PRODUCT DEVELOPMENT OF GALLEY AIR EXTRACTION UNIT

Lappeenranta–Lahti University of Technology LUT

Master's Programme in Mechanical Engineering, Master's thesis

2024

Jaakko Ranta

Examiners: Docent Harri Eskelinen

Katriina Mielonen, D.Sc. (Tech.)

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT School of Energy Systems

Mechanical Engineering

Jaakko Ranta

Product development of galley air extraction unit

Master's thesis

2024

85 pages, 47 figures, 5 tables

Examiners: Docent, Harri Eskelinen and Katriina Mielonen D.Sc. (Tech)

Keywords: Product development, USPHS, VDI2221, marine industry

The goal of this thesis was to complete the product development process for the Galley Air Extraction Unit (GAEU) -product, and have it structurally developed in such a way that it meets the USPHS requirements. Ships and cruise ships sailing in US territorial waters must meet these requirements with approval.

GAEU is a kitchen ventilation product that will be sold by the target company's sister companies to, for example, restaurants and public spaces and facilities where cooking takes place.

The target company itself sells its products to maritime industry facilities such as cruise ships. For Galley Air Extraction Unit to be suitable for the target company's markets, its structural solutions must be suitable for the application to meet the requirements.

A product development project was performed, and it followed the guidelines of the VDI2221 systematic product development process and carried out the working steps instructed by it. The scope of the work focuses on three selected challenging structural problem points, for which solutions were planned and designed. For each of the three problem structures, three principled alternative solutions were presented, and finally, using a value analysis, the most suitable solution was chosen. Design of selected solutions was finalized and completed.

The work provided the target company with a model for a systematic product development process and promoted the product development and market launch of the GAEU product as desired, while creating structural solutions that can also be applied to other company products in the future.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUTin energiajärjestelmien tiedekunta

Konetekniikka

Jaakko Ranta

Galley air extraction unit tuotekehitys

Konetekniikan diplomityö

2024

85 sivua, 47 kuvaa, 5 taulukkoa

Tarkastajat: Dosentti Harri Eskelinen ja Katriina Mielonen TkT

Avainsanat: Tuotekehitys, USPHS, VDI2221, meriteollisuus

Tämän diplomityön tavoitteena oli suorittaa tuotekehitysprosessi Galley Air Extraction Unit (GAEU) tuotteelle ja saada se kehitettyä rakenteellisesti sellaiseksi, että se täyttää USPHS vaatimukset. Laivojen ja risteilijöiden, jotka seilaavat Yhdysvaltojen aluevesillä, tulee hyväksytysti täyttää nämä vaatimukset.

GAEU on keittiöilmanvaihtotuote, jota tullaan myymään kohdeyrityksen sisaryhtiöillä esimerkiksi ravintoloihin, kouluihin, ym. julkisiin tiloihin, joissa tapahtuu ruoanlaittoa.

Kohdeyritys itse myy tuotteitaan luksusristeilijöihin, jahteihin, laivastokohteisiin ym. meriteollisuuden kohteisiin. Jotta Galley Air Extraction Unit olisi soveltuva kohdeyrityksen markkinoille, tulee sen rakenteelliset ratkaisut olla oikeanlaiset vastaamaan vaatimuksia.

Tuotteelle toteutettiin tuotekehitysprojekti, joka seurasi VDI2221 järjestelmällisen tuotekehitysprosessin ohjeistoa ja toteutti sen ohjeistamia työvaiheita. Työ on rajattu niin, ettei kokonaista valmista tuotetta esitellä, vaan työ keskittyy kolmeen valittuun haastavaan rakenteelliseen ongelmakohtaan, joihin suunniteltiin ja haettiin ratkaisuja. Jokaista kolmea ongelmarakennetta kohtaa esiteltiin kolme periaatteellista vaihtoehtoista ratkaisua, joista lopuksi arvoanalyysiä käyttäen valittiin sopivin ratkaisua, jonka pohjalta suunnittelu saatettiin maaliin.

Työ tuotti kohdeyritykselle mallin järjestelmälliseen tuotekehitysprosessiin ja edisti toivotulla tavalla Galley Air Extraction Unit tuotteen tuotekehitystä ja markkinoille saattamista, luoden samalla rakenneratkaisuja, joita voidaan jatkossa soveltaa myös muihin yrityksen tuotteisiin.

ACKNOWLEDGEMENTS

I would like to express great gratitude to my supervisors from LUT University, Harri Eskelinen and Katriina Mielonen, for guiding me through this long-lasting project. Also, huge thanks to my thesis supervisor from target company's side, as well as to all colleagues that have helped me inside the, especially R&D and Technology team. Thanks to my own supervisor for flexibly arranging time for me to proceed with thesis, as it was taking time from my everyday work tasks.

The time of thesis work surely was not optimal for me. During this thesis work a lot happened outside the school world: I bought my first house, we had our second daughter born, I watched my first daughter turn 4 years old, I suffered from health issues and also suffered great loss when losing a loved one. Timing could have been better, but for some reason these big events of life tend to happen on eras when you may not be expecting them.

Despite everything I managed to finish my thesis, but I surely couldn't have done this all by myself. I am lifetime grateful for my beloved girlfriend Minna who took major role and responsibility about baby care and woke up at nights with the baby allowing me to sleep-in so I could have energy to continue finishing my thesis along with my job. Luckily, we shared a mutual understanding that my graduation benefits our whole family greatly, and Minna supported that goal fully and did far more than her part of everyday household tasks and childcare to provide me time to focus on thesis, and for that I am forever grateful.

Thanks also to my family members and in-laws who have supported me during this project. And let's not forget about my friends, my brothers, who have kept my sanity and belief in myself by allowing me to vent my frustration and disbeliefs in those beer-fuelled marathon sauna-nights and encouraged and supported me by saying we are almost at the finish line.

Jaakko Ranta

Orimattila, 17.4.2024

ABBREVIATIONS

AI	Artificial Intelligence
CAD	Computer-aided design
CDC	The Centers for Disease Control and Prevention
FEM	Finite-element method
GAEU	Galley Air Extraction Unit
HVAC	Heating, ventilation, and Air Conditioning
IoT	Internet of Things
R&D	Research and Development
SOLAS	Safety of Life at Sea
USPHS	U.S. Public Health Service
VDI	Verein Deutscher Ingenieure
VSP	Vessel Sanitation Program

Table of contents

Figures

Tables

1 Introduction

This introduction chapter firstly describes the background of the research and what are the base circumstances, and reasons this research is made. Goal of the research is precisely described along with desired outcome to target company.

After that research problem is described in detail. The research question follows this chapter and gives reader the compact idea what issue the thesis handles. After earlier mentioned, follows the brief presentation of research methods and scope of the research. Lastly target company and its main area of industry is presented.

1.1 Background

On cruise ships, vessels, and other larger marine vehicles. galleys are to provide food for customers and working staff. In these targets space for cooking facilities is quite limited as in many cases space for customers is prioritized and it is tried to be maximized. Galleys are provided with cooking devices such as oven and deep fryers, dishwasher etc. everything related to preparing food and cooking along with kitchen maintenance. For chefs, cleaners, maintenance workers and to all other staff working even in the short term in kitchen facilities, well designed and produced indoor solutions are a must for safe and comfortable working environment. Cooking and kitchen devices produce a large amount of steam and hot air with grease and removing this air is key factor for safe and pleasant indoor environment.

Usually, kitchen ventilation is performed with hoods and canopies over the kitchen devices. Hoods can be over individual device or modularized over kitchen island creating groups of hoods or canopies.

On figure 1 below an example of cruise ship crew mess kitchen facilities layout is visualised.

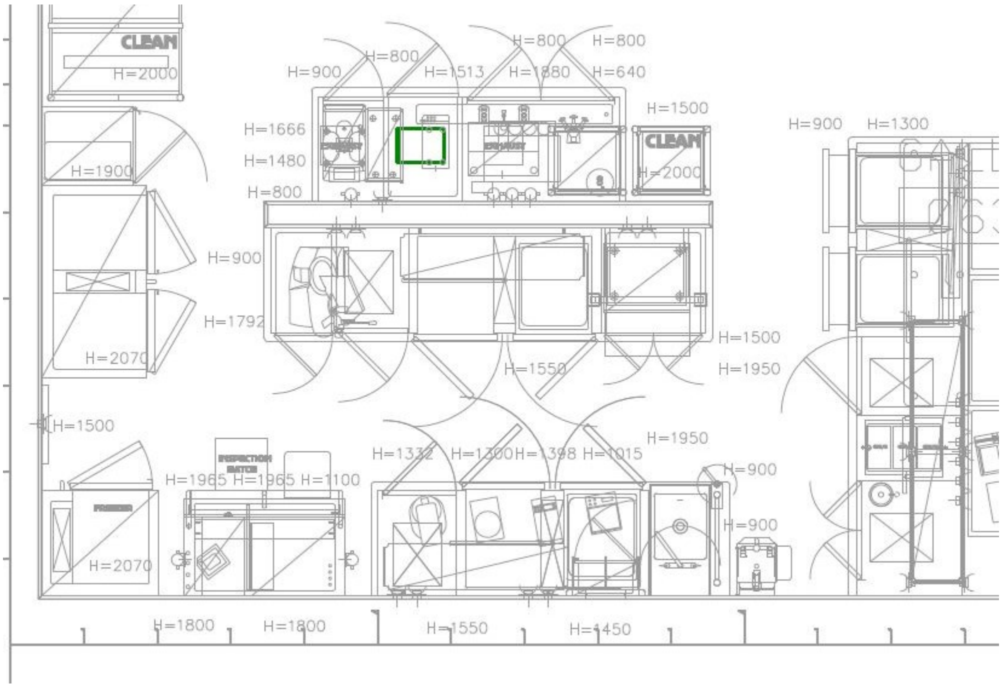

Figure 1. Cruise ship kitchen layout example

Example of kitchen solution used in cruise ship can be seen in figure 2. It gives example of devices used in galleys and how they are positioned in the area.

Figure 2. Cruise ship kitchen

As can be seen from figure 2. Hoods and canopies are installed into ceiling. Installation height usually just above chef's head in about two meters average. Kitchen devices can have height of anything from 70 cm in deep fryers or griddle grills to 1,8 meters with combi ovens. When device is and its steam source is at lower level near the floor, air has to move up to 1,5 meters up to hood and its filters and exhaust plenum. Exhaust is connected to ships ventilation duct system. For air to rise to hood, a suction to ducts is needed. Further the distance, the more powerful suction is needed and more power from engine, therefore more energy is required from the machines creating the suction to duct. From outside the box thinking and in purpose to save significant amount of energy and even space in crew mess and kitchen, product GAEU (Galley Air Extraction Unit) was invented.

Energy consumption of ventilation systems depends largely on airflows going from air supply to air exhaust. Thermal plumes of the hot air produced by kitchen appliances are calculated with formulas from VDI1999 (Verein Deutscher Ingenieure) standard.

The formula for calculating thermal plumes is presented below:

$$V_{th} = k * Q_{s,k}^{\frac{1}{3}} * (z + 1,7 * d_{hydr})^{\frac{5}{3}} * r$$

Where, V_{th} represents convective thermal plume at a defined height, k is empirical coefficient, $Q_{s,k}$ is convective loads of cooking appliances, z is free height above cooking appliances, d_{hyrd} represent hydraulic diameter and r is hood installation configuration factor.

Briefly, the main idea behind GAEU is to connect the traditional hood close to the actual kitchen device, bringing it from the ceiling directly above the kitchen device. Distance the air has to travel can lower from 2 meters to just 0,5 meters which lowers the need for air suction and requirement for energy significantly. Energy matters and sustainability are major things today in various industries, and in marine as well. If energy requirements of kitchen hoods can be lowered, the whole kitchen consumes less energy. Consuming less energy leads to consuming less fuel and engine will require less power to operate. Engine size and power can be optimized, and power can be directed to where it's needed to most from those areas where its consumption can be lowered, creating the most economically and environmentally reasonable and sustainable solution.

1.2 Thesis goal

Goal of the thesis is to design, develop and present several different solutions for variety of selected structural issues and problems of GAEU's structure. Three different structures are selected, and for those few optional solutions are investigated, evaluated and studied. Those options are presented and evaluated in thesis, and the most suitable one for target company will be chosen for this application with justification.

Design process in this thesis will create model of systematic product development process which target company can use and apply in suitable similar projects to come. Thesis itself follows the main points of VDI2221 systematic product development process guide.

1.3 Research problem

GAEU isn't ready product for target company's usage as it doesn't fill the USPSH (U.S. Public Health Service) requirements and the SOLAS (Safety of Life at Sea) demands, which are precisely described later on this thesis. Mechanical structure of the product isn't suitable for application target company desires it to be utilized in, and product development is required to make GAEU to fulfil the demands and becoming as suitable product for markets.

GAEU is originally target company's sister company's' product. This sister company provides product to other business area which are not under same regulations as target company is. This means that the design is not based on same rules and requirements as marine site products. USPSH demands that clearances between parts and structures above cooking level must be tight. As well there cannot be any strict corners as every 90-degree corner in parts or in between parts must have a minimum inner radius or 9.5 mm. Joins that are made with welding have requirements of continuous weld between parts and intermittent welds are not allowed. These regulations target is to make sure products are cleanable and safe. Originally GAEU is designed with 1,0 mm of sheet thickness, but in marine usage the sheet thickness must be minimum on 1,25 mm. Because of this, parts must be modified, or in some case even remodelled and manufacturing drawings must be remade as thicker material has effect on dimensions. All demands are for sanitary, safety and healthy purposes as the ease the cleaning of products and increase fire safety for example.

Manufacturing of GAEU as it was at starting point was expected to be non-productive and not optimized as it was originally designed for different manufacturing facilities and machinery base.

Measures to improve manufacturability and assembly will also be performed during this product development process but the focus in this thesis will be problematic structures from regulated demands point of view.

Three different cases will be studied and presented, and for each several possible solutions will be designed and presented. Best solution for each case is selected and selection will be justified.

1.4 Research questions

In this chapter the research questions of this thesis are presented. The questions are following:

What kinds of structural changes and solutions must be made at product development process to make Galley Air Extraction Unit to meet the USPHS requirements and other quality demands presented by target company and its' customers, and why?

1.5 Research methods

This thesis is utilizing four research methods which are evaluated by thesis worker to be most suitable for this thesis subject and project. First method is literature review where data concerning this subject and related subject are being searched and investigated.

Second research method is value analysis where different features cornering developed structures are numerically evaluated and scored. Data for value analysis is gathered from the results received from other research methods used in this thesis. With scoring different solutions and their suitability for the application can be compared numerically.

Third method is expert interview based on Delphi method. where several experienced persons from ship industry will be interviewed with predetermined questions.

Fourth research method used is experimental research which plays the major role in this thesis as challenges to be solved requires physical testing, prototypes and testing of developed parts and structures.

1.6 Scope of research

The purpose of this thesis is not to present and illustrate the complete product which will be on the markets. Thesis separates and studies different kind of problematic structures and challenges in manufacturing and design phase. Selected structures are related to USPSH demands and they are concerning things such as clearances between parts, rounding at the corner structures and air tightness. Selection of those problems are further investigated and studied for finding and providing solutions for the complete product. Product development processes can take years, and it is not realistic to expect the GAEU to be market ready product by the end of this thesis. That is why scope is set to consist only major structural and mechanical problematics and finding solutions and options for those. Justification for selected structures will be presented in results chapter in this thesis.

1.7 Target company

Target company which the thesis is made for is global technology leader designing, manufacturing, and delivering indoor air solutions for demanding spaces. Company's one of the main product categories is kitchen hoods which are being delivered to cruise vessels, navy ships or even to energy facilities such as oil rigs etc. Company is family owned and operates all over the world but is established in Finland and has two factories in Finland. 95% of the products are exported to global markets. All manufactured products are sheet metal products manufactured with laser cutting and punching, bending, and welding. Products also include lot of electrical components and systems. Quality requirements of target company's products are high and focus of business is on high quality with good margins over high volume with low margin.

2 Literature review

This chapter is literature review including information and data about topics concerning product development process of GAEU. All product development performed in this thesis is based on standards and determined requirements which will be introduced first. Chapter 2.1 opens the abbreviation USPHS, what it is, what are its principles and meaning in this work.

Product development work is done by following the steps and guidelines VDI2221, the standard of systematic product development process, and this is furtherly introduced in chapter 2.2.

2.1 United States Public Health Service

United States Public Health Service is originally established over 200 years ago and its primary objective was providing the immigrants and sailors the protection of their health. It has evolved through time and history now plays vital role in regulations, research and in healthcare delivery. (U.S. Department of Health and Human Services 2024.)

Concerning maritime safety USPSH provides two important and informative documents called VSP (Vessel Sanitation Program) Construction Guidelines and VSP Operations Manual. These documents give instructions and determine the limitations and regulations which products on maritime facilities must fulfill. Construction Guidelines determines the structural issues on building phase of ships when Operations Manual focus on equipment used on ships, how they should be cleaned, how food should be preserved, issues about pot water, demands for air ventilation and these kinds of things. (U.S. Public Health Service Oper. 2018, pp. 1-3.) The VPS Construction Guidelines document is further introduced in the next chapter.

VSP is originally established by CDC (The Centers for Disease Control and Prevention) in 1975. It was created in cooperation with the maritime industry creating cruise vessels and most of the biggest ship builders and shipyards have been involved in their effort in it. Improved health of crew and passengers is the main goal of these instructions. By setting these construction guidelines, framework and demands the industry is forced to develop and implement these sanitation programs which can be considered comprehensive. VSP organizes biannual operational inspections in which timetables are unannounced. These inspections concern vessels that carry 13 or more passengers and sails to port of U.S. Inspections can also be arranged voluntarily if some ship builder or shipyard is for example improving and rebuilding old ship and wants to get it approved by VSP for larger markets. (U.S. Public Healt Service 2018, pp. 1-2.)

The most relevant and important chapter of Construction Guidelines is chapter 14 which is solely dedicated to the hood systems of cruise vessels. Chapter determines the structural requirements for hood systems for example that hood, or canopy overhang must be a minimum 150 mm from the steam outlet, otherwise capturing the heat and steam and prevention of condensate water cannot be guaranteed. The chapter also presents the guidelines for a variety of aspects that occur in vessel galley. Filters used in hoods must be removable and cleanable and access for ducts and hood exhausts must be ensured in order to maintenance and inspection to be doable. About construction is said, that if hood has straight 90-degree corners, they must be rounded to have minimum radius of 9,5 mm or otherwise they will collect impurities. Material of hood must be stainless steel with sheet thickness minimum of 1,25 mm and welds must be continuous. (U.S. Public Healt Service 2018, pp. 39-42.)

Construction demands presented in the chapter above are just a few examples of all the information in the Construction Guideline of VSP. Those that are mentioned are the most relevantly relating to products under development in this thesis. For example, the overhang and requirement of corner radius are issues that were faced several times during this thesis' product development project.

2.1.1 Safety of life at sea - Convention

SOLAS is international convention which is one of IMO conventions. IMO is abbreviation from words International Maritime Organization. IMO was established 1948 when it was recognized that united and regulations are needed to improve the safety at seas. (Brief history of IMO 2024.)

It can be said that SOLAS is the most important agreement of maritime safety rules and guidelines. It has had several versions and revision through the years, and first one was approved in year 1914, two years after the sinking of Titanic, and it was direct response for that accident. The SOLAS convention agrees that all the ships that are registered in countries that have signed the convention, will pass the minimum regulations that are set for safety. They are concerning for example functions of the ship, equipment and the structure. SOLAS specifies these minimum standards concerning construction and other aspect mentioned earlier. Some certificates are also determined in convention and inspections are made when there is believe that some ship doesn't fulfil all requirements set in convention. Later versions of SOLAS are from years 1929, 1948, 1960 and 1974. The 1974 version can be seen as the main version which still is referred even today. Last version is revised and updated countless times and constantly under observation to keep it up to date. (International Convention for the Safety of Life at Sea 1974 2024.)

As SOLAS sets the maritime safety framework, which is comprehensive, the scale of different regulations is wide. The content of the convention is listed below at the title level, as titles reveal the basic topics of content of it in the most effective way. Next list of chapter titles is and straight quotation from SOLAS Consolidated edition. (IMO 2001.)

"Chapter 1: General provisions, Chapter 2-1: Construction - Structure, subdivision and stability, machinery and electrical installations, Chapter 2-2: Construction – Fire protection, fire detection and fire extinction, Chapter 3: Life-saving appliances and arrangements, Chapter 4: Radiocommunications, Chapter 5: Safety of navigation, Chapter 6: Carraige of cargoes, Chapter 7: Carriage of dangerous goods, Chapter 8: Nuclear ships, Chapter 9: Management for the safe operations of ships, Chapter 10: Safety measures for high-speed craft, Chapter 11: Special measures to enhance maritime safety, Chapter 12: Additional safety measures for bulk carriers. Chapter 13: Verification of Compliance, Chapter 14: Safety Measures for Ships Operating in Polar Waters"

SOLAS doesn't apply to all ships sailing, there are some exceptions. The ships that SOLAS doesn't apply to are fishing vessels, primitive build or wooden ships, war ships nor to cargo ships that are carrying less than 500 tons worth of cargo.

2.2 Product development and VDI 2221 guidelines

This chapter introduces the systematic product development guide VDI2221 which four fundamental phases are followed during this thesis product development process withing the guidelines set.

The need for product development arises when a new product or improvement for an old product is needed. The process is always based on the customer's needs. Target customers for a product must always be clear and truly exist, otherwise the development project is not based on real need and therefore should not be performed. From a very start, an unambiguous list of product specifications must be made in order to get the details and functions of the product to fulfill the needs and requirements of the customer. For the product development process, the preliminary study should be performed to gain as much data and information as possible concerning the product's usage environment, its required functionality, possible limitation, size of markets etc. The scope of the preliminary study depends highly on the product and its concept. The study might for example be done by one person, or by a small group of people involving different departments in the company such as sales, marketing, and production. (Välimaa,Kankkunen,Lagerroos& Lehtinen 1994, pp. 25-28.)

Product development projects are often costly and time consuming. Their length can be months or even years and they often use lots of resources. For these reasons often company management is the entity to either approve or decline the starting of product development projects. To support the decision making, the product plan should be executed and presented based on the preliminary study's results. The following data should, at minimum, be included to product plan, which is presented to deciding party:

- Specifications
- Strategy
- Customer of customer groups
- Novelty value of the product
- Limitations with sales
- Competitive situation of products in the markets

- Profitability
- Forecasted lifecycle of the product
- Time of publication
- Risk analysis

Before the project is started, all matters mentioned above should be clear to make sure that all relevant information has been taken into account in decision making. (Välimaa,Kankkunen,Lagerroos& Lehtinen 1994, pp. 47-49.)

2.2.1 Goals and objectives of systematic product development process

VDI2221 guideline present and illustrates the design approach method that can be considered generic and be applied to designing of systems and products that are mechanical. The guideline highlights the approaches general suitability in process engineering, software, control, precision, and mechanical fields. The goal of guidelines is to simplify and produce the more efficient style of working with product development processes. The presented guideline includes four main phases which consist of seven working steps. The committee that has created the guidelines consisting of Germanys design methodologists and senior designer that can be considered comprising. (Pahl,Beitz,Feldhusen& Grote 2007, p. 18.)

According to Ulrich, Eppindger and Yang (2020, p.12) a product development process is "the sequence of steps or activities that an enterprise employs to conceive, design, and commercialize a product. Many of the steps and activities are intellectual and organizational rather than physical."

2.2.2 Phases and steps of product development

The working steps of VDI2221 are presented in figure 3 illustrated in next page of this thesis. Figure shows the basic guidelines to follow when proceeding with systematic product development process. As the discussion is about guidelines not rules of standard for example, the process doesn't always follow the steps identically when compared to designed process model. Sometimes some stages might be skipped, or to some step or phase might be returned even though the design project would be at further stage.

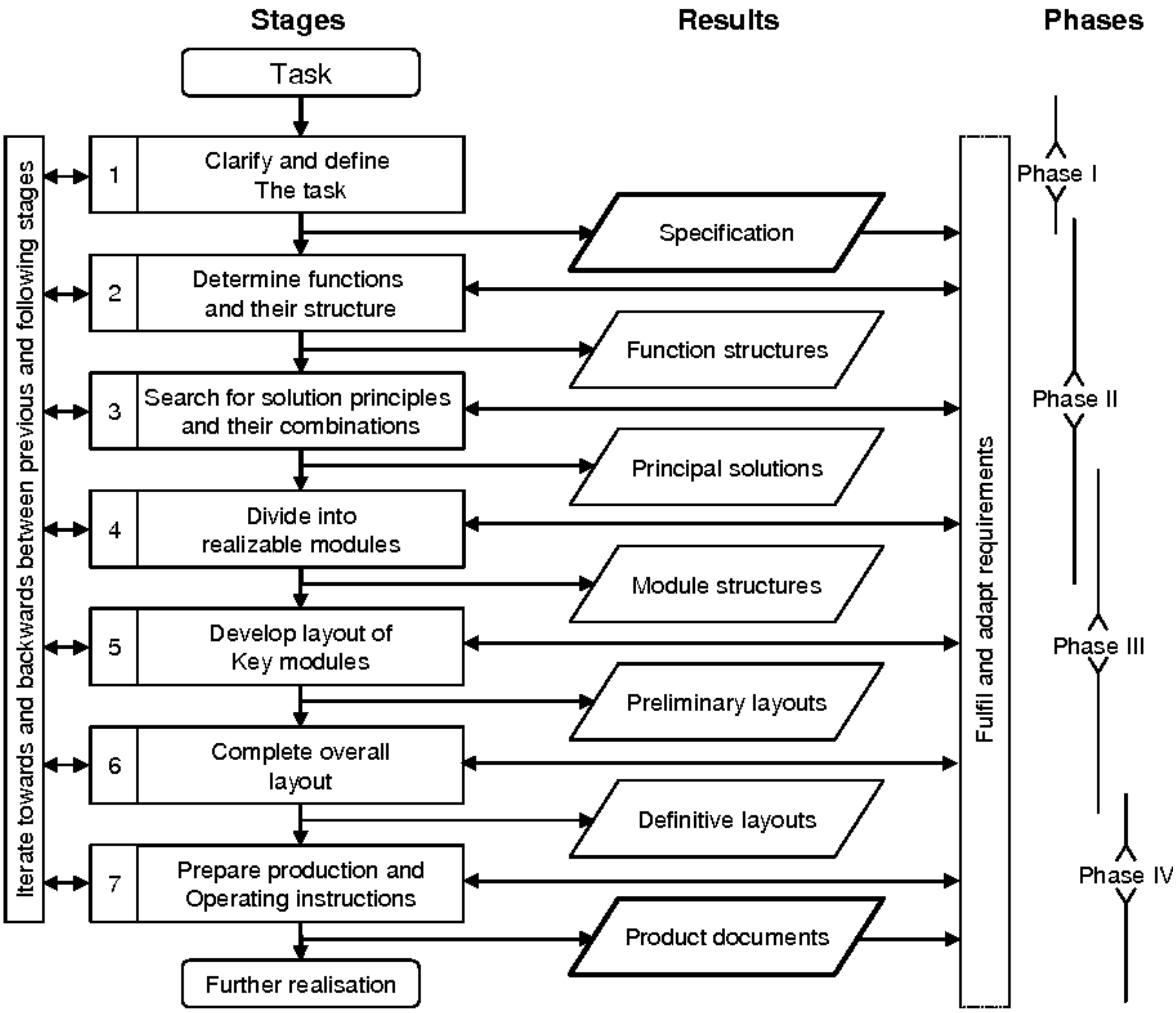

Figure 3. Guideline of VDI2221 (Pahl,Beitz,Feldhusen& Grote 2007, p. 19).

Figure above illustrates the structure and order of actions presented in form of easily readable graph. In next chapters the different phases of VDI2221 are introduced and described.

The first phase of VDI2221 guidelines main focus is on clarifying and defining the objectives, tasks and requirements set for product development. First phase is also called Task clarification. All the information and data concerning the requirements set to the product is gathered. Purpose is to define the list of requirements as clearly as possible. If product has some limitations, those must be defined, and their importance noticed. As a result of phase one, list of requirements is formed. All the following design steps are based on this list of requirements created. (Pahl,Beitz,Feldhusen& Grote 2007, p. 131.)

The layout for requirement list is illustrated in figure 4.

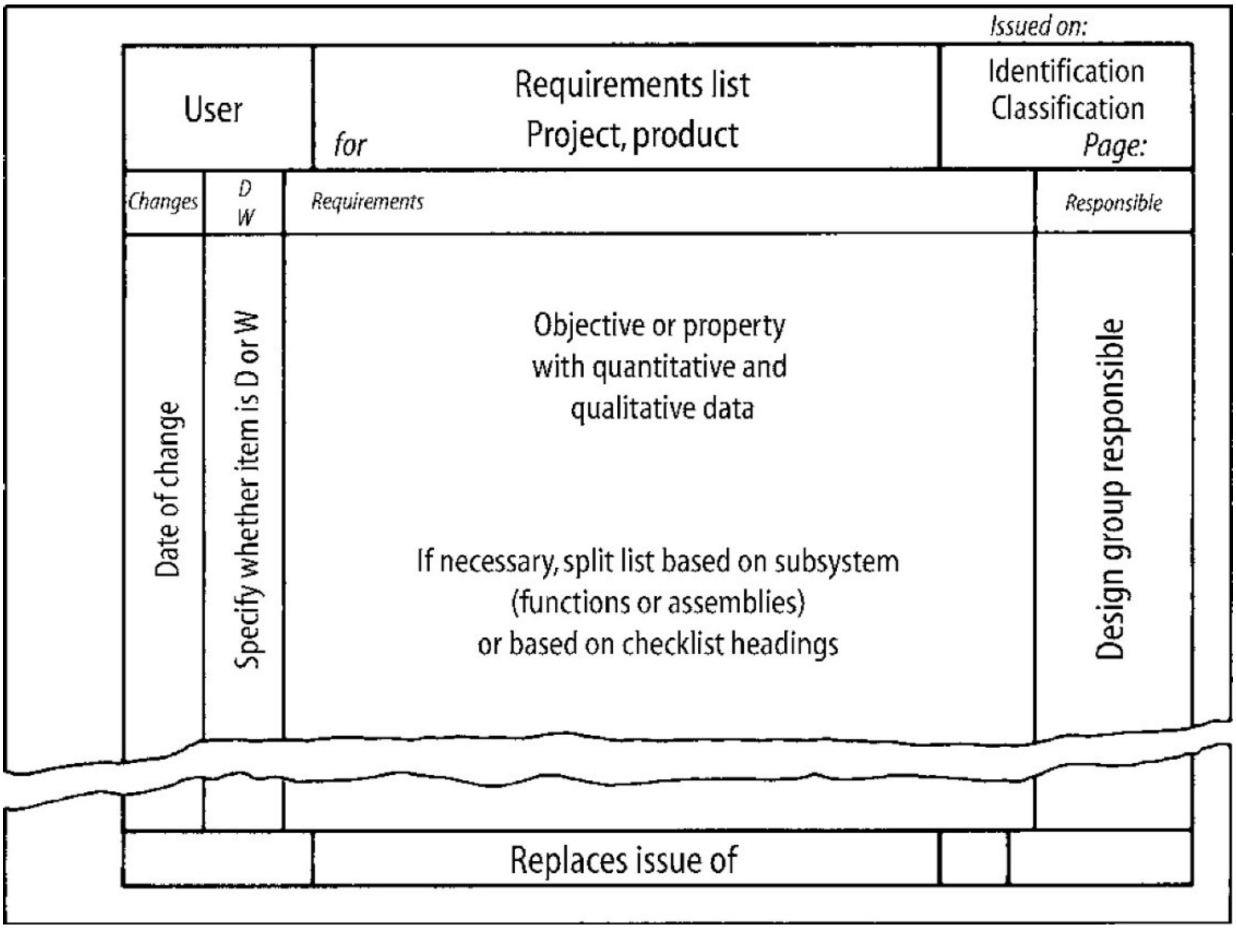

Figure 4. Layout of a requirements list (Pahl,Beitz,Feldhusen& Grote 2007, p. 148).

Figure above illustrates the requirement list which contains the information such as what will be the date of change, which issue the product replaces, how is responsible of design etc.

The second phase of guideline is called Conceptual Desing. In conceptual design phase the design ideas are created on principle level. Solutions presented for problems only consider of principle solutions and not take account details, only concept idea of what must be done and how result could be achieved is presented. This phase doesn't produce complete manufacturing files such as drawings, but only concept level solutions. Preliminary plan for design must include information about dimensional scaling with rough dimensioning, estimation of manufacturing technologies to be used and general idea of material. This means for example the specific steel grade is not determined, but information if steel to be used should be galvanized or stainless steel must be known. Often the requirement list already might narrow down the options as some limitations might be set at task clarification phase. Usually at this point there are several collateral product ideas that are estimated using different tools and techniques. Number of solutions can vary at his point of conceptual design. Combining factor is that all solution variants must fulfil the minimum requirements set at phase one. If solutions is against requirements, it should be removed from list of ideas to be developed. Design is furtherly developed into more concrete representation so it's suitability can be more precisely estimated. (Pahl,Beitz,Feldhusen& Grote 2007, pp. 131-132.)

The third phase of product development process guideline presented in VDI2221 is called Embodiment Design. In this phase the design is taken from conceptual principal level to more detailed and concrete one. The required details, technical aspects are taken into consideration and design is focused on creating concrete solutions in form of prototypes or drawing etc. In this phase also manufacturing methods must be clear but some details may still stay under investigation. (Pahl,Beitz,Feldhusen& Grote 2007, pp. 227-228.)

Figure 5 below demonstrates the checklist for embodiment design that should be checked during design process.

Headings	Examples
Function	Is the stipulated function fulfilled? What auxiliary functions are needed?
Working principle	Do the chosen working principles produce the desired effects and advantages? What disturbing factors may be expected?
Layout	Do the chosen overall layout, component shapes, materials and dimensions provide: adequate durability (strength) permissible deformation (stiffness) adequate stability freedom from resonance unimpeded expansion acceptable corrosion and wear with the stipulated service life and loads?
Safety	Have all the factors affecting then safety of the components, of the function, of the operation and of the environment been taken into account?
Ergonomics	Have the human–machine relationships been taken into account? Have unnecessary human stress or injurious factors been avoided? Has attention been paid to aesthetics?
Production	Has there been a technological and economic analysis of the production processes?

Figure 5. Checklist for embodied design (Pahl,Beitz,Feldhusen& Grote 2007, p. 234).

Quality control	Can the necessary checks be applied during and after production or at any other required time, and have they been specified?
Assembly	Can all the internal and external assembly processes be performed simply and in the correct order?
Transportt	Have the internal and external transport conditions and risks been examined and taken into account?
Operation	Have all the factors influencing the operation, such as noise, vibration, handling, etc. been considered?
Maintenance	Can maintenance, inspection and overhaul be easily performed and checked?
Recycling	Can the product be reused or recycled?
Costs	Have the stipulated cost limits been observed? Will additional operational or subsidiary costs arise?
Schedules	Can the delivery dates be met? Are there design modifications that might improve the delivery situation?

Figure 5 continues. Checklist for embodied design (Pahl,Beitz,Feldhusen& Grote 2007, p. 234).

By checking each item on the list, the situation with product design is clear.

Last phase of design process is called Detail Design. In this phase all the detail for products design is determined precisely. Detail concern for example the specification of material, dimensions of product and possible tolerances to be used, surface quality, manufacturing methods including which machine will manufacture the parts and with which tools. Also, final manufacturing files and documents are produced including technical drawings and 3D-files depending on manufacturing methods to be used. Cost-estimations are done to justify the reasonability of the product and its manufacturing. This phase of design process is error prone as distractions in focus may occur as project might have been going on for years and this stage seems like close to finish line. Focus must be kept so all design details are well taken in consideration as corrections at this point are usual. (Pahl,Beitz,Feldhusen& Grote 2007, pp. 436-437.) The steps of detail design phase in illustratively presented in figure 6.

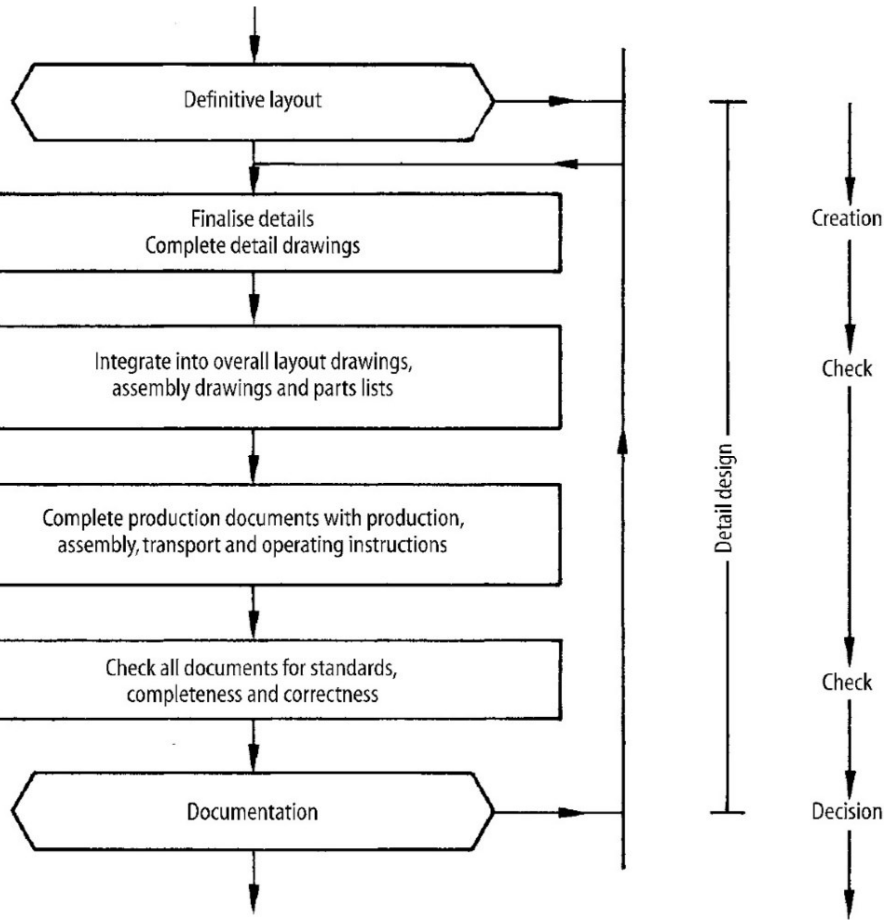

Figure 6. Steps of detail design (Pahl,Beitz,Feldhusen& Grote 2007, p. 437).

Figure gives straight forwarded and easily repeatable guideline and order of actions to support the product design process.

The description of systematic product design process is thoroughly followed during this thesis product development project. Process is made step by step following the guidelines and instructions given in VDI2221. The guidelines accept the deviation when considering the order of steps and allows certain type of freedom when proceeding with the project and this is taken into consideration.

The product development strictly follows the demands of UPSHS which are presented in this chapter, as they are the cornerstone of this product development project. Demand for easiness and safeness of cleaning, rounded 90-degree corners, and the minimum requirements for the galley air ventilation product's material will be faced in each development target presented in this thesis. The rules that limit the freedom of design on those targets are directly based on these USPHS demands.

3 Methods

Chapter three describes what scientifical methods were used in this thesis to gather desired information and data in order to complete the product development project. Each method is presented and described in detail as accurately as possible to make research reproducible and unequivocal. First chapter briefly describes how literature review is utilized as data gathering method. In second subchapter value analysis and how it was executed is described. Usage of value analysis matrix is justified, and scoring is explained. Third research method is professional interview which gives valuable information about the background, future trends and upcoming potentials in ship building business overall. Last method is experimental testing which plays very important role in this thesis, as physical product suitable for markets is the outcome of the product development process.

These four methods provide sufficient amount of data for thesis to produce reliable and valid outcome. With these four methods triangulations is ensured as data and information are gathered from various sources. Triangulation in this matter is combination of parts of method and source triangulation.

Basic principle of triangulation is that at least three perspectives, both theoretical and methodological are used in research to ensure enough data is gathered from various sources to increase the validity and reliability of the research. In triangulation often qualitative and quantitative data gathering methods are combined in phase of data collection, and that is also desirable. (Flick 2013, p. 14.)

Professional interview represents qualitative research method when experimental testing is representing quantitative method. Value analysis includes both quantitative and qualitative aspects. With these methods mentioned earlier being used, the reliability and validity data used in this thesis can be ensured.

3.1 Literature review

Literature review is first of research methods utilized in this thesis. Subjects of it consists of USPHS standard and its requirements as well as SOLAS conventions, their background, meaning and relation to this thesis subject. VDI2221 represents another large subject represented in this thesis as product development process is performed based on that guideline.

Literature review of USPHS gathers relevant info from the subject and compiles the key requirements for the product to be successfully approved for the application. USPHS is huge entity, and this review focuses on Vessel Sanitation Program's Construction Guidelines and Operation Manual -documents published by USPHS as they are the document that determine the requirements for cruise vessel construction structure which is heavily guiding the product development of GAEU.

Second large entity in literature review is VDI2221. Its main goals, phases and steps are described as the product development process follows those steps.

Information for literature review is gathered from versatile sources including physical books, articles and electronic books. Scope of data is strictly determined to consist only valid data from ship building industry and product development process itself and focus is on main points. Other data relevant for this research is gathered with other methods which will be introduced in chapter three subchapters to come.

3.2 Value analysis

The value analysis is a method that investigates the ratio between price and quality of the product, service or process. When value analysis is taken as part of designing a product the method is called Value Engineering. Value Engineering is about providing solutions for the customer in the most cost-efficient way while also fulfilling customers' demands regarding quality, functionality and other aspects required. Cost structure is optimized, and functions are limited to those only required, by removing unnecessary functions and optimizing manufacturing costs. (Prilutskaya Maria 2021, p. 2.)

Value analysis was executed with scoring matrix which was used to separate and numerically evaluate different development solutions characteristics and specified properties.

Value factors were selected to support as well as possible the nature of solution as there are assemblies which number of components vary a lot when smallest having three components and largest having over 20 components. Evaluation scale for each factor is being mentioned on right side column of the table three presented later in “Results” chapter. In five value factors evaluation is done by scoring the characteristic on a scale from one to five. Scaling was directed so that highest score is always desired. In five other factor evaluations was done by scoring solutions A, B and C in order of preference, number one being the least suitable option while number five being the best option.

Value analysis was done after third phase of VDI2221 based product development process. Three solution options were selected for each development target for further investigation and value analysis, which would eventually determine the final selection. Selection of the best options for each development target was based on results from value analysis presented on tables to come in “Result” chapter.

3.3 Expert interview

One of research methods used in this method is professional interview, which was to be performed with mini-Delphi method, but due to low number of survey respondents’, characteristics of Delphi method wasn’t fulfilled. Selection of experts representing wide areas of expertise were well selected to provide broad area of answers but apparently survey was badly timed on very busy season of industry.

Interviewees were chosen to be interviewed for their comprehensive expertise and experience in ship industry, and due to targets company’s Technology Leader’s suggestion. Their different career paths and orientation gave research valuable and diverse experience-based knowledge which was highly appreciated.

Those few interviewees that answered had decades of work experience in ship industry in several different roles and positions. Present statues of interviewees varied from “Head of HVAC Desing” to “Specialist, HVAC, and Refrigeration plants” in market leader organizations. The interview question presented to interviews was following:

“How do you see the ship building industry evolving in the next 5-10 years, especially concerning ventilation/air conditioning? Evaluate future trends and technological changes.”

For raising interesting comparison, the same question for presented to AI ChatGPT3.5.

3.4 Analyzed case examples of product development target structures

Research are performed for two main reasons, either to increase the information and knowledge of researcher's himself, or to add or gather new information or data to one discipline. Theoretical information often may require practical testing of applications and examination of physical phenomena. (Gliner,Morgan& Leech 2017, p. 13.)

Experimental research method played the major role in thesis as parts and assemblies had to be made in order to get full understanding and practical experience about manufacturing times, assembly times and efficiency, difficulty and effortless of manufacturing etc. As solutions are being utilized in real products, practical testing had to be done to get solid proofs and justifications for solutions and their execution. This chapter describes how the process of experimental phase of the project was executed.

First the critical components and assemblies were selected from original design of the product to be developed. As product's potential market is large and volume of the sales would be high, the viewpoint of selection was mainly focused on different characteristics and challenges of manufacturing and assembling. Visual appeal also was factor in evaluation. Manufacturing and assembly should be as efficient and productive as possible, taking in count usage of material, manufacturing and assembly times, costs of these actions etc. Three critical structures were selected which all differed from each other. They represented different kind on structural features which each were very typical in products the target company manufactures. When these recurring structured can be developed into better versions, the principles can be utilized in other products in target company's product repertoire such as kitchen hoods. This will provide benefits when redesigning and developing other products.

Experimental phase consisted of lot of 3D-modelling with SolidWorks CAD (computer assisted drawing) software, as well as creating manufacturing drawings and simulating fixings of parts and assemblies through different mates. In multiple occasions virtual simulation didn't provide concrete evidence of solutions suitability, so prototypes were manufactured to get physical products and part to be investigated. With manufactured parts, assemblies were made and fitment of parts, visual look, rigidness of structures, manufacturability and other aspects could be taken into further evaluation. In some solutions, virtual investigation was enough to provide evidence needed to give proper evaluation of solutions suitability, and its pros and cons.

4 Galley Air Extraction Unit -product and original design

This chapter describes the starting situation of Galley Air Extraction Unit when thesis project started. Original design and structure if described at general level. Some of the used solutions are further studied and illustrated in detail. Joining methods of different parts and subassemblies are presented as well as manufacturing methods being used to manufacture the product. In figure 7 below the marketed concept and model of GAEU is illustrated.

Figure 7. Concept art and marketing material of Galley Air Extraction Unit

Ship kitchen in figure eight is simplified illustration of area and place where GAEU could be located in. Usually, premises are more complex and crowded with kitchen equipment.

4.1 Starting situation

The thesis worker and director of thesis from company side were under impression that GAEU is complete product at target company’s sister company, and it’s already been manufactured. Base idea of thesis was that this complete product would be “Marinated”. Term means that product, which is already been on landside markets, will go through product development process to be approved also for seaside usage and to fill all requirements and demands needed.

As base study and investigation for this project was made, it turned out that the information available wasn’t accurate. After gathering several different contacts from all colleagues that had any information about the product, the main source of information appeared to be two sister companies which will be presented as Factory “A” and Factory “B” in this thesis. The new very surprising information received from those foreign contacts, was that Galley Air Extraction Unit was not ready even at their side for inland targets, and it was at prototype phase and under development.

After contacting and discussing with engineers from both parties it turned out both models were very different from each other. Factory “B”’s designer described that their solution technically works but structure was too difficult and time consuming to manufacture for it to be profitable product. Also turned out that Factory “A” version is structurally good with only sheet metal parts, but functionality of product wasn’t as required and test results concerning air flow values were not acceptable for the application.

Actual development process would start by creating a physical prototype of developed structures to investigate them and the areas that need to be modified or improved. As there wasn’t complete product to manufacture, some creativity had to be used.

Factory “B” engineer advice was to take “A” versions mechanical structure and combine that to “B” solution with exhaust air channel.

As the starting situation was very different from earlier assumed information, the thesis worker had to adjust the approach and viewpoints of this work, as now the situation wasn’t just to modify the already existing product but to take part and measures in actual products design process.

Before doing the development process to marine side usage, it was important to evaluate and highlight the critical structures and solutions that needs to be modified. For that creating a physical prototypes of development targets were key factor. As there wasn’t ready 3D-model of a complete product, the Factory “B” engineer’s suggestions were taken in count and prototype to manufacture was combination of “B” and “A” version, including “A” chassis and structure with “B” exhaust duct.

Change of exhaust duct is illustrated in figure 8 below. Left figure shows the updated structure for prototype, as on a right-side original design is visible.

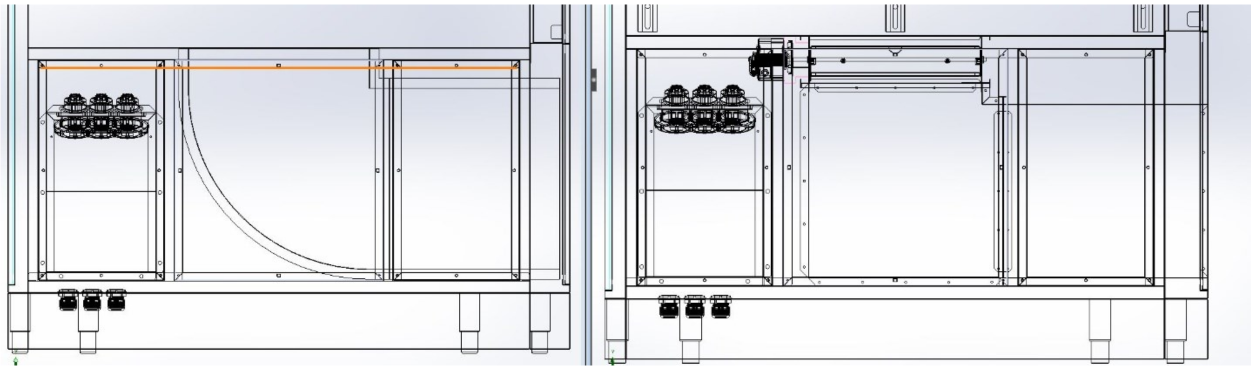

Figure 8. Wireframe view of duct chambers, left the updated one, right side the original one

Exhaust duct update was only fundamental design change at this point. Idea was to get a prototype which is as identical as possible to “A” prototype, even though this might have not even been the latest version.

4.1.1 Original design and prototyping

As a start of the product development process the original, in this case “A” protype model adjusted with “B” factory’s exhaust solution, had to be studied throw to gain understanding about the overall structure, joining of parts, critical point etc. 3D-model received from Factory “A” included drawings as well, which made the prototype manufacturing process to proceed well.

4.1.2 Structure of original Galley Air Extraction Unit

When original structure was studied, several matters appeared that had to be taken care before manufacturing the prototypes. Firstly, the manufacturing methods used in Factory "A" and those used in Lahti had to be compared in order to find out if original structure was doable with structures and solutions it at the moment included.

Lahti has two laser cutting device and one laser/punch combi machine so cutting the sheet blanks held no problem as these machine base provides large number of possibilities and variation if necessary. In Factory "A" they had also used laser cutting when cutting blanks so there was no problem to reach equally good cutting quality and precision.

With bending some problematic occurred. Even though 3D-models included drawings, those weren't relevant as for some reason Factory A engineers use zero radius when modelling bends to sheet metal parts. This phenomenon is presented in figure 9 below.

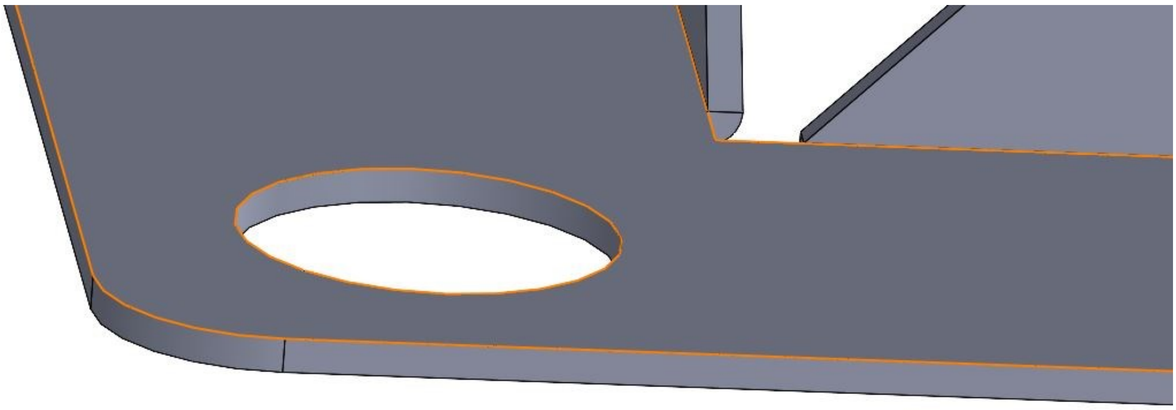

Figure 9. Zero radius bending

This effects on dimensions of flatten blank which is cut with laser as in target company's default inner radius of 1,5 mm is being used. Also, it was discovered that Factory "A" uses 1,0 mm stainless steel on GAEU. As sister company "A" produces and provides products for inland targets such as schools, public spaces etc. so they are not required to follow as strict regulations as target company which targets to offshore and even more demanding heavy industry. When product is sold to offshore targets it must fulfil USPHS regulations, that's why 1,0 mm thickness had to be replaced immediately. Regulations demands minimal sheet thickness of 1,25 mm. This was more precisely described in chapter two.

Material to be used on prototype was to be EN 1.4301 stainless steel with sheet thickness of 1,25 mm at minimum. Good quality of that steel is proven as suppliers are well known and target company's hoods and canopies made in Lahti are mostly also manufactured from this specific material. As thickness of material and bend radius had changed, it was decided that new drawings must be made at some point. Also, original drawings and part names was in foreign language which Factory "A" represents, so updating to target company's drawing templates and renaming the parts would have been faced eventually. As this phase of project, it was still decided that first proto parts will be manufactured based on original drawings as dimensional differenced were estimated to be small enough not to disturb and greatly effect on assembly phase. Most likely effect targets on air tightness issues but those are not relevant concerning first prototype. Main purpose of the first prototype is to discover those mechanical solutions and problematic structures that need to be developed in order to get GAEU appropriate for marine use.

Factory "A" uses quite complex parts and designs concerning geometries in several sheet metal parts. Some of those seemed that manufacturing could be difficult or even impossible with target company's machine base and might require some special tools or structural changes in parts for them to be suitable machinery available. Some of the structures are illustrated in figures 10 and 11 below.

Figure 10. Demanding bending geometry

As some parts and solutions appeared demanding, it was decided to manufacture test pieces to recognize possible difficulties. Result of practical manufacturing test is visible in figure 11 below.

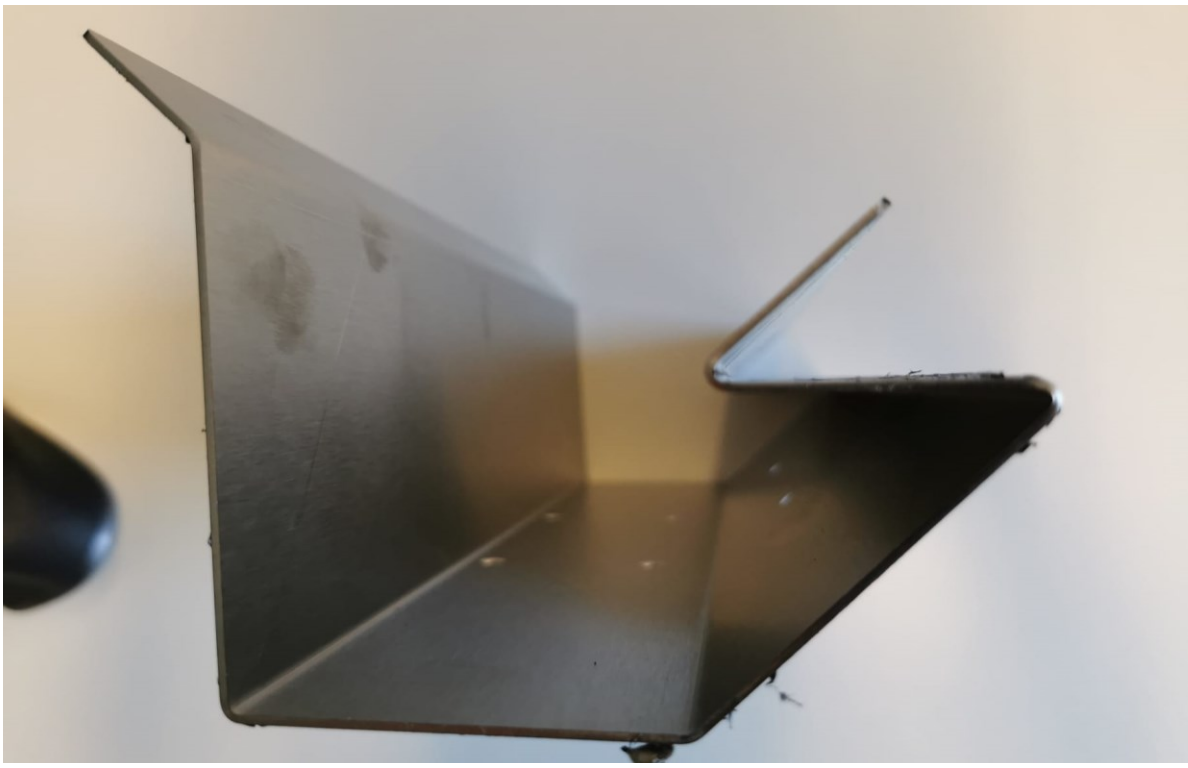

Figure 11. Practical manufacturing test

As can be seen from figures above, bend radiuses differ a lot from 3D-model. This probably leads to changes in blank sizes, but conclusions can be made properly after first prototype built.

Test pieces were made with thicker 1,25 mm stainless steel, even though 3D-model were made with thickness of 1,0 mm. This way it was already possible to recognize possible development targets if for example some bending angles were too narrow for tools available.

Original parts used flattening's on several occasions for strengthening purposes (figure four right end of part). As in marine-use the thickness off material is increased from original design, it was evaluated that flattening can be removed as higher strength properties of thicker material compensates the need for strengthening feature. Removal was done to improve manufacturability and to lower manufacturing time of certain parts significantly. Other test piece of practical manufacturing test is visible in figures 12 and 13 below.

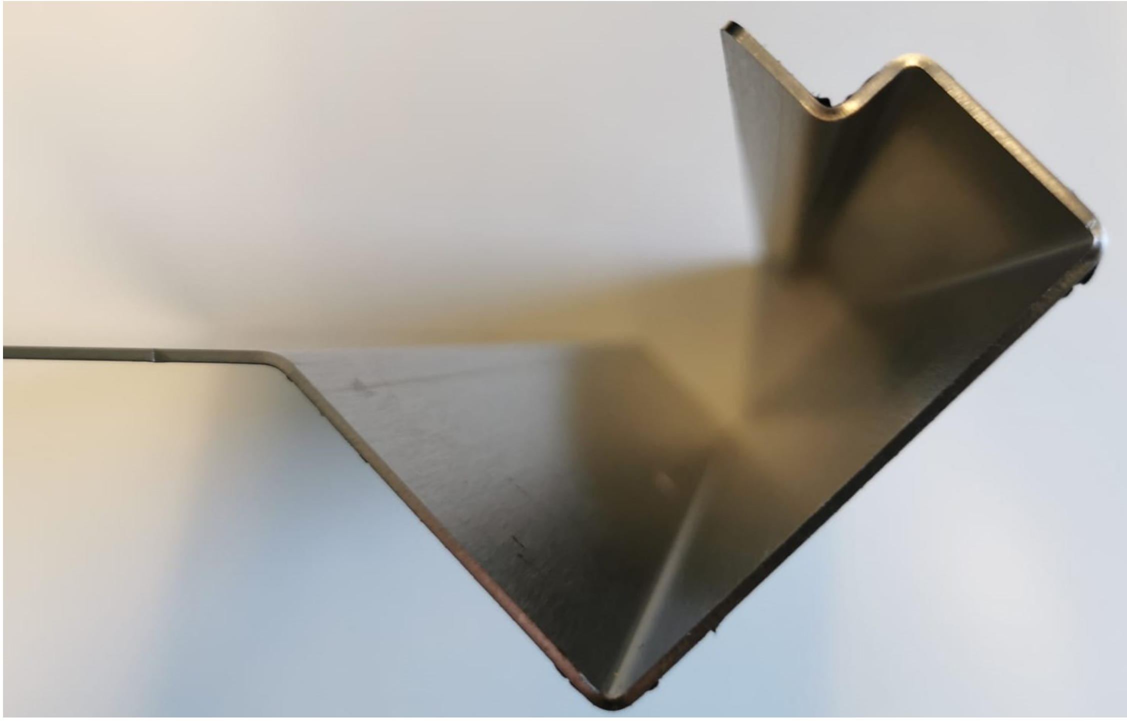

Figure 12. Bend test piece number two

Positive outcome of bend tests was that geometries of original parts were possible to manufacture with dimensional accuracy high enough for prototype build. Final compatibility of parts will become clear later on during assembly phase.

After drawings were checked the first few parts were manufactured. Cutting and bending worked well but with welding some issues were found. As parts were manufactured with original drawings but bending radius and material thickness different from original design, some gaps evolved which makes welding difficult and more time consuming. First gap can be seen in figure 13.

Figure 13. Welding gap number one

Second part had even bigger gaps for welder to fill, this is visual in figure 14. Welds must be seal in order to fulfil the requirements of airtightness.

Figure 14. Welding gap number two

Even with gaps dimensional accuracy of parts was sufficient and the parts to be connected were compatible with each other.

These first manufactured parts gave enough information so decision could be verified that all 3D-models must be re-modelled or modified to have proper bend radius and material thicknesses. After corrections part blanks size differ a bit from original and bending can be made more precisely, and time consumption of welding process can be reduced significantly as gap sizes are optimized.

4.1.3 Attachments and joining

In original structure joining methods differed from target company´s manners. Without any kind of installation guides etc. available some of attaching methods were based on guesses and logical reasoning. Original design included lot of different bolt sizes, guesses by hole sizes, and installation order was occasionally very difficult to come by with. There were situations where clearly one part had several different hole sizes and was designed to be attached with other parts with multiple different bolt sizes. Some attaching components varied a lot from what was used in target company's production. Figure 15 below demonstrates the plate nuts that were designed to be used in several structures.

Figure 15. Plate nuts

Target company uses lots of rivet nuts and welded stud bolts in several different occasions in multiple product category. Usage of both mentioned will surely take place in new design of target product, as applying them have been noticed to be beneficial as they are reasonably priced, fast to attach and make assembly more convenient.

4.2 Manufacturing and assembly

After overall examination of parts and assemblies, a few conclusions were made. Parts had many difficult and complex structures and working phases that lead manufacturing of parts being laborious, time consuming, and unoptimized. Safety factor used to ensure parts rigidness is excessive and much less would be appropriate, sufficient for the application, and more optimized from many viewpoints. By increasing the sheet thickness and re-designing stiffener solutions, many difficult bends and welds can be avoided to make manufacturability of parts improved.

Assembly of Galley Air Extraction Unit clearly included issues and difficulties that had to be solved. On many occasions some bolts or attachments located in places that could not possibly be reached or used no matter what order parts or subassemblies were assembled and joined. Effectiveness of assembly has not been prioritized when creating a design. Some problems could have been solved in early stage as easily as adding some service hatches with screws, but much more benefits will be achieved when redesigning major part of the structures. Required spaces for tools or persons ability to reach into necessary locations was not taken into consideration by anyhow.

5 Product development and development targets

Chapter five focuses on the actual product development project and its different phases and challenges. Product development is performed following guidelines and structure of VDI2221 standards model of systematic product development process. Earlier chapters have described original design of Galley Air Extraction Unit and its problematic structures. In chapter five first the demand list for product development is presented. After that the development targets are presented.

Each development target part or structure is studied. Firstly, problems and challenges of each case is explained and for each situation several different solutions are designed, tested, evaluated, and compared between each other's. Chapter five introduces all possible solutions and later in chapter six the chosen best solution for each situation is selected and presented with justification.

For each development target multiple possible solutions are brainstormed on principal level in this conceptual design -phase. Connecting factor with all solutions is that they all must fulfil demands listed on the demand list. This part of product development is based on standard VDI2221 phase two which is, in a nutshell brainstorming phase. In all cases parts and assemblies are representing principals, so models, drawings and prototypes are not always resembling the final result.

In next phase designs are taken into more detailed and concrete level. 3D-models are more accurate, and they resemble outcome and drawings for prototyping are ready. Solutions must be taking into level of concrete so prototypes will be made when necessary, and their functionality and other characteristics will be tested.

In the last phase of design process results of development are presented and the most suitable one for the application for each case will be chosen with justification. Results are presented in chapter six.

Phases two and three of VDI2221 product development are under each development target's subchapter, and phase four with final results are presented in chapter six as mentioned earlier.

5.1 Demands for product development

This chapter contains list of demands which product's each developed structure must fulfil. Demands include qualitative aspects, and aspects concerning usability or manufacturing. Demands are presented in order of their priority in development project and level of priority is verbally determined and described. List of demands is presented in table one below:

Table 1. Demands for the product development

Demands	**Importance level**
Products suitability for the application achieved → Fulfillment of USPHS requirements (development from food service- usage to Marine-usage)	Main priority
Visual appearance	Medium
Manufacturability aspects:	
Assembly time reduced	High
Welding time reduced	High
Improved usage of material	Medium
Reliability increased	Low

Main priority of product development is to make GAEU meet and fulfil USPHS requirements which are more precisely presented and described in chapter 2.1. Without meeting these requirements, the product isn't suitable for application and markets it is designed for. Visual appearance of product is also important as GAEU might be placed in kitchens that are visible for ship customers.

Second most important factors are the manufacturing and assembly aspects. Parts from original design were designed in a way which weren't the most suitable for targets company's manufacturing methods and machine base. Significant part of time used in manufacturing phase were due to bad designing of parts which didn't take specific needs of welding processes in a count. Welding is the most time consuming and the most expensive work phase in target company's production lines.

Demand of reduced assembly time is also set to high priority. Building a prototype structure demonstrated that product had large number of problematic structures that made assembly time consuming and challenging.

Improved usage of material is desired, but importance of that aspect is low as main part of cost structure of product consists of labour and design work. Improved usage of material comes as positive side effect of developing part to be more easily manufactured and assembled. Product isn’t something that will be done in serial production and is higher quality - lower quantity tailored products with high gross margin, so optimized nesting and usage of steel sheets doesn’t make significant improvement financially although it is still aspirational.

Next chapters will present the development targets and their examined solutions. First target presented is lower centre frame subassembly.

5.2 Lower centre frame subassembly

First development target was lower centre frame subassembly. The structure was built in very complex way and many solutions that are difficult and inefficient occurred when studying the structure. The target is basically the base for the whole Galley Air Extraction Unit, and it mainly hold the exhaust and some electrical connections while creating a rigid base for rest of assembly. The structure is illustrated in figure 16.

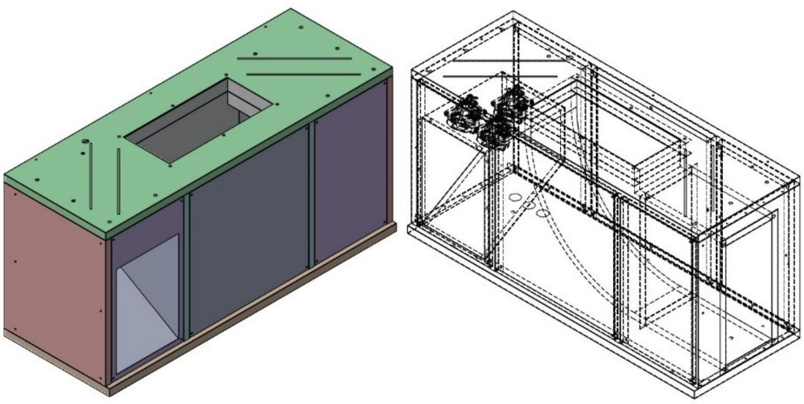

Figure 16. Lower centre frame subassembly

Parts and connections were built in complex way and focus has clearly been on stiffness and reliability of the body. Material that was used was stainless steel EN 1.4301 with thickness of only one millimetre. With thickness that low, reliability has been ensured with creating more bends to provide strength required from the body. Example of bends in parts is illustrated in figure 17 below. Despite the low thickness of the material, number of bends was exaggerated causing major decrease in manufacturability and assembly speed.

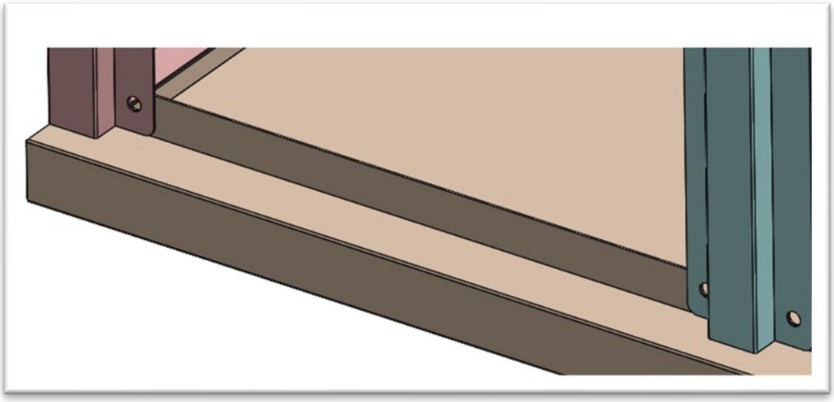

Figure 17. Parts with multiple bends

Also, complex bending solutions caused welding of corners to be inefficient and difficult to perform. Example can be seen in figure 18 below.

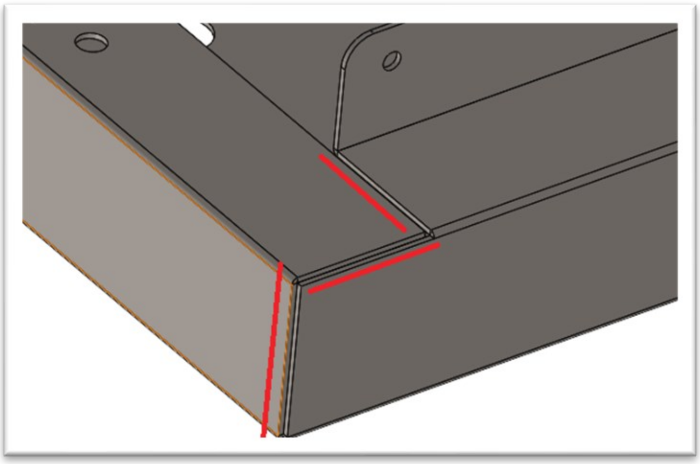

Figure 18. Inefficient welded corner

Covering plate part is presented here as an example of solutions used in this subassembly. Structure shown on figure 18 above on its own took 23 minutes of welding time due to corners that demanded three welds. Manufacturing time of simple cover plate part shown in figure 13 took 45 minutes, from cut blank to being welded and post-processed, welding taking 51 % of the time. Welding preparations took seven minutes while post-processing took 15 minutes. Part is visual completely on figure 19 below.

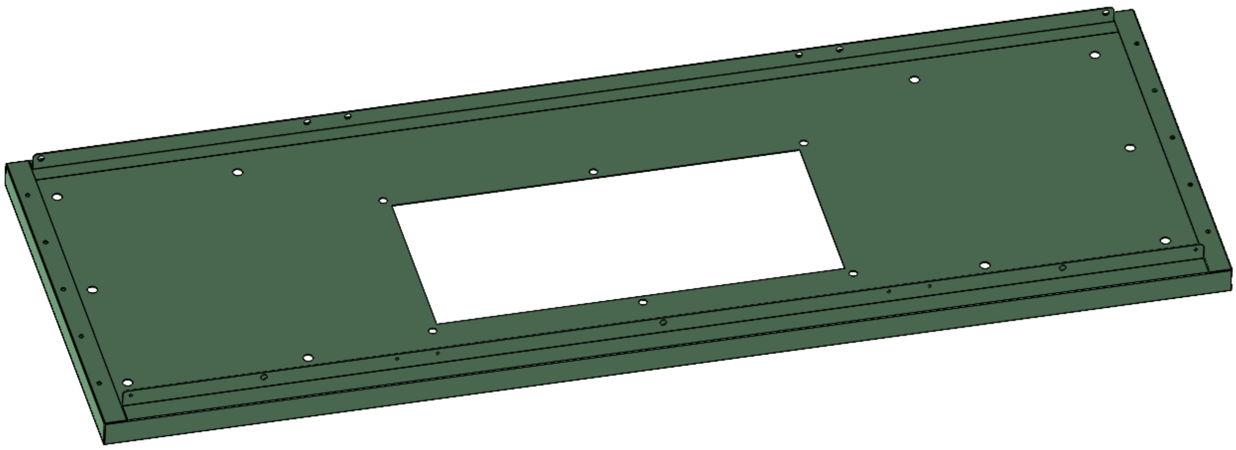

Figure 19. Cover plate, manufacturing time 45 minutes

Welding time of each part concerning this assembly were examined and reported. Other parts used similar solutions as example part presented in above. As welding time reduction was high priority improvement desired, part manufacturing mainly focuses on time consumption of welding, as well as assembly when discussing in overall picture. Cutting time was irrelevant as discussion is not about high volume, but high value product. Table including welding times are illustrated in table two below.

Table 2. Welding times of original parts

Part name/number	Welding prep.	Welding time	Post-processing	Total time per part	QTY of parts in assembly	Total welding time in assembly
CH003-08-22	7	23	15	45	1	45
CH009-08-22	7	23	12	42	1	42
CH001-08-22	7	15	10	32	1	32
CH020-08-22	5	7	5	17	1	17
CH002-08-22	3	7	5	15	2	30
CH015-08-22	3	5	4	12	1	12
CH008-08-22	5	20	15	40	2	80
CH006-08-22	4	3	10	17	1	17
CH005-08-22	4	6	8	18	2	36

Values mentioned in table two are the starting values that are improved during product development. In chapter five’s subchapters, different development solutions are presented, and their benefits and improvements are described. Some models and drawings are on basic level and only showing the principles of solutions. Those details are described under each solution´s chapter.

5.2.1 Solution 1 – Sheat structure

Solution number one is the idea of using sheath structure on side panels of assembly. Solution would lower the number of parts used in covering the frame. Sheat structure principle can be seen in figure 20.

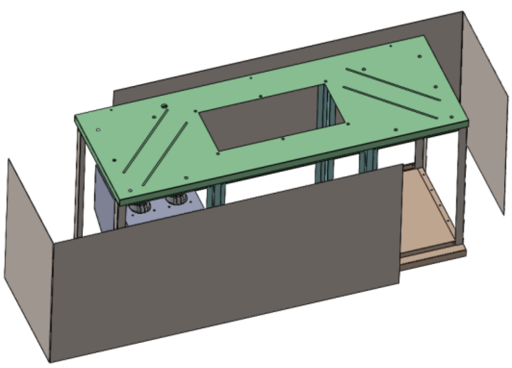

Figure 20. Sheat structure principle

Benefits of this solution would be:

- Shorter manufacturing time of parts and less working phases as number of bends and difficult welds decrease majorly.
- Deduction of assembly time.
- Less material usage

Challenges and downsides of the solution are the following:

- Handling large sheet metals parts in production is more difficult. Flattened sheet would be around 1700 mm so bending requires two persons to handle the work.
- Size limits will come up if product is later determined to be size configurable and more length is required.

5.2.2 Solution 2 – U-profile built frame

In solution two, the focus has been on remodelling the frame structure which holds the walls and cover plates. Original frame beams were too complex to manufacture for such a simple part. There were total of four bends in beam and geometry of them forced to use specific type of cover plates around the chassis. Number of beams was originally eight, and structure is visual in figure 16 in chapter 5.2.

Frame beams were remodelled into U-shaped structure. U-shape is utilized in two ways: Cross section of beam uses the shape, and one long beam is bended creating the whole chassis frame, decreasing the number of parts by four. U-shape is rigid enough, but geometry is achieved with only two bends. Drafted beams are illustrated in figure 21 below.

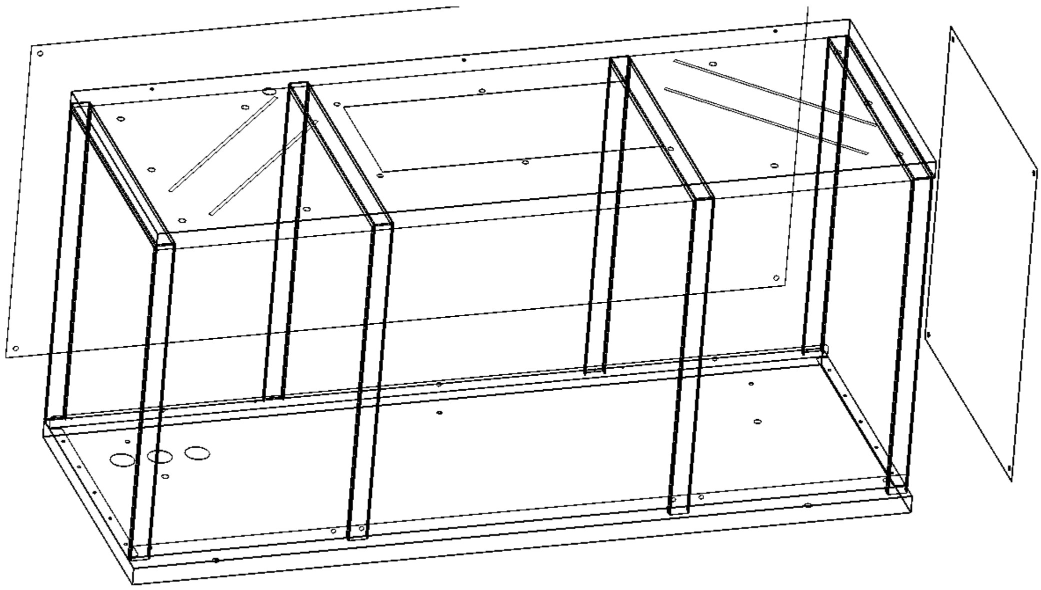

Figure 21. U-shaped chassis beams

This kind of structure benefits assembly phase as whole chassis can be established in minutes when attachments are made mechanically. Manufacturing of parts is easier and faster than with original structure.

Challenge may occur with chassis beams as they are 1550 mm in length as blanks. Impact with bending machine's frame is a risk, but, if necessary, it can be prevented by using partial bends which will be finished outside bending machine manually. This causes welder more work as he must do more pre-processing to ensure perpendicular angles fit tolerances before welding the corners.

5.2.3 Solution 3 – Front/roof cover plate with L-structure

Solutions three main idea is to ease manufacturing and assembly by minimizing the number of parts by using larger individual parts. Main part is one-piece L-shaped cover plate which unites the front wall and roof level of original structure. Cover plate will be attached to frame chassis by using rivet nuts which allow fast and easy assembly. Overall look of structure is visual in figure 22.

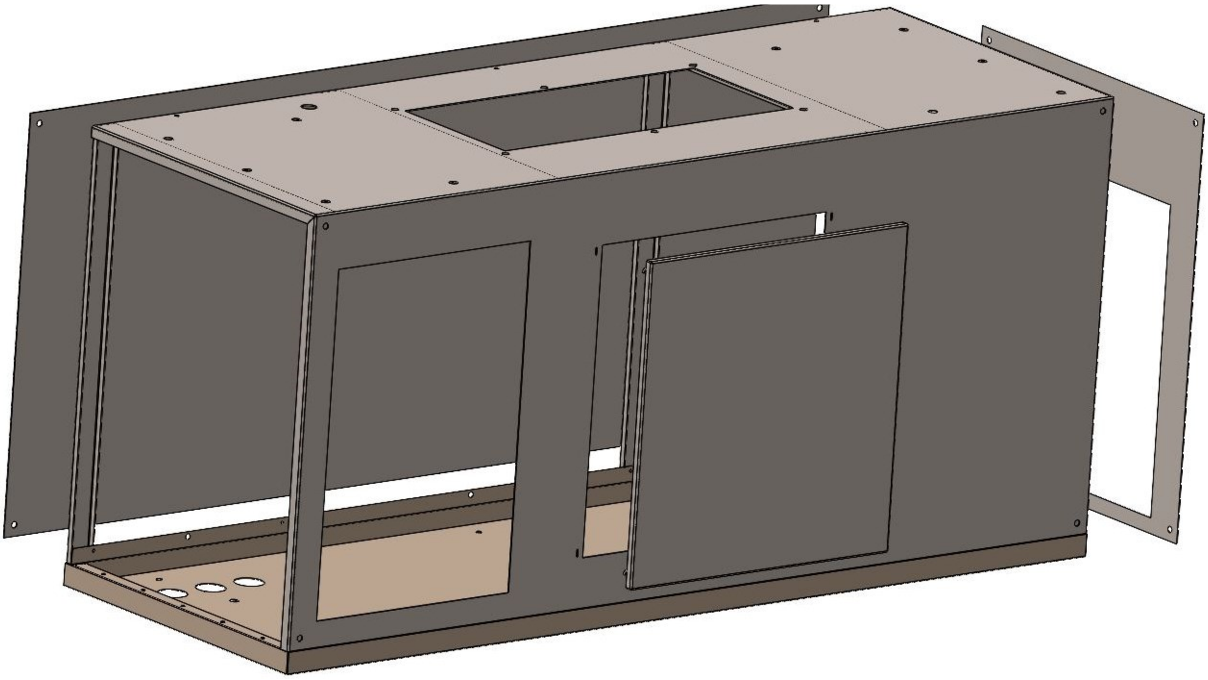

Figure 22. L-profile coverplate with service hatch

L-shaped cover plate is easy to manufacture and at assembly phase it settles down above the chassis beam making assembly effortless. Maintenance hatches are protruding from cover plate and attached mechanically using only notches and claws shaped as part of the hatch. This is illustrated in figure 23.

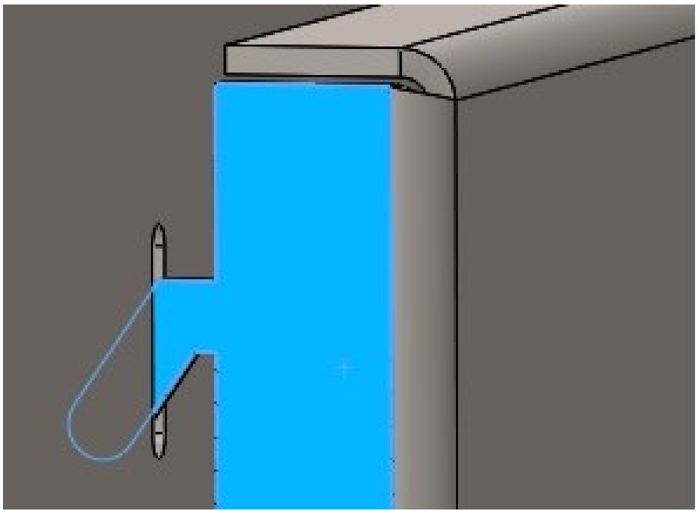

Figure 23. Service hatch notches and claws

Claw's slot is shaped like wedge and its width is smaller than sheet thickness. When hatch is attached the joint tightens as edge of notch reaches the slot's end. With small claws and slots the risk is that they will loosen over time due to vibration of ships, and if hatches are opened and closed carelessly too many times.

5.3 Blind filter

Second development target was blind filter. Steam and air produced when cooking or using kitchen appliance such as dishwasher, travels from the device to exhaust chamber of the hoods, where it continues its travel to ventilation ducts. Entrance of hood is covered with KSA filters, which are mechanical grease filters which use cyclonic geometry to separate grease from the air.

KSA filters requires certain air flow rate in order to work. One filter can handle "X" amount of air litres per second. KSA filter is always 500 mm in length. For example, if hood is 1200 mm in length, it fits two KSA filters. The rest of the air entrance area cannot be left blank, otherwise greasy, and unfiltered air would access the ventilation ducts. This increases the risk of grease fires and reduces the safety of the ship and is against safety regulations. Empty areas must be filled with so called blind filters, which basically blocks the empty area of hood entrance so air must travel through the filters. Original design of GAEU's blind filter is presented in figure 24 below.

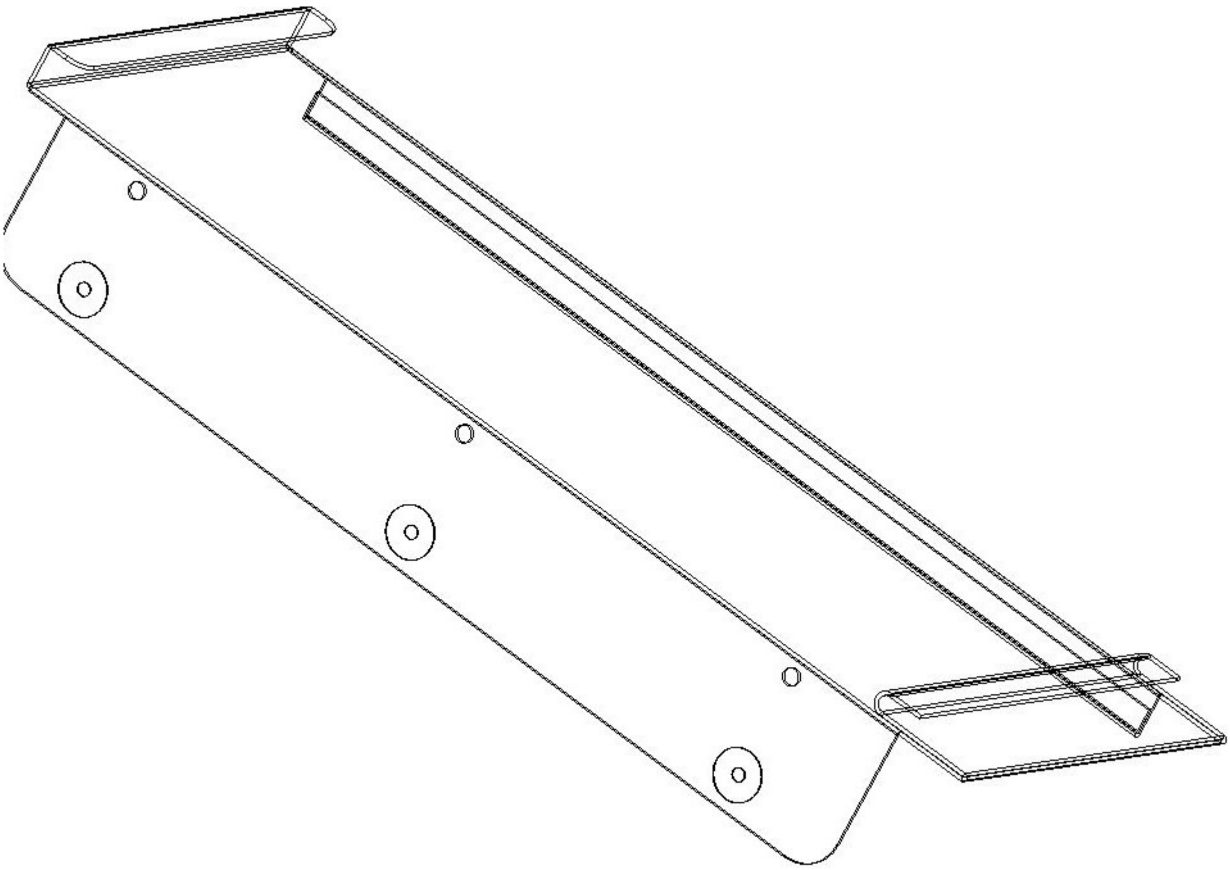

Figure 24. Blind filter original design

The original filter is manufactured with one sheet metal piece. All geometrical features are achieved with bending. The idea of using less parts is generally desirable, but in this case, design is not optimal. Filter has a total of seven bends including two flattening presses which are demanding. The filter was produced with target company’s bending machines and tools, and manufacturing, when measuring only bending time, took four minutes including one tool change which was required to achieve the geometry. Usage of so-called gooseneck tool was necessary to finish the part. The manufactured part can be seen in figure 25.

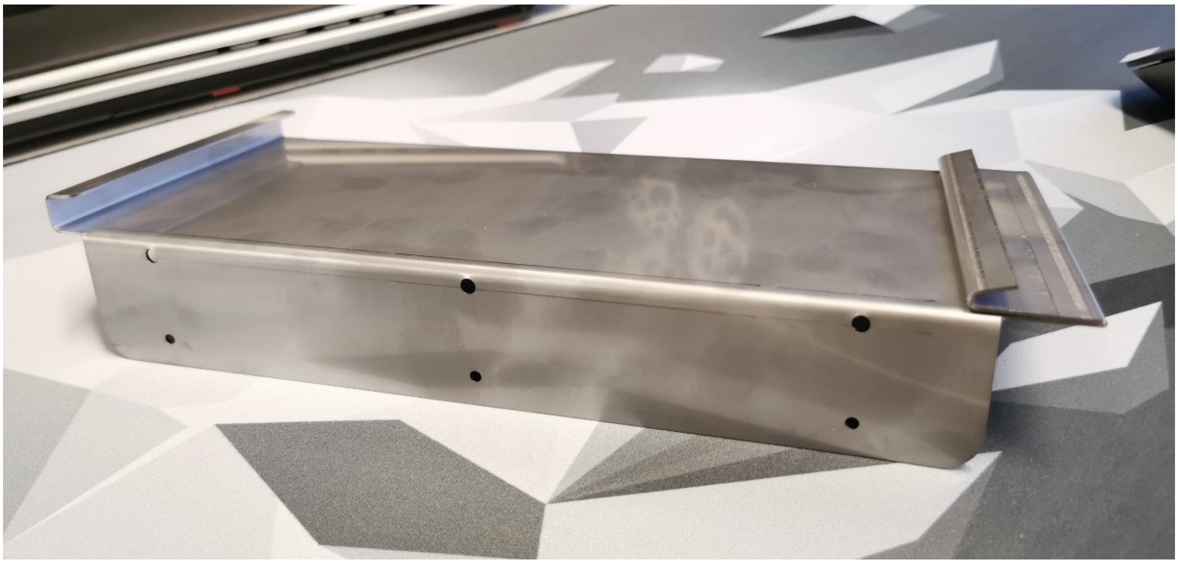

Figure 25. Original blind filter product with target company’s machine base

Blind filter took four minutes manufacturing time, including only bending. Due to complex bending structure geometry could not be achieved with one bending blade but one tool change had to be performed to complete the part.

The market for blind filters is roughly estimated to be 1500-2500 units per year, depending on the number of ship projects there are ongoing. The goal is to make manufacturing of blind filter faster and less demanding. The viewpoint of development is manufacturing, and assembly focused.

5.3.1 Solution 1 – Spot welded lower fixing stripe

In the first solution the number of manufacturing methods is actually increased. Spot welding is an everyday used method at target company’s production so implementing that to filter manufacturing doesn’t require any investments. By using spot welding bending is easier as flattening of low end of filter can be removed. This also removes the need for tool change to gooseneck tool which is a relatively time-consuming operation in such short manufacturing total time. The first proposed design is visualized in figure 26 below.

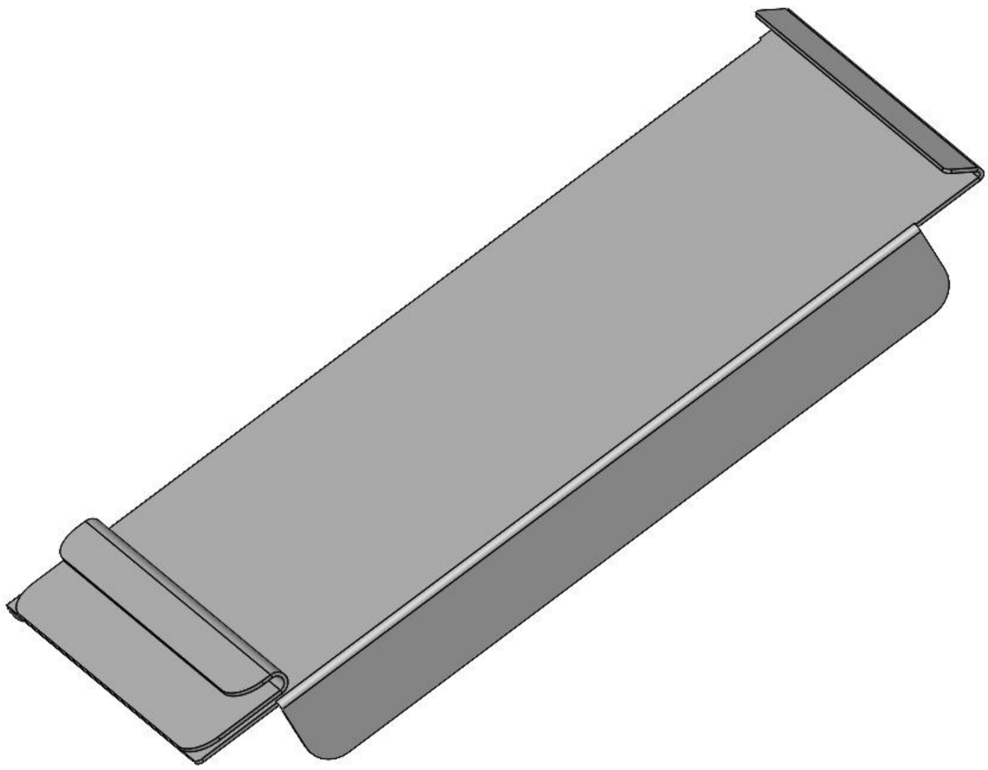

Figure 26. Spot welded lower fastening strip

Bending the lower fastening strip from one sheet blank, is replaced by separate fixing strip which will be spot welded to main frame with three spots. Number of bends is decreased from seven to four even the number of parts has increased from one to two. Originally sheet thickness was 1,0 mm but with USPHS required 1,25 mm thick stainless steel, the flattening bend made for strength properties could be removed.

When size of available blind filters is determined in advance, parts can be manufacture and stored in pallet places of storage shell. This compensates the time usually spent in moving parts from one manufacturing phase to another. When production order is made, assembly worker takes premanufactured parts from storage place and spot welds them to complete the assembly. This could also be done in advance.

This solution was not prototyped, as manufacturing times could be estimated roughly as similar product were produced earlier. Manufacturing of this solution was estimated to take total of two minutes, bending taking 40 seconds while spot welding taking 80 seconds per unit when the time spent moving the pieces is included. Decrease in total manufacturing time is 120 seconds per unit.

5.3.2 Solution 2 – Updated one-piece blind

Solution two uses a slightly updated version of the original design, by taking advantage of material change. As mentioned in chapter above, material must be changed from 1,0 mm to have a thickness of 1,25 mm minimum to fulfill USPSH requirements. Blind is made with one piece using only cutting and bending as manufacturing methods. Design is visible in figure 27 and 28 below.

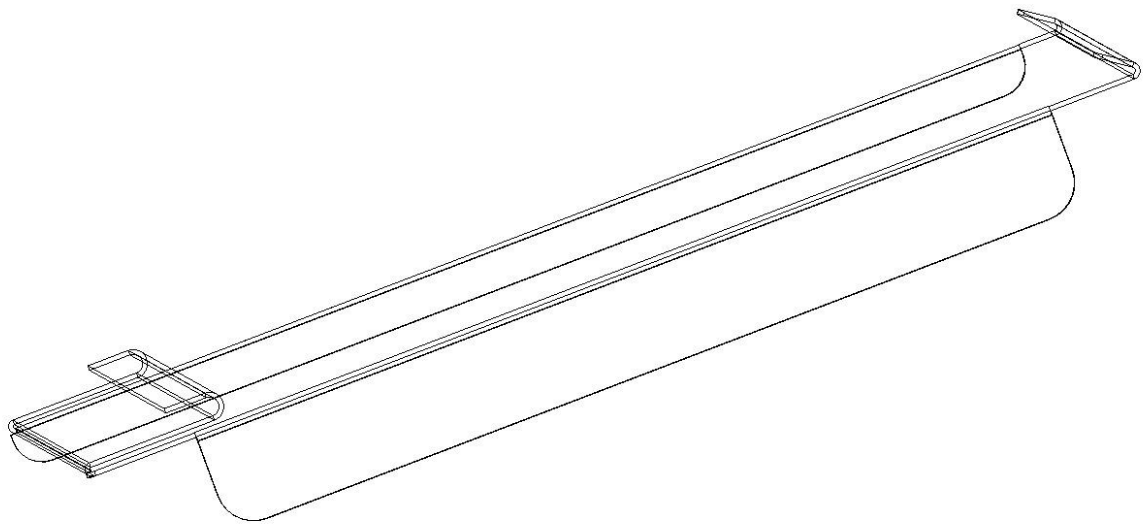

Figure 27. Sketched blind design from one sheet

Challenges with bending lower fixing stripe (flattened structure) still exists but requirement for tool change is deleted. Usage of special tools such as gooseneck tool is no longer required.

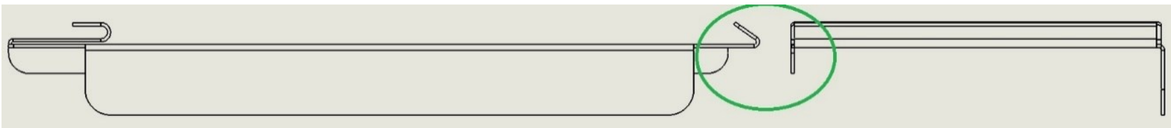

Figure 28. Removed flattening bend and facilitated fixing

In figure 28 above re-designed features are indicated with green circle. This solution was not prototyped as changes made were minor, so the effect on manufacturing time could be estimated on a decent level.

5.3.3 Solution 3 – Claw fixture

Solution number three is also from one sheet metal blank. The idea is to create claws, which are illustrated in figure 29, that work as fixture elements on lower part of the blind filter. Claws are produced with either a bending machine or with punching. Target company has Finn-Power LP6 laser punch combination machine which could be suitable for punching claws directly so they would be ready before bending phase.

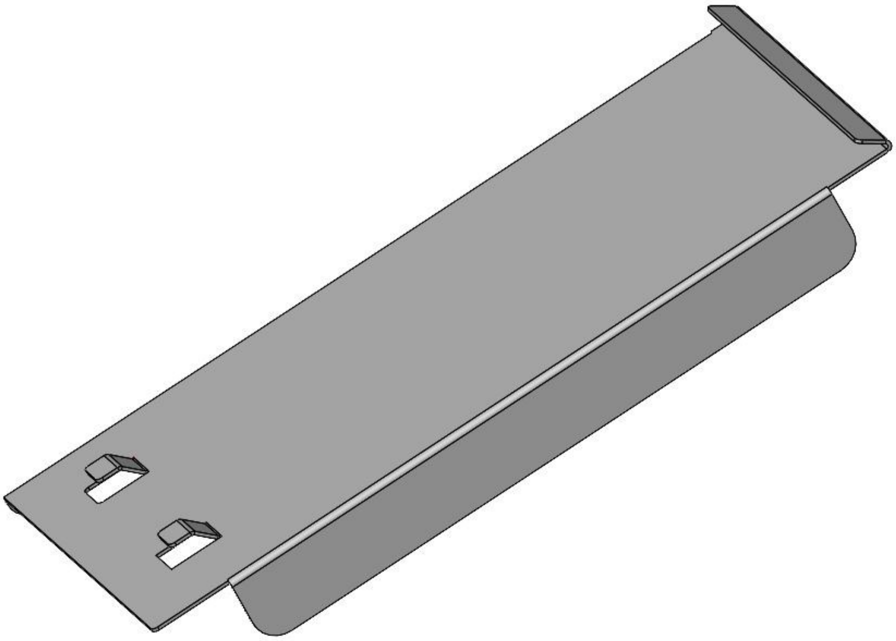

Figure 29. Fixture designed with pressed claws

Using claws would make material waste minimal, optimize the number of working phases as no spot welding or flattening bends would be required.

One moulding tool was available, and the result of its action was tested on test piece which can be seen in figure 30.

Figure 30. Sheet moulding made with available tool

Unfortunately, tool could not be used to test the application as it is designed for 1,0 mm material thickness, and tool has no adjustment possibility. Test piece was produced by creating relief cuts for claw with laser cutting, and lifting claws was done manually to test the principle in action. Part can be seen in figure 31.

Figure 31. Blind filter with opened claws

Claws were opened with screwdriver so that the investigating of the fixing to assembly could be done. Functionality of claw was tested also in test assembly which can be seen in figure 32.

Figure 32. Fitment of claw

Fitment of the part was decent but can be easily improved by fixing dimensioning and placing of the claw. Structure was as simple as desired. Bending time was reduced by 3,5 minutes when comparing to original structure. Downside of this solution is, that for efficient manufacturing for this solution claw should be punched simultaneously with cutting, so special tool must be ordered for LP6 machine. Target company only has one combi laser-punch machine so manufacturing will only rely on one of the three cutting machines. Though investment of such tool can be calculated in hundreds of euros, so in long term investment is very cheap and reasonable and can be well justified.

5.4 Filter fixing in exhaust chamber

Last development target was assembly which connects KSA filter and KSA blind filter to Galley Air Extraction Unit's centre frame. KSA filter is bought from the supplier as standard size of 500 mm of length is used in hood products in target company. For that reason, KSA filter was desired to stay without modifications. Original construction is visualized in figure 33.

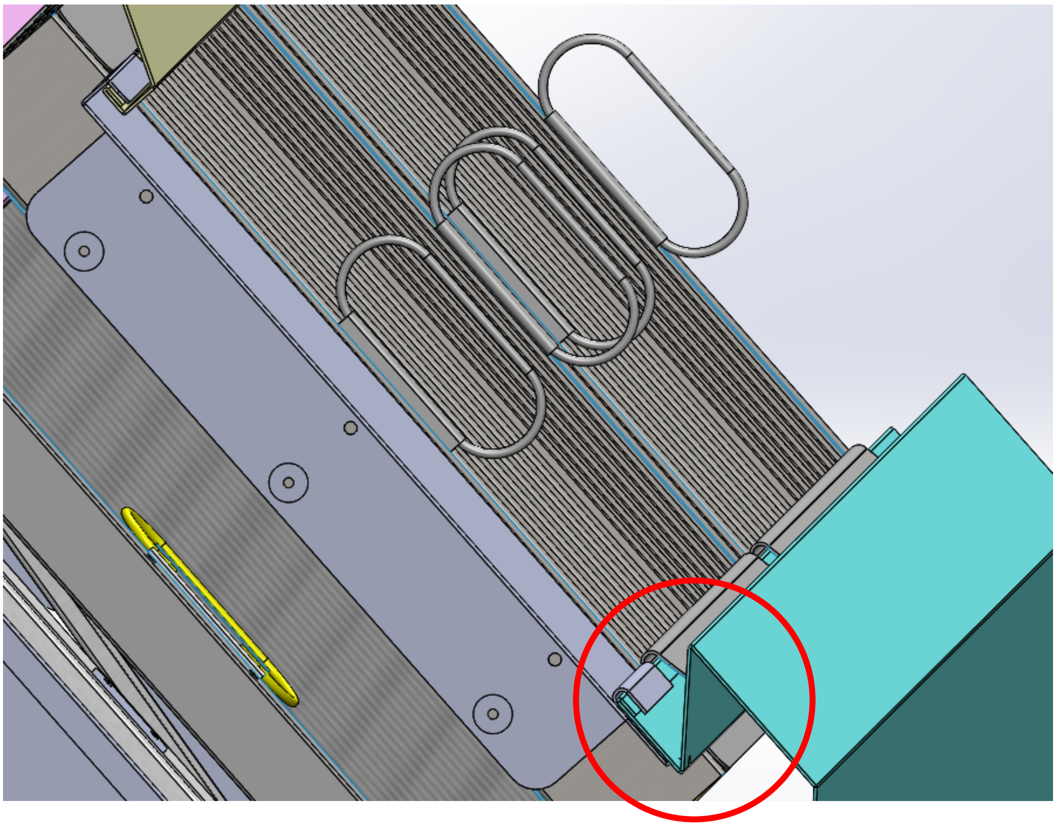

Figure 33. Blind filter and KSA filter attachment

Structure as it is, wasn't suitable for the application it is desired. Front plate, which is teal coloured sheet metal part, where filter's bottom part is attached, is against USPSH regulations. Sharp V-taper is apt to collect grease and dirt from cooking air, and it isn't cleanable easily, which is one requirement set by standard.

Structure of assembly must be developed to meet the requirements set by standard, and manufacturing of parts must be improved as they now include complex characters and geometries that make manufacturing slow and inefficient.

5.4.1 Solution 1 – Front gutter for filter assembly

First solution enables filter attachment assembly to follow USPHS requirements as sharp corner in front plate is rounded. To make concrete testing with developed rails the special made testing assembly was built. Design and execution can be seen in figures 34 and 35 below.

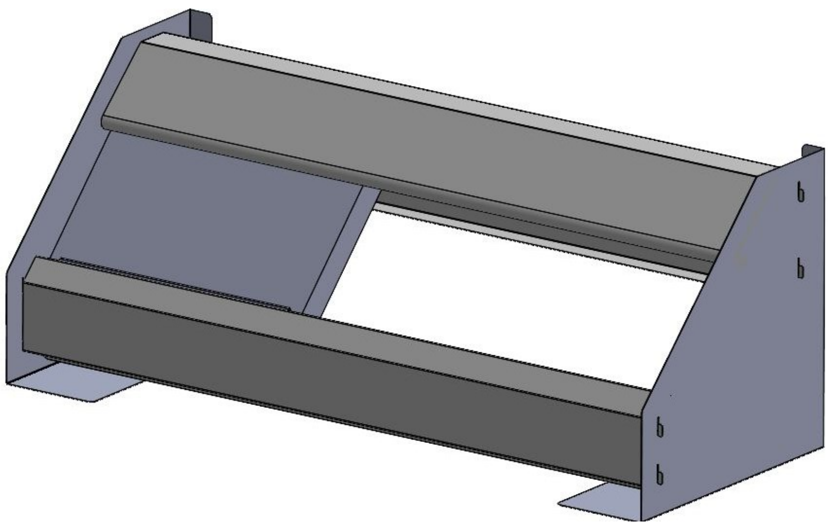

Figure 34. Test build for developed rails, 3D-modelled

The test fixing rails were designed to have same cross section as actual product has, and length 1250 mm is also determined to follow the dimensions of GAEU prototype.

Figure 35. Rounded front plate

Fixing of filters worked as designed and solutions seemed reasonable. Manufacturability of parts was good and not considered as too demanding. Gutter solution in front was visually impressive and gives finished visual appearance. Whole structure is visualized in figure 36.

Figure 36. Front look of filter assembly

Visual appearance was good and finished. Unfortunately, lower front plate was bended into wrong direction so polished surface remained inside the product, it should have been other way around. Overall visuals of assembly can still be inspected and evaluated.

5.4.2 Solution 2 – Covered filter attachments.

In second solution filters are fixed to rails from below and covered with rounded sheet. This solution deletes the need for gutter at lower rail of filters. Solution makes manufacturing of parts easier but also adds working phase as fixing stripes must be either spot welded or mechanically attached. This is illustrated in figure 37 below.

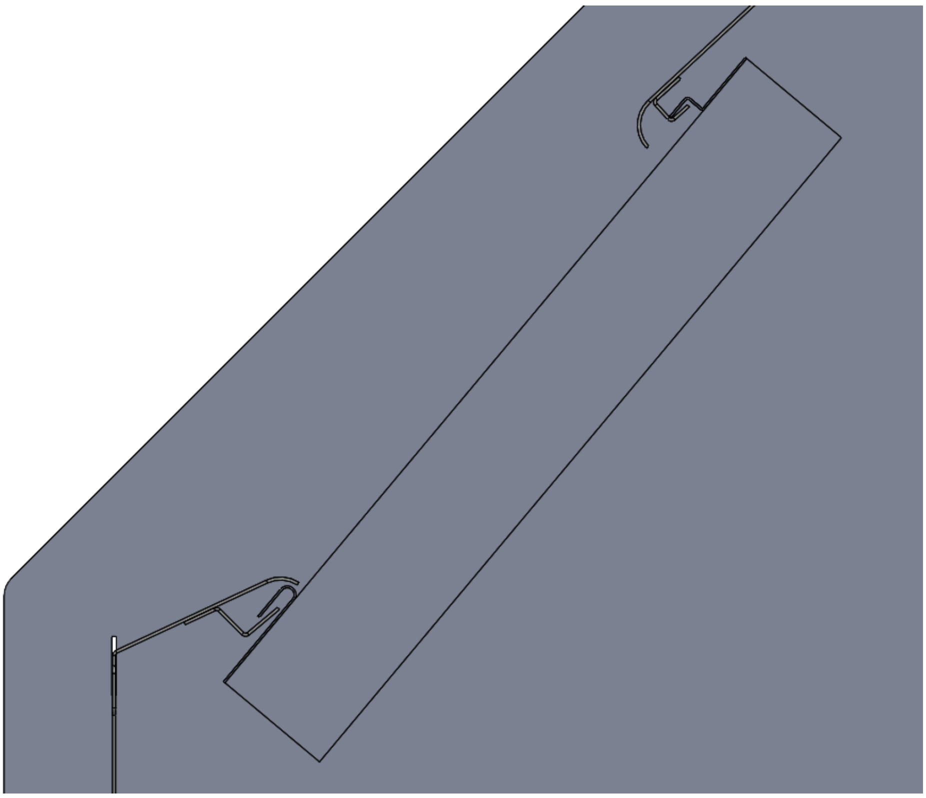

Figure 37. Fixing of filters under the cover

Solution would give finished and impressive visual appeal to product as attachment would be covered with 12,5 radius bended shapes. Also, geometry of parts is very simple and doesn't include complexity. Number of parts increases by two and fixing stripe has to be attached to lower rail mechanically or by welding, so manufacturability suffers but impression of quality increases. When sold products compete with quality rather than sales volume, this is a good thing.

5.4.3 Solution 3 – Fixing rack for filters

In solution number three the filter fixing has been implemented by using united fixing rack instead of individual filter fixing. The idea is that when rack is open, the filters can be installed easily just from the upper fixing stripe. After filters are in place, the rack is locked from the bottom to front plate of the frame. The solution in principle level is illustrated on figure 38 below.

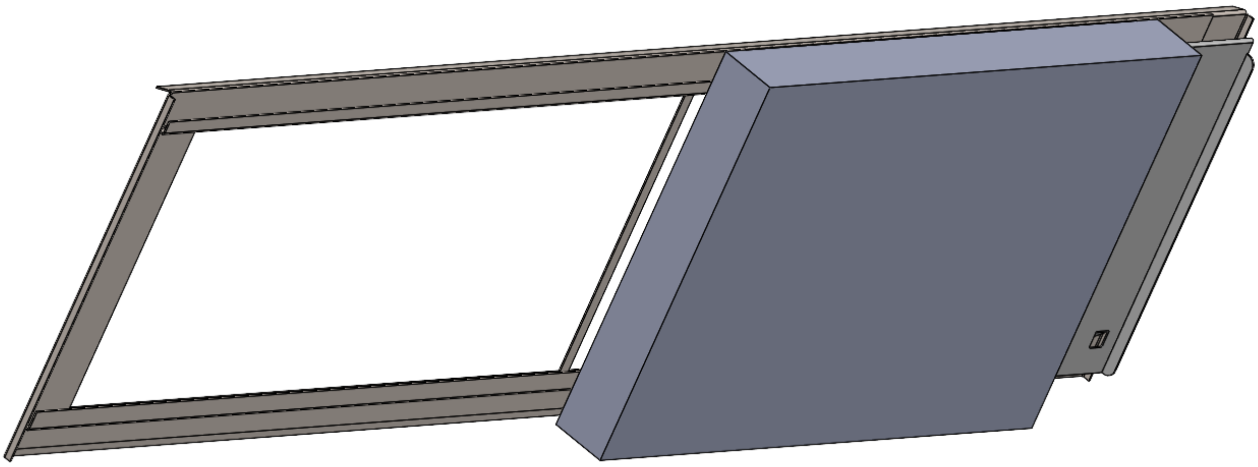

Figure 38. Filter fixing rack

In figure above the rack separated from the GAEU is shown. In GAEU the rack would be hinged from the upper edge of rack so installing the filters is effortless and efficient. This is illustrated in figure 39 below.

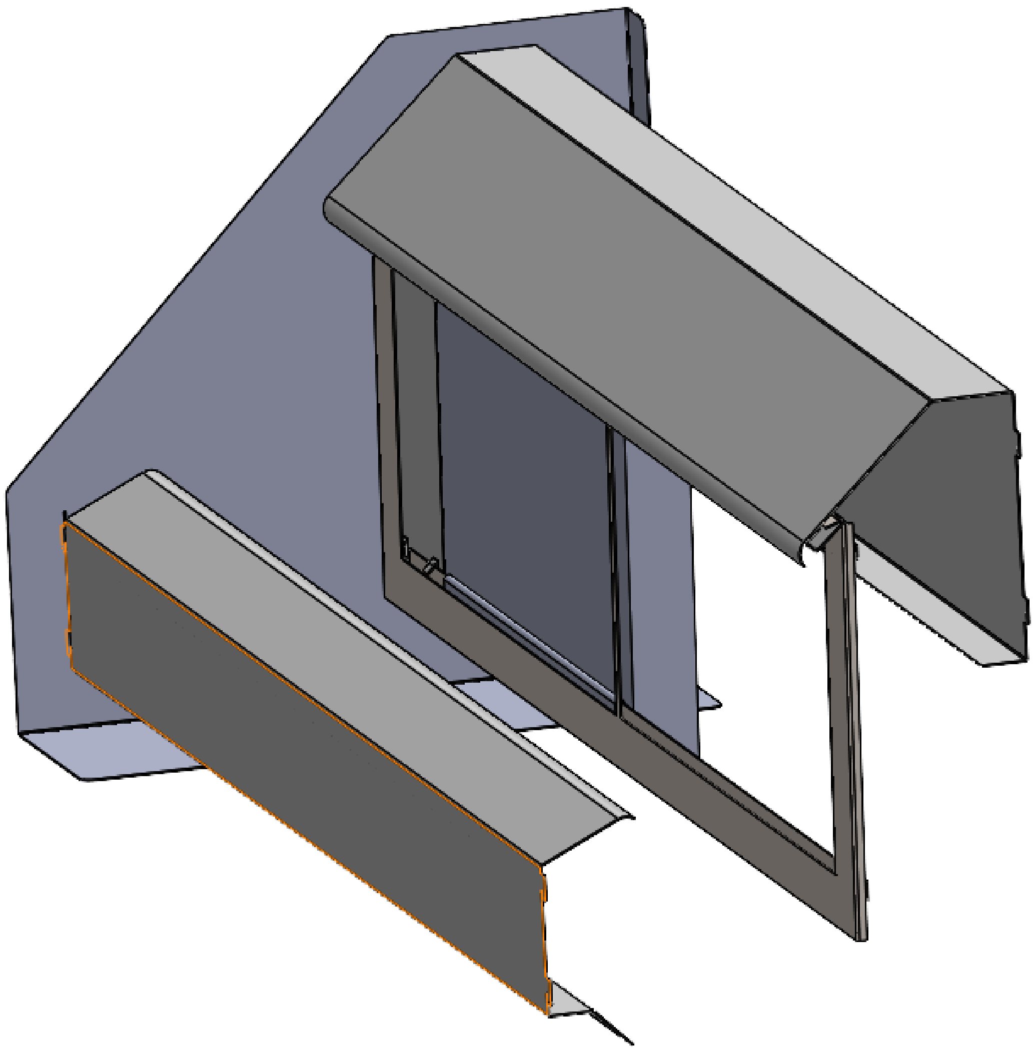

Figure 39. Hinged rack fixed from top

After the filters are fixed to the rack, the rack itself is pulled so that the bottom part of it will lock the assembly to the frame. Locking is implemented using special shaped counterpart from sheet metal. The rack's edge will cross the locking bump shape as counter parts material will slightly bend as pushed. When edge has crossed the bump, the rack will be locked. This is illustrated in figure 40.

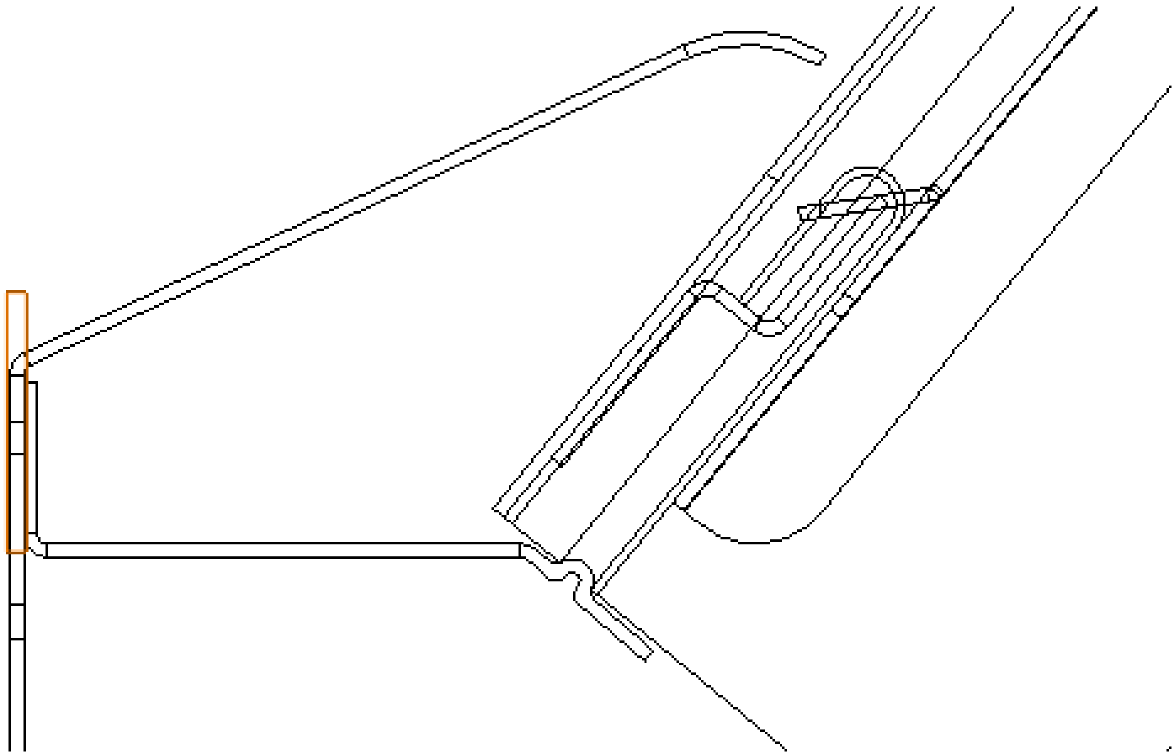

Figure 40. Filter rack locked with counterpart

The challenges of this solution are that in order to locking to work properly and reliably, the dimensioning must be very accurate to have material behaving as desired. It should be tested that material won't suffer too much from fatigue when used hundreds of times, as there might appear malfunction with locking system. For manufacturing the counterpart, the contact must be made to tool provider as special tool must be ordered for sheet metal fabrication centre to be able to produce the long hump elevation geometry.

6 Results

In chapter six the results of product development process are presented. Firstly, the result gathered from expert interview is presented. After that chapter six represents the phase four of VDI2221. All possible solutions for each case were studied and the most suitable option considering all perspectives and viewpoints is chosen with justification. Solution alternatives for each structure are studied in chapter five.

After all development targets and chosen solution are explored, the improvements and differences in manufacturing and assembling work phases are briefly studied and the effect of product development on this matter are described and evaluated. Lastly the outcome and benefits achieved by the target company from this thesis are reported.

6.1 Result of expert interview

In answers clearly certain themes repeated. Focus was heavily on sustainability and energy efficiency, and what are their part and role in future ship building. In answers it shows that it is highly anticipated that as nowadays energy efficient and sustainable solutions are desirable and more like marketing advantage, but in future those aspects will be demands and requirements from the ship owner. Shipyards and their subcontractors and equipment supplier must fulfil the environmental and sustainability demands set by ship owner in order to make sales and have orders at all.

One repetitive matter was the systems and devices that could kill and prevent viruses such as covid in the future at cruise ships and other vessels, and therefore make travelling safer and not depended on world situation so much. Demand for such solutions already exists, but companies that create affordable and proven concept to be presented to ship owners will gather great marked advantage. Role of AI (artificial intelligence) was speculated in answers.

Anticipation was that AI controlled automation could play huge role in the future with ventilation systems. AI could control the devices and systems and optimize the energy usage of them creating huge savings in form of energy. AI controlling and monitoring could also predict maintenance requirements. It could also regulate the air flow in public areas like hallways etc. based on number of customers in certain areas.

As sampling of survey was so small, to add some interesting viewpoint, the same question was presented to AI tool ChatGPT free version 3.5. The bullet pointed answer below is directly quoted from ChatGPT answer and purely provided by AI:

“In the next 5-10 years, the shipbuilding industry will experience notable changes in ventilation and air conditioning systems:

- Energy Efficiency: Shipbuilders will prioritize energy-efficient designs with variable frequency drives and advanced insulation to meet environmental regulations and reduce operating costs.
- Smart Technologies: Integration of IoT solutions and sensors will optimize HVAC performance, enabling predictive maintenance and enhancing passenger comfort.
- Air Quality and Comfort: Advanced filtration, UV sterilization, and air purification technologies will improve indoor air quality for passengers and crew, ensuring a healthier environment.
- Sustainability: Adoption of eco-friendly refrigerants, green materials, and renewable energy sources like solar power will minimize environmental impact.
- Customization and Modular Design: More customizable and modular solutions will enable easier installation, maintenance, and upgrades to meet diverse vessel requirements.
- Material Science: Advancements in materials will lead to lighter, stronger, and corrosion-resistant components, enhancing durability and efficiency in marine environments.
- Crew Welfare: Focus on enhancing crew welfare through optimal thermal comfort, humidity control, and noise reduction will improve working conditions onboard ships.

Overall, these trends reflect a shift towards safer, more efficient, and comfortable maritime transportation driven by technological advancements and regulatory compliance.”

Answers between interviewees and AI had a lot of similarities. Noticeable is that ChatGPT3.5 uses data from internet latest from January 2022. Themes that were both in inquiry answers and AI answers were energy efficiency, sustainability, and quality of air. Also, smart technologies were mentioned by both, but AI specifically mentioned IoT (Internet of Things) which didn't come up in other answers.

AI was very optimistic about material science evolving and that new materials would replace currently used. This clearly shows difference when human consideration and experience is missing. As materials to be used are determined in USPHS regulations, the changing one is a long route. In addition to other features, price of material is the most important factor as companies live to make profit. No newer material will replace the old ones as far as regulations forbit it, and price is reasonable to make replacement profitable.

6.2 Developed lower centre frame subassembly

The lower centre frame represented the largest ensemble which was studied in this thesis. This target was also the most expensive one when considering material usage, manufacturing, and design hours, and for that playing significant role in product. Product has several large ensembles likes the one in question, so result from this target gives data which can be utilized when creating hypothesis of results concerning remaining ensembles in product. The most suitable solution option was option three: Front/roof cover plate with L-structure.

As original structure had large amount of individual component, one of the main viewpoints was to reduce the number of components, improve the manufacturability and make assembling more efficient. The principles and characterises of solutions three represented this ideology in the best way. As development project proceeded the idea and principles were refined and solutions improved. The finalized design is illustrated in figure 41.

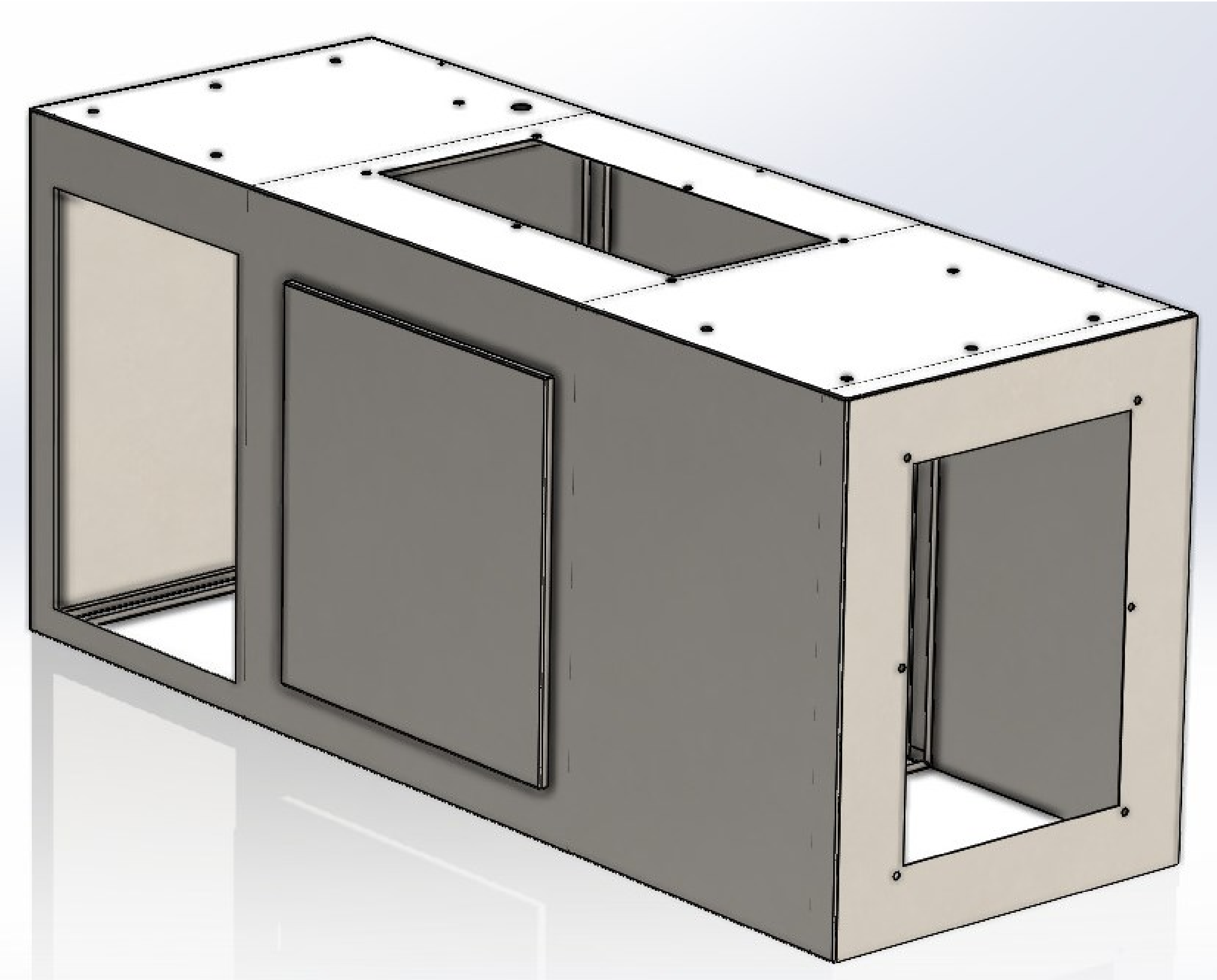

Figure 41. Final design of lower centre frame

Originally design had lot of mechanical joining with nuts and bolts, but as exhaust chamber must be airproof, those were replaced with welded seams. This increases the amount of welding significantly, but mechanically joined sheet are extremely difficult to make airproof. Sealing compound should be used, but as kitchen conditions are harsh, the endurance of the sealing compounds isn't sufficient. As product is also heavily exposed to vibration which ships cause when sailing, the welded joint fits perfectly as nut and bolts can loosen up after time being.

The solutions were analysed and compared regarding different features and characteristics and final result of comparison is visualised in table 3 at next page.

Table 3. Target one value analysis matrix

	Target 1 solutions			Evaluation
Value factors	**1**	**2**	**3**	
Ease of fabrication	2	2	3	Scoring in scale 1-5 (1 hard, 5 easy)
Number of components	1	3	5	Comparing A,B,C with point 1,3 or 5 (1 most components, 5 least)
Material cost (steel usage)	1	3	5	Comparing A,B,C with point 1,3 or 5 (1 most , 5 least)
Manufacturing cost	1	3	5	Comparing A,B,C with point 1,3 or 5 (1 most costs, 5 least)
Manufacturing lead time	5	1	3	Comparing A,B,C with point 1,3 or 5 (1 most time, 5 least)
Assembly time	3	1	5	Comparing A,B,C with point 1,3 or 5 (1 most time, 5 least)
Assembly/fixing difficulty	1	4	5	Scoring in scale 1-5 (1 acceptable, 5 great)
Visual appearance/impression of quality	4	2	5	Scoring in scale 1-5 (1 acceptable, 5 great)
Principles potential for modularity/product family approach	3	1	5	Scoring in scale 1-5 (1 least, 5 most potential)
Efficiency of manufacturing (fixing time/number of components)	1	4	5	Scoring in scale 1-5 (1 acceptable, 5 great)
Total score	21	20	41	

Structure and ideology behind the tables presented in “Results” chapter is described in chapter “3.2. Value analysis”, so they are not repeated in chapters to come. The scoring of table is justifying the selection of solution three to be used as the total score is highest. The exploded view of solution is illustrated in figure 42.

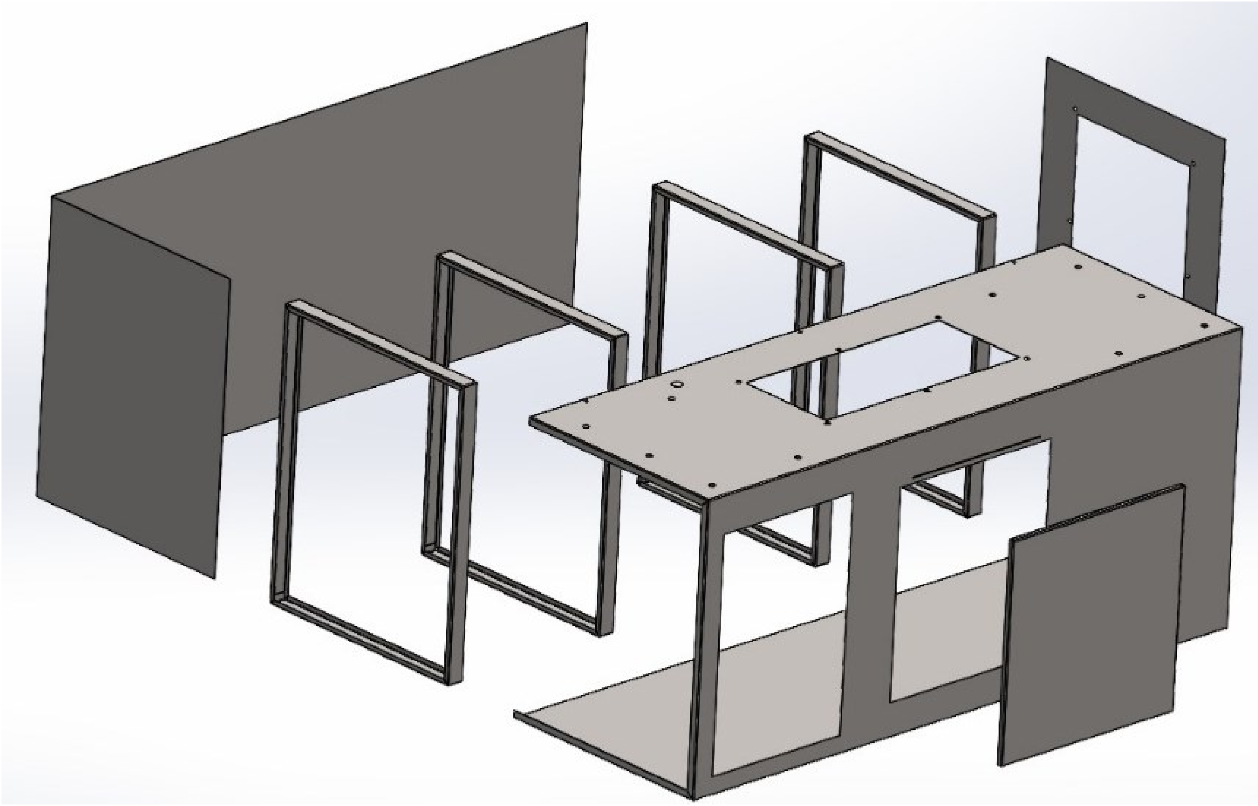

Figure 42. Final design of lower subframe

As can be seen from the figure above, the design has evolved from L-shaped cover plate to U-shaped. By doing this modification, the number of components could be furtherly reduced and almost whole subframe is covered with singe sheet. This reduces long weld beams which are difficult due to high input of welding, which can cause sheets to behave in a way not desired. They are also highly time consuming.

The frame is supported by four beams that are made from sheet metal as well. The idea of using U-profile beam is from solution two, but it was improved to make full square shape to provide more rigidness to the frame. The usage of claws with attaching the service hatch was also updated to have only one 350 mm length horizontal claw in upper part of hatch as the risk with small claws is that they bend during the usage and then won’t fit the slots anymore, or they might even break.

Figure 43 below visualises and compares the values from original and developed design. Same information table with original design only was earlier presented in chapter 5.2.

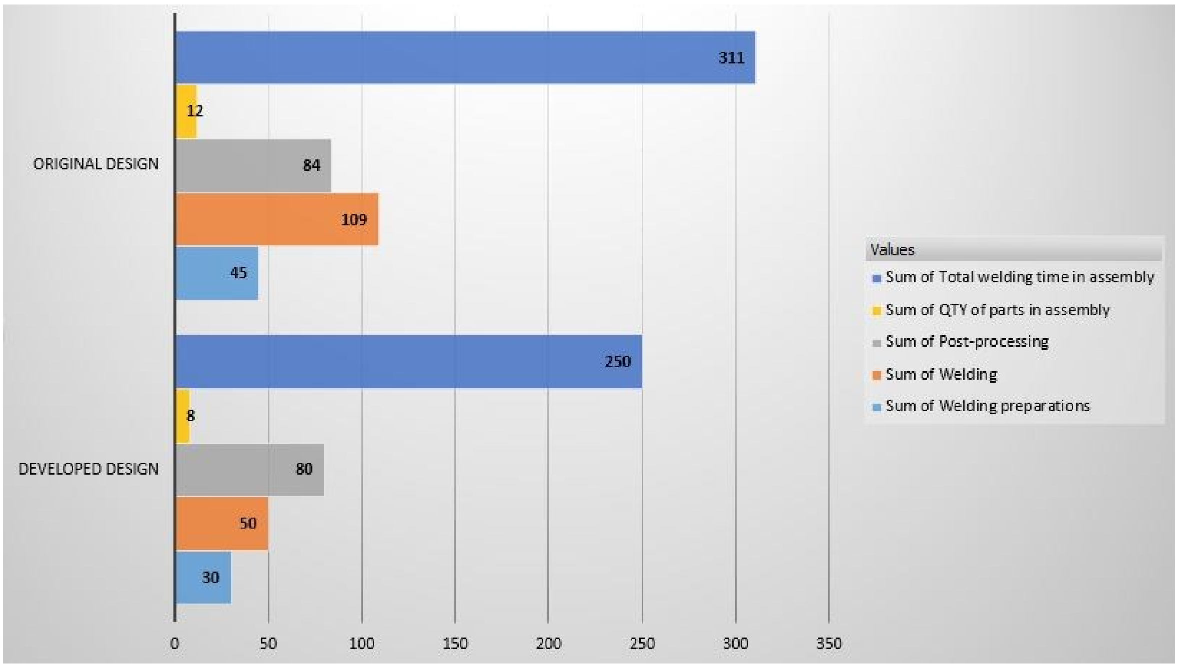

Figure 43. Original and developed designs in comparison

Values the chart is showing are listed on the right side of table. Most of them indicates time in minutes but yellow one the quantity of parts. The figure 44 below sums up the achieved results of product development.

	Decrease in time
Sum of Total welding time in assembly	61
Sum of QTY of parts in assembly	4
Sum of Post-processing	4
Sum of Welding	59
Sum of Welding preparations	15

Figure 44. Summary of decrease in time

The improvement with manufacturing efficiency can be considered significant. Number or components lowered total of 33 % from 12 to eight. and manufacturing times were reduced. The welding time of whole assembly was reduced by an hour. This can be considered significant achievement, as decreasing the welding time was achieved while still removing the mechanical bolt-nut attaching of parts.

The fulfilment of UPSHS requirements can be considered successful as material and structures are not against any regulations nor demands. The visual appearance of assembly suits the product well and gives finished impression for customer.

6.3 Developed blind filter

For development target two, the selection for the most suitable solution was solution three. It slightly exceeded the value analysis points over solution two. Result of value analysis matrix is illustrated in table 4. As table shows, the choice was not overwhelming as solution two was rated only three points less than option three.

Table 4. Target two valua analysis matrix

	Target 2 solutions			Evaluation
Value factors	1	2	3	
Ease of fabrication	4	4	3	Scoring in scale 1-5 (1 hard, 5 easy)
Number of components	1	5	5	Comparing A,B,C with point 1,3 or 5 (1 most components, 5 least)
Material cost (steel usage)	1	3	5	Comparing A,B,C with point 1,3 or 5 (1 most , 5 least)
Manufacturing cost	1	5	3	Comparing A,B,C with point 1,3 or 5 (1 most costs, 5 least)
Manufacturing lead time	1	3	5	Comparing A,B,C with point 1,3 or 5 (1 most time, 5 least)
Assembly time	1	5	5	Comparing A,B,C with point 1,3 or 5 (1 most time, 5 least)
Assembly/fixing difficulty	4	5	5	Scoring in scale 1-5 (1 acceptable, 5 great)
Visual appearance/impression of quality	3	4	3	Scoring in scale 1-5 (1 acceptable, 5 great)
Principles potential for modularity/product family approach	2	2	5	Scoring in scale 1-5 (1 least, 5 most potential)
Efficiency of manufacturing (fixing time/number of components)	4	3	5	Scoring in scale 1-5 (1 acceptable, 5 great)
Total score	18	36	39	

Using only one sheet with blind filter was considered desirable because the use of spot welding could be removed. Usage of claws was innovative, and the principle can be with high possibility, used in other applications as well. Design itself didn’t evolve a lot from what is presented in chapter 5.2.3, but material usage was studied to make it more optimized. The final result is illustrated in figure 45 below.

Figure 45. Final design of blind filter

USPSH requirements were fulfilled concerning material and design of parts as it has no restricted geometries. As mentioned in earlier chapters, special tool for punching machine must be ordered to create the claw fixing.

As was presented in chapter 5.3.3 the bending time was degreased from 4 minutes to 30 seconds, so the improvement can be considered significant. Yearly saving in time was almost 12 working days annually when yearly market is set to 1500 units. Old design took 13,3 working days of 7,5 hours in a year as the new design only requires 1,7 days. Savings in working hours is far more significant than savings with material optimizations as benefits with that are marginal. Visual appearance didn’t play big role in this part as only visual surface is the blank area that covers the free air flow area of exhaust chamber.

6.4 Developed KSA filter fixing

For the third development target the most suitable and optimized solutions turned out to be solution number one. As can be seen in value analysis matrix table 5 below, the solution one had significant difference on value point when compared to other two options. The choice was clear. Visual appearance of solution one was unique and gives customer a finished and technical impression of product.

Table 5. Target three value analysis matrix

	Target 3 solutions			Evaluation
Value factors	1	2	3	
Ease of fabrication	3	1	3	Scoring in scale 1-5 (1 hard, 5 easy)
Number of components	5	1	3	Comparing A,B,C with point 1,3 or 5 (1 most components, 5 least)
Material cost (steel usage)	3	1	5	Comparing A,B,C with point 1,3 or 5 (1 most , 5 least)
Manufacturing cost	5	3	1	Comparing A,B,C with point 1,3 or 5 (1 most costs, 5 least)
Manufacturing lead time	5	3	1	Comparing A,B,C with point 1,3 or 5 (1 most time, 5 least)
Assembly time	5	3	1	Comparing A,B,C with point 1,3 or 5 (1 most time, 5 least)
Assembly/fixing difficulty	5	2	2	Scoring in scale 1-5 (1 acceptable, 5 great)
Visual appearance/impression of quality	4	5	3	Scoring in scale 1-5 (1 acceptable, 5 great)
Principles potential for modularity/product family approach	1	3	3	Scoring in scale 1-5 (1 least, 5 most potential)
Efficiency of manufacturing (fixing time/number of components)	3	3	3	Scoring in scale 1-5 (1 acceptable, 5 great)
Total score	36	22	22	

The available bending tools could be utilized in design and geometries not suitable for USPSH requirements were removed and replaced with acceptable ones. In this solutions material was also updated to 1,25 mm EN 1.4301 as originally the thickness was not fulfilling the requirements. Gutter structure can once more be seen in figure 46.

Figure 46. Side of gutter

As can be seen in figure, the end part of gutter now has 90-degree angle towards side wall which is not allowed by USPHS. The solution for removing sharp corner has been solved but it is included in Galley Air Extraction Unit’s side assembly, which is not presented in this thesis. The dimensioning of part was improved to make fixing of filter more effortless and the fitment to be more rigid and manufacturing friendly. As mentioned earlier, ships create a lot of vibration so fitments must be tight enough so parts will stay put and don’t make unnecessary noise.

Manufacturability of parts increased, and manufacturing time decreased as geometries for fixing rails was simplified from original design. By using thicker material, the flattening bends could be removed, as they are time consuming and difficult to manufacture. Also, number of bends was optimized without sacrificing the visual appearance of the product. Simplified geometry of upper fixing rail is presented as an example of simplification in figure 47.

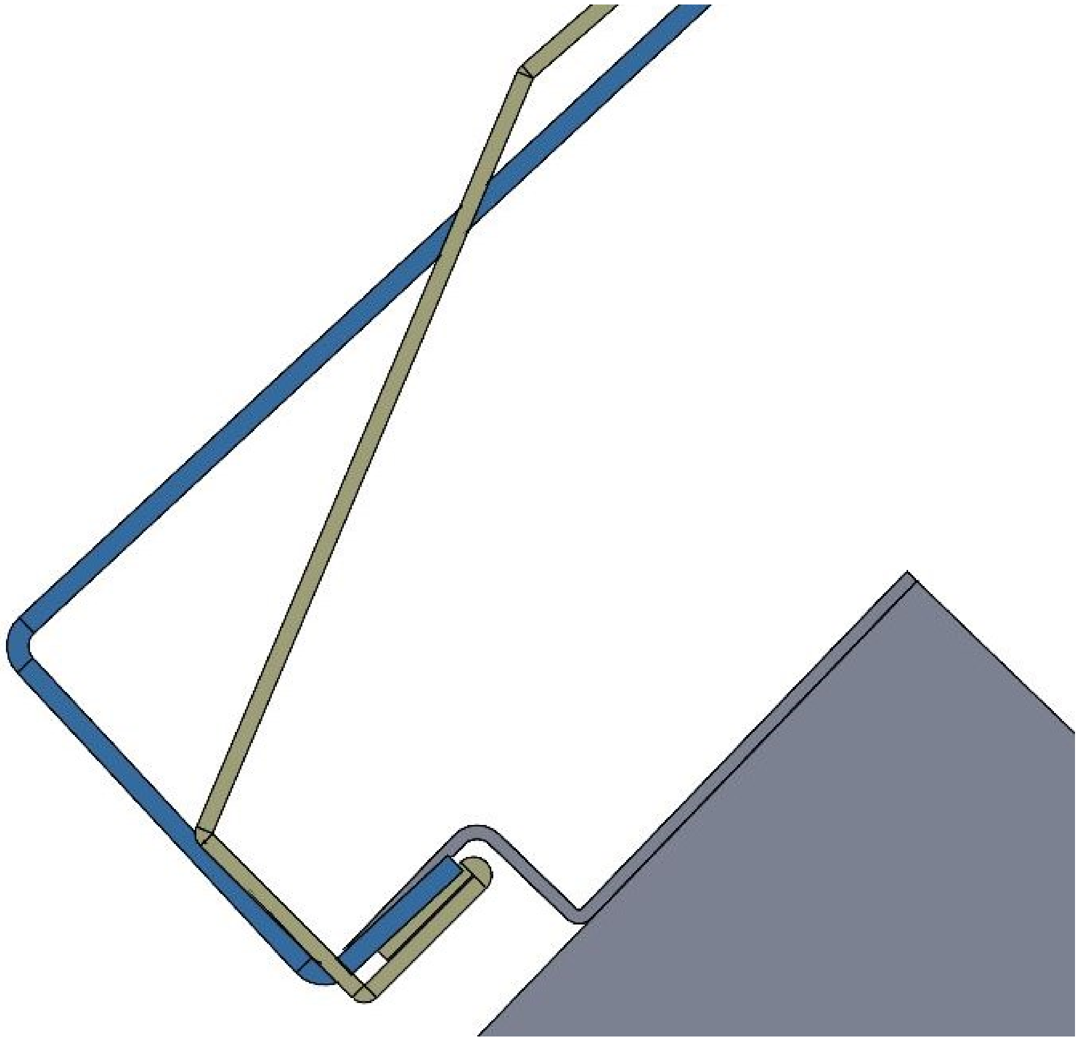

Figure 47. Simplified upper fixing rail

In illustrative figure the green coloured geometry is original design and blue one is simplified one. From cross-sectional view the new one looks blocky and unesthetic, but when part was produced the visual appearance was far more impressive and so can be concluded that visual aspects improved as was desired. This whole assembly is one of the most visually observed ensembles so appearance of it is important.

6.5 Outcome for the company

Outcome for the target company from this thesis can be considered appropriate and desirable. Product development of GAEU proceeded well and gave result that was desired. Product’s prototype will next be built again with solutions found in this thesis and prototype will be tested for its functionality and features. When those aspects will be proven and functionality and reasonable manufacturing ensured, the focus will be turned to business side and development of conceptual design concerning questions like, is the size of the product tailored by customers' needs or provided by standardized dimensions. These questions require discussions between several different department including at least R&D (research and development), sales, export and manufacturing, as well as logistics.

Thesis also gives great example to study future product development processes and if they could be improved and optimized or not. Many times, designers have their own way of doing things as we are individuals, but following the specific guidelines and frames could help with communication and cost estimations between different departments, as progress and status of projects could easily described, as an example "We are currently at phase two of VDI2221 of our development project.". Hopefully this kind of approach would be at least tested in target companies R&D and Desing department as benefits can only be guessed until the mode of operation has been tested appropriately in everyday action.

In summary outcome for the company was the Galley Air Extraction Unit product that has been developed, and example model of systematic product development process utilized in target company's facilities and operating environment, which can be implemented into future projects.

7 Discussion

This chapter concludes the discussion about result and matters regarding them. Firstly objectivity, validity and reliability of the research is evaluated. This is followed by chapter discussing about assessment of the results and key findings. Lastly the novelty value of the research is evaluated and possible topics for the future research is discussed and proposed.

7.1 Objectivity and reliability of the research

For data gathering, triangulation was accomplished well by taking advantages of different methods such as inquiry, experimental testing, literature review and value analysis. Utilizing variety of sources improved and ensured the reliability of the research. Sources and citations in literature review and in other chapters were valid and they were mostly searched from LUT Primo, Google Scholar and from physical science books so their reliability can be considered credible. The articles were referred only from reliable sources from scientific publications which could be verified.

It benefitted the objectivity of research that thesis worker doesn't have a long work history in target company so product and industry itself could be considered rather new for him. This helped the research because the previously tested and proven bad or good solutions were not known to the author, so start for development project was somewhat new and not heavily guided and therefore free for new innovations.

7.2 Assessment of the results and key findings

Results can be considered valuable for the target company. When GAEU is well prepared and presented to markets it can create good sales and revenue for the company. Product must sell well, be cost-efficient and sustainable, has the demanded functionality and visually impressive and appealing appearance. When manufacturing and assembly phases are well designed and cost structure is optimized, the product provides the best possible gross margin for the company.

Results from product development supports the goals presented in chapter above. Solutions achieved with development process match the goals as they are optimized for manufacturing at target company's facilities and assembly is well improved from original design which was not suitable for the application.

Fulfilling USPHS requirements was done by changing the material and redesigning the geometries of sheet metal parts and redesigning assemblies. In many parts and structures, it was noticed that simple geometries provide best results, when result were observed from viewpoints mentioned earlier in this thesis. Some to mention for example: visual appearance, functionality, manufacturability, and cost-efficiency. Simple structures had the best looks, they were the most functional and easy to manufacture, which leads to cost-efficiency in manufacturing. Assembling was more efficient and reasonable with simple structures.

7.3 Novelty value of the results

Novelty value of the research to the science community itself was less significant than value to target company and the whole concern. Some of the solutions in the thesis included features and characteristics that can be implemented into other products and product categories in target company product catalogue, and with new products. Those opportunities will be studied with current products and those to come. Results provided fresh new ideas of utilising different features that has not yet been used in company's sheet metal products. Some of them can provide significant improvements in the future.

7.4 Topics for future research

As manufacturing of Galley Air Extraction Unit includes a lot of welding, including more difficult welds but also a lot of straight welds with easy access, the possible applicability of robot welding would be great topic for the future research. By making profitability assessment and designing different weld platforms and jigs it would be extremely interesting to see how the calculations look; would it be beneficial and profitable to create robot welding cells for the product, releasing welders to carry their work effort with other products.

For this topic, to be further investigated, the concept of GAEU should be clear in several aspects, for example the size question. It affects greatly on welding procedure and jig design if products have three to four standardized sizes or whether it is size variable product with dozens of size possibilities.

8 Summary

The purpose of this thesis was to perform product development process for Galley Air Extraction Unit -product, for it to be suitable of fulfilling the USPSH requirements and so to become suitable for target company's global market. While thesis contributes to getting the product onto the markets, it also created a usable model of systematic product development process model for company to use in the future.

The purpose and goals of the thesis were well fulfilled as several problematic structures could be solved so releasing process of final product proceeded as desired. Thesis created 3D-models and manufacturing drawings of parts and assemblies in question, which will be used when developed product goes under production. Systematic product development process -model was also great addition to contribution for company, that can be used in several projects to come.

The starting point of the project was that GAEU had prototypes built, but they were directed to product to be sold in inland targets, not to offshore markets. Original design was complex, not optimized, and had lots of structural features that were laborious and time consuming to manufacture by target company. Optimizing the geometries of parts played big role in this product development process and in this thesis. Some of the complex geometries and difficult bending series could be improved significantly by changing the material to thicker 1,25 mm stainless steel, which was also one of the USPHS requirements.

Development project was performed by following guidelines and steps of VDI2221 standard of systematic product development process. When the project started the first thing was to get knowledge about background of the product and environment it would be used in. All the background data available was studied and using that information, the critical and problematic structures and parts when determined. Before that, the scope was set to consist only of three development targets, as time to be used with thesis is limited. After the targets where clear the actual development process was performed step by step following VDI2221. With some solutions, prototypes were made, and physical fitment testing performed, and with some solutions estimations and conclusions could be done without physical test pieces.

It would have been desired and interesting from authors point of view to be able to present the complete product in this thesis but due to long during of product development processes in general it simply is not possible with cases like this. Due to that scope had to be limited to consist only few structural examples in whole project. Creating a scope for such large ensemble was challenging at start as estimating the time consumption was difficult to determine.

Galley Air Extraction Unit ensemble is so large and includes so complex structures, that one or two more thesis like this could be done to solve all structural problems. Although many of those structural problems could be solved with solutions found in this thesis work.

References

Flick, U. 2013. *The SAGE Handbook of Qualitative Data Analysis.* London: SAGE Publications. 13 p.

Gliner, J. A., Morgan, G. A., & Leech, N. L. 2017. *Research methods in applied settings.* New York: Routledge. 13 p.

Halton Oy. Cruise ship kitchen. Referred 4.1.2024. Available at https://www.halton.com/fi/solutions/merituulivoimalat/laivakeittioiden-ilmanvaihto-merituulivoimaloiden-sahkoasemilla/

IMO. 2001. *SOLAS Consolidated Edition.* London: International Maritime Organization. Pp. 7-8.

IMO. 2024. *International Convention for the Safety of Life at Sea,1974*. Referred 21.2.2024. Available from IMO web site: https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx

IMO, About IMO. 2024. *Brief history of IMO.* Referred 21.2.2024. Available at IMO Web site: https://www.imo.org/en/About/HistoryOfIMO/Pages/Default.aspx

Jänsch, J., & Birkhofer, H. 2006. The Development of the guideline VDI2221 - The change of direction. *International design conference*. Dubrovnik: Design 2006. Pp.45-52.

Pahl, G., Beitz, W., Feldhusen, J., & Grote, K.-H. 2007. *Engineering Desing.* London: Springer. Pp. 18-19, Pp. 131-132, 148 p, Pp. 227-228, 234 p. Pp. 436-437

Prilutskaya Maria, M. A. 2021. Mechanical engineering product value desing applying the value engineering method. *International Conference on Modern Trends in Manufacturing Technologies and Equipment (ICMTMTE)*. Ekaterinburg: EDP Sciences. Pp. 1-8.

U.S. Department of Health and Human Services. 2024. *U.S. Department of Health and Human Services*. Referred 10.3.2024. Available at History: http://www.usphs.gov

U.S. Public Healt Service. 2018. *The VSP 2018 Construction Guidelines.* Atlanta: Centers for Disease Control and Prevention. Pp. 1-2.

U.S. Public Healt Service. 2018. *The VSP 2018 Operations Manual.* Atlanta: Centers for Disease Control and Prevention. Pp. 1-3.

U.S. Public Health Service Oper. (2018). *VSP 2018 Operations Manual.* Atlanta: U.S. Public Health Services. Pp. 39-42.

Ulrich, K. T., Eppinger, S. D., & Yang, M. C. (2020). *Product design and development.* New York: McGraw-Hill Education. 12 p.

Välimaa, V., Kankkunen, M., Lagerroos, O., & Lehtinen, M. (1994). *Tuotekehitys - Asiakastarpeesta tuotteeksi.* Helsinki: Painatuskeskus Oy. Pp. 25-28, Pp. 47-49.