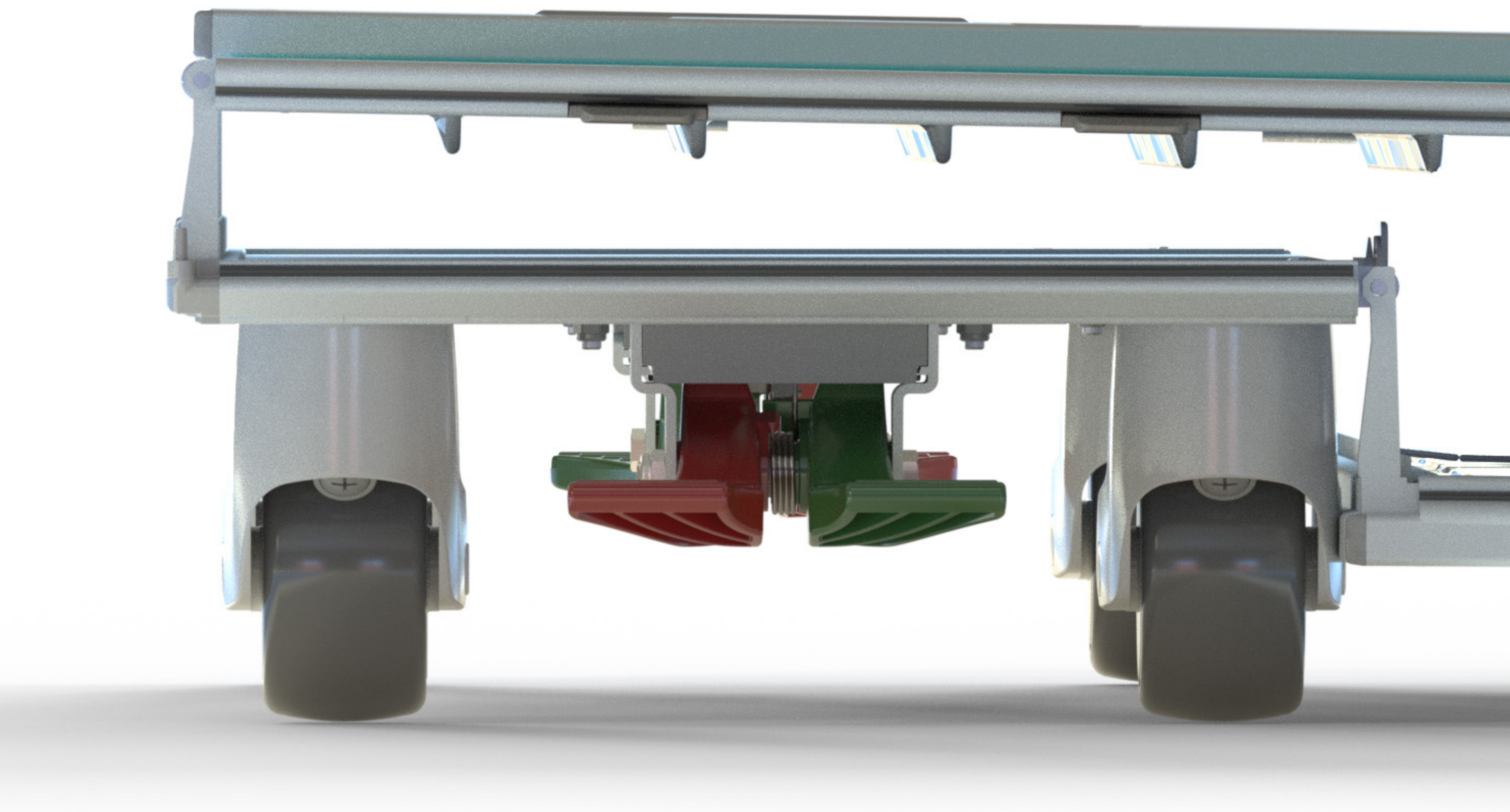
Flatpack Redesign of the Airline Catering Trolley

by Wendy Pruppers



Master Thesis
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DRIESSEN

TU Delft

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Master Thesis

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Executive summary

Airline catering trolleys play a crucial role in in-flight service and logistics. However, current trolleys are shipped fully assembled, resulting in the inefficient transport of large volumes of air. This leads to high shipping costs and a significant environmental footprint, which conflicts with the aviation industry's growing focus on sustainability and cost optimisation.

The goal of this project is to develop an innovative airline catering trolley design that can be transported as a flat-pack solution. This allows more trolleys to be shipped in the same volume, while maintaining strength, safety, and usability during assembly and operation.

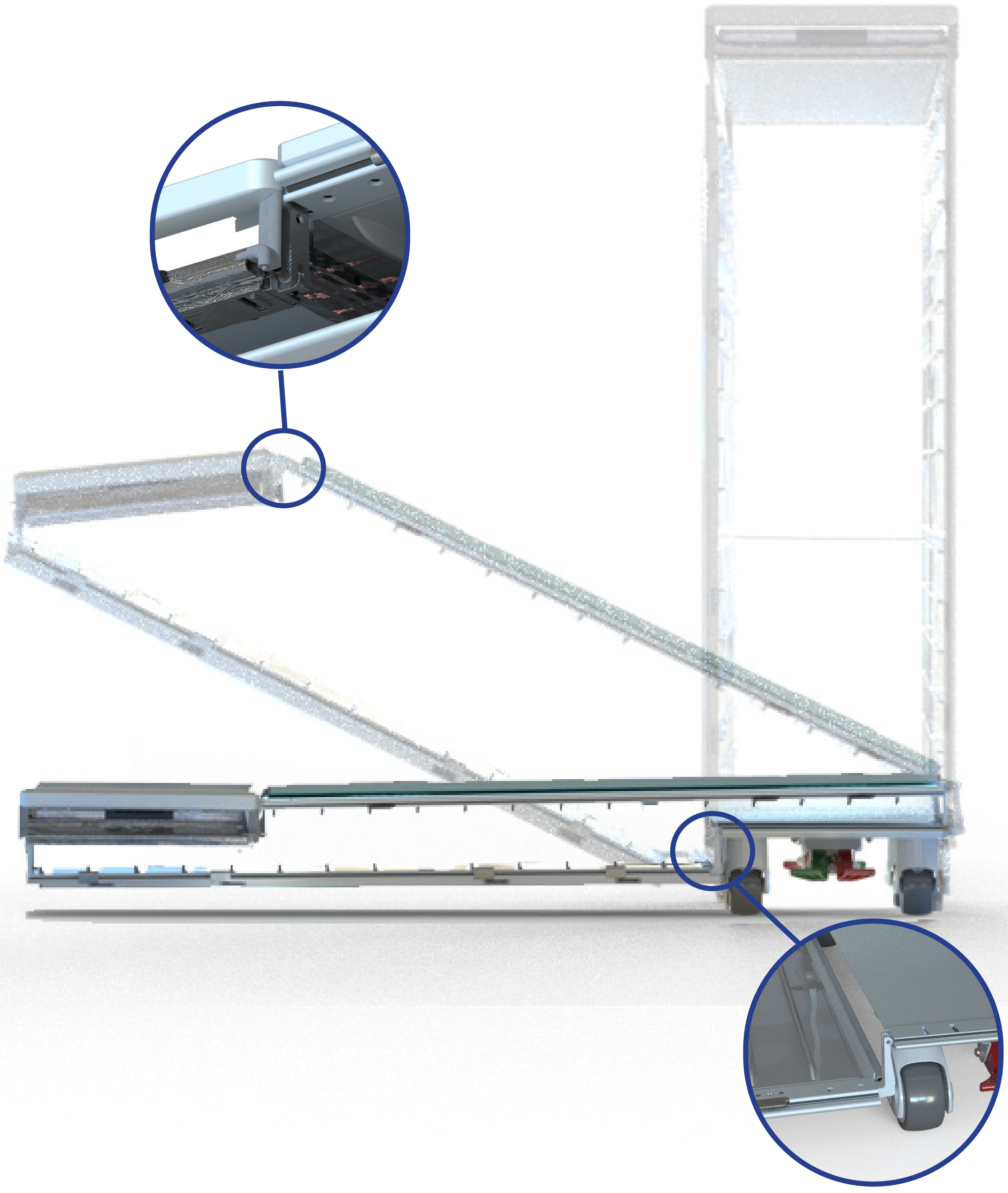
The project followed an iterative design process, including market research, concept development, technical feasibility studies, and prototyping. Structural simulations and cost analyses were conducted to validate the mechanical integrity, ease of assembly, and economic benefits of the design.

Results: The final result is a re-engineered flat-pack trolley, based on the original Driessen trolleys that can be folded into a flat package. The design reduces transport volume by 42.5% and therefore also 42.5% emission reduction and cost savings within the distribution phase. Additionally, the trolley can be manufactured using existing production facilities, enabling implementation without major investments in new equipment.

Advantages: The flat-pack trolley meets strict certification standards, is easy to assemble without tools in under five minutes, remains airtight and lightweight, and fits standard galley dimensions. Its fool-proof design ensures safe and intuitive handling.

Limitations: The reliance on snap-fit connections introduces challenges, including strict tolerance requirements and potential metal fatigue over time, which may affect long-term durability and raise concerns about achieving a 10-year service life. Moreover, the folded trolley exceeds standard block pallet dimensions (120 × 100 cm), potentially complicating logistics and shipping processes.

Practical Relevance: This project directly addresses the demand for innovative, sustainable solutions in aviation. The flat-pack trolley not only offers economic advantages through lower transport costs but also strengthens airlines' environmental and brand positioning.



Keywords: Airline Catering trolley, Innovation, Aviation, Sustainability, cost optimisation, mechanical product design, flat-pack solutions.

Preface and Acknowledgements

Dear reader,

With this final thesis, I conclude both my graduation project and my studies at TU Delft. After five years of learning, experimenting, and growing as a designer, this thesis marks the final step in my academic journey.
My interest in this project started during the first year of my master's in Integrated Product Design, when I participated in the course Advanced Embodiment Design. During that course, I had the opportunity to already work on a project at Driessen Catering. I really enjoyed the technical nature of the work and the chance to develop a tangible, physical product. That experience inspired me to return to Driessen for my graduation project.

First and foremost, I would like to thank **Driessen Catering** for welcoming me back and giving me the opportunity to work on this project. I am grateful for the support I received across all departments, which helped me bring this project to life.
A special thanks goes to my company mentor, **Sergio Gomes**, for his close involvement, continuous support, and for offering me full access to the company's resources. His valuable feedback and ideas throughout the process played a key role in shaping this thesis.

I also wish to thank **Peter Beets**, Product Engineer at Driessen, for his technical insights, collaboration, and ideas, and **Henk Kempe**, Support Engineer, for his help in building and realizing my prototype.

I am also deeply thankful to my TU Delft coaches, **Bart Bluemink** and **Ernest van Breemen**, for their critical feedback, thoughtful guidance, and the knowledge they shared from their respective fields.

To my friends and family: thank you for standing by me throughout my studies. A special shout-out to **Iris** and **Kim**, who have been my study buddies and emotional anchors during the tougher moments of this thesis journey. And to my parents, thank you for believing in me and supporting me in countless ways. This achievement would not have been possible without you.

Finally, thank you, reader, for taking the time to engage with my thesis. I hope you find it both insightful and inspiring.

During the writing of this thesis, I used ChatGPT to help rewrite and clarify my self-written texts. All content is entirely my own work.

Warm regards,

Wendy Pruppers

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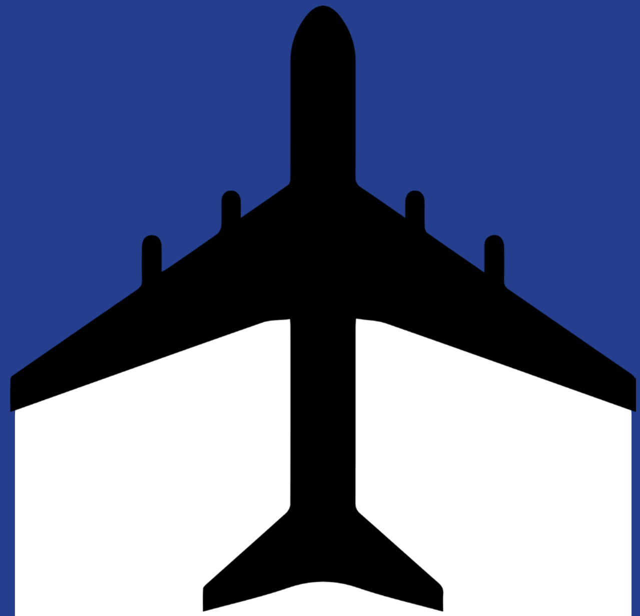

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LIST OF ABBREVIATIONS

AS Aerospace Standard
CCE Cabin & Cargo Equipment
CMM Component Maintenance Manual
ETSO European Technical Standard Order
EASA European Union Aviation Safety Agency
FAI First Article Inspection
IPL Illustrated Part List
MRO Maintenance, Repair and Operations
OEM Original Equipment Manufacturers
PO Production Organisation
POA Production Organisation Approval
SAE Society of Automotive Engineers

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Introduction

This chapter introduces the background, context, and objectives of the research on a flat-pack airline catering trolley for Driessen Catering Equipment BV. It begins by outlining the current industry challenge of inefficient transportation of fully assembled trolleys, leading to unnecessary costs and CO_2 emissions. The chapter then presents the commissioning company, Driessen Catering Equipment BV, highlighting their expertise and relevance to this project.

Following this, the problem statement clarifies the research gap and the unique constraints of the aviation sector. The research objectives and questions are then outlined to guide the study, while the scope and limitations section delineates the focus areas and boundaries of this research. Finally, the report outline offers a roadmap of how this research is structured, providing the reader with an overview of the upcoming chapters.

Figure 1: Driessen Catering Half Size Meal Trolley (Lexicon, 2024)

1.1 Project Introduction

Every year, airlines transport thousands of catering trolleys around the world. Most of them travel fully assembled, yet empty, wasting valuable cargo space, increasing shipping costs, and contributing to unnecessary CO_2 emissions. There are lots of projects looking at reducing the weight of the trolley to become more sustainable in their use phase, however looking at the stage of shipping to the customer is mostly overlooked. Currently, the trolleys are shipped in their fully assembled state, meaning that a significant portion of the transported volume consists of empty space. Given the fluctuating costs of ocean freight, the overall cost of the trolley is highly dependent on shipping expenses. During the COVID-19 pandemic, these shipping costs tripled, which increased their costs immensely.
To mitigate this risk and reduce costs for customers, this thesis is an investigation into the feasibility of a flat-pack trolley design. By reducing the trolley's volume during the initial transport from manufacturer to the client, more units could be shipped per container, leading to lower transportation costs and a reduced environmental impact. However, the aviation industry is highly regulated, and any new design must comply with strict safety and operational standards. This research focuses on assessing the feasibility of a flat-pack trolley within the current regulatory framework and designing a viable solution that meets industry requirements.

1.1.1 Driessen Catering Equipment BV

This project is commissioned by Driessen Catering Equipment BV (hereafter referred to as Driessen). Their headquarters are based in Alkmaar, The Netherlands, and their factory is based in Lamphun, Thailand.

Figure 2: Different Driessen Trolley Types (Equipment, 2025)

Driessen is a leading provider of advanced catering solutions, specializing in high-quality galley equipment for the aviation, railway, and maritime industries (Driessen Catering, 2025a). With decades of expertise, the company has established itself as a key partner for airlines and other transportation service providers, offering durable and efficient catering equipment that adheres to the highest industry standards.
Committed to continuous innovation and sustainability, Driessen actively develops new solutions aimed at reducing weight, enhancing durability, and improving the efficiency of onboard catering operations. As the frontrunner in trolley innovation, the company plays a vital role in shaping the future of onboard catering equipment.
Driessen's product portfolio includes trolleys, containers, and customized galley solutions designed to optimize space utilization, enhance workflow efficiency, and ensure compliance with stringent safety regulations (Driessen Catering, 2025b). Driessen's range of trolleys include meal trolleys, cooling trolleys, waste trolleys, retail trolleys, and high-top trolleys, available in both half-size and full-size configurations. The scope of this specific project is a Full size Dry-ice trolley, with a preference on the solution that can be implemented across other configurations of trolleys.

1.2 Problem statement and research gap

The primary issue addressed in this research is the inefficiency of the current shipping method for airline catering trolleys, where approximately 70% of the transported volume consists of unnecessary air. This inefficiency leads to high shipping costs and increased environmental impact. Although flat-pack designs are common in other industries, their application in the aviation sector presents unique challenges due to stringent regulatory requirements and operational constraints.
Although existing research and industry efforts have largely focused on lightweight trolley designs and material innovations, they have not thoroughly investigated the potential of flat-pack solutions for aviation use. While some competitors have experimented with flat-pack concepts for trolleys, these efforts were mainly marketing exercises rather than viable field-tested solutions, and therefore never advanced to production. This research aims to close that gap by evaluating the feasibility of a flat-pack trolley that meets aviation regulations and by developing a prototype that ensures safety, durability, and ease of assembly.

1.3 Research objectives and questions

The primary objective of this research is to design and evaluate a prototype for a flat-pack airline catering trolley for Driessen. The goal is to minimize initial transportation costs from the manufacturer to the client while ensuring the trolley remains durable, fully functional throughout its lifespan, and compliant with airline industry regulations, without compromising on sturdiness and weight.
To achieve this, the study will first analyze the regulatory requirements governing airline catering trolleys to determine the constraints and feasibility of a flat-pack design. It will then examine the current context, focusing on current shipping methods, construction methods, and supply chain logistics. Additionally, the research will explore the material properties of existing trolley components and identify potential improvements suited for a flat-pack solution. A comparative analysis of flat-pack solutions from other industries will be conducted to extract relevant design principles that could be adapted for this project.
This report will conclude with a design proposal of a flat-pack trolley, with a functional prototype showing how the mechanism works, and with an explanation of its opportunities and restraints. Finally, the study will evaluate the overall feasibility of implementing a flat-pack trolley by assessing its performance, cost-effectiveness, and potential environmental benefits.

The main research question is:

"How can a flat-pack airline catering trolley be designed to reduce transportation costs while maintaining durability, usability, and compliance with airline industry regulations?"

This question contains the following sub questions:

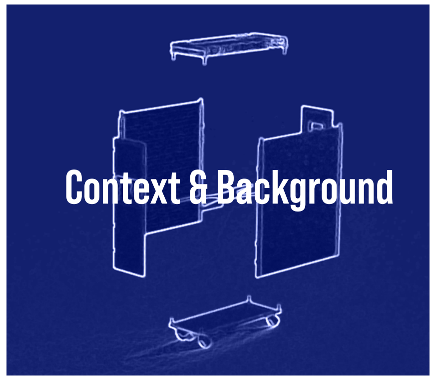
1. What is the context in which the airline catering trolley currently operates?
2. What is the structure and design of the trolley?
3. What existing solutions or alternative designs for foldable or modular trolleys are available in the market?
4. What are the key airline industry regulations governing catering trolleys, and how do they impact the feasibility of a flat-pack design?
5. What mechanical and structural solutions can be applied to ensure the trolley remains sturdy, easy to assemble, and without applying weight?
6. What are the potential cost savings and environmental benefits of a flat-pack trolley compared to the traditional design?

1.4 Scope and limitations

This research explores the feasibility and design of a full size flat-pack airline catering trolley, with a focus on regulatory compliance, structural integrity, and logistical efficiency. The primary objective is to analyze the existing safety regulations applicable to airline catering trolleys and assess how a flat-pack design could be implemented as an alternative to the current full-size trolleys shipped to customers.
The study will further investigate potential mechanical and material solutions that enable a collapsible design while maintaining the required strength and durability.
Additionally, the research will evaluate how such a trolley would integrate into the existing manufacturing processes and logistical framework. A preliminary calculation of the potential environmental and cost benefits of a flat-pack design will also be included.
The scope of this research is limited to regulatory analysis specifically concerning the feasibility of a flat-pack design. Broader regulatory aspects unrelated to the collapsible structure are beyond the scope of this study. Furthermore, a comprehensive context design will not be conducted. While regulatory requirements will be considered in the design phase, the development of certification documentation, including manuals and training materials for production and assembly, falls outside the project's scope. The study will take into account the production process when designing the trolley; however, the feasibility of large-scale manufacturing will not be examined in detail, as the focus remains on conceptual design and prototyping.
Prototype testing will be conducted on a limited scale to assess fundamental functionality, but extensive validation and certification testing of the redesigned trolley are beyond the scope of this research.

1.5 Report Outline

The structure of this midterm report is as follows:



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This chapter addresses Research Questions 1-3:

1. What is the context in which the airline catering trolley currently operates?
2. What is the structure and design of the trolley?
3. What existing solutions or alternative designs for foldable or modular trolleys are available on

This chapter answers Research Question 4:
 4. What are the key airline industry regulations governing catering trolleys, and how do they impact the feasibility of a flat-pack design?

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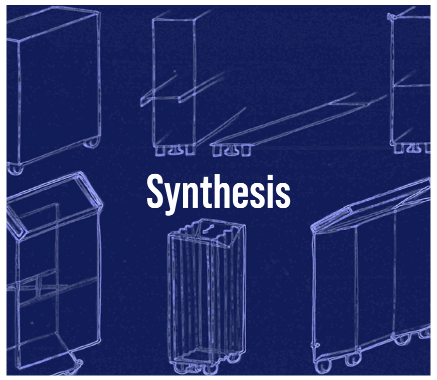

04

This chapter consolidates the research findings into a clear problem definition and outlines the design requirements for the start of the design project.

This chapter explores multiple flat-pack solutions and answers Research Question 5:
 5. What mechanical and structural solutions can be applied to ensure the trolley remains sturdy, easy to assemble, and lightweight?

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06

This chapter details the proposed flat-pack solution developed during the research.

This chapter evaluates the design through a volume assessment, cost analysis, and sustainability analysis.

07

08

This chapter summarizes the research findings, identifies the challenges the proposed design addresses, discusses the limitations, offers recommendations for future research, and includes a personal reflection

02

Context & Background

This chapter examines the context in which this project takes place by analyzing the current airline catering trolley system. It addresses the following sub-research questions:

1. What is the context in which the airline catering trolley currently operates?
2. What is the structure and design of the trolley?
3. What existing solutions or alternative designs for foldable or modular trolleys are available in the market?

Understanding the existing system is essential for identifying design constraints and opportunities for innovation. By exploring how airline catering trolleys function within their operational environment and evaluating current market alternatives, this chapter provides a foundation for determining the feasibility and potential advantages of a flat-pack trolley solution.

2.1 Prior to Use

The life of an airline catering trolley begins long before it ever enters a plane. It starts at the design stage, where engineers and designers define its dimensions, materials, and functionalities based on the operational needs of airlines and the strict safety and compliance standards set by aviation authorities. In Europe, these standards are governed by the European Union Aviation Safety Agency (EASA), which outlines the requirements for onboard equipment such as trolleys in terms of fire resistance, weight limitations, secure stowage, and crash safety. These regulations form the baseline for any trolley concept, shaping not only what is possible but also what is permissible in the highly regulated environment of commercial aviation. Chapter 3 - Regulatory Framework will explain what these regulations will mean for and within this project.

Once the design complies with these regulatory constraints and functional demands, it is passed on to the manufacturing stage, where materials are selected and components are assembled to meet both quality and certification standards.

2.1.1 Trolley Design

The trolley consists of multiple components, which can be grouped into seven main subassemblies:

1. Top
Different types of tops are used, including high tops, deep tops, and tops with a dry-ice compartment. For this design assignment, the focus is on the dry-ice top, as it is the most common in trolleys and presents the greatest design challenges. Successfully addressing this configuration means the design can be easily adapted to other top variants. They also incorporate corner pieces that help the trolley remain square and prevent it from deforming into a parallelogram under load.

2. Bottom Assembly
The bottom section of the trolley houses the brake system, which is essential for safe operation during service. This system is mandatory on all trolleys, making it an important design consideration in this project. The bottoms also contain the corner pieces which hold the same function as the corner pieces on the top assembly.

Figure 3: Exploaded view Driessen Full Size Premium Meal Trolley

3. Front Door
The front door includes a locking mechanism and anti-theft features, ensuring that no unauthorized objects (such as knives or other contraband) can be hidden inside.

4. Rear Door
The rear door functions similarly to the front door, maintaining security and structural integrity.

5. Left Side Panel
The side panels are connected to the top and bottom through extrusions which connect to the corner pieces. These side panels house the runners on which the drawers slide.

6. Right Side Panel
This component mirrors the functionality of the left side panel, ensuring symmetry and stability.

7. Horizontal Divider
The function of the horizontal divider is twofold: first, it distributes forces from front to back, particularly when the door is pulled open; second, the bar connecting the two side panels prevents the trolley from bowing outward when heavy drawers are placed on the runners. As a result, this central bar primarily experiences tensile forces rather than compressive forces. It must be able to withstand a maximum load of 9.0 g.

2.1.2 Trolley Material

The primary material used in Driessen's trolleys is aluminum, chosen for its lightweight and sturdy properties, which are essential in the airline industry, where minimizing weight is crucial. Aluminum offers a unique combination of characteristics that make it well-suited for this application. It is lightweight, corrosion-resistant, nonmagnetic, and highly ductile. Additionally, it has a low melting point, a moderately high coefficient of expansion, and excellent thermal and electrical conductivity (Chakrapani & Suryakumari, 2021). These properties make aluminum not only easy to process but also highly adaptable to various manufacturing techniques.

The elasticity of aluminum enables the use of snap-fit connections, which allow for faster assembly compared to conventional methods like screwing or welding. A reusable snap-fit connection requires an angle (α) of 45°, whereas permanent connections have an angle of 0° or negative (Sapa Profiler AB et al., 2007). The length of the snap-fit joint influences the design, and the resilient leg should not be shorter than 15 mm. In some cases, longer resilient legs must be pressed under pre-tension, eliminating the need for special tolerances.

By utilizing these advanced manufacturing techniques, aluminum is transformed into lightweight yet durable components that meet the stringent requirements of the airline industry, ensuring both efficiency and reliability in Driessen's trolley designs.

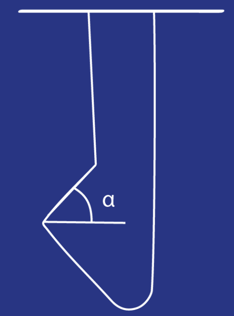


Figure 4: Snap fit angle

2.1.3 Trolley Packaging and Shipping

When the trolley is designed and manufactured it is ready to be shipped. Some customers place a high priority on keeping trolleys free from scratches, making protective packaging essential. The standard packaging consists of an individual box for each trolley, with the trolley enclosed in a foam bag and a protective cover box before being placed on a pallet (Driessen Catering Equipment Ltd., 2024). Typically, six boxed trolleys fit on one pallet, whereas unboxed trolleys can be packed more efficiently, with up to eight per pallet. The pallets used by Driessen include Block Pallet 120-100 and Euro Pallet 120-80. Certain customers require additional protection, such as 3 cm PU foam on the sides of the boxes. Loose assemblies are wrapped to prevent damage during transit.

Trolleys are primarily shipped by sea in 40-foot containers with 193 trolleys per container, see Appendix 10.10. The freight costs fluctuating significantly. On January 3rd, 2025, the cost of these containers, according to the Freightos Baltic Index - Global, was $4,290.5, but by March 28, 2025, this had dropped to $2,049.8 (Freightos Terminal - Global Air And Ocean Market Intelligence, z.d.). Due to this volatility, the attractiveness of a deal can vary significantly. This risk could be mitigated by implementing a flat-pack trolley model, as it would allow for more trolleys to be transported per container, reducing the proportion of transport costs per trolley. With the current design 220 trolleys are shipped per 40 foot container.

While most shipments follow the standard packaging process, some airlines prefer to minimize waste from cardboard boxes and foam covers. To accommodate these preferences, trolleys can also be shipped directly on pallets upon client request. Additionally, interviews have highlighted key considerations for designing a flat-pack solution, such as packaging materials and increasing transport efficiency. Moreover, damages occurring during the assembly phase must be minimized, necessitating the implementation of additional protective packaging measures.

Figure 5: Fluctuating cost of one 40ft container from 18-02-22 to 14-02-25, Freightos Baltic Index Global

2.2 Use Phase

Driessen's clients consist of both Original Equipment Manufacturers (OEMs) and individual airlines. The number of trolleys ordered per batch varies significantly, ranging from as few as one unit to as many as a thousand. OEMs tend to purchase trolleys in smaller quantities, incorporating them into new aircraft during production. In contrast, airlines typically place larger orders and are therefore the primary clients for the flat-pack trolley concept. The viability of a flat-pack solution may therefore depend on batch sizes, as larger orders could benefit more from space-efficient shipping and storage.

Upon arrival at their destination, trolleys are received either at airline warehouses or catering facilities. In catering facilities, the person responsible for unpacking the trolley is often also in charge of its initial cleaning. In the case of the flat-pack solution, this same individual is likely the one who assembles the trolley into its operational form. During airline operations, trolleys pass through multiple stakeholders, including catering staff who handle loading and stocking, ground transportation teams responsible for moving them from storage to the aircraft, and flight attendants who depend on ergonomic and functional designs for efficient in-flight service.

The average lifespan of a trolley is approximately ten years, with a rotation cycle in airline operations of around three days. However, trolleys used on shorter flights experience more frequent use and wear, often leading to earlier damage. Due to the demanding and fast-paced environment of catering facilities, trolleys are frequently handled roughly, thrown, or misused, which accelerates deterioration. When a trolley sustains damage, flight crews are responsible for reporting the issue, and the damaged unit should be replaced. However, in practice, these reports are often not made, and damaged trolleys continue to be used, potentially leading to safety risks.

2.2.1 Carbon Footprint Trolley

To integrate sustainability into this project, it is essential to understand the environmental impact of an airline catering trolley. In 2023, Driessen conducted a study to assess the potential contribution of its trolleys to global warming, expressed in CO_2-equivalent (CO_2e) emissions (Driessen Thailand Greenhouse Gas Management Organization, 2023). This study quantified all significant greenhouse gas (GHG) emissions across the entire product life cycle, including all key phases: material acquisition, production, distribution, use, and end-of-life, without exclusions or cut-off criteria. The results of this assessment are presented in Table 1.

The findings indicate that the use phase has the highest environmental impact. However, this does not diminish the importance of addressing emissions in other phases, particularly distribution, which is the focus of this project. While optimizing the distribution phase may not drastically reduce the overall carbon footprint of a trolley, it still represents an opportunity for improvement. Due to this assessment it is clear that weight is an important requirement as it has a direct effect on the use phase, and that materials are not so important as the impact is marginal. So weight is king, sustainable materials are less important. Acknowledging that the impact of this intervention may be relatively small, it nonetheless contributes to broader sustainability efforts by enhancing transport efficiency and reducing emissions in a critical part of the supply chain.

Stages	Carbon Footprint	
	(kg CO_2e)	(%)
Raw material acquisition	123.78	0.06
Production	16.00	0.01
Distribution	4.24	0.00
Use	224,323.13	99.94
End-of-life	0.62	0.00
Total	224,467.77	100.00

Table 1: Life Cycle CO_2e Emissions of an Airline Catering Trolley (Driessen, 2023)

2.3 Flat-pack Solutions in Market

Avius Containers

AviusULD, a subsidiary of the Cabin & Cargo Equipment (CCE) Group, specializes in air cargo transport solutions and already employs a flat-pack model for cargo units. This system relies on certified MRO stations for assembly, ensuring compliance with strict aviation regulations (Appendix 10.2).

AviusULD collaborates with Unilode, a global repair provider offering fixed pricing, reducing costs for larger-scale assembly. However, smaller MRO stations without fixed pricing may require additional training, increasing costs. To maintain quality control, a dedicated team oversees assembly, using First Article Inspection (FAI) for the initial unit, followed by simplified documentation for subsequent units.

Figure 6: AVIUS Cargo Container

The assembly process follows technical guidelines, including the Component Maintenance Manual (CMM) and the Illustrated Parts List (IPL). Subcontracting adds costs related to labor and certification, but AviusULD is working on an improved approval structure to streamline processes.

This flat-pack approach could serve as a model for Driessen's trolley solution. However, refining training, certification, and approval processes will be essential to maintaining efficiency and compliance. Unlike cargo containers, which are significantly larger and require 3 to 6 hours for assembly, service trolleys can be assembled in just 5 to 10 minutes. This key difference highlights the potential for a much faster and more efficient implementation of a flat-pack trolley model.

Avius Collapsible Containers

Avius also offers a collapsible container designed with user convenience as a top priority. These containers are delivered pre-assembled, eliminating the need for initial assembly at an MRO station. They can be deployed by a single person in less than a minute, without requiring any tools. However, their relatively high weight limits their adoption by clients.

Figure 7: AVIUS Collapsible Cargo Container

While this container is considerably larger than a catering trolley, its folding mechanism and overall approach to collapsibility can serve as an inspiration for developing a flat-pack trolley design. By studying the principles of this design, valuable insights can be gained into how to create efficient and user-friendly folding solutions within the aviation industry.

Foldable Service Cart

A specific type of foldable service trolley is already available on the market, typically featuring two- or three-shelf configurations designed for use in first-class and business-class cabins. These trolleys are certified because they arrive as a single, fully integrated unit that matches the approved design drawings. Consequently, they require no additional assembly

Figure 8: Driessen foldable service cart

or connection of parts after delivery, enabling certification to occur at the time of manufacture.

This design serves as an inspiration for ensuring that a flat-pack design could also achieve certification. By studying this approach, it may be possible to incorporate similar design and assembly principles into a future flat-pack trolley concept, facilitating compliance with certification requirements.

SPICE Foldable Service Cart

Airbus previously developed the SPICE (Space Innovative Catering Equipment) project, aimed at creating a new galley system to improve weight efficiency, space utilization, and crew usability. This concept was recognized with an IDEA award in 2008 (Formation Design Group - Spice, z.d.). As part of the SPICE system, a foldable service trolley was also designed. However,

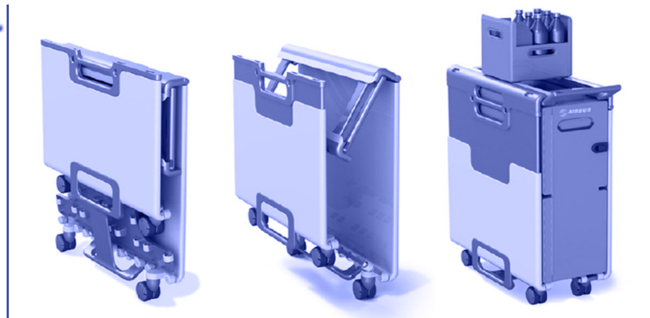


Figure 9: Spice foldable service cart

the project was never brought into production but remains a valuable source of inspiration.

Although this design offers an interesting perspective on alternative approaches to creating a foldable trolley, it is less relevant to this project. Implementing such a design would require a complete overhaul of the aircraft galley, and it does not currently meet existing regulations, making it impractical in the short term.

Flightweight LTD smartcart

One notable attempt at a lightweight, flat-pack airline trolley was developed in 2013 by Flightweight Ltd, a company specializing in aviation security solutions and lightweight trolley designs (Half-size Aircraft Meal Cart, z.d.). Their concept introduced a modular, flat-pack structure aimed at simplifying repairs and reducing downtime for airlines.

Figure 10: Flightweight LTD smartcart

The trolley's modular construction required precise manufacturing of individual panels, which were assembled using bolts and aluminium corner extrusions. Ogle, the manufacturing partner, employed a milling machine to drill the extrusions for the fixing points, ensuring that the panels could be securely slotted together at the base. However, despite its promising design, the exact mechanism of the flat-pack functionality remains unclear, and the product never reached commercial production.

2.4 Conclusion

In conclusion, this chapter has provided a comprehensive overview of the operational context, design characteristics, and existing market alternatives for airline catering trolleys, addressing the first three sub-research questions:

1. **What is the system in which the airline catering trolley currently operates?**
2. **What is the current trolley design?**
3. **What existing solutions or alternative designs for foldable or modular trolleys are available on the market?**

The analysis revealed that the trolley comprises seven main subassemblies, each fulfilling a distinct function. The trolleys are predominantly made from aluminum due to its lightweight nature and compatibility with snap-fit connections, an important consideration for potential flat-pack designs.

Currently, trolleys are shipped either boxed or unboxed, depending on customer requirements, with a maximum of 220 trolleys fitting into a 40-foot container. The feasibility and interest in a flat-pack design may vary depending on order size.

From a sustainability perspective, the use phase of the trolley contributes the most to its environmental footprint, making weight reduction a key priority in the design process. Although the distribution phase has a relatively lower impact, it remains important to consider it to minimize the trolley's overall footprint.

The review also highlighted attempts by other companies to introduce flat-pack solutions, offering valuable insights into different folding mechanisms and potential assembly strategies. For example, solutions like Avius's collapsible containers demonstrate the possibility of shipping flat-pack trolleys that can be assembled at MRO facilities, while foldable service carts illustrate how a fully integrated design could eliminate the need for additional assembly by MRO's. These examples serve as inspiration for developing an innovative, flat-pack trolley concept that aligns with industry requirements and sustainability goals.

03

Regulatory Framework

This chapter explores the regulatory landscape governing airline catering trolleys, with a focus on identifying opportunities for implementing a flat-pack trolley design. To achieve this, it addresses the fourth sub-research question:

"What are the key airline industry regulations governing catering trolleys, and how do they impact the feasibility of a flat-pack design?"

By analyzing relevant aviation regulations and standards, this chapter aims to pinpoint design constraints and identify potential gaps where a flat-pack solution could be viable. The goal is to determine how such a trolley could function within existing airline operations while ensuring full compliance with safety, durability, and usability requirements.
Within the aviation industry the products have to follow the regulations of the European Union Aviation Safety Agency (EASA) before the trolley is approved to be used in the airplane. EASA is responsible for Ensuring safety and environmental protection in civil aviation in Europe (European Union Aviation Safety Agency | European Union, z.d.). EASA is also the organisation who check and certifies the aircrafts, parts and equipments by approving and overseeing organisations in all aviation domains (The Agency | EASA, z.d.).

The trolley has to apply to four different regulation manuals, EASA Part 21, EASA CS-25, ETSO C175 and AS8056. These documents will be explained in the following sub chapters.

3.1 EASA Part 21

This EASA Part 21 contains the aviation rules for the 21st century. These rules are the core of the EU civil aviation system (“Easy Access Rules For Initial Airworthiness And Environmental Protection (Regulation (EU) No 748/2012”, 2024). EASA Part 21 establishes standardized technical requirements and administrative procedures for ensuring the airworthiness and environmental compliance of all aviation products, parts, and appliances.
It outlines the approval process for design changes, repairs, and production organizations, as well as compliance with environmental and noise regulations.
The EASA Part 21 regulation also defines requirements for product identification, airworthiness directives, and declarations of design and production capability.
Additionally, it governs the certification processes for aircraft and their components, including type certificates, airworthiness certificates, and permits to fly. TThis is an important part of the assignment, as it is necessary to know when the designed trolley is permitted to fly. For this, understanding the EASA Form 1 is essential.

3.1.1 EASA Form 1

The EASA Form 1 is the Authorized Release Certificate released by a Production Organisation Approval (POA) holder for stating that a product, a part, or a component was manufactured in accordance with approved/not approved design data (EASA, 2015). Design data includes CAD models, drawings and technical specifications (Design Data Definition: 112 Samples | Law Insider, z.d.). This form is given upon the initial transfer by it of ownership of such a product, presented by the competent authority, in our case Driessen. Then, the competent authority shall validate by counter-signature the statement of conformity if it finds after inspection that the product, part or appliance conforms to the applicable design data and is in condition for safe operation.
An EASA Form 1 has to be issued by appropriately qualified authorized staff. Part 21 does not require authorized staff to be on-site when issuing an EASA Form 1. However, strict risk management, equipment suitability, and cybersecurity measures must be in place.

3.1.2 Production Organisation

As said, EASA part 21 also defines requirements for production capability. Within this assignment it is important to understand which people are required to assemble and to which point organisations should be certified to fulfill tasks as for example unfold a flat pack trolley.

According to the EASA Part 21, a Production Organisation (PO) is a company or entity that has the approval to manufacture aircraft, aircraft parts, engines, or components in compliance with aviation regulations. Not every company can produce these items because aviation authorities, such as EASA, require strict controls to ensure safety, quality and conformity to approved design data. A PO that holds a POA has demonstrated that it has the necessary infrastructure, quality systems, processes, and personnel to manufacture aerospace products consistently and safely. This approval allows them to produce and certify their products without needing direct oversight for each individual item.

Within this regulation document it is also stated that production without POA is possible, and the difference lies in the level of oversight and certification process. A fully approved PO has been assessed by the competent authority and given ongoing approval to manufacture and certify their own products. This means they can issue the necessary certificates, such as EASA Form 1 for parts and appliances, without needing additional inspections for each product. On the other hand, companies that manufacture under Production without POA do not have this blanket approval. Instead, they must apply for approval on a case-by-case basis for each individual product or batch they produce. They are required to demonstrate conformity with the design data for every product they manufacture, and the competent authority must be directly involved in verifying compliance. This process is more restrictive because these companies do not have a fully approved quality and production system that allows for continuous, independent manufacturing.

In summary, a PO with POA has the privilege of producing and certifying aerospace products under its own responsibility, while those without POA must rely on external validation for each production run. This distinction ensures that only organisations with proven, reliable, and well-controlled manufacturing processes can operate independently in the aerospace industry. This gives the opportunity that uncertified organisations can do an easy last step of assembly, as long as the last check is done by the competent authority, in this case, Driessen.

3.2 EASA CS-25

The EASA CS-25 Certification Specifications apply to turbine-powered large aircraft and their components, including galley carts and service trolleys, ensuring compliance with structural, safety, and operational requirements (“Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes (CS-25),” 2021). This document provides broad guidelines on equipment compliance, stating that it must be designed appropriately for its intended function, labeled with its identification, function, or operating limitations (see AMC 25.1301(a)(2)), and installed according to the specified limitations for that equipment. However, CS-25 does not explicitly outline specific requirements for catering trolleys. While it is important to acknowledge this document, it is less relevant for this flat-pack trolley research, as other regulatory documents provide clearer guidance on the specific requirements the trolley must meet.

3.3 ETSO C175

The European Technical Standard Order (ETSO) C175 sets the requirements in accordance with Part 21 which Galley Cart, Containers and Associated Components must meet in order to be identified with the applicable ETSO marking to demonstrate that the installation complies with the applicable certification basis(ETSO Authorisations | EASA, 2017). This ETSO document says that the trolley must meet the Society of Automotive Engineers (SAE) AS8056 (European Aviation Safety Agency, 2008), which is the document explained in the next subchapter.

3.4 AS8056

This SAE Aerospace Standard (AS) defines the minimum design and performance criteria for carts, containers, and related components used in galleys and other sections of transport-category aircraft (Society of Automotive Engineers (SAE) & European Organization of Civil Aviation Equipment (EUROCAE), 2009). Which means that the eventual design has to comply with the requirements stated in this document. This document also states what the compliance method is per requirement.

With eye on the flat-pack trolley assignment, the following requirements within this document are the most important regarding this project:

Wear and Tear
Hinges, latches, and other moving components, such as springs, must be designed for durability and resistance to wear over time (European Commission, 2012).

Unacceptable Features
Any design elements known to be unreliable should be avoided. This includes:
Snaps or attachment mechanisms prone to clogging with waste.
Hollow-core (pop) rivets.
Plates, doors, and panels that lack sufficient stiffness and exhibit “oil-canning” behavior.

Scissor Type Devices
The cart's folding mechanism must be designed to minimize the risk of injury. Scissor-type folding mechanisms with exposed parts are not acceptable.

Continued Airworthiness
Maintenance instructions must be provided to ensure the trolley remains in an airworthy condition. These instructions should address potential wear and the effects of rough handling during regular use.

Local attachment factor
A safety factor of 1.33 must be applied to attachment points such as door hinges, latches, and retaining devices, as these components may degrade over time before their scheduled replacement.

Doors and hinges
Hinges must be designed to minimize hazards to personnel and should not protrude excessively in either the open or closed position.

3.4.1 Product Testing

The initial qualification of the equipment must be conducted through testing.
Any subsequent qualification of design modifications for similar equipment may be carried out through analysis, provided it is supported by existing test data. When testing is performed, the test specimen must be identical to the final production model.
The test which are relevant for the flat pack trolley project are as follows.

Structural tests
Load Testing: The trolley must withstand emergency landing forces, turbulence, and ground handling.
Static Load Testing: Forces are applied to simulate weight and impact loads, using load factors such as: 9.0g forward/aft, 6.0g downward, 3.0g upward, 9.0g sideward.
Adjacent Equipment Loading: The trolley must be tested with simulated forces from other carts stored next to it.
Retention Testing: Ensures doors, hinges, and latches can keep contents secure under extreme loads.

Fire safety tests
Flammability Test: Materials must comply with FAA 14 CFR 25.853.
Heat Release and Smoke Density Test: The top, sides, front, and back of the trolley must be tested per Appendix F, Parts IV and V.

Maneuverability and Stability Testing
The trolley must be stable during:
Opening/closing doors.
Loading/unloading contents.
Moving on carpeted airplane aisles, lift platforms, and ground kitchen floors.
It must remain stable whether empty or fully loaded.

3.5 Conclusion

This chapter explored the regulatory framework governing airline catering trolleys to assess the feasibility of implementing a flat-pack design. The research question

“What are the key airline industry regulations governing catering trolleys, and how do they impact the feasibility of a flat-pack design?”

was addressed by analyzing four key regulatory documents: EASA Part 21, EASA CS-25, ETSO C175, and SAE AS8056.

ETSO C175 and **SAE AS8056** define critical design constraints for catering trolleys, particularly regarding structural integrity, safety, and usability. These regulations emphasize the importance of wear and tear resistance, stability, and durability of hinges and folding mechanisms, which are crucial for the feasibility of a collapsible trolley. Additionally, fire safety regulations impose strict material requirements that must be adhered to, further influencing design choices.

EASA Part 21 outlines the certification requirements for POs involved in manufacturing aircraft components. However, a key insight from this regulation is that final assembly does not necessarily require a certified production organization, as long as the completed product undergoes inspection and approval by a competent authority such as Driessen.

This regulatory document also suggests that if a flat-pack trolley is designed with a sufficiently simple assembly process, it could be argued that assembly errors are highly unlikely. In such a case, the only requirement would be issuing a Form 1 certificate at the place of assembly. Additionally, considering that form 1 certificates verify that the assembled trolley conforms to the approved design drawings, would mean if the flat-pack trolley consists of a single primary structure that aligns with the final design specifications, Form 1 certification could be granted at the manufacturing stage, just as it is currently done with traditional trolleys.

04

Synthesis

This chapter synthesizes the findings from the previous chapters. It aims to integrate these insights to define a coherent basis for the design phase. Based on the findings from the research phase, several potential strategies were identified for how Driessen can ship trolleys in a flat-pack form. These strategies vary depending on where the final assembly takes place and who issues the necessary certifications.

4.1 Possible Design Directions

From the research, three primary pathways emerged:

1. Flat-pack parts shipped and assembled at a Part-145 station (MRO), with Form 1 issued there, this would require a PO extension under EASA Part 21G.
2. Flat-pack parts shipped and assembled at the client site, raising questions about who is responsible for assembly and certification.
3. Foldable trolley assembled and certified (Form 1) at the manufacturer.

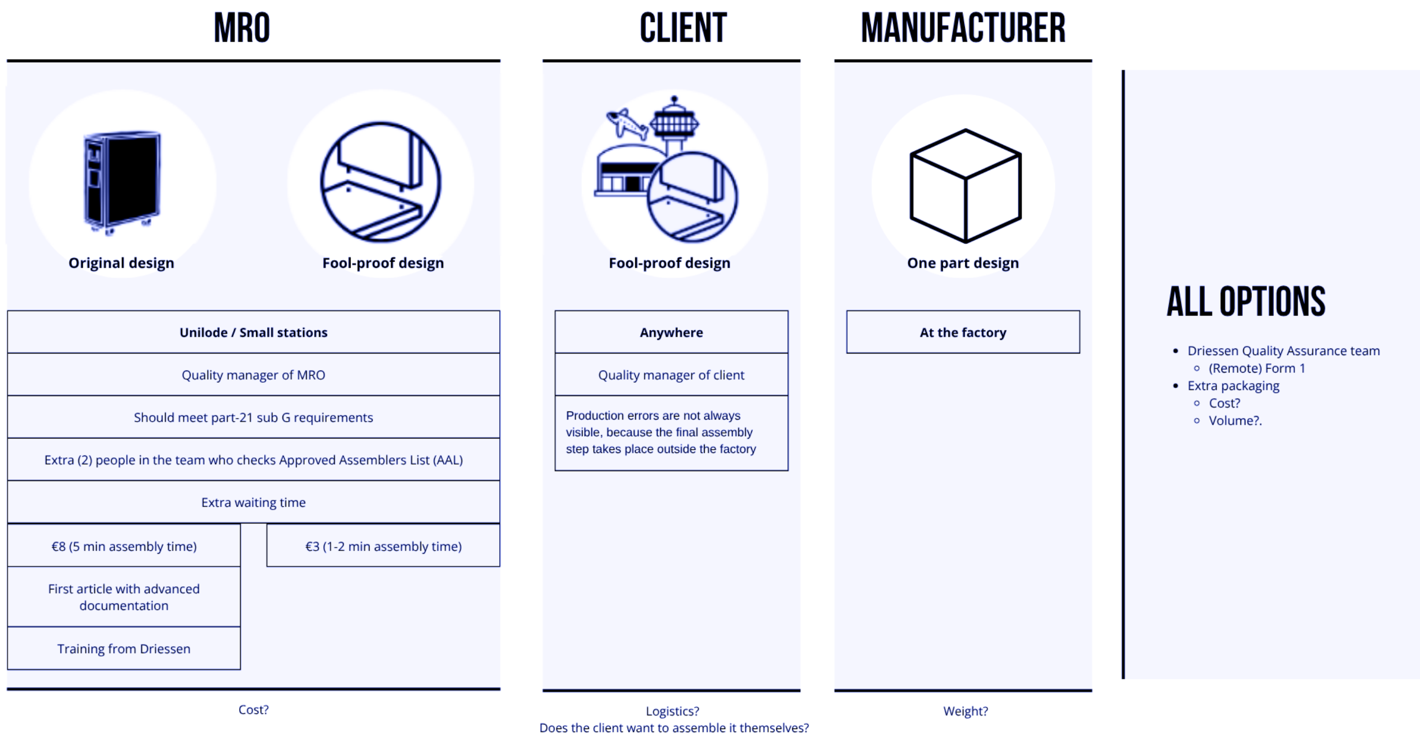


Figure 11: Design context possibilities, explained with their changes in the system

These pathways lead to two main design directions:

- **One-part design:** The trolley is shipped in a foldable form that meets all design specifications upon leaving the manufacturer. In this case, Form 1 can be issued at the manufacturing site, avoiding additional assembly steps, costs, or certification complexities.
- **Modular design:** The trolley is divided into components that are assembled at the destination. If assembly requires tools, this would need to be done at certified MRO (Maintenance, Repair & Operations) stations by trained personnel, under supervision from Driessen.

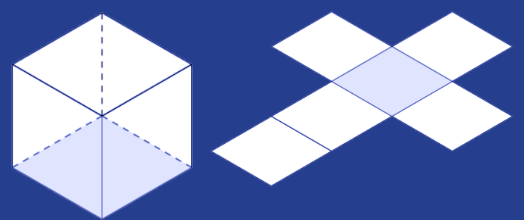


Figure 12: Unfolded cube, which works as inspiration for the one-part design

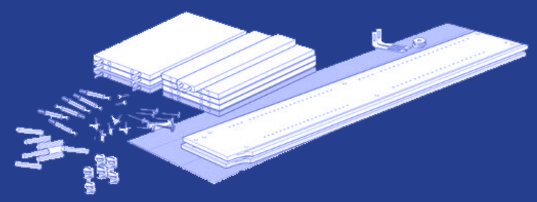


Figure 13: Ikea flat-pack package, which works as inspiration for the one-part design

However, if a modular design is foolproof and tool-free, it could potentially be assembled by uncertified personnel, for example, at the client's facility. In this scenario, the assembly would fall under **EASA Part 21 Subpart F: Production Without Production Organisation Approval (POA).** This approach involves several requirements:

- The client must implement a **production inspection system** to ensure each trolley meets the approved design and is safe to operate.
- A manual must be provided, outlining the inspection procedures.
- For each assembled trolley, a s**tatement of conformity** (or EASA Form 1) must be issued and signed by an authorized person in the client's organization.
- Driessen must **validate** this statement through inspection and a counter-signature, confirming that the trolley conforms to design standards and is safe to use.

Further, less critical regulatory requirements are outlined in Appendix 10.3

This design phase will explore both directions in detail to determine the most feasible and efficient solution for flat-pack trolley implementation.

4.2 Cost Calculation

Before the start of the design phase, an initial cost analysis is relevant to evaluate potential savings based on varying levels of volume reduction. The table below illustrates how many trolleys could fit into a shipping container at different volume reduction levels, along with the corresponding cost per shipment batch.

		50% volume reduction	66% volume reduction	80% volume reduction
N per batch	220	440	660	1100
Cost of batch	€ 3.000,00	€ 3.000,00	€ 6.000,00	€ 12.000,00
	€ 5.000,00	€ 5.000,00	€ 10.000,00	€ 20.000,00
	€ 7.000,00	€ 7.000,00	€ 14.000,00	€ 28.000,00
	€ 10.000,00	€ 10.000,00	€ 20.000,00	€ 40.000,00
		Cost saving per batch		

Table 2: Cost saving per 40-ft container per % trolley volume reduction

These figures demonstrate the potential cost savings per container if more trolleys can be shipped due to a reduction in their packed volume. For example, a 50% volume reduction allows for double the number of trolleys (440 units) to be transported per container, effectively saving the cost of one full container (e.g., €3,000). The actual savings depend on both container prices and the total number of trolleys that can fit per shipment.

Currently, it is already possible to ship the trolley in separate parts and assemble it at a MRO station. Assembly can be relatively quick, taking approximately 5 minutes per unit. However, this approach involves additional costs, as shown in table 3.

Cost Part 145 Stations (EUR/h)	€ 95,00
Assembly time 1 trolley (min)	5
N assembled trolleys per hour	12
Cost per batch (660)	€ 5.225,00

Table 3: Estimated MRO costs per batch of trolleys assuming a trolley assembly time of 5 minutes

Note: These are rough estimates. Additional costs apply for training MRO personnel at partner facilities such as Unilode, and for the transportation of components to certified Part-145 stations.

The analysis shows that shipping trolleys with a **60% volume reduction** (allowing for 660 units per batch) can result in cost savings. However, the margin is relatively small, and relying on MRO stations for assembly adds logistical complexity and costs.

Therefore, the next chapter: design process focuses on two optimized design approaches:

1. **A foolproof, tool-free design** that enables assembly at the client site, eliminating the need for certified personnel or MRO involvement.
2. **A one-part, foldable design** that can be shipped fully assembled and certified directly from the manufacturer.

These directions aim to simplify logistics and maximize both cost efficiency and scalability.

4.4 List of Requirements

Within this list of criteria, only the criteria for the trolley that are relevant for the project are placed here, other requirements are out of scope since the flat-pack-design doesnt have to be accountable with these. The source of each requirement is stated so that the strictness of the requirement can be determined.

	Requirement	Description	Source
1.	**Standard Dimensions**	The trolley must have dimensions 303x430x1016.5 mm (LxDxH) to meet airline standards.	ATLAS*
2.	**Weight Limit**	The design solution should be a maximum of 100 grams more weight than the current solution.	Driessen
3.	**Fire Test**	The trolley must be airtight to stop possible fires to grow within the trolley.	EASA
4.	**Assembly Time**	The trolley must be able to be assembled within 5 minutes.	Driessen
5.	**Tool-free Assembly**	The trolley must be assembled without tools, so no PO is needed when final assembly.	EASA
6.	**Horizontal Divider**	The horizontal divider must be able to withstand a load of 9g on the whole trolley.	ATLAS*
7.	**Structural integrity**	The trolley must not jiggle or move in unwanted places when assembled after flat-pack	EASA
8.	**Durability**	The trolleys lifetime should remain approximately 10 years	Driessen
9.	**Fool-proof**	The design needs to be so clear, easy and intuitive that no one can assemble it wrong	EASA
10.	**Regulations**	The design fits to the standard trolley regulations	EASA

Table 4: List of Requirements

**ATLAS specifications define the standard dimensions and technical requirements for airline catering equipment, especially trolleys and containers, to ensure they are interchangeable across different aircraft and airlines.*

4.5 List of Wishes

This list of wishes contains Driessen's wishes for the project, which the new trolley design should fulfill.

	Wish	Description	Source
1.	**Volume**	The flat-pack solution must at least reduce 50% of the volume of the original trolley during transport	Driessen
2.	**Foldability**	The trolley must collapse efficiently for transport while maintaining easy deployment for use.	Driessen
3.	**Quick Folding mechanism**	Ideally a one-step or automated folding system for maximum efficiency.	Driessen
4.	**Amount of Parts**	The trolley needs to add at least parts as possible to keep assembly as efficient as possible.	Driessen
5.	**Sustainability**	The distribution phase of the trolley should reduce with 50%.	Driessen
6.	**Design Similarity**	Stays similar to the original design as possible, so that the implementation of the design is easier for Driessen.	Driessen
7.	**System**	The operational system stays the same. No new complex systems arise and the implementation for driessen will be easier.	Driessen
8.	**Versatility**	The design is applicable to other driessen trolley types	Driessen
9.	**Half-size**	The design is applicable to the full size and the half size trolley	Driessen

Table 5: List of Wishes

05

Design Process

This chapter elaborates on the development of the design strategies used to create a redesigned flat-pack trolley concept, building on the insights gained from the previous chapters. It will also show different possibilities and ideas to approach this design.

The design process aims to translate both theoretical and practical knowledge into tangible design solutions. This section describes the steps taken to develop the final design proposal, highlighting the considerations, trade-offs, and methodologies that informed the proposed design.

“What mechanical and structural solutions can be applied to ensure the trolley remains sturdy, easy to assemble, and lightweight?”

Figure 14: Brainstorm session with Driessen Engineers

5.1 Collaborative Session

To explore innovative design strategies for the trolley, a collaborative brainstorming session was conducted with the Engineering team in Alkmaar. Their deep understanding of the trolley's construction and functionality made them invaluable participants during this ideation phase.

5.1.1 Objective

The primary goal of the session was to explore folding mechanisms, to generate potential (mechanical) solutions that would enable compact trolley transport without compromising robustness or increasing weight.

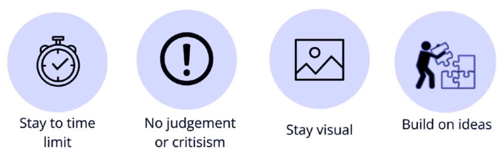
5.1.2 Method

The session was structured around six design questions, each written on a separate sheet of paper.

1. In what ways can the trolley be divided into separate components for efficient transport?
2. How can the trolley maintain strength and stability while being designed for efficient transport?
3. What innovative mechanisms or materials could simplify the assembly and disassembly process?
4. Connecting mechanisms that don't need tools for assembly
5. How to minimize space during transportation of the trolley?
6. How to make the trolley as compact as possible?

Participants rotated between the questions, spending three minutes per sheet to generate ideas. After each round, the paper was passed to the next person, who continued building on the previous ideas. This fast-paced format helped create a focused, open-minded atmosphere where critique was naturally avoided due to time constraints.

The following ground rules were set to guide the process:



Once every participant had engaged with all six questions, a final round took place where each person presented and explained the ideas on the sheet in front of them. Following the individual brainstorming rounds, a planetary brainstorming session was held to reflect collectively on alternative flat-pack solutions and key considerations for future development.

5.1.3 Key Insights

The most promising concepts identified through this process are shown in Image 15. The other ideas are documented in Appendix 10.4.
Based on the discussions and outcomes of this session, I created a series of concept sketches. While these ideas are not being pursued further at this stage, primarily due to feasibility concerns within the current project timeline, several concepts hold promise for future exploration. Noteworthy examples include plastic hinges and detachable wheels, which offer potential for improving compactness without sacrificing structural integrity.

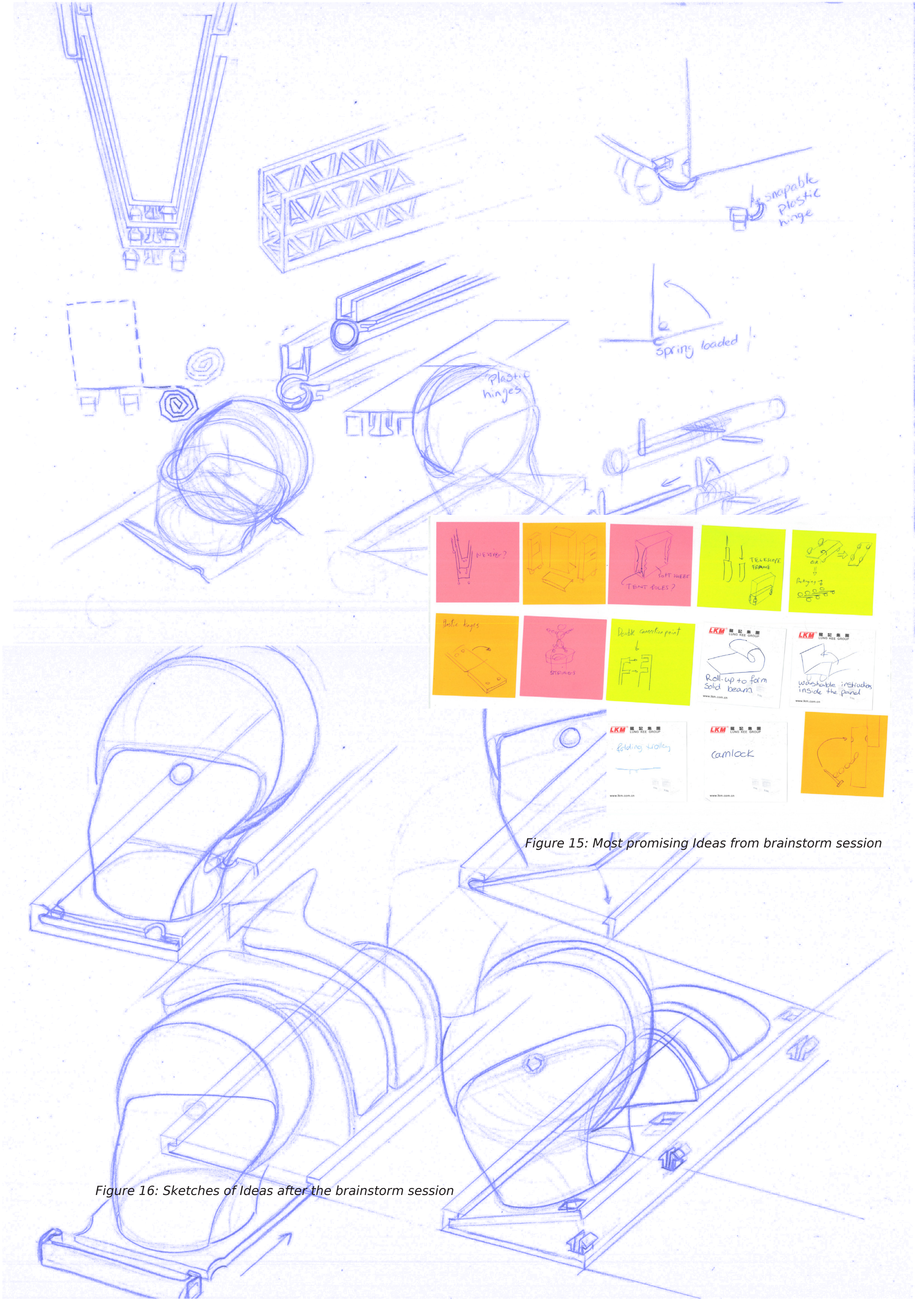


Figure 15: Most promising Ideas from brainstorm session

Figure 16: Sketches of Ideas after the brainstorm session

5.2 Initial Concepts

For the individual brainstorm I continued with the design ideas from the collaborative session and the knowledge from the previous chapters. As described in Chapter 4, there are two main approaches to creating a flat-pack design for the trolley: a foolproof, tool-free design made up of multiple parts (similar to an IKEA flat-pack) or a single-piece, foldable design. To explore these options, brainstorms on both these configurations were held to come to a decision.

5.2.1 Multiple-part Trolley

For the multiple-part trolley an analysis was conducted to understand how the trolley is currently assembled and to determine how it could be divided into as few parts as possible while still achieving significant volume reduction. The analysis revealed several logical configurations (see Appendix 10.5). A five part trolley design would be the most optimal solution, this configuration is shown in figure 17.

Further research was carried out on how to assure easy, foolproof and sturdy assembly. Snap-fits emerged as the most promising solution, even when working with aluminum. As a result, a more in-depth brainstorming session focused on aluminum snap-fits was held (see Appendix 10.6). Various implementation concepts were sketched, some of which are shown in image 19.

The most promising concepts were prototyped using 3D printing to evaluate their functionality. However, snap-fitting large extrusion surfaces requires significant force and can increase weight. A more effective approach was found by adapting the existing corner components of the trolley into snap-fits.

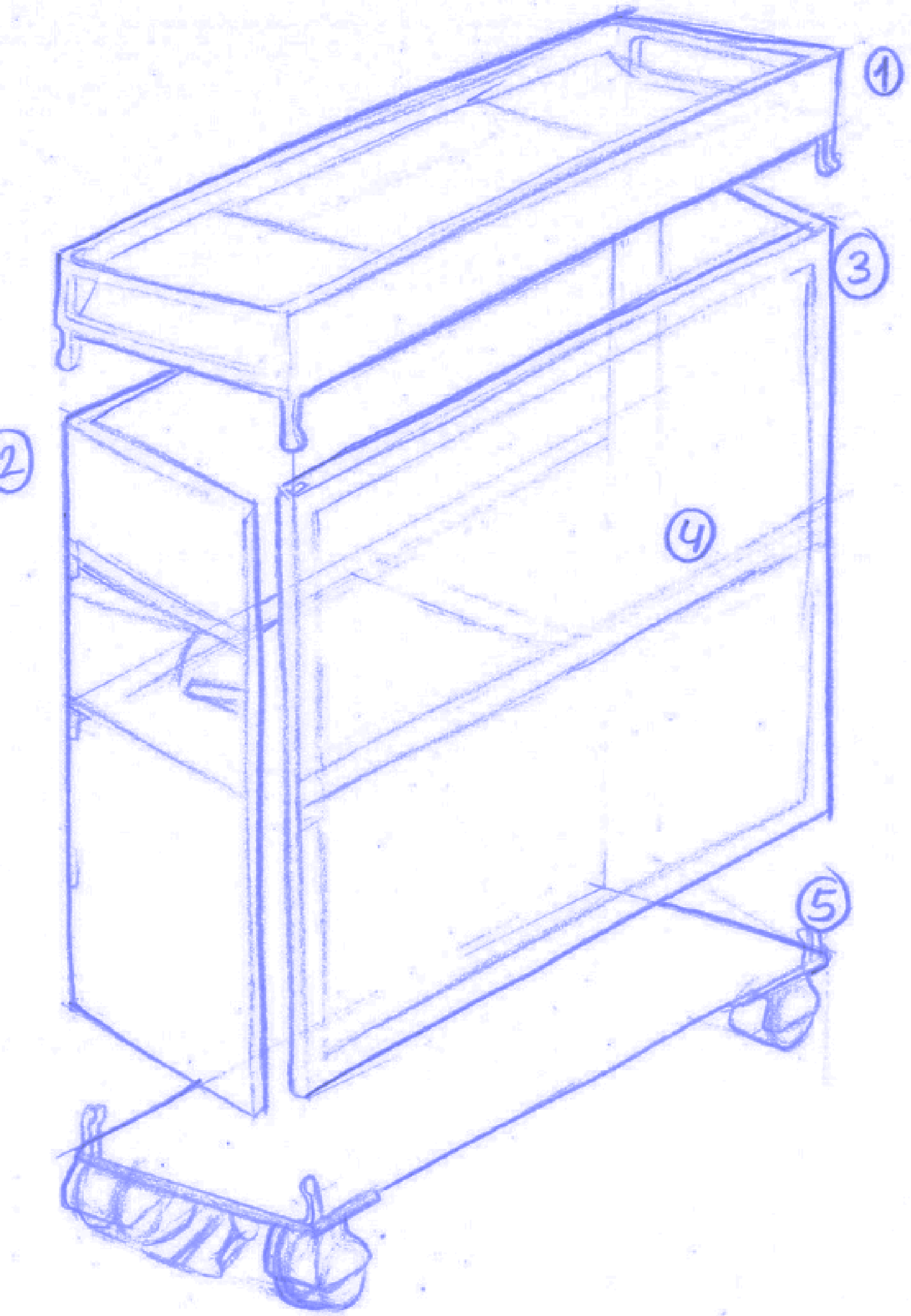


Figure 17: Sketch of multiple-part trolley, showing its 5 different components

Figure 18: 3D printed snap-fit extrusions

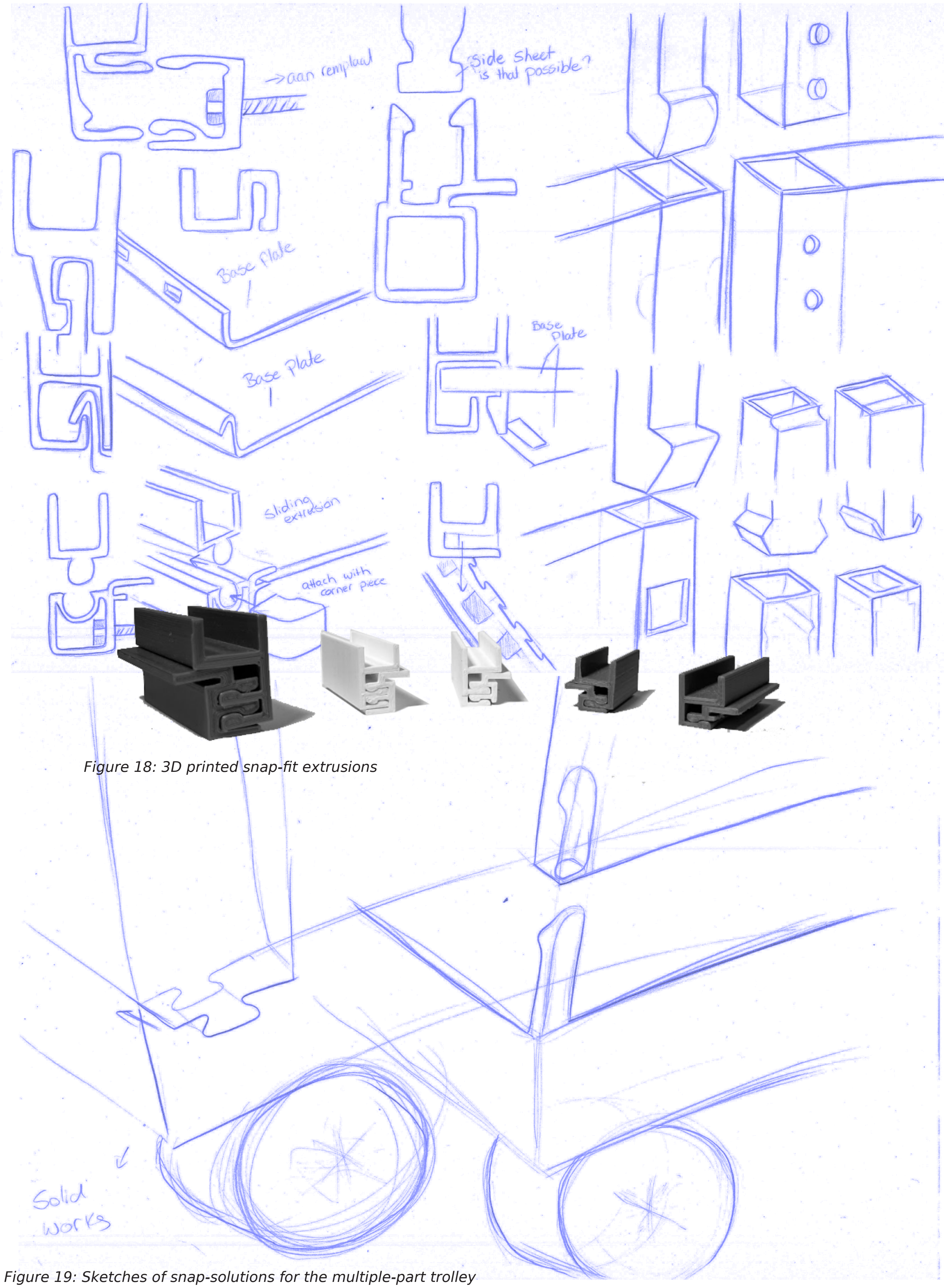


Figure 19: Sketches of snap-solutions for the multiple-part trolley

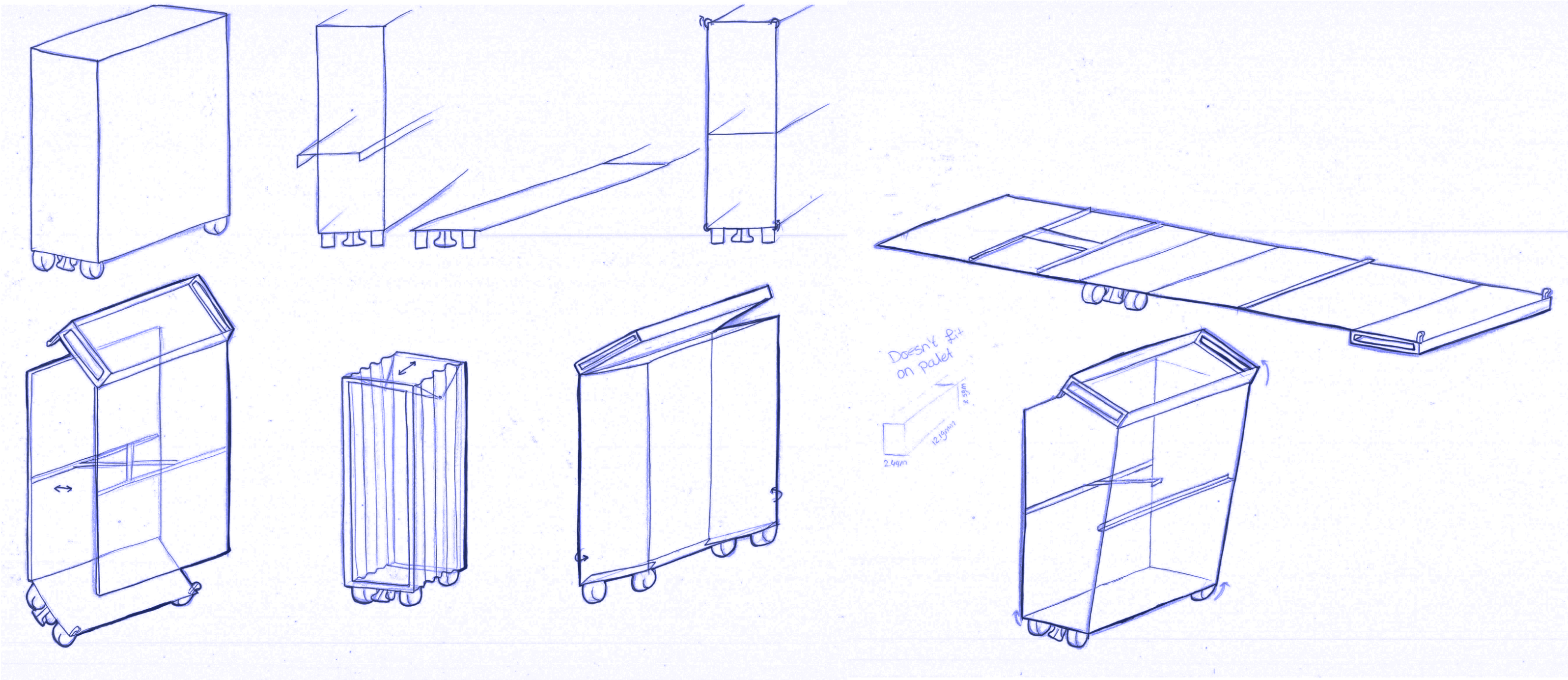


Figure 20: Sketches of different folding possibilities for the trolley

5.2.2 One-part Trolley

For the one part trolley a brainstorm was conducted to explore different folding techniques for a trolley inspired by the designs of chapter 2.3 Flat-pack Solutions in Market, see fugure 20. It was chosen to continue with the second design to be able to stay as close to the current trolley as possible to make this project work in the given time frame as well as the implementation for Driessen would be easier. This concept and way of folding is sketched in figure 21.

For the one-part design, research was conducted into (aluminum) hinge mechanisms, Appendix 10.7. A promising solution involved replacing the current extrusions with hinge-based extrusions. This extrusion would be a modified version of an existing barrel hinge profile, incorporating snap-fit features to ensure it remains securely in place when folded. These design solutions will be further explored in the next subchapter.

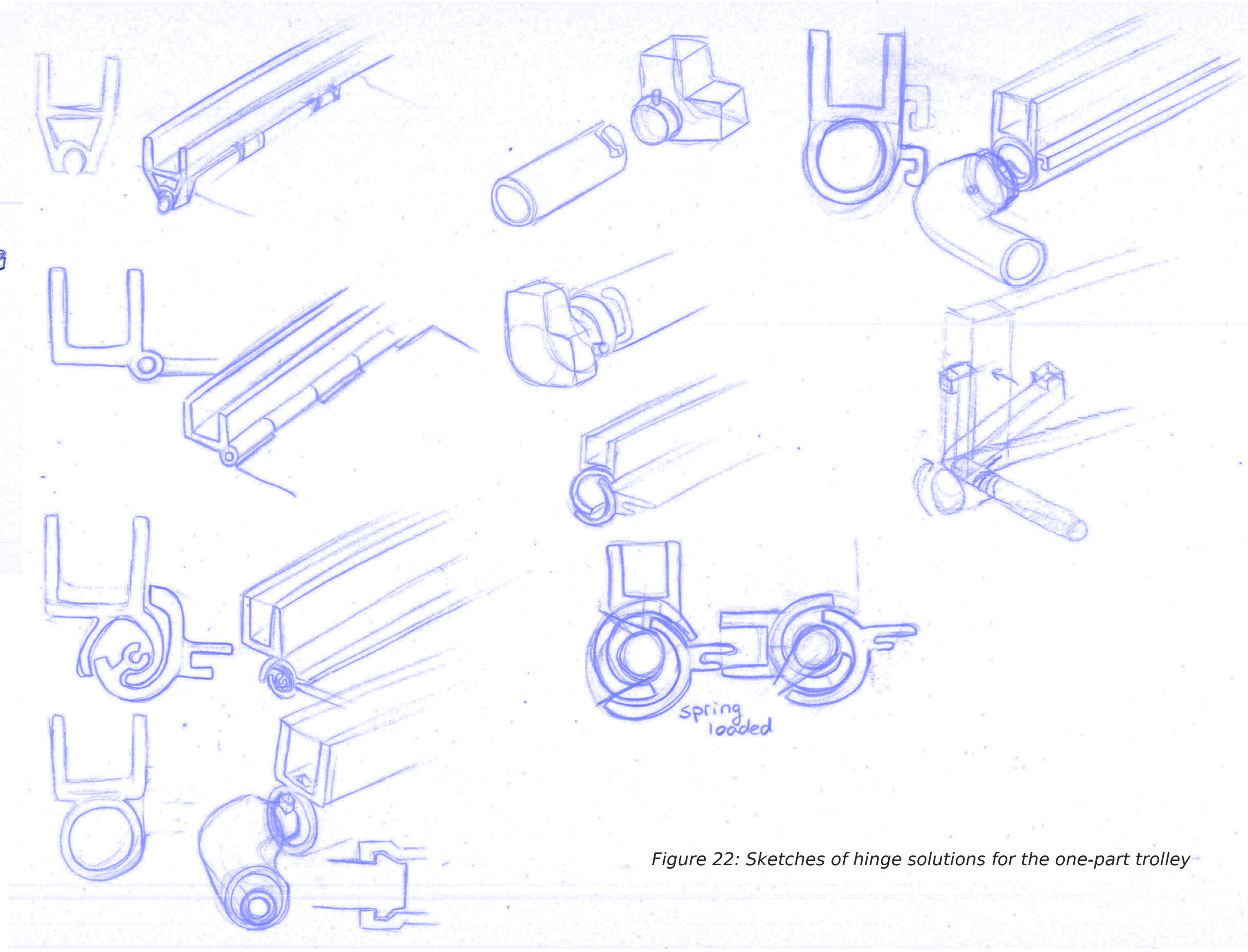


Figure 22: Sketches of hinge solutions for the one-part trolley

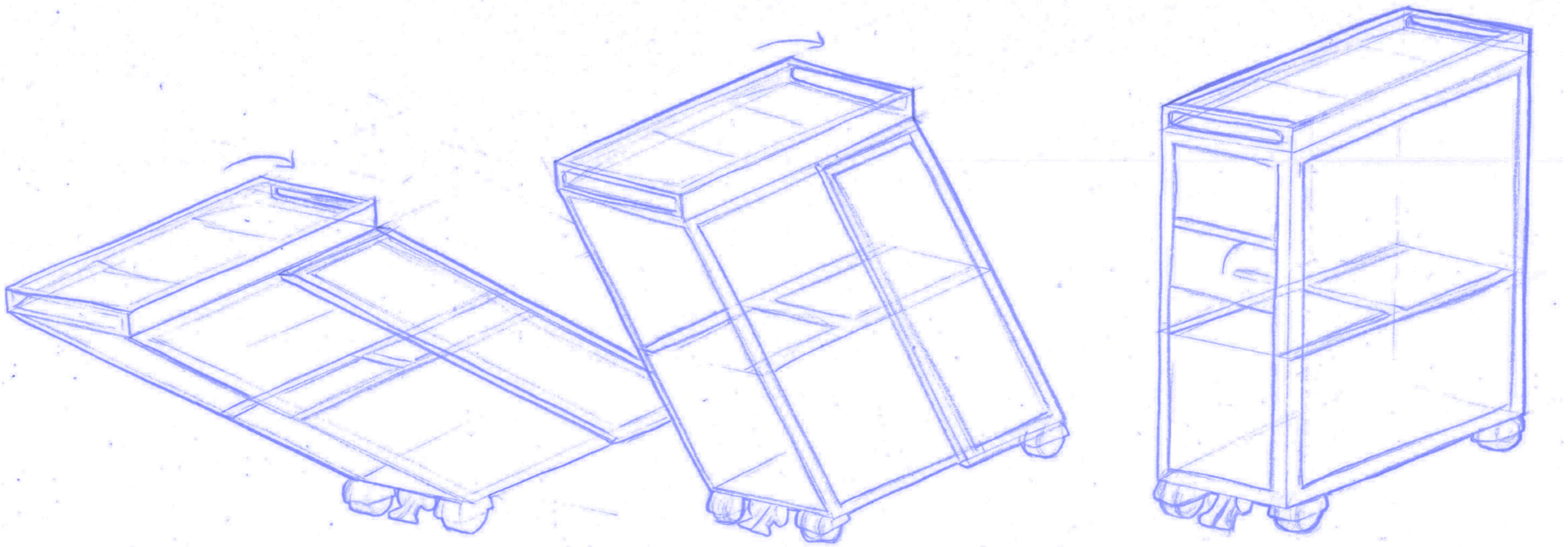


Figure 21: Sketch of one-part design trolley and its way of folding

Figure 23: 3D printed barrel hinge profile

5.2.3 Concept Selection

Table 6 presents a Harris Profile that compares and ranks both concepts according to the requirements.During the midterm meeting with the TU Delft team and Driessen, a decision was made to proceed with the one-part foldable design. This option was seen as a more significant design challenge compared to the multiple-part trolley.

The rationale was that a Driessen engineer would likely be able to figure out the multiple-part design fairly easily, whereas the foldable trolley would be more likely met with initial skepticism about its feasibility. To maximize the value of this project for Driessen, it was therefore decided to continue developing the one-part foldable trolley.

The next subchapter will focus on generating ideas and solutions for this configuration.

Figure 24: One-part trolley vs. Multiple-part trolley

Requirements	--	-	+	++		--	-	+	++	
1. Standard Dimensions			■	■				■	■	
2. Weight Limit			■					■	■	
3. Fire Test			■	■				■	■	
4. Assembly Time			■	■			■			
5. Tool-free Assembly			■	■		■	■			
6. Horizontal Divider			■					■	■	
7. Structural Integrity		■						■	■	
8. Durability		■						■		
9. Fool-proof			■	■			■			
10. Regulations			■	■				■		

Table 6: Harris Profile of one-part trolley vs. multiple part trolley

5.3 Concept Development

When folding the trolley into its compact form, two key design challenges must be addressed:
1. Ensuring that the sides can rotate smoothly
2. Allowing the horizontal divider to move in tandem with the folding action

This subchapter provides a brief overview of the design processes undertaken to address these challenges.

5.3.1 Development of Extrusions and Corner pieces

The exploration of how the trolley could fold began with an investigation into possible extrusions that might enable the folding mechanism. Early concepts included the barrel hinge extrusion, a hinge integrated into the side panels, and an aluminum Hylite hinge, figure 25. Although these ideas initially appeared promising, prototype testing revealed that implementing these solutions in a way that was both strong and reliable enough to prevent the panels from detaching would be challenging, see appendix 10.8.

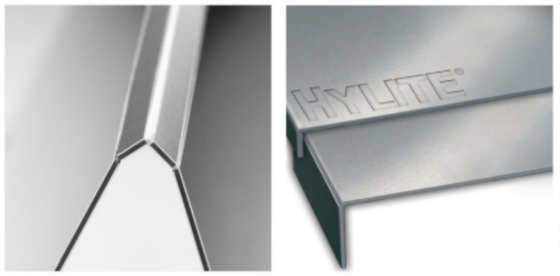


Figure 25: Hylite hinge

During this exploration phase, it also became apparent that one side of the trolley would require a higher rotation point, because of the runners and horizontal divider, to achieve the flattest possible fold. Additionally, since the folding is intended to occur only once in the trolley's lifetime, it was important to avoid including components that would serve no further purpose after that initial fold.

To address these challenges, a brainstorming session was conducted to explore different materials and mechanisms that could potentially solve the problem and create temporary hinges (see Appendix 10.9). However, this idea is not feasible because part numbers would need to change if the part changes over time, which is not allowed under current regulations. Therefore, it was decided to proceed by adapting the corner pieces so that they could rotate while still providing their essential structural function once assembled. Several iterations of these corner pieces are shown in figure 27.

Figure 27: 3D printed corner piece iterations

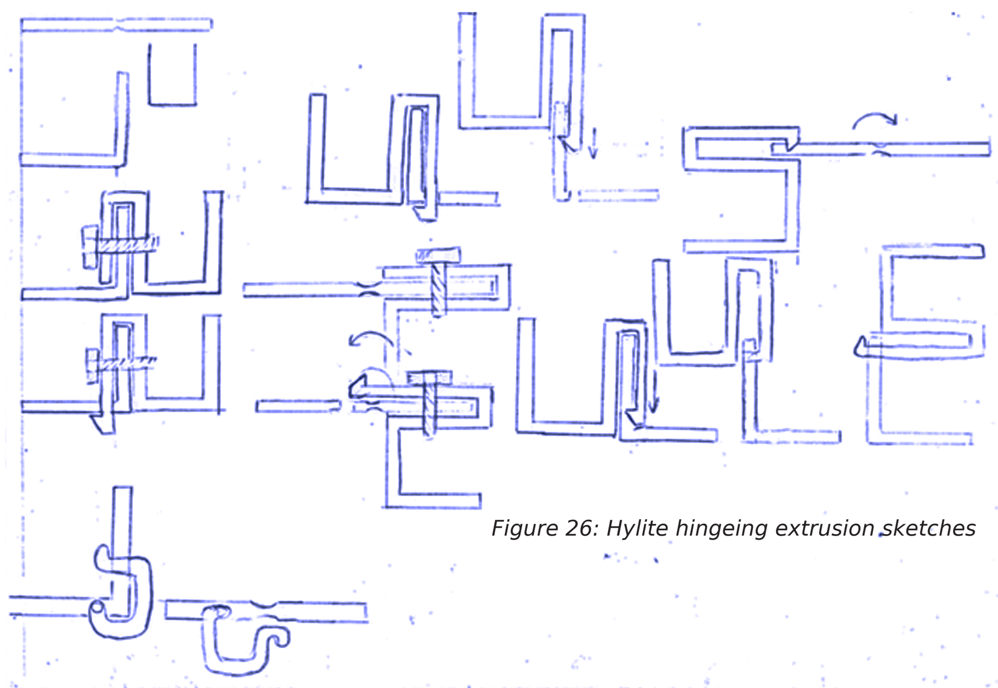


Figure 26: Hylite hingeing extrusion sketches

In order to evaluate the functionality of the corner pieces, multiple tests were conducted to develop an optimal snap-fit design. The goal of these tests was to achieve a balance between strength and flexibility: the corner pieces needed to be robust enough to securely hold the entire trolley structure in place, while also being sufficiently flexible to allow a single person to easily assemble and disassemble the trolley without the need for additional tools. Through iterative prototyping and testing, different design variations were assessed to determine the ideal geometry and material properties that would meet these requirements. This process ensured that the final design would not only be structurally reliable during use but also user-friendly during assembly.

Figure 28: Different snap-fit iterations

Snap-fit Calculation

Both the corner pieces and the snap-fit mechanisms will be made of aluminum, AL 6061. Since the snap-fits replace traditional screws, they must be strong and durable, making aluminum the ideal material for these components. But the snapfit must be also easy to click by just one person and without any tools, to then come to the form of the snap-fits the snap-fits are calculated to have the ideal stiffness and strength to come to its form.
To calculate this the formula

$$\delta = \frac{FL^3}{3EI}$$

of the Euler Bernoulli beam theory can be used when rearranging it to the formula

$$F = \frac{3EI\delta}{L^3}$$

where I is the moment of inertia, which is for a rectangular beam cross-section

$$= \frac{bt^3}{12} \text{ so } F = \frac{3E\left(\frac{bt^3}{12}\right)\delta}{L^3} = \frac{Ebt^3\delta}{4L^3}$$

where:
- F is the lateral force at the beam tip [N]
- E is the Young's modulus of the material [Pa]
- I is the second moment of inertia of the beam cross-section [m⁴]
- δ is the required tip deflection to clear the undercut [m]
- L is the unsupported length of the cantilever [m]
- b is the beam width [m]
- t is the beam thickness (in bending direction) [m]

The axial pull-out force F_pull, i.e. the force required to disengage the snap-fit along the insertion axis, depends on the wall angle θ and is given by

$$F_{pull} = \frac{F}{\tan(\theta)}$$

combining these equations

$$F_{pull} = \frac{Ebt^3\delta}{4L^3\tan(\theta)}$$

Solving this equation for t (beam thickness) for a given F_pull, δ, L, b, θ, and E:

$$t = \left(\frac{4L^3F_{pull}\tan(\theta)}{Eb\delta}\right)^{\frac{1}{3}}$$

With the snap-fit beam being L = 15 mm, b = 15 mm, and δ = 1 mm, and a desired pull-out force of 100 N for aluminum E=70 GPa, Wall angle θ = 0.5°

Lateral force required at the beam tip to deflect 1 mm:
F ≈ 77.8 N

Axial pull-out force required (along the beam axis):
F_pull ≈ 8,912 N (≈ 8.9 kN)

To achieve an axial pull-out force of approximately 100 N with your current snap-fit design, the retaining wall angle (θ) would need to be about: θ ≈ 37.87°

This means the snap ledge would need to slope back at nearly 38° from vertical, allowing the beam to escape with much less axial force.

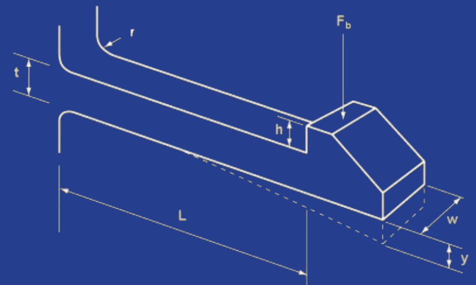
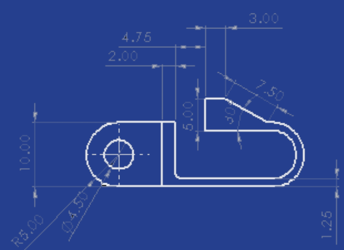
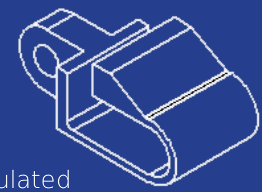


Figure 29: Snap-fit dimensions

Figure 30: First aluminium snap-fit





Aluminium snap-fit

The snap-fit design, with its calculated dimensions, was subsequently made in its intended material, aluminium. After testing, this snap-fit proved to function as intended. However, one final design iteration was carried out to further improve its performance. This last modification aimed to reduce the tendency of the snap-fit to slide out unintentionally and to ensure that it would engage more easily and securely into its designated slot. The technical drawing of the final snap-fit design is shown in appendix 10.11

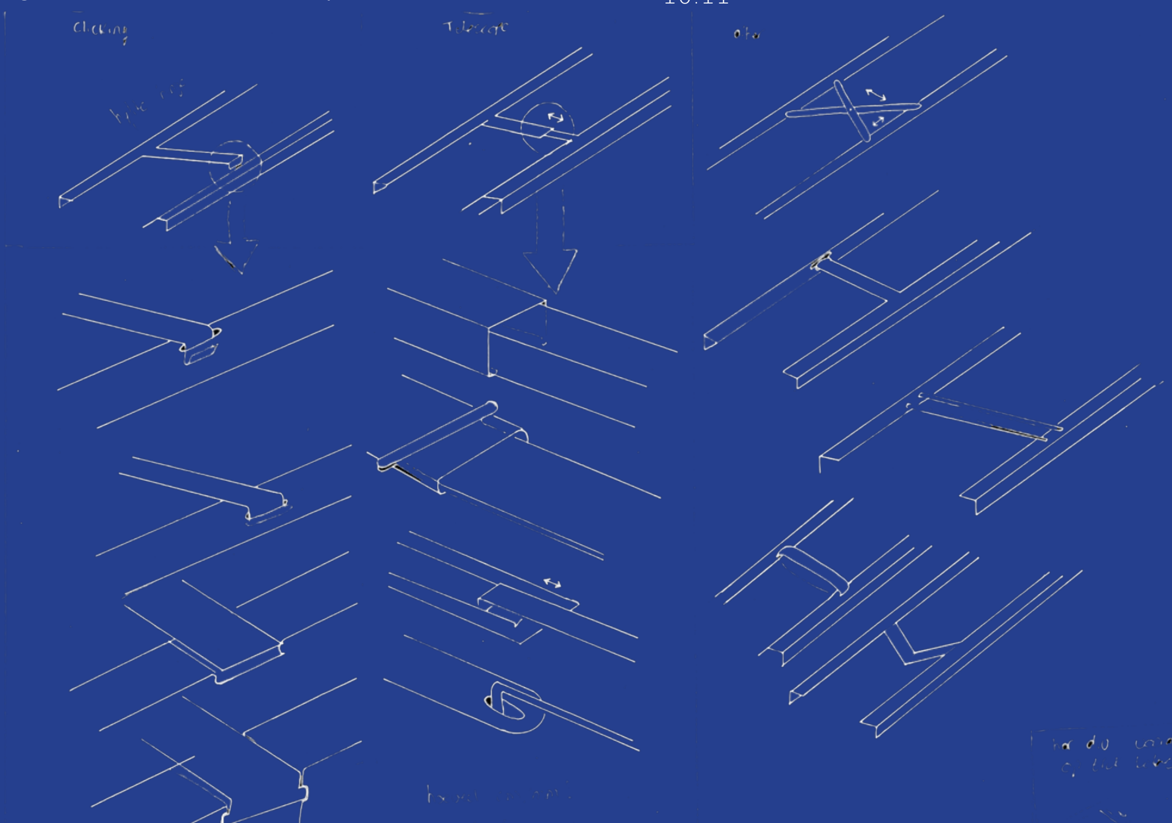


Figure 31: Horizontal divider brainstorm

5.3.2 Development of the Horizontal Divider

To enable a flat-pack trolley design, the horizontal divider also needed to be redesigned, as it must be integrated into the folding mechanism. While developing this component, it was essential to consider the requirement that the horizontal divider must withstand a load of 9g. Additionally, it is important to note that the divider is primarily subjected to tensile forces and does not need to resist compressive loads. To explore potential solutions, several brainstorming sessions were conducted to generate and evaluate different design concepts for the new horizontal divider.

Following a SolidWorks simulation of the folding trolley, it became evident that the distance between the two panels in the folded state is greater than in the operational (assembled) state. As a result, only two design options for the horizontal divider remain feasible. The first option involves a horizontal divider equipped with a Hylite hinge, which allows it to pivot and lock into place on the opposite side when the trolley is in its operational position.

5.3 Conclusion

This chapter presented the design process undertaken to develop a flat-pack trolley concept, addressing **Research Question 5:** ***What mechanical and structural solutions can be applied to ensure the trolley remains sturdy, easy to assemble, and lightweight?***

Various mechanical and structural solutions were explored throughout the process. A collaborative brainstorming session with the Driessen engineering team, combined with several individual brainstorming rounds, led to the development of both a more detailed multiple-part flat-pack trolley and a one-part trolley concept. After the midterm review, the decision was made to continue with the one-part flat-pack trolley (hereafter referred to simply as "flat-pack trolley").

Various folding solutions were explored, ultimately leading to the decision to incorporate hinged corner pieces. These were prototyped and refined through several iterative cycles. Testing further revealed that the horizontal divider also needs to be able to rotate and must accommodate a greater distance when the trolley is folded. To address this, a horizontal divider equipped with a Hylite hinge was developed, allowing it to pivot effectively and adapt to the changing geometry.

The insights gained from this design process will inform the next phases of development, including further testing and final design refinement.

06

Product Design Proposal

This chapter presents the final design proposal for the flat-pack trolley developed during this project. Building upon the insights, design strategies, and iterations discussed in the previous chapters, the final design embodies the key objectives of the project: ensuring sturdiness, ease of assembly, and limiting extra weight.

This section will detail the design features, materials, and functional considerations that define the flat-pack trolley. Each aspect will be explained with reference to the mechanical and structural solutions that emerged from the design process, illustrating how these solutions work together to achieve the project's goals.

Through this final design proposal, the project aims to offer a comprehensive and practical solution that addresses the challenges identified earlier while aligning with the needs of both users and manufacturers.

6.1 Flat-pack Trolley Design

The final design of the flat-pack trolley features a folding mechanism based on a parallelogram linkage motion. This movement is made possible by eight specially designed corner pieces that incorporate a hinged snap-fit system. To assemble the trolley, it is first unfolded using the parallelogram motion. This can be done either by moving the top and bottom parts while the trolley lies on its side, making it easier to handle, or by unfolding it directly into a standing position. Once unfolded, the top section is pushed downward until it clicks into place, after which the side panels are pressed together to securely lock the structure. Finally, the horizontal divider is unfolded and attached to the opposite panel, completing the assembly.

6.1.1 Corner Pieces

The corner pieces have been redesigned so that they enable the hinging mechanism of the flat-pack trolley. In the new design, each corner piece integrates a snap-fit element added to the original corner geometry. These snap-fits function as hinges within the corner pieces, allowing rotational movement during folding and unfolding. The snap-fit is made from aluminum and is specifically designed to utilize the material properties of aluminum — allowing it to flex and then snap securely into place, creating a strong and reliable connection. The shape of the corner piece ensures that when the snap-fit is retracted, it automatically locks itself, preventing it from slipping out and thereby contributing to a robust overall design.

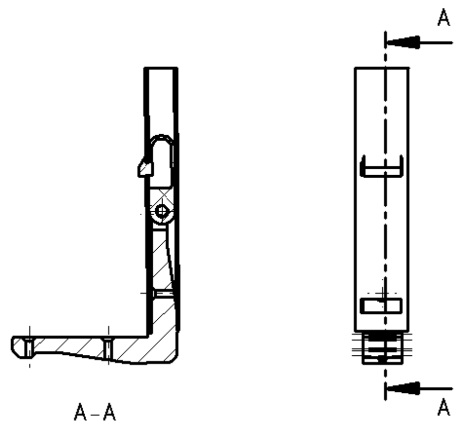
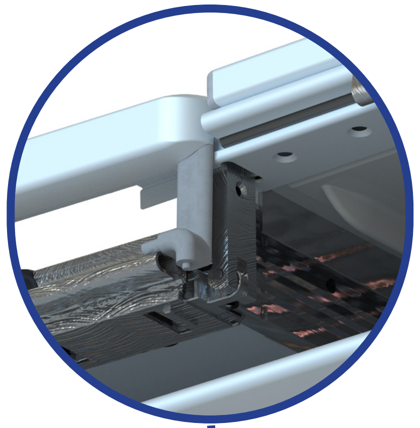


Figure 32: Corner piece and extrusion drawings with its cross section



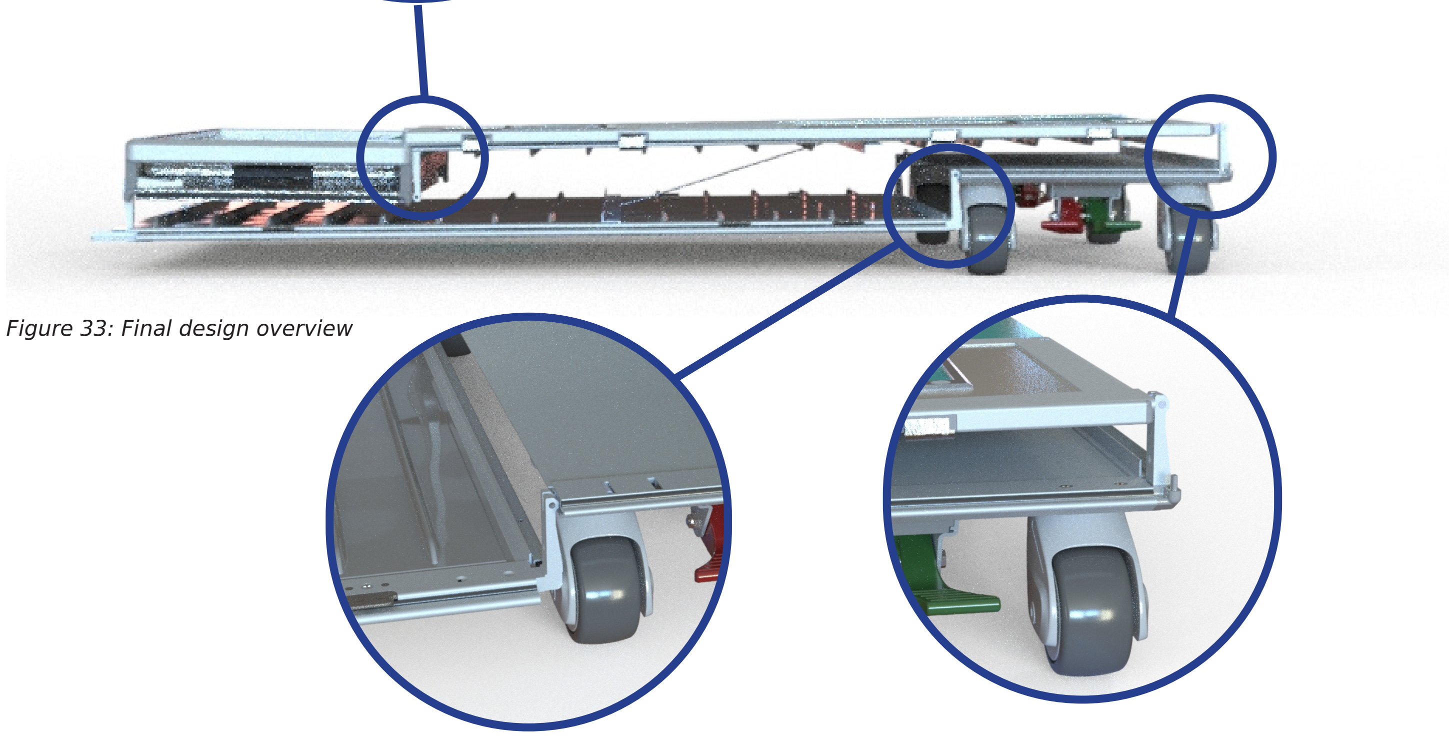
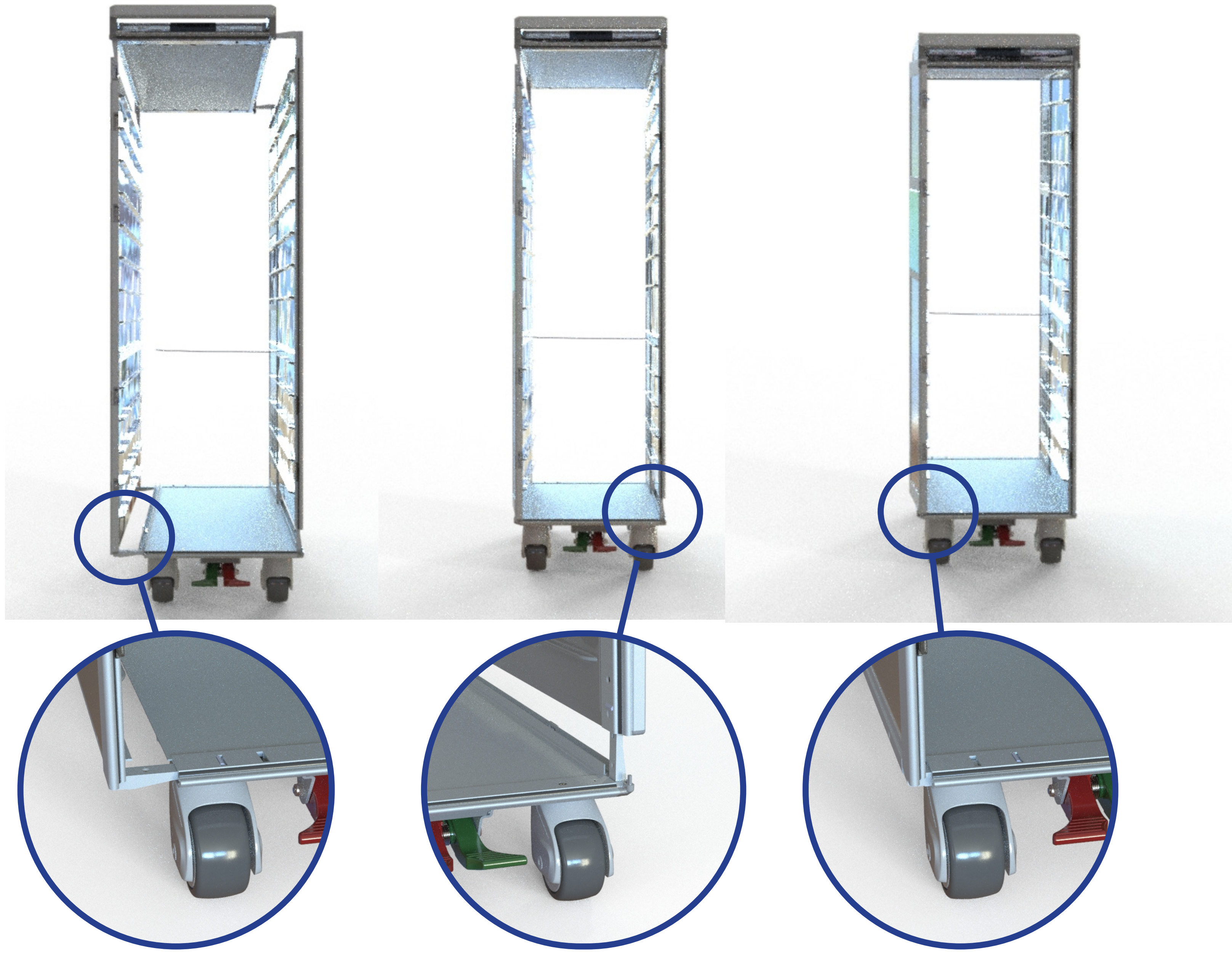


Figure 33: Final design overview

When unfolding the trolley, the corner pieces operate as follows: in the folded state, the corner pieces remain in their initial position, allowing free rotational movement. As the trolley is unfolded, the corner pieces slide deeper into the extrusions, causing the snap-fit to engage and lock into a second position. This locking mechanism secures the trolley in its fully unfolded state, preventing unintended parallelogram movements. Additionally, this design allows the trolley to reach a higher extrusion point, enabling it to fold as flat as possible while still ensuring the structural strength of the corners once assembled.

6.1.2 Horizontal Divider

The horizontal divider is made of Hylite, using the material's integrated hinge functionality to enable folding. Once the trolley is in its operational state, the horizontal divider can be clicked and secured to the opposite side of the trolley. Hylite has a tensile strength of 380 N/mm² (3A Composites GmbH, 2017), while the polypropylene core used in the hinge area has a tensile strength of 35.7 N/mm² (Hashimoto et al., 2012). The area of the Hylite hinge is $30 \times 1 \times 2 = 60$ mm², allowing it to withstand a force of up to 2,142 N. These properties ensure that the horizontal divider is sufficiently strong to withstand the tensile forces exerted by the drawers within the trolley, maintaining structural integrity during use.



6.2 Physical Prototype

The physical prototype of the flat-pack trolley was built and functions as described previously. The corner pieces and snap-fits are made from the intended material, aluminum, see figure 35. The prototype is based on an existing Driessen premium deep top trolley. The only modifications needed to adapt the original design were: milling holes in the extrusions to allow the snap-fit to lock in place, milling holes in the corner pieces, adding aluminum snap-fits and axles, and creating a new horizontal divider made of Hylite with an integrated click mechanism to secure it to the opposite side. The sides of the horizontal divider were reused from the original divider.

Figure 35: Aluminum snap-fits

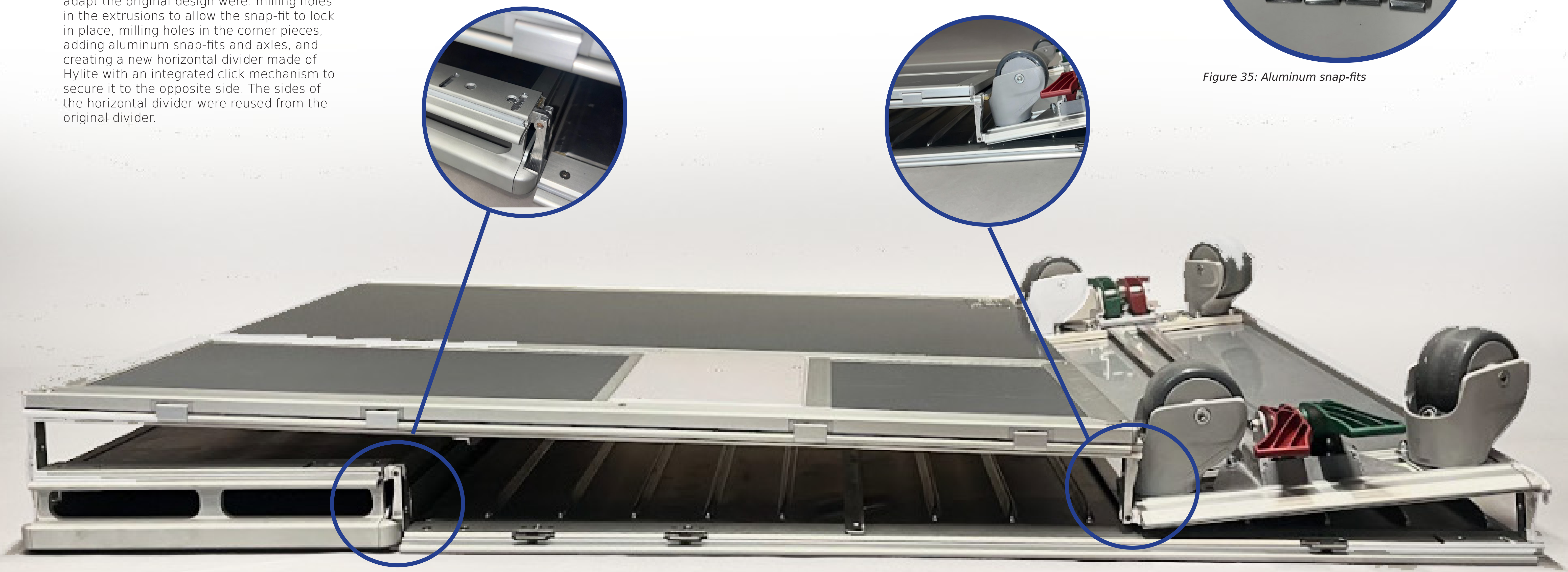


Figure 34: Photo Physical Prototype

07

Concept Evaluation

This chapter provides a detailed examination of the redesigned flat-pack trolley. It covers the changes in volume and weight, and how these affect transportation and usability. The sustainability impact is assessed, focusing on CO_2 emissions during distribution. A cost analysis highlights potential savings in shipping. Finally, the usage context is discussed.

Together, these insights give a clear overview of the key aspects and considerations of the new design.

7.1 Volume Assessment

In its folded state, the redesigned flat-pack trolley has compact dimensions of 852 x 1370 x 169 mm (length x depth x height). When compared to the original trolley, which measures 852 x 384 x 994 mm, this new design achieves a significant reduction in volume. Specifically, the folded flat-pack trolley requires only 57.5% of the volume of the original design, representing a substantial 42.5% decrease. This considerable reduction not only optimizes space during transport and storage but also contributes to more efficient logistics and potentially lower environmental impact due to fewer shipments needed.

	Old Volume (mm)	New Volume (mm)
Length	852	852
Depth	384	1298
Hight	994	169
Total	**325204992**	**186896424**
% volume new trolley	57,47034289	

Table 7: Volume calculation proposed flat-pack design

6.1.1 Shipping

This reduction in volume offers significant advantages for the shipping and storage of the trolley. However, it is important to note that, in its folded state, the trolley exceeds the dimensions of a standard pallet, making it unsuitable for traditional pallet-based transportation. As a result, the trolleys will primarily be shipped in boxes.

Because these boxes themselves occupy additional space, an estimated 3% increase in volume is considered to account for packaging inefficiencies. When shipping one trolley per box, the effective volume per trolley would be approximately 60.5% of the original trolley volume.

Furthermore, in its flat-pack form, the trolleys can be stacked more efficiently. By arranging them so that the wheels of one trolley nest into the top section of the trolley below, as illustrated in figure 36, multiple trolleys can be packaged together in a single box. This configuration not only reduces packaging space by an additional 1% but also allows the trolleys to fit more compactly, resulting in an additional space saving of 2.5% per trolley.

Combining these optimizations leads to a total space reduction of 3%, resulting in a final effective volume of 57.5% compared to the original design. This improvement highlights the logistical benefits of the flat-pack design, ultimately contributing to lower shipping costs and a reduced environmental footprint.

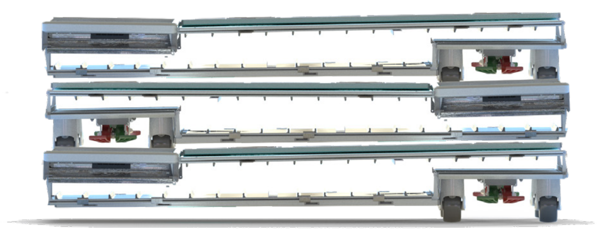


Figure 36: Space-Efficient Trolley Packing Layout

7.2 Weight Assessment

To evaluate the impact of the redesign on the overall weight of the trolley, a detailed weight assessment was conducted. This involved comparing the weight reduction resulting from modifications to the existing trolley with the additional weight introduced by new components in the flat-pack design. Specifically, material was removed from the original design, for instance, by adding holes in the corner pieces, which contributed to a slight weight reduction. On the other hand, new components such as snap-fit connectors and an updated horizontal divider were added, resulting in a minor increase in weight.

The redesigned corner pieces account for an added weight of approximately 10.1 grams. Meanwhile, the revised horizontal divider, although slightly modified, contributes an additional 1.3 grams. In total, the overall weight increase for the flat-pack trolley amounts to just 11.4 grams.
This minimal weight gain remains well within the target constraint of keeping any additional weight under 100 grams. Thus, it can be concluded that the flat-pack trolley meets the weight requirements without compromising functionality or performance.

Weight Calculation	
Weight of new snap fit	4,92
Weight of removed corner piece	3,07169
Weight of axle	0,51
Weight screw	1,1
Extra weight per corner piece	1,25831
Weight removed hor. div.	26,53
New weight hor. div.	27,85
Total extra weight trolley (grams)	11,38648

Table 8: Weight calculation proposed flat-pack design

7.3 Sustainability Analysis

Although sustainability analyses at this stage of the design process can be somewhat preliminary, an indicative assessment of the potential environmental impact is useful to understand the broader implications of the design. This analysis focuses on the distribution phase of the trolley's life cycle, evaluating the changes resulting from the redesigned, foldable flat-pack concept.

Since not every client is located the same distance from the manufacturing site, this analysis offers an estimation rather than an exact calculation. To approximate the potential emissions savings, the distribution emissions are calculated from the manufacturing facility in Lamphun, Thailand, to Schiphol Airport in Amsterdam, assuming transportation by sea and truck. The Ecotransit emission calculator was used to estimate these values (Emission Calculator, z.d.).

For one 40-foot container, the estimated emissions are 4321.9 grams of CO_2e. Dividing this by the number of trolleys that fit in a container, the current (non-flat-pack) trolley design results in approximately 19.6 grams of CO_2e emissions per unit. With the redesigned flat-pack concept, which allows for a 40% volume reduction, approximately 11.8 grams of CO_2e per trolley would be emitted. This equates to a savings of 7.8 grams of CO_2e per trolley during the distribution phase.

However, it is important to place this savings in perspective. Over the entire life cycle of a trolley, estimated at 224,323.13 grams of CO_2e, the reduction from shipping represents only a very small fraction. Nevertheless, in the distribution phase, emissions would decrease by approximately 40%, highlighting a clear advantage in that segment.

Figure 37: Travel distance Driessen manufactury to Amsterdam Schiphol Airport

Figure 38:Total impact of a 40-ft containr

Figure 39: Impact of the original trolley in distribution phase

Figure 40:Impact of the flat-pack trolley in distribution phase

7.4 Design For Different Trolley Configurations

The design presented in this report has been continuously developed and tested on the premium Driessen trolley equipped with a dry-ice compartment. However, there are multiple trolley configurations available, including meal trolleys, cooling trolleys, waste trolleys, retail trolleys, and high-top trolleys, all offered in both half-size and full-size variants. The design is intended to be adaptable to all full-size Driessen trolleys; although the top section may vary between models, this specific design was created with a dry-ice compartment in mind, under the assumption that it could be implemented across other configurations as well.

However, this specific design is not compatible with half-size trolleys. In a half-size trolley, there is no second door at the back; instead, it has a fixed rear panel. As a result, the parallelogram linkage motion required for folding cannot be achieved, making this design unsuitable for half-size trolley configurations.

7.5 Cost Analysis

This section focuses primarily on the potential cost savings achieved by reducing the volume of the trolleys during the initial shipping phase. A brief cost analysis has been performed based on the cost of shipping a 40-foot ocean freight container and the increased number of trolleys that could fit in the container due to the flat-pack design.

In the current system, approximately 220 fully assembled trolleys fit into a single 40-foot container. With the new flat-pack design, the folded volume allows for an estimated 336 trolleys to fit in the same container, a 52% increase in container utilization.

Assuming an average container shipping cost of $3,000, the cost per trolley for shipping is:
Current design: $3,000 ÷ 220 trolleys = $13.64 per trolley
Flat-pack design: $3,000 ÷ 382 trolleys = $7.85 per trolley

This results in a savings of approximately $5.79 per trolley on shipping costs. This is a reduction of 42.4%.

While the exact savings depend on factors like shipping routes and order sizes, this initial estimate demonstrates the potential cost benefit of implementing a flat-pack design.

7.6 Context Change

The context in which the redesigned flat-pack trolley will be used does not significantly differ from the operational environment of the current trolley. Since the design is a single-piece concept that meets all necessary design specifications, the Form 1 document can be issued at the manufacturer's facility, allowing assembly to be performed by uncertified personnel.

This means that the client can designate any suitable staff member, typically the same person who currently unpacks the trolley from its packaging, to handle assembly. The trolley can be easily unfolded and assembled by one person, who simply folds out one side of the trolley and then the other to complete the setup.

7.7 Conclusion

This chapter has examined the redesigned flat-pack trolley in terms of volume, weight, sustainability, cost, and usage context. The design achieves a 42.5% reduction in folded volume, enabling a higher container capacity and reducing shipping costs by approximately 42.4% per unit. Although emissions savings in distribution are modest relative to the total life cycle, they are meaningful in that phase.

The weight assessment revealed minor changes, but further testing is needed to confirm the strength and durability of key components. Operationally, the trolley remains straightforward to assemble by current staff. Overall, the flat-pack design shows promise for improved shipping efficiency and cost reduction, though additional refinement is required before full implementation.

Figure 41: Context sketch showing factory-prepared trolley, only unfolding needed by client

08

Conclusion & Recommendations

This thesis explored the feasibility and design of a flat-pack airline catering trolley, addressing the challenge of developing a trolley that is sturdy, easy to assemble, and reduces its environmental footprint.

8.1 General Conclusion

Overall, this research demonstrates that it is possible to design a flat-pack airline catering trolley. Two primary approaches were identified:

- A design that is shipped as multiple parts and assembled at the client site, where airworthiness certification is completed.
- A design that leaves the manufacturer in a pre-certified state according to its design drawings, with only final unfolding required by the client.

This thesis focused on the second option, exploring various design strategies to achieve this. The resulting design incorporates hinging snap-fit corner pieces and a flexible horizontal divider made from hylite. This design allows the trolley to fold compactly and later be unfolded and locked into its final form.

Testing and design evaluations revealed that the new flat-pack trolley achieves a volume reduction of 42.5% compared to the traditional design, with a minor weight decrease of 11 grams. This translates to a 35 % reduction in shipping costs, approximately $4.72 per trolley, while also improving the overall sustainability footprint by 40% in the distribution phase.

In summary, the design developed in this project demonstrates a viable pathway for transforming airline catering trolleys into more space-efficient, sustainable, and cost-effective products without compromising functionality or airworthiness. This outcome not only answers the research question but also offers valuable insights for future development and industrial implementation.

8.2 Tackled Challenges

Throughout the development of the flat-pack trolley, several key challenges were addressed to meet both functional and regulatory requirements.

The first challenge concerned compliance with the regulatory framework established by EASA. To ensure that the flat-pack trolley design aligns with airworthiness certification requirements, it was essential to navigate these regulations effectively. This was accomplished by adopting a one-part trolley design. Unlike a multi-part assembly, the one-part design allows for pre-certification at the manufacturer's facility, ensuring that airworthiness checks can be completed before shipping. Additionally, this approach avoids introducing any post-assembly steps that would require tools, aligning with the operational requirements of airline catering staff who must assemble the trolley quickly and safely on-site.

The second challenge was to develop a mechanism that enables the trolley to fold and unfold without the use of tools within 5 minutes. This was addressed through the design of hinging snap-fit corner pieces that allow for intuitive and secure folding. An additional consideration was the horizontal divider, which needed to move seamlessly with the folding action while retaining its stiffness and structural integrity. This was achieved by integrating a flexible yet strong horizontal divider, using a cable solution, ensuring that the divider could accommodate the trolley's movement without compromising performance.

Beyond these technical and regulatory challenges, several additional requirements were met:

- Airtightness: The trolley design is airtight to ensure it passes the required fire tests, a critical aspect of airline equipment safety.
- Dimensional Compliance: The trolley dimensions do not exceed the standard envelope of 852 × 384 × 994 mm (L × D × H), maintaining compatibility with existing galley equipment and storage.
- Weight Constraint: The design stays within the maximum additional weight allowance of 100 grams, ensuring no significant impact on operational performance or fuel efficiency.
- Fool-proof Assembly: The design prioritizes a clear, intuitive, and fool-proof assembly, ensuring that it is virtually impossible to assemble incorrectly—an essential feature for airline operators.

Collectively, these solutions address the key technical, regulatory, and operational hurdles, resulting in a flat-pack trolley that is certifiable, robust, easy to assemble, and practical for airline use. In Table 9 the requirements are listed along with an indication of whether they have been met or not.

	Requirement	*Source*	*Status*
1.	**Standard Dimensions**	ATLAS	[green]
2.	**Weight Limit**	Driessen	[green]
3.	**Fire Test**	EASA	[green]
4.	**Assembly Time**	Driessen	[green]
5.	**Tool-free Assembly**	EASA	[green]
6.	**Horizontal Divider**	ATLAS	[orange]
7.	**Structural Integrity**	EASA	[orange]
8.	**Durability**	Driessen	[orange]
9.	**Fool-proof**	EASA	[green]
10.	**Regulations**	EASA	[green]

	Wish	*Source*	*Status*
1.	**Volume**	Driessen	[green]
2.	**Foldability**	Driessen	[green]
3.	**Quick Folding mechanism**	Driessen	[green]
4.	**Amount of Parts**	Driessen	[green]
5.	**Sustainability**	Driessen	[orange]
6.	**Design Similarity**	Driessen	[green]
7.	**System**	Driessen	[green]
8.	**Versatility**	Driessen	[green]
9.	**Half-size**	Driessen	[red]

Table 9: List of requirements and list of wishes with their source and with the status if they are met, uncertain or not.

8.3 Limitations

This design was developed using the premium trolley model, which is an older version of the Driessen trolley and slightly heavier than their latest ultralight variant. While the design can be adapted to the ultralight configuration, some adjustments would be necessary to align with its construction and weight specifications. The premium trolley was chosen as the base because it features a separate subassembly for the top, simplifying certain design modifications during the prototyping phase.

One limitation of the design is its reliance on snap-fit connections to hold the trolley together. Snap-fits require tight tolerances, which can make consistent production challenging. Moreover, snap-fits are prone to metal fatigue over time, which could eventually weaken their grip and compromise the trolley's structural integrity.

As a result, there is a concern that the design might be less sturdy than conventional trolleys, raising uncertainty about whether it would achieve the same 10-year service life that is typical for Driessen trolleys. This potential durability challenge highlights an area for further testing and optimization in future design iterations.

Another concern is that the folded dimensions of the trolley exceed 120 × 100 cm, meaning it does not fit on a standard block pallet. This could complicate logistics and make shipping more difficult.

8.4 Recommendations

Further research is essential to refine the flat-pack trolley design and ensure its technical and practical viability for real-world use. One of the most critical aspects that needs to be addressed is the performance of the **snap-fit connection**s. These connections must be thoroughly tested to confirm that they are strong enough to withstand repeated use over the entire lifetime of the trolley, without loosening or failing due to material fatigue. Over time, repetitive stress can cause deformation or reduced clamping force in snap-fits, potentially compromising safety and usability. To address this, incorporating springs into the snap-fit design could be a promising solution. By adding springs, the snap-fits would retain constant tension, providing a more reliable and durable locking mechanism even after extensive use.

In addition to the snap-fit system, the **horizontal divider** must be rigorously tested to verify its structural performance. Specifically, it should undergo a buckling test to ensure it can withstand loads equivalent to 9.0 g within the whole trolley, as required for aviation catering equipment. Passing this test is crucial to guarantee that the divider can safely support the drawers and their contents without deforming or collapsing under operational stresses.

Another important area for improvement is the **side panels**. Redesigning these panels so that they can slide more easily into the extrusions during assembly would not only simplify the construction process but also improve the overall stability of the trolley. A more intuitive panel insertion system would reduce the risk of incorrect assembly and enhance user confidence. Furthermore, adjusting other critical parts of the trolley, such as the **extrusions and the top section**, will help achieve a more precise fit between components, allowing for smoother folding and locking motions. This seamless integration is essential to ensure that the trolley can be quickly and reliably assembled and disassembled in practical settings.

Equally important is the development of comprehensive **assembly instructions**. Clear, step-by-step instructions should be created and rigorously tested with users to verify that the assembly process is intuitive, ergonomic, and foolproof. Observing users as they fold and assemble the trolley will reveal potential pain points or misunderstandings that can be addressed through design improvements or instructional refinements.

In parallel, a **specialized tool** should be developed for safely removing the snap-fits when maintenance or repair is needed. This tool would enable authorized personnel to disassemble the trolley without damaging components, while also preventing unauthorized disassembly. In addition, the **snap-fits** themselves must be redesigned in such a way that tampering or **misuse is prevented**, ensuring the trolley remains secure and robust during operation.

Another crucial aspect to consider is **packaging design.** Appropriate packaging solutions should be developed to protect the trolley during transport and storage, reducing the risk of damage before it reaches its destination. This includes conducting drop tests and vibration tests to identify the weakest points in the design and reinforce them where necessary.

Finally, a **detailed cost analysis** is needed to evaluate the economic feasibility of the design. This analysis should include manufacturing costs, assembly time, material choices, and potential savings in transportation and storage due to the flat-pack concept. Moreover, further optimization of the corner pieces is recommended to achieve the ideal balance between weight reduction and structural strength. Improving these elements will enhance the overall durability and performance of the trolley, contributing to a more competitive and reliable final product.

8.5 Reflection

With this thesis, I conclude my master's degree in Integrated Product Design at TU Delft. This project on the flat-pack trolley has been the longest individual and full-time project I have undertaken so far, and also the first project in which I collaborated so closely with the company that commissioned it. It has been a journey to figure out how to approach this project and how to navigate the collaboration with my team.

The project started off at a rapid pace; in the very first week, I already gathered much more information than I had ever had at the beginning of previous projects. Thanks to the expertise and knowledge at Driessen, I was able to gain a head start and avoid spending unnecessary time on basic research. This allowed me to quickly progress through the research phase and establish a strong foundation of knowledge from which I could move on to the ideation phase.

Designing this product was both exciting and challenging. An airline catering trolley must comply with many strict regulations, leaving limited room for design freedom. In addition, there were specific requirements from both Driessen and TU Delft, as well as my own personal ambitions. My goal was to develop a foldable trolley within the given timeframe of 20 weeks. The design I have developed is a relatively simple solution, chosen deliberately to stay as close as possible to the existing Driessen trolley design. This approach makes it more feasible to implement the flat-pack concept within the company and realistic to achieve within my 20-week project period.

"Designing this product was both exciting and challenging"

During the project, I also explored alternative solution directions. However, these proved to be less realistic to implement and therefore less feasible within the scope of this project. Nevertheless, I hope that if someone continues this project in the future, they will also consider these ideas as inspiration for potential new designs.

Over the past 20 weeks, I have learned an incredible amount. Having access to so many resources enabled me to maintain a consistently steep learning curve. I learned how to collaborate effectively with a team, how to integrate feedback and decisions from the management team into the project, and how to respectfully push back when I disagreed, explaining and defending my design decisions with solid arguments. The most valuable learning experiences came during the brainstorming sessions and the actual realization of my product. I participated in many brainstorming sessions, both formal and informal, where I learned how industry professionals approach design challenges, where they find inspiration, and which existing techniques they draw upon. Even though I could not apply all of these techniques in this project, I am confident that my overall understanding of products and mechanisms has greatly expanded. During the realization phase, I also gained significant hands-on knowledge. Working in the workshop taught me new techniques, what is and isn't feasible, and how to work with common components such as pop rivets and solid rivets. I learned about milling aluminum and the design constraints that come with it. As a result, I now have a much deeper understanding of how products are assembled and how they are brought to life in practice.

One of the biggest challenges in this project was managing and juggling all the different aspects and requirements. At times, there were so many factors, rules, and constraints that I lost oversight and missed critical elements, only to discover later that certain ideas were not feasible because I had overlooked an important detail. This led to some loss of time and required me to revise my direction. Another challenge was working with a very large SolidWorks model that included many parts and complex assemblies. Before this project, I had never worked with such a large and detailed SolidWorks file, which led to some frustrations and errors along the way. This is an area where I would like to further improve my skills in the future.

Overall, I am very happy with how this project turned out. In advance, I was afraid that I would quickly lose time and get stuck for long periods, but this did not happen, largely thanks to being able to work on location at Driessen. In the end, I was able to deliver a final result that I am proud of. While this project is certainly not perfect, it has taught me an enormous amount, and I can confidently say that this project has been a valuable and rewarding culmination of my studies.

09

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10

Appendix

10.1 Original Project Brief

Name student Wendy Pruppers **Student number** 5,268,656

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Flatpack Redesign of the Airline Catering Trolley

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The airline industry is a highly regulated and competitive domain, where efficiency and cost-effectiveness are critical. This project focuses on redesigning the airline catering trolley for Driessen Catering, a manufacturer serving prominent airlines. The goal is to develop a flat-pack design for the trolley, allowing it to be shipped more efficiently from the manufacturer to the client, thus reducing transportation costs, and if possible making the shipping of the trolleys more sustainable.
Driessen Catering plays a key role as the primary stakeholder, driven by the goal of being innovative and reducing shipping costs while ensuring the redesigned trolley maintains high standards of quality and compliance. The airline companies, Driessens' Clients, are also deeply invested in the project. For them, it is essential that the new design is both durable and lightweight, seamlessly integrating into their existing operations without compromising on functionality or safety.
Regulatory bodies and inspectors are also key players, as the trolley must meet strict aviation rules on weight, strength, and safety. This is also one of the limitations of the project. Other challenges include making sure the trolley stays as strong, lightweight and long-lasting as the current design, figuring out who will assemble it, creating a foolproof assembly process and working within time and resource limits.
This project is an exciting chance to combine cost savings, smart design, and compliance, helping airlines and manufacturers move toward more efficient and sustainable solutions.

→ *space available for images / figures on next page*

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The goal of this project is to explore the feasibility of introducing a flat-pack trolley design into the airline industry, particularly within the current regulatory framework. I will investigate whether such a design aligns with existing regulations or if there is room to adapt or reinterpret these rules. If it is not possible to implement the design now, I aim to identify the factors that could enable its adoption in the near future.
Following this research, I plan to create a functional prototype of the flat-pack trolley, focusing on a mechanism that is sturdy, easy to assemble (foolproof), and meets industry standards. Additionally, I will explore how this design could fit into the supply chain, including identifying who would be responsible for assembling the trolleys upon delivery.
For Driessen Catering, this project will demonstrate whether their flat-pack idea is achievable within current constraints. For their clients, such as airlines, the benefits include reduced transportation costs, improved sustainable shipping and a well-designed, innovative and easy-to-use trolley. This project aims to deliver added value by combining innovation with cost savings while addressing stakeholder needs and ensuring practical implementation within the industry.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence)
As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format*:*

Design a prototype to create and evaluate the flat pack trolley for Driessen, aiming to reduce transportation costs while maintaining durability and usability in the context of airline operations and regulations.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

To carry out my graduation project, I will begin by researching the airline industry regulations to understand the requirements and constraints for a flat-pack trolley design. I will also analyze the current assembly process of trolleys, including their parts and construction methods and their supply chain. Next, I will explore the materials currently in use, assessing their properties and opportunities for improvement. This will be complemented by an investigation of existing flat-pack solutions in other industries to identify ideas that could be adapted for the trolley design. I will then research the assembly process at the destination, determining who will assemble the trolley, their skills, and the environment in which assembly takes place. Based on these insights, I will develop a prototype and conduct iterative testing. User tests, interviews, and discussions with stakeholders. I will then iterate on the mechanisms and needed assembly systems until the design meets the requirements for functionality, durability, and usability within the airline context.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting***, ***mid-term evaluation meeting***, ***green light meeting*** *and* ***graduation ceremony***. *Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.

The four key moment dates must be filled in below

Kick off meeting	10 Feb 2025
Mid-term evaluation	9 Apr 2025
Green light meeting	4 Jun 2025
Graduation ceremony	10 Jul 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	22
Number of project days per week	5,0

Comments:

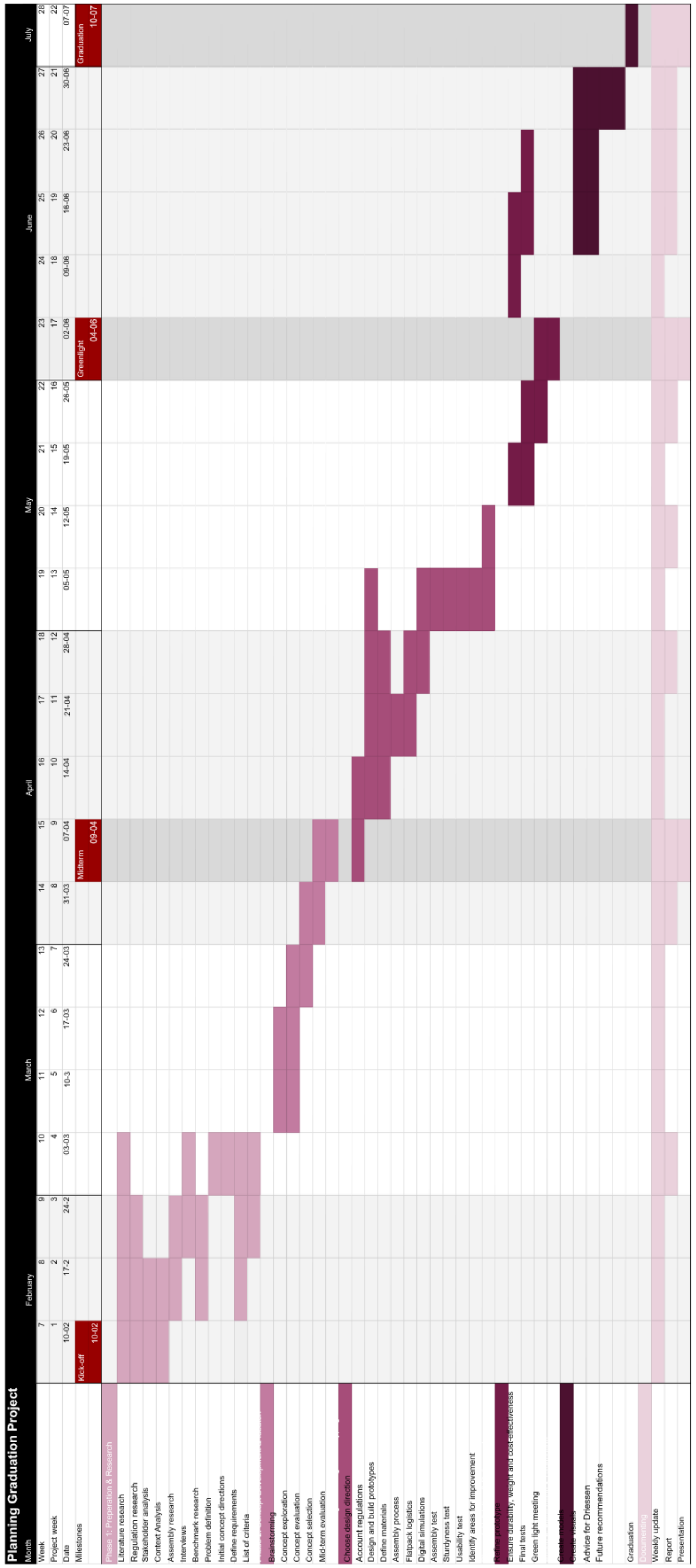
I will account for national holidays, adding an extra week, along with an additional week as a buffer, making the total project duration 22 weeks.

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

I chose this project because I am passionate about the practical aspects of design, especially mechanical systems and functional solutions. I find it exciting to explore how things work and how they can be optimized, rather than focusing solely on aesthetics. This project aligns perfectly with my interest in understanding and developing mechanical systems, assembly processes, and functional prototypes. Through this project, I aim to deepen my knowledge of materials and production methods, particularly in the context of manufacturing for the airline industry. I want to explore different mechanisms, fasteners, and assembly techniques to ensure the trolley design is both innovative and practical. Additionally, I hope to develop my skills in user-centered design by engaging with stakeholders, conducting user tests, and iterating on the prototype. On a personal level, I want to expand my competencies in combining regulatory research with hands-on design and prototyping, ensuring the final solution is both compliant and functional. This project offers an excellent opportunity to bridge the gap between theoretical knowledge and practical application, increasing my expertise as a well-rounded industrial design engineer.



10.2 AVIUS ULD Notes

This appendix are the notes of the Avius ULD visit. Avius transports their containers as flatpack and let them assemble at the place of destination. These notes explain what their system looks like.
Part 145 Stations:
These are the maintenance stations responsible for the final assembly step of Avius products.
EASA Form 1:
The release certificate issued for each trolley after full assembly.
A dedicated quality department is required to oversee and inspect the assembly stations. Many workers in these stations have relatively low qualifications, so a quality manager must be present to ensure proper assembly and documentation.
Unilode:
A global repair and maintenance company that Avius collaborates with. The pricing for services at Unilode is fixed, preventing additional costs if assembly takes longer than expected.
Unilode also has a facility at Schiphol Airport. If a visit is needed, a simple email request should suffice.
Smaller Maintenance Stations:
Unlike Unilode, these stations do not operate with fixed pricing and require additional training. If assembly takes twice as long, the costs can also double. Inefficiencies in their workflow often contribute to extended assembly times.
These stations typically have limited capabilities, often operating in basic workshop environments. For example, adhesive bonding is often not feasible due to the specific conditions required for proper application, such as controlled humidity levels.
Avius is responsible for providing training to these stations to ensure correct assembly procedures.
These training sessions are often conducted via conference calls and also serve as documentation.
PM22:
This is the methodology governing the assembly process. Training certifications under PM22 are valid for two years, meaning retraining is only required after that period.
Quality Manager Responsibilities:
Overseeing and documenting the assembly process at maintenance stations.

Conducting First Article Inspections (FAI), where the first assembled unit undergoes extensive documentation. Final approval photos are sent to Avius, and this unit remains on-site as a reference for subsequent production. The first article is the last to leave the facility, allowing early detection of potential production issues.

After the first article, the quality manager only needs to perform simplified documentation for the remaining trolleys, which must be submitted to obtain Form 1 certification.

While the quality manager can issue Form 1 certificates after maintenance, they are not authorized to do so after final assembly. Instead, they are only responsible for documentation.

Cost Considerations for Maintenance Partnerships:
Partnering with maintenance stations incurs significant costs, which vary depending on the production location. Since these stations charge by the hour, assembly time directly impacts expenses. It is essential to evaluate whether the cost structure remains viable.
Training and Certification:
Avius provides training sessions that are directly linked to product certification and specific assemblies or parts.

Certification is tied to part numbers (P/Ns), but it would be more efficient if one certification covered multiple product series. This should be verified with Driessen, as otherwise, a new training session would be required for every minor product variation, such as a thicker panel.

Challenges with Third-Party Assembly:
Outsourcing part of the production process introduces additional waiting times before trolleys become available for use. This can create time pressure at assembly stations, leading to longer delivery times.

Production defects may not be immediately visible when assembly occurs off-site, even if they are critical.

Next Steps and Considerations:
Repair Manual: Locate the existing repair manual to determine which components can currently be assembled by the maintenance stations. This information will be useful for designing the trolley, ensuring that assembly aligns with existing capabilities.

Approval Team: A new team is required to manage the issuance of Form 1 certificates and oversee approval processes.

Packaging Materials: Additional packaging will be necessary to ensure trolleys arrive undamaged. The associated costs and volume impact should be evaluated.

Additional Note:
A video demonstration is available in which Henk assembles the Improved Hybrid Trolley from a flatpack configuration in under five minutes. This may serve as a reference for future design improvements.

10.3 SUBPART F – PRODUCTION WITHOUT PRODUCTION ORGANISATION APPROVAL

The applicant shall be entitled to have a letter of agreement issued by Driessen agreeing to the showing of conformity of individual products, parts and appliances under this Subpart, after:
having established a production inspection system that ensures that each product, part or appliance conforms to the applicable design data and is in condition for safe operation;

having provided a manual that contains:

a description of the production inspection system required under point (a)
a description of the means for making the determination of the production inspection system;

a description of the names of persons authorized for the purpose of point 21.A.130(a) (Statement of conformity); (c) demonstrating that it is able to provide assistance in accordance with points 21.A.3A (Failures, malfunctions and defects:) and 21.A.129(d) (Obligations of the manufacturer).

21.A.3A: have a system for collecting, investigating and analyzing reports of and information related to failures, malfunctions, defects or other occurrences which cause or might cause adverse effects on the continuing airworthiness of the product, part or appliance covered by the type-certificate.

design changes, including material substitutions, have been approved under Subpart D or E and controlled before being incorporated in the finished product.

The production inspection system required by point 21.A.125A(a), shall also be such as to ensure that: materials subject to damage and deterioration are suitably stored and adequately protected; rejected materials and parts are segregated and identified in a manner that precludes installation in the finished product;

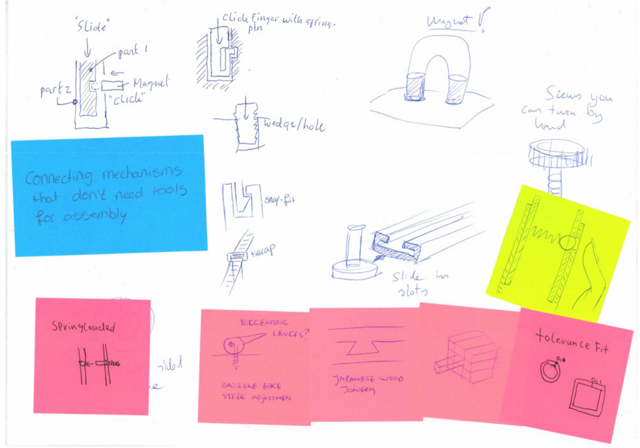
records produced under the production inspection system are maintained, identified with the completed product or part where practicable, and retained by the manufacturer in order to provide the information necessary to ensure the continued airworthiness of the product.

report to the holder of the design approval, all cases where products, parts or appliances have been released by the manufacturer and subsequently identified to have deviations from the applicable design data, and investigate with the holder of the type-certificate, restricted type-certificate or design approval to identify those deviations which could lead to an unsafe condition;

Each manufacturer of a product (...) manufactured under this Subpart shall raise a statement of conformity (...), or EASA Form 1 (see Appendix I), for other products, parts or appliances. This statement shall be signed by an authorised person who holds a responsible position in the manufacturing organisation.

Driessen shall validate by counter-signature the statement of conformity if it finds after inspection that the product, part or appliance conforms to the applicable design data and is in condition for safe operation.

10.4 Flat-pack Brainstorm



FLAT-PACK BRAINSTORM

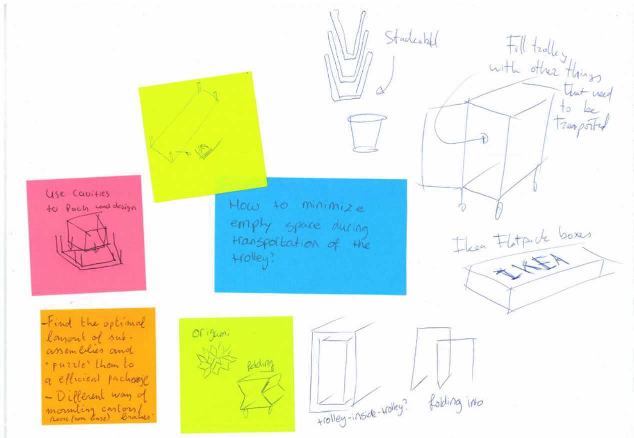
GOAL **Explore Folding Mechanisms** – Brainstorm potential (mechanical) solutions to allow compact trolley transport. while maintaining robustness and without increasing weight

RULES

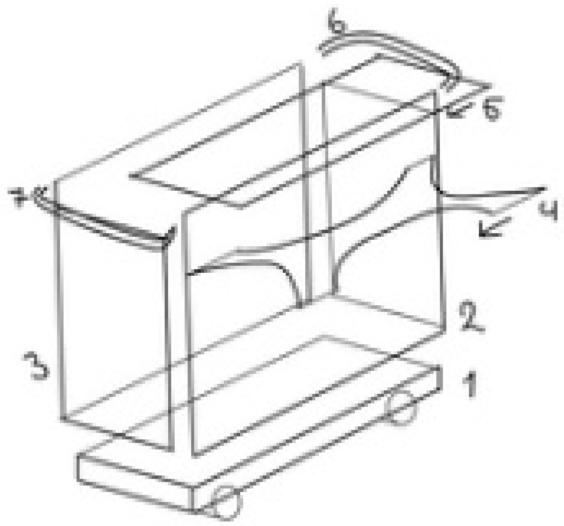
- Stay to time limit
- No judgement or critisism
- Stay visual
- Build on ideas

AGENDA

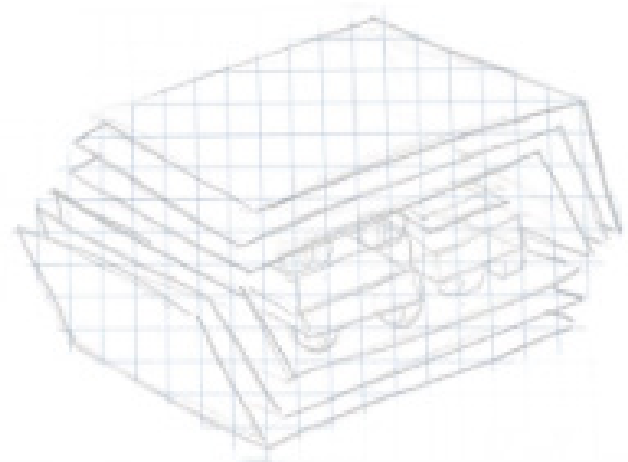
13:30 -13:45 Opening
13:45 -14:00 Individual brainstorm
14:00 -14:15 Discuss
14:15 -14:30 Plenary brainstorm



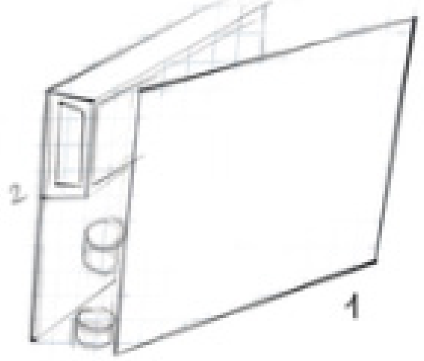
10.5 Different Trolley Configurations



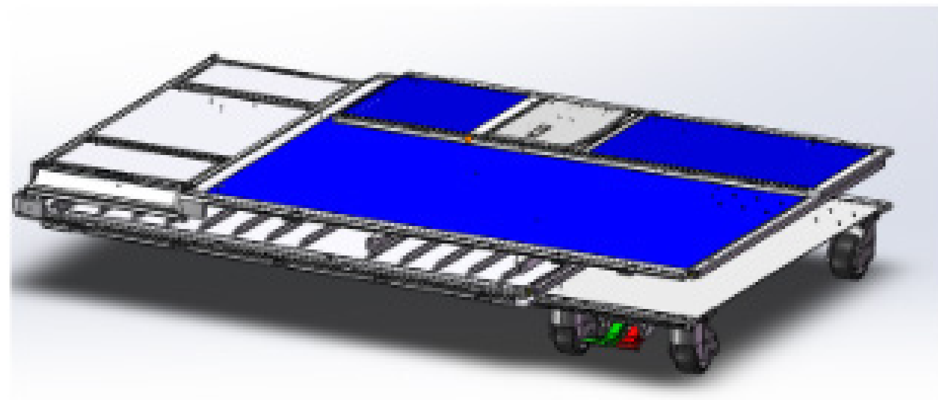
7 parts



4 parts



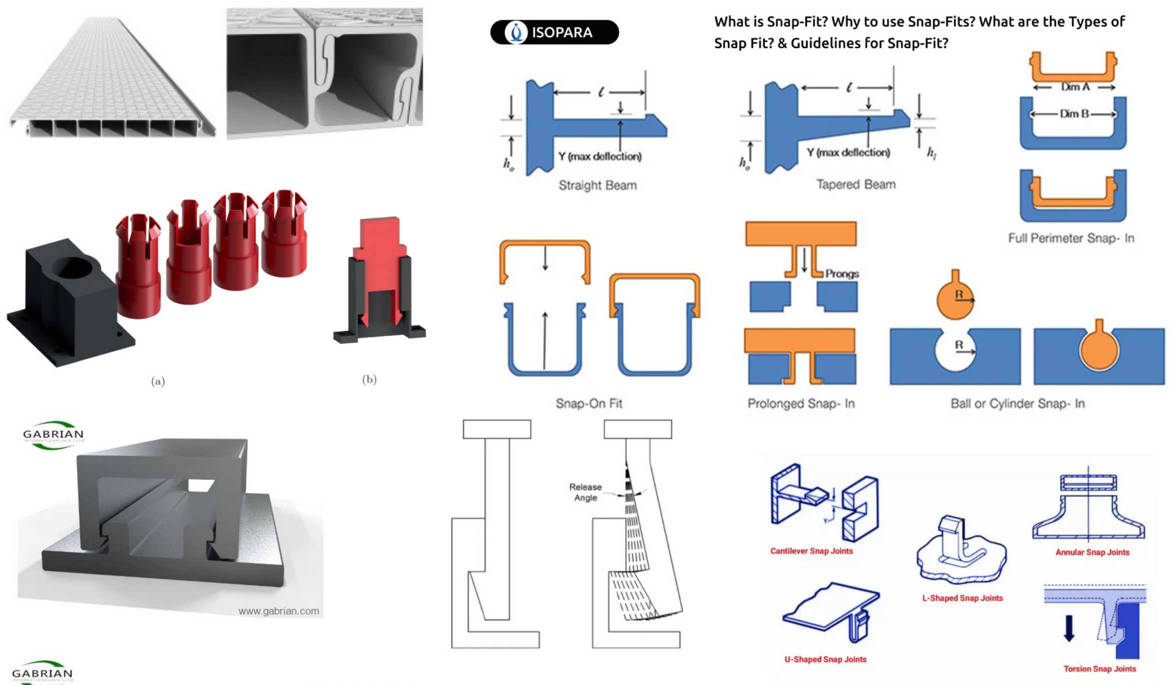
2 parts

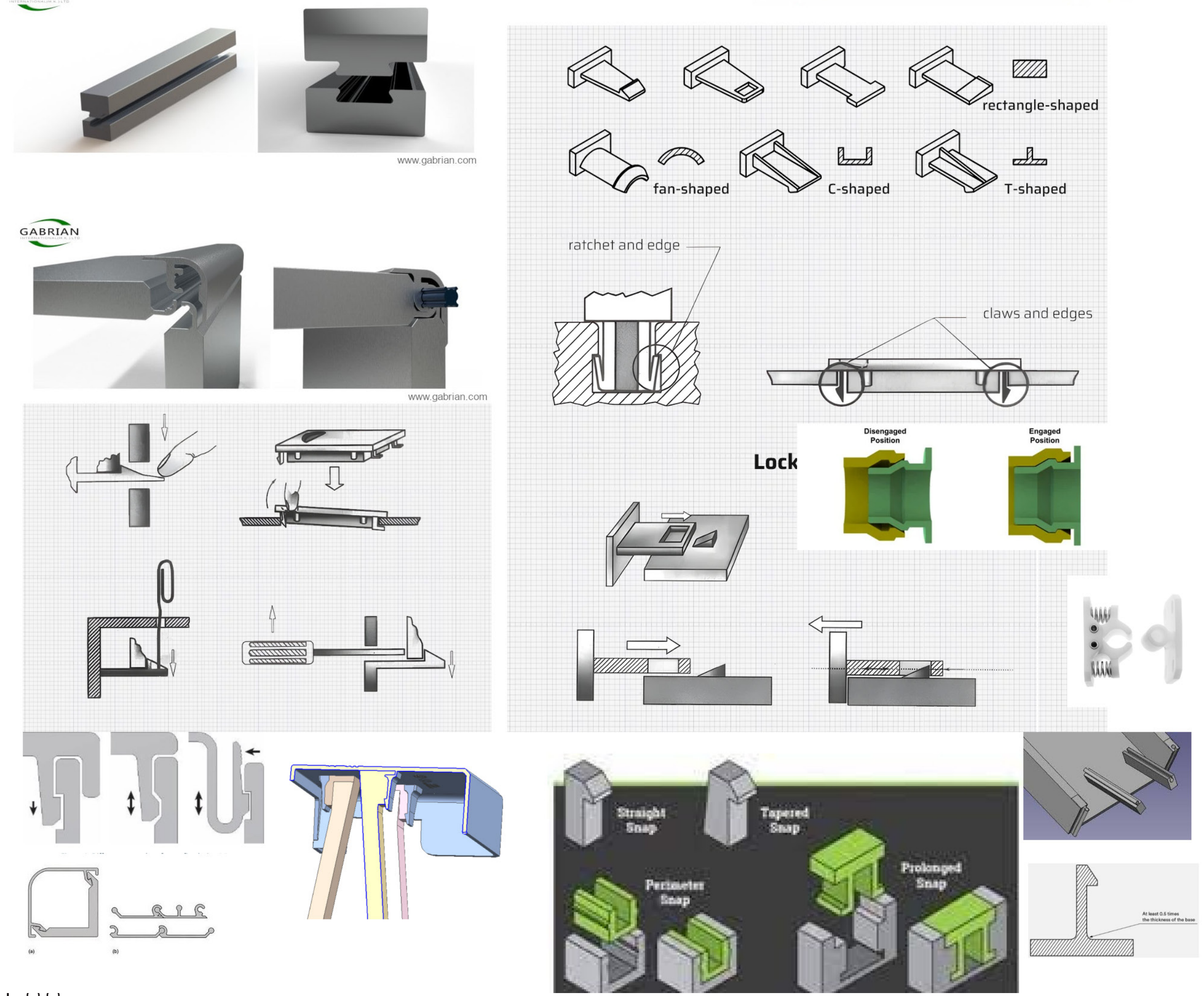


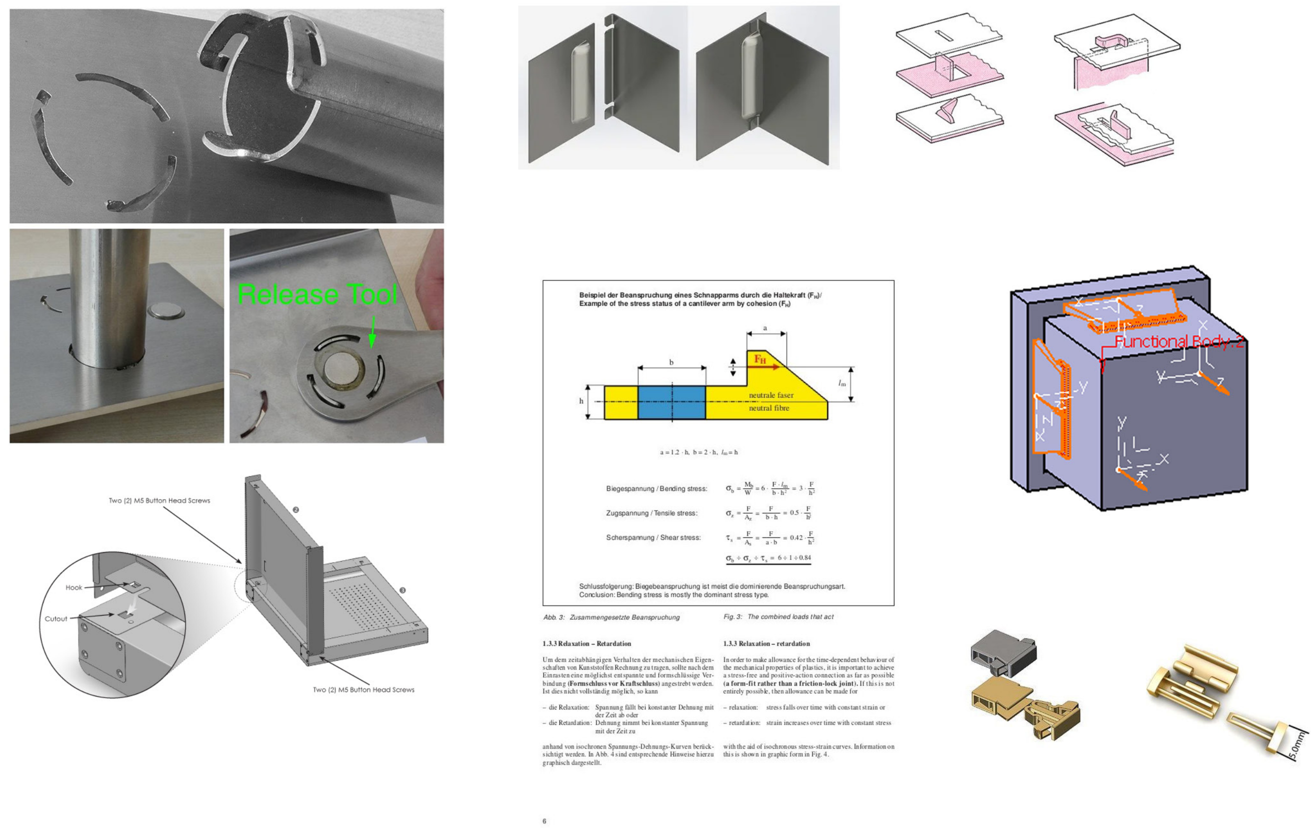
1 part

10.6 Snap-fit Brainstorm

Aluminium snap fit







Snap Fit

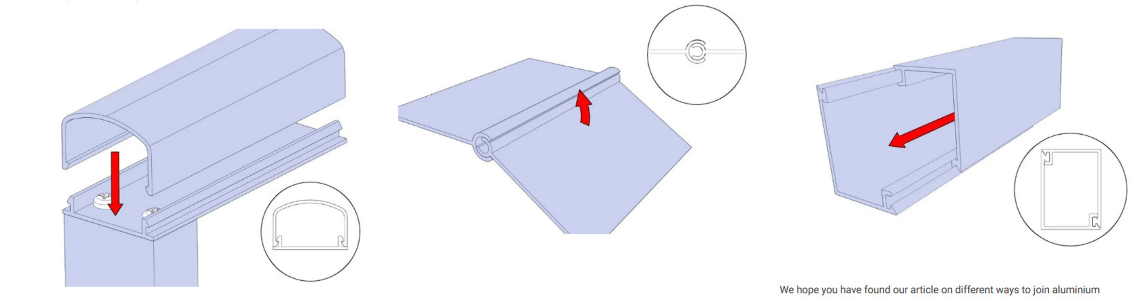
A quick and easy way to secure two extrusions together is a snap fit. This can be used as a decorative feature to hide unsightly screw heads. It requires no foreign fixings, which simplifies recycling. The lead-in barbs allow the top extrusion to slide and clip over the bottom extrusion, and the natural flex in the aluminium provides a positive snap. However, be aware that a barb with no reverse chamfer will create a permanent snap-fit.

Hinge

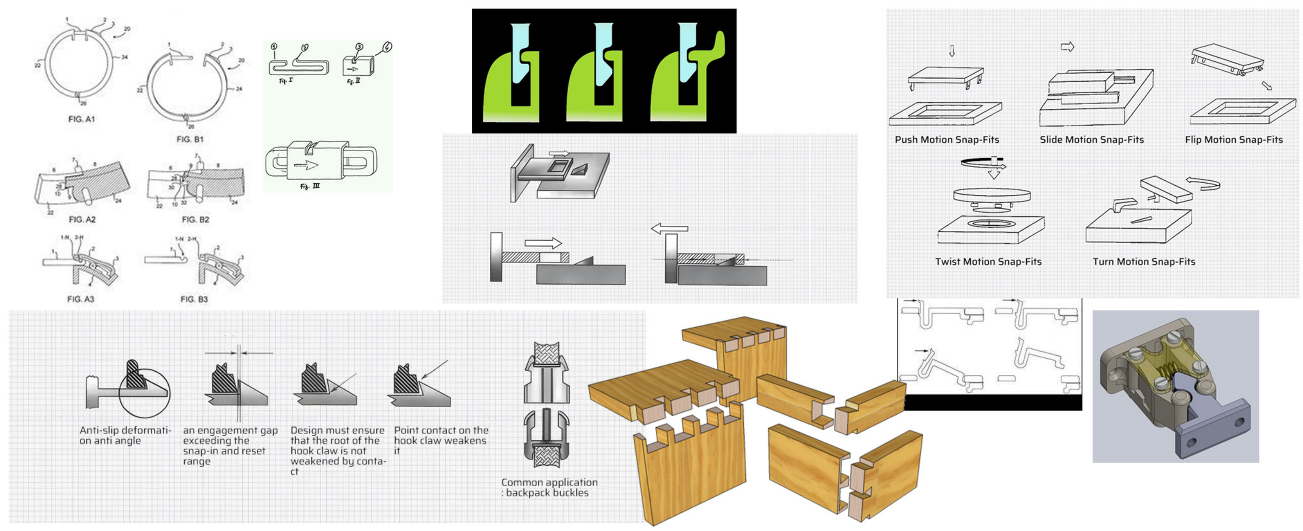
A hinge is a great way to fix two aluminium profiles together whilst allowing movement. This can be achieved in many ways, using two cylindrical features. The design below utilises a screw port, allowing a screw and washer to be fixed, preventing longitudinal movement.

Interlocking

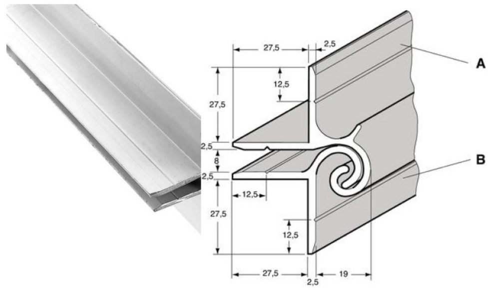
Very simple and effective, interlocking two extrusion profiles allows for a strong and quick fix. This can be achieved by sliding one feature over the other. You may notice that the extrusion below has both the male and female feature in the same profile, which means the same extrusion can be used for base and lid. Be aware however that this requires sliding its entire length, so may not be suitable for use in confined spaces.

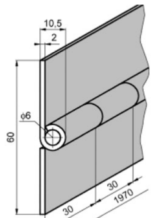


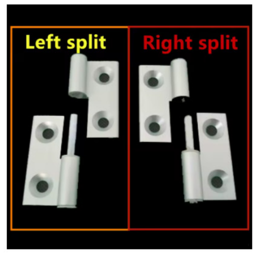
We hope you have found our article on different ways to join aluminium extrusions interesting - and useful! For more great articles, take a look at our

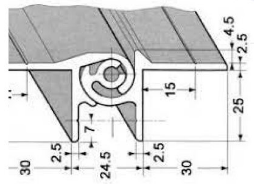


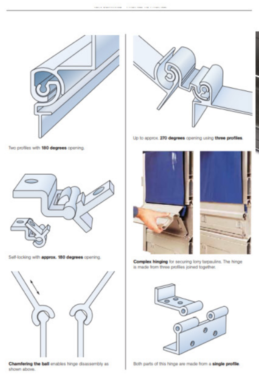
10.7 Aluminum Hinge Brainstorm

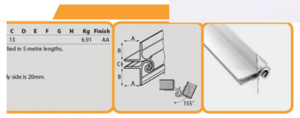


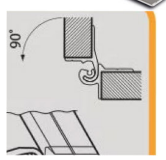


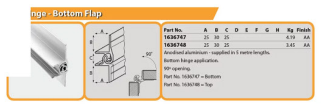


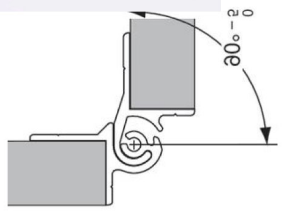


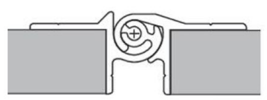


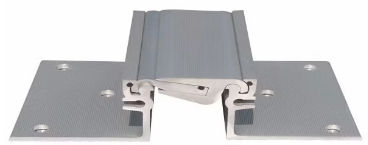


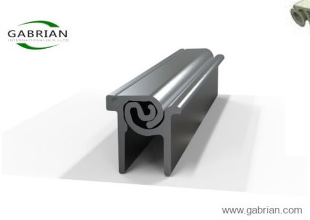


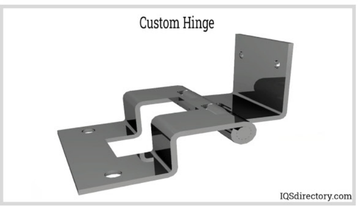






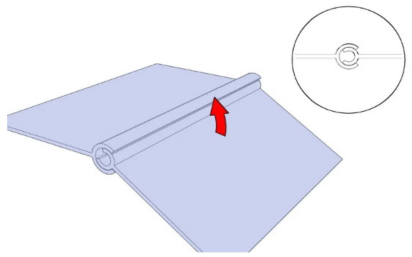


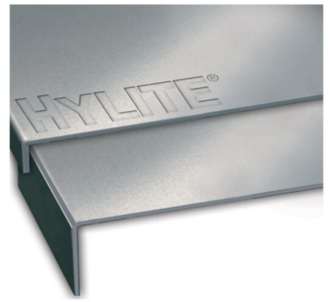


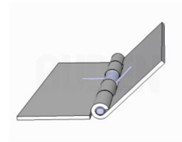


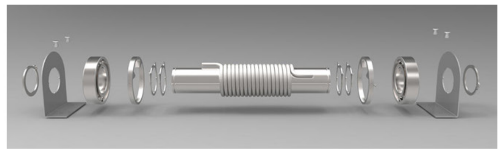
Hinge

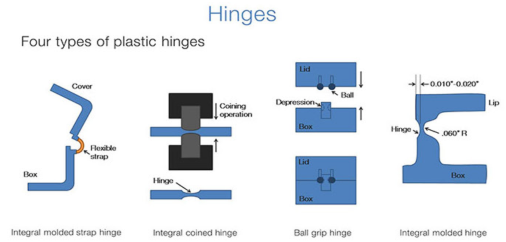
A hinge is a great way to fix two aluminium profiles together whilst allowing movement. This can be achieved in many ways, using two cylindrical features. The design below utilises a screw port, allowing a screw and washer to be fixed, preventing longitudinal movement.

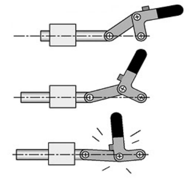


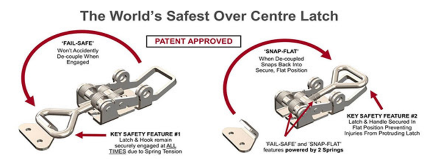


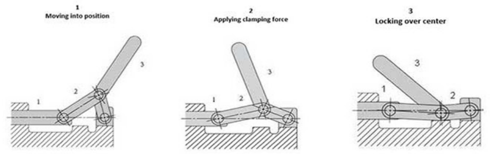


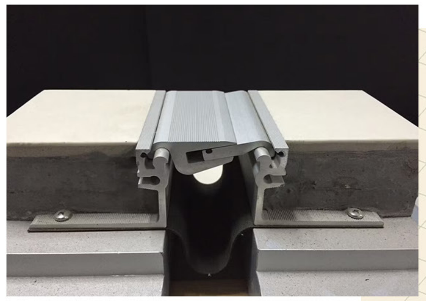


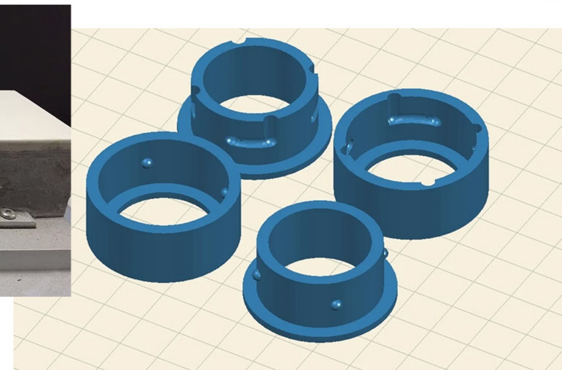


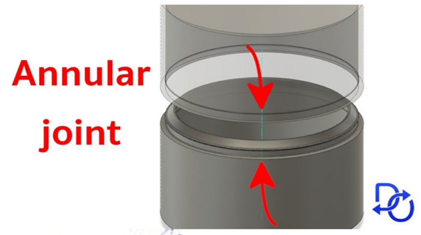


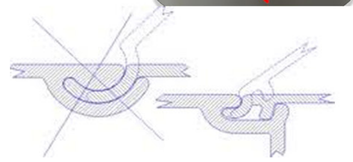










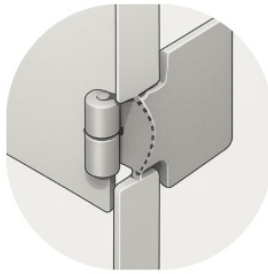


10.8 Hylite Test





10.9 Temporary Hinges


Snap-off or breakaway hinges


Heat-activated release hinges


Water soluble hinges


Magnetic or clip-in hinges


Biodegradable or reactive glues

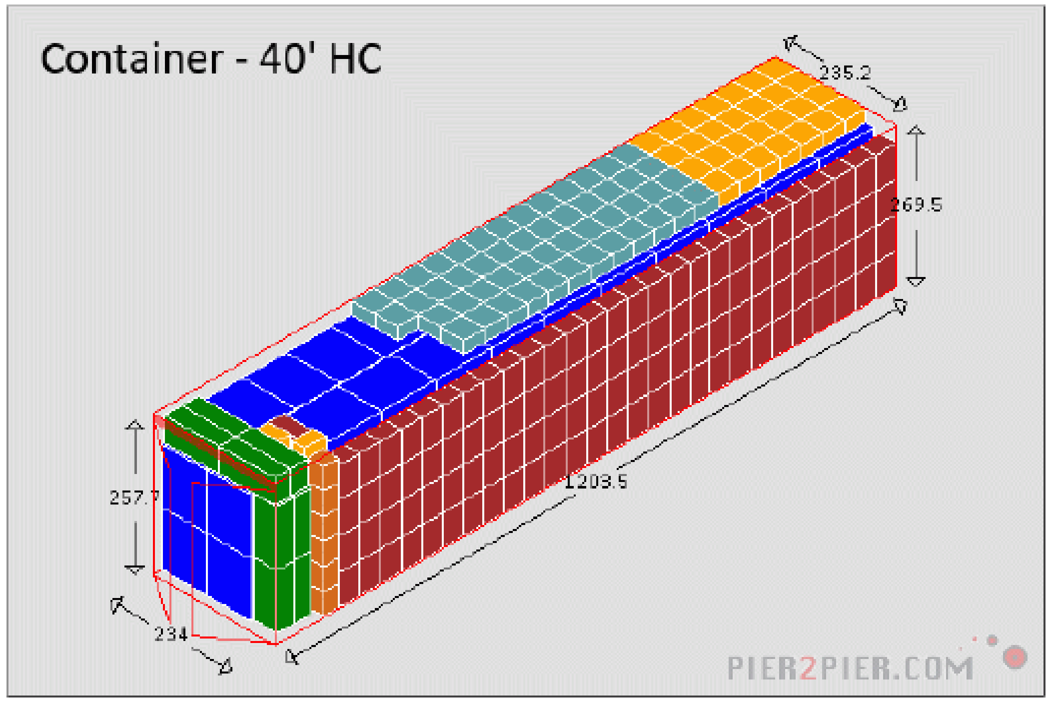
Hinge as a jig

10.10 Trolley Shipping

Equipment Packing Report PIER2PIER.COM

Following cargo shall be loaded in 1 * Container - 40' HC # 1 with your ref. Random 8920

Cargo name	Length	Width	Height	Weight total	Quantity	Colour
Trolley 1/1	[redacted]				193 / 400	
[redacted]					8 / 200	
					109 / 800	
					30 / 30	
					50 / 50	
					6 / 10	
Total : 70.866 cubic meter / 1188 cm floor length used				5655 kg	396	



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10.11 Snap-fit Technical Drawing