

Design of Tomorrow's Marine Engine Covers

Research and Development of the noise absorption, aesthetic, and durability characteristics of a marine engine cover

Master's thesis in Product Development

Madalena Almeida
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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2025
www.chalmers.se

MASTER'S THESIS 2025

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Master's Thesis 2025

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Cover: Wind visualization constructed in Matlab showing a surface of constant wind speed along with streamlines of the flow.

Typeset in L^AT_EX

Printed by Chalmers Reproservice

Gothenburg, Sweden 2025

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Abstract

This thesis explores the redesign of the D6 engine cover with the objectives of improving noise reduction, aesthetics, and durability. The primary motivation for the project was to achieve a measurable reduction in engine noise through modifications to the cover alone, without altering the engine itself. Additionally, the existing cover has remained unchanged for several years, highlighting an opportunity for design improvement. The project adopts a traditional design methodology based on sequential engineering, guiding the process from problem identification to concept generation and prototyping.

A series of design concepts were developed and evaluated according to acoustic performance, visual appeal, and structural resilience. These concepts were iteratively refined, leading to the selection of one final design considered the most promising based on a combination of theoretical performance and practical feasibility. This final concept was further developed using CAD modeling tools and subsequently prototyped through 3D printing, enabling preliminary physical evaluation.

Although the project resulted in a tangible prototype, the findings underline the need for continued research, particularly in advanced acoustic testing, material optimization, and long-term durability studies, to validate the design under realistic operating conditions. This work provides a foundation for future development and highlights the value of design-focused interventions in addressing performance and aesthetic challenges in marine engine components.

Keywords: marine engine covers, noise reduction, acoustic insulation, product development, design improvement, durability, Volvo Penta D6, material selection, Finite Element Analysis, 3D printing, customer needs

Acknowledgements

We would like to thank everyone who supported us during this thesis project.

At Volvo Penta, a big thanks to Hans, Andreas and Anna for all the feedback, discussions, and practical input. Your guidance, technical knowledge, and constant support were essential to the progress and direction of the work. Your constructive feedback and openness to discussion played a crucial role in shaping the outcome of this thesis.

To the other thesis students we had the pleasure of working side by side with: thank you for the teamwork, shared struggles, and good company. It made a big difference to go through this experience alongside you.

Thanks to Kristina for the feedback and check-ins from Chalmers. And most of all, a big thanks to Alex, your support, input, and clear guidance really helped us stay on track. We always appreciated your sound advice and commitment throughout the entire process.

Madalena Almeida & Anton Hellberg, Gothenburg, June 2025

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AI	Artificial Intelligence
Active Noise Control	ANC
CAD	Computer-Aided Design
CNC	Computer Numerical Control machining
European Union	EU
FEA	Finite Element Analysis
FEM	Finite Element Method
GDPR	General Data Protection Regulation
KJ	Kawakita Jiro
PLA	Polylactic Acid
SOLAS	Safety of Life at Sea

Nomenclature

Below is the nomenclature of indices, sets, parameters, and variables that have been used throughout this thesis.

Indices

Al	Indices for aluminium material
C	Indices for cork material

Parameters

ρ	Density [kg/m ³]
ρ_o	Density of the air [kg/m ³]
c	Speed of sound in the air [m/s]
π	Pi (mathematical constant)

Variables

V	Volume [[m ³]]
A	Area [[m ²]]
d	Thickness [mm]
m	Mass [kg]
m''	Mass per area[[kg/m ²]]
f	Frequency [Hz]
P	Sound power level [dB]
R_{\perp}	Sound transmission loss [dB]
f_0	Lowest order structural resonance [dB]
f_a	Antiresonance frequency [dB]



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1

Introduction

This chapter provides the background of the project, outlines its goals, discusses its limitations, and presents the key research questions. It concludes by examining the societal, ethical, and ecological aspects of the research.

1.1 Background

The maritime industry is undergoing major transformations, driven by technological advancements and shifting market demands (Virtue Marine, 2025). One key area of innovation is the development of marine engine covers, which play a crucial role in sound reduction, durability, and overall vessel aesthetics. As outboard engines continue to replace traditional inboard engines (Global Market Insights, 2024a, Global Market Insights, 2024b), there is a need to optimize engine covers to maintain their competitiveness appeal. So, new design solutions that address both functional and aesthetic considerations are necessary.

A well-designed marine engine cover serves multiple purposes. It helps reduce engine noise, providing a more comfortable experience for passengers and crew. Additionally, engine covers protect the motor from harsh marine environments, improving durability and extending the engine's lifespan (GetMyBoat, 2024). Furthermore, aesthetics are an important factor, as modern boat owners and manufacturers seek sleek and visually appealing designs that integrate seamlessly with the overall look of the vessel (Yate, 2024).

This thesis, in collaboration with Volvo Penta, explores the development of next-generation marine engine covers for the D6 engine (see figure 1.1), using advanced materials and structural design to optimize sound absorption without compromising durability or aesthetics. By analysing existing designs and identifying their strengths and weaknesses, this research aims to propose innovative concepts that enhance both performance and appearance.

1.2 Aim

This thesis aims to develop a marine engine cover that performs highly in sound reduction, aesthetics, and durability. To do so, this study will focus on customer, market, and technology analysis, as well as technical aspects, such as material research and FEA (Finite Element Analysis).



Figure 1.1: Volvo Pentas D6 engine

The expected outcomes of this thesis can be divided into two steps. The first to discard unfeasible concepts until a small number (ideally 2 to 3) remain. These will be a marker of the halfway stage of this project and will be of low development maturity, consisting primarily of sketches. The last outcome, which will be achieved at the end of this study, is the development of a CAD (computer-aided design) model and scaled 3D printed prototype of the concept that the project members find most interesting and promising in balancing sound absorption, aesthetics, and durability.

1.3 Limitations

- **Prototype Focus:** Due to time constraints, the final physical prototype emphasizes aesthetic and design elements, with limited attention to fully functional aspects such as the fastening system. This restricts the evaluation of the prototype's mechanical performance.
- **Access to Engine Model:** Regular access to a D6 Volvo Penta engine was necessary for testing and evaluation. However, only an exposition model was provided, which could not be disassembled for detailed analysis. This limited the ability to assess integration and maintenance-related aspects.
- **Confidentiality Restrictions:** Certain details regarding Volvo Penta's products and internal procedures could not be disclosed and therefore were excluded from the project analysis. This affected the completeness of the internal benchmarking and technical validation.

1.4 Research questions

Given the aim and limitations of this project, the following research questions will be addressed:

1. What are the advantages and disadvantages of existing marine engine covers, with regard to sound absorption, aesthetics, and durability?
2. What design features should be adopted to balance sound absorption, aesthetics, and durability in the next generation of marine engine covers?

1.5 Societal, ethical and ecological aspects

Societal Aspects

Through the development of innovative marine engine covers, the safety, usability and aesthetic appeal of marine engines increases. These are relevant aspects that impact societal needs. By incorporating sound absorption technology, there will be a decrease in sound pollution, improving the quality of life for both the individuals living near marine ecosystems and those who work on the engines and vessels (Gannouni et al., 2024). The improved access to engine components will also contribute to reduced maintenance time and effort, benefiting the users of this solution. Furthermore, by complying with safety standards, this project promotes safer work environments and usage for the users, potentially reducing accidents. Additionally, the modernization of the marine industry's image through the implementation of futuristic aesthetic designs can potentially attract younger talent and boost the public interest in marine technology.

Ethical Aspects

This project will follow the General Data Protection Regulation (GDPR) to protect the privacy of the participants involved in the necessary research steps (e.g. interviews and surveys). The participation in these activities will be voluntary and will have the option for anonymity. Proprietary and confidential information provided by the partnering company, Volvo Penta, and shared with the team will be safeguarded from unauthorised disclosure by the signing of a Thesis Work Agreement, which includes a Confidentiality Undertaking section.

Ecological Aspects

The project aims to reduce the environmental footprint of the engine covers by researching and incorporating sustainable materials. Lightweight and durable materials will enhance fuel efficiency in marine operations, contributing to lower carbon emissions. Prototyping and testing processes will be performed with the goal to minimize material waste and allow for recycling wherever possible. One of the strategies for this is the use of 3D printing, a new and innovative technology that allows for material waste reduction (Nadagouda et al., 2020). Lastly, the emphasised focus of the project on sounds absorption will improve the efforts to mitigate the impact of underwater sound pollution on marine life, a growing concern in ecological conservation.

2

Theoretical Framework

This chapter provides an overview of essential theoretical information, aiming to aid in the understanding of the project's issues and context. This includes information about different engines and their compartments, as well as the process of noise transmission through barriers.

2.1 Inboard and outboard engines

Inboard engines are installed within the boat's hull, typically placed in the bilge or a dedicated engine room on larger vessels. These engines drive a propeller via a shaft that extends through the hull, while steering is managed using one or more rudders positioned behind the propeller (Matson, 2022).

One drawback of inboard engines is the vibrations they generate, which can transmit through the hull and impact onboard comfort. Moreover, the confined engine compartments can make maintenance and repairs more difficult and time-consuming. Further, inboard engines often add significant weight to the stern, potentially affecting the vessel's trim and overall performance (Ribs, 2023).

Outboard engines are mounted externally on the boat's rear. This positioning allows easier access, simplifying maintenance and repairs compared to inboard engines (Ribs, 2023). Additionally, outboard engines can be removed from the boat when necessary, facilitating off-season storage. (Matson, 2022).

However, outboard engines come with certain drawbacks. Their weight distribution at the stern, similar to the inboard, can impact the boat's trim and performance, particularly in rough water conditions (Ribs, 2023). Additionally, the exposed propeller presents a safety risk to swimmers and passengers boarding the vessel. Some outboard engines may also generate higher noise levels, potentially affecting onboard comfort, especially on smaller boats (Matson, 2022).

2.1.1 Volvo Penta D6 engine

The Volvo Penta D6 is a 6-cylinder, 5.5-liter diesel inboard engine, renowned for its robust construction and performance (Volvo Penta, 2024). This project focuses on the engine's cover and parts that require frequent maintenance, highlighted in figure 2.1.

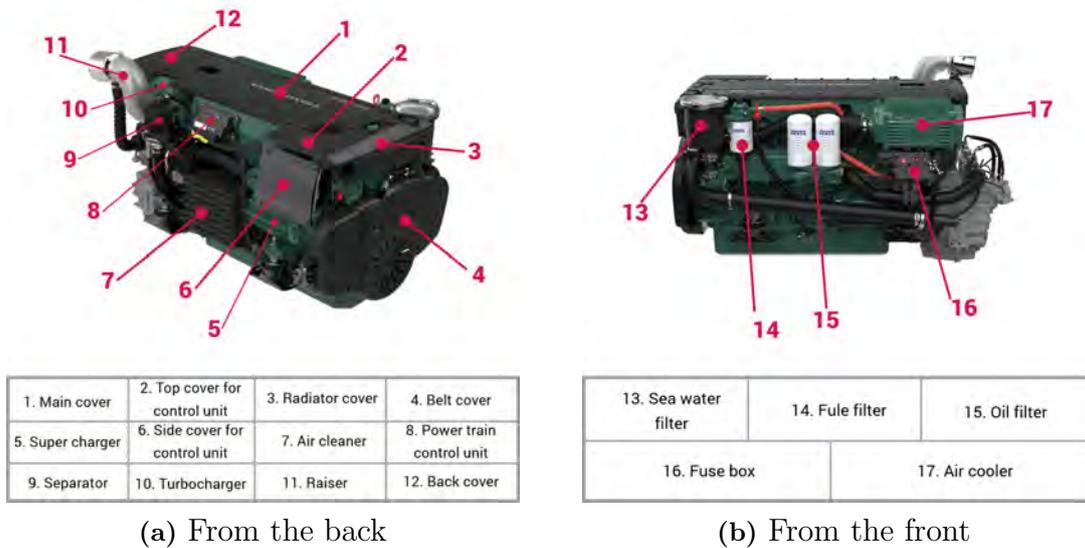


Figure 2.1: Important components in the Volvo Penta D6 engine

When designing the new cover, it is important to identify which components can be removed or redesigned, and which must be retained and integrated into the new design. The components that can be removed or redesigned are:

- 1. Main cover
- 2. Top cover for control unit
- 4. Belt cover
- 6. Side cover for control unit
- 12. Back cover

2.1.2 Engine compartments

Volvo Penta does not manufacture boats, instead, they supplies engines to customers who manufacture the boats where these engines are placed. Therefore, it is crucial that the engines are easy to install in the customers' engine compartments. Since the dimensions of the engine compartment vary across different boat models, the new cover must be adaptable to fit all these compartments. To better understand the available space in these compartments some illustrations are shown in figure 2.2.



(a) Two D6 engines in a large compartment.



(b) Two D6 engines in a cramped compartment



(c) Two D8 engines in an large compartment, with some space on both sides of the engines



(d) Two D4 engine with a small space in the rear end, bit more on the front and sides.

Figure 2.2: Four different engine compartments for Volvo Penta engines

2.2 Sound transmission loss calculation

As sound reaches an acoustic barrier, three events can happen: absorption, transmission, and reflection (see figure 2.3). Absorption relates to the barrier's capacity to absorb the sound and convert it into heat; transmission refers to the amount of sound that passes through the barrier; and reflection regards the sound reflected off the barrier (Siemens, 2019).

In this project, the phenomenon of importance is the transmission of sound through the engine cover. However, the sound transmission loss of a material differs significantly with frequency. There are three types of waves: low-, medium- and high-frequency, and the D6 Volvo Penta engine generates different waves in all these categories. Low frequency waves typically occur at 500Hz or less and are often felt as vibrations (Technicon Acoustics, 2021). Due to the characteristics of low frequency waves, especially their wavelength, the best way to reduce the noise that they generate is not through noise shielding (SoundStop, 2024), but by improving

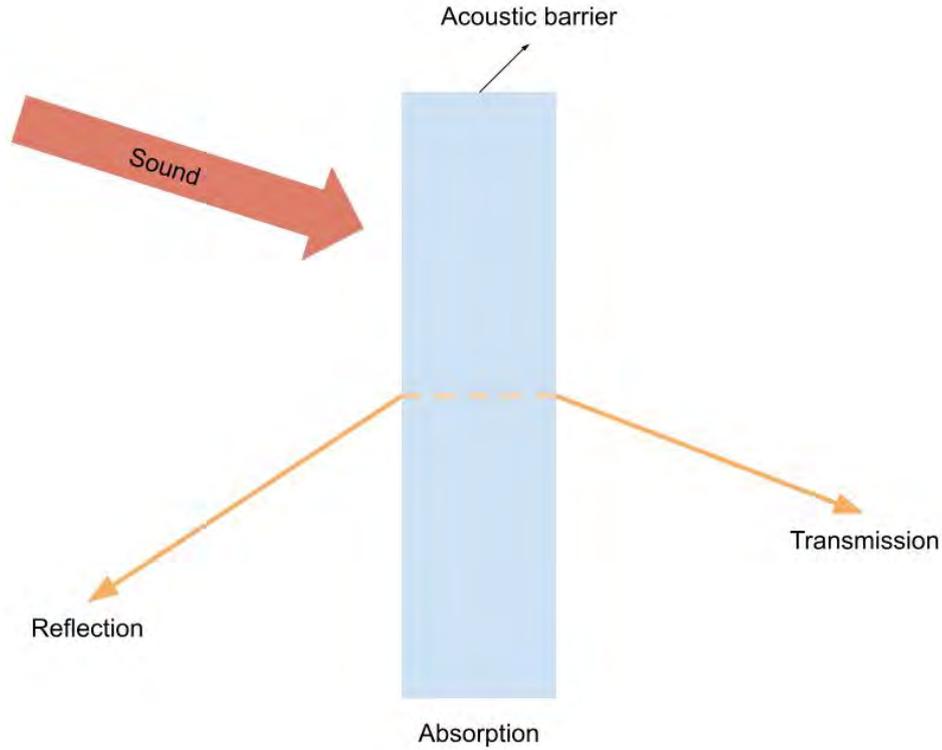


Figure 2.3: Different sound events through an acoustic barrier

the structure and mounting connections of the engine. Therefore, the focus will be placed on mid-frequency waves, in this case 1000Hz, and on waves that travel perpendicularly to the cover.

If the barrier can be analysed as a single section, the representation of the mathematical model used to calculate the transmission loss can be seen in figure 2.4, and the following equations apply:

$$V = Ad[m^3] \quad (2.1)$$

$$\rho = \frac{m}{V} \left[\frac{kg}{m^3} \right] \quad (2.2)$$

$$m'' = \rho d \left[\frac{kg}{m^2} \right] \quad (2.3)$$

$$R_{\perp} = 20 \log \left(\frac{wm''}{2\rho_0 c} \right) - 3[dB] \quad (2.4)$$

$$P_{12} = P_1 - (R_{\perp 1} - 3)[dB] \quad (2.5)$$

However, if an air gap is introduced between the barrier layers, the calculations presented in the book Osama A. B. Hassan, 2009 apply and can be seen below.

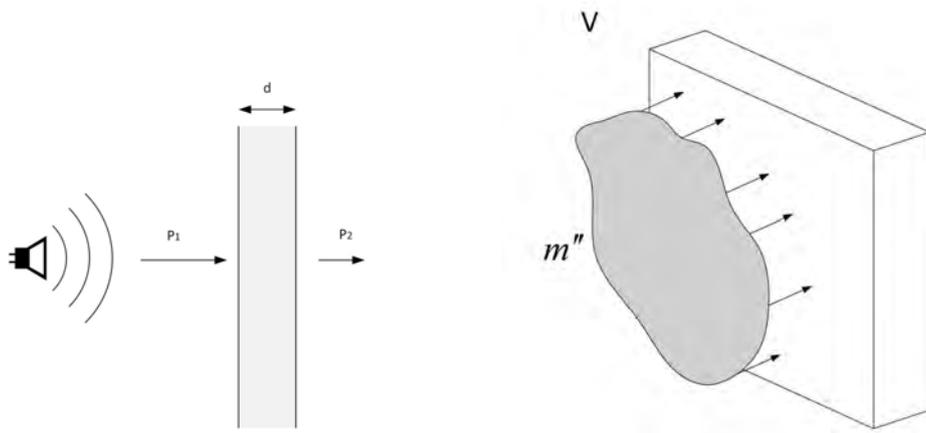


Figure 2.4: Mathematical representation of the model

$$if \left(f_o = \frac{c}{2\pi} \left[\frac{\rho_0}{d} \left(\frac{1}{m''_{Al}} + \frac{1}{m''_{Cl}} \right) \right] \right)^{1/2} < f < f_a = \frac{c}{2\pi d} \quad (2.6)$$

$$then (R_{\perp} = 20 \log(m''_{Al} + m''_{Cl}) + 20 \log(f) - 47.3[dB]) \quad (2.7)$$

$$P_2 = P_1 - R_{\perp} + 6[dB] \quad (2.8)$$

3

Methods

This chapter outlines the methodology followed throughout the project, serving as the foundation for the results presented in Chapter 4. It describes the overall development approach and the specific methods applied during each phase, including research, concept generation, evaluation, and testing. The chosen methods were selected based on their relevance to the project goals and constraints, as well as input from industry experts. The chapter aims to provide a clear understanding of how the project was carried out and how each method contributed to the development of the final concept.

3.1 Design process

The methodology used during the thesis is the traditional design methodology, or sequential engineering, from the book *Product Design and Development* (Ulrich & Eppinger, 2016). The diagram, see figure 3.1, illustrates the traditional product development process, starting from the planning phase and moving through concept development, system-level design, detailed design, testing and refinement, and finally production ramp-up. Each phase builds upon the previous one, creating a structured and sequential workflow for developing complex products.

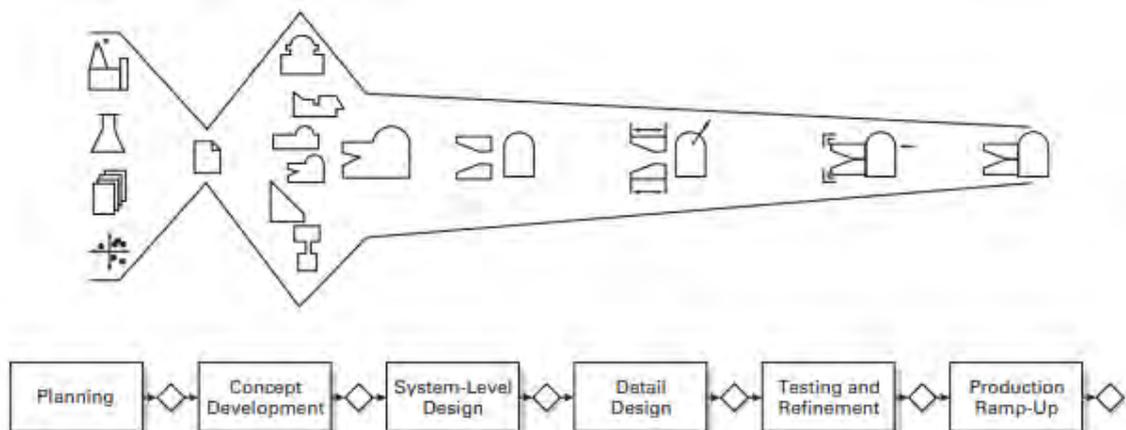


Figure 3.1: The generic product development process

Although an Agile approach was considered, it requires rapid prototyping and iterative development loops or sprints (Rigby et al., 2016). Essentially, this method

speeds up the traditional approach by breaking it into smaller iterations with regular testing and refinement after each sprint. Unfortunately, given the scale and complexity of this project, rapid and frequent prototyping would be challenging and impractical.

Concurrent development was also an option, where work and tasks are done in parallel (Raudberget, 2010). However, this approach relies on cross-functional teams for success, and in this case, there are only two students working together. Therefore, a more traditional development process will be followed. Nevertheless, if testing smaller subsystems or components is feasible, selected smaller iterations or "sprints" may be implemented to validate these functions efficiently.

Lastly, it was contemplated to follow a set-based Concurrent Engineering method (see figure 3.2) during the "Detailed design & Testing and refinement" phase. By doing so, each of the final 2-3 concepts generated until this stage would be developed until there was enough information to declare it the weakest of the group and, therefore, disregard it. By delaying the decision-making moment, decisions can be made with more information. Nonetheless, the current resources and time limit of this work do not allow for the thorough development of multiple concepts.

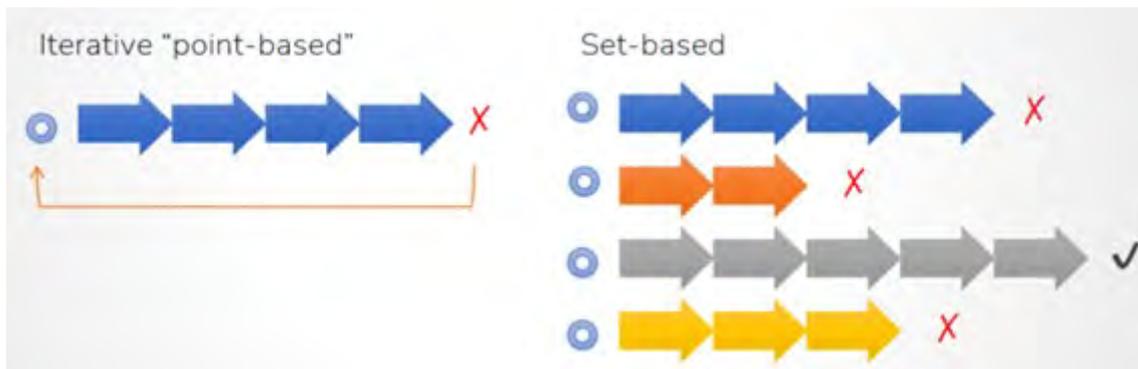


Figure 3.2: Set-based Concurrent Engineering

3.2 Customer needs study

Analysing and identifying who the customer is and what their needs are is an important step to developing a product that is unique and attractive to the customer (Miller, 2020). The customer identification process relied on information provided and discussed with Volvo Penta. In order to study the needs of the customer, several methods were utilised. Regardless of the data collection method, a five-step process was followed (Ulrich and Eppinger, 2016):

1. Gather raw data from customers;
2. Interpret the raw data in terms of customer needs;
3. Organise the needs into a hierarchy of primary, secondary, and (if necessary) tertiary needs;

4. Establish the relative importance of the needs;
5. Reflect on the results and the process.

The research relied solely on qualitative data collection methods, due to the subjectivity involved in certain parameters, like the user's opinions and experiences (Grand Canyon University, 2023). Interviews and observations were chosen over surveys and focus groups due to time constraints, easier access to individual users, and the need to capture deeper insights into customer behaviour and expectations. These methods also allowed for greater flexibility and context-specific understanding, which was essential for accurately translating user input into product requirements.

Additionally, the KJ-method (Scupin, 1997) was used to gather and interpret the data collected through a website called Mural. This method is beneficial for identifying similarities and trends in unstructured qualitative data (Interaction Design Foundation, 2024).

3.2.1 Interviews

A total of 12 interviews were conducted and followed an unstructured format. An introduction to the thesis topic was initiated, and an emphasis was placed on its goals. This interview style allows the interviewee to follow and share their thinking process, guiding the interview to the topics they have higher expertise or viewpoint on (Denscombe, 2010). All the interviews involved an in-person meeting between one or two informants and the two researchers, lasting between 30 minutes and one hour. Both researchers participated in the discussion, but one was responsible for taking notes of relevant topics discussed since no other recording or transcription method was used. Lastly, the scope of interviewees was set to internal Volvo Penta employees. This decision was based on the financial model at Volvo Penta. Since they sell their products to vessel manufacturers who, in turn, assemble them and sell the finished vessels, it proved difficult to make contact with the vessel manufacturers and future owners during the limited time frame of this step. During this process, 15 employees were interviewed, and the focus was placed on expertise in design, noise and vibration, thermal management, and maintenance, as well as selecting members who have used and/or maintained a marine engine. To choose the participants, some were suggested by the team's manager at Volvo Penta, others were looked for based on their work title, and the rest were recommended by some of the interviewees, as they would be relevant given the topics discussed.

3.2.2 Observation

The group visited Krossholmen, Volvo Penta's marine leisure testing facility. During this time, it was possible to observe, experience and analyse how a certain user segment interacts with the product in a non-biased way. That is, the analysis is only subjected to the interpretation of the observer and not to the participant's (Ellis, 2023). The group conducted a participant observation since it allows for a better understanding of the users' needs and practices (Denscombe, 2010).

3.3 Benchmarking

In this project, benchmarking was conducted to understand the design, material, and sound emissions of market products. The benchmarking process was based on the 8-step methodology (Boxwell & Robert, 1994).

The first step in the benchmarking process was to decide the focus, and that is in- and outboard engines, specifically examining noise emission, aesthetics, and cover material. The next step involved identifying which companies to benchmark against. Volvo Penta does not maintain an internal list of competitors, so the identification was based on an external search. The benchmarking was documented in Excel, which eased the organization and analysis of the collected data. This analysis provided insights into what other competitors are doing, and based on the findings, it can be helpful to use similar designs in the idea generation phase.

3.4 Regulatory compliance

In the maritime industry, there is a need to follow laws, regulations and standards. By doing so, safety, protection of the environment, enhancement of operational efficiency, as well as maintenance of stakeholder trust are ensured, and avoidance of legal and financial consequences (Orcades Marine, 2024).

To ensure that the relevant information was gathered, a meeting with a representative of the Regulatory Compliance Department of Volvo Penta, as well as with relevant experts in the field were conducted. This allowed the collection of pertinent and product-oriented legal requirements, as well as internal standards of Volvo Penta.

The gathered information was systematically reviewed and translated into specific design constraints and requirements, ensuring that the final product complies with applicable regulations while aligning with Volvo Penta's internal practices. This process helped guide design decisions, particularly regarding material selection, accessibility, labelling, and safety features.

3.5 Requirement management

Requirement management is a key process to develop a solution that is customer- and market-focused. This ensures that the goals and scope of the project are clear, identifies and reduces potential risks and that the end solution is of high quality, resulting in high stakeholder and customer satisfaction (Jonker and Gomstyn, 2025). To guarantee it is done in a structured and thorough manner, it was divided into four steps, based on the process proposed by specialists at IBM (Jonker and Gomstyn, 2025):

1. Requirement collection: collect initial requirements from stakeholders through the customer needs study;
2. Requirement analysis: analysis to guarantee a comprehensive understanding of needs and expectations;
3. Requirement definition: development of a requirement list, with clear prioritisation, justification and validation/verification method;
4. Requirement revision: revision of the requirement list, if changes occurs throughout the project.

Additionally, this process will be complemented by the use of Pugh's balloons (Pugh, 1990), please see figure 3.3, to ensure the development of a comprehensive requirement list.

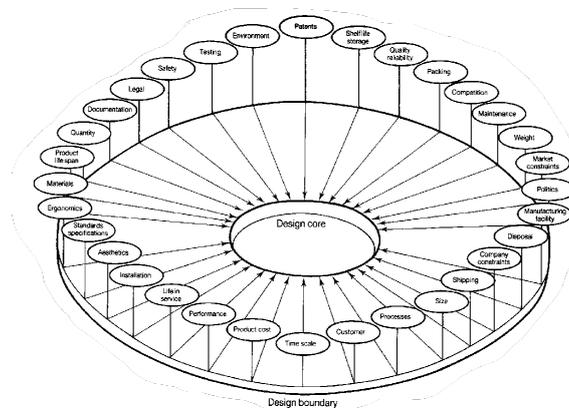


Figure 3.3: Pugh's balloons

3.6 Mood boards

The use of mood boards offers several benefits. They support inspiration, help define a coherent colour palette and style, and enhance communication within the team and with stakeholders to achieve aligned results (Design4Users, 2025).

In this project, mood boards played a critical role during the early stages of the product development process, especially in exploring and communicating the aesthetic direction of the engine cover. Since aesthetic qualities weigh heavily in the quality of the final outcome of the project, are subjective and often difficult to convey verbally, mood boards were used to visually express different stylistic themes and material inspirations.

To develop the mood boards, existing examples from related products and design concepts were researched and analysed as a starting point. The platform Mattoboard was used to compile and present the boards. These were then shared with Volvo Penta employees and relevant stakeholders to gather feedback and initiate dialogue. This approach facilitated clearer communication about the intended look and feel of the design and helped align visual expectations early in the development. It also

enabled the team to receive concrete feedback on an otherwise intangible product characteristic (aesthetics), ensuring that stylistic decisions were grounded in both user perception and brand identity.

3.7 Early design drafts

The initial design phase involved the creation of early drafts using generative AI tools, specifically Gemini, ChatGPT, and Adobe Firefly. These tools were used in combination with the previously developed mood boards in section 3.6 to generate visual concepts aligned with the intended aesthetic direction.

A series of prompts were crafted and input into the AI image generators to produce initial concept sketches. In total, approximately 10 images were generated, and the prompts were iteratively refined based on the results, adjusting parameters such as style, material cues, proportions, and design language, until the outputs aligned more closely with the desired look and feel. This iterative process enabled rapid exploration of design alternatives, which would have been significantly more time-consuming with traditional sketching or 3D modeling.

The generated images served as a foundation for internal discussion and evaluation, helping to narrow down visual directions before moving on to more detailed digital modeling.

3.8 Functional description

To break down the problem into its functions and corresponding solutions, interactions, and constraints, an Enhanced Function-means Tree was used. This allowed for an increasing knowledge of dependencies between the different functions (Müller et al., 2019) and to identify potential conflicts early in the design process, reducing the risk of costly alterations later on (Johannesson, 2004).

3.9 Concept generation

Based on the Enhanced Function-means Tree developed in section 3.8, a Morphological Matrix was generated. This tool allows for an extensive exploration of the design space, as well as guaranteeing that each generated concept is feasible (Fargnoli et al., 1951). The concepts were generated by "mixing and matching" the different solutions to the different functions, while considering their interdependencies.

3.10 Concept screening

The concepts generated in section 3.9 were evaluated through the use of an Elimination matrix with the critical criteria that the solution must adhere to. Following, the remaining concepts were further developed and a Weighted-Pugh matrix was used.

This allowed for an objective comparative analysis, to define the relative importance of the different criteria, and to enhance the understanding of the different trade-offs between the requirements (Six Sigma, 2024). The metrics and corresponding weights were derived from customer needs analysis, product specifications, and the group's interpretation of Volvo Penta's values.

It was observed that the generated concepts could be distinctively categorised by the overall structure of the cover or by the material types and layers that the cover would use. Therefore, the decision was made to break down the concepts into these two categories for further analysis and development, ensuring a minute exploration of the design space.

Subsequently, the generated concepts for the overall structure of the cover were evaluated with the use of a Kesselring matrix. This is a very useful decision-making tool, as it takes into consideration the interactions between the different criteria by weighing their importance relative to each other and allows for clear visualisation and communication of the results (Zeiler et al., 2007). Additionally, this tool evaluates each concept against an idealised perfect system (one with perfect scoring in each criteria), and not against each other, removing any bias that might be present.

Lastly, the concepts for the material types and layers that the cover would use were further developed by conducting a material selection study. The tool GRANTA EduPack was used and the following methodology was used (Michael F. Ashby, 2005):

1. Translation — convert the design requirements into material properties.
2. Screening — remove the materials that do not comply with the previously set constraints.
3. Ranking — identify the materials best suited to fulfil the requirements.
4. Seeking supporting information - collect further details about the prevailing materials to ensure a holistic final decision.

The materials were explored based on three categories: load bearing, sound insulation and heat insulation properties. The materials were explored in the 1st level of GRANTA and gradually in the 2nd and 3rd level to generate detailed results.

3.11 Aesthetic design

Based on the benchmarking results and the mood boards, different concepts were developed through 3D modelling. After doing so, the design themes explored were identified and thoroughly defined. In order to decide which style to select for the final concept, two evaluation methods were used: an internal survey at Volvo Penta and an external survey through different media platforms. Both these surveys aimed at understanding what the experts and users prioritise when selecting an engine solely based on its aesthetic look. The final decision was made by the team's judgment of

the results of the surveys conducted, as well as their expertise acquired during the project development.

3.12 Concept selection

A table compiling the remaining concepts for the overall design of the cover and the material layers that the cover would use was generated. From this table and the previous decision of an aesthetic style, a final concept was selected by combining the different possibilities based on the group's expertise and engineering assessment.

3.13 Detailed design of the final concept

From the table presented in figure 4.18, three concepts were developed using CAD softwares, two in Autodesk Alias and one in Creo. Once all concepts had reached a sufficient level of maturity, a final concept was selected for further development.

3.14 Performance evaluation of the final concept

The final concept underwent a series of performance evaluations to assess its overall effectiveness, and the methods used for these assessments can be seen in this section.

3.14.1 Material layer

In order to evaluate the performance of the material layer selected, comparison was done between the current solution and different new ones generated, based on theoretical calculations. However, due to the limited knowledge of the group in the field of sound and vibrations, the evaluation was supplemented by results of experiments conducted by researchers that were deemed relevant to this topic.

3.14.2 FEM analysis

The FEM analysis was done in CREO, with the Live Simulation tool. The part was loaded with a force of 92 kN, which came from the requirement that it needs to withstand a force of 1000 N per 70x70 mm. This process was iterative, when the deformation was too big, the part was redesigned to add more support structures, and then a new analysis was done.

3.15 Manufacturing assessment

First, each material layer was individually evaluated to determine the most suitable manufacturing process based on its specific material properties and geometry. The selected processes were then assessed against key criteria, including cost-effectiveness, scalability for future production, and the ability to preserve the material's critical characteristics. Following this, appropriate joining methods were

explored to effectively bond the different layers. These activities were carried out in parallel with ongoing discussions with experts within the company, whose insights helped guide decisions and validate the feasibility of proposed methods. As a result, adjustments were made to both the structural design and the layering of materials to ensure manufacturability without compromising the product's core performance requirements.

3.16 Final product

Although a concept was selected and developed in section 3.13, the subsequent development phases, such as CAD modeling and stakeholder feedback, revealed new insights that prompted several modifications to the final product. The process followed was similar to that used during the concept development phase: iterative refinement based on practical constraints, visual evaluation, and ongoing dialogue with Volvo Penta.

For example, during the 3D CAD modeling stage, it became clear that certain aesthetic features from the original concept were too complex to manufacture or did not align well with internal component geometries. As a result, these elements were simplified or restructured to improve manufacturability and fit, while still retaining the intended design language.

During this stage, different colour combinations were explored to find the best aesthetic look. They were presented to Volvo Penta, to see if they aligned with the Volvo design language, and the best ones were chosen.

3.17 3D printing

The final step was to create a 3D-printed prototype to obtain a more realistic evaluation of the engine cover. The decision was made to produce the prototype at a reduced scale of 1:15, using a Prusa MK4 printer with a 0.4 mm nozzle and a PLA (Polylactic Acid) filament. Since the main objective is to assess the aesthetics, this approach allowed for a quick and resource-efficient way to do so, removing the need for full-scale prototyping. PLA was chosen due to its affordability, ease of use, and low environmental impact compared to other materials ((HuAlicia, 2025)).

When scaling down the CAD model, some walls became too thin to print reliably and therefore had to be thickened. Post-processing was performed to remove support marks and improve the fit between parts, and all components were painted to enhance the overall realism.

4

Results

Following the methodology outlined in Chapter 3, the results generated throughout the development process are presented here. The structure of this chapter follows the main stages of the product development methodology: research, concept development, evaluation, and testing. The focus is on presenting the raw outcomes of each phase, while deeper analysis, interpretation, and reflection are reserved for Chapter 5. To support the flow of information, more detailed data, calculations, and secondary findings are provided in the appendices and are referenced throughout the chapter where relevant.

4.1 Customer needs study

The data collected through qualitative methods, interviews and observation, and analysed through a KJ-method is presented, as well as its outcomes and deliverables.

4.1.1 Customer and user identification

The customer information provided by Volvo Penta served as the foundation for the customer and user identification, shown in table 4.1.

Segment	Description
Customers	1. Vessel manufacturers (the complete engine is sold to these companies, who, in turn, assemble them in the vessels they sell). 2. Boat owner
Primary users	Vessel operators/owners
Secondary users	Maintenance technician (internal or external)
Stakeholders	1. Health, Environmental and Work Safety Organizations 2. People who live near harbours and bodies of water

Table 4.1: Customer and user identification

4.1.2 Data interpretation from customers

The KJ analysis used to interpret the data collected from customers can be seen in appendix D, and the following main set of takeaways was made:

- The access to engine components needs to be as easy as possible;
- There is little space inside the engine rooms;
- Futuristic can mean adding functionality and/or improving the product's sustainability;
- Sound reduction is looked for, either through the whole use of the engine or solely during cruise and idle mode;
- There is a significant amount of heat radiating from the engine.;
- The cover is used as a stepping point.

4.1.3 Customer needs list

The customer needs list represents a structured translation of the data collected in the earlier stages into development-oriented language. It is used to systematically capture and organize the needs of the customer, and can be found in table 4.2.

No.	Category	Need	Imp.
1	Sound absorption	Reduces the engine noise as much as possible	3
2	Aesthetic & maintenance	Able to be walked on	3
3	Maintenance	Allows easy access to engine components	3
4	Sound absorption	Reduces the engine noise in specific modes	2
5	Aesthetic & maintenance	Does not accumulate water and debris	2
6	Aesthetics	Has an aesthetically pleasing look	2
7	Maintenance	Minimum use of fasteners	2
8	Maintenance	Minimum use of tools	2
9	Maintenance	Minimum use of instructions	1
10	Aesthetic	Displays the engine's horsepower/specifications	1

Table 4.2: Customer needs list (3 - high importance; 2 - medium importance; 1 - low importance)

4.2 Benchmarking

Most of the the companies do not disclose the complete specification list of their products. Therefore, sound emission values and identification of materials used could not be benchmarked, only the aesthetics could be evaluated.

The result from the outboard engine benchmarking shows the existence of different design styles in the market. Therefore, the engines were classified into six different categories based on the similarity of their aesthetics. The categories are: *typical*, *robust*, *fully covered*, *minimal*, *sport*, and *semi-sport*. All benchmarked engine models can be found in Appendix A.

Typical: This category represents the design style of inboard engines that most resembles the Volvo Penta D6 Engine. The design that stands out the most is the CAT C7.1 (see figure 4.1), which features an interesting design, only covering half of the engine. Additionally, the Volvo Penta D6 engine also sets apart from the rest due to its distinct green colour.



Figure 4.1: Typical engine - The CAT C7.1

Robust: Engines in this category are similar to the typical engines but have a more robust look with larger covers. The standout here is the Scania DI16 072M engine, which addresses the issue of people stepping on the engine by using a metal sheet as a cover (see figure 4.2).



Figure 4.2: Robust engine - The Scania DI16 072M engine

Fully covered: This category comprises engines that are fully covered in different ways, and the two main representatives are from SeaTek and Panda. The SeaTek is the only manufacturer that produces engines with side covers and all their engines have a similar appearance. The Panda, a generator, uses a box-design for their engine and was, therefore, deemed relevant for the benchmarking. It is also important to note that this genset is smaller compared to the others. See both in 4.3.



(a) The SeaTek 660 Plus engine



(b) The Panda 8000i

Figure 4.3: Fully covered engines

Minimal: Engines in this category have either no covers or very minimal engine covers. An example of this is the Crusader Classic 6.0L MPI with a small engine cover on the top, see figure 4.4.



Figure 4.4: Minimal engines - The Crusader Classic 6.0L MPI engine

Sport: This category includes engines with a sporty aesthetic. Ilmor, a company known for racing engines, has transitioned into the inboard engine industry while retaining their racing engine aesthetics. See figure 4.5 for two different Ilmor engines.



(a) Ilmor Supercharged 6.2L



(b) Ilmor 6.2L GDI

Figure 4.5: Sport engines

Semi-sport: Engines in this category are too sporty for the typical category but

not sporty enough for the sport category. The MerCruiser 6.2L V8 and the MAN V12 - 1900 fall into this category, see figure 4.6.

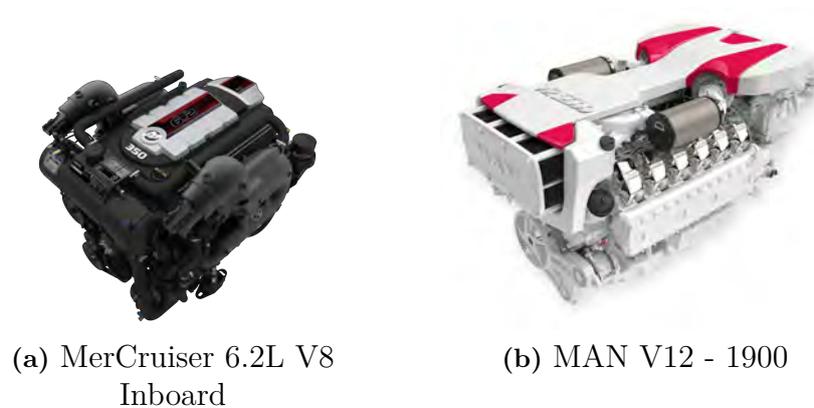


Figure 4.6: Semi-sport engines

4.3 Regulatory compliance

The information gathered with guidance from Volvo Penta's Regulatory Compliance Department ensure the product meets all regulatory requirements and can be seen in this section.

One of the most important regulations to follow is SOLAS (Safety of Life at Sea). This is an international treaty that specifies minimum safety standards for the construction, equipment and operation of ships (IMO, 1974). Additionally, the Directive 2013/53/EU of the European Parliament and of the Council regulates the safety and environmental characteristics of vessels that the Volvo Penta D6 engine can be incorporated into (European Commission, 2013). Regardless of these or other treaties and directives, the focus was put on compliance with internal Volvo Group and Volvo Penta's standards, as these set specific internal goals, and are in accordance with external requirements. However, due to non-disclosure exigencies, the exact information stated in these standards cannot be divulged.

4.4 Requirement list

The requirement list, see appendix B, helps to understand what the product needs to fulfil to make the customer and users satisfied. The most critical requirements can be found in table 4.3.

Requirement	Explanation
Must reduce the noise generated by the engine.	This requirement is crucial for maintaining the product's competitiveness and increasing its appeal to customers. Improved noise reduction distinguishes it from current solutions and adds tangible user value.
Must be possible to walk on it.	The engine cover is often used as a stepping point when accessing the engine compartment. Therefore, it must be strong and durable enough to support a person's weight.
Must consist of a standardized interface for installation.	The cover needs to be compatible with the existing engine interface to avoid requiring modifications to the engine block, which would increase cost and complexity.
Should not require specialized tools or skills.	Simplifying the installation process by eliminating the need for specialized tools or expertise promotes wider adoption and reduces labour time and cost.
Must fit in current vessels	Redesigning engine compartments would be costly and impractical for boat manufacturers. Therefore, ensuring compatibility with existing vessel layouts is essential for feasibility.
Must withstand the harsh environment	To ensure long-term durability, the engine cover must be resistant to oil, saltwater or brackish water, and diesel etc..
Should cover the belt of the engine	Covering the belt improves user safety by preventing accidental contact with moving parts.
Should be weighing around 9 kg	A lightweight cover facilitates easy removal for maintenance and emergency access to the engine.
Should convey a premium look	Ensures that the product appears to be of high-quality, refined, and well-crafted, enhancing the perceived value.

Table 4.3: List of the most critical requirements



(a) Minimalistic design



(b) Monolithic design

Figure 4.8: Other mood boards

4.6 Early design drafts

The early AI design drafts are illustrated in figure 4.9. The AI received as prompt the mood boards and key words like; futuristic, robust, minimalistic, and specific things like "Volvo Penta D6 outboard engine" and materials (e.g cork or carbon fibre).

4.7 Functional description

The complete Functional-means tree can be found in appendix C, where connections between solutions were made. The main functions that were identified are:

- Reduce sound
- Withstand load
- Protect from heat
- Mount to engine
- Withstand vibration
- Visualise stepping point

Both *Reduce Sound*, *Withstand Load* and *Protect from heat* have common solutions: the use of material layers and the choice of the material's structure.

The *Mount to engine* function has two possible solutions: using either screws or nails.



(a) Sound absorbing material in the middle



(b) Futuristic design, with LED-lights



(c) Clean and robust design



(d) Carbon fibre material

Figure 4.9: Early designs by generative AI

4.8 Concept generation

To initiate the concept generation process, a Morphological Matrix was developed to link the various sub-solutions. See image 4.10 for the detailed matrix. This approach resulted in the generation of 4500 possible combinations. The combinations that were selected were then transformed into eight concepts that are presented below.

Concept 1 - The honeycomb: A three-layer cover with an outer material designed to withstand load. The other two layers consist of a honeycomb structure and a sound insulation layer. The surface features elevations and textures to indicate where to step. The fastening system uses regular screws, and vibrations are mitigated by a vibration insulation strip (e.g., rubber or cork) around the bottom edge of the cover.

Concept 2 - The honeycomb vibes: Similar to Concept 1, but instead of the vibration insulation strip, an anti-vibration mount is used where the screws are mounted.

4. Results

	Conceptual solution 1	2	3	4	5	6
Function						
Reduce sound	ANC speakers	Material layer	Material structure/design	Material layer & Material structure/design	Material layer & Material structure/design & ANC speaker	
Withstand load	Material layer	Material structure/design	Material layer & Material structure/design			
Protect from heat	Material layer	Material structure/design	Material layer & Material structure/design	Ventilation system	Liquid cooling system	Material layer & Material structure/design & Ventilation/liquid cooling system
Withstand vibration	Springs	Material layer	Earthquake foundation	Anti-vibration mount	Gas damper	
Mount to engine	Screws	Nails	Clips			
Visualize stepping point	Elevation	Indentation	Texture	Elevation & Texture	Indentation & Texture	

Figure 4.10: Morphological matrix

Concept 3 - The indented: The surface has indentations and textures to indicate where to stand. The structure is supported with beams, and insulation material is placed between them. The materials must withstand heat. The structure is secured with screws and a vibration insulation strip (as in Concept 1).

Concept 4 - The indented vibes: Similar to Concept 3, but an anti-vibration mount is used instead of the vibration insulation strip.

Concept 5 - The I beam: Similar to Concept 2, but with beams instead of the honeycomb pattern. In-between these beams there is sound insulation material.

Concept 6 - The gas one: Similar to Concept 1, but gas dampers are added instead of the vibration insulation strip.

concept 7 - The earthquake box: a box design with multiple layers and a fan system, mounted on the engine-supporting structure with ball bearings to dampen the vibration (base isolation). Lastly, if the top surface has no-step zones, these will be marked by an indentation showing "no step" or "X".

Concept 8 - The ANC one: a "traditional" cover design with two layers (a top stiff layer, e.g. aluminium, and a lower sound and vibration-dampening layer, e.g. cork) attached by screws. Additionally, ANC technology is incorporated into the engine-supporting structure. Lastly, if the top surface of the cover has no-step zones, these will be marked by an elevation showing "no step" or "X".

Concept 9 - The bread box: a box design with a fan system and multiple layers (a top stiff layer, e.g. aluminium, a medium sound-damping layer, e.g. foam and honeycomb structure, and a bottom heat resistant layer, e.g. cork with a coating). The side of the engine with the most frequent maintenance needs has a "bread box door" type of opening, while the rest can be dismantled similarly to the Panda 8000i engine, seen in figure 4.3. The cut-out for the IPS connection is sealed with rubber. Lastly, if the top surface has no-step zones, these will be marked by an indentation showing "no step" or "X".

Concept 10 - The freezer: Similar to Concept 9, but instead of the "bread box door" there is a sliding lid, just like the supermarket freezers.

Concept 11 - The trunk: Similar to Concepts 9 and 10, but the lid is opened like the trunk lid on a car.

4.9 Concept screening

This section presents the results of the structured concept screening. An Elimination Matrix was first used to discard concepts that failed to meet key criteria, followed by a Weighted-Pugh Matrix to compare the remaining ones based on prioritised requirements. Concepts were then split into two categories: overall structure and material layers, for further analysis. Structural concepts were assessed with a Kesselring Matrix, while material layers were evaluated using GRANTA EduPack through Ashby's methodology.

4.9.1 Elimination matrix

The results from the elimination matrix, see table 4.4, show that concept 6 should be eliminated. This is because the engine would move around on the ball bearings, which is not feasible as the engine needs to be rigidly fixed to the hull.

Concepts 2, 4, 6, and 8 require further research regarding safety and cost before the next screening step, the Weighted-Pugh matrix.

Further research of concepts

Concepts 2 and 4 both utilize anti-vibration mounts. While initial concerns existed regarding load capacity and size, suitable mounts with a compression load exceeding 200 kg have been identified. These mounts, positioned at the screw locations, should adequately support the load (RS, 2025). Therefore, this approach is deemed feasible.

Concept 6, which incorporates gas dampers, has been deemed infeasible. The size of dampers necessary to support the required weight would be excessively large (JP, 2023), and when dealing with a cramped engine room, the cover would not fit. Additionally, the oil within the dampers poses a fire risk in the event of a leak (Industrial

Gas Springs, 2018), leading to the rejection of this concept.

Concept 8 explores the use of ANC technology as a potential solution for reducing low-frequency noise. ANC works by emitting sound waves that are phase-inverted to the incoming noise, thereby cancelling it out (Kuo & Morgan, 1999). This technology is already established in the automotive sector, where it is commonly integrated with the vehicle’s speaker system to enhance cabin comfort (Hyundai New Zealand, 2020). There is growing interest in adapting ANC for marine applications; however, implementation challenges persist, most notably the difficulty of determining optimal speaker placement within the vessel structure (Elharoun & Al-Bahadly, 2022). Despite these challenges, ANC remains a promising avenue and Concept 8 is still considered a viable alternative worthy of further investigation and development.

Concept	Solves main problem	Fulfills all demands	Compatible	Reasonable cost	Safe	Fits portfolio	Pass/fail
1	+	+	+	+	+	+	PASS
2	+	+	+	+	?	+	PASS
3	+	+	+	+	+	-	PASS
4	+	+	+	+	?	+	PASS
5	+	+	+	+	+	+	PASS
6	+	+	+	+	?	+	PASS
7	+	-					FAIL
8	+	+	+	?	+	+	PASS
9	+	+	+	+	+	+	PASS
10	+	+	+	+	+	+	PASS
11	+	+	+	+	+	+	PASS

Table 4.4: Elimination matrix - (+) Fulfils the requirement, (-) Does not fulfils the requirement, (?) Need more research

4.9.2 Weighted-Pugh matrix

Figure 4.11 presents the results of the Weighted-Pugh matrix analysis. The analysis identified the ANC concept as the top-ranked option. The bread box design is in second place. In third place are three concepts, categorized as 'traditional covers': the honeycomb vibes, the indented vibes, and the I-beam.

The freezer and trunk box designs were eliminated because they would obstruct the hatch range of motion within the cramped compartment. The honeycomb and indented were eliminated due to their less effective sound insulation capacities compared to the other concepts.

PUGH-MATRIX		Concept A	Concept B	Concept C	Concept D	Concept K	Concept G	Concept H	Concept I	Concept J
Selection criteria	Weight (1-5)	The honeycomb	The honeycomb vibs	The indented	The indented vibs	The I beam	The ANC one	The bread box	freezer	The trunk
Access to maintenance points	3	D A T U M	0	0	0	0	0	-	-	-
Can be used as a stepping point	5		0	+	+	+	0	0	0	0
Must fit in current vessels	5		0	0	0	0	0	0	-	-
Ability to reduce sound emissions	5		0	-	-	-	+	+	+	+
Ability to reduce vibration	2		+	0	+	+	0	+	+	+
Positives (score)		0 (0)	1 (2)	1 (5)	2 (7)	2 (7)	1 (5)	2 (7)	2 (7)	2 (7)
Neutrals		0	4	3	2	2	4	2	1	1
Negatives (score)		0 (0)	0 (0)	1 (-5)	1 (-5)	1 (-5)	0 (0)	1 (-3)	2 (-8)	2 (-8)
Net Score		0	2	0	2	2	5	4	-1	-1
Rank		6	3	6	3	3	1	2	8	8

Figure 4.11: Pugh matrix for the selection of structure concept

4.9.3 Kesselring matrix and Overall structure

The final concepts from the structure design are: the ANC, the bread box, and "traditional" covers (the honeycomb vibs, the indented vibs, and the I-beam), illustrated in figure 4.12. The advantages and disadvantages of each concept are found in table 4.5.

A more detailed rating of all the concepts is given in the Kesselring matrix, see table 4.6. This shows that a traditional cover design is the "winner".

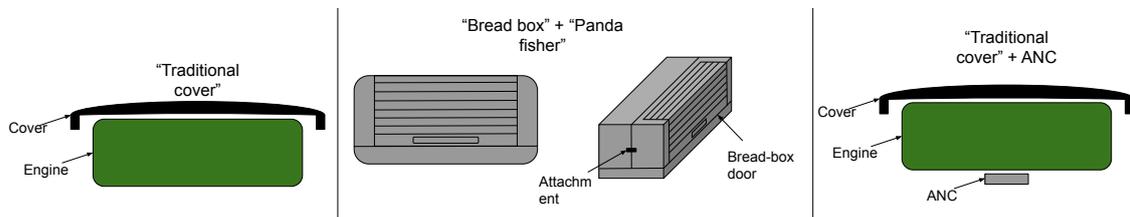


Figure 4.12: Sketches of the selected concepts

Notes	Pugh matrix	Selection Criteria	Weight [%]	Ideal		The current cover		Concepts					
				Rating	Weighted score	Rating	Weighted score	The box		Traditional		ANC	
								Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Big is bad, small is good	Access to maintenance points	Accessibility	17,5	5	87,5	5	87,5	2	35	5	87,5	5	87,5
	Can be used as a stepping point	Steppability	15	5	75	4	60	4	60	5	75	5	75
	Must fit in current vessels	Size	17,5	5	87,5	5	87,5	1	17,5	5	87,5	4	70
	Ability to reduce sound/vibration emissions	Sound/vibration reduction	25	5	125	1	25	5	125	2	50	3	75
e.g. air intake, cooling system		Manufacturability	15	5	75	5	75	4	60	5	75	5	75
		"Prototypability"	10	5	50	5	50	5	50	5	50	1	10
		Total	100		500		385		347,5		425		392,5

Table 4.6: Kesselring matrix of the overall structure concepts. Ranking scale: 5 Very good/Very easy, 4 Good/Easy, 3 Ok, 2 Bad/Hard, 1 Very bad/Very hard

Concept	Explanation	Advantage	Disadvantage
The traditional cover	A traditional engine cover, but incorporated with sound absorbing insulation, honeycomb, beams, or a combination of all of them.	<ul style="list-style-type: none"> • "Easy" access to all service points • "Easy" design • Fewer parts • Less material use • Maintains engine structure (attachment points) 	<ul style="list-style-type: none"> • Not as efficient in sound and vibration reduction • Restriction with attachment points and cut-outs (design)
The ANC	This is similar to the traditional covers, but adds an ANC module to the engine, which will reduce the sound.	Same as the traditional cover + <ul style="list-style-type: none"> • Sound reduction • Market differentiator 	<ul style="list-style-type: none"> • Higher cost compared to passive noise reduction • Lack of expertise and knowledge about implementation of ANC • Unpredictable frequencies • Restrictions with attachment points and cut outs (design)
The bread box	This is a box that covers the whole engine, and on one of the sides, there is a bread box lid, that can be opened to reach important maintenance points.	<ul style="list-style-type: none"> • Sound reduction • Possibility to build in a fire prevention system • Market differentiator 	<ul style="list-style-type: none"> • Cramped engine compartment space • More parts • More material • "Harder" access • Air intake system • Integrated cooling system • "Harder" design

Table 4.5: Advantages and disadvantages of the selected structure concepts

4.9.4 Material types and layers

This section presents the results of the different combinations of layers and materials for the engine cover.

Layers

From the concepts generated through the Morphological matrix, see section 4.8, different material layers were defined, illustrated in figure 4.13. This gives five different categories:

1. *Resit load*: A layer designed to withstand load while being lightweight. It must also resist environmental factors such as oil, sea water, and gasoline.
2. *Insulated I-beam*: A layer featuring I-beams that holds insulation panels, and

thus supports both the load bearing and sound insulation capabilities of the cover.

3. *Sound insulation*: A layer of standard insulation material aimed to reduce sound transfer and is non-flammable.
4. *Heat-resistant insulation*: A specialized material layer focused solely on withstanding high temperatures, while also being non-flammable.
5. *Insulated honeycomb structure*: A lightweight honeycomb structure designed to reduce sound, further enhanced with sound insulation material placed within the cells.

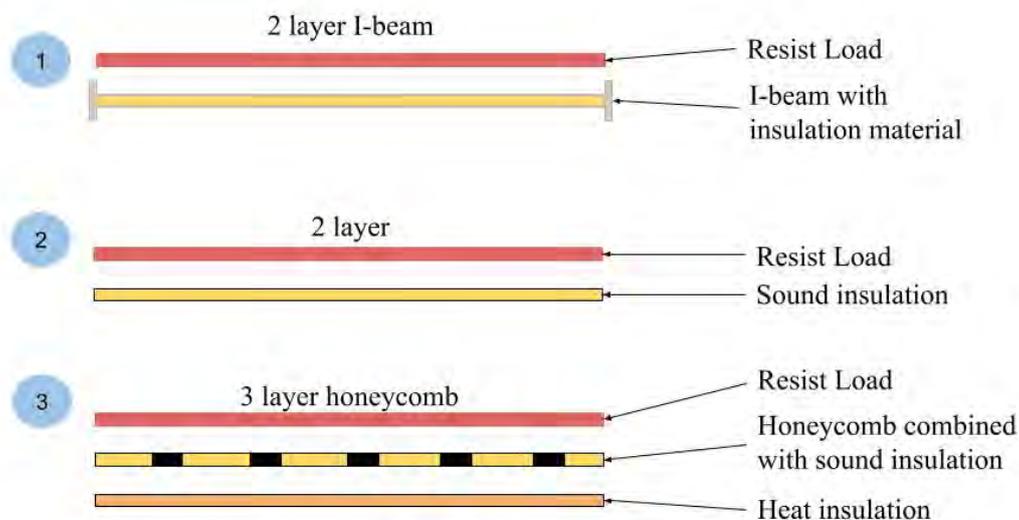


Figure 4.13: The different Layer structures

Materials

The identification and evaluation of suitable materials for each layer based on performance requirements can be found here. It presents the chosen materials, their properties, and respective advantages and limitations in the context of the design's functionality. Based on the Functional Description, see section 4.7, the boundary conditions for the selection of materials can be seen in table 4.7, 4.8 and 4.9.

1. *Resist Load*: The result, illustrated in figure 4.14, shows that composites, metals and alloys are suitable materials. Diving deeper into the material families shows that composites perform the best, like carbon fibres or epoxy glass fibre. Metals and alloys, like Aluminium or tool steel are still good since they are not as brittle as composites (Junaedi et al., 2020).
2. *I-beam*: The I-beam should have the same properties as the resist load layer, but it can not be brittle, thus a metal or alloy is a good fit.
3. *Sound insulation and heat insulation layer*: The result, illustrated in 4.16, showcase that the two layers share the same materials, and that is: Cork, melamine foam, polypropylene (PP), ABS, glass foam, graphite foam.

Function	Withstand load
Constrains	Must withstand a weight of 1000 N on a 70x70 mm area & must withstand the marine environment & must not be flammable
Objective	Maximize Young's Modulus and Yield Strength, while minimising Density
Free variables	Choice of material

Table 4.7: Load bearing layer

Function	Absorb sound
Constrains	Must withstand the marine environment & must not be flammable
Objective	Maximize mechanical loss coefficient ($\tan \delta$), while minimising Density
Free variables	Choice of material

Table 4.8: Sound insulation layer

Function	Protect from heat
Constrains	Must withstand the marine environment & must not be flammable
Objective	Minimise thermal conductivity and Density
Free variables	Choice of material

Table 4.9: Heat insulation layer

4. *Honeycomb structure:* The structures should be made of aluminium, as shown in figure 4.15. It has both low density and low thermal conductivity.
5. *Honeycomb filling:* This will be the same as the insulation materials.

Layer and material screening

There were six different combinations created:

1. An I beam of aluminium with glass foam as insulation, and a resist load layer of aluminium.
2. An I beam of aluminium with polymer foam as insulation, and a resist load layer of metal foam.
3. A 2 layer structure with melamine foam as the sound insulation layer and titanium as the resist load layer.
4. A 2 layer structure with cork as the sound insulation layer and a resist load layer of aluminium.
5. A honeycomb layer of aluminium with melamine foam as filling. A heat insulation layer of glass foam and aluminium as the resist load layer.

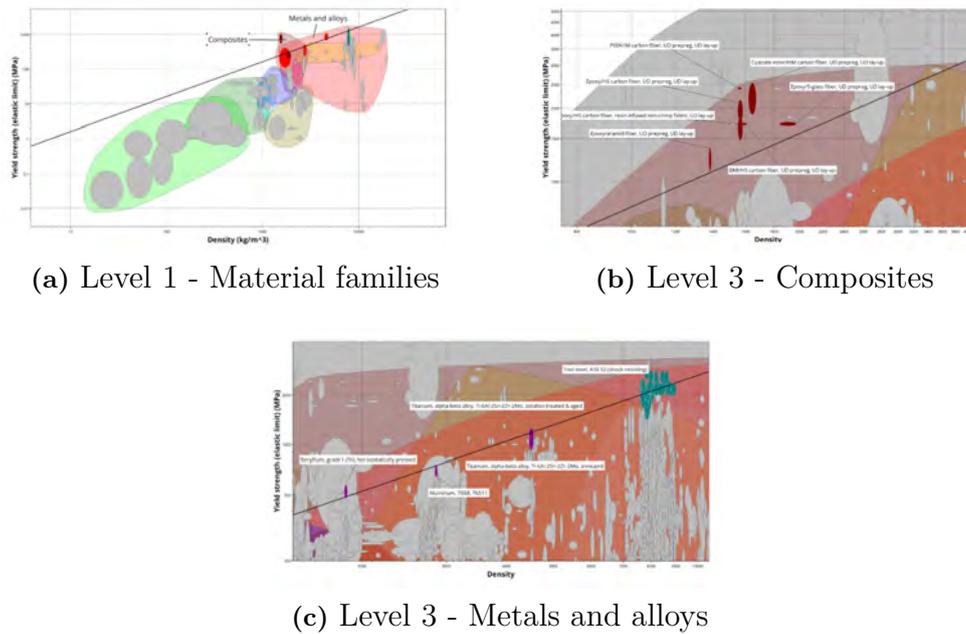


Figure 4.14: Granta plots for the selection of the resist load layer.

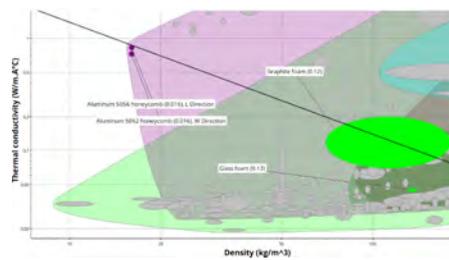


Figure 4.15: Granta plot level 3 for Honeycomb material.

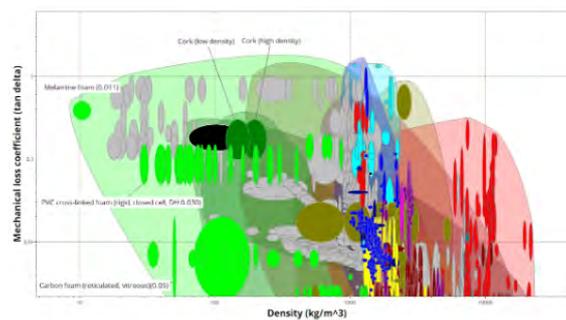


Figure 4.16: Granta plot for sound insulation and heat insulation layer

6. A honeycomb layer of aluminium with polymer foam as filling. A heat insulation layer of cork and aluminium as the resist load layer.

The second concept, with metal foam as the resist load layer, will not be selected due to that it's used for insulation, and should not be stepped on. The third concept will also be eliminated because titanium is highly expensive compared to aluminium,

that has similar properties (Redstone Manufacturing, 2023). Thus, there are four concepts left.

4.10 Aesthetic design

In this section, the creation and selection of the aesthetic style of the cover is presented.

4.10.1 Design styles

Based on the mood boards, see section 4.5, the following designs were created and matched with similar designs, illustrated in figure 4.17. It is important to note that these design styles are not mutually exclusive and can be combined to create unique and innovative products. For example, a cover can be both minimalistic and robust, or sporty and monolithic. Here is a short description of the design styles:

- Sporty: Dynamic, energetic, and performance-oriented.
- Minimalistic: Simple, clean, and focused on essential elements.
- Monolithic: Solid, unified, and emphasizing strength and permanence.
- Robust: Durable, reliable, and designed for heavy-duty use.



Figure 4.17: Different design styles

More extensive explanation of the design styles:

Sporty: The Sporty style is characterized by a dynamic aesthetic, often employing sharp angles, aerodynamic curves, and bold colour palettes. This approach prioritizes the visual representation of speed, agility, and performance, frequently seen in products designed for active pursuits. Visible mechanical elements, such as exposed engine components, further emphasize functionality and power, aligning with a user experience focused on engagement and excitement.

Minimalistic: In contrast to the sporty design, the Minimalistic style adheres to principles of simplicity and reduction. Designs within this category exhibit clean lines, basic geometric forms, and a deliberate absence of superfluous ornamentation. Neutral colour palettes and a focus on essential elements contribute to a sense of clarity and order. Emphasis is placed on material quality and tactile experience, reflecting a design philosophy rooted in functionality and understated elegance.

Monolithic: The Monolithic style is distinguished by its unified, robust forms, often employing large, uninterrupted surfaces and strong geometric shapes. This approach conveys a sense of permanence, strength, and scale, reflecting design principles associated with architecture and industrial applications. The emphasis on material integrity and the seamless integration of elements create a visually imposing and structurally sound aesthetic.

Robust: The Robust style prioritizes durability and reliability, evident in thick, solid forms and protective features designed to withstand harsh conditions. Functional detailing, such as visible fasteners and reinforced components, underscores the design's emphasis on practicality and resilience. This style is often associated with products intended for heavy-duty use or challenging environments, where longevity and performance are paramount.

4.10.2 Ranking and selection of design style

This section presents the results of both the internal and external surveys, offering insights from stakeholders within the organization as well as from external users.

4.10.2.1 Internal survey

The internal survey was answered by 10 people inside Volvo Penta's organisation, and the result can be summarised in table 4.10.

Respondent	Sporty	Minimalistic	Monolithic	Robust
Average	2	2,3	3,8	1,9

Table 4.10: Internal aesthetic survey results (1-best one, 4-worst one)

Additionally, while the internal survey was conducted, several participants highlighted their interest in a combination of different design styles, e.g. a combination

of Robust and Minimalistic or Sporty and Minimalistic.

4.10.2.2 External survey

The external survey can be seen in appendix E. Despite its distribution through different media platforms, the survey received no answers.

4.10.3 Aesthetic design decision

The result from the surveys show that the Sporty, Robust and Minimalistic styles are the top selections. Therefore, the decision was made to create a combination of these three styles and apply it to the final concept. The final style is called *Dynamic Flow* and blends strength, elegance, and performance. It is characterized by obvious geometric shapes that provide a sense of structure and stability while maintaining smooth transitions and rounded edges for a seamless, aerodynamic flow. Exposed engine components and functional details remain integral to the design, reinforcing the emphasis on power and mechanical precision.

4.11 Concept selection

The table generated to select the final concept can be seen in figure 4.18. The selection can be made by "mix and match" of the different alternatives presented, as they are all compatible with each other.

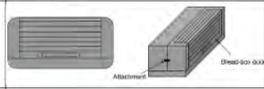
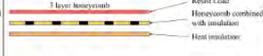
	"Traditional"	"Traditional" + ANC	Bread box	
Structure				
Material layer	 <p>Resist load: Aluminium I-beam: Aluminium Sound insulation: glass foam</p>	 <p>Resist load: Aluminium Sound insulation: Cork</p>	 <p>Resist load: Aluminium Honeycomb structure: Aluminium Honeycomb sound insulation filling: Melamine foam Heat insulation: Glass foam</p>	 <p>Resist load: Aluminium Honeycomb structure: Aluminium Honeycomb sound insulation filling: Rigid polymer foam (low density) Heat insulation: Cork</p>

Figure 4.18: Final concept selection table

The final concept that will be further developed is a concept with a traditional cover structure design, a resist load layer made of aluminium, a sound insulation layer consisting of aluminium honeycomb with melamine foam, and cork insulation. Additionally, it will follow the *Dynamic Flow* style (see section 3.11).

4.12 Detailed design of the final concept

The three concepts developed can be seen in figure 4.19, and the decision was made to move forward with option 3.

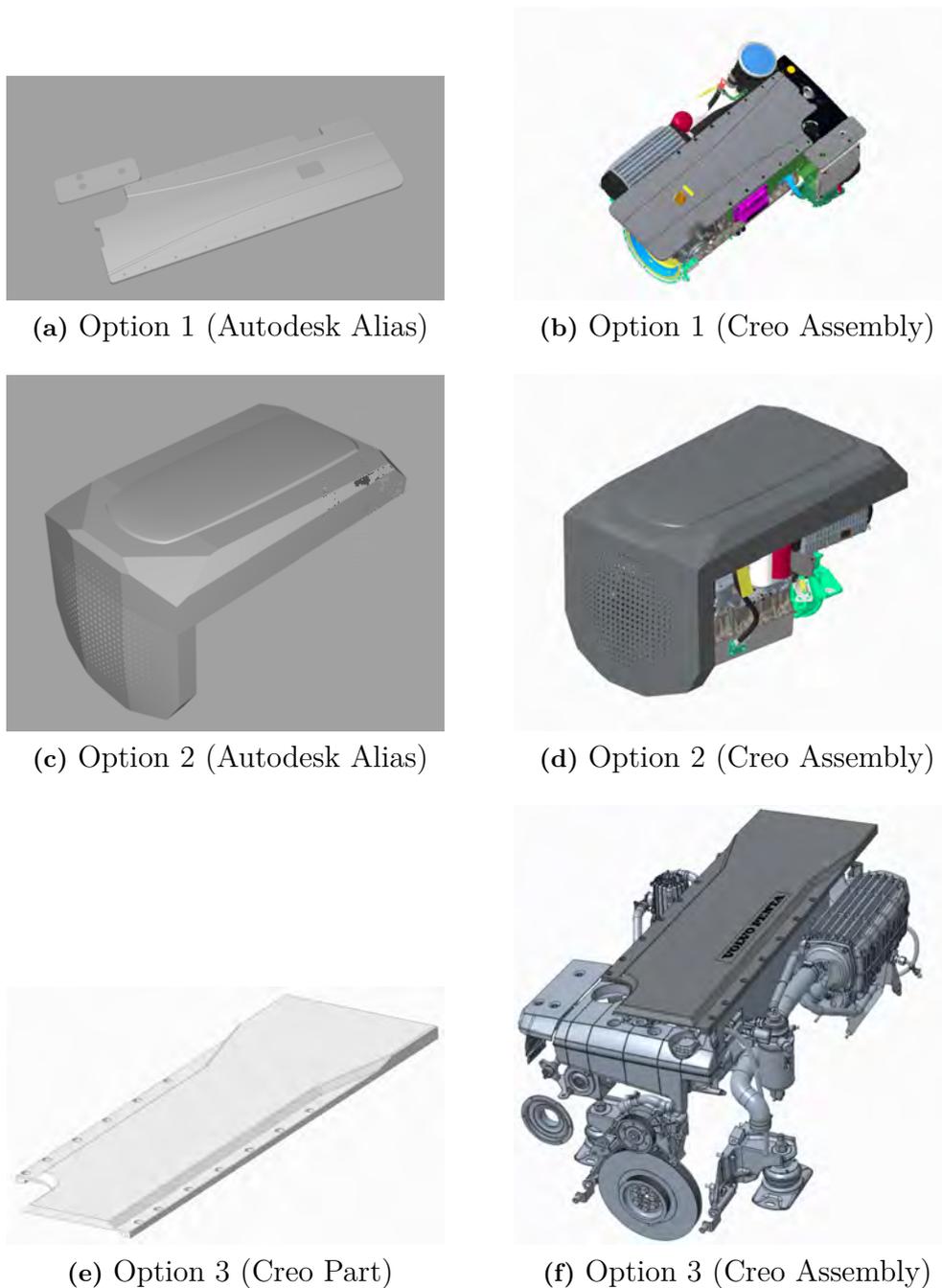


Figure 4.19: Maturely developed concepts for final decision making

The final cover design consists of three main components: the main top cover, the smaller side top cover, and the belt cover. These are illustrate in figure 4.20. All the cover parts are clipped using fasteners, which gives a better aesthetic look, and also eliminates the need for tools. The main top cover is divided up in two, see figure 4.21, to make it more manufacturable, as it would be too expensive otherwise. The two parts are connected with fastener clips or screws.

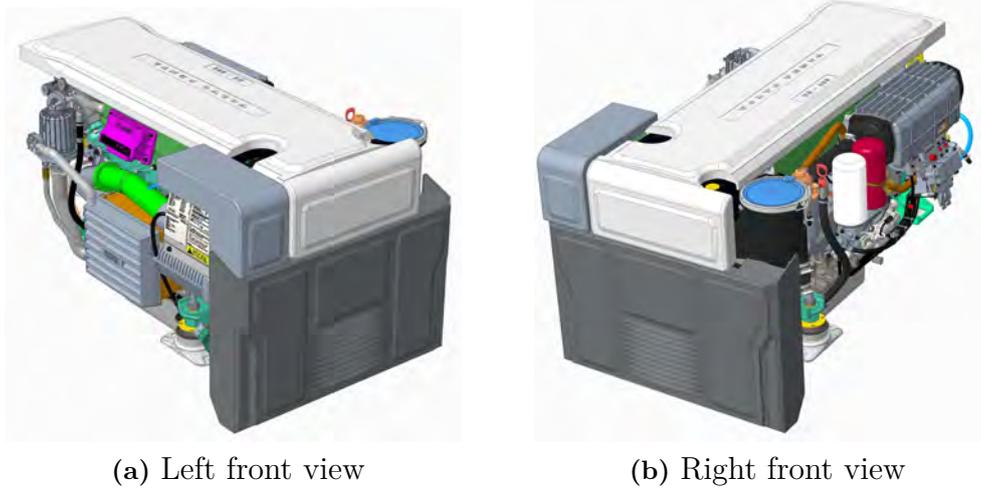


Figure 4.20: The final design - Main top cover (white), Side cover (light grey), and Belt cover (dark grey).

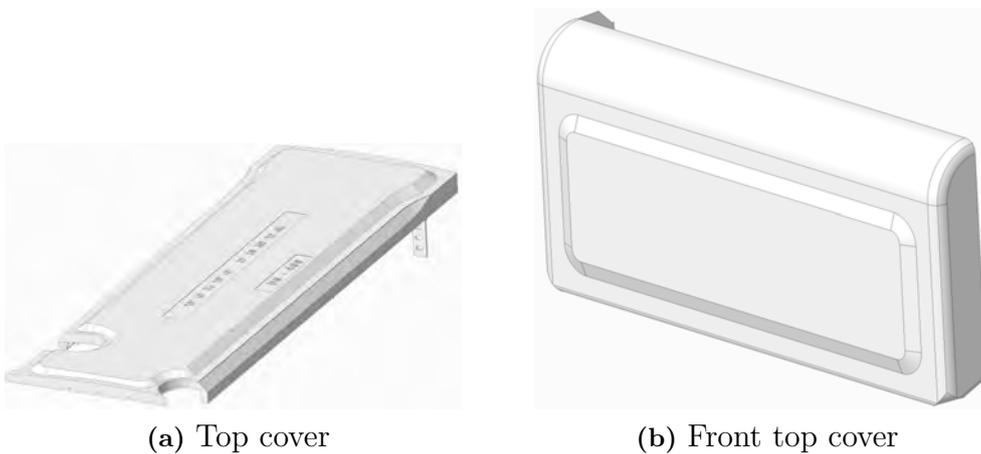


Figure 4.21: The top cover is divided into two pieces.

4.13 Performance evaluation of the final design

This section presents the findings from the performance evaluations conducted on the final concept, highlighting how it met the criteria established during the assessment phase.

4.13.1 Material layer

Four cases were analysed:

1. aluminium (current solution);
2. aluminium and cork;
3. aluminium, honeycomb with no filling and cork;

4. aluminium, honeycomb filled with melamine foam and cork.

The theory that supports the calculations performed on the first three cases is presented in section 2.2 and the results can be seen in table 4.11, while the detailed calculations can be found in Appendix F.

Configuration	Transmission Loss (R)	Sound Level (P2)	Total thickness
Aluminium 2mm	29.3 dB	76.7 dB	2mm
Aluminium 2mm + Cork 2mm	36 dB	70 dB	4mm
Aluminium 2mm + Honey- comb with no filling 10mm + cork 2mm	27 dB	79 dB	14mm

Table 4.11: Results of the calculations of the sound transmission loss through different material layers

In addition to the calculations presented above, data was gathered from different research papers and will be summarised in this paragraph. An air gap is an efficient method for reducing sound transmission, with the thickness of the gap playing a crucial role in its effectiveness. The thicker the gap, the less vibration and sound are transmitted (Osama A. B. Hassan, 2009). Also, melamine foam, known for its excellent performance as an acoustic attenuator, has been shown to provide increasing transmission loss with thickness in aerospace applications. Specifically, transmission loss increases by 2-4 dB with a 25mm thickness, 4-6 dB with a 50mm thickness, and 6-8 dB with a 75mm thickness (Zai et al., 2021). Additionally, research comparing the transmission loss of aluminium panels with varying thicknesses of melamine foam (30mm, 50mm, and 70mm) shows that porous materials between double aluminium panels greatly enhance the transmission loss, especially at high frequencies. While porous materials improve sound insulation, their effect is limited at low frequencies (Bai et al., 2014). Moreover, the presence of carbon face sheets and melamine foam lining can significantly impact transmission loss (Zai et al., 2022). Lastly, honeycomb cellular structures, often made of aluminium, are advantageous for applications requiring a high stiffness-to-weight ratio. These structures, commonly used in sandwich construction, are known for their lightweight properties, impact absorption, low energy loss, and thermal management capabilities (Griese et al., 2015).

4.13.2 FEM analysis

The cover must withstand a force of 1000 N distributed over a 70×70 mm area. Given that the top cover measures approximately 360×1250 mm, the total distributed force amounts to around 92 kN.

The initial simulation indicated a deformation of 220 mm in critical areas, as shown in figure 4.22, thus requiring a redesign.

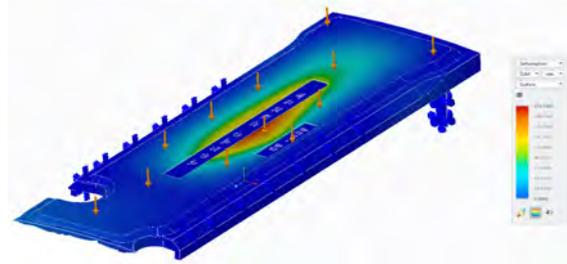


Figure 4.22: First FEM analysis

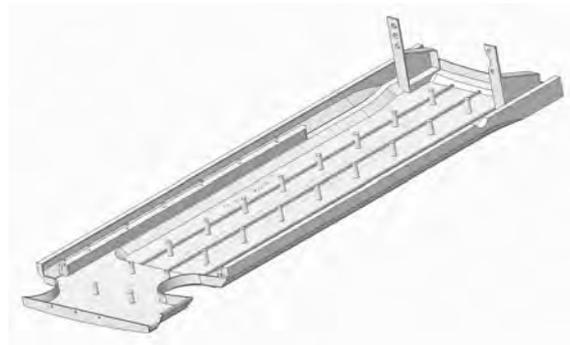
New support points were introduced, as shown in figure 4.23a. These include previously existing support locations that the team had initially overlooked, mistakenly assuming they were intended for the pipes beneath the hood. However, additional support points were still required. Since the current engine design does not accommodate these, six new support points must be added. This revised design reduced deformation in critical areas to 4 mm, as illustrated in figure 4.23b.

4.14 Manufacturing

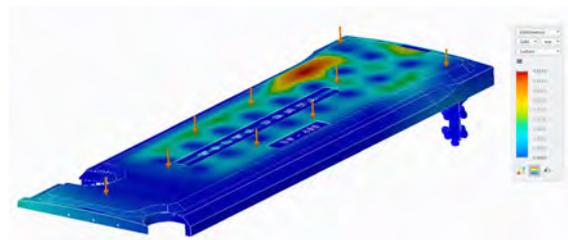
A variety of manufacturing processes are available for fabricating aluminium components, each suited to different geometries, production volumes, and functional requirements (Davantech, 2019). Common methods include sheet metal bending, casting, die casting, extrusion, and CNC machining.

For instance, the side top cover, characterized by its simple geometry and thin profile, is well-suited for sheet metal bending—a cost-effective and efficient process for forming flat aluminium sheets. In contrast, components with more complex or curved shapes, such as the main top cover, are better suited for casting or die casting, which allow for intricate geometries and integrated features. For smaller volumes or prototyping, sand casting or CNC milling may also be considered viable alternatives.

Upon further analysis, it was determined that parts such as the belt cover and the front top cover would not be subjected to significant mechanical stress. This insight opened the possibility of manufacturing these components from plastic rather than aluminium, offering the advantages of reduced weight, easier handling, and potentially lower production costs (Chen, 2024).



(a) Underside of the top main cover, with the supports in place



(b) Fem calculations of the new design

Figure 4.23: New design with supports

Multiple manufacturing processes are available for plastic components (Star Rapid, 2018). The two most suitable for this application are:

- **Vacuum casting** – Ideal for small-series production, offering good surface finish and dimensional accuracy.
- **Injection moulding** – Best suited for high-volume production, providing fast cycle times and excellent repeatability.

Other viable options include thermoforming (for large, thin-walled parts), rotational moulding (for hollow or double-walled structures), and 3D printing for low-volume, customized, or iterative prototyping.

As for the insulation layers, such as melamine foam and cork, these materials can be easily cut using standard tools like a band saw. Assembly can be done using contact adhesives, such as epoxy glue, which is widely recognized for its strong bond and resistance to moisture, temperature fluctuations, and vibration (**epoxy_glue**). This adhesive can also be used to bond the foam to aluminium surfaces, ensuring durability and stability of the insulation layer.

4.15 Final product

The final product is illustrated in figure 4.24. Table 4.12 presents the modifications made to the final concept described in section 4.12, along with explanations for each change.

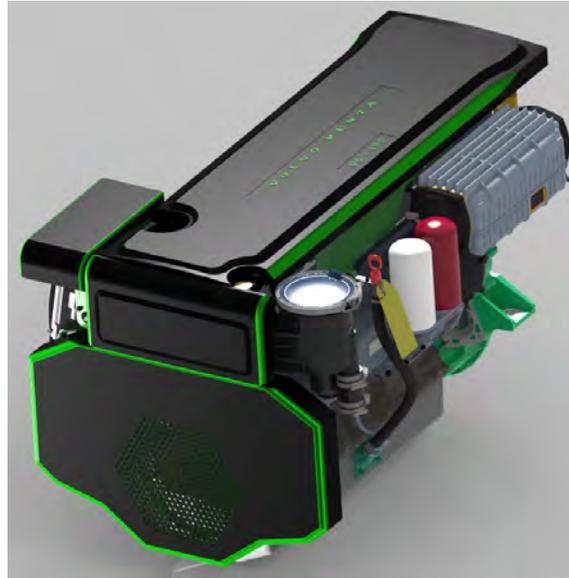


Figure 4.24: Render of the final design

Modification	Explanation
No honeycomb structure	Because of the difficulty to calculate how much sound this structure would reduce, and also the size of the honeycomb structure, the decision was made to remove it. Instead, melamine foam will be used by itself.
Belt cover redesign	Due to the shape of the boat's hull and the position of the engine inside the boat, the belt cover in figure 4.20 had to be redesigned to account for the necessity of a new shape.
Support point on main cover	Due to the removal of the honeycomb structure, beams were added. There were also support points located on the engine that were used.
Belt cover made of plastic	The belt cover will not be stepped on, so it does not need to handle the 1000 N per 70x70 mm requirement. This means that it can be of a different material, like plastic that is much easier and cheaper to manufacture.

Table 4.12: Modifications to the final product

4.15.1 Colours

The colour of the engine cover plays an important role in conveying its intended use and maintenance context. White is typically used in clean engine rooms where visibility of leaks is a priority, as it makes spotting oil or fluid stains easier. Black, on the other hand, is the most commonly used colour (see Section 4.2), as it effectively hides dirt and oil spills. This reduces the need for frequent cleaning to maintain a neat appearance. These two colours are standard choices in the marine industry, thus will be selected for this engine cover as well. Still, there are ways to differentiate with colours, as it can be used to highlight special design elements. Thus, different colours are used on the cover to make it stand out, see the example in figure 4.25.



Figure 4.25: Different colour variant of the cover

4.16 3D printed prototype

The result of the 3D printing can be seen in figure ???. It demonstrates a good design, validating the CAD modeling and print settings. The scaled model is not mounted on an accurate engine model. Instead, it is a basic cardboard box that simulates the real engine block.



Figure 4.26: 3D printed model

5

Discussion

This chapter provides a comprehensive discussion of the project as a whole. It reflects on the key decisions made throughout the process, analyses how well the outcomes align with the initial objectives, and considers the broader implications of the work.

5.1 Research questions and deliverables

At the beginning of the project, two primary research questions were established to guide the development process:

1. What are the advantages and disadvantages of existing marine engine covers, with regard to sound absorption, aesthetics, and durability?
2. What design features should be adopted to balance sound absorption, aesthetics, and durability in the next generation of marine engine covers?

During the research phase, the first question proved to be more challenging than expected. While aesthetic evaluations were possible to be made through market analysis, images, and promotional materials, reliable data regarding sound absorption and durability of existing marine engine covers was extremely limited or simply unavailable. Most manufacturers do not disclose technical details about their covers' acoustic performance or other mechanical characteristics, likely due to proprietary concerns or lack of standardized testing. As a result, only partial conclusions could be drawn: aesthetic trends were identified, but deeper insights into sound absorption and durability had to be inferred from general product descriptions or related literature. This lack of data represents a significant limitation and highlights a broader issue in the industry: the absence of transparent benchmarking or comparative studies on engine cover performance.

Regardless of the difficulties faced during the process, the following provides an answer to the **first research question**:

Sound reduction:

- *Advantages*: complete coverage of the engine (outboards).
- *Disadvantages*: partial coverage of the engine (inboards); minimal use of Passive Noise Cancelling; no use of ANC.

Aesthetics:

- *Advantages:* the cover conveys the purpose of the engine (e.g. industrial VS leisure application) and performs as a market differentiator.
- *Disadvantages:* there are many similar design in the market and the majority does not offer customisation options; exposure to marine environment may damage the cover and, therefore, it needs to be resilient to it.

Durability:

- *Advantages:* can be stepped on (inboards) and commonly use aluminium and metal alloys.
- *Disadvantages:* the rubber seals and gaskets used eventually wear out.

The **second research question**, however, could be addressed more effectively through concept development and prototyping. Despite the missing data on existing products, it was still possible to explore and evaluate new design features that aim to balance sound control, visual appeal, and robustness. Therefore, the answer to the second research question is as follows:

Sound reduction:

- Multi-layered material structure with varying densities, acoustic properties and patterns;
- Integrate vibration dampeners at engine mounting points and within the cover structure;
- Minimize the presence of large, flat surfaces that tend to resonate;
- Implement ANC technology into the cover.

Aesthetics:

- Offer a range of colours, finishes, and customizable panels so the buyers can personalize their engine covers;
- Use of high-quality, visually appealing materials that are resistant to the environment;
- Development of a design base for adaptation to the different engines that Volvo Penta offers.

Durability:

- Utilize materials that are resistant to saltwater corrosion, UV radiation, and extreme temperatures;
- Design the cover for easy access to the engine for maintenance and repairs;
- Ensure the cover can support the weight of people stepping on it for maintenance or operation without compromising structural integrity.

5.2 Design process

In the end, the traditional development method proved effective during the conceptualisation phase. However, the process was still filled with uncertainties, for example, in terms of requirements and legal considerations. These unknowns often made it challenging to strictly follow a structured approach. In hindsight, integrating elements from more flexible or iterative methodologies could have helped adapt

more easily to the evolving context and incomplete information.

During the CAD development and testing phases, the process became highly iterative, as new and previously unknown information emerged continuously. This led to frequent revisions and adjustments, particularly as deeper insights were gained about material behaviour, design feasibility, and manufacturing constraints. In hindsight, a more explicitly iterative and "Build-Test-Design" approach may have been more suitable. This methodology would have allowed for structured cycles of prototyping and evaluation, supporting more responsive decision-making and potentially accelerating the path to a well-informed final concept.

The choice of methodology significantly influences the final outcome. Therefore, it is important to acknowledge that selecting an alternative approach could have led to a substantially different result.

In terms of **deliverables**, the project progressed according to plan. The halfway milestone consisted of selecting a small number of theoretical concepts, three low-fidelity designs, which served as a foundation for further development. These initial ideas were primarily communicated through sketches and low-development CAD models. By the end of the project, the best idea had evolved into a fully realized CAD model, along with a scaled 3D-printed prototype. These deliverables represent a tangible demonstration of the project's goals and reflect the iterative design process undertaken throughout the study.

5.2.1 Design trade-offs and challenges

Throughout the development process, several design trade-offs had to be considered, particularly concerning functionality, aesthetics and practicality. One of the initial concepts consisted of a fully enclosed cover, which would grant high performance in reducing engine noise. However, this idea quickly revealed certain difficulties. Fully boxing in the engine results in significantly harder access to key maintenance points, likely complicating servicing or inspection tasks. Additionally, completely enclosing the engine may negatively affect the thermal management of the engine and its components, as well as air circulation, particularly if the engine relies on passive air cooling. Striking a balance between sound insulation and accessibility became a central design challenge. In the end, further development of this concept proved to be unfeasible, as it would require longer time than that available, and would be a substantial challenge to solve during this thesis.

Thus, it was decided to carry on with a more "traditional" cover design. This made it possible to create a CAD model while also having time to 3D print the new solution. Still, the CAD design process itself presented its own set of hurdles. The model was created using Creo, which proved difficult to work with when designing complex curved surfaces. As a result, many of the final parts consist of flat surfaces and angular geometry, which was not the desired outcome. While this simplified manufacturing and 3D printing, it limited some of the design flexibility and aes-

thetic potential. Another design compromise involved the fastening system for the belt cover. In the current version, existing fastener points on the engine were used simply to attach the prototype and evaluate the overall aesthetics. However, this solution is not ideal for long-term use. In future iterations, new fastener points should be added to improve structural integrity and ensure a better fit, which may also require altering the geometry of the cover itself.

A further challenge was the limited technical information available about the engine itself. Although some dimensions and basic layouts were provided, a fully detailed description, especially regarding the location and design of engine supports and mounting points, was missing. This introduced uncertainty into the CAD modeling and attachment strategy, as assumptions had to be made without fully confirmed data. Consequently, certain aspects of the design may need to be adapted once more detailed technical information becomes available.

Another challenge during the design phase was the lack of detailed information about certain engine components. For example, the structural supports located on top of the engine were initially assumed to be intended for pipe routing, but later it became clear that they were supports for the main top cover. Having a clearer and more detailed demonstration of the critical engine features from Volvo Penta would have been beneficial early in the project. A better understanding of such elements could have influenced the design decisions more accurately, potentially avoiding misunderstandings and leading to a more refined final product.

Lastly, the 3D printing process presented several challenges, particularly related to the scaling of the CAD model. Since some features were already quite thin in the original 1:1 design, reducing the model to a 1:15 scale made certain details either too fragile to print accurately or completely unrecognisable. This limitation affected the overall fidelity of the prototype. Additionally, because the prototype is not full scale, it cannot be tested directly on the actual engine. As a result, the fit and integration of the design could only be evaluated in the CAD environment, leaving uncertainty about how well the cover would function and fit in a real-world application.

5.2.2 Uncertainties and challenges

This project was also impacted by several uncertainties that limited how far some aspects could be developed or tested. One key issue was the inability to experience a boat operating with a D6 engine function and thus hear the engine in operation. As a result, assumptions about the noise level perception and the necessity of certain acoustic solutions had to be made without first-hand experience. This limited the ability to design specifically for the sound profile of the engine, and leaves some uncertainty as to how effective the current cover would be in practice.

Further uncertainties stemmed from limited supplier communication and unavailable data. For example, the idea of integrating ANC speakers was discussed, but at the time of writing, no final answer had been received from contacted suppliers re-

garding feasibility or cost. Even if technically viable, cost and implementation may be a major barrier, especially in a market that tends to be cautious about adopting new technologies.

Additionally, when conducting competitor research, it became apparent that the company did not have a comprehensive list of relevant competitors. As a result, the group conducted its investigation to identify similar products or solutions. While this helped inform our design, it is possible that some key competitors or innovative solutions were missed. This may have led to overlooking valuable design inspirations or market standards.

Moreover, a decision was made to not conduct a patent search. This decision was primarily influenced by time constraints and the preferences expressed by Volvo Penta, which prioritized other aspects of the project over intellectual property considerations at this stage. On the positive side, this choice enabled more efficient use of limited project time and resources, and aligned the work with the company's current strategic focus. However, not conducting a patent search introduced a potential risk of unknowingly developing a solution that may already exist and is protected by intellectual property. This could limit the future commercial viability or patentability of the final concept. Nonetheless, given the scope and timeline of the project, the decision was considered appropriate, with the understanding that a patent review could be pursued in a later phase, if necessary.

Lastly, the major challenge faced during the project was its broad and multidisciplinary nature. The project encompassed material selection, development of noise reduction strategies, evaluations and analysis of the mechanical performance of concepts, developing and evaluating aesthetics, as well as analysing the manufacturability of the product. This posed significant difficulties in terms of time management and the depth of exploration. Each area could only be briefly addressed, resulting in surface-level development rather than detailed analysis or refinement. Consequently, decisions often had to be made rapidly and based on preliminary insights rather than thorough investigations. Although this wide scope underscored the value of integrating design, engineering, and user-focused thinking, ultimately, the available time and resources proved insufficient to thoroughly address the project's scope.

5.3 Material considerations

Finding the perfect solution proved challenging, as only informed suggestions could be made without the ability to fully verify their effectiveness. For instance, the team lacked the expertise to theoretically calculate the impact of filling the honeycomb layer between the aluminium and cork layers with melamine foam. Additionally, simulating the concept using a 3D model was not feasible due to the significant time constraints and the lack of available resources within the company to support such efforts. Finally, budget constraints prevented physical tests from being conducted, further limiting the ability to validate the proposed solutions.

On a positive note, the research into melamine foam performance introduced the promising concept of combining carbon fibre face sheets with melamine foam linings. This combination was found to significantly improve transmission loss. Therefore, it is recommended that this be further explored by Volvo Penta.

5.4 Market and adoption

From a broader perspective, one important consideration is the conservative nature of the marine market. Innovation in this industry can be slow, as both manufacturers and customers often prefer proven solutions over new, untested alternatives. This conservatism can be attributed to factors such as safety regulations, reliability concerns, and long product lifespans. As such, even if the new engine cover design offers improved aesthetics or reduced noise, its adoption may face resistance unless its benefits are clearly demonstrated. This underlines the importance of balancing innovation with practical, incremental improvements that align with market expectations.

5.5 Future recommendations to Volvo Penta

Looking ahead, several promising opportunities for further development and innovation have emerged over the course of this project. The three notable areas for future exploration include the traditional cover (the final concept), integration of ANC systems, and the development of a fully enclosed engine cover, referred to the "the bread box" solution.

5.5.1 Traditional cover concept

The final concept selected and developed in this project represents a promising direction for improving marine engine covers, particularly in terms of aesthetics, modularity, and alignment with user needs. However, while the project achieved key milestones, including a detailed CAD model and a 3D-printed prototype, several areas require further development to fully realize the concept's potential for implementation.

5.5.1.1 Fastening system development

One of the most critical aspects that remains unresolved is the fastening system. While the overall form and fit of the cover have been addressed, the specific type of fasteners and attachment methods still needs to be determined. These decisions will significantly affect usability, ease of installation, maintenance accessibility, and structural integrity. The fastening solution must ensure a secure fit while also allowing for quick and tool-free removal if possible, in line with the identified customer

requirements. Future work should involve evaluating different fastening mechanisms, such as a snap-fit systems, and testing them under marine conditions.

5.5.1.2 Sound and vibration simulations

Due to time and resource constraints, it was not possible to carry out sound and vibration simulations during this project. These analyses are essential to validate whether the design delivers meaningful improvements in noise reduction and to avoid unintended amplification through resonance. Collaborating with the sound and vibration engineering team in future phases will be necessary to simulate and, eventually, physically test the acoustic performance of the design. These simulations will also help in optimizing wall thicknesses, materials, and internal damping strategies.

5.5.1.3 Belt cover integration challenges

A recurring challenge in marine engine cover design, as observed during the benchmarking phase, is the belt cover. It is often treated as a separate element, and in most competitor designs it does not seamlessly integrate with the top cover. This issue was also encountered in the current concept. Achieving a cohesive and functional integration between the belt cover and the main housing remains a complex task, both in terms of geometry and accessibility for maintenance. Further iterations should focus on generating alternative design solutions that better address this interface, possibly through more modular components or flexible joint systems, while maintaining safety and manufacturability.

5.5.1.4 Need for full-scale prototyping

Although a scaled 3D-printed prototype was produced to visualize and assess the design, certain aspects, such as ergonomics, real-world fitment, and perceived quality, can only be properly evaluated through a full-scale physical prototype. A 1:1 prototype would allow for hands-on testing, particularly in relation to how the cover is handled, walked on, or removed during servicing. This step is vital for validating the feasibility of design decisions and for collecting additional stakeholder feedback before moving to production.

5.5.2 Active noise control

ANC presents a compelling opportunity to significantly reduce perceived engine noise, especially in the mid-to-high frequency ranges that are harder to attenuate through passive insulation alone. However, initial investigations revealed that information from potential ANC suppliers was limited, making it difficult to assess feasibility, integration complexity, and expected performance gains at this stage.

For future projects, it is recommended that Volvo Penta deepen its collaboration with ANC technology providers. Establishing clearer technical communication and

partnership frameworks could provide more reliable data on cost, space requirements, power consumption, and system performance. Importantly, ANC systems would need to be carefully evaluated for reliability in harsh marine environments, where vibration, moisture, and temperature variation could impact long-term functionality.

5.5.3 Enclosed engine box concept

The concept of a fully enclosed engine box offers significant potential for noise reduction and a sleeker aesthetic. However, it introduces several technical and organisational challenges that must be addressed through cross-functional collaboration.

One of the primary concerns is thermal management. Enclosing the engine will increase the internal temperature, necessitating early and close involvement from the thermodynamics team to evaluate ventilation, heat dissipation, and material selection. Without proper thermal management, there is a risk of overheating, which can compromise engine performance and component longevity.

Secondly, the sound and vibration team must be consulted to ensure that the box design does not inadvertently act as a resonant chamber or "speaker," amplifying rather than reducing engine noise. Material choice, internal geometry, and damping treatments will play a critical role in this.

Thirdly, the introduction of a full enclosure may require new fastening points on the engine or surrounding structure. This has implications not only for in-house engineering but also for boat builders, who may need to adjust mounting strategies or redesign portions of the engine compartment. Engaging external partners early in the development process is essential to ensure compatibility and buy-in.

6

Conclusion

This project successfully addressed the two research questions by analysing the advantages and disadvantages of existing marine engine covers and identifying critical design features for future development. Through an iterative design process, the work resulted in the development of a detailed CAD model and a scaled 3D-printed prototype of the final engine cover concept, demonstrating the potential of the proposed solution.

Beyond these deliverables, a selection table was developed to support future ideation. This tool allows designers to mix and match various features, promoting creativity and flexibility while maintaining a structured approach to concept development. It provides a scalable framework for adapting to different customer needs, technological advancements, or design trends.

One of the most valuable insights gained during the project is the significant role the engine cover can play in reducing the sound emissions of the complete engine. While limitations in time, expertise and resources restricted the extent of acoustic testing, preliminary findings suggest that the current design direction holds considerable promise in improving onboard comfort and reducing environmental noise impact.

Given these outcomes, it is strongly recommended that Volvo Penta continue to explore and refine this concept. With further testing, simulation, and cross-functional collaboration, particularly in the field of acoustics, thermal management, and installation, the engine cover could evolve into a key differentiator in the marine propulsion market, offering enhanced performance, usability, and customer satisfaction.

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A

Appendix 1 - Benchmarked engines

Typical	Semi-sport	Sport	Robust	Minimal	Fully covered
Volvo Penta D6	MerCruiser 6.2L V8	Indmar Raptor 440	Volvo Penta D13	Crusaider The Classic 6.0L MPI	SeaTek 660 Plus
Volvo Penta D8	Mercury Diesel 3.0L	Ilmor 6.2L GDI	CAT C32B Sequential Turbo	Ilmor 6.0L MPI	PANDA 8000i
CAT C7.1	MAN V12 - 1900	Ilmor 5.3L GDI HO	Scania DI16 072M	MerCruiser 8.2L V8 Sterndrive	
Yanmar 4JH110		Ilmor Supercharged 6.2L		Scania DI13 071M	
Yanmar 6LY400		PCM ZR4			
Yanmar 8LV370 (Z)					
Mercury Diesel 6.7L					
Mercury Diesel 2.0L					
FPT Cursor 16					
FPT Cursor 9					

Table A.1: Benchmarked inboard engines

B

Appendix 2 - Requirement list

B. Appendix 2 - Requirement list

Requirement specification list (R=Requirement, D=Desire)			
Nr	Requirement	Comments:	Evaluation / Verification
1	Life in service		
R1.1	Must not fail before a period of 6000 hours years	To generate value to the customer compared to competitors	Accelerated extreme conditions usage simulation
D1.1	Should achieve a service life of 25 years	To generate value to the customer compared to competitors	Accelerated extreme conditions usage simulation
2	Installation		
R2.1	The installation must be finished before 10min time	To keep down cost and time of staff	Trials
R2.2	Must be less than 1 day of training required to perform installation	To keep down cost and time of training staff	Trials
R2.3	Must consist of a standardized interface for installation	To be compatible with current used interfaces	Engineering assessment
R2.4	Must require only one person to perform the installation	To keep down cost and time of staff	Trials
D2.1	Should not require specialized tools or skills	To ease the installation work and keep costs low	Trials/engineering assessment
D2.2	Should have clear installation instructions	To ease the installation work	Trials/engineering assessment
D2.3	Should be safe for the installer, with no risk of injury	To protect the installation workers	Trials/engineering assessment
3	Aesthetics		
D3.1	Should convey a premium look	To promote purchase	Focus group/surveys
D3.2	Should be pleasing to the eye	To promote purchase	Focus group/surveys
4	Standard specification		
R4.1	Must adhere to the Classification Society DNV requirements	To promote purchase	Engineering assessment
R4.2	Must adhere to Volvo Group and Volvo Penta Internal Guidelines	To promote high quality and performance	Engineering assessment
5	Ergonomics		
R5.1	The product must promote comfortable and efficient handling	To increase the user friendliness of the product	Trials and engineering assessment
D5.1	The product should be ergonomic for all individual's, with regards to size, strength, skill, speed, and vision	To increase the user friendliness of the product	Engineering assessment
6	Material		
R6.1	Must be corrosive resistant	To withstand environment	Accelerated extreme conditions usage simulation
R6.2	Must be oil resistant	To withstand environment	Accelerated extreme conditions usage simulation
R6.3	Must be saltine/brackish water resistant	To withstand environment	Accelerated extreme conditions usage simulation
R6.4	Must be fresh water resistant	To withstand environment	Accelerated extreme conditions usage simulation
R6.5	Must be diesel and gasoline resistant	To withstand environment	Accelerated extreme conditions usage simulation
R6.6	Must be coolant resistant	To withstand environment	Accelerated extreme conditions usage simulation
R6.7	Must be acid resistant	To withstand environment	Accelerated extreme conditions usage simulation
R6.8	Must be alkali resistant	To withstand environment	Accelerated extreme conditions usage simulation
R6.9	Must have low flammability	To promote safety	Engineering assessment
R6.10	Must withstand high-pressure cleaning	High-pressure cleaning of the engine compartment will most probably be performed many times during the service life of the vessel	Test plan / Engineering assessment
R6.11	Must be fire retardant	To promote safety	Engineering assessment
R6.12	Must withstand a weight of 1000 N on a 70x70 mm area	To adhere to the requirements of the Classification Society DNV	Test plan / Engineering assessment
D6.1	Should be renewable/environmental friendly	To achieve SDG	LCA
D6.2	Should be UV resistant	To withstand environment	Engineering assessment
D6.3	Should be Ozone resistance	To withstand environment	Engineering assessment
7	Product lifespan		
D7.1	The product should be easy to disassemble for recycling	To ease recycling of individual components	LCA
D7.2	The product should be easily disposed	To achieve SDG	LCA
8	Documentation		
R8.1	The product must have a user manual	To ensure ease of use	Focus group
9	Legal		
R9.1	Must follow ISO 10088 and ISO 7840 Annex A	To comply with the law (all components in the fuel system must be able to withstand a 2.5 minute fire test)	Fire test
R9.2	Must follow SOLAS (Safety of Life at Sea)	To comply with the law	Engineering assessment
R9.3	Must follow the 2013/53/EU directive	To comply with the law	Engineering assessment
10	Safety		
R10.1	Must not be harmful to the user	To ensure safe usage of the product	Engineering assessment
R10.2	Must have a surface temperature lower than 60°C	To ensure safe usage of the product	Accelerated extreme conditions usage simulation
R10.3	Must allow easy cleaning and removal of dirt	To decrease the risk of fire caused by dirt	Engineering assessment
D10.1	Should cover the belt of the engine	To promote safety	CAD / Prototype assessment
11	Testing		
R11.1	Must cover sound emission test	To ensure proper functionality of the product	Test plan / Engineering assessment
R11.2	Must cover durability test	To ensure proper functionality of the product	Test plan / Engineering assessment
D11.1	Should be easily tested	To ensure proper functionality of the product	Engineering assessment
12	Competition		
D12.1	Should have a differentiating factor in the market	To promote purchase	Focus group
13	Maintenance		
R13.1	Must be able to be disassemble for maintenance within 3 min and with a maximum of 5 steps	To be competitive	Trials
R13.2	Must be maintainable on site	To keep a low cost of the product and service	Test plan / Engineering assessment
R13.3	Must be possible to replace individual parts without compromising the rest of the product	Less expenses and less time consuming for the user, extend life span of the product	Prototype test
D13.1	Should be possible to be maintained without the need for a user manual	The user should be able to do small maintenance acts on the product without having any specific knowledge	Trials
D13.2	Should use as much standardized components as possible (e.g. bolts, screws)	Less expenses and less time consuming for the user	CAD / Prototype assessment
14	Weight		
R14.1	The weight must not exceed 15kg	To be competitive / ease of handling	Scale
D14.1	Should be weighing around 9kg	To be easy to handle for portability	Scale
15	Size		
R15.1	Must fit in current vessels	To not require need for boat manufacturers to rebuild their current vessels to fit the new engine cover	Measure in CAD
16	Product cost		
R16.1	Must be manufactured for a maximum cost of 1.200sek	To keep a sustainable profit margin, whilst allowing for a competitive pricing	Calculation of component cost and manufacturing expenses.
17	Performance		
R17.1	Must reduce the noise generated by the engine	To be competitive and promote purchasing	Test plan / Engineering assessment
R17.2	Must be possible to walk on it	To be competitive and promote purchasing	Test plan / Engineering assessment
18	Manufacturability		
R18.1	Must be able to be produced by common manufacturing processes	To reduce costs and time-to-market	CAD / Prototype assessment
D18.1	Should be able to source parts locally	To reduce costs and time-to-market	CAD / Prototype assessment

Figure B.1: Requirement list

C

Appendix 3 - Functions-mean tree

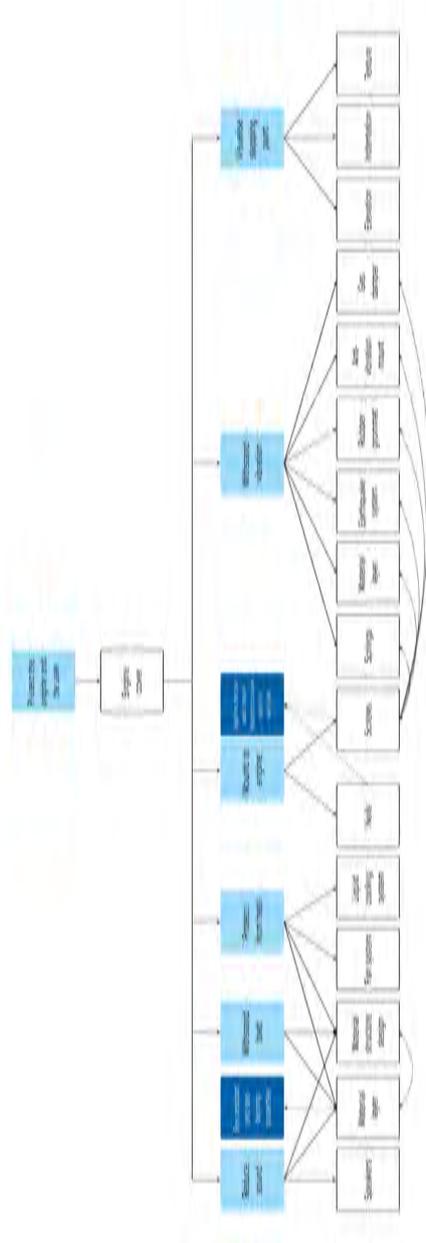


Figure C.1: Functional tree

E

Appendix 5 - External aesthetic survey



Marine Engine Cover Design

We are designing a new marine engine cover for leisure boats and want your help to understand what you associate an engine cover with. This survey should take about 3 minutes to complete.

mmva13@gmail.com [Switch accounts](#)

Not shared

* Indicates a required question

Which words best describe how a marine engine cover should look? (Select up to 5)

- Sleek
- Bold
- Powerful
- Minimalist
- Luxurious
- High-tech
- Dynamic
- Aggressive
- Aerodynamic
- Compact
- Robust
- Other (please specify)

Figure E.1: External aesthetic survey part 1

Please order your previous selection from most to least important. *

Your answer _____

Which of these designs best represents the words you selected? (Select one) *

	
<input type="radio"/> Option 1	<input type="radio"/> Option 2
	
<input type="radio"/> Option 3	<input type="radio"/> Option 4
	
<input type="radio"/> Option 5	

Figure E.2: External aesthetic survey part 2

Do you have any other comments you would like to share with us?

Your answer

Send Clear Form

Never send passwords through Google Forms.

This content was not created or approved by Google. - [Terms of Use](#) - [Privacy Policy](#).

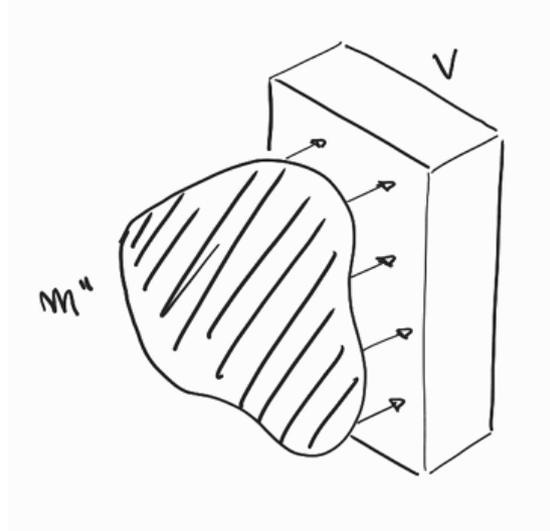
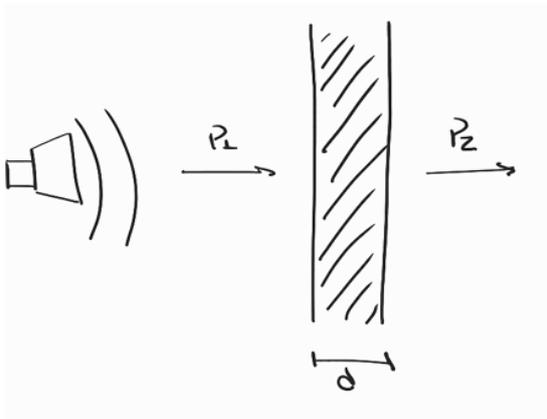
Does this form look suspicious? [Report](#)

Google Forms

Figure E.3: External aesthetic survey part 3

F

Appendix 6 - Sound transmission calculations



$$V = A \times d$$

$$\rho = \frac{m}{V} \left(\frac{\text{kg}}{\text{m}^3} \right)$$

$$m'' = \rho \times d \left(\frac{\text{kg}}{\text{m}^2} \right)$$

$$R_{\perp} = 20 \log_{10} \left(\frac{\omega \times m''}{2\rho_0 \times c} \right) - 3$$

$$P_{12} = P_1 - (R_{\perp 1} - 3)$$

$$P_2 = P_{12} - (R_{\perp 2} - 3) = P_1 - (R_{\perp 1} + R_{\perp 2}) + 6 \quad (\text{dB})$$

Case 1: current plate

- Material: Aluminium
- Thickness: 2 mm
- Density: 2700 kg/m³
- Frequency: 1000 Hz
- Room temperature conditions:
 - $\rho_0 = 1.204 \text{ kg/m}^3$
 - $c = 343 \text{ m/s}$
- Sound pressure: 100 dB

Calculations:

$$\begin{aligned}
 m''_{Al} &= \rho_{Al} \times d_{Al} = 2700 \times 0.002 = 5.4 \text{ kg/m}^2 \\
 \omega &= 2\pi f = 2\pi \times 1000 = 6283.2 \text{ rad/s} \\
 R_{\perp} &= 20 \log_{10} \left(\frac{\omega m''}{2\rho_0 c} \right) - 3 \\
 &= 20 \log_{10} \left(\frac{6283.2 \times 5.4}{2 \times 1.204 \times 343} \right) - 3 = 29.3 \text{ dB} \\
 P_2 &= P_1 - R_{\perp} + 6 = 100 - 29.3 + 6 = 76.7 \text{ dB}
 \end{aligned}$$

Case 2: aluminium plate with cork insulation

- Material 1: Aluminium
- Thickness 1: 2 mm
- Density 1: 2700 kg/m³
- Material 2: Cork
- Thickness 2: 2 mm
- Density 2: 200 kg/m³
- Frequency: 1000 Hz
- Room temperature conditions:
 - $\rho_0 = 1.204 \text{ kg/m}^3$
 - $c = 343 \text{ m/s}$
- Sound pressure: 100 dB

Calculations:

$$\begin{aligned}
 m''_{Al} &= \rho_{Al} \times d_{Al} = 2700 \times 0.002 = 5.4 \text{ kg/m}^2 \\
 m''_c &= \rho_c \times d_c = 200 \times 0.002 = 0.4 \text{ kg/m}^2 \\
 \omega &= 2\pi f = 2\pi \times 1000 = 6283.2 \text{ rad/s} \\
 R_{\perp Al} &= 20 \log_{10} \left(\frac{\omega m''}{2\rho_0 c} \right) - 3 \\
 &= 20 \log_{10} \left(\frac{6283.2 \times 5.4}{2 \times 1.204 \times 343} \right) - 3 = 29.3 \text{ dB} \\
 R_{\perp c} &= 20 \log_{10} \left(\frac{\omega m''}{2\rho_0 c} \right) - 3 \\
 &= 20 \log_{10} \left(\frac{6283.2 \times 0.4}{2 \times 1.204 \times 343} \right) - 3 = 6.7 \text{ dB} \\
 P_2 &= P_1 - (R_{\perp Al} + R_{\perp c}) + 6 = 100 - (29.3 + 6.7) + 6 = 70 \text{ dB}
 \end{aligned}$$

Case 3: aluminium plate, honeycomb and cork insulation

- Material 1: Aluminium

- Thickness 1: 2 mm
- Density 1: 2700 kg/m³
- Material 2: Cork
- Thickness 2: 2 mm
- Density 2: 200 kg/m³
- Honeycomb: 10 mm
- Frequency: 1000 Hz
- Honeycomb: 10 mm
- Room temperature conditions:
 - $\rho_0 = 1.204 \text{ kg/m}^3$
 - $c = 343 \text{ m/s}$
- Sound pressure: 100 dB

Calculations:

$$\begin{aligned}
 m''_{Al} &= \rho_{Al} \times d_{Al} = 2700 \times 0.002 = 5.4 \text{ kg/m}^2 \\
 m''_c &= \rho_c \times d_c = 200 \times 0.002 = 0.4 \text{ kg/m}^2 \\
 \omega &= 2\pi f = 2\pi \times 1000 = 6283.2 \text{ rad/s} \\
 f_0 &= \frac{c}{2\pi} \left[\frac{\rho_0}{d} \left(\frac{1}{m''_{Al}} + \frac{1}{m''_c} \right) \right]^{1/2} \\
 &= \frac{343}{2\pi} \left[\frac{1.204}{0.01} \left(\frac{1}{5.4} + \frac{1}{0.4} \right) \right]^{1/2} = 981.6 \text{ Hz} \\
 f_a &= \frac{c}{2\pi d_h} = \frac{343}{2\pi \times 0.01} = 5459 \text{ Hz}
 \end{aligned}$$

Note: $f_0 < f < f_a \implies \text{Regime B}$

$$\begin{aligned}
 R_{\perp Al} &= 20 \log_{10} \left(\frac{\omega m''}{2\rho_0 c} \right) - 3 \\
 &= 20 \log_{10} \left(\frac{6283.2 \times 5.4}{2 \times 1.204 \times 343} \right) - 3 = 29.3 \text{ dB} \\
 R_{\perp c} &= 20 \log_{10} \left(\frac{\omega m''}{2\rho_0 c} \right) - 3 \\
 &= 20 \log_{10} \left(\frac{6283.2 \times 0.4}{2 \times 1.204 \times 343} \right) - 3 = 6.7 \text{ dB} \\
 R_{\perp} &= R_{\perp Al} + R_{\perp c} + 20 \log_{10}(fd) - 29 \\
 &= 29.3 + 6.7 + 20 \log_{10}(1000 \times 0.01) - 29 = 27 \text{ dB} \\
 P_2 &= P_1 - R_{\perp} + 6 = 100 - 27 + 6 = 79 \text{ dB}
 \end{aligned}$$

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