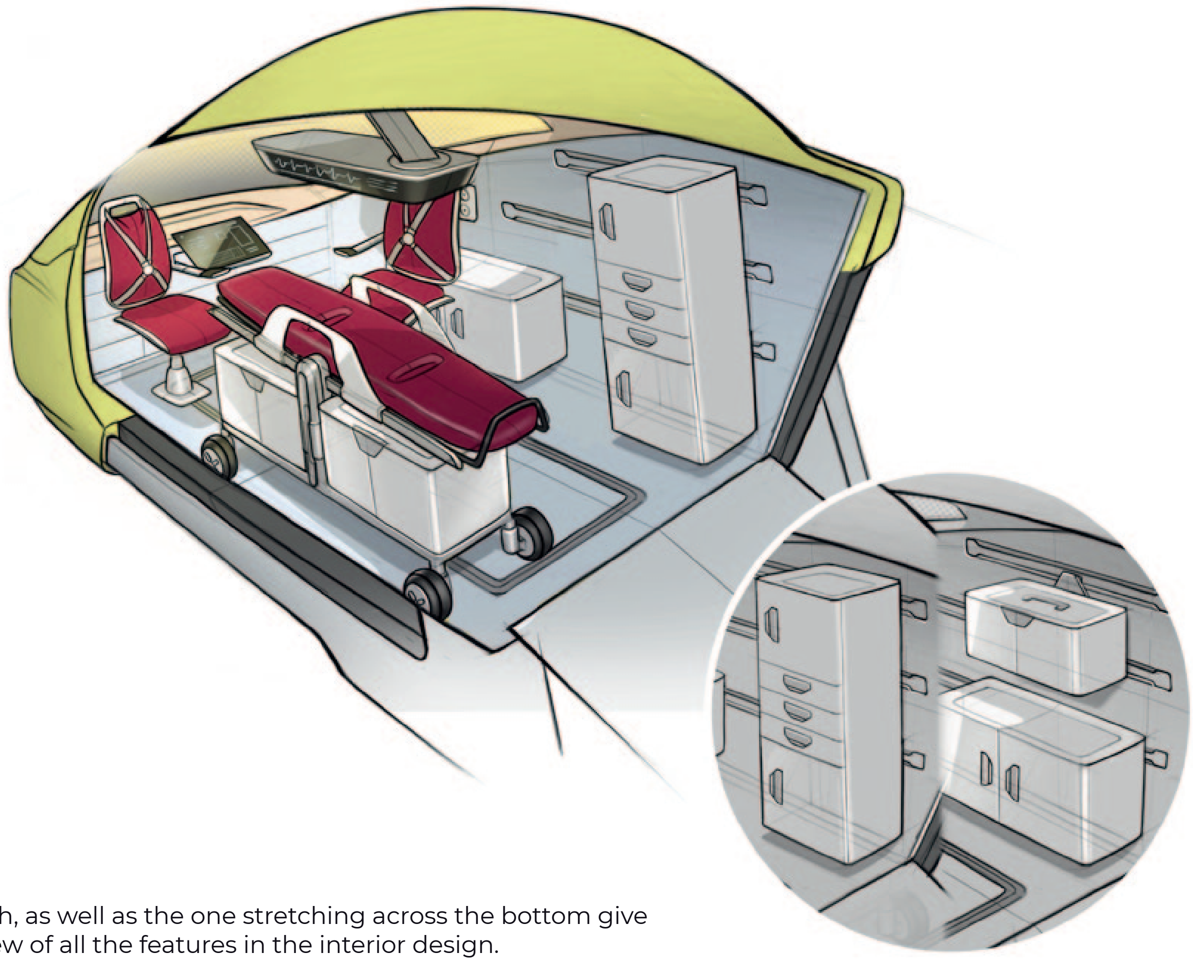
The interior layout is the most important part of the design of AirMedic.
This is because one of the ambulance drone's main benefits is having the freedom to design it for its purpose of treating and transporting patients, from the ground up. So it made sense to design the AirMedic from inside out, starting with the interior.

1. BASED ON CONCEPT 1 & 3 - The interior design was based on concept 1 and 3 and adjusted based on the feedback from experts (paragraph 7.5.2). This means modularity became a major focus point. What was carried over from the interiors of concept 1 was the general layout, with the stretcher on one side and the storage units on the other side. The rear loading ramp was also carried over from this concept. In general this interior layout is simple and compact. From concept 3 the exterior storage unit on the front of the drone was taken, as well as the monitor unit above the patient. The chairs on rails in concept 3 have also been encorporated in the final design.

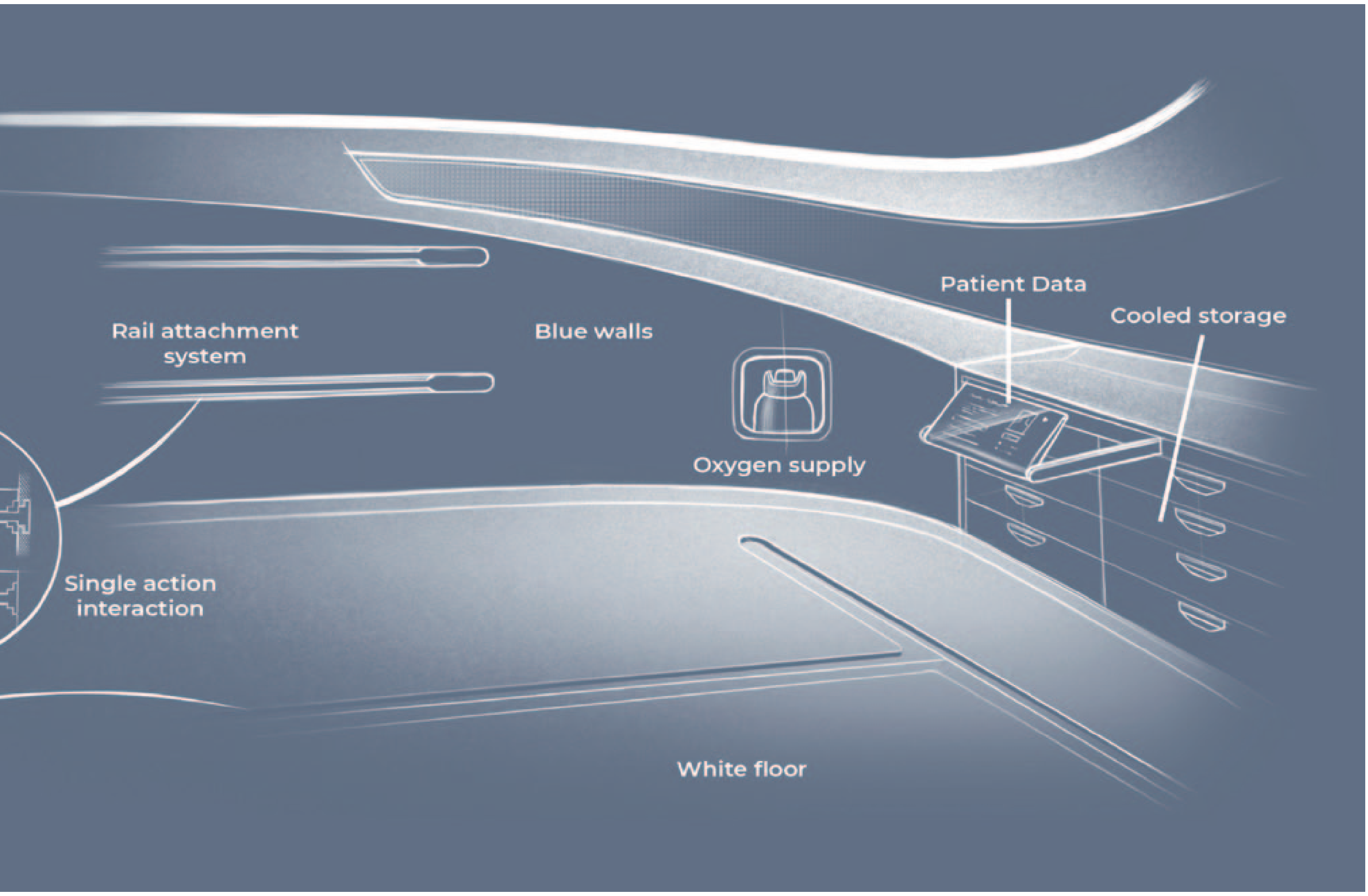

Concept 1


Concept 3

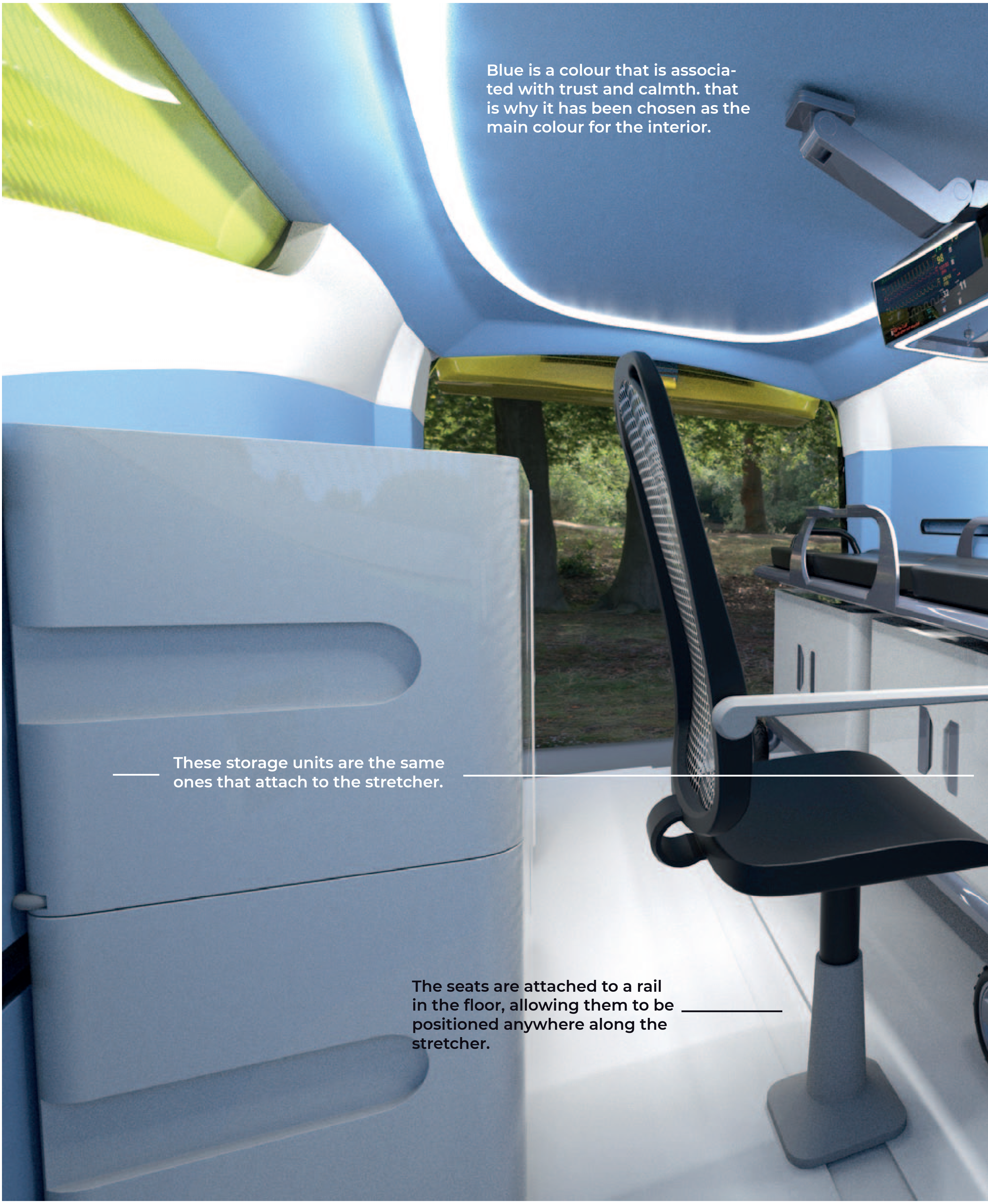


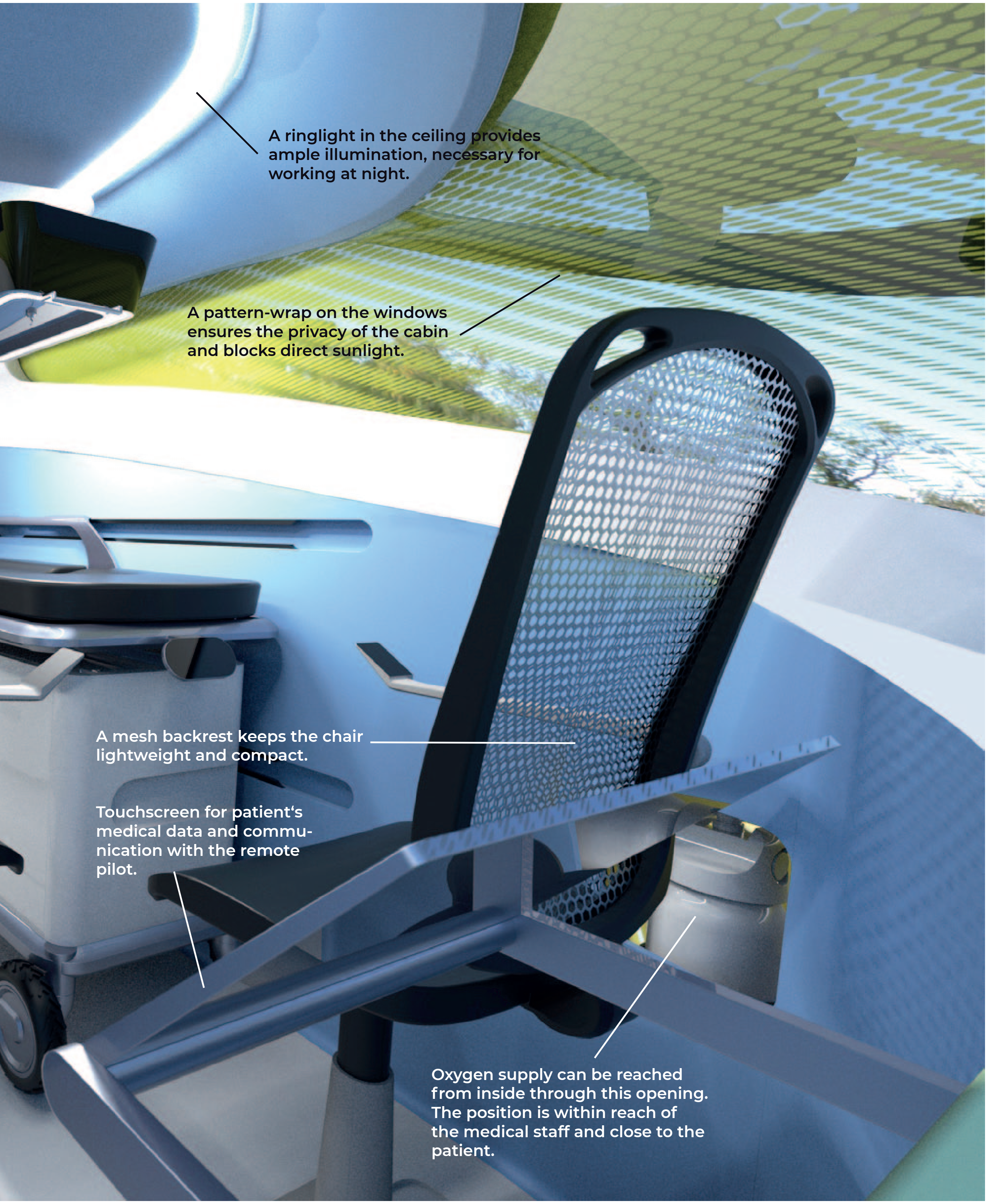


This sketch, as well as the one stretching across the bottom give an overview of all the features in the interior design.
In the rest of this paragraph these features are explained in depth.



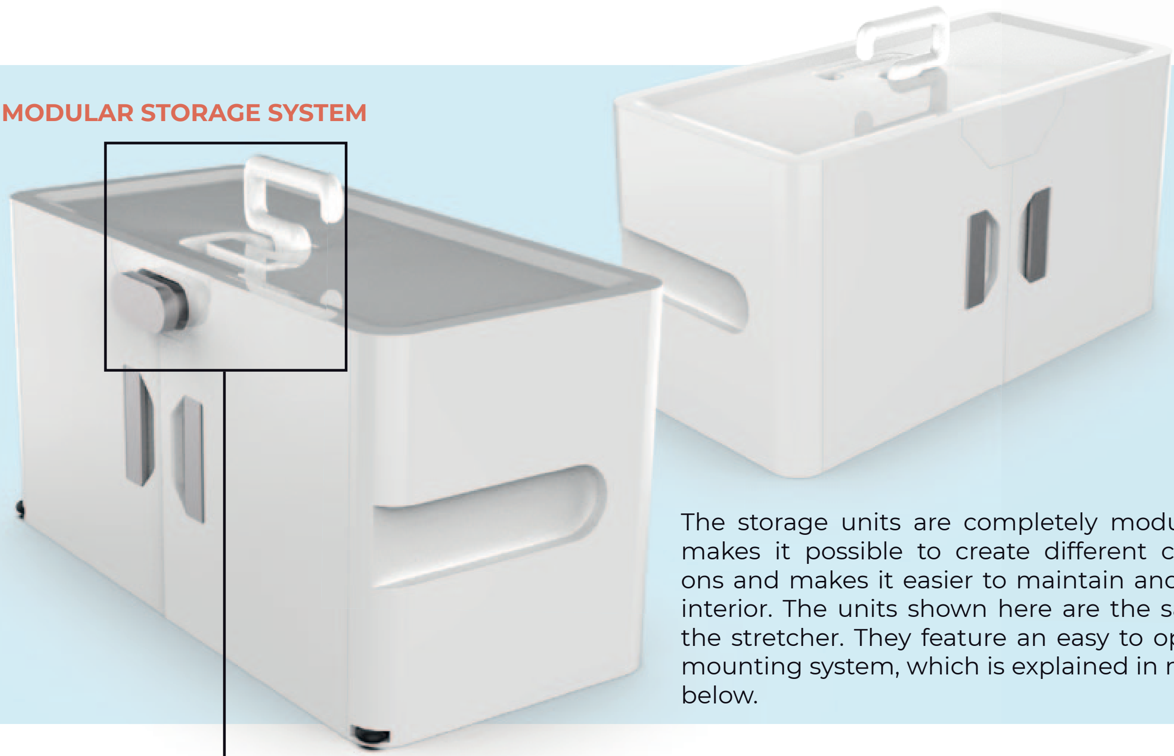
2. THE INTERIOR




A ringlight in the ceiling provides ample illumination, necessary for working at night.
A pattern-wrap on the windows ensures the privacy of the cabin and blocks direct sunlight.
A mesh backrest keeps the chair lightweight and compact.
Touchscreen for patient's medical data and commu-nication with the remote pilot.
Oxygen supply can be reached from inside through this opening. The position is within reach of the medical staff and close to the patient.


Doctor
Wall mounted storage units.
Touchscreen for patient's
medical data.
Refridgerated drawers for drip
bags and blood.
Seats are adjustable in height
and can rotate 360 degrees.

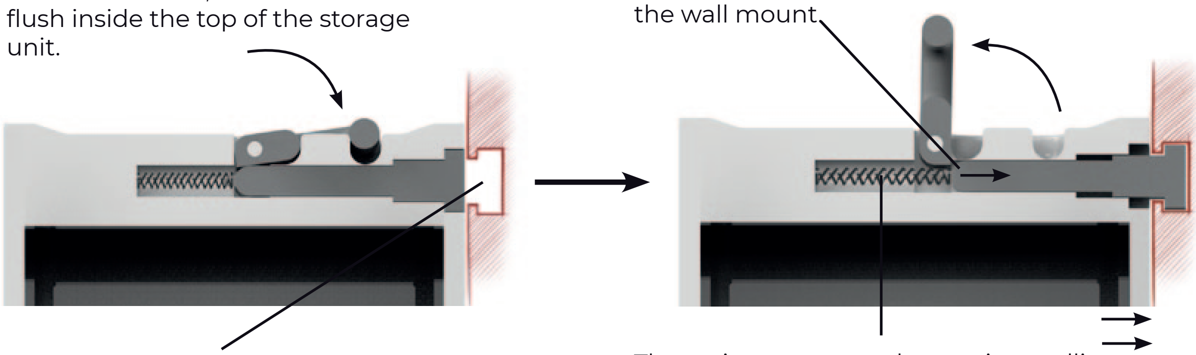
3. MODULAR STORAGE SYSTEM



The storage units are completely modular, which makes it possible to create different configurations and makes it easier to maintain and clean the interior. The units shown here are the same as on the stretcher. They feature an easy to operate wall mounting system, which is explained in more detail below.

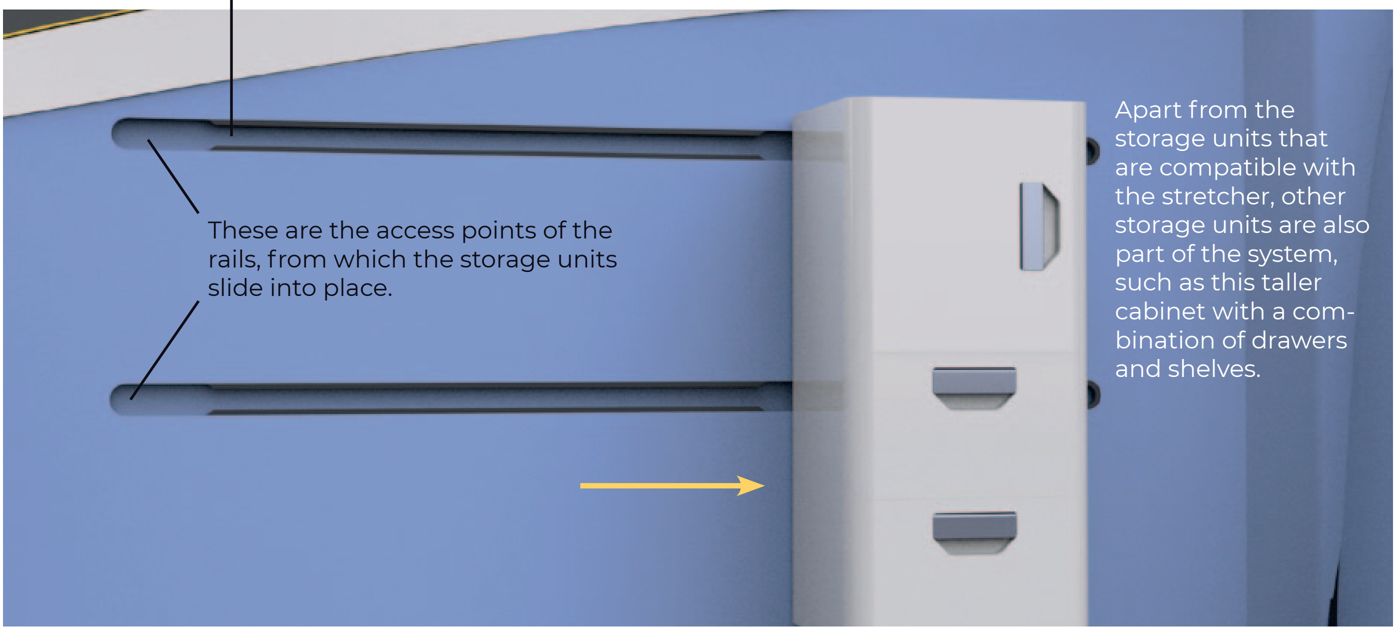
When not in use, the handle sits flush inside the top of the storage unit.

Flipping the handle pushes out the wall mount.



Railing in the wall.

The spring comes under tension, pulling the storage unit tight against the wall.

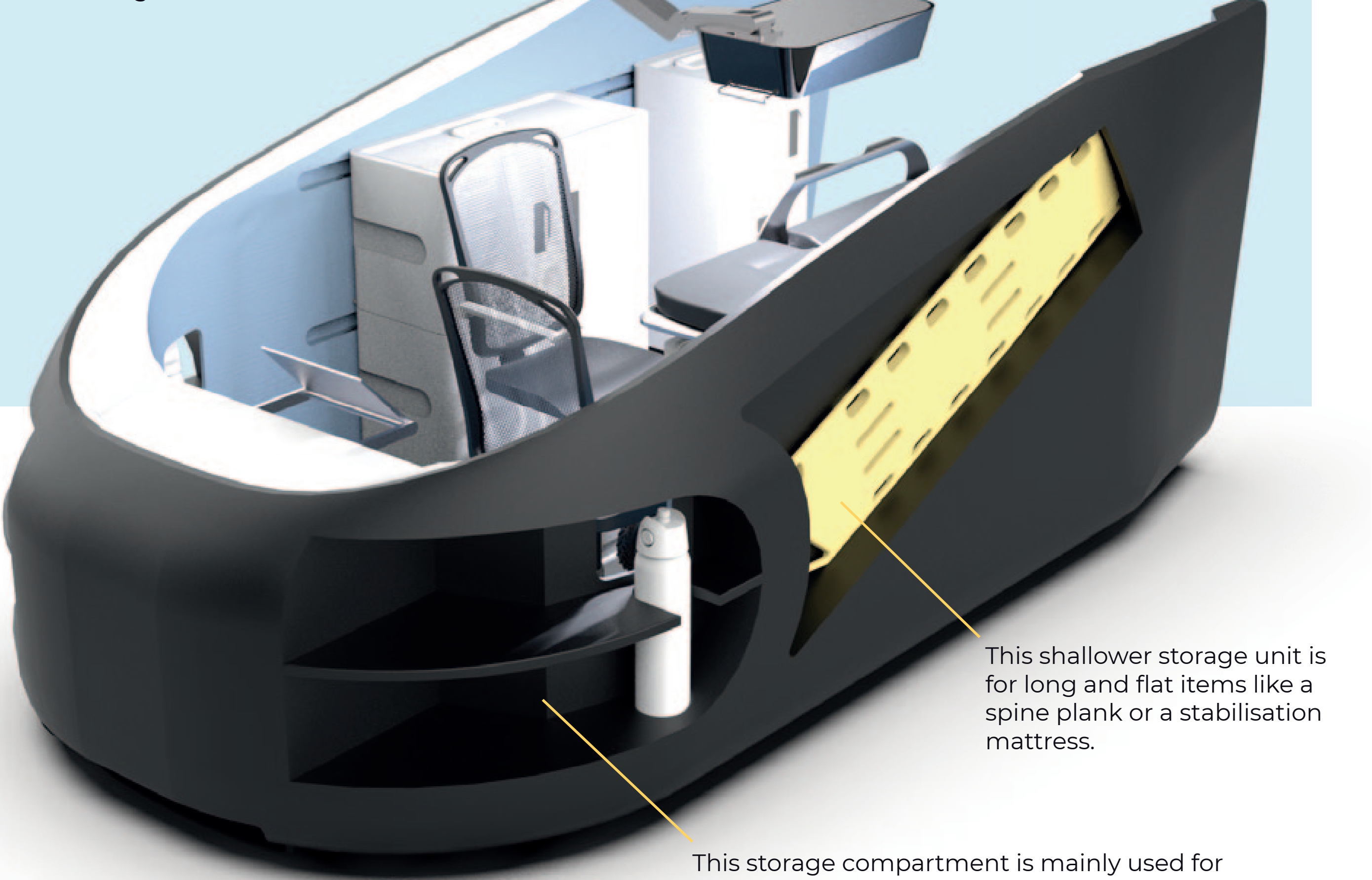


These are the access points of the rails, from which the storage units slide into place.

Apart from the storage units that are compatible with the stretcher, other storage units are also part of the system, such as this taller cabinet with a combination of drawers and shelves.

4. EXTERIOR STORAGE

The image below shows the shell of the interior, basically the chassis of the AirMedic. On both sides there are exterior storage compartments. This makes it easy for the medical staff to extract equipment that is solely used outside, without having to enter the aircraft.



This shallower storage unit is for long and flat items like a spine plank or a stabilisation mattress.

This storage compartment is mainly used for smaller gear, such as face shields, helmets and bags. It also stores the oxygen bottles, which allows it to easily be replaced from outside.

5. MONITOR

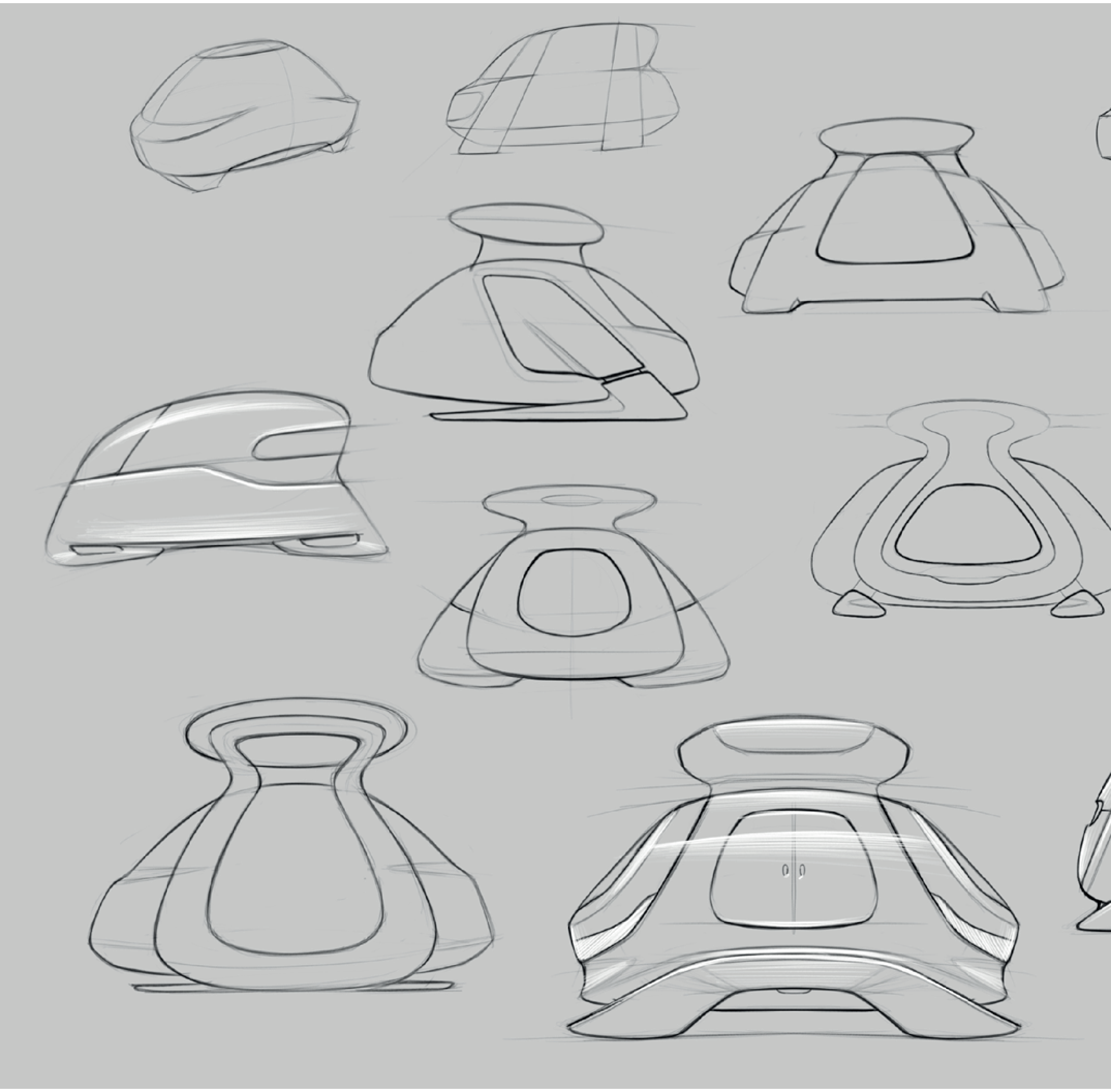
This monitor has an articulating arm, that way it can be raised or lowered and swiveled from side to side. The wrap-around display ensures that the data is visible from all sides. The built in light bar on the bottom turns the monitor into a work light. The bottom of the monitor also has hooks to which drip bags can be attached.

8.4 DESIGN CHALLENGE 3: VISUAL IDENTITY

The last, but certainly not the least step is the exterior design. With the interior completed, the exterior can be designed. However, it needs to take into account more than just the interior layout. In the vision, the styling philosophy has also been established. This pointed to a balance between professionalism, friendliness and innovation.

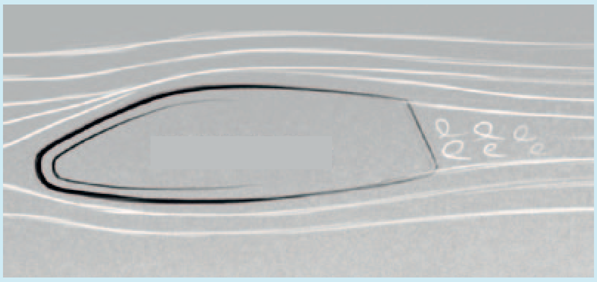
Next to the vision, experts also pointed towards the overall shape of the exterior, which needed to be more aerodynamic.

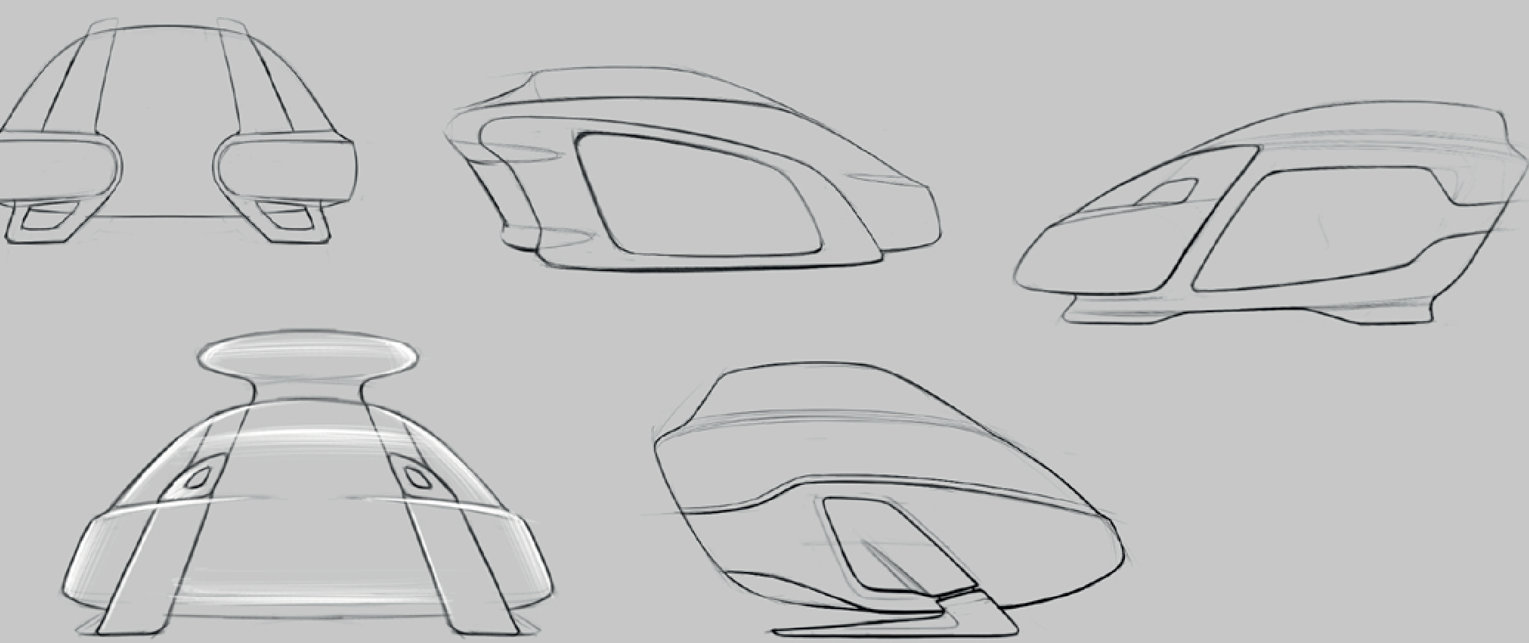
In the rest of this paragraph all the exterior features are explained.



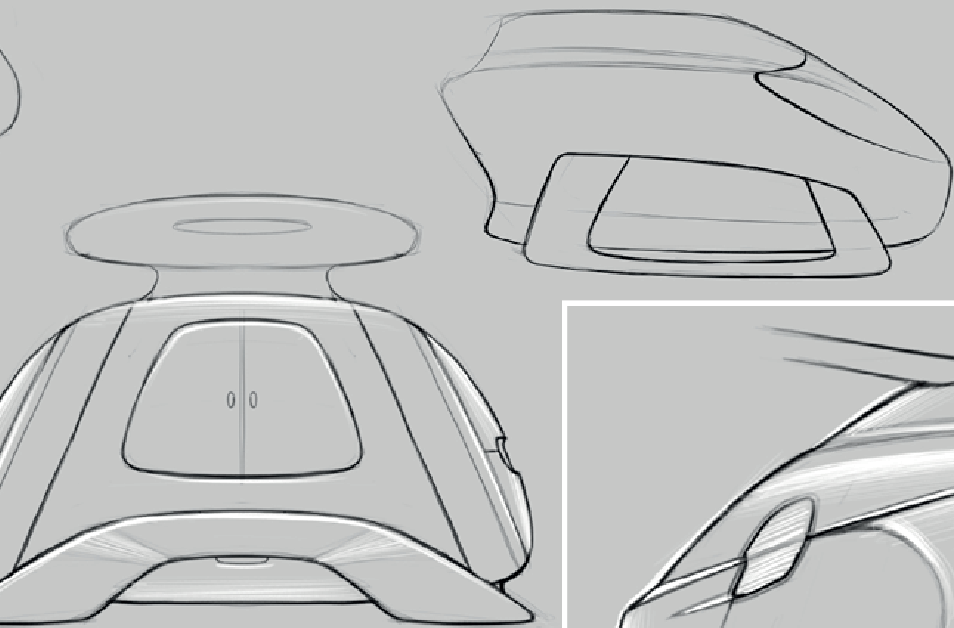
1. EXTERIOR SHAPE

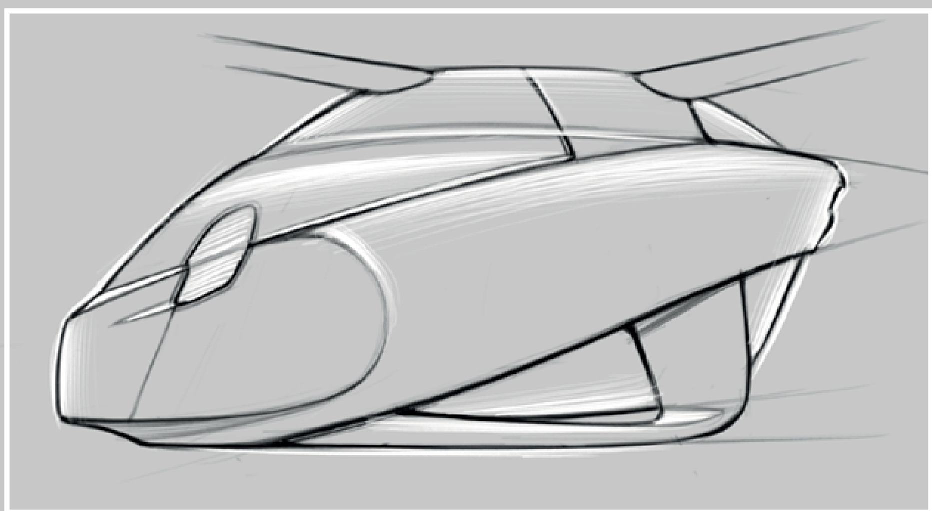
As mentioned, the aerodynamic requirements are important for the exterior shape. This means that the symmetrical shapes that were part of the concepts are not the most ideal shape. In fact, the most aerodynamic shape is that of an airfoil. It is not possible to achieve a full airfoil shape, as this is not a shape that is suitable for maximizing interior space. The next best option is a cut-off airfoil shape, like a wedge, as can be seen on the right.





2. EXPLORATION - After the concept phase a new exterior shape was investigated, based on the aforementioned insights. This led to the shape below, which has a wedge shaped profile and features a landing gear placed along the length of the aircraft. It wraps around the entire aircraft, giving a sense of stability, similar to Concept 1. It also has a dynamic mid section which flows from front to back. The organic shapes help to give it a sense of speed but also make it look soft and approachable.





2. REFINEMENT

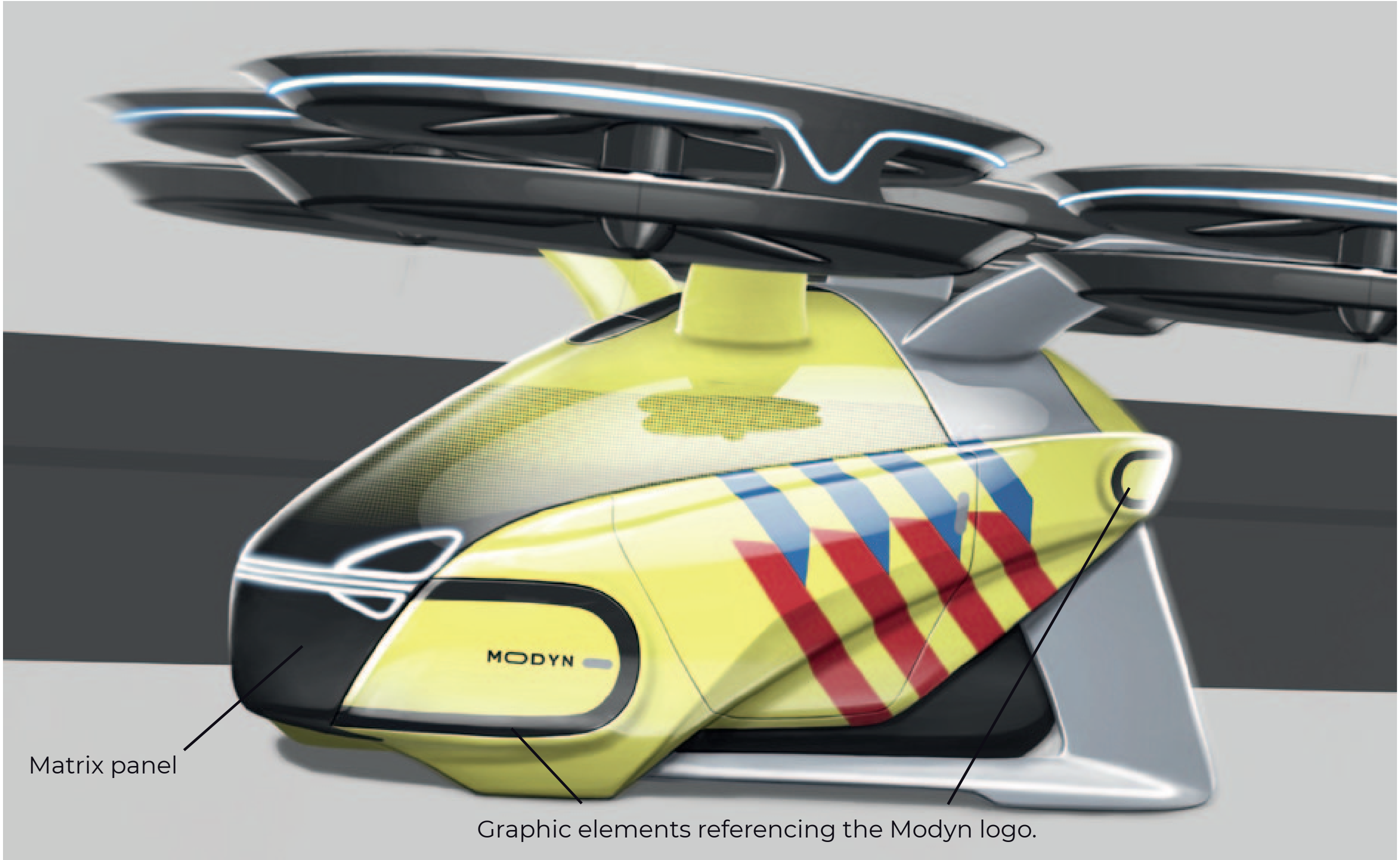
The sketch shown in the previous exploration was just the first quick idea. A lot of refinement needed to be done in order to make it compatible with the interior and look good. In this section the iterations towards the final exterior design are explained.

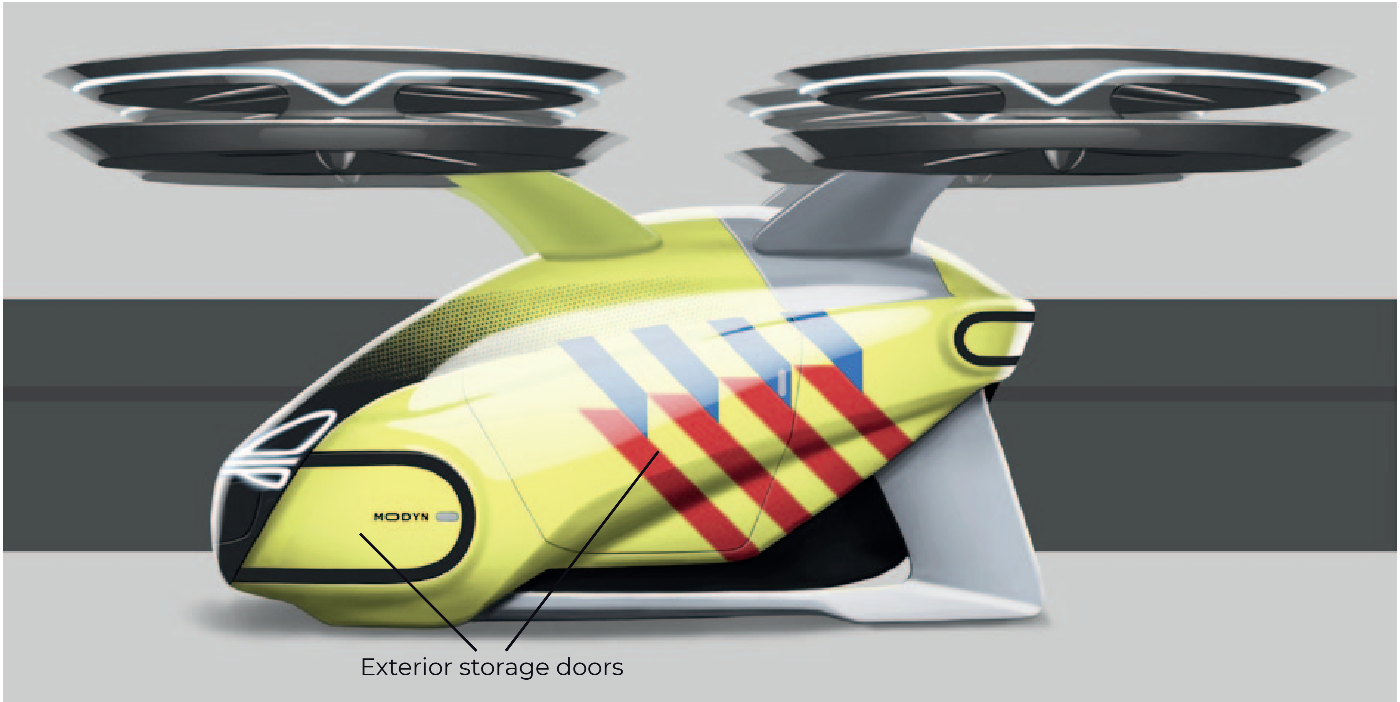
The sketches below show the first iteration.

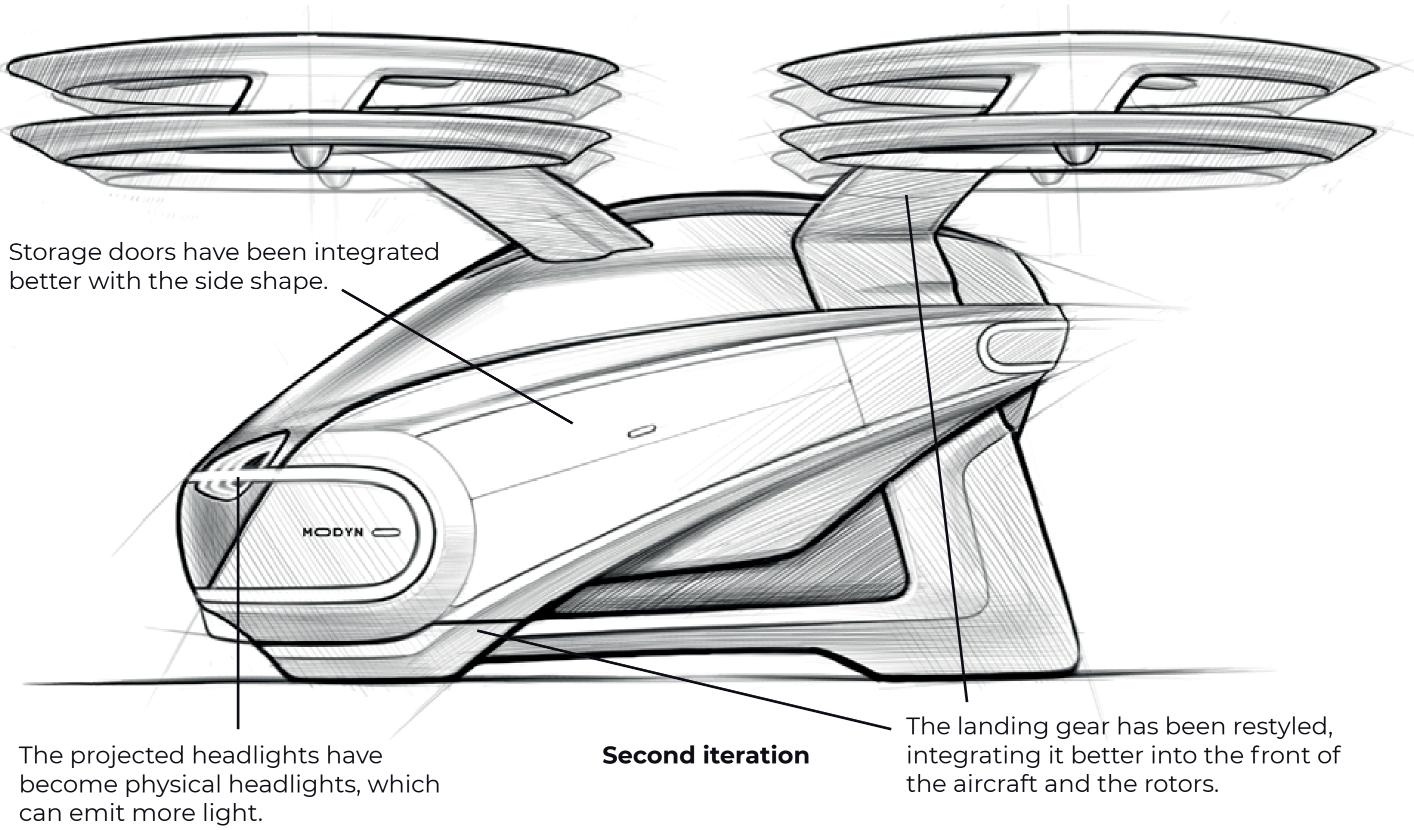
This iteration features open rotor ducts, because the decision was not yet made to make the rotors tilting.

The nose of the aircraft has a big matrix panel on which the headlights are projected. Next to that, in can be used to display messages to bystanders. The window has a pattern wrap, which blocks sunlight and adds privacy.

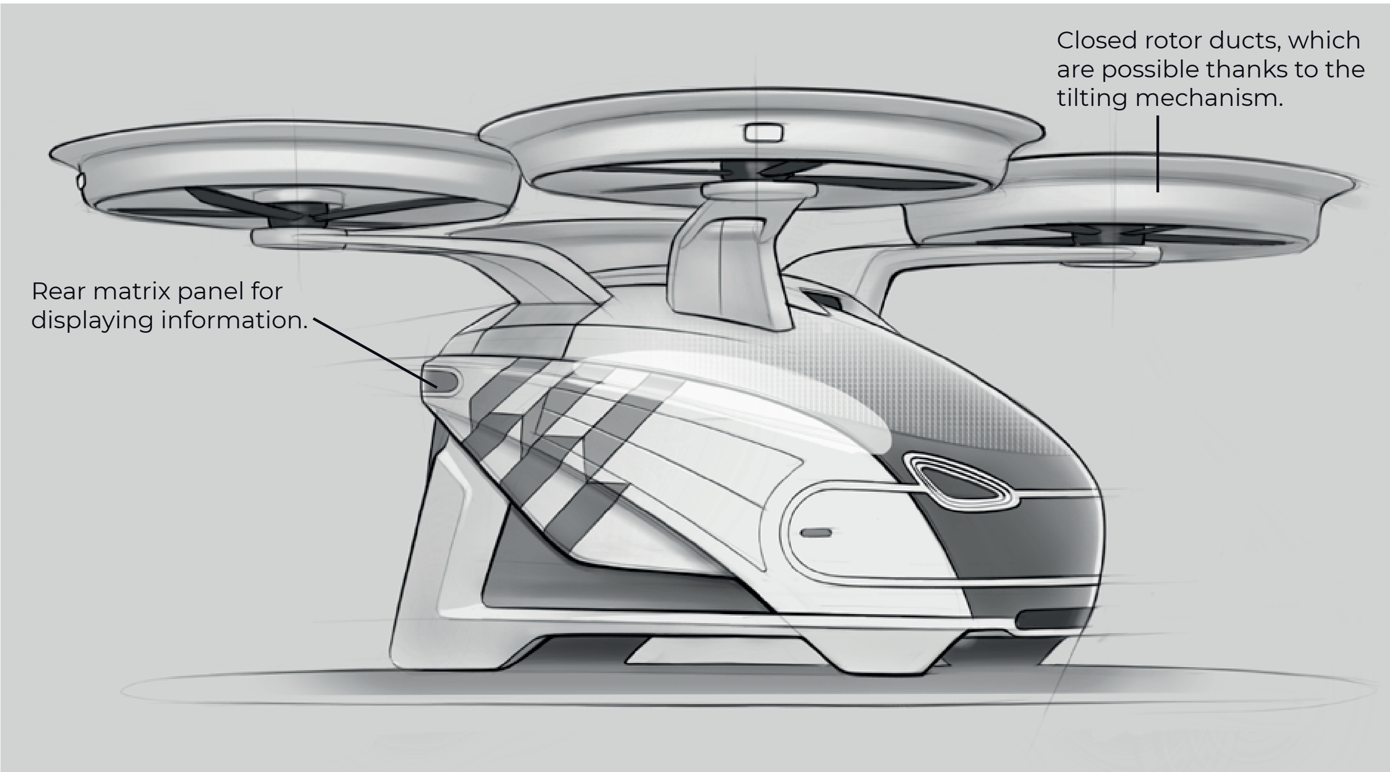
First iteration







Second iteration



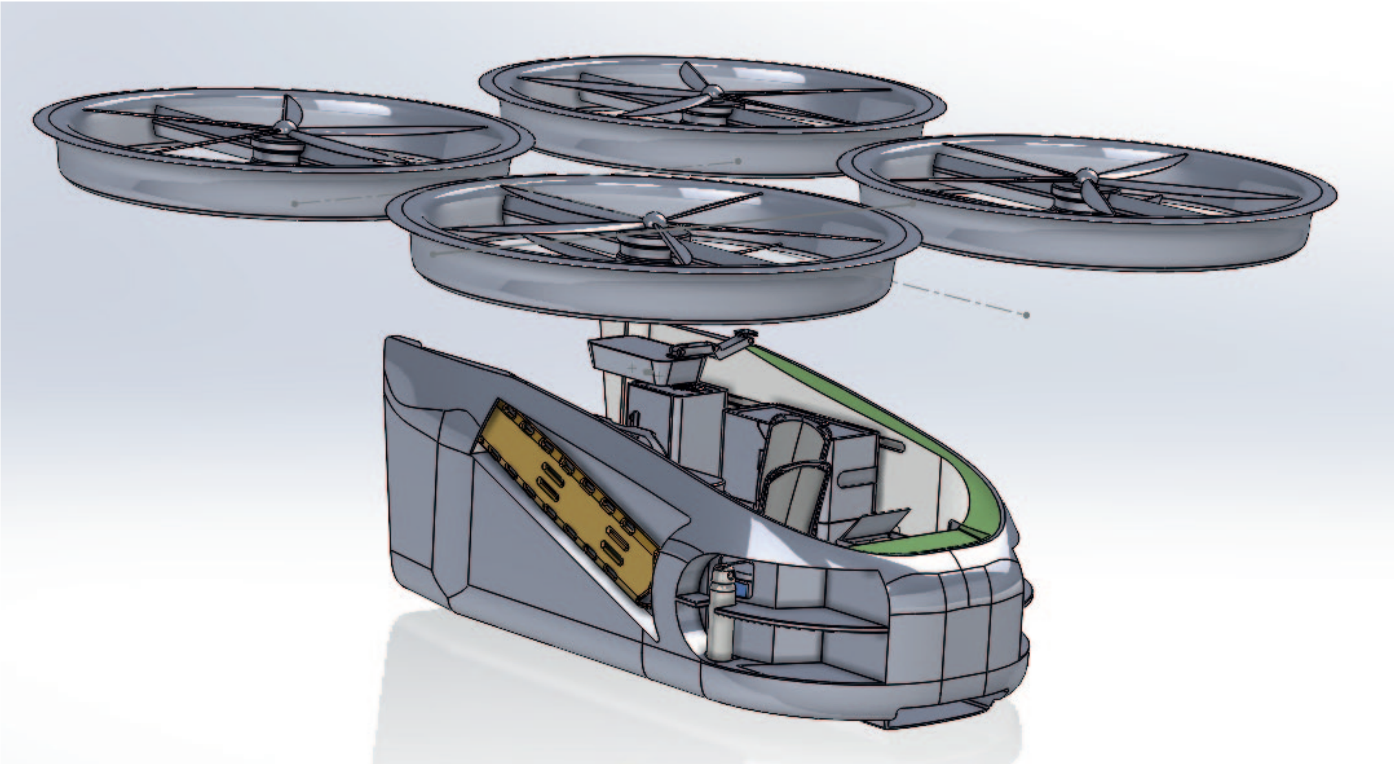
Final iteration

3. CAD MODEL

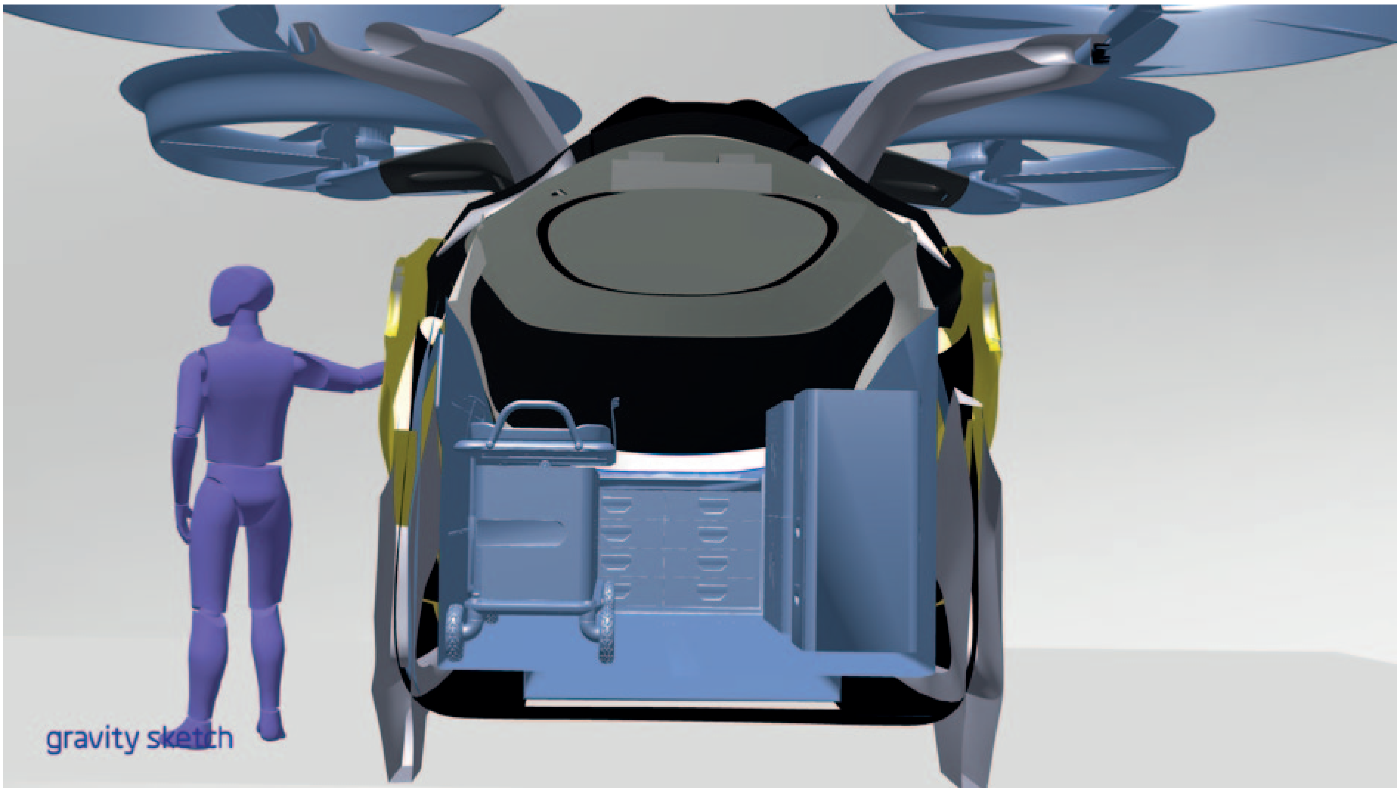
In order to visualise the final design and be able to make video animations, a CAD model was made.
First, the interior was made in SolidWorks. In SolidWorks the assembly components could be mated, allowing them to be moved realistically. This would come in handy for the video animations.

The SolidWorks model was then imported into the VR program Gravity Sketch, where it was used as the basis for the exterior surfacing.
Both the exterior and interior were imported into rendering software, where video animations and images were rendered.

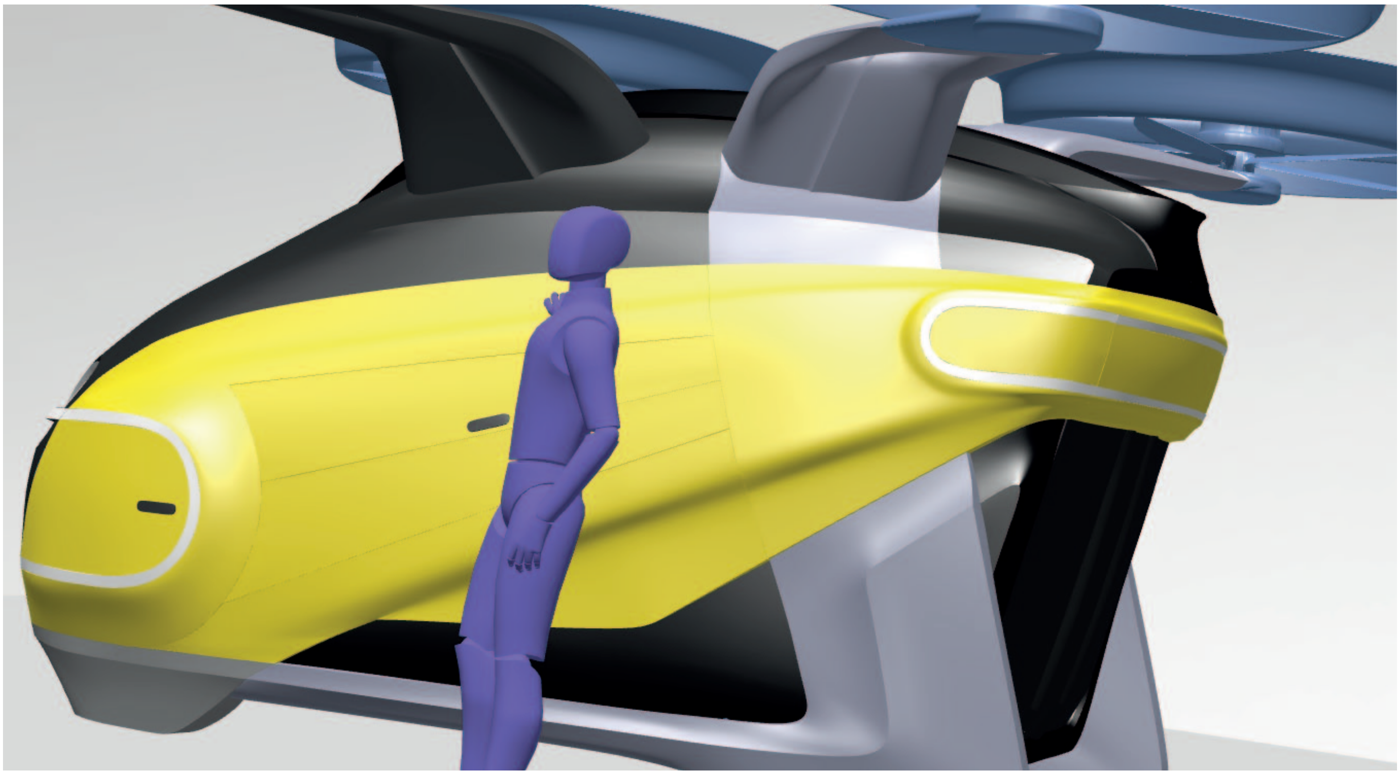
SolidWorks model



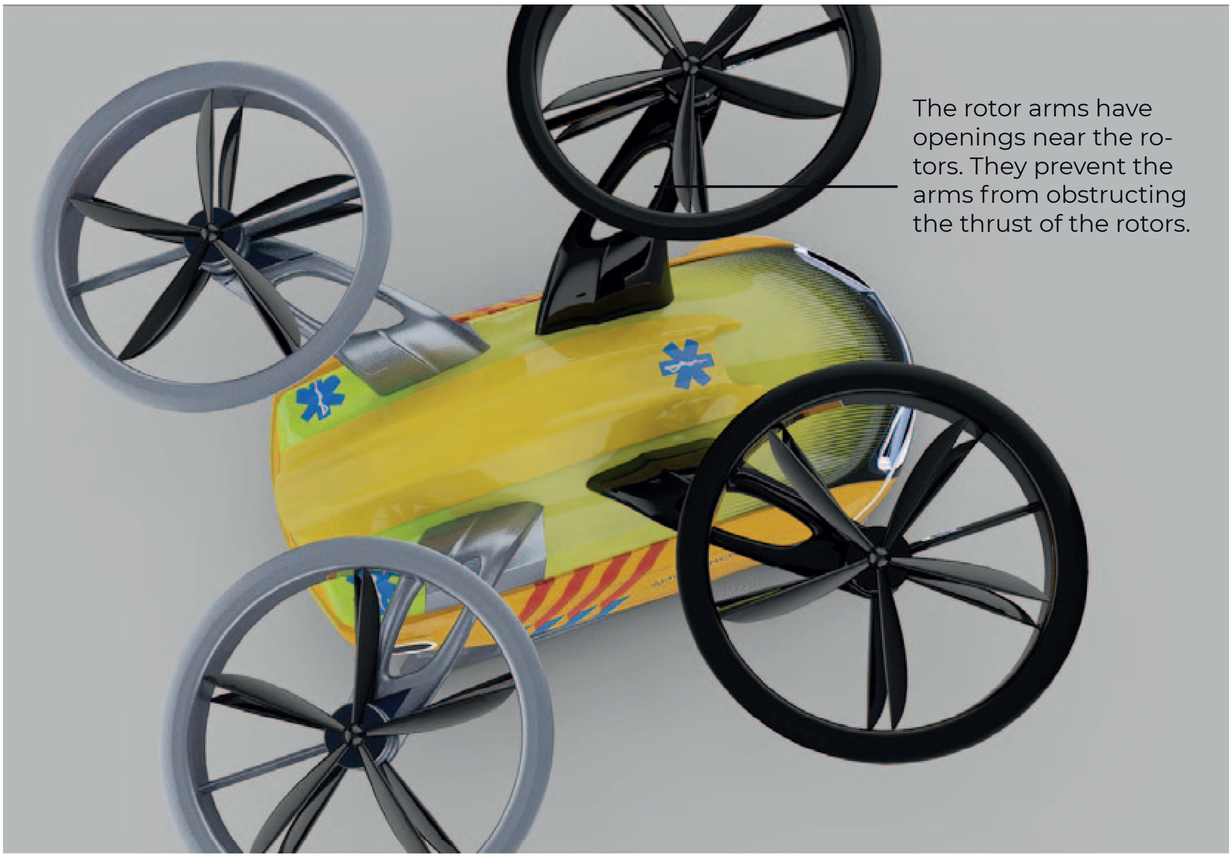
SolidWorks model inside the exterior

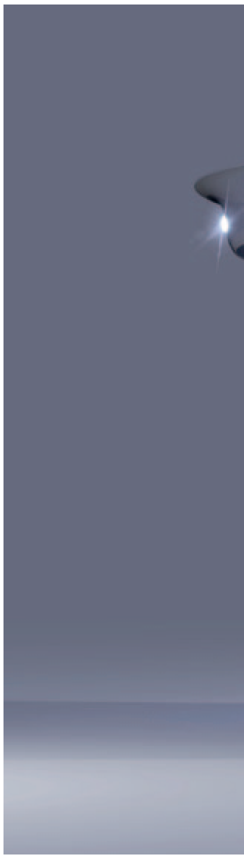


Exterior surfacing in Gravity Sketch



4. FINAL DESIGN SHOWCASE





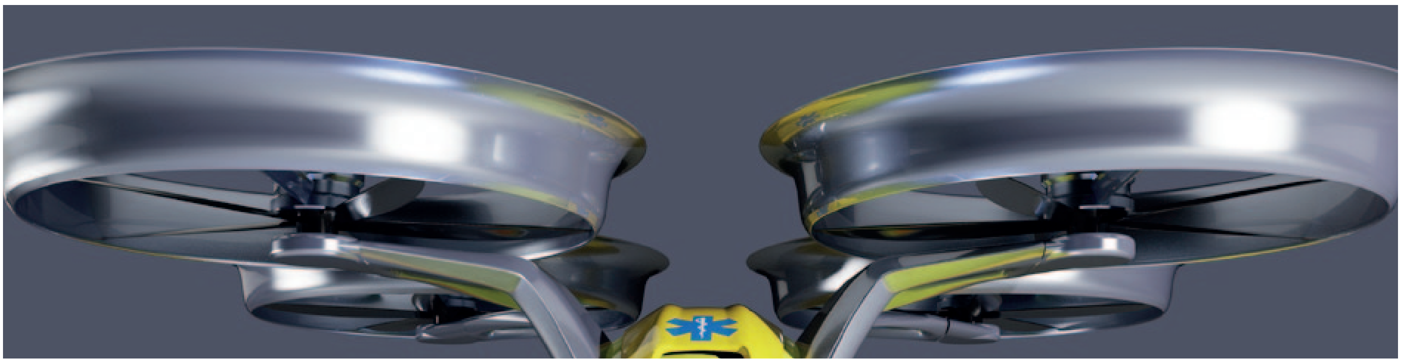
The lighting gives the drone a friendly face, making it relatable.


AMBULANCE
MODYN
MOBIEL MEDISCH TEAM

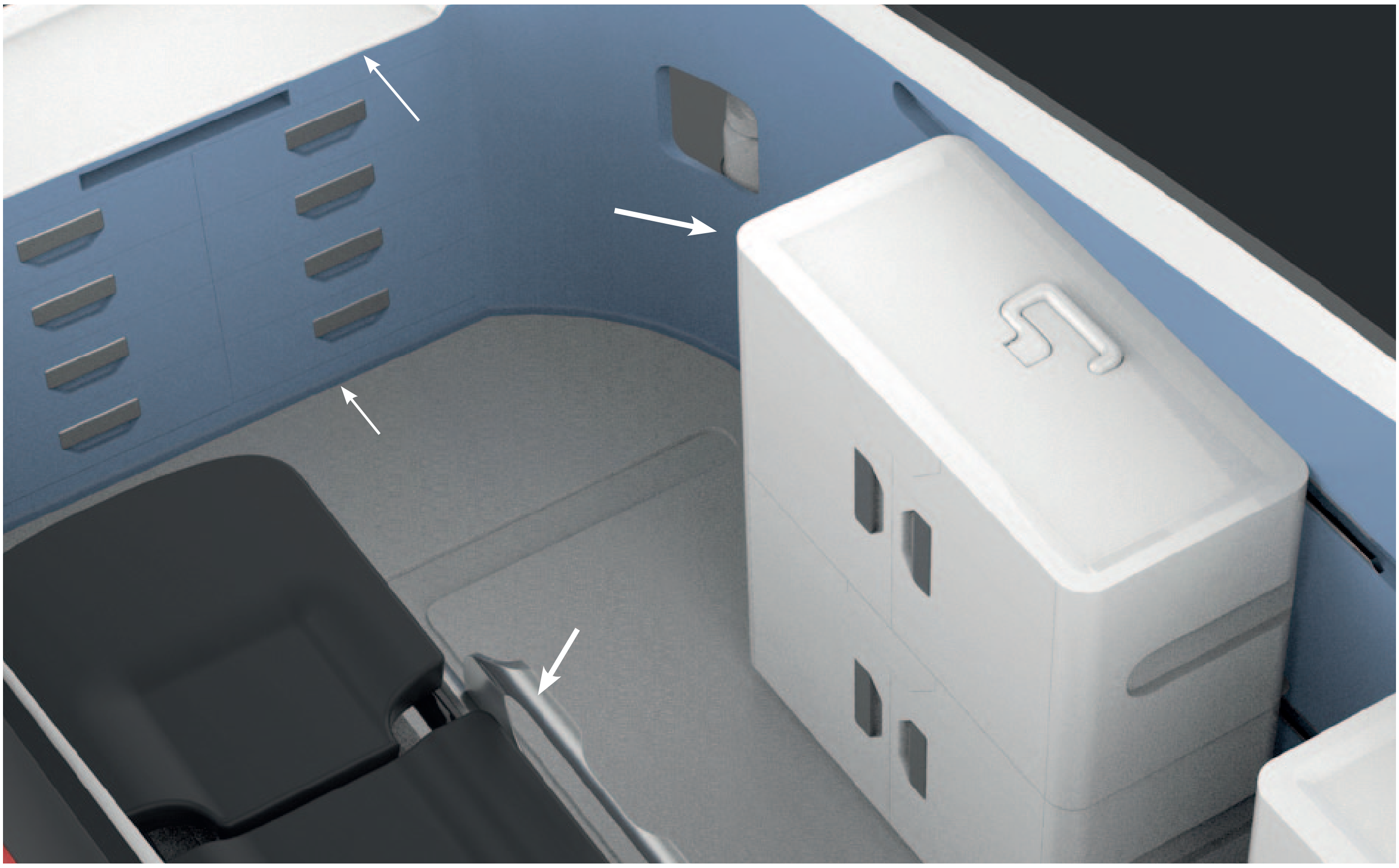
8.5 DESIGN CHALLENGE 4: SAFETY & COMFORT

Ensuring the safety and comfort of all people on board the ambulance drone is of course paramount. Several solutions have been implemented in the AirMedic, which are explained in this paragraph.

1. TILTING ROTORS - tilting the rotors ensures that the cabin stays level, instead of having to tilt the entire aircraft forward in order to travel forward. This provides the medical staff with a more stable environment to work in and it keeps the patient steadier.



2. ROTOR DUCTS - the ducts around the rotors protect the rotors from foreign objects. Similarly, it also protects people from the rotors themselves. The ducts also help to lower rotor noise, enabling the staff inside the AirMedic to communicate better with each other and the patient.



3. ROUNDED EDGES - The interior features rounded edges and flush handles. That way no one can accidentally bump into a protruding or sharp point.

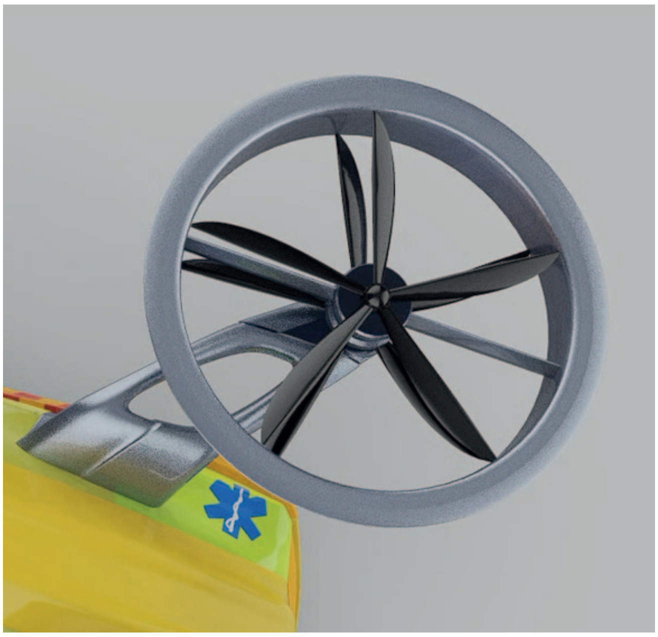
4. SECURED STRETCHER - The stretcher is anchored to the floor by a support that raises up from the floor. The wheels of the stretcher also lock when the AirMedic is flying, keeping the stretcher firmly in place.

8.6 DESIGN CHALLENGE 5: TECHNICAL ARCHITECTURE

The last step in the design is the integration of the technical package. During the design phase, as it became more clear what the Air-Medic would look like, the technical architecture was formed and relevant performance factors were identified.

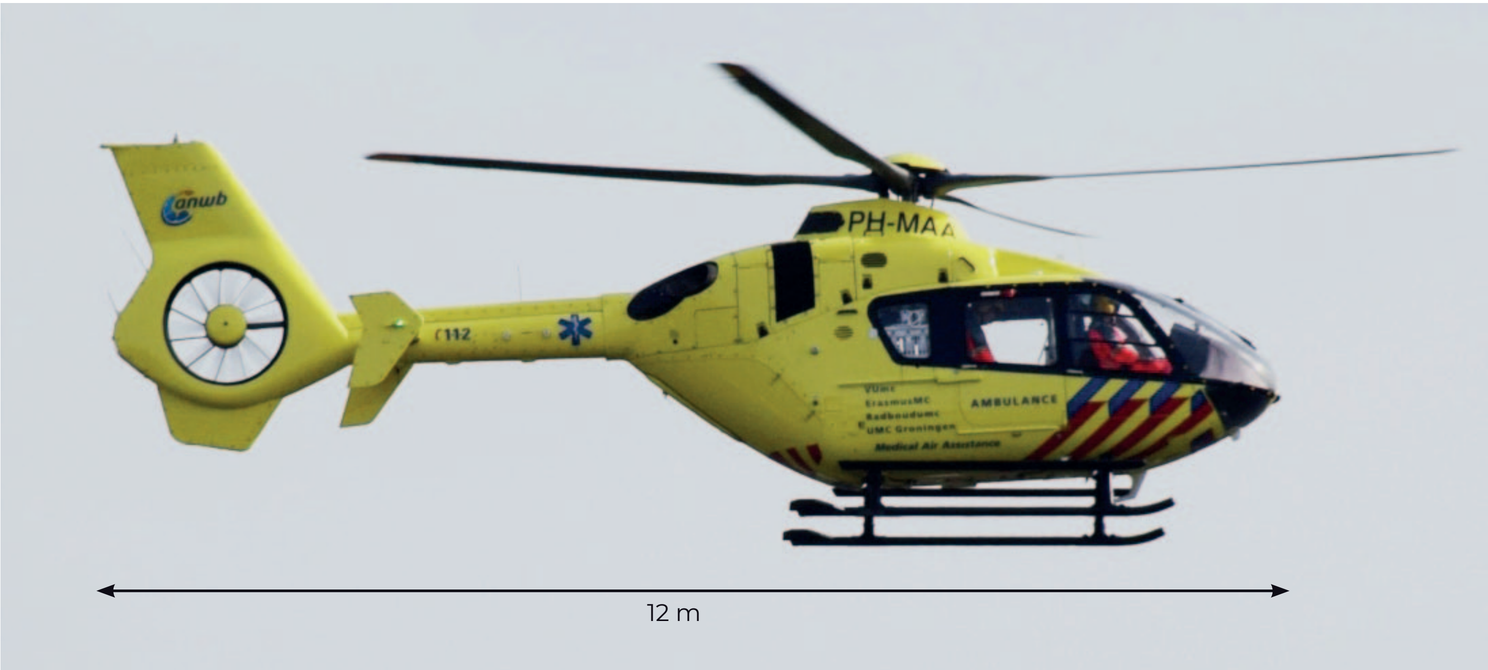
The estimates of the performance factors and technical aspects of the AirMedic were made by comparing the AirMedic with an existing eVTOL, the CityAirbus, which is similar in terms of size and performance requirements.

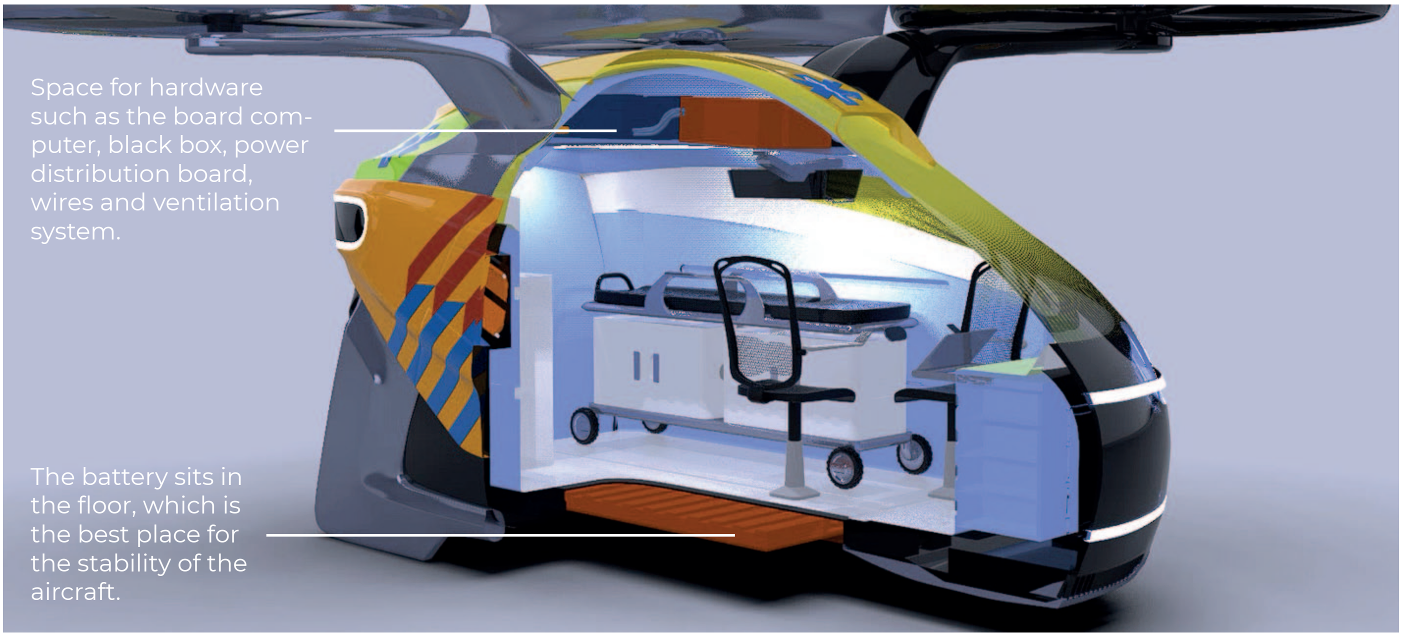
Using ratios, the performance factors of the CityAirbus were extrapolated to the AirMedic. This gives a general idea of what the statistics of the AirMedic would become, which are explained in this paragraph.



1. ROTORS - The rotors are coaxial. This means that there are two rotors placed on top of each other. The benefits of this are explained in appendix D. In total the AirMedic features eight propellers with a diameter of 250 cm each.

2. DIMENSIONS - Thanks to the simpler technical architecture, the AirMedic is a lot smaller than the current ambulance helicopter. Yet, the interior space of the AirMedic is larger and more practical as well. The compact size makes the AirMedic suitable for smaller landing areas, reducing the distance towards the scene of the incident and ultimately creating lower response times.

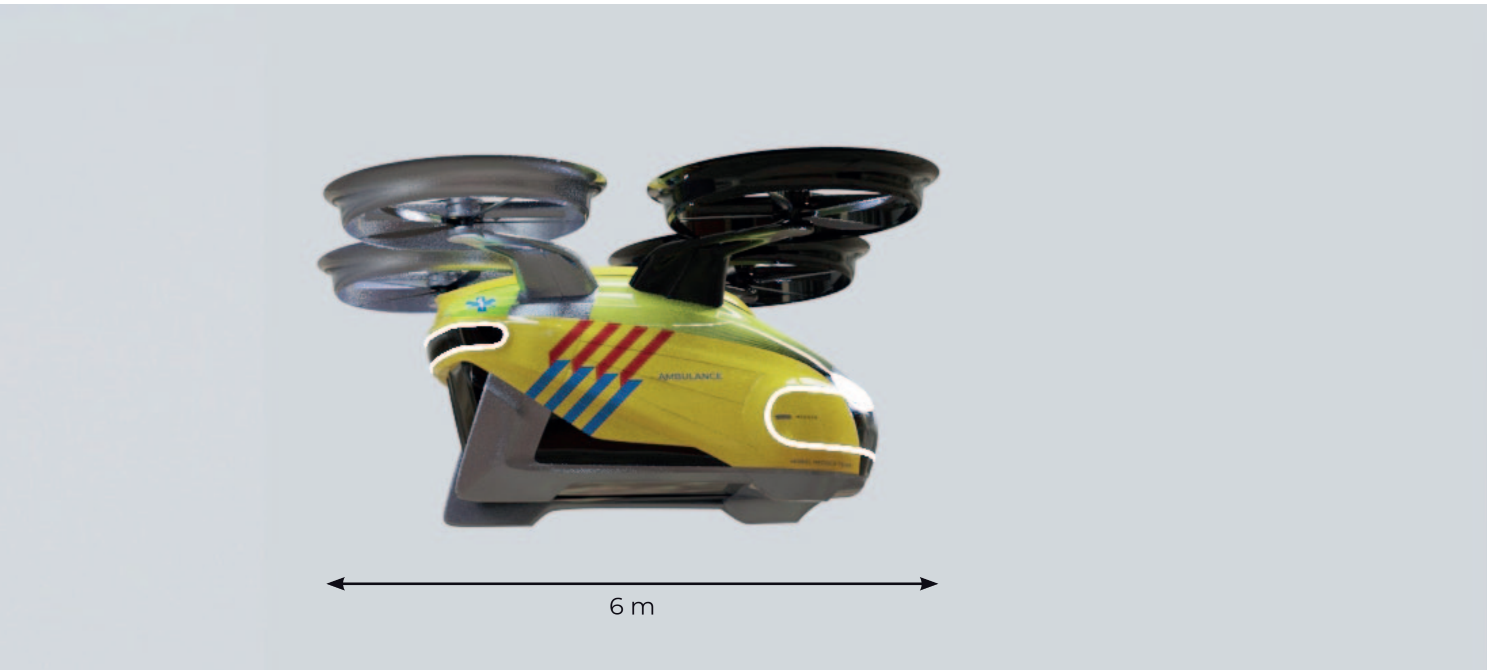




3. BATTERY - The battery is the most critical part of the technical architecture. It was therefore important to get a good estimate on its size and performance, based on the expected battery developments that will have occurred by 2035.

Extrapolating the battery performance was not as simple as using the CityAirbus as a reference. Instead, it needed to be based on the predicted battery technology by 2035. To make the most realistic estimate possible, experts were consulted (appendix G). This yielded a battery mass of circa 580 kilograms and a size of 100 x 206 x 10 cm. The scale of the battery means that it can be integrated into the floor of the AirMedic. For the full calculation of the battery see appendix I.

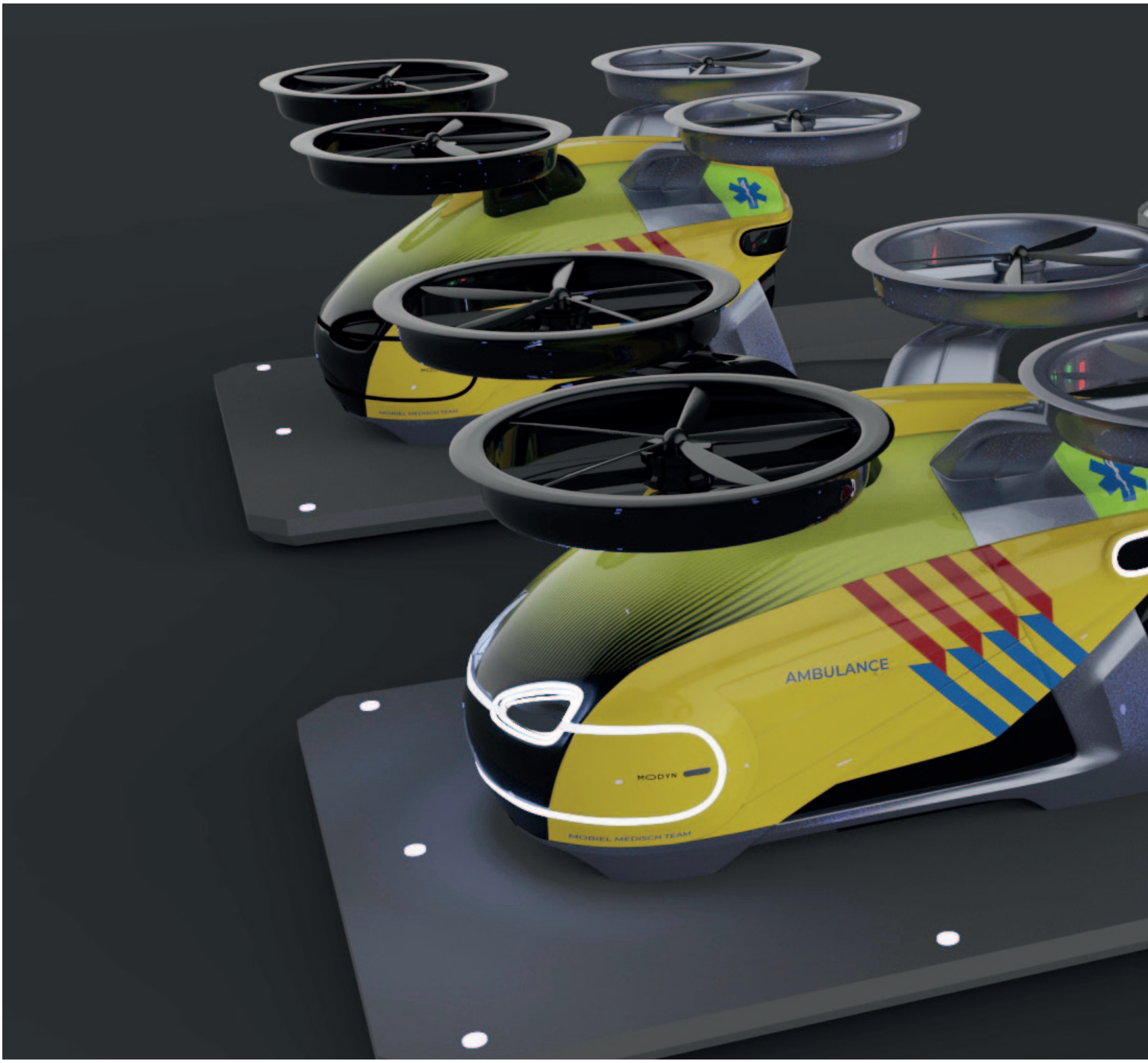
4. MAXIMUM TAKE-OFF WEIGHT - Based on the CityAirbus, it was estimated that the AirMedic would have an empty weight of around 1850 kg (appendix I). Add to this three people, the stretcher, equipment and storage units, a total payload of somewhere between 500 and 750 kg is realistic. This puts the max. take-off weight at around 2350 to 2600 kg. This is lightly lighter than the ambulance helicopter.



8.7 VERTIPORT

In appendix B, three scenarios for the implementation of ambulance drones in The Netherlands were investigated. Based on these scenario's, three concepts were created, which are explained in appendix C.

With the AirMedic design completed, it is possible to think about how the take-off and landing platform and maintenance infrastructure could be facilitated. A proposal for this is shown below.



The facility features seperate charging docks and a mobile landing platform that can be rolled out of the maintenance hall. Robotic carts are responsible for swapping the battery.

Basically, the AirMedic could be distributed as a total package, including platform, carts and charging facilities.

This enables the AirMedic to be housed in any existing building that is large enough and has sufficient space outside for take-off and landing. It is a cheap and simple solution, with no need for new buildings.

CHAPTER 9
DISCUSSION

9.1 INTRODUCTION

In this short chapter the project is concluded and evaluated. It starts with a conclusion of the result of the project. Then follows the recommendations, explaining what challenges still need to be tackled when the AirMedic is developed further. Next is an evaluation of the process, followed by a personal evaluation.

9.2 CONCLUSION

Contrary to what the project's title and premise might imply, the AirMedic is not a wildly conceptual result. In fact, it could be considered an iteration of the current ambulance van and helicopter. As stated in the synthesis of chapter 3, the ambulance van is a very complete product in many ways. The AirMedic takes learning from this and improves on it wherever possible. It truly is the next generation flying ambulance.

The previous chapter showed how each design challenge was solved. But that is only one part of the equation. Looking at the Design Fundamentals will tell whether the solutions hold true to the vision of the project.

The first fundamental, trust, has been encorporated into the design. The AirMedic's identity is unique, making it fit the innovative nature of the ambulance drone as a product. Yet, its appearance is also recognisable enough so that it can clearly be distinguished as an ambulance vehicle. This familiarity helps to evoke trust.

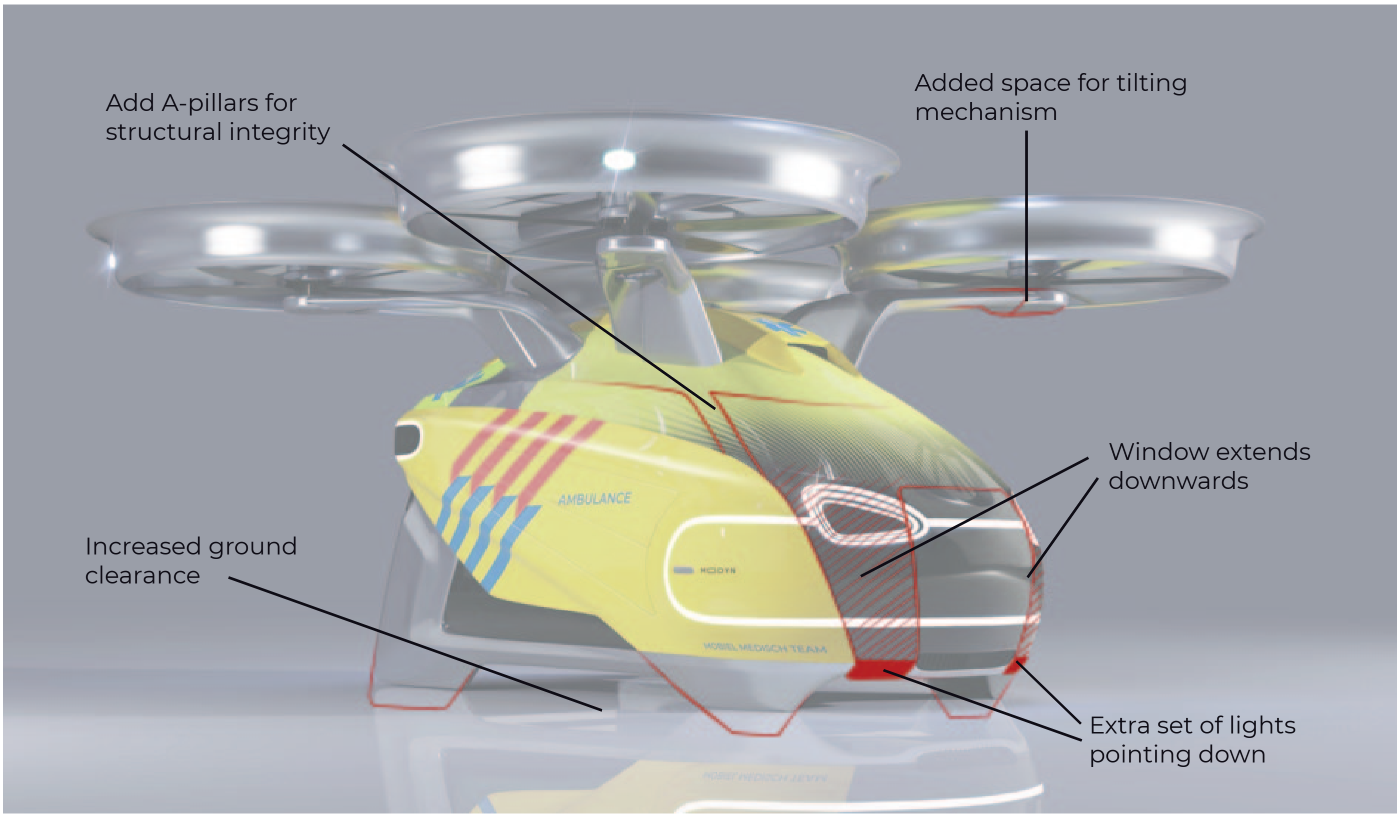
In terms of the second fundamental, simplicity, the AirMedic has succeeded as well. The interior is clean and minimal, yet functional. It has few distractions or unnecessary complexity. It is also highly modular, which ties into the last two design fundamentals of efficient maintenance and adaptability.

Zooming out and looking at a potential ambulance drone system in The Netherlands, it can be said that it would be a luxury to have. The Netherlands has such a strong ambulance system already that there is no urgent need for an ambulance drone system. However, the Dutch system is only as good as it is because it constantly aims for the best and never settles for less. An ambulance drone system may therefore be the key in staying on top of the game for generations to come.

9.3 RECOMMENDATIONS

Given the complexity of the AirMedic and the relatively short duration of this graduation project, there are still some areas of the design that require attention or optimisation.

In the interior, a few things require some more attention. Ideally, the storage units would not only attach to the walls, but also to the floor. This is more stable and prevents the walls from



having to support all the weight, which means they can be lighter.

The floor rail for the seats needs some more research in order to determine which mechanism would be suitable. There are some concerns with the strength of the floor rail and whether it provides enough contact points for the chair to stay rigid in situations of quick deceleration.

There are currently no A-pillars connecting the ceiling to the side walls of the AirMedic. They may need to be added for sufficient structural support.

Lastly, it would be beneficial to have more visibility towards the ground. This could be achieved by removing part of the fixed storage drawers in the nose of the AirMedic and extending the window down towards the floor. This helps the crew to orient themselves better before landing.

In terms of the exterior, there are some things that could be optimized. The headlights are placed a little too high. It is more useful to have the lights pointing downwards slightly in order to illuminate obstructions below the aircraft.

Secondly, the tilting mechanism for the rotors require more space inside the arms of the rotors. Lastly, the landing gear needs some more ground clearance. Currently the clearance is around 30 centimeters, but 40 centimeters would ideally be the minimum.

9.4 PROCESS EVALUATION

The execution of the graduation project itself went smoothly and it surprised me how well I was able to follow the planning. It turned out to be estimated well in terms of the allocation of time for all the different stages of the project.

There were a few concessions that needed to be made however. In the project brief the idea was to also make a physical model of the AirMedic, but there eventually was not enough time left to make it. Next to that it was doubtful how much value it would bring, compared spending that extra time on improving the design itself.

Looking back, I think I would have spent slightly less time on the research phase and a little more on the design. It could have freed up time to explore the full range of possibilities regarding the modularity of the AirMedic's interior.

All in all, there were no significant choke points in the project, which means that the complexity was handled sufficiently. Also, the involvement of experts went well and I was lucky that so many people were willing to share their insights. From a project management perspective this project was a success.

9.5 PERSONAL EVALUATION

Executing this project taught me a lot as a designer and a human being. It is the longest individual project I have carried out so far. This required discipline and constant motivation over a long period of time, something I have struggled with in the past. Thankfully I managed this really well and had the drive to work hard every day of the project. In a way this is a new personal achievement.

The conceptual nature of the project had a risk of becoming overwhelming. While I already knew I was not afraid of conceptual projects from prior experience, it was still intimidating in the beginning. In the end, I think I managed to retain a good level of realism and relevance in the design of the AirMedic. Handling the complexity of such a project is a new achievement as a designer and one I am certain was only possible thanks to prior projects in my Master studies at the TU.

REFERENCES

ADAC Luftrettung. (2021). Luftrettung mit bemannten Multikoptern ist möglich, sinnvoll & verbessert die Notfallversorgung. Retrieved from https://luftrettung.adac.de/volocopter/

Airbus. (sd). CityAirbus. Opgehaald van https://www.airbus.com/innovation/zero-emission/urban-air-mobility/cityairbus.html#configuration

ambulanceblog.nl. (2013). Beter comfort dankzij de Arpemat Wervelplank Matras. Retrieved from https://www.ambulanceblog.nl/beter-comfort-dankzij-de-arpemat-wervelplank-matras/

Ambulancedienst Zuid-Holland Zuid. (2015). Vroeggeborene? Brancard eruit, couveuse erin. Retrieved from https://ravzhz.nl/nieuws/vroeggeborene-brancard-eruit-couveuse-erin/

ambulancezorg.nl. (2021). Bekostiging en financiering ambulancezorg. Retrieved from https://www.ambulancezorg.nl/themas/financiering/financieringsstelsel/bekostiging-en-financiering-ambulancezorg
ambulancezorg.nl. (2021). Facts & Figures 2018. Retrieved from https://www.ambulancezorg.nl/sectorkompas/facts-figures-2018

anwb.nl. (2021). ANWB Medical Air Assistance. Retrieved from https://www.anwb.nl/maa
Association Of Ambulance Chief Executives. (2020). AACE welcomes new £5,000 per annum grant for student paramedics. Retrieved from https://aace.org.uk/news/aace-welcomes-new-5000-per-annum-grant-for-student-paramedics/

Davenport, T., & Kalakota, R. (2019). The potential for artificial intelligence in healthcare. Future Healthc J., 6(2), 94-98. doi:10.7861/futurehosp.6-2-94

de Koning, A. (2020). Steile trappen of het strand: nieuwe ambulancemotor kan alles aan. Retrieved from https://www.ad.nl/auto/steile-trappen-of-het-strand-nieuwe-ambulancemotor-kan-alles-aan~a2200bfc/

docukit.nl. (unknown). de ambulance. Retrieved from https://www.docukit.nl/spreekbeurt/de-ambulance
Doustmohammadi, M. (2015, March 31). How can I find structure and parameter of Brushless DC Motor? Retrieved from https://www.researchgate.net/post/How-can-I-find-structure-and-parameter-of-Brushless-DC-Motor

Frame. (2015). ALEC MOMONT'S AMBULANCE DRONE SEIZES VOTERS' HEARTS TO WIN THE FRAME PUBLIC AWARD. Opgehaald van https://www.frameweb.com/article/alec-momonts-ambulance-drone-seizes-voters-hearts-to-win-the-frame-public-award

George Bower. (2019, February 7). Tesla Model 3 2170 Energy Density Compared To Bolt, Model S P100D. Opgehaald van https://insideevs.com/news/342679/tesla-model-3-2170-energy-density-compared-to-bolt-model-s-p100d/#:~:text=That%20puts%20energy%20density%20by%20weight%20for%20one,volumetric%20energy%20density%20at%2011.9%2F.0165%20liters%3D%20721%20watt-hours%2Fliter

HPFY. (2021). Optec Proglide Cervical Collar Neck Brace. Retrieved from https://www.healthproductsforyou.com/p-optec-proglide-cervical-collars-neck-brace.html
ikebho.nl. (2018). De ambulance. Retrieved from https://ikehbo.nl/hulpdiensten/ambulance/ambulance.php

Jager, W. d. (2020, December 30). Innovatieplatform Dutch Drone Delta officieel van start. Retrieved from https://www.dronewatch.nl/2020/09/30/innovatieplatform-dutch-drone-delta-officieel-van-start/

Kraft, D. (2019, January). 12 innovations that will revolutionize the future of medicine. The Future of Medicine. National Geographic.

Kunst, A. (2019). Heel Europa wil deze nieuwe ambulance uit Twente. Retrieved from https://www.tubantia.nl/hengelo/heel-europa-wil-deze-nieuwe-ambulance-uit-twente~a40d6738/

NLR. (2021, January 22). Europa test luchttaxi's en drones voor stedelijke mobiliteit. Retrieved from https://www.nlr.nl/nieuws/europa-test-luchttaxis-en-drones-voor-stedelijke-mobiliteit/

overheid.nl. (2021). Wet veiligheidsregio's. Retrieved from https://wetten.overheid.nl/BWBR0027466/2021-01-01/#Bijlage

Rai, A. (2020, May 6). What is Big Data – Characteristics, Types, Benefits & Examples. Retrieved from https://www.upgrad.com/blog/what-is-big-data-types-characteristics-benefits-and-examples/#Healthcare

Srfotografie. (2014). Opendag Smellinghe. Retrieved from https://www.waldnet.nl/wn/fotonieuws/11704/Opendag_Nij_Smellinghe_druk_bezocht.html

Tulatech. (2021). Brancard Elektrisch. Retrieved from https://www.tulatech.nl/brancards/2/brancard-elektrisch
van der Laan, M. (2019, december 10). Nieuwe traumahelikopter, nu met achteruitkijkspiegel. Retrieved from https://www.dvhn.nl/groningen/Nieuwe-traumahelikopter-nu-met-achteruitkijkspiegel-25125624.html

Van Loon, W. (2016). Ambulances hebben te veel werk en zijn vaak te laat. Retrieved from https://www.metronieuws.nl/in-het-nieuws/2016/07/ambulances-hebben-te-veel-werk-en-zijn-vaak-te-laat/

112-Zuidland. (2019, May 9). Traumahelikopter ingezet voor medische noodsituatie. Opgehaald van https://www.112-zuidland.nl/2019/05/09/traumahelikopter-ingezet-voor-medische-noodsituatie/